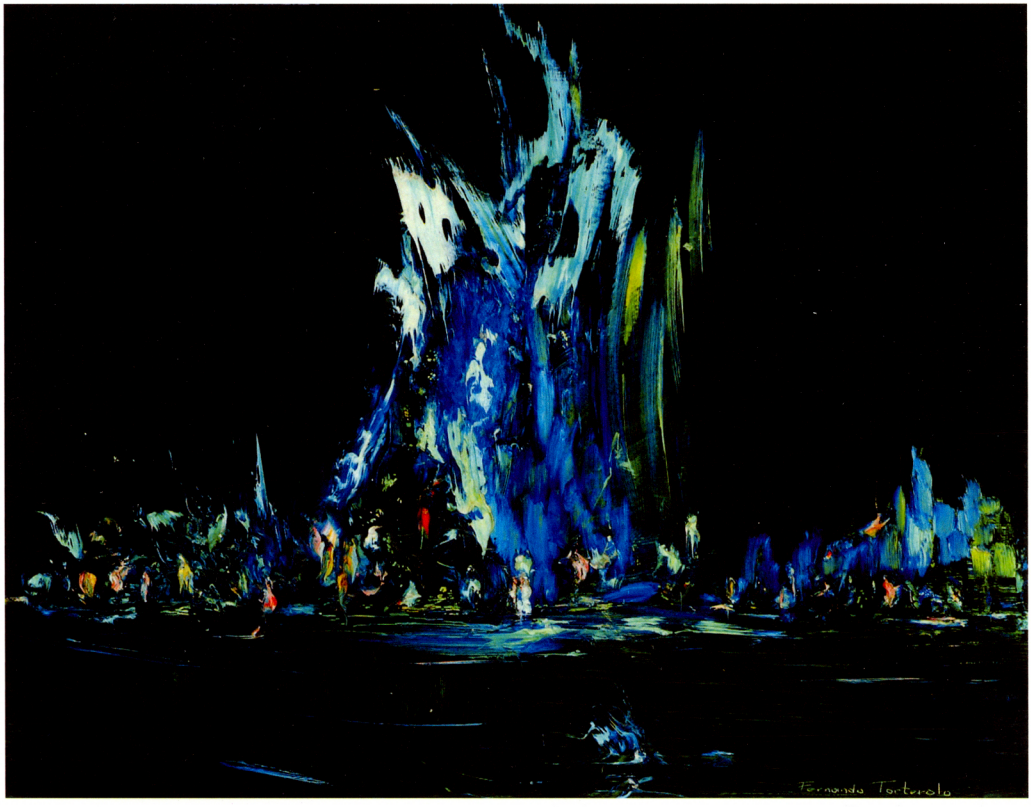
Monetary Policy under Inflation Targeting

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Monetary Policy under Inflation Targeting: An Introduction

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With the end of intermediate exchange rate regimes, countries are either abandoning domestic monetary policy (by choosing super-hard pegs or relinquishing their national currencies altogether) or strengthening independent monetary policymaking (by adopting floating exchange rates, of either the clean or dirty variety) (Fischer, 2001; Calvo and Mishkin, 2003). Among monetary regimes, inflation targeting has become the natural complement of flexible exchange rate regimes. Many countries—which differ in size, structural features, and development level—have selected inflation-targeting-cum-floating as their preferred framework for pursuing a more independent and effective monetary policy. This choice is often made by instrument-independent central banks in open economies with a history of inflation, which need to establish a credible monetary anchor to promote price stability (Mishkin and Schmidt-Hebbel, 2002). Therefore, since New Zealand first adopted inflation targeting in 1990, a steadily growing number of industrial and emerging economies have implemented an explicit inflation

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target as their nominal anchor. Eight industrial countries and seventeen emerging economies currently have full-fledged inflation targeting in place, and many more emerging economies are planning to adopt inflation targeting in the next few years.

The theory and practice of monetary policy under inflation targeting have evolved hand in hand, with mutually beneficial effects. Academic researchers and central bankers are collaborating in analyzing monetary theory and policy results, as well as improving policy design and conduct, in both inflation-targeting and nontargeting central banks. This collaboration gives rise to joint academic–central bank research, conferences, and publications, like the one for which this introduction is written.

Several volumes have been published on the theory, design, implementation, and performance of inflation-targeting regimes, including Haldane (1995), Leiderman and Svensson (1995), Lowe (1997), Bernanke and others (1999), Bank of Thailand (2000), Carson, Enoch, and Dziobek (2002), Loayza and Soto (2002), Truman (2003), Reserve Bank of Australia (2004), and Bernanke and Woodford (2005). These works typically combine the study of theoretical questions on monetary theory and policy design under inflation targeting with new empirical evidence on policy and macroeconomic performance, based on the growing body of data pertaining to the rising number of inflation-targeting countries.

In the following section, we selectively review the literature on inflation targeting. We then discuss the new research on monetary policy under inflation targeting introduced here (in this volume) and summarize its main findings.

1. A Selective Review of Research on Inflation Targeting

A large and growing literature focuses on monetary theory, monetary policy, and macroeconomic performance under an inflation-targeting regime. This is part of a much larger analytical and empirical literature on monetary theory and policy outcomes. The boundaries between the general research and that referring specifically to inflation targeting are sometimes blurred, as is clear in this review. Considering the latter fact and the sheer size of the current research, we focus selectively on six issues of monetary policy design and practice that are of central relevance to the inflation targeting debate.

1.1 Practice and Optimality of Inflation-Targeting Regimes

A growing literature addresses the optimal choice of the parameters that define an inflation-targeting regime. While all countries have formally chosen inflation over price-level targeting to date, the debate about the optimality of inflation versus price-level targeting has not been closed. Inflation targeting dominates price-level targeting in riding out temporary inflation shocks and in avoiding costly contractionary policy offsets and excessive inflation variability (Fischer, 1996). Price-level targeting, however, may do a better job than inflation targeting in avoiding a random drift in the price level and reducing price-level uncertainty (Fischer, 1996); in delivering lower output and inflation volatility (Svensson, 1999; Chadha and Nolan, 2002); in allowing relative prices to allocate resources and reducing distortions and unintended wealth transfers (Barnett and Engineer, 2000); and in lessening the problems associated with the zero nominal interest floor (Eggertsson and Woodford, 2003; Svensson, 2003). Hybrid rules that combine inflation and price-level targeting may be superior to either of the two extremes (Cecchetti and Kim, 2005; Nessén and Vestin, 2005).

Most countries have chosen the headline consumer price index (CPI) as their target measure; alternative measures based on core inflation measures are exceptions. While there are good practical arguments for choosing the headline CPI as the official measure (including its status as a widespread and trusted measure of overall inflation and its use for indexation), the literature identifies several reasons that alternative price-level measures are potentially a better choice. Central banks are more likely to have stronger and quicker effects on core inflation than headline inflation and on nontradable than tradable goods inflation. When the production of final consumption goods involves different stages of processing, it may be optimal for monetary policy to react not only to output and CPI variability, but also to producer price inflation variability (Huang and Liu, 2004). Countries have not chosen nominal income as their target measure for a variety of reasons, including the lack of readily available high-frequency data on gross national income and the equal weight attached to inflation and output in nominal income. Nevertheless, nominal-income targeting may be superior to inflation targeting under certain conditions (McCallum and Nelson, 1999).

Another design dimension of an inflation-targeting regime is the monetary policy horizon—that is, the time targeted by the central

bank to return inflation to the target level after an inflation shock. The optimal horizon will depend on the nature and persistence of the shock, the structure of the economy (including the extent of nominal and real rigidities), and central bank preferences (Batini and Nelson, 2001). The discussion of the optimal horizon is also linked to the choice between inflation and price-level targeting (King, 1999; Cecchetti and Kim, 2005).

1.2 Inflation Targeting and Optimal Monetary Policy

Recent research follows the advice of McCallum (1988) and investigates the robustness properties of alternative monetary policy rules by evaluating them in a variety of models. However, the dichotomy between economic structure and policy objectives could be inappropriate. First, the central bank's quadratic loss function can be interpreted as an approximation of the welfare of the representative agent (Woodford, 1993). Second, loss functions are endogenous to model structure; for example, increased price rigidity raises the relative weight of the inflation objective in the optimal loss function that an inflation-targeting central bank should use (Walsh, 2004).

Researchers generally agree that inflation targeting has led to major progress in the practice of monetary policy (see, for example, Woodford, 2004). The early literature that describes inflation targeting as a regime of constrained discretion (Bernanke and others, 1999) underscores its potential benefit of allowing sufficient discretion (as required in the face of policy uncertainty) within a rule-based framework that is consistent with Kydland and Prescott's rules versus discretion paradigm (see Kydland and Prescott, 1977).

Yet is monetary policy as currently practiced by inflation-targeting central banks optimal? Many authors point to the suboptimality of implicit policy rules and weakness in communicating policy rules, internal evaluations, and projections of future policy and performance variables to the public. The optimal targeting rules derived by Giannoni and Woodford (2005) imply forecasts for interest and inflation paths several years into the future, which are inconsistent with assumptions of constant future interest rates and constant medium-term policy horizons, as still practiced by several inflation-targeting central banks. Other authors call for clear central bank communication of point and density forecasts for their policy instrument and objectives, as well as their likely course of policy under alternative or risk scenarios (Svensson, 1997; Faust and Henderson, 2004; Woodford, 2004).

1.3 Uncertainty, Learning, and Monetary Policy under Inflation Targeting

Central bankers face different types of uncertainty that may affect monetary policy decisions, such as uncertainty about current (real-time) and future data, the most appropriate model (including specification, parameters, and the dynamics that govern monetary policy transmission), and preferences (of the representative consumer and even of the central banker). Brainard (1967) was the first to explore how a (monetary) policymaker should respond to uncertainty, showing that if uncertainty is additive, a policymaker with a quadratic objective function should display certainty equivalence. A more cautious policy is optimal, however, if uncertainty is multiplicative (Brainard's conservative principle). If uncertainty is Knightian—that is, when probability distributions over possible events are unknown—robust control methods lead policymakers to minimize the loss that arises when uncertainty turns out to be most unfavorable (Hansen and Sargent, forthcoming).

Early work on inflation targeting under uncertainty suggests that parameter and lag uncertainty should have little effect on policy behavior, while uncertainty about the nature of shocks tends to raise interest rate smoothing (Srour, 1999). For the case of parameter uncertainty, and in the framework of the Svensson (1999) model, forward-looking expectations imply that a more aggressive monetary policy yields greater stability than interest rate smoothing (Demertzis and Viegi, 2004). Uncertainty about key natural rates (namely, natural unemployment and interest rates) can result in persistent monetary policy errors (Orphanides and Williams, 2002; Cukierman and Lippi, 2005) and propagate macroeconomic disturbances, with first-order implications for monetary policy (Gaspar and Smets, 2002; Orphanides and Willliams, 2004a). Inflation targeting can be particularly successful in reducing the latter risks by better anchoring inflation expectations under imperfect knowledge of key variables and private perception of monetary policy behavior.

The signal extraction problem that accompanies imperfect knowledge of key input or target variables causes both central banks and the private sector to learn gradually about the realization of shocks. This form of bounded rationality—a departure from rational expectations—provides a plausible framework for modeling the behavior of central banks and private agents (Evans and Honkapohja, 2001) and seems to be empirically reasonable

(Orphanides and Williams, 2004b). Adaptive learning on the part of central banks implies that they will have a relatively muted response to cost-push shocks (Smets, 1999; Orphanides and Williams, 2002; Gerali and Lippi, 2002). When private sector expectations are determined by adaptive behavior, optimal monetary policy responds more persistently to cost-push shocks. The higher the private sector's initially perceived inflation persistence, the stronger and more persistent is the optimal policy response (Gaspar, Smets, and Vestin, 2006).

When the central bank's uncertainty about potential output leads to central bank learning behavior, the optimal choice of whether to target output growth, the price level, or inflation will depend on the weight of inflation stability and the degree of learning efficiency (Yetman, 2005). The interaction between private sector uncertainty about the central bank's inflation target level (in other words, the central bank's lack of credibility) and the central bank's uncertainty regarding the private sector's uncertainty about the inflation target can have serious implications for monetary policy, leading to policy errors and raising inflation persistence (Aoki and Kimura, 2005).

1.4 Transparency, Communication, and Accountability under Inflation Targeting

Transparency, communication, and accountability are key to successful inflation targeting. This belief has motivated inflation-targeting central banks to undertake ongoing efforts to upgrade these three features of their policy framework (Roger and Stone, 2005). The recent analytical literature focuses increasingly on these features and their relation to monetary policy uncertainty and optimality.

Optimal inflation targeting balances the need for accountability with monitoring capabilities (Walsh, 2003). If the central bank has little information about inflation shocks or if policy is transparent, then more weight should be placed on the inflation objective. Multiplicative uncertainty leads to more cautionary monetary policy (Brainard, 1967), but it also raises the value of central bank accountability for achieving the inflation target (Walsh, 2003). If the private sector has diverse information about aggregate shocks, and if this information is less accurate than the central bank's, then full transparency is generally optimal for inflation targeters, unless they are inflation nutters or put an excessive weight on output gap stability (Amato, Morris, and Shin, 2002; Walsh, 2005).

1.5 Asset Prices and Monetary Policy under Inflation Targeting

A heated debate has taken place in recent years regarding the optimality of monetary policy—whether under inflation targeting or alternative monetary regimes—to react to asset prices or perceived asset price misalignment. Cecchetti and others (2000) argue that reacting to asset prices, in addition to inflation and the output gap, is likely to achieve superior performance and a smoother inflation path by reducing the likelihood of an asset price bubble. (This view was restated by Cecchetti, Genberg, and Wadhwani, 2002, in their response to some of the counterarguments presented next.) Much of the academic and policy literature reacted with skepticism to their proposal. Bernanke and Gertler (2001) contend that reacting to equity prices is counterproductive (over and above its effects on inflation and the output gap), while Batini and Nelson (2000) state that reacting to the exchange rate is not optimal (over and above its effects on inflation and the lagged interest rate). A related argument holds that since inflation-targeting central banks focus on inflation expectations, they need not target asset prices directly, but rather can use them to improve their prediction of the path of future inflation (Bean, 2003).

Most inflation-targeting (and other) central banks have thus far sided with the skeptical view on monetary policy reaction to asset prices. Reasons for skepticism include the difficulty of measuring asset price misalignment, the difficulty of anticipating future asset price booms and busts or the future effects of preventive nonmonotonic policy actions, the difficulty in discriminating among different asset prices (such as housing prices, equity prices, and the exchange rate), and the possible dilution of the inflation objective.

1.6 Economic Performance under Inflation Targeting and in Comparison with Nontargeting Regimes

Empirical evidence on the links between inflation targeting and particular measures of economic performance generally supports the view that inflation targeting is associated with an improvement in overall economic performance (Bernanke and others, 1999; Corbo, Landerretche, and Schmidt-Hebbel, 2002; Neumann and von Hagen, 2002; Hu, 2003; Truman, 2003; Mishkin, 2006). In one of the few empirical papers critical of inflation targeting, Ball and Sheridan

(2005) argue that inflation targeting does not make a difference in industrial countries; rather, the apparent success of inflation-targeting countries simply reflects regression toward the mean. Ball and Sheridan's findings are heavily disputed by Hyvonen (2004), Vega and Winkelried (2005), and IMF (2005), who present evidence—generated with different specifications and estimation techniques and based on samples that include emerging economies—that inflation levels, persistence, and volatility are lower in inflation-targeting countries.

Output volatility has not worsened after the adoption of inflation targeting; if anything, it has improved (Corbo, Landerretche, and Schmidt-Hebbel, 2002). Evidence on inflation targeting's impact on sacrifice ratios is also mildly favorable. Bernanke and others (1999) do not find that sacrifice ratios in industrialized countries fell with the adoption of inflation targeting, while Corbo, Landerretche, and Schmidt-Hebbel (2002) conclude, based on a larger sample of inflation targeters, that inflation targeting did lead to an improvement in sacrifice ratios.

Bernanke and others (1999) and Levin, Natalucci, and Piger (2004) do not find that inflation targeting leads to an immediate fall in expected inflation, but Johnson (2002, 2003) does find some evidence that expected inflation falls after the announcement of inflation targets. However, inflation expectations appear to be better anchored for inflation targeters than nontargeters: inflation expectations react less to shocks to actual inflation for targeters than nontargeters, particularly at longer horizons (Gürkaynak, Levin, and Swanson, 2006; Levin, Natalucci, and Piger, 2004; Castelnuovo, Nicoletti-Altimari, and Rodríguez Palenzuela, 2003).

Finally, the evidence increasingly indicates that inflation targeters are successful in meeting their targets. A virtuous circle seems to be at work here, with inflation targeting being adopted in conjunction with institutional improvements that help strengthen monetary policy credibility. Central bank independence, fiscal policy credibility, overall institutional strength, and financial sector development all contribute to reducing the size of inflation target misses (Calderón and Schmidt-Hebbel, 2003; Albagli and Schmidt-Hebbel, 2004; Gosselin, 2006). While inflation targets are never met exactly, the success and resilience of the regime—no country has dropped inflation targeting to date—are attributed to its flexibility and its improvements in monetary policy formalization and transparency (Roger and Stone, 2005).

2. Overview of the Volume

Our selective review of the literature on inflation targeting suggests a significant number of open issues. Which further challenges are faced by economists and policymakers to lock in the benefits of low world inflation and minimize the transition costs toward inflation targeting in currently nontargeting countries? Is inflation targeting still optimal when considering real-world features of fiscal policy, like distortionary taxation and nonguaranteed intertemporal solvency? Which features of inflation targeting could be key when private knowledge of central bank goals and reactions is imperfect, raising the risk of endogenous drift of private expectations away from the central bank's inflation goal? How is the Ramsey-optimal inflation level affected by the degree of price stickiness and the zero bound on the nominal interest rate—and which variables determine the Ramsey-optimal policy rule? How can central banks improve their current communication practice to raise the efficiency of monetary policy under inflation targeting? If the private sector has diverse information that is generally inferior to that of the central bank, what determines the optimal degree of policy transparency?

How does output persistence affect the optimal weights of price-level and inflation targeting, and what does cross-country data reveal about how close inflation targeters are to price-level targeting? What have been the benefits of inflation targeting for the world sample of targeting countries, in terms of macroeconomic performance and monetary policy efficiency, both over time and in comparison to successful nontargeters? What is the evidence on the pass-through of exchange rate devaluation to inflation, exchange rate volatility, and the role of the exchange rate in policy rules under inflation targeting? Are inflation expectations better anchored in inflation-targeting countries than in the United States? Has inflation targeting improved the anchoring of inflation and inflation expectations and reduced volatility in emerging economies—and are the results sensitive to a country's having met preconditions at the start of inflation targeting? How important are real and nominal rigidities in explaining monetary policy and macroeconomic dynamics in Chile, and has the weight attached to inflation relative to output declined since the adoption of full-fledged inflation targeting in 1999? Finally, has Chile experienced changes in price rigidity, price indexation, devaluation-inflation pass-through, and the policy rule since attaining full-fledged inflation targeting and stationary inflation?

The papers in this volume address these thirteen questions. The introductory essay by Anne Krueger assesses the benefits of a low-inflation environment for the world economy. The author starts by reviewing the main costs of inflation—namely, how it distorts the calculus of profitability, encouraging short-term projects at the expense of longer-term investment and diminishing the value of relative price signals. She then reviews the progress that most countries have made in recent years toward achieving low inflation. The new low-inflation environment has brought noticeable gains—faster global growth, increased stability, and reduced vulnerability. The role of the IMF in helping foster a low-inflation environment is also discussed, highlighting the Fund's important support for policy reform efforts in its member countries. To conclude, Krueger identifies future challenges for economists and policymakers: locking in the benefits of low inflation, identifying how far policies should go toward lowering inflation further, and expanding the knowledge frontiers on the transition toward adopting inflation targeting.

Pierpaolo Benigno and Michael Woodford extend the theoretical literature on inflation targeting by focusing on the fiscal consequences of committing to an inflation target. They analyze the nature of an optimal monetary policy commitment under alternative assumptions about fiscal policy, ranging from distorting revenue to deviations from intertemporal insolvency. While the fiscal policy regime has important consequences for the optimal conduct of monetary policy, a suitably modified form of inflation targeting will still be a useful approach to optimal monetary policy. Benigno and Woodford show that the optimal targeting rule for monetary policy, which applies to the alternative fiscal regimes considered, involves commitment to an explicit target for an output-gap-adjusted price level. The optimal policy allows temporary deviations from the long-run target rate of economic growth in the gap-adjusted price level in response to disturbances that affect the government budget. However, such a policy also requires a commitment to return quickly to normal growth following these disturbances, so that medium-term inflation expectations remain firmly anchored despite the occurrence of fiscal shocks.

The paper by Athanasios Orphanides and John Williams reexamines the role of the key elements of the inflation-targeting framework in the context of an economy with imperfect knowledge. In their model, private agents attempt to infer the central bank's goals and reactions through past actions. The novelty of the approach is that inflation expectations can endogenously drift away from the

central bank's inflation goal. Using an estimated model of the U.S. economy, Orphanides and Williams show that monetary policy rules that would perform well under the assumption of rational expectations do very poorly when imperfect knowledge is introduced. The authors then examine the performance of an easily implemented policy rule that incorporates three key features of inflation targeting—namely, transparency, commitment to price stability, and close monitoring of inflation expectations—and find that all three play important roles in ensuring success. Their analysis suggests that simple difference rules excel at tethering inflation expectations near the central bank's target and, in doing so, achieve superior stabilization of inflation and economic activity in an environment of imperfect knowledge.

Stephanie Schmitt-Grohé and Martín Uribe study the characterization and implementation of optimal monetary policy in the context of a medium-scale macroeconomic model that has been estimated to fit postwar U.S. business cycles. The main finding of the paper is that mild deflation is Ramsey-optimal in the long run. However, the optimal inflation rate appears to be highly sensitive to the assumed degree of price stickiness. This sensitivity disappears when lump-sum taxes are unavailable, in which case mild deflation is robustly optimal. In light of the result that the optimal inflation rate is negative, Schmitt-Grohé and Uribe find it puzzling that inflation-targeting countries pursue positive inflation goals. They also argue that the zero bound on the nominal interest rate, which is often cited as a rationale for a positive inflation target, is of no quantitative relevance in their model. Finally, the authors characterize operational interest rate feedback rules that best implement optimal stabilization policy and find that the optimal interest rate rule is sensitive to price and wage inflation, insensitive to output growth, and moderately inertial.

Lars Svensson claims in his paper that while inflation-targeting central banks have made impressive achievements, there is still ample room for progress in the development and effectiveness of this new regime. He explains that inflation-targeting central banks can improve their aim by being more specific, systematic, and transparent about their operational objectives (by using an explicit intertemporal loss function), their forecasts (by deciding on optimal projections of the instrument rate and the target variables), and their communication (by announcing optimal projections of the instrument rate and target variables). According to Svensson, further progress can be made by systematically incorporating central bank judgment and model uncertainty into the forecasting and decisionmaking process. In

particular, incorporating model uncertainty would lead central banks to engage in a more general "distribution forecast targeting" rather than the usual, more restrictive form of "mean forecast targeting" under the assumption of approximate certainty equivalence.

Carl Walsh extends the literature on central bank transparency under inflation targeting by exploring two dimensions of transparency that are typically overlooked: the quality of the information the central bank provides and how widely that information is publicized. Employing a simple new Keynesian framework with private and diverse information, Walsh finds that announcements about short-run targets allow price setters to distinguish policy actions designed to offset demand shocks from those designed to partially offset the inflation effects of cost shocks. Announcements can thereby prevent demand shocks from affecting inflation, but private sector decisions become more sensitive to central bank forecast errors, raising inflation variability. It may then be advantageous for the monetary authority to make partial announcements. Walsh shows that the optimal degree of partial announcements depends on the persistence of cost and demand shocks, the relative weight of inflation and output gap objectives, and the information asymmetry between the central bank and the public. Full transparency is optimal for a central bank that has reasonable preferences (a central bank that is neither an inflation nor an output gap nutter) and has more accurate information than the private sector.

The paper by Stephen G. Cecchetti and Stefan Krause revisits the relative merits of price-level targeting and inflation targeting. According to the authors, whether the optimal approach is pure inflation targeting, pure price-path targeting, or some hybrid depends on the country's output persistence. Furthermore, any hybrid rule can be optimal once policymakers realize that the horizon for target evaluation can vary. For example, a rule that heavily weights inflation targeting but is evaluated over a long horizon will be equivalent to a rule that heavily weights price-path targeting but is evaluated over a shorter horizon. The authors confront these ideas empirically with data drawn from a large panel of countries. Their evidence shows that output and price-level persistence vary significantly across countries. Inflation targeters show a distinctly lower degree of price-level persistence than nontargeters. More generally, output persistence did not change much between the 1980s and the 1990s, whereas price-level persistence declined—possibly a result of inflation targeting—and the optimal horizon for target evaluation grew shorter.

Cecchetti and Krause conclude that countries may be closer to price-path than to inflation targeting.

Frederic S. Mishkin and Klaus Schmidt-Hebbel revisit the issue of whether inflation targeting is associated with an improvement in overall economic performance. They extend the previous empirical literature on this ongoing debate by focusing on a panel of data comprising the world population of inflation-targeting countries and a control group of high-achieving industrial economies that do not target inflation. The authors find that inflation targeting has helped inflation-targeting countries reduce their long-run inflation levels, diminish the inflation response to oil-price and exchange rate shocks, strengthen monetary policy independence, improve monetary policy efficiency, and lower the deviations of inflation outcomes from inflation goals. Many of these benefits increase once inflation targeters attain stationary target levels. Despite the improvements obtained by inflation targeters relative to their past performance, the evidence generally rejects the notion that inflation-targeting countries perform better than the control group of nontargeters. Mishkin and Schmidt-Hebbel show, however, that inflation targeting helps all country groups move toward control-group performance—and industrial inflation targeters' performance is at the level of the control group.

Sebastian Edwards analyzes core issues on the relation between exchange rates and the inflation-targeting regime. He uses a dataset for two advanced and five emerging inflation-targeting economies to empirically address three issues: the relation between devaluation-inflation pass-through and the effectiveness of the nominal exchange rate as a shock absorber (that is, the extent to which a nominal devaluation causes a real exchange rate depreciation); the effects of inflation targeting on exchange rate volatility; and the role of the exchange rate in monetary policy rules. Edwards finds that countries that have adopted inflation targeting have experienced a decline in the pass-through from the exchange rate to inflation—for both producer and consumer price (nontradables) inflation. He finds no evidence, however, of changes in the degree to which the nominal exchange rate acts as a shock absorber. Adoption of inflation targeting has not led to higher nominal or real exchange rate volatility, although adoption of exchange rate floats has increased the volatility of exchange rates in three out of five countries. Finally, Edwards reports a wide range of estimates of the effects of the exchange rate on central banks' interest-setting behavior, ranging from nil (Chile) to high (Mexico).

The paper by Refet Gürkaynak, Andrew Levin, Andrew Marder, and Eric Swanson investigates the extent to which long-run inflation expectations are well anchored in three Western Hemisphere countries—namely, Canada, Chile, and the United States—based on a high-frequency event study. Their contribution to the literature consists in empirically verifying the success of inflation-targeting regimes in helping to anchor long-term inflation expectations. The authors use daily data on long-run forward inflation compensation measures—that is, the difference between forward rates on nominal and inflation-indexed bonds—as an indicator of financial-market perceptions of inflation risk and the expected level of inflation at long horizons. For the United States, Gürkaynak, Levin, Marder, and Swanson find that far-ahead forward inflation compensation reacts significantly to macroeconomic data releases, suggesting that long-run inflation expectations are not strongly anchored. In contrast, Canadian and Chilean inflation compensation data do not exhibit significant sensitivity to either domestic or external macroeconomic news, which is consistent with the view that inflation targeting in these two countries has succeeded in anchoring long-run inflation expectations.

Nicoletta Batini and Douglas Laxton analyze the effects of inflation targeting in emerging-market economies. They conducted a detailed survey of central banks, which they use to show that inflation targeting in emerging economies brings significant benefits compared with countries that adopt alternative nominal anchors (namely, monetary growth and exchange rate targets). They report that inflation targeters, unlike countries that pursue alternative monetary regimes, attain significant improvements in anchoring both inflation and inflation expectations, with no adverse effects on output performance; in reducing the volatility of interest rates, exchange rates, and international reserves; and in lowering the risk of currency crises. Batini and Laxton also find that countries do not have to meet a stringent set of institutional, technical, and economic preconditions before adopting inflation targeting for the subsequent success of this regime. In fact, most countries build up these conditions gradually after inflation targeting is in place. They show that the feasibility and success of inflation targeting instead depends on policymakers' commitment and ability to plan and drive institutional change after introducing the new regime.

Rodrigo Caputo, Felipe Liendo, and Juan Pablo Medina develop a dynamic stochastic general equilibrium (DSGE) model to analyze the extent to which nominal and real rigidities play a role in explaining

the behavior of aggregate data in Chile. This issue is particularly important from a central banker's perspective, since the existence (or absence) of certain rigidities may have important implications for the trade-off between output and inflation stabilization. Unlike previous DSGE models for Chile, their specification features habit formation, sticky prices and wages, price and wage indexation, and imperfect pass-through from the exchange rate to domestic prices of imports. Caputo, Liendo, and Medina use Bayesian techniques to estimate the model. Their main finding is that adding price and wage rigidities, wage indexation, and imperfect pass-through improves the fit of the model. Real rigidities, such as habit formation, also deliver a better account of aggregate data, although their effects are quantitatively small. Finally, their subsample analysis indicates that monetary policy has reacted less aggressively to inflation relative to output since 2000, suggesting a lower sacrifice ratio—a result they attribute to the increased credibility of full-fledged inflation targeting.

Luis Céspedes and Claudio Soto's paper revisits the argument that inflation targeting in Chile has made a major contribution to lowering inflation to around 3 percent per year by enhancing the credibility of monetary policy. The authors use a new Keynesian Phillips curve to show that price rigidity has intensified in the past few years, while the degree of indexation in the economy has declined and the exchange rate pass-through to traded-goods inflation has fallen. They also find that the monetary policy rule has become more forward-looking in terms of inflation and more resolute in fighting inflation deviations from target. Céspedes and Soto's findings are consistent with the notion that monetary policy credibility in Chile has been strengthened over time. As monetary policy has become more credible, costly price adjustments are undertaken less frequently, indexation based on past inflation has become less widespread, and the central bank has been able to fight inflation deviations from target more strongly and at lower output costs.

We end this introduction by summarizing selectively the main lessons drawn from our preview of the new findings on monetary policy and inflation targeting reported in this volume.

Countries considering adoption of inflation targeting should not wait to meet the stringent preconditions identified in older research and policy recommendations—the evidence shows that most countries build up these conditions gradually after adoption. Instead the success of inflation targeting depends on central banks' commitment and ability to adopt institutional changes after introducing the new regime.

On the optimal design of inflation-targeting regime parameters and rules, this volume presents novel analytical results. When fiscal regimes are considered, the optimal targeting rule for monetary policy involves commitment to an explicit target for an output-gap-adjusted price level. Then the optimal policy allows deviations in the gap-adjusted price level in response to fiscal disturbances, which need to be temporary in order to allow medium-term inflation expectations to remain firmly anchored. Regarding the choice of the inflation-target level, mild deflation is Ramsey-optimal, but this inference depends on the degree of price stickiness and the availability of lump-sum taxes.

The choice between price-path, inflation-level targeting, or a hybrid rule depends on the degree of output persistence and the horizon for target evaluation. The optimal policy horizon is determined by the persistence of the shocks faced by central banks, the volatility of output, and the preferences of central bankers. The cross-country evidence suggests that the horizon for target evaluation has become shorter and that countries may be closer to price-path than to inflation targeting.

Macroeconomic performance has improved significantly and by large measures in inflation-targeting countries. After adopting the new regime, the level, persistence, and volatility of inflation have improved, output volatility has declined, monetary policy efficiency has improved, and inflation outcomes are closer to target levels. The response of inflation to oil-price and exchange-rate shocks is smaller and monetary policy rates are less responsive to international interest rates. Some of the latter benefits are larger when countries achieve stationary inflation targets. Most of the gains have been larger for emerging-economy targeters, although industrial-country targeters by-and-large perform better than emerging-economy targeters. However, macroeconomic performance of inflation targeters is generally not better than that of nontargeters like the United States, the Eurozone, and Japan. The one exception to the latter is on long-term inflation expectations, which seem to be better anchored in inflation-targeting countries (specifically in Canada and Chile) than in nontargeting countries (specifically the United States).

Inflation targeting and nontargeting central bankers alike face the challenge of dealing adequately with data and model uncertainty. Uncertainty implies that learning about data and models is key to understand the behavior of economic agents and central banks, as reflected in a growing body of theoretical and empirical research on monetary policy. This work shows that both monetary policy efficiency and consumer welfare increase when uncertainty and learning are explicitly considered in agents' and central banks' decisionmaking.

Monetary policy rules that would perform well under the assumption of rational expectations do poorly when imperfect knowledge is introduced. Transparency, commitment to price stability, and close monitoring of inflation expectations play a key role in monetary policy under imperfect knowledge. In particular, simple difference rules are better in guiding expectations toward inflation target levels, reducing inflation and output volatility.

Transparency and communication are another areas where central banks—both inflation targeters and nontargeters—should aim at further improvements. Incorporating central bank judgment and model uncertainty explicitly into the forecasting and decisionmaking process—for example, engaging in "distribution forecast targeting" rather than the usual "mean forecast targeting"—would improve monetary policy efficiency further. Yet the optimal degree of central bank transparency is also shown to depend on the quality of information provided by the central bank and how widely that information is publicized. Full transparency is optimal under reasonable central bank preferences and when the central bank has more accurate information than the private sector.

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A Prize Worth Having: the IMF and Price Stability[1]

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It is always a pleasure to be in Santiago and I am especially pleased to be able to join you at this annual conference which in its nine years has established a high reputation for the quality of the papers and the discussion.

This year's conference is focusing on the subject of inflation targeting. I want to set the scene for the two days of discussions by putting this in a broader context. My aim this morning is to assess the benefits to the world economy of a low inflation environment. I will start by reviewing the progress made in almost every country in recent years towards achieving low inflation. I will next analyze the gains that have accompanied this changing environment—notably more rapid global growth, greater stability, and reduced vulnerability. And finally I will say something about the role the IMF plays in helping to foster an environment of low inflation, especially as we seek to support the policy reform efforts of our members.

Much has been written about the origins of the worldwide decline in inflation. Ken Rogoff has argued persuasively that globalization and the growing importance of competition as economies become more integrated have made a major contribution to lowering inflation. But, equally important, we experienced an inflationary environment, and we learned its costs. As these were better understood, advances in our understanding, and practice, of monetary policy enabled most countries to bring inflation rates down, as I shall argue shortly.

It is clear that the more rapid growth of the world economy reflects, in part, improved macroeconomic management in general across an

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increasing number of countries. We've seen evidence of this in every region of the world.

The topic for this conference underlines the extent of the global interest in the pursuit of sound monetary and fiscal policies. Twenty one countries currently have inflation targeting, and thirteen of those are emerging market economies. Inflation targeting isn't appropriate for every country. But it has a remarkable record of success and it arouses interest among policymakers because it is a benchmark of best practice, to use the language of modern management. Its track record is good, if short. And as the discussion here will demonstrate, we are still learning.

We at the Fund have found there is equal interest among members in other aspects of macroeconomic management. As we all learn from the experience of others, we have been able to refine our definition of sound fiscal policies, for example, so that it encompasses public expenditure management, tax administration, and structural balance, among other things; with clear and effective budgetary control at all levels of government, and long-term debt sustainability so that fiscal objectives are not undermined.

There is also an increased appreciation of the extent of complementarity of monetary, fiscal and indeed structural economic policies. We have seen enough examples of the problems that can ensue when structural and institutional weaknesses in one area can critically undermine policy achievements in another sphere of macroeconomic management. The failure to control inflation in the late 1960s, 1970s and 1980s was at least a contributing factor to the disappointing growth performance in many parts of the world over an extended period.

The Costs of Inflation

Yet it is perhaps only with hindsight that we can truly appreciate the costs of the worldwide inflationary surge that we experienced from the 1970s onwards. We knew about the dangers and the very high costs of hyperinflation. We had seen what this could do to a society in Germany in the 1920s and again in the immediate aftermath of the Second World War.

So the dangers of runaway inflation were clear. It undermined social cohesion. It distorted the economy in arbitrary ways. It redistributed wealth in a random fashion. It wiped out those, especially the poor, on fixed incomes and who were unable to hedge. It undermined longer-term growth prospects by creating uncertainty

and acting as a disincentive to longer-term investment.

What was less obvious in the 1960s and later was that many of these costs were not confined to episodes of hyperinflation. Inflation at moderate levels was thought to be manageable. Indeed, it was regarded by governments and many academics as a useful tool to circumvent budgetary constraints, as for example, with the U.S. government during the war in Vietnam. Inflating out of trouble was politically tempting for governments around the world; and it was regarded as imposing relatively few long-term economic costs.

Other actors in society readily conspired with governments. Those with incomes that rose in real terms and those with debts that could be monetized were untroubled by moderate inflation and often welcomed it. By and large, people in upper and middle income groups could protect themselves and their assets. The poor, the most vulnerable, were those hardest hit.

The relaxed approach to inflation was already showing some signs of strain in the early 1970s. It was widely believed that the inflation rate could not be brought down without very high costs and that relatively high inflation would therefore always be with us. People thought the costs of reducing the inflation rate would be too great. But the policy response to the dramatic rise in the price of oil—by January 1974 it was 350 percent higher than the year before—turned out to be both misguided and harmful. Attempts to ease the impact of the oil shock by accommodative monetary policy helped fuel inflationary pressures, undermined fiscal discipline and resulted in significantly weaker growth in most industrial countries.

In the 1970s and 1980s, governments in both industrial and emerging market countries discovered that the more tolerant of inflation they were, the more inflation was likely to trend upwards, and the smaller the trade-off, if any, perceived between more unemployment and more inflation.

Inflation is damaging in its own right: it distorts the calculus of profitability, encouraging short-term investments and projects at the expense of longer-term investment; and it diminishes the value of relative price signals. But weak government responses that try to contain inflation simply raise its costs. Trying to administer price controls introduces further distortions into the economy without addressing the fundamental problem. Providing subsidies to offset cost increases feeds through to the fiscal deficit and accelerates inflation.

In this context, the British experience is a salutary one. In the 1970s, successive British governments struggled to control, let alone

reduce, inflation through a variety of means: voluntary and statutory wage restraints, and price controls. In the 1980s, the emphasis shifted to control of the money supply and, in turn, the adoption of an exchange rate anchor. Each of these approaches achieved some short-term success. But governments, especially in the 1980s, were too quick to assume that success would be long-lasting. They relaxed their grip, loosened policy and could then only watch as the rate of inflation rose once more.

Continuing failures undermined the efforts of the authorities to establish credibility for themselves. And the failure to build credibility in turn undermined the confidence of economic actors about the long-term prospects for price stability.

Among the industrial countries, Britain had perhaps the worst chronic problem with inflation. But the stop-go cycle familiar to Britons was equally familiar to many in emerging market economies. The reforms introduced in Turkey from 1980 onwards were undermined to a considerable extent because of the persistent failure to tackle the problem of inflation. The result was the boom-bust cycle that characterized Turkish economy policy until 2000, with inflation averaging well above 60 percent over two decades and, crucially, lower average rates of growth than would have been possible in a low inflation environment.

The Success of Counter-inflationary Policy

Conversely, countries that were successful in reducing inflation experienced more rapid growth. In the United States, the Federal Reserve under Paul Volcker re-established its credibility in counter-inflationary policy, and Alan Greenspan consolidated it. In the past two decades or so, the U.S. economy has been one of the most rapidly growing industrial countries and, indeed, over that period has grown more rapidly than many emerging market and low income countries.

Canada and Australia, too, have experienced more rapid growth, in part as a result of sound macroeconomic policies, not least of which is effective monetary policy.

And following monetary policy reforms started in 1992, Britain has at last overcome its chronic inflation problem. Inflation declined sharply in the wake of the reforms, and has remained low as a result of the implementation of a credible monetary policy, including inflation targeting. In 1997 these reforms were buttressed when the Bank of England became independent. From its most recent peak, almost 8

percent in 1991, the inflation rate has declined almost continuously: it is projected to be 1.99 percent this year, almost exactly the target rate of 2 percent.

The consequence of the markedly improved inflation performance in Britain has been more than a decade of uninterrupted growth.

Among emerging market economies, of course, it would be hard to find a better example of successful counter-inflationary strategy than Chile. In the early 1970s, inflation averaged somewhere between 500 percent and 1000 percent depending on the index used. Yet since that time, with only a few brief exceptions, inflation has declined sharply.

In 1980, steps were taken to insulate monetary policy from the political process; and in 1989, the central bank was made independent. Inflation targeting was introduced from 1990. The results of these policy reforms are clear. The average inflation rate has fallen in successive decades. In the ten years to 2004 the average inflation rate was below 5 percent. In September, twelve month inflation was 3.8 percent.

The result of these policies, along with reforms in other areas, including fiscal, social security and trade policies, has been sustained and high growth rates over a very long period. Chile stands out among its neighbors, but also among emerging market economies more generally, as a strong and stable economy, growing rapidly and capable of withstanding shocks.

More recently we have seen other dramatic examples of successful counter-inflationary policy. In Turkey reforms introduced from 2000 onwards have been designed to bring macroeconomic stability and create the conditions for rapid growth. The success of these reforms has exceeded all expectations. In 1997, Turkish inflation peaked at almost 85 percent. This year it declined to single digits, for the first time in 35 years. That by itself is a remarkable achievement, and reflects the success of sound monetary and fiscal policies. But this decline in inflation has been achieved at a time of remarkably rapid economic growth.

The progress made in countries like Chile and Turkey is indeed striking. But the drop in inflation is a truly global phenomenon.

The global inflation rate has declined from an annual average of close to 15 percent in 1980-84 to 3.7 percent in 2004. The average inflation rate in the industrial economies fell from almost 9.5 percent between 1975 and 1979, and nearly 9 percent in the early 1980s, to 2 percent in 2004 and a projected 1.6 percent this year.

In developing countries, the decline has been steeper and more rapid. In the early 1990s, the average inflation rate in developing

countries was just over 80 percent; by 2004, that had declined to 5.8 percent, and is projected to rise only slightly, to 5.9 percent, this year. Even in the transition economies, which in the early 1990s experienced average inflation rates of more than 360 percent, the average rate of inflation was down to 9.2 percent in 2004.

Last year, only three of the IMF's 184 members had inflation rates in excess of 40 percent: Angola, the Dominican Republic and Zimbabwe. Indeed, only eight countries experienced inflation above 20 percent last year and only 32 countries had double digit rates of inflation. That is a remarkable global transformation, relative to the 1970s and 1980s.

As I already noted, accompanying this significantly improved inflation performance has been more rapid global growth. In 2004, the world economy grew more rapidly than at any time in the past three decades, with growth in every region. Periods of global expansion are longer, and worldwide slowdowns are fewer and shorter. At a time of considerable geopolitical uncertainty and shocks that have included a sharp rise in oil prices, the world economy has exhibited more resilience than we would have anticipated a few years ago. Improved macroeconomic performance of which the fall in inflation rates is part goes at least part of the way towards explaining this.

Towards Price Stability

In part, at least, the story of falling inflation worldwide is simply one of success breeding success. In many cases, initial efforts to curb and then permanently reverse the rise in inflation rates were made by policymakers confronting rates in excess of 20 percent. These efforts needed tough monetary medicine, with the focus particularly on quantitative controls on the money supply. Typically, this approach had, in its initial stages at least, a sharp impact on growth.

But as persistence paid off, and inflation rates did indeed start to fall towards 10 percent, it became increasingly apparent that the benefits of lower inflation exceeded the short-term costs of counter-inflationary policy; and that as inflationary expectations responded to declining inflation rates those benefits increased. As a result, the focus of policy shifted again, towards getting inflation rates into single digits, and aiming for price stability.

The adoption of inflation targeting has played a key role in the success that many countries have achieved in moving towards price stability. Inflation targeting has so far been successful in both the industrial and emerging market countries that have adopted

it. Regardless of the origins of the inflation targeting policy, the evidence suggests that inflation targeting can contribute significantly towards the achievement of price stability. It helps build credibility for the monetary authorities, crucial given the important role that expectations play in determining the future path of inflation. And in spite of the wide variations in the economic and institutional circumstances of the countries that have so far adopted inflation targeting, they share common factors: central bank independence, improvements in implementation and increasing transparency.

IMF research shows that missing the target may not undermine the longer-term success of a targeting regime. Among countries targeting stable inflation, the targets were missed about 30 percent of the time. Among countries seeking to achieve significant disinflation, the figure is even higher. This is not a sign that inflation targeting has failed however. No country has abandoned inflation targeting as a result of missing its targets, even when the target has been missed by a significant margin, or for a prolonged period. Rather, people have sought to learn from experience. Inflation targeting appears to be a resilient policy framework, providing flexibility in the face of shocks, as well as transparency and accountability. To be sure, credibility is a key aspect, and the monetary authorities must focus single-mindedly on the targets to which they commit.

Inflation targeting anchors expectations and so helps lock in the benefits of declining inflation. It strengthens the independence of the monetary authorities, and reduces the risk that short-term political objectives will undermine policy. And because experience with inflation targeting has tended to highlight the importance of transparency in policymaking, it has brought important and, we hope, lasting improvements in economic governance. Of course, there is still much to learn about why inflation targeting has been so successful and about its design and implementation and this is why we are here today.

The Benefits of Low Inflation

Inflation targeting has already contributed to our awareness of the benefits of low inflation. At one time, the most powerful argument in favor of firm policy action to reduce inflation was to reduce its associated costs, although it was perhaps not always appreciated that one of these costs was growth foregone. In countries that succeeded in reducing inflation, distortions were fewer. The uncertainty that

inhibited investment and affected consumers' behavior was greatly reduced. The prospects for economic growth improved as did the ability to withstand shocks. Low and falling inflation made macroeconomic stability attainable.

But as inflation has declined worldwide, the benefits have become increasingly obvious. As I noted, economic growth has accelerated in those countries that have experienced significant declines in inflation. Even in Africa, the countries that have done most to achieve macroeconomic stability—of which low inflation is an essential element—are generally the ones that have started to see higher growth rates. In spite of higher oil prices and poor harvests, inflation performance has continued to improve across the continent. This year, 30 sub-Saharan African countries will achieve inflation rates in single digits, up from 28 countries in 2004. Average inflation rates across the region should fall to 8.3 percent next year.

And the growth numbers are equally striking. The IMF expects three non-oil producing countries in Sub-Saharan Africa—Ethiopia, Mozambique and Sierra Leone—to experience real GDP growth in excess of 7 percent this year; growth in real per capita GDP should approach or exceed 5 percent in those countries. Ghana, Tanzania and Uganda are among other African economies with continuing strong performance. Sub-Saharan Africa as a whole should grow by 5.3 percent next year. There is still a way to go to achieve growth rates that will permit significant poverty reduction, but compared with the growth rates experienced even just a few years ago, the signs are hopeful.

As the Chileans here today know, countries with low inflation do significantly better in terms of growth performance than countries with higher rates of inflation, even in the same region. Chile's success over a prolonged period reflects a sustained commitment to reform across a wide range of economic policies. But low inflation has been a critical element of those reforms. Similarly in Turkey: rapid growth is the result of strict adherence to monetary, fiscal and structural reforms: but again, the objective of a rapid decline in inflation was a central part of the reform strategy. And Turkish growth rates during a period of major fiscal consolidation have been well above even the most optimistic expectations.

South Africa has experienced a doubling of its growth rate, to a projected 4.3 percent this year, compared with the average growth rate in the decade to 1996 of 1.7 percent. And its inflation rate has fallen dramatically over the same period from an average of 12 percent in the ten years to 1996 to 3.9 percent projected this year.

As the benefits of low inflation become apparent, and as governments learn more about how to reduce inflation, so inflation is projected to continue to decline, albeit it at a much more modest pace according to the IMF's latest World Economic Outlook.

Beyond the recognition that economic performance improves as inflation declines, perhaps the most important lesson learned from the experience of recent years is that reducing inflation can impose fewer short-term costs on an economy that is sufficiently flexible than had previously been thought. The stop-go or boom-bust cycles to which I referred earlier had led many policymakers to believe that a rapid decline in inflation could only be achieved by severely squeezing domestic demand, with obviously painful consequences. This led policymakers, first, to postpone counter-inflationary policies until action was forced on them in the context of a crisis of one kind or another; and then to relax policy as rapidly as they could. The inevitable result of such an approach was a failure to ensure inflation was on a declining path.

In recent years, however, we have seen that this cycle was far from inevitable. An increasing number of countries have experienced the benefits that Chile and others have long enjoyed—a virtuous circle, whereby low inflation helps create macroeconomic stability which is the prerequisite for sustained rapid growth. A credible monetary policy reduces economic uncertainty among all actors; and it reduces the distortions caused by actors anticipating a pickup in inflation.

Low inflation is also an important tool in the effort to reduce poverty. First, since the poor are those most vulnerable to the effects of high inflation and least able to hedge against the risks, sustained low inflation brings obvious benefits for them. And second, low inflation is a prerequisite for, and a precursor of, more rapid growth which is, in turn, essential for a sustained reduction in poverty.

But in this new world of low inflation other benefits are becoming apparent. The greater stability that national economies experience as a result of price stability has a global impact as more countries achieve it. Global growth is less volatile—and higher. Low inflation helps national economies reduce their vulnerability to shocks, and to cope more comfortably with cyclical slowdowns. This, too, has an impact on the global economy. The global slowdown of 2001 was more modest than previous episodes, and the world economy recovered more rapidly.

Low inflation ensures that there are fewer government-induced shocks in an economy, although it does not, of course, eliminate economic shocks altogether. Nor can it insulate economic actors, or national economies, or the global economy, from such shocks. But it does help reduce the impact

of those shocks. It can help raise potential growth rates and it can make economies more resilient. Effective monetary policy aimed at controlling inflation can also help offset the second round effects of shocks instead of exacerbating them as we saw in the 1970s oil price increases.

The Role of the IMF

Essentially, I have been describing a global learning process as the benefits of low inflation have become increasingly apparent in recent years. We at the Fund have learned as much as anyone from this process.

Just how far the economic profession has come in understanding the benefits to be had can be found in the October 1959 volume of IMF Staff Papers. U Tun Wai, then chief of the Statistics Division at the Fund, set out to explore the links between inflation and growth. Let me quote his opening sentence:

> "The relation between inflation and economic growth in less developed countries is a subject on which there are still very wide differences of opinion."

Mr. Tun Wai's contribution was significant: using statistical analysis he was able to conclude that where the data existed for a long enough period, and for countries that had experienced wide variations in inflation, low inflation was clearly linked with economic growth.

The Fund works with members to advance the process of reducing the inflation rate in a number of ways. Surveillance is at the heart of the Fund's work, of course. We conduct Article IV consultations with our members to identify policy weaknesses and successes. Where governments are seeking to implement appropriate polices we can be supportive; where we identify policy shortcomings we can try to persuade the authorities of the need for reforms.

Our surveillance work is greatly strengthened by the Fund's unique cross-country insight. Our ability to monitor closely the economies of all 184 members enables us to identify what works and what doesn't. It helps inform our research as we seek to improve our understanding. Our membership gains directly from that: they can benefit from experience elsewhere when shaping their own policy framework to their national concerns and priorities.

The Fund's efforts go beyond surveillance and policy advice to technical assistance with policy implementation. This is particularly

important for our low income members. Having the right policy objectives is one thing: lacking the technical expertise to implement these objectives can be a significant obstacle for some countries, and the Fund can help. We provide technical assistance on a wide range of issues, not least in the area of monetary policy and central bank strategies.

And the Fund has been active in fostering research into, and discussion of, inflation targeting. The latest World Economic Outlook, for example, contains a wide-ranging assessment of experience with inflation targeting. And, as you can see from the conference timetable, IMF economists are presenting papers at this conference, a further reflection of the Fund's active research agenda into this important topic. The more we know about inflation targeting, its effectiveness and its implementation, the more we can assist our members both through our surveillance work but also through the provision of advice and technical expertise to those countries adopting, or considering, inflation targeting.

The Ongoing Challenge

Much has been achieved in recent years in terms of delivering low inflation and experiencing the benefits of macroeconomic stability. The challenges for economists and policymakers going forward are threefold.

First is to ensure that the benefits are locked in-and that means putting in place policies that will continue to lower inflation and then maintain price stability within a given target range. Currently we are seeing a worrying tendency among some governments to try to protect consumers from the impact of higher oil prices. This is distortionary, and the fiscal impact can itself be inflationary: it is not possible to protect economic actors from market realities indefinitely. Trying to do so stores up enormous problems for governments: the cost of subsidies, for example, places an unsustainable burden on government budgets, undermining attempts to maintain fiscal discipline. If consumers are not exposed to market realities they will not have the incentive to adjust their behavior and, in the case of higher oil prices, act to conserve energy and so reduce demand for oil.

The consequences of such distorting behavior will, ultimately, be higher inflation rates and lower growth rates as the objectives of macroeconomic stability are progressively undermined. So far in most countries there is little evidence of second round effects of the

energy price increases. It is particularly encouraging, for example, to see the government of Indonesia recognizing the inherent dangers of fuel subsidies and seeking to remove them and provide direct targeted assistance to the poor who are most vulnerable to the effects of more expensive fuel.

The second challenge facing policymakers is, in a sense, a consequence of recent success in achieving price stability. How far should policies to lower inflation go? I noted that the costs of lowering inflation, when there is sufficient flexibility in the economy, had been much less than had been assumed by many policymakers in the past. That is certainly true. When we look at the more rapid growth that has accompanied the dramatic fall in Turkish inflation, for example, we can see clearly that the benefits far outweigh the costs.

And finally, we need to know far more than we yet do about the transition to inflation targeting: how best to design and implement the new framework, and how to decide on issues such as defining the target and introducing an appropriate degree of transparency. Which brings us to this conference. These, of course, are some of the issues that will be discussed here over the next two days.

Conclusion

So let me sum up briefly. The sharp decline in inflation rates we have witnessed has been as remarkable as it has been widespread. It has been achieved at a lower cost than we would have thought possible twenty five years ago; and the benefits have been greater than once seemed likely. Low inflation has been at the heart of the improved economic performance we have witnessed. No country has achieved sustained rapid growth without low inflation—just as no country has achieved sustained rapid growth without opening up to the rest of the world.

Successful monetary policy that consistently delivers low inflation is therefore critical to long-term economic success. And monetary policy can only be successful over time with a proper institutional framework, one that makes it difficult for long-term stability to be sacrificed for short-term political advantage. Inflation targeting is clearly one solution that provides this framework, hence its attractiveness for many, and hence the focus of this conference.

The challenges I have identified for policymakers going forward are a consequence of success. When inflation is high, or rising rapidly, the question of how to maintain price stability once achieved seems a rather less pressing one. These are challenges that apply regardless

of the means adopted for achieving and maintaining price stability. But any policy framework must be capable of assuring its continuity. And any framework needs some way of assessing the benefits and costs of particular policy options if it is to succeed over the medium and longer term.

This is an area where the Fund, with the unique overview that its surveillance provides, along with the extensive research work we undertake, can contribute. We can help identify best practice in inflation targeting; and, as we do in many other areas of economic policy, provide advice, support and technical assistance tailored to the individual needs of our member countries.

As a relatively new development in economic policymaking, inflation targeting is an area rich in opportunities for research. We have much to learn, and countries seeking to achieve price stability have, potentially, much to gain from the fruits of economic research—and from the Fund's surveillance activities. This conference is therefore both timely and important and I look forward to hearing much of the discussion.

Thank you.

Optimal Inflation Targeting under Alternative Fiscal Regimes

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Inflation targeting has become an increasingly popular approach to the conduct of monetary policy worldwide since the early 1990s. Most of the countries that have adopted inflation targeting judge the experiment favorably, at least thus far. In many countries, the adoption of inflation targeting has been associated with reductions in both the average level and the volatility of inflation. Inflation targeting has been especially successful in stabilizing inflation expectations.[1] This stems from inflation-targeting central banks' emphasis on a clear medium-term commitment for inflation (while temporary departures from the inflation target are allowed) and their increased communication with regard to the outlook for inflation over the next few years.

This approach to monetary policy, however, may not be equally suitable for all countries, regardless of their existing institutions, the disturbances to which their economy is subject, and the other policies pursued by the government. One question worthy of discussion is how a country's fiscal policies might affect the suitability of inflation targeting as an approach to the conduct of monetary policy.

The theoretical literature that develops the case for inflation targeting largely neglects the fiscal consequences of a commitment to

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1. Levin, Natalucci, and Piger (2004) compare inflation expectations in inflation-targeting and non-inflation-targeting countries.

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an inflation target.[2] The models used to analyze monetary stabilization policy usually abstract from the government's budget and the dynamics of the public debt, so that any fiscal effects of monetary policy decisions are tacitly assumed to be irrelevant. This may be an acceptable simplification if one is choosing a policy for an economy with sound government finances, by which we mean one with relatively nondistorting sources of revenue and an unquestionable political will to maintain government solvency. The degree to which such an idealization of the circumstances of fiscal policy is realistic varies across countries. As inflation targeting becomes popular in developing countries that have recently had serious problems with inflation precisely because of their precarious government finances, one may wonder how safe it is to ignore the interrelation between monetary and fiscal policy choices.

A number of authors suggest that the appropriateness of inflation targeting as a policy recommendation may depend critically on the nature of fiscal policy. For example, Fraga, Goldfajn, and Minella (2004), in their discussion of inflation targeting for developing countries, remark that

> "...the success of inflation targeting (...) requires the absence of fiscal dominance" (p. 383).

They go on to stress that not only must fiscal policy be sound in this respect, but its continued soundness must be credible. Their intent is not to suggest developing countries ought not adopt inflation targeting, but rather to emphasize the importance of enacting credible fiscal reforms, as well. Nevertheless, their insistence on the need for fiscal commitments that are not obviously present in many developing countries raises the question of whether inflation targeting is ill-advised in such countries.

Sims (2005) enunciates exactly this view. He argues that some countries' fiscal policies may make the achievement of a target rate of inflation by the central bank impossible, in the sense that there is no possible rational-expectations equilibrium in which the target is fulfilled, regardless of the conduct of monetary policy. He further asserts that in such a case, attempting to target inflation may not only be doomed to frustration, but could even be harmful, by leading to less stability (even less stability of the inflation rate) than might

2. See, for example, King (1997), Svensson (1997, 1999, 2003), Woodford (2003, chaps. 7–8), Walsh (2003, chap. 11), or Svensson and Woodford (2005) for the theoretical case for some version of inflation targeting as an optimal policy.

have been achieved through other policies. His essential argument is that if the fiscal regime ensures that primary budget surpluses are not (sufficiently) increased in response to a monetary tightening, then a policy intended to contain inflation—namely, raising nominal interest rates sharply when inflation rises above the inflation target—may cause an explosion of the public debt, which ultimately requires even larger price increases than would have been necessary had the debt not grown. Loyo (1999) and Blanchard (2005) provide examples of models in which "orthodox" monetary policies of this kind lead to explosive debt dynamics.

Our goal in this paper is to analyze the character of an optimal monetary policy commitment under alternative assumptions about the character of fiscal policy, in order to determine the conditions under which an optimal policy will be similar to inflation targeting and the extent to which the form of an optimal monetary policy rule depends on the nature of fiscal policy. To address these issues, we extend the framework used to analyze optimal monetary stabilization policy in Benigno and Woodford (2005a), which allows us to explicitly model debt dynamics and the conditions required for intertemporal government solvency and also to treat the effects of tax distortions. We consider a variety of assumptions regarding the character of fiscal policy, including the kind of fiscal regime—under which the real primary budget surplus is not adjusted to prevent explosion of the public debt as a result of an interest rate hike—that is at the heart of the Loyo (1999) and Blanchard (2005) examples of possible perverse effects of tight-money policies.

1. A Model with Nontrivial Monetary and Fiscal Policy Choices

We use a standard new Keynesian model of the trade-offs involved in monetary stabilization policy, augmented to take account of tax distortions.[3]

1.1 The Model

The goal of policy is assumed to be the maximization of the level of expected utility of a representative household. In our model, each household seeks to maximize

3. Further details of the derivation of the structural equations of our model of nominal price rigidity can be found in Woodford (2003, chap. 3).

$$U_{t_0} \equiv E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[\tilde{u}(C_t;\xi_t) - \int_0^1 \tilde{v}(H_t(j);\xi_t) dj \right], \tag{1}$$

where C_t is a Dixit-Stiglitz aggregate of consumption of each of a continuum of differentiated goods,

$$C_t \equiv \left[\int_0^1 c_t(i)^{\theta/(\theta-1)} di \right]^{(\theta-1)/\theta}, \tag{2}$$

with an elasticity of substitution equal to $\theta > 1$, and $H_t(j)$ is the quantity supplied of labor of type j. Each differentiated good is supplied by a single monopolistically competitive producer. We assume that there are many goods in each of an infinite number of industries; the goods in each industry, j, are produced using a type of labor that is specific to that industry, and their prices are also changed at the same time. The representative household supplies all types of labor and consumes all types of goods. To simplify the algebraic form of our results, we restrict attention in this paper to the case of isoelastic functional forms,

$$\tilde{u}(C_t;\xi_t) \equiv \frac{C_t^{1-\tilde{\sigma}^{-1}} \bar{C}_t^{\tilde{\sigma}^{-1}}}{1-\tilde{\sigma}^{-1}} \text{ and}$$

$$\tilde{v}(H_t;\xi_t) \equiv \frac{\lambda}{1+\nu} H_t^{1+\nu} \bar{H}_t^{-\nu},$$

where $\tilde{\sigma}, \nu > 0$ and $\{\bar{C}_t, \bar{H}_t\}$ are bounded exogenous disturbance processes. (We use the notation ξ_t to refer to the complete vector of exogenous disturbances, including $\bar{C}_t$ and $\bar{H}_t$.)

We assume a common technology for the production of all goods, in which (industry-specific) labor is the only variable input,

$$y_t(i) = A_t f(h_t(i)) = A_t h_t(i)^{1/\phi},$$

where A_t is an exogenously varying technology factor, and $\phi > 1$. We invert the production function to write the demand for each type of labor as a function of the quantities produced of the various differentiated goods, and we use the identity

$$Y_t = C_t + G_t$$

to substitute for C_t, where G_t is exogenous government demand for the composite good. We can then write the utility of the representative household as a function of the expected production plan, $\{y_t(i)\}$.[4]

The producers in each industry fix the prices of their goods in monetary units for a random interval of time, as in the model of staggered pricing introduced by Calvo (1983). We let $0 \leq \alpha < 1$ be the fraction of prices that remain unchanged in any period. A supplier that changes its price in period t chooses its new price $p_t(i)$ to maximize

$$E_t\left[\sum_{T=t}^{\infty}\alpha^{T-t}Q_{t,T}\Pi(p_t(i),p_T^j,P_T;Y_T,\tau_T,\xi_T)\right], \tag{3}$$

where $Q_{t,T}$ is the stochastic discount factor by which financial markets discount random nominal income in period T to determine the nominal value of a claim to such income in period t, and α^{T-t} is the probability that a price chosen in period t will not have been revised by period T. In equilibrium, this discount factor is given by

$$Q_{t,T} = \beta^{T-t}\frac{\tilde{u}_c(C_T;\xi_T)P_t}{\tilde{u}_c(C_t;\xi_t)P_T}. \tag{4}$$

The function,

$$\Pi(p,p^j,P;Y,\tau,\xi) \equiv (1-\tau)pY(p/P)^{-\theta} - \mu_t^w\frac{\tilde{v}_h\left(f^{-1}\left(Y(p^I/P)^{-\theta}/A\right);\xi\right)}{\tilde{u}_c(Y-G;\xi)}p\cdot f^{-1}\left(Y(p/P)^{-\theta}/A\right)$$

indicates the after-tax nominal profits of a supplier with price p, in an industry with common price p^j, when the aggregate price index is equal to P, aggregate demand is equal to Y, and sales revenues are taxed at rate τ. Profits are equal to after-tax sales revenues net of the wage bill. The real wage demanded for labor of type j is assumed to be given by an exogenous markup factor μ_t^w (which is allowed to vary over time, but is assumed common to all labor markets) times the marginal rate

4. We assume that the government needs to obtain an exogenously given quantity of the Dixit-Stiglitz aggregate in each period, in a cost-minimizing fashion. The government thus allocates its purchases across the suppliers of differentiated goods in the same proportion as do households, and the index of aggregate demand, Y_t, is the same function of the individual quantities, $\{y_t(i)\}$, as C_t is of the individual quantities consumed, $\{c_t(i)\}$, defined in equation (2).

of substitution between work of type j and consumption, and firms are assumed to be wage takers. We allow for wage markup variations in order to include the possibility of a pure cost-push shock that affects equilibrium pricing behavior while implying no change in the efficient allocation of resources. Variation in the tax rate, τ_t, has a similar effect on this pricing problem (and hence on supply behavior), so when the evolution of the tax rate is treated as an exogenous political constraint, variations in the tax rate also act as pure cost-push shocks.

We abstract here from any monetary frictions that would account for a demand for central bank liabilities that earn a substandard rate of return; we nonetheless assume that the central bank can control the riskless short-term nominal interest rate i_t.[5] This, in turn, is related to other financial asset prices through the arbitrage relation,

$$1 + i_t = (E_t Q_{t,t+1})^{-1}. \tag{5}$$

We assume that the zero lower bound on nominal interest rates never binds under the optimal policies considered below. We therefore do not need to introduce any additional constraints on the possible paths of output and prices associated with the need for the chosen evolution of prices to be consistent with a nonnegative nominal interest rate.

Our abstraction from monetary frictions, and hence from the existence of seignorage revenues, does not mean that monetary policy has no fiscal consequences, since interest rate policy and the equilibrium inflation that results from it have implications for the real burden of government debt. In our baseline analysis, we assume that all public debt consists of riskless nominal one-period bonds.[6] The nominal value, B_t, of end-of-period public debt then evolves according to a law of motion,

$$B_t = (1 + i_{t-1}) B_{t-1} - P_t s_t, \tag{6}$$

where the real primary budget surplus is given by

$$s_t \equiv \tau_t Y_t - G_t - \zeta_t, \tag{7}$$

where ζ_t represents the real value of (lump-sum) government transfers. Rational-expectations equilibrium requires that the expected path

5. For a discussion of how this is possible even in a cashless economy of the kind assumed here, see Woodford (2003, chap. 2).

6. The consequences of longer-maturity public debt are discussed in section 3.3.

of government surpluses must satisfy an intertemporal solvency condition,

$$b_{t-1}\frac{P_{t-1}}{P_t} = E_t\sum_{T=t}^{\infty} R_{t,T}s_T \ , \tag{8}$$

in each state of the world that may be realized at date t, where $R_{t,T} \equiv Q_{t,T}P_T/P_t$ is the stochastic discount factor for a real income stream.

We consider alternative assumptions about the degree of endogeneity of the various contributions to the government budget in equation (7). In the conventional literature on optimal monetary stabilization policy, both G_t and τ_t are exogenous processes (among the real disturbances to which monetary policy may respond), but ζ_t can be adjusted endogenously to ensure intertemporal solvency in a way that creates no deadweight loss, so that the fiscal consequences of monetary policy are not significant for welfare. We also consider a more realistic case in which G_t and ζ_t are exogenous disturbances, and additional government revenue has a positive shadow value, but τ_t can be varied endogenously to minimize deadweight loss. In the most constrained case, where the concerns stressed by Sims (2005) arise, G_t, τ_t, and ζ_t are all exogenous processes determined by political constraints.

1.2 An Associated Linear-Quadratic Policy Problem

We approximate the solution to our optimal policy problem by the solution to an associated linear-quadratic (LQ) problem; the derivation of the approximations is presented in detail in Benigno and Woodford (2004). We show that we can define an LQ problem with the property that the solution to the LQ problem is a linear approximation to optimal policy in the exact model when the exogenous disturbances are small enough.

First, we show that maximization of expected utility is (locally) equivalent to minimization of a discounted loss function of the form

$$E_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left[\frac{1}{2}q_y\left(\widehat{Y}_t - \widehat{Y}_t^*\right)^2 + \frac{1}{2}q_\pi\pi_t^2\right], \tag{9}$$

where the target output level, $\widehat{Y}_t^*$, is a function of exogenous disturbances. If steady-state tax distortions are not too extreme, then q_y, $q_\pi > 0$ and the loss function is convex, as assumed in conventional accounts of the goals of monetary stabilization policy.

The constraints on possible equilibrium outcomes are given by log-linear approximations to the structural equations of the model described above. Here we omit derivations and proceed directly to the log-linear forms. First, there is an aggregate supply relation between current inflation and real activity,

$$\pi_t = \kappa\left(\hat{Y}_t + \psi\hat{\tau}_t + c_\xi'\boldsymbol{\xi}_t\right) + \beta E_t\pi_{t+1}, \tag{10}$$

where κ, $\psi > 0$. This is the familiar new Keynesian Phillips curve, augmented to include the cost-push effects of variations in the sales tax. We can write the constraint in terms of the welfare-relevant output gap,

$$y_t \equiv \widehat{Y}_t - \widehat{Y}_t^*,$$

in which case equation (10) becomes

$$\pi_t = \kappa(y_t + \psi\hat{\tau}_t + u_t) + \beta E_t\pi_{t+1},$$

where u_t is a composite cost-push term associated with exogenous disturbances other than variations in the tax rate.[7] In other words,

$$\pi_t = \kappa\left[y_t + \psi\left(\hat{\tau}_t - \hat{\tau}_t^*\right)\right] + \beta E_t\pi_{t+1}, \tag{11}$$

where $\hat{\tau}_t^*$ is a function of exogenous disturbances that indicates the tax change needed to offset the other cost-push terms.

Another constraint on the possible equilibrium paths of inflation, output, and tax rates is the condition for intertemporal government solvency (equation 8).[8] A log-linear approximation to equation (8) takes the form

7. An obvious source of such disturbances would be variations in the wage markup, μ_t^w. This is the only source of variations in u_t when the steady-state involves no distortions. In the case of a distorted steady state, however, most other kinds of real disturbances also have cost-push effects (as shown in Benigno and Woodford, 2004), since they do not move the flexible-price equilibrium level of output to precisely the same extent (in percentage terms) as they move the efficient level of output. The latter sources of cost-push terms become more important as the magnitude of the steady-state distortions increases.

8. This does not amount to requiring that fiscal policy be Ricardian; we consider below the consequences of non-Ricardian fiscal policies of the kind assumed in the warnings of Sims (2005). Instead, equation (8) is a condition that must hold *in equilibrium* under any policy, and it constrains the possible outcomes that can be achieved in determining the best equilibrium under certain constraints on possible policies.

$$\hat{b}_{t-1} - \pi_t - \sigma^{-1} y_t = -f_t + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} \left[b_y y_T + b_\tau \left(\hat{\tau}_T - \hat{\tau}_T^* \right) \right], \tag{12}$$

where f_t is a composite of the various exogenous disturbances that we refer to as fiscal stress. We have written the constraint in terms of the output gap and the tax gap, $\hat{\tau}_T - \hat{\tau}_T^*$, which indicates departures of the tax rate from the level consistent with complete stabilization of both inflation and the output gap. Therefore, the term f_t (or, more precisely, the sum $\hat{b}_{t-1} + f_t$) measures the extent to which intertemporal solvency prevents complete achievement of the stabilization goals represented in equation (9).

Here we have substituted equation (4) for the stochastic discount factor (and replaced C_t by $Y_t - G_t$) to obtain a relation that involves only the initial public debt and the paths of inflation, output, taxes, and the various exogenous variables. The effects of interest rate policy on debt dynamics are the key to the scenarios of Loyo, 1999, and Blanchard, 2005, under which tight money can be inflationary. We take these effects into account through the presence of the stochastic discount factor in equation (8), which is linked to the interest rate controlled by the central bank through equation (5). Interest rates do not appear in equation (12) because we have already substituted for them using the connection between interest rates and the paths of output and inflation that must hold in equilibrium, but the effect of tight money on the burden of the public debt is nonetheless taken into account in this equation.

In writing equation (12) in the form given, we have treated ζ_t (real net transfers) as one of the exogenous disturbances that affects the fiscal stress term. For the case in which net transfers are endogenous and can be varied to ensure solvency, we need to separate out the ζ_t term from the other (exogenous) determinants of f_t. The solvency constraint ceases to bind, however, given that the level of transfers affects neither the aggregate supply trade-off (equation 11) nor the loss function (equation 9), so that policymakers are free to vary ζ_t as necessary to satisfy equation (12). Thus we do not need to write the solvency constraint, except for the case in which ζ_t is exogenous.

2. Optimal Inflation Targeting: The Conventional Analysis

We begin by using the framework sketched in the previous section to recapitulate well-known arguments for a form of flexible inflation

targeting as a way of implementing an optimal state-contingent monetary policy, highlighting the role of (often tacit) assumptions about fiscal policy in deriving these familiar results.[9] The conventional analysis of optimal monetary stabilization policy in a new Keynesian model corresponds to the case of the above model in which the processes $\{G_t, \tau_t\}$ are both exogenously given as political constraints on what policy can achieve, while the level of net lump-sum transfers, ζ_t, is an endogenous policy variable (along with the short-term nominal interest rate). When lump-sum transfers can be chosen to facilitate stabilization policy, the intertemporal solvency constraint ceases to bind, and it can be omitted from our description of the policy problem. We can similarly omit any reference to the path of the public debt. Moreover, when the level of distorting taxes is given exogenously, we can treat the $\hat{\tau}_t$ term in equation (10) the same as the other cost-push terms.

The problem of optimal stabilization policy is then simply to find paths $\{\pi_t, y_t\}$ to minimize equation (9) subject to the single constraint,

$$\pi_t = \kappa(y_t + u_t) + \beta E_t \pi_{t+1}, \tag{13}$$

where the definition of u_t is now modified to include the cost-push effects of variations in τ_t (if these are present). This is the optimal policy problem treated, for example, in Clarida, Galí, and Gertler (1999). Here we emphasize how this conception of the goals of monetary stabilization policy provides an argument for inflation targeting.

A first, simple conclusion about optimal policy under these assumptions is that in the absence of cost-push disturbances, optimal policy would involve adjusting interest rates as necessary to maintain zero inflation at all times. This is easily seen from the fact that if $u_t = 0$ at all times, equation (13) is consistent with maintaining both a zero inflation rate and a zero output gap at all times, and such an outcome obviously minimizes the loss function (equation 9).

This provides one argument for inflation targeting: if cost-push shocks are unimportant (because distortions from market power and taxes are both small, on average, and fairly stable over time), then a low, stable inflation rate is optimal, regardless of the degree of variability in real activity that this may entail (owing to the effects

9. See, for example, Clarida, Galí, and Gertler (1999), Svensson (2003), Woodford (2003, chaps. 7–8; 2004), or Svensson and Woodford (2005) for more detailed presentations of the arguments summarized here.

of preference and technology disturbances on Y_t^*). It also implies something of more general validity: even when random cost-push shocks of substantial magnitude do occur, optimal policy should involve zero inflation, on average. (This follows from the previous result using the certainty-equivalence property of linear- quadratic optimization problems.)[10] The optimal long-run inflation target is thus quite low (zero, in our simple model), regardless of the degree of distortions in the economy or the degree to which the optimal output level may exceed the level associated with stable prices. Given that any departures from this constant long-run average inflation rate stemming from cost-push shocks should be transitory, expected inflation in the medium term should always be near zero. Therefore, our result justifies a policy that seeks to maintain low and stable medium-term inflation expectations, as at least one criterion that an optimal policy should satisfy.

The conception of optimal stabilization policy just proposed provides an important reason for a central bank to commit itself to an explicit target for inflation, rather than for other variables (such as real activity), even when cost-push shocks are expected to be nontrivial. In the optimal control of a forward-looking system—the kind of problem just posed above—the advance commitment of policy generally offers advantages by influencing expectations at earlier dates in a way that improves the available stabilization outcomes at those dates. But what aspect of future expectations matter? When the only constraint on what policy can achieve is the aggregate supply relation (equation 13), the only aspect of future expectations that affects the inflation and output gap that can be achieved in some period t is expectations regarding future inflation, $E_t\pi_{t+1}$. Hence, this type of commitment is directly relevant: committing to achieve a particular inflation rate in the future, which might be different from what would otherwise be chosen later to best achieve one's stabilization goals. Given that the role of a policy commitment should be to anchor the public's inflation expectations, a commitment regarding future inflation and the central bank's communication of the outlook for inflation are straightforward ways to achieve the benefits associated with an optimal policy commitment.

10. See Svensson and Woodford (2003) for a discussion of certainty equivalence in the context of policy problems with forward-looking constraints, like the one considered here.

Beyond these general considerations, one can easily characterize the optimal state-contingent evolution of prices and quantities under a particular assumption about the character of the disturbances affecting the economy (though this aspect of our conclusions depends strongly on the precise details of our assumed model of the transmission mechanism of monetary policy). The following first-order conditions are associated with the policy problem stated above:

$$q_\pi \pi_t = \kappa^{-1}(\varphi_t - \varphi_{t-1}) \text{ and} \tag{14}$$

$$q_y y_t = \varphi_t, \tag{15}$$

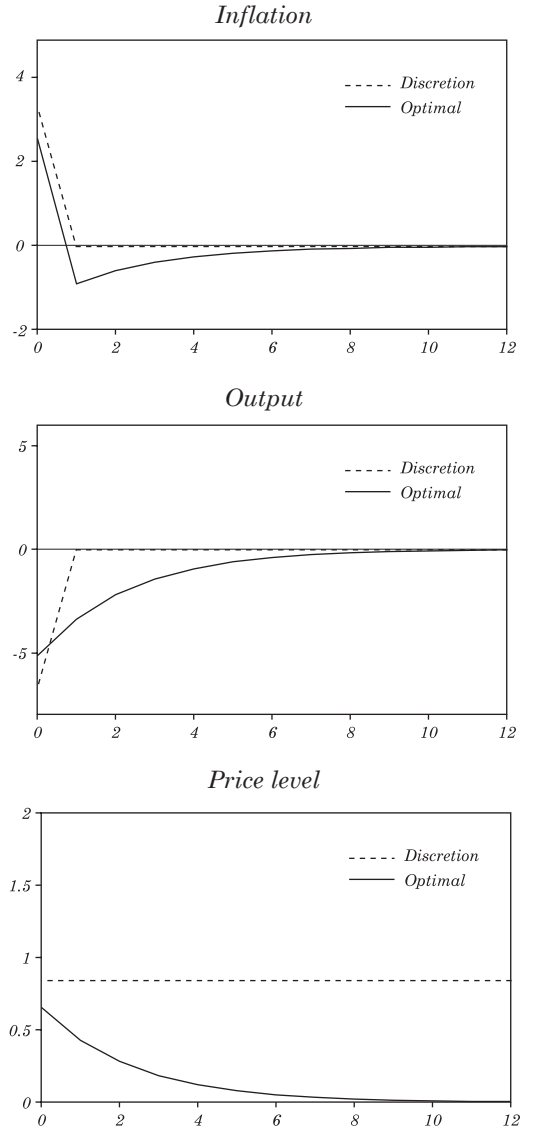
each of which must hold for each $t \geq 0$. Here, φ_t is the Lagrange multiplier associated with the aggregate supply constraint (equation 13). We can solve conditions (14) and (15), together with the aggregate supply relation (equation 13), for the optimal evolution of $\{\pi_t, y_t\}$ given the disturbances $\{u_t\}$.

The optimal state-contingent responses can be implemented through commitment to a constant target for the output-gap-adjusted price level:

$$\tilde{p}_t \equiv p_t + \frac{q_y}{\kappa q_\pi} y_t, \tag{16}$$

where p_t denotes log P_t, as discussed in Woodford (2003, chap. 7). A targeting rule of this form determines the optimal trade-off between price increase and output decline that should be selected when the shock occurs; the policy stance should be neither so tight as to cause $\tilde{p}_t$ to decline (as would be required for there to be no increase in prices) nor so loose as to allow $\tilde{p}_t$ to rise (as would be required for there to be no reduction in output relative to target output). At the same time, commitment to adhere to such a rule in the future automatically implies invariance of the expected long-run price level and output gap, and it determines the optimal rate of return of both variables to those long-run levels. The output gap should not return to zero too quickly (which would allow prices to remain high and so involve an increase in the gap-adjusted price level) or too slowly (which would cause the gap-adjusted price level to fall once the cost-push disturbance had dissipated). Figure 1 provides an example of the optimal impulse responses of inflation and the output gap to a purely transitory positive cost-push shock (that is, the solution to the first-order conditions listed

Figure 1. Impulse Responses to a Transitory Cost-Push Shock under Discretionary Policy and an Optimal Commitment.



Source: Woodford (2003, chap. 7, fig. 7.3).

above in the case of such a disturbance).[11] The dynamic paths of the log price level and the output gap are perfect mirror images of one another, up to scale, so that $\tilde{p}_t$ is not allowed to vary.

This is an example of a robustly optimal policy rule in the sense of Giannoni and Woodford (2002): commitment to the same target criterion is optimal, regardless of the statistical properties of the disturbance process. (The optimal dynamic responses shown in figure 1 will be different in the case of a shock that is not completely transitory or not wholly unexpected when it occurs, but the optimal responses of p_t and y_t will always mirror one another in the way shown in the figure.) The first-order conditions of equations (14) and (15) can be used directly to show that $\tilde{p}_t$ must not change over time under an optimal policy, without making any assumptions about the nature of the disturbance.

Such a policy prescription can be viewed as a form of flexible inflation targeting, since the requirement that $\Delta \tilde{p}_t = 0$ can equivalently be written as

$$\pi_t + \frac{q_y}{\kappa q_\pi} \Delta y_t = 0 \cdot$$

In this form, the rule states that the acceptable rate of inflation at any point in time should vary depending on the rate of change of the output gap. Svensson and Woodford (2005) discuss a more realistic version of this prescription, which incorporates delays in the effects of monetary policy on spending and prices. Here, we are interested in the ways in which this familiar analysis must be complicated under alternative assumptions about fiscal policy.

3. Optimal Policy When Only Distorting Taxes Are Available: The Case of Optimal Tax Smoothing

It is more realistic to assume that lump-sum taxes are not available to offset the fiscal consequences of monetary policy decisions. When we assume the process $\{\zeta_t\}$ to be exogenously given, the intertemporal solvency condition represents an additional binding constraint on the set of possible equilibrium paths for inflation and output. In Benigno

11. This calculation is further explained in Woodford (2003, chap. 7). The parameter values assumed are $\beta = 0.99$, $\kappa = 0.024$, and $q_y/q_\pi = 0.048$. The figure also shows, for purposes of comparison, the equilibrium responses that would occur under discretionary optimization. In this case, the gap-adjusted price level does not change in the period of the shock, but it is expected to be allowed to rise subsequently. This expectation results in a less favorable inflation-output trade-off for the central bank in the period of the shock.

and Woodford (2004), we consider optimal monetary policy in such an environment, under the assumption that the path of the distorting tax rate, $\{\tau_t\}$, is chosen optimally in response to the various types of real disturbances considered in the model. Here we recapitulate the main conclusions of that analysis, before turning to cases in which fiscal policy is assumed to be less flexible or not optimally determined.

In this case, we view monetary and fiscal policy decisions as being jointly determined in a coordinated fashion, so as to solve a single social welfare problem. The planning problem is to find state-contingent paths $\{\pi_t, y_t, \hat{\tau}_t\}$ to minimize equation (9) subject to the two constraints of equations (11) and (12). An especially simple version of this problem is the limiting case in which prices are perfectly flexible. This case clearly illustrates why the absence of lump-sum taxes can make it optimal for the inflation rate to be highly responsive to fiscal developments, contrary to what inflation targeting is generally assumed to imply. Some authors argue that this kind of analysis is relevant to the choice of monetary institutions in Latin America (Sims, 2002).

3.1 Optimal Policy If Prices Are Flexible

In the flexible-price limit of the above model, the coefficient q_π in equation (9) is equal to zero, and κ in equation (11) is also zero (that is, the aggregate supply relation is completely vertical). The policy problem reduces to the minimization of

$$\frac{1}{2} q_y E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} y_t^2 , \tag{17}$$

subject to the constraints

$$y_t + \psi\left(\hat{\tau}_t - \hat{\tau}_t^*\right) = 0 \tag{18}$$

and equation (12). Using equation (18) to substitute for y_t in equation (17) allows us to equivalently write the stabilization objective as

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left(\hat{\tau}_t - \hat{\tau}_t^*\right)^2 ,$$

in which case the policy objective can be thought of as tax smoothing, as in Barro's (1979) classic analysis.[12]

12. Thus our stabilization objective (equation 9) does not omit the concerns of the literature on optimal tax smoothing; the welfare losses associated with a failure to optimally time the collection of taxes are implicit in the output-gap stabilization objective.

The solution will involve $y_t = 0$ at all times, since it is feasible to achieve this if the monetary and fiscal authorities cooperate. The fiscal authority must choose $\hat{\tau}_t = \hat{\tau}_t^*$ at all times to ensure this, while the monetary authority must vary the inflation rate, π_t, to ensure government solvency. Equation (12) requires that in such an equilibrium,

$$\pi_t = \hat{b}_{t-1} + f_t .$$

Thus unexpected changes in the fiscal stress term must be accommodated entirely by surprise variations in the inflation rate, as in Chari and Kehoe (1999). The tax rate should fluctuate only to the extent that $\hat{\tau}_t^*$ fluctuates; that is, only to the extent that variations in the tax rate are useful as a supply-side policy, to offset inefficient supply disturbances.[13]

This conclusion implies that an optimal policy will involve highly volatile inflation and extreme sensitivity of inflation to fiscal shocks. This is the basis of Sims' (2002) critique of dollarization as a policy prescription for Mexico; at least a strict form of inflation targeting would presumably be rejected on the same grounds. This analysis, however, neglects the welfare costs of volatile inflation, which are stressed in the literature on inflation targeting. Here we consider the importance of the Chari-Kehoe argument in the presence of a realistic degree of price stickiness.

3.2 Optimal Policy If Prices Are Sticky

In the more general case of our model (with some degree of price stickiness), the first-order conditions for the optimal policy problem stated above are

$$q_\pi \pi_t = \kappa^{-1}(\varphi_{1,t} - \varphi_{1,t-1}) - (\varphi_{2,t} - \varphi_{2,t-1}), \tag{19}$$

$$q_y y_t = \varphi_{1,t} - \left[(1-\beta)b_y + \sigma^{-1}\right]\varphi_{2,t} + \sigma^{-1}\varphi_{2,t-1}, \tag{20}$$

$$\varphi_{2,t} = E_t \varphi_{2,t+1}, \text{ and} \tag{21}$$

13. As shown in Benigno and Woodford (2004), a wide range of inefficient supply disturbances may require such an offset, if the steady state is sufficiently distorted as a result of either market power or a large public debt.

$$\psi\varphi_{1,t} = (1-\beta)b_{\tau}\varphi_{2,t}, \tag{22}$$

where now $\varphi_{1,t}$ is the Lagrange multiplier associated with the aggregate supply relation and $\varphi_{2,t}$ is the multiplier associated with the intertemporal solvency condition. Conditions (19)–(22), together with the two structural equations (11) and (12), are to be solved for the paths of the endogenous variables, $\{\pi_t, y_t, \hat{\tau}_t, \hat{b}_t, \varphi_{1,t}, \varphi_{2,t}\}$, given an exogenous process for $\{f_t\}$.

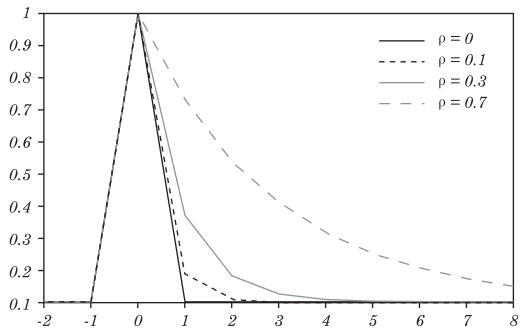
The type of response to shocks implied by these equations can be illustrated using a numerical example. We adopt the same numerical parameter values as in Benigno and Woodford (2004), implying that $\beta = 0.99$, $\sigma^{-1} = 0.157$, $\kappa = 0.0236$, $\psi = 0.397$, $b_{\tau} = 8.33$, and that the relative weight on output-gap stabilization is $q_y/q_{\pi} = 0.0024$.[14] As in that paper, we examine the effects of an exogenous increase in transfer programs, $\hat{\zeta}_t$, equal to one percent of steady-state GDP. Here, however, we consider the consequences of alternative degrees of persistence of such a disturbance; we assume that the value of $\hat{\zeta}_t$ following the shock is expected to decay at the rate ρ^t, where the coefficient of serial correlation, ρ, is allowed to take values between zero (the case shown in the earlier paper) and 0.7.

Figure 2 shows the impulse response of the shock, $\hat{\zeta}_t$, for the different values of ρ considered. Figure 3 then shows the impulse response of the public debt, $\hat{b}_t$, in response to a pure fiscal shock of this kind under the optimal policy, for each of the alternative values of ρ. Figure 4 shows the corresponding responses of the tax rate, $\hat{\tau}_t$, under the optimal policy, and figure 5 the associated responses of the inflation rate. In contrast to the optimal policy in the case of flexible prices (discussed further in Benigno and Woodford, 2004), it is optimal to respond to a pure fiscal shock of this kind by permanently increasing the level of real public debt and planning a corresponding permanent

14. Here the interest-sensitivity of expenditure and the slope of the Phillips curve are calibrated to agree with the econometric estimates of Rotemberg and Woodford (1997) for the US economy, and the fiscal parameters are calibrated to imply that steady-state tax revenues are 20 percent of GDP and that the steady-state public debt is 60 percent of annual GDP. The assumed weights on the two stabilization objectives in the loss function (9) are the ones that correspond to maximization of expected utility, given the parameters of the model, as explained in Benigno and Woodford (2004). Note that in our present notation, π_t is a quarterly inflation rate; if we instead write the loss function in terms of an annualized inflation rate, the relative weight on output-gap stabilization would instead be 0.038. This is slightly smaller than the value quoted in Rotemberg and Woodford (1997), mainly as a consequence of the tax distortions assumed here, but abstracted from in that paper.

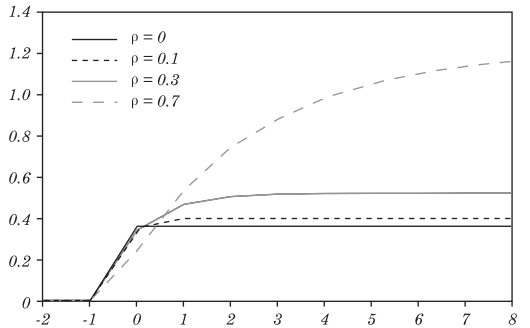
increase in the tax rate. (The increase in the level of real public debt under the optimal policy is more gradual the more persistent the fiscal shock, whereas it was immediate in the case of the purely transitory shock considered in our previous paper.) Optimal policy does involve some unanticipated inflation at the time of the shock, as in the Chari-Kehoe analysis, but it is not nearly large enough to completely offset the fiscal stress, which is why future taxes are also increased.

Figure 2: Alternative Fiscal Shocks



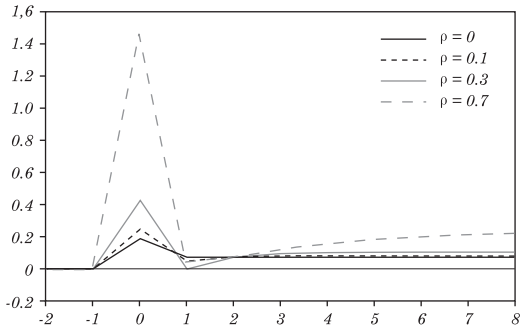
Source: Authors' computations.

Figure 3: Impulse Response of the Public Debt to a Pure Fiscal Shock, for Alternative Degrees of Persistence



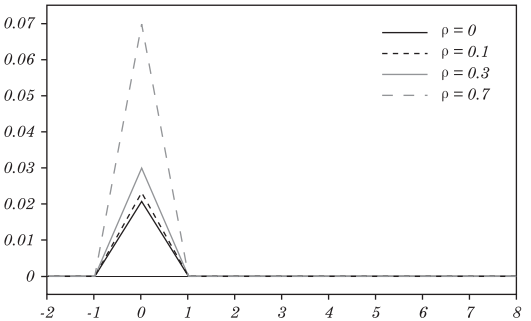
Source: Authors' computations.

Figure 4: Impulse Response of the Tax Rate to a Pure Fiscal Shock, for Alternative Degrees of Persistence



Source: Authors' computations.

Figure 5: Impulse Response of the Inflation Rate to a Pure Fiscal Shock, for Alternative Degrees of Persistence



Source: Authors' computations.

As shown in figure 5, the inflationary impact of a fiscal shock under the optimal policy regime is quite small. In the case of a purely transitory (one-quarter) increase in the size of transfer programs by an amount equal to one percent of GDP, optimal policy allows an increase in the inflation rate that quarter of only two basis points (at an annualized rate).[15] Moreover, the increase in inflation is

15. The log price level is thus allowed to increase that quarter by only half a basis point.

limited to the quarter of the shock. This compares with an increase in the inflation rate of nearly two percentage points under the optimal policy in the case of flexible prices. This conclusion that the optimal inflation response is small does not depend on an extreme calibration of the degree of price stickiness. In Benigno and Woodford (2004), we show that the optimal response to a purely transitory fiscal shock is similarly small even if prices are assumed to be much less sticky than under the calibration used here; there is a dramatic difference between optimal policy under fully flexible prices and under even slightly sticky prices (that is, the short-run aggregate supply trade-off is not completely vertical). The optimal inflation response is larger if the shock is more persistent, since in this case the cumulative cost of the increased transfers—and thus the total increase in fiscal stress—is several times as large. Even when $\rho = 0.7$, however, the optimal increase in the inflation rate is only about seven basis points. Finally, the effect on inflation is purely transitory under optimal policy, regardless of the degree of persistence of the fiscal shock itself.

This last conclusion—that variations in inflation should be purely transitory under the optimal policy, so that the expected rate of inflation never varies at all—is quite robust to the type of shock considered. The conclusion follows directly from the first-order conditions that characterize optimal policy. Condition (19) implies that forecastable variations in the inflation rate should be allowed only to the extent that there are forecastable variations in one or the other of the Lagrange multipliers. Condition (21) implies that there are no forecastable variations in the multiplier associated with the solvency constraint, while condition (22) implies that the two multipliers should covary perfectly with one another, so that there are no forecastable variations in the multiplier associated with the aggregate supply constraint either, under an optimal policy.

The fiscal consequences of monetary policy thus matter if all sources of government revenue are distorting. This creates additional reasons for departures from strict price stability to be optimal. It is now optimal for the inflation rate to vary, at least to some extent, in response to disturbances (such as a change in the size of government transfer programs) that are irrelevant in the classic analysis reviewed in the previous section. Even so, optimal policy continues to possess important features of an inflation targeting regime. The rate of inflation that is forecastable for the

future should never vary, regardless of the kind of disturbances hitting the economy, and the unforecastable variations in inflation that should be allowed are quite small.

It is no longer optimal to target a constant value for the output-gap-adjusted price level, $\tilde{p}_t$. In fact, the optimal policy now involves some degree of base drift in the price level, since the transitory inflation shown in figure 5 permanently shifts the price level. Nonetheless, optimal monetary policy can be characterized by commitment to a target criterion that is only a slight generalization of the one presented above for the case of lump-sum taxes. We return to this topic in section 6 below.

3.3 Consequences of Additional Fiscal Instruments

The analysis of Benigno and Woodford (2004) assumes that a small and quite specific set of policy instruments are available to the fiscal authority: the only source of government revenue is a proportional sales tax, and the only kind of government debt that may be issued is a very short-term (one-period) riskless nominal bond. Here we briefly discuss the consequences of allowing for additional instruments and, hence, a broader range of possible fiscal policies.

Not surprisingly, additional fiscal instruments, if used skillfully enough, can allow a better equilibrium to be achieved. This can make it simpler to characterize optimal monetary policy, since we no longer have to rely on a limited set of instruments to simultaneously serve multiple stabilization objectives. Suppose, for example, that it is possible to independently vary the level of several different types of distorting taxes. With two distinct tax rates, the cost-push term, $\psi\hat{\tau}_t$, in equation (10) becomes $\psi_1\hat{\tau}_{1,t} + \psi_2\hat{\tau}_{2,t}$, while the term $b_\tau\hat{\tau}_t$ in equation (12) becomes $b_1\hat{\tau}_{1,t} + b_2\hat{\tau}_{2,t}$. In general, not only will there be different elasticities in the case of different taxes, but the ratios of the elasticities will not be the same in the two equations; the fact that a given percentage increase in one tax rate results in a 20 percent larger increase in revenues than that resulting from a similar increase in a second tax rate does not imply that it also results in a 20 percent larger cost-push effect. The existence of multiple taxes that can be independently varied (and are not at some boundary value under an optimal policy) thus allows the fiscal authority to independently shift the aggregate supply relation and affect the government's budget.

If this is possible, then a lump-sum tax is essentially possible, as some combination of tax increases and decreases will be able to increase tax revenues without any net effect on the aggregate supply relation.[16] We are not, however, returning to the classic situation analyzed in section 2. This setup actually simplifies matters, for tax policy can now be used to offset the cost-push effects of other disturbances, without any consequences for government solvency. Constraint (12) therefore ceases to bind, as in section 2, but tax policy can be used to shift the aggregate supply relation, as in sections 3.1 and 3.2. Optimal policy then involves using taxes to offset the cost-push term, u_t, entirely and then applying monetary policy to completely stabilize both inflation and the output gap. (Taxes are also used to ensure that this equilibrium is consistent with intertemporal government solvency.) In such a case, the optimal monetary policy will be a strict inflation target that maintains $\pi_t = 0$ at all times, regardless of the shocks to which the economy may be subject.[17]

The case for inflation targeting is thus quite strong indeed when tax policy can be varied in any of a range of directions and the fiscal authority can be expected to exercise its power skillfully. This may not be of the greatest practical interest, however. For instance, if the tax rates are each required to be nonnegative, then it may be optimal to raise all revenue using only one tax—namely, the one with the lowest ratio of ψ_j to b_j (and thus with the least distortion created per dollar of revenue raised). The optimal policy problem would then end up being similar to the one treated above, in which there is assumed to be only a single type of distorting tax.

Allowing for the possibility of issuing other forms of government debt would also increase the flexibility of fiscal policy and reduce the constraints on what monetary policy can achieve. For example, if it were possible to issue arbitrary kinds of state-contingent debt, then in principle it would be possible to arrange for $\hat{b}_{t-1}$ to vary with the state that is realized at date t in such a way that $\hat{b}_{t-1} + f_t$ never varies, regardless of the exogenous disturbances. Complete stabilization of both inflation and the output gap would again be possible, and the optimal monetary policy would be a strict inflation target of zero.

16. Here we assume that the various taxes in question affect all sectors of the economy identically, as in the presence of both a sales tax and a wage income tax. Under this assumption, taxes create no distortions other than the effect indicated by the cost-push term in the aggregate supply relation.

17. Our ability to achieve the first-best outcome with a sufficient number of taxes is reminiscent of the conclusion of Correia, Nicolini, and Teles (2003) in the context of a model with a different kind of price stickiness.

However, the supposition that state-contingent payoffs on government debt can be arranged with such sophistication is hardly realistic.

One possibility is for countries to use maturity to vary the kind of debt that they issue. If government debt does not all mature in one period, then $\hat{b}_{t-1}$ is no longer a predetermined state variable; instead, it depends on the market valuation of bonds in period t, which generally depends on the shocks that occur at that date. Since the prices of bonds with different maturities respond distinctly to shocks occurring at date t, different maturity structures of the public debt will have varying effects on the state contingency of $\hat{b}_{t-1}$. With a sufficient number of maturities available, it may well be possible once again to bring about the kind of state contingency that makes $\hat{b}_{t-1} + f_t$ independent of shocks, thereby eliminating the need for state-contingent debt, as proposed by Angeletos (2001). Both inflation and the output gap can thus be fully stabilized, and a strict inflation target would again be the optimal monetary policy. To develop these points in more detail, we extend out analysis to allow for the existence of longer-maturity nominal government debt. In the most general case, the intertemporal budget constraint (equation 8) takes the form

$$E_t\left(\sum_{T=t}^{\infty} R_{t,T} s_T\right) = E_t\left(\sum_{T=t}^{\infty} R_{t,T} b_{t-1,T} \frac{P_{t-1}}{P_T}\right),$$

where for any $T \geq t$, $b_{t-1,T}$ denotes the real value at time $t-1$ of the debt that matures at time T. A log-linear approximation can be computed as before, yielding

$$\begin{aligned} &\hat{b}_{t-1} - E_t \sum_{T=t}^{\infty} d_{T-t+1}\left(\sigma^{-1} y_T + \sum_{s=t}^{T} \pi_s\right) = \\ &-f_t + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t}\left[b_y y_T + b_\tau\left(\hat{\tau}_T - \hat{\tau}_T^*\right)\right]. \end{aligned} \tag{23}$$

Here we have defined

$$\hat{b}_{t-1} = \sum_{T=t}^{\infty} \beta^{T-t} \frac{b_{t-1,T} - \bar{b}_{T+1-t}}{\bar{b}},$$

where $\bar{b}_i$ is the steady-state real value of i-period debt, and $\bar{b}$ is the steady-state real value of all outstanding government liabilities, given by

$$\bar{b} = \sum_{i=1}^{\infty} \beta^{i-1} \bar{b}_i \, .$$

The weights, d_i, are defined as

$$d_i = \frac{\beta^{i-1} \bar{b}_i}{\bar{b}}$$

for each $i \geq 1$. Finally, the composite fiscal stress term, f_t, is now defined by

$$f_t = E_t \sum_{T=t}^{\infty} d_{T-t+1} \left[\sigma^{-1} \left(g_T - \hat{Y}_T^* \right) \right] - (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} \left(b_y \hat{Y}_T^* + b_\tau \hat{\tau}_T^* + b_\xi' \xi_T \right),$$

which can be written more compactly as

$$f_t = E_t \sum_{T=t}^{\infty} d_{T-t+1} h_\xi' \xi_T + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} f_\xi' \xi_T \, , \tag{24}$$

again using the notation defined in Benigno and Woodford (2004).

The planning problem is to find state-contingent paths $\{\pi_t, y_t, \hat{\tau}_t\}$ to minimize equation (9) subject to constraints (11) and (23). As before, the composite disturbance, f_t, completely summarizes the information at date t about the exogenous disturbances that interfere with complete stabilization of inflation and the output gap. In contrast to the case of one-period debt, output and inflation can now be stabilized at their optimal level even when prices are sticky by appropriately choosing the steady-state structure of maturity. This is because the stochastic properties of the fiscal stress term now depend on the maturity structure. With an appropriate choice of the maturity structure, one can even ensure that f_t is identically equal to zero at all times, in which case complete achievement of both stabilization objectives will be possible.

Let government debt have a maximum maturity of N periods and let J be the number of stochastic disturbances of the model. Let us further suppose (purely for illustrative purposes, for our argument could easily be generalized) that the disturbances are all first-order autoregressive, or AR(1), processes,

$$\xi_t^j = \rho_j \xi_{t-1}^j + \varepsilon_t^j \, ,$$

where ε_t^j is a white-noise process and $|\rho_j| < 1$ for each disturbance j. In this case, equation (24) takes the form

$$f_t = \sum_{i=1}^{N} d_i \sum_{j=1}^{J} \rho_j^i h_{\xi_j} \xi_t^j + (1-\beta) \sum_{j=1}^{J} (1-\rho_j \beta)^{-1} f_{\xi_j} \xi_t^j ,$$

where h_{ξ_j} and f_{ξ_j} are the jth components of the vectors h_ξ and f_ξ, respectively.

It now follows (generically) that for f_t to be zero at all times, it is necessary and sufficient that

$$\sum_{i=1}^{N} \rho_j^i d_i = z_j , \tag{25}$$

where z_j is defined by

$$z_j = (1-\beta)(1-\rho_j \beta)^{-1} h_{\xi_j}^{-1} f_{\xi_j} ,$$

for each j. Then the set of J equations (25) together with the identity

$$\sum_{i=1}^{N} d_i = 1 , \tag{26}$$

forms a set of $J + 1$ equations in the N unknowns, $\{d_i\}$. We can write this system of linear equations using matrix notation. To this end, we define the matrix

$$\mathbf{A} \equiv \begin{bmatrix} 1 & \rho_1 & \cdots & \rho_1^{N-1} \\ 1 & \rho_2 & \cdots & \rho_2^{N-1} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & \rho_J & \cdots & \rho_J^{N-1} \\ 1 & 1 & \cdots & 1 \end{bmatrix},$$

and let $\mathbf{z}$ be the vector whose first J elements are the z_j, and whose final element is 1. We can then write the system of linear equations in the compact form,

$$\mathbf{A}\mathbf{d} = \mathbf{z} , \tag{27}$$

where **d** is the vector of coefficients d_i. Standard results ensure that there is a solution of equation (27) as long as **A** is of full rank. In this case, there is at least one vector **d**—that is, at least one steady-state maturity structure—such that $f_t = 0$, so that complete stabilization of both inflation and the output gap can be achieved.

In particular, if $N = J + 1$, there is exactly one solution for any given **z**, when **A** is of full rank. For example, in the case of a single stochastic disturbance ($J = 1$), the matrix **A** is always of full rank, and the first-best outcome can be achieved simply by issuing nominal debt with one- and two-period maturities. The optimal maturity structure in this case depends on the persistence of the shock, as well as on its contribution to movements in the fiscal stress measure, f_t. If $J > 1$, **A** is of full rank if and only if $\rho_i \neq \rho_j$ for each i and j. (Otherwise there generally is no solution.)

Angeletos (2001) shows in a flexible-price model that to complete the markets, it is necessary and sufficient to issue nominal debt that has at least N-period maturity, where N is the number of states of nature in the model. Here we establish that in a log-linear model, what matters is not the number of distinct states of nature, but only the number of stochastic disturbances, as Angeletos conjectured on the basis of his numerical results. As long as debt can be issued in moderately long maturities, it will generally be possible, at least in principle, to choose a maturity structure that achieves the first-best outcome. The optimal monetary policy will simply aim at complete price stability, while the distorting tax rate will be used to offset cost-push disturbances, so that zero inflation is compatible with a zero output gap.

As Buera and Nicolini (2004) note in a related context, however, the maturity structure required for such an outcome may be implausible, involving very large long and short positions in different maturities. They also show that the optimal maturity structure may be extremely sensitive to small changes in model parameters, such as small changes in the serial correlation of disturbance processes.[18] Here again, while in principle the opportunity to increase the flexibility of fiscal policy in this way can greatly facilitate monetary stabilization policy, the practical relevance of this case is open to question. We accordingly restrict the remainder of our analysis to the case of a single maturity of government debt, specifically, one very short-term (single-period) debt. In fact, most

18. This can be seen from our analysis above, since a small change in these parameters can cause the rank condition to fail.

countries with serious fiscal imbalances issue almost exclusively short-maturity debt, so our assumption seems likely to represent the most relevant case for the countries facing the concerns addressed in this paper. This emphasis is also consistent with our desire to consider the cases in which possible constraints on fiscal policy are most likely to create problems for inflation targeting. The presence of a larger number of fiscal instruments, or fewer constraints on how they are used, will generally strengthen the case for inflation targeting. Our interest, however, is in the extent to which a form of inflation targeting continues to be desirable even when fiscal policy is much less helpful.

4. Optimal Monetary Policy When Fiscal Policy Is Exogenous

This section explores a still more constrained case, in which $\{G_t, \zeta_t, \tau_t\}$ are all assumed to be exogenous processes, determined by political factors that the central bank cannot influence. This is the type of fiscal policy assumed by Loyo (1999), which Sims (2005) uses in his critique of inflation targeting. In a flexible-price model such as Loyo's, this policy implies a purely exogenous evolution of the real primary government budget surplus, $\{s_t\}$. The central bank must beware that a tight-money policy does not cause explosive growth of the public debt, for it is assumed that neither taxes nor government spending will be adjusted to prevent such dynamics.

In this case, the intertemporal solvency condition (equation 12) constrains the possible paths for inflation and output that can be achieved by any monetary policy, and no endogenous fiscal instruments are available to adjust this constraint. At the same time, the possible paths for inflation and output are constrained by the aggregate supply trade-off (equation 11), and there is no endogenous fiscal instrument that can shift this relation either, in contrast with the assumption in the previous section. The central bank's ability to achieve its inflation and output-gap stabilization objectives is accordingly more tightly constrained.

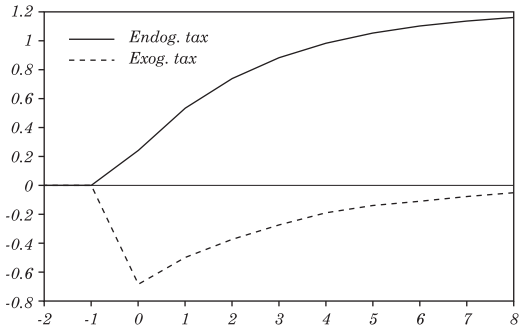
As Sims (2005) notes, full price stability (or even complete stabilization of the inflation rate at some nonzero value) will typically be infeasible under these assumptions—unlike the situation considered in the previous section, where this is a possible, though not quite optimal, monetary policy. Condition (11) allows us to easily derive the unique output-gap process consistent with complete stabilization of the inflation rate. However, the process $\{y_t\}$ obtained in this way (together with the assumed constant inflation rate and the exogenously given

tax process) will almost surely not satisfy the intertemporal solvency condition (equation 12) for all possible realizations of the disturbances that affect the fiscal stress term, f_t. This does not mean that monetary policy is powerless to stabilize either nominal or real variables. While one cannot commit to completely stable inflation both immediately and for the indefinite future, policymakers can choose among alternative paths for inflation, some of which involve inflationary spirals of the sort modeled by Loyo, and others of which involve a fairly quick return to price stability. Here we consider the central bank's optimal choice among the set of possible equilibria, given the constraints implied by exogenous fiscal policy.

The optimization problem in this case is to find paths, $\{\pi_t, y_t\}$, that minimize equation (9) subject to the constraints in equations (11) and (12), in which we now treat $\{\hat{\tau}_t\}$ as another exogenous disturbance process. The first-order conditions for this optimization problem are the same as before (conditions 19–21). The only difference is that condition (22) need no longer hold (as the tax rate need not be chosen optimally); this condition is replaced by the exogenously given process, $\{\hat{\tau}_t\}$.

Optimal state-contingent responses to exogenous disturbances of various types can easily be derived in this case, using the same methods as in the previous section. For purposes of illustration, we again consider a pure fiscal shock, by which we mean an exogenous increase in the size

Figure 6: Impulse Response of the Public Debt under Optimal Monetary Policy and Two Assumptions about Tax Policy[a]

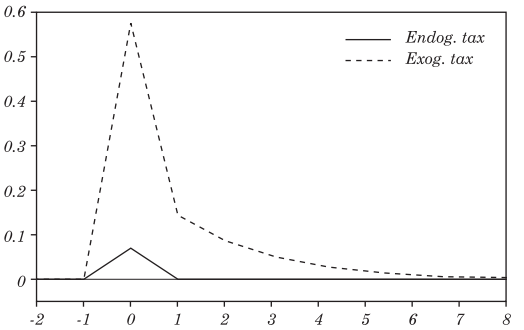


a. The figure shows the impulse response of the real public debt to a pure fiscal shock under optimal monetary policy, both under the assumption that tax policy also responds optimally (solid line; same as in figure 3) and under the assumption that the path of the tax rate does not respond at all (dashed line).

of government transfer programs. To simplify our figures, we present results only for the case of $\rho = 0.7$. Figure 6 shows the impulse response of the real public debt to such a shock under optimal monetary policy, both under the assumption that tax policy also responds optimally (as in the previous section) and under the assumption that the path of the tax rate does not respond at all. Figure 7 shows the impulse response of the inflation rate under optimal monetary policy, under the same two alternative assumptions about fiscal policy.

As figure 7 indicates, the degree to which it is optimal to allow a fiscal shock to affect the inflation rate is much greater when tax policy cannot be expected to adjust in response to the shock. The optimal immediate effect on the inflation rate is about eight times as large, in our calibrated example, under the exogenously given path for the tax rate; it is also slightly more persistent, so the inflation rate expected over the next few quarters should be allowed to rise slightly in response to such a shock. The larger immediate increase in inflation means that the reduction of the real burden of the public debt through unexpected inflation plays a bigger role in offsetting the fiscal stress in this case. This is necessary because under the assumption of an exogenous path of taxes, the long-run level of the real public debt cannot be increased (as would occur under the optimal fiscal policy); instead, it must continue to equal the unique level consistent with

Figure 7: Impulse Response of the Inflation Rate under Optimal Monetary Policy and Two Assumptions about Tax Policy[a]



a. The figure shows the impulse response of the real public debt to a pure fiscal shock under optimal monetary policy, both under the assumption that tax policy also responds optimally (solid line; same as in figure 3) and under the assumption that the path of the tax rate does not respond at all (dashed line).

intertemporal solvency given the expected long-run tax rate. As shown in figure 6, the level of the real public debt must fall, rather than rise, in response to the fiscal shock so that it can approach its unchanged long-run level from below. (The real public debt must be expected to grow over the quarters in which the size of transfer programs is still temporarily high, but this is no longer a surprise.) This can occur only through a sufficiently large surprise increase in inflation in the quarter in which the shock occurs, just as under the optimal policy for the flexible-price economy analyzed by Chari and Kehoe (1999).

Even under this extreme assumption about the nonresponsiveness of tax policy, an optimal monetary policy does not involve too great an increase in inflation in response to a disturbance that increases fiscal stress. In the case of the shock considered in figure 7, the cumulative increase in the price level is still only about a quarter of a percentage point, whereas the price increase under optimal policy for the flexible-price economy would be about six times as large. Even when tax increases do not contribute to relieving fiscal stress at all, less inflation is required to maintain intertemporal solvency in the case of a sticky-price economy, because inflationary policy stimulates real activity. The resulting higher real incomes imply higher tax revenues, which contribute substantially to government solvency in the equilibrium shown by the dashed lines in figures 6 and 7.

This illustrates an important benefit of an appropriately managed inflation-targeting regime, even when fiscal policy is purely exogenous, as in the pessimistic case considered by Sims (2005). The central bank is able to maintain intertemporal solvency without too much inflation in our example precisely because inflationary expectations are contained even while transitory inflation is allowed to erode the real value of existing nominal claims on the government. If expected inflation does not increase much at the time of the fiscal shock, the aggregate supply trade-off (equation 11) implies a relatively large increase in real output for a given increase in the current inflation rate, so a substantial improvement in government solvency can be obtained without too much inflation. If, instead, the expected future inflation rate were to rise as much as the current inflation rate (or even more), the increase in real activity resulting from inflationary monetary policy would be tiny or nonexistent—or even of the opposite sign. In that case, tax revenues would increase little if at all, and all of the fiscal stress would have to be offset through a reduction in the real value of the public debt owing to unexpected inflation; the required immediate increase in inflation would then be many times larger.

We can illustrate this trade-off quantitatively by considering alternative responses to a disturbance to the fiscal stress.[19] Suppose that in response to such a shock in period t, monetary policy allows the path of inflation to change in such a way that

$$E_t \pi_{t+j} - E_{t-1} \pi_{t+j} = \tilde{\pi}_t \lambda^j ,$$

for all $j \geq 0$, for some initial inflation response, $\tilde{\pi}_t$, and some persistence factor, $0 \leq \lambda \leq 1$. In addition, suppose for simplicity that the disturbance does not change the expected path of the tax gap, [20]

$$E_t \left(\hat{\tau}_{t+j} - \tau^*_{t+j} \right).$$

For any choice of λ, there exists a unique value of $\tilde{\pi}_t$ (given the size of the shock at date t) such that this represents a possible equilibrium response under a suitable monetary policy. We can then consider how $\tilde{\pi}_t$—and hence the entire path of the inflation response—varies with the choice of λ.

Solving equation (11) for the implied response of the output gap, we find that

$$E_t y_{t+j} - E_{t-1} y_{t+j} = \frac{1 - \beta\lambda}{\kappa} \tilde{\pi}_t \lambda^j ,$$

for each $j \geq 0$. Substituting this and the conjectured inflation response into the intertemporal solvency condition (equation 12), we find that the condition is satisfied if and only if

$$\tilde{\pi}_t = \frac{\tilde{f}_t}{1 + \sigma^{-1}(1 - \beta\lambda) + (1 - \beta) b_y / \kappa} . \tag{28}$$

This indicates how the initial effect on inflation relates to the expected degree of persistence of the shock's effect on the inflation rate.

19. This might be the pure fiscal shock considered in the numerical examples presented, but it might also be any other kind of exogenous disturbance that affects the term f_t.

20. If the path of the tax gap also changes, a derivation like the one sketched below is again possible, except that in the numerator of equation (28), instead of $\tilde{f}_t$, one has $\tilde{f}_t$ plus a multiple of the present value of changes in the expected tax gap. The conclusions obtained below on how $\tilde{\pi}_t$ depends on the value of λ continue to apply.

A higher value of λ makes the denominator of equation (28) a smaller positive quantity, meaning that $\tilde{\pi}_t$ must be larger. Thus a policy that makes the shock's effect on inflation more persistent will involve a larger initial effect on inflation, as well as (a fortiori) a larger effect on inflation at all later dates.

Even under the constraints assumed in this section, the central bank should credibly commit itself to restoring low inflation relatively soon after a disturbance that creates fiscal stress. This requires both that monetary policy be clearly focused on inflation control and that the central bank's commitment to an essentially constant medium-term inflation target be unwavering, even when fiscal stress requires a short-run departure from the medium-term target. The credibility of such a commitment will be greater to the extent that the central bank is able to explain why the size of departure that is currently occurring is consistent with the principles to which it is committed, rather than representing an abrogation of those principles or a concession that they are frequently inapplicable. We next consider the formulation of a more flexible form of target criterion that would be suitable for this purpose.

5. An Optimal Targeting Rule for Monetary Policy

We have argued that even in the case of severe constraints on the degree to which an optimal adjustment of tax policy can be expected, an optimal monetary policy will involve a commitment not to allow temporary increases in inflation to persist, so that medium-term inflation expectations remain well anchored. This raises the question of what kind of commitment regarding the future conduct of monetary policy would serve this purpose, without appearing to promise different conduct in the future than what is exhibited in the present—a promise that would not easily be made credible. The answer, in our view, is that monetary policy should be conducted in such a way as to seek at all times to conform to an appropriately formulated target criterion. The target criterion should both explain how much inflation can be allowed in the short run, in response to a given type and size of disturbance, and guarantee (if it is expected to be followed in the future, as well) that no significant fluctuations in the inflation rate should be forecasted more than a few quarters into the future.

To identify a criterion that will serve this purpose under each of the assumptions about the fiscal regime considered above and for all

the different types of disturbances that might affect the economy, we use the method illustrated in section 2—that is, we use the first-order conditions that characterize optimal policy to derive a target criterion that must be satisfied in an optimal equilibrium.[21] Conditions (19)–(21) must hold if monetary policy is optimal, under all the fiscal regimes considered thus far.[22] Consequently, a target criterion that follows from (and, in turn, guarantees) these conditions will be a criterion for the optimality of monetary policy that will generally be useful. Since the first-order conditions also apply regardless of the nature of the (additive) exogenous disturbances that may perturb the model structural relations, the resulting criterion is also robust to alternative assumptions about the statistical properties of the disturbances, as stressed by Giannoni and Woodford (2002).

A robustly optimal target criterion that is equivalent to demanding the existence of Lagrange multiplier processes $\{\varphi_{1t}, \varphi_{2t}\}$ that satisfy equations (19)–(21) can be formulated as follows. As in the simpler case treated in section 2, optimal policy can be described in terms of commitment to a target for the output-gap-adjusted price level, $\tilde{p}_t$, defined in equation (16). The central bank should use its policy instrument to ensure that each period, p_t satisfies

$$\tilde{p}_t = p^*_{t-1} + (1+\eta)(p^*_t - p^*_{t-1}), \tag{29}$$

where

$$\eta \equiv \frac{\sigma^{-1}}{(1-\beta)b_y + \kappa} > 0$$

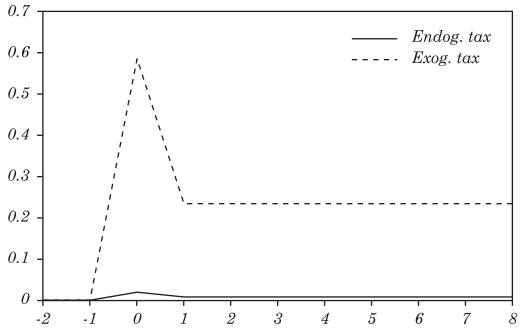
and p_t^* is the central bank's estimate (conditional on information at t) of the long-run (output-gap-adjusted) price level consistent with intertemporal government solvency.

Implementation of policy in accordance with this criterion would require the central bank to estimate the current value of the long-run price-level target, p_t^*, as part of each decision cycle. This would be determined, in principle, as follows. Equation (29) implies that

21. Further details of the derivation are given in Benigno and Woodford (2005b), where we also discuss the form of targeting rule that is appropriate under a broader class of possible assumptions about fiscal policy.

22. These conditions also hold in the case of lump-sum taxes, as assumed in section 2, but with the additional condition that $\varphi_{2t} = 0$ at all times, which allows the first-order conditions to be reduced to the system of equations (14) and (15).

Figure 8: Optimal Response of the Output-Gap-Adjusted Price Level under the Two Polar Assumptions about Fiscal Policy



Source: Authors' computations.

$$E_t \tilde{p}_T = p_t^*,$$

for all $T \geq t + 1$. A value for p_t^* thus implies not just a value for $\tilde{p}_t$, but a complete expected path, $\{E_t \tilde{p}_T\}$, for all $T \geq t$. The central bank's model of the economy—including its model of the behavior of the fiscal authority—can then be used to derive the implied forecast paths for the other endogenous variables corresponding to a given current estimate of p_t^*. The right estimate of p_t^* is then the one that leads to a set of forecast paths consistent with intertemporal government solvency.

The degree to which p_t^* will be found to increase in response to a given disturbance depends on the nature of the fiscal regime. Figure 8 shows the optimal responses of the path of the output-gap-adjusted price level for both an endogenous (optimal) and an exogenous path for the tax rate, for the same kind of real disturbance as in figures 6 and 7. In both cases, the shape of the optimal response of this variable is the same; the response is simply scaled in proportion to the different-sized jump in the long-run price level.[23]

The same would be true if we were to plot optimal responses to other types of exogenous disturbances, or if we assumed a different

23. The same is true when the tax rate is predetermined for a certain period of time, after which it adjusts optimally (see Benigno and Woodford, 2005b). In such a case, the size of the response is intermediate between the two cases shown in figure 8.

degree of persistence of the disturbance; this is the feature of optimal policy that allows such a simple target criterion to provide a robust guide for policy. The same kind of criterion also applies in the case of lump-sum taxes, as assumed in section 2. In this case, however, there is never any need to vary the long-run price-level target to ensure solvency, so equation (29) applies with p_t^* equal to a constant p^*.

Implementing this kind of targeting procedure requires the central bank to make projections not only of the future evolution of prices and real activity, but also of the evolution of the government finances and the public debt, so as to evaluate the consistency of alternative monetary policies with intertemporal government solvency. Some may fear that this sounds like a prescription for exactly the sort of fiscal dominance of monetary policy against which Fraga, Goldfajn, and Minella (2004) warn. It is true that we have described a regime under which monetary policy could be conducted in a constrained-optimal way, even if the fiscal authority were understood to be completely unwilling ever to adjust fiscal instruments to maintain intertemporal solvency. However, the knowledge that the central bank reasons in this way should not provide an incentive for the fiscal authority to be profligate, relying on the central bank to adjust monetary policy as necessary to accommodate any degree of spending. Under the regime proposed here, the central bank would make its own judgment regarding the degree of fiscal adjustment that could properly be expected, given the constraints under which fiscal policy is expected to be determined, and then target a path for the output-gap-adjusted price level accordingly. It would be appropriate for the central bank to publicize the projections that serve as the basis for this decision. Among other things, this would inform the fiscal authority of the degree of eventual revenue increases expected by the central bank, which will be necessary to maintain intertemporal solvency given the central bank's target path for the gap-adjusted price level.

6. Conclusions

The nature of fiscal policy has important consequences for the optimal conduct of monetary policy, for two reasons. On the one hand, monetary policy has consequences for the intertemporal solvency of the government under a given fiscal policy, so a change in monetary policy can require corresponding changes in fiscal policy, which will

have welfare consequences if all sources of government revenue are distorting. On the other hand, fiscal policy decisions generally have supply-side consequences that affect the available trade-off between inflation stabilization and the central bank's ability to stabilize the welfare-relevant output gap. Hence, alternative assumptions about the set of instruments available to the fiscal authority and the flexibility and accuracy with which they will be adjusted can greatly change the complexity of the challenges involved in monetary stabilization policy.

Nonetheless, we have argued that it is possible to prescribe an optimal approach to the conduct of monetary policy that is applicable to a range of different assumptions regarding fiscal institutions and the character of fiscal policy. The problem of monetary stabilization policy is likely to be more complex, under realistic assumptions about fiscal policy, than in familiar analyses that abstract altogether from interactions between monetary and fiscal policy decisions. We found, however, that even under considerably more general assumptions, an optimal monetary policy has important aspects of a flexible inflation-targeting regime.

Under all of the regimes considered, optimal monetary policy can be implemented through a commitment to use policy to guarantee fulfillment of a target criterion, which specifies the acceptable level of an output-gap-adjusted price level given the central bank's current projections of the economy's possible future evolution. A credible commitment to such a rule should serve to anchor inflation expectations. As we have seen, commitment to the target criterion implies that there should be no forecastable variation in the growth rate of the output-gap-adjusted price level over any horizons beginning a quarter or further in the future. This means that any variations in the inflation forecast must be fully justifiable in terms of the projected change in the output gap over the same horizon. Moreover, since forecastable changes in the output gap over periods more than a few quarters in the future will always be negligible, this implies that medium-term inflation forecasts must essentially be constant.

Thus an important feature of an optimal policy commitment is a credible commitment by the central bank to return inflation to its long-run target level fairly promptly after any unforeseen disturbance that justifies a temporary departure from that target. When the set of available fiscal instruments is fairly constrained, it is important to allow for temporary variations in the inflation rate in response to exogenous disturbances, and disturbances that affect the economy

mainly through their impact on the government budget are among the types of disturbances that should be allowed to have a transitory effect on the inflation rate. Nevertheless, even while the central bank allows such disturbances to affect the current rate of inflation (and its current target for the gap-adjusted price level), it should stress the fact that the size of the one-time effect on prices is calculated to be consistent with a prompt stabilization of prices. The development of an explicit calculus that can be used to justify temporary departures from the inflation target, which would have been maintained in the absence of the shock, is an important project for adapting the practice of inflation targeting to the circumstances of countries with frequent and urgent fiscal imbalances.

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Inflation Targeting under Imperfect Knowledge

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A central tenet of inflation targeting is that establishing and maintaining well-anchored inflation expectations are essential. Well-anchored expectations enable inflation-targeting central banks to achieve stable output and employment in the short run, while ensuring price stability in the long run. Three elements of inflation targeting have been critically important for the successful implementation of this framework.[1] First and foremost is the announcement of an explicit quantitative inflation target and the acknowledgment that low, stable inflation is the primary objective and responsibility of the central bank. Second is the clear communication of the central bank's policy strategy and the rationale for its decisions, which enhances the predictability of the central bank's actions and its accountability to the public. Third is a forward-looking policy orientation, characterized by the vigilant monitoring of inflation expectations at both short-term and longer-term horizons. Together, these elements provide a focal point for inflation, facilitate the formation of the public's inflation expectations, and provide guidance on actions that may be needed to foster price stability.

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1. A number of studies have examined in detail the defining characteristics of inflation targeting. See Leiderman and Svensson (1995); Bernanke and Mishkin (1997); Bernanke and others (1999); Goodfriend (2004).

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Although inflation-targeting central banks stress these key elements, the literature that studies inflation targeting in the context of formal models largely describes inflation targeting in terms of the solution to an optimization problem within the confines of a linear rational expectations model. This approach is limited in its appreciation of the special features of the inflation-targeting framework, as emphasized by Faust and Henderson (2004), and it strips inflation targeting of its *raison d'être*. In an environment of rational expectations with perfect knowledge, for instance, inflation expectations are anchored as long as policy satisfies a minimum test of stability. Furthermore, with the possible exception of a one-time statement of the central bank's objectives, central bank communication loses any independent role because the public already knows all it needs in order to form expectations relevant for its decisions. In such an environment, the public's expectations of inflation and other variables are characterized by a linear combination of lags of observed macroeconomic variables, and, as such, they do not merit special monitoring by the central bank or provide useful information to the policymaker for guiding policy decisions.

In this paper, we argue that in order to understand the attraction of inflation targeting to central bankers and its effectiveness relative to other monetary policy strategies, it is essential to recognize economic agents' imperfect understanding of the macroeconomic landscape within which the public forms expectations and policymakers formulate and implement monetary policy. To this end, we consider two modest deviations from the perfect-knowledge rational expectations benchmark, and we reexamine the role of the key elements of the inflation-targeting framework in the context of an economy with imperfect knowledge. We find that including these modifications provides a rich framework in which to analyze inflation-targeting strategies and their implementation.

The first relaxation of perfect knowledge that we incorporate is to recognize that policymakers face uncertainty regarding the evolution of key natural rates. In the United States, for example, estimates of the natural interest and unemployment rates are remarkably imprecise.[2] This problem is arguably even more dramatic for small

2. For discussion and documentation of this imprecision, see Orphanides and Williams (2002); Laubach and Williams (2003); Clark and Kozicki (2005). See also Orphanides and van Norden (2002) for the related unreliability regarding the measurement of the natural rate of output and implied output gap.

open economies and transitional economies that have tended to adopt inflation targeting. Policymakers' misperceptions on the evolution of natural rates can result in persistent policy errors, hindering successful stabilization policy.[3]

Our second modification is to allow for the presence of imperfections in expectations formation that arise when economic agents have incomplete knowledge of the economy's structure. We assume that agents rely on an adaptive learning technology to update their beliefs and form expectations based on incoming data. Recent research highlights the ways in which imperfect knowledge can act as a propagation mechanism for macroeconomic disturbances in terms of amplification and persistence that have first-order implications for monetary policy.[4] Agents may rely on a learning technology to guard against numerous potential sources of uncertainty. One source could be the evolution of natural rates in the economy, paralleling the uncertainty faced by policymakers. Another might involve the policymakers' understanding of the economy, their likely response to economic developments, and the precise quantification of policy objectives. Recognition of this latter element in the economy highlights a role for central bank communications, including that of an explicit quantitative inflation target, which would be absent in an environment of perfect knowledge.

We investigate the role of inflation targeting in an environment of imperfect knowledge using an estimated quarterly model of the U.S. economy. Specifically, we compare the performance of the economy subject to shocks with characteristics similar to those observed in the data over the past four decades under alternative informational assumptions and policy strategies. Following McCallum (1988) and Taylor (1993), we focus on implementable policy rules that capture the key characteristics of inflation targeting. Our analysis shows that some monetary policy rules that would perform well under the assumption of rational expectations with perfect knowledge perform very poorly when we introduce imperfect knowledge. In particular, rules that rely on estimates of natural rates for setting policy are susceptible to persistent errors. Under certain conditions, these errors can give rise to endogenous inflation scares, whereby inflation expectations become unmoored from the central bank's desired anchor. These

3. For analyses of the implications of misperceptions for policy design, see Orphanides and Williams (2002); Orphanides (2003b); Cukierman and Lippi (2005).

4. See Orphanides and Williams (2004, 2005a, 2005b, 2005c); Gaspar and Smets (2002); Gaspar, Smets and Vestin (2005); Milani (2005).

results illustrate the potential shortcomings of such standard policy rules and the desirability of identifying an alternative monetary policy framework when knowledge is imperfect.

We then examine the performance of an easily implemented policy rule that incorporates the three key characteristics of inflation targeting highlighted above in an economy with imperfect knowledge. The exercise reveals that all three play an important role in ensuring success. First, central bank transparency, including explicit communication of the inflation target, can lessen the burden placed on agents to infer central bank intentions and can thereby improve macroeconomic performance. Second, policies that do not rely on estimates of natural rates are easy to communicate and are well designed for ensuring medium-run inflation control when natural rates are highly uncertain. Finally, policies that respond to the public's near-term inflation expectations help the central bank avoid falling behind the curve in terms of controlling inflation, and they result in better stabilization outcomes than policies that rely only on past realizations of data and ignore information contained in private agents' expectations.

A reassuring aspect of our analysis is that despite the environment of imperfect knowledge and the associated complexity of the economic environment, successful policy can be remarkably simple to implement and communicate. We find that simple difference rules that do not require any knowledge of the economy's natural rates are particularly well suited to ensure medium-run inflation control when natural rates are highly uncertain. These rules share commonalities with the simple robust strategy first proposed by Wicksell (1936 [1898]), who, after defining the natural interest rate, pointed out that precise knowledge about it, though desirable, was neither feasible nor necessary for policy implementation aimed toward maintaining price stability.

> "This does not mean that the bank ought actually to *ascertain* the natural rate before fixing their own rates of interest. That would, of course, be impracticable, and would also be quite unnecessary. For the current level of commodity prices provides a reliable test of the agreement or diversion of the two rates. The procedure should rather be simply as follows: *So long as prices remain unchanged, the bank's rate of interest is to remain unaltered. If prices rise, the rate of interest is to be raised; and if prices fall, the rate of interest is to be lowered; and the rate of interest is henceforth to be maintained at its new level until a further movement in prices calls for a further change in one direction or the other (...)*

> In my opinion, the main cause of the instability of prices resides in the instability of the banks to follow this rule."[5]

Our analysis confirms that simple difference rules that implicitly target the price level in the spirit of Wicksell excel at tethering inflation expectations to the central bank's goal. In so doing, they achieve superior stabilization of inflation and economic activity.

The remainder of the paper is organized as follows. Section 1 describes the estimated model of the economy. Section 2 lays out the model of perpetual learning and its calibration. Section 3 analyzes key features of the model under rational expectations and imperfect knowledge. Section 4 examines the performance of alternative monetary policy strategies, including our implementation of inflation targeting. Section 5 concludes.

1. A Simple Estimated Model of the U.S. Economy

We use a simple estimated quarterly model of the U.S. economy from Orphanides and Williams (2002), the core of which consists of the following two equations:

$$\pi_t = \phi_\pi \pi^e_{t+1} + (1-\phi_\pi)\pi_{t-1} + \alpha_\pi (u^e_t - u^*_t) + e_{\pi,t}, \quad e_\pi \sim \text{iid}(0,\sigma^2_{e_\pi}); \tag{1}$$

$$\begin{aligned} u_t = {} & \phi_u u^e_{t+1} + \chi_1 u_{t-1} + \chi_2 u_{t-2} + \chi_3 u^*_t \\ & + \alpha_u (r^a_{t-1} - r^*_t) + e_{u,t}, \quad e_u \sim \text{iid}(0,\sigma^2_{e_u}). \end{aligned} \tag{2}$$

Here π denotes the annualized percent change in the aggregate output price deflator, u denotes the unemployment rate, u^* denotes the (true) natural rate of unemployment, r^a denotes the (ex ante) real interest rate with one-year maturity, and r^* the (true) natural real rate of interest. The superscript e denotes the public's expectations formed during $t-1$. This model combines forward-looking elements of the new synthesis model studied by Goodfriend and King (1997), Rotemberg and Woodford (1999), Clarida, Galí, and Gertler (1999), and McCallum and Nelson (1999), with intrinsic inflation and unemployment inertia as in Fuhrer and Moore (1995b), Batini and Haldane (1999), Smets (2003), and Woodford (2003).

5. Wicksell (1936 [1898] p. 189; emphasis in original).

The Phillips curve in this model (equation 1) relates inflation in quarter t to lagged inflation, expected future inflation, and expectations of the unemployment gap during the quarter, using retrospective estimates of the natural rate discussed below. The estimated parameter ϕ_π measures the importance of expected inflation for the determination of inflation. The unemployment equation (equation 2) relates unemployment in quarter t to the expected future unemployment rate, two lags of the unemployment rate, the natural rate of unemployment, and the lagged real interest rate gap. Here, two elements reflect forward-looking behavior: the estimated parameter ϕ_u, which measures the importance of expected unemployment, and the duration of the real interest rate, which serves as a summary of the influence of interest rates of various maturities on economic activity. We restrict the coefficient χ_3 to equal $1 - \phi_u - \chi_1 - \chi_2$ so that the equation can be equivalently written in terms of the unemployment gap.

In estimating this model, we face the difficulty that expected inflation and unemployment are not directly observed. Instrumental variable and full-information maximum likelihood methods impose the restriction that the behavior of monetary policy and the formation of expectations be constant over time, neither of which appears tenable over the sample period that we consider (1969–2002). Instead, we follow the approach of Roberts (1997) and use survey data as proxies for expectations.[6] In particular, we use the median forecasts from the Survey of Professional Forecasters from the prior quarter as the relevant expectations for determining inflation and unemployment in period t; that is, we assume expectations are based on information available at time $t - 1$. We also employ first-announced estimates of these series in our estimation, to match the inflation and unemployment data as well as possible with the forecasts. Our primary sources for these data are the Real-Time Dataset for Macroeconomists and the Survey of Professional Forecasters, both currently maintained by the Federal Reserve Bank of Philadelphia (Zarnowitz and Braun, 1993; Croushore, 1993; Croushore and Stark, 2001). Using least squares over the sample 1969:1 to 2002:2, we obtain the following estimates:

$$\pi_t = \underset{(0.086)}{0.540}\,\pi^e_{t+1} + \underset{(--)}{0.460}\,\pi_{t-1} - \underset{(0.099)}{0.341}\,(u^e_t - u^*_t) + e_{\pi,t}, \qquad (3)$$

SER = 1.38; DW = 2.09.

6. See also Rudebusch (2002); Orphanides and Williams (2005c).

$$u_t = \underset{(0.084)}{0.257}\, u^e_{t+1} + \underset{(0.107)}{1.170}\, u_{t-1} - \underset{(0.071)}{0.459}\, u_{t-2} - \underset{(--)}{0.032}\, u^*_t + \underset{(0.013)}{0.043}\, (r^a_{t-1} - r^*_t) + e_{u,t}, \quad (4)$$

SER = 0.30; DW = 2.08.

The numbers in parentheses are the estimated standard errors of the corresponding regression coefficients; SER is the standard error of the regression and DW is the Durbin-Watson statistic. (Dashes are shown under the restricted parameters.) The estimated unemployment equation also includes a constant term (not shown) that captures the average premium of the one-year Treasury bill rate we use for estimation over the average of the federal funds rate, which corresponds to the natural interest rate estimates we employ in the model. For simplicity, we do not model the evolution of risk premiums. In the model simulations, we impose the expectations theory of the term structure, whereby the one-year rate equals the expected average of the federal funds rate over four quarters.

1.1 Natural Rates

We assume that the true processes governing natural rates in the economy follow highly persistent autoregressions. Specifically, we posit that the natural rates follow

$$u^*_t = 0.01\bar{u}^* + 0.99u^*_{t-1} + e_{u^*,t}, \text{ and}$$

$$r^*_t = 0.01\bar{r}^* + 0.99r^*_{t-1} + e_{r^*,t},$$

where $\bar{u}^*$ and $\bar{r}^*$ denote the unconditional means of the natural rates of unemployment and interest, respectively. The assumption that these processes are stationary is justified by the finding, based on a standard augmented Dickey-Fuller (ADF) test, that one can reject the null hypothesis of nonstationarity of both the unemployment rate and the ex post real federal funds rate over 1950–2003 at the 5 percent level. To capture the assumed high persistence of these series, we set the first-order autoregressive, or AR(1), coefficient to 0.99 and then calibrate the innovation variances to be consistent with estimates of time variation in the natural rates in postwar U.S. data.

As discussed in Orphanides and Williams (2002), estimates of the variances of the innovations to the natural rates differ widely. Indeed, owing to the imprecision in estimates of these variances, the postwar

U.S. data do not provide clear guidance regarding these parameters. We therefore consider three alternative calibrations of these variances, which we index by s. The case of $s = 0$ corresponds to constant and known natural rates, where $\sigma_{e_{u^*}} = \sigma_{e_{r^*}} = 0$. For the case of $s = 1$, we assume $\sigma_{e_{u^*}} = 0.070$ and $\sigma_{e_{r^*}} = 0.085$. These values imply an unconditional standard deviation of the natural rate of unemployment (interest) of 0.50 (0.60), which is in the low end of the range of standard deviations of smoothed estimates of these natural rates suggested by various estimation methods (see Orphanides and Williams, 2002, for details). Finally, the case of $s = 2$ corresponds to the high end of the range of estimates; for this case we assume $\sigma_{e_{u^*}} = 0.140$ and $\sigma_{e_{r^*}} = 0.170$. The relevant values of s for many small open economies and transitional economies may be even higher than estimates based on U.S. data, given the relative stability of the post-war U.S. economy.

1.2 Monetary Policy

We consider two classes of simple monetary policy rules. First, we analyze versions of the Taylor rule (Taylor, 1993), where the level of the nominal interest rate is determined by the perceived natural rate of interest, $\hat{r}_t^*$, the inflation rate, and a measure of the level of the perceived unemployment gap (namely, the difference between the unemployment rate and the perceived natural rate of unemployment, $\hat{u}_t^*$):

$$i_t = \hat{r}_t^* + \bar{\pi}_{t+j}^e + \theta_\pi (\bar{\pi}_{t+j}^e - \pi^*) + \theta_u (u_{t+k}^e - \hat{u}_t^*), \tag{5}$$

where $\bar{\pi}$ denotes the four-quarter average of the inflation rate, π^* is the central bank's inflation objective, j is the forecast horizon of inflation, and k is the forecast horizon of the unemployment rate forecast. We consider a range of values for the forecast horizons from –1, in which case policy responds to the latest observed data (for quarter $t - 1$), to a forecast horizon up to three years into the future. When policy is based on forecasts, we assume that the central bank uses the same forecasts of inflation and the unemployment rate that are available to private agents.

We refer to this class of rules as level rules because they relate the level of the interest rate to the level of the unemployment gap. Rules of this type have been found to perform quite well in terms of stabilizing economic fluctuations, at least when the natural rates of interest and unemployment are accurately measured. For our analysis, we consider a variant of the Taylor rule that responds to

the unemployment gap instead of the output gap, recognizing that the two are related by Okun's (1962) law. In his 1993 exposition, Taylor examines response parameters equal to 0.5 for the inflation gap and the output gap, which, with an Okun's coefficient of 2.0, corresponds to setting $\theta_\pi = 0.5$ and $\theta_u = -1.0$.

If policy follows the level rule given by equation (5), then the policy error introduced in period t by natural rate misperceptions is given by

$$\left(\hat{r}_t^* - r_t^*\right) - \theta_u\left(\hat{u}_t^* - u_t^*\right).$$

Although unintentional, these errors could subsequently induce undesirable fluctuations in the economy, worsening stabilization performance. The extent to which misperceptions regarding the natural rates translate into policy-induced fluctuations depends on the parameters of the policy rule. As is evident from the above expression, policies that are relatively unresponsive to real-time assessments of the unemployment gap—that is, those with small θ_u—minimize the impact of misperceptions regarding the natural unemployment rate.

As discussed in Orphanides and Williams (2002), one policy rule that is immune to natural rate mismeasurement of the kind considered here is a difference rule, in which the change in the nominal interest rate is determined by the inflation rate and the change in the unemployment rate:

$$\Delta i_t = \theta_\pi\left(\overline{\pi}_{t+j}^e - \pi^*\right) + \theta_{\Delta u}\Delta u_{t+k}. \tag{6}$$

This rule is closely related to price-level targeting strategies. It corresponds to the first difference of the rule that would be obtained if the price level were substituted for inflation in the level rule (equation 5).[7] This policy rule is as simple, in terms of the number of parameters, as the original formulation of the Taylor rule. However, the difference rule is simpler to communicate and implement in practice than the Taylor rule because it does not require knowledge of the natural rates of interest or unemployment. Policy guided by a difference rule can thus be more transparent than policy guided by a level rule.

7. For related policy rule specifications, see Judd and Motley (1992); Fuhrer and Moore (1995a); Orphanides (2003a). See also Orphanides and Williams (2002, 2005b) for analyses of a generalization that nests the level rule (equation 5) and difference rule (equation 6).

2. Perpetual Learning

Expectations play a central role in determining inflation, the unemployment rate, and the interest rate in the model. We consider two alternative models of expectations formation. One model, used in most monetary policy research, is rational expectations, that is, expectations that are consistent with the model. The second model is one of perpetual learning, where agents continuously reestimate a forecasting model and form expectations using that model.

In the case of learning, we follow Orphanides and Williams (2005c) and posit that agents obtain forecasts for inflation, unemployment, and interest rates by estimating a restricted vector autoregression (VAR) corresponding to the reduced form of the rational expectations equilibrium with constant natural rates. We assume that this VAR is estimated recursively with constant-gain least squares.[8] Each period, agents use the resulting VAR to construct one-step-ahead and multi-step-ahead forecasts. This learning model can be justified in two ways. First, in practice agents are working with finite quantities of data, and the assumption of rational expectations only holds in the distant future when sufficient data have been collected. Alternatively, agents may allow for the possibility of structural change and therefore place less weight on older data, in which case learning is a never-ending process.

Specifically, let $\mathbf{Y}_t$ denote the 1 x 3 vector consisting of the inflation rate, the unemployment rate, and the federal funds rate, each measured at time t: $\mathbf{Y}_t = (\pi_t, u_t, i_t)$. Let $\mathbf{X}_t$ be the j x 1 vector of a constant and lags of $\mathbf{Y}_t$ that serve as regressors in the forecasting model. The precise number of lags of elements of $\mathbf{Y}_t$ that appear in $\mathbf{X}_t$ depends on the policy rule. For example, consider the difference rule (equation 6) when policy responds to the three-quarter-ahead inflation forecast, $j = 3$, and the lagged change in the unemployment rate, $k = -1$. (This is one of the policies for which we present detailed simulation results later in the paper). In this case, two lags of the unemployment rate and one lag each of inflation and the interest rate suffice to capture the reduced-form dynamics under rational expectations with constant natural rates, so $\mathbf{X}_t = (1, \pi_{t-1}, u_{t-1}, u_{t-2}, i_{t-1})'$.

The recursive estimation can be described as follows: let $\mathbf{c}_t$ be the j x 3 vector of coefficients of the forecasting model. Then, using data

8. Sargent (1993, 1999) and Evans and Honkapohja (2001) discuss properties of constant-gain learning.

through period t, the parameters for the constant-gain least squares forecasting model can be written as

$$\mathbf{c}_t = \mathbf{c}_{t-1} + \kappa \mathbf{R}_t^{-1} \mathbf{X}_t (\mathbf{Y}_t - \mathbf{X}_t' \mathbf{c}_{t-1}), \text{ and} \tag{7}$$

$$\mathbf{R}_t = \mathbf{R}_{t-1} + \kappa (\mathbf{X}_t \mathbf{X}_t' - \mathbf{R}_{t-1}), \tag{8}$$

where $\kappa > 0$ is a small constant gain.

This algorithm estimates all parameters of the agent's forecasting system and does not explicitly incorporate any information regarding the central bank's numerical inflation objective. Later, we introduce this element of inflation targeting by positing that the announcement and explicit commitment to a quantitative inflation target simplifies the agent's forecasting problem by reducing by one the number of parameters requiring estimation and updating.

A key parameter for the constant-gain-learning algorithm is the updating rate, κ. To calibrate the relevant range for this parameter, we examined how well different values of κ fit the expectations data from the Survey of Professional Forecasters, following Orphanides and Williams (2005c). To examine the fit of the Survey of Professional Forecasters (SPF), we generated a time series of forecasts using a recursively estimated VAR for the inflation rate, the unemployment rate, and the federal funds rate. In each quarter, we reestimated the model using all historical data available during that quarter (generally from 1948 through the most recent observation). We allowed for discounting of past observations by using geometrically declining weights. This procedure resulted in reasonably accurate forecasts of inflation and unemployment, with root mean squared errors (RMSE) comparable to the residual standard errors from the estimated structural equations (equations 3 and 4). We found that discounting past data with values for κ in the range of 0.01 to 0.04 yielded forecasts closer to the SPF, on average, than the forecasts obtained with lower or higher values of κ. Milani (2005) finds a similar range of values in an estimated dynamic stochastic general-equilibrium (DSGE) model with learning. In light of these results, we consider three alternative calibrations of the gain: $\kappa = \{0.01, 0.02, 0.03\}$, with $\kappa = 0.02$ serving as a baseline value.[9] As in the case of natural rate variation, the relevant values of κ may be higher for small open economies and transitional

9. The value $\kappa = 0.02$ is also in line with the discounting that Sheridan (2003) finds to best explain the inflation expectations data reported in the Livingston Survey.

economies than for the U.S. data, owing to the relative stability of the post-war U.S. economy.

Given this calibration of the model, this learning mechanism represents a relatively modest deviation from rational expectations and yields reasonable forecasts. Indeed, agents' average forecasting performance in the model is close to the optimal forecast.

2.1 Central Bank Learning

In the case of level rules, policymakers need a procedure to compute real-time estimates of the natural rates. If policymakers knew the true data-generating processes governing the evolution of natural rates, they could use this knowledge to design the optimal estimator. In practice, however, considerable uncertainty surrounds these processes, and the optimal estimator for one process may perform poorly if the process is misspecified. Williams (2005) shows that a simple constant-gain method to update natural rate estimates based on the observed rates of unemployment and (ex post) real interest rates is reasonably robust to natural rate model misspecification. We follow this approach and assume that policymakers update their estimates of natural rates using simple constant-gain estimators given by the following equations:

$$\hat{r}^*_t = \hat{r}^*_{t-1} + 0.005\left(i_{t-1} - \pi_{t-1} - \hat{r}^*_{t-1}\right), \text{ and}$$

$$\hat{u}^*_t = \hat{u}^*_{t-1} + 0.005\left(u_{t-1} - \hat{u}^*_{t-1}\right).$$

3. Effects of Imperfect Knowledge on Economic Dynamics

We first present some simple comparisons of the economy's behavior under rational expectations with known natural rates and under learning with time-varying and unobservable natural rates. Under learning, the economy is governed by nonlinear dynamics, so we use numerical simulations to illustrate the properties of the model economy, conditional on the policymaker following a specific policy rule.

3.1 Simulation Methodology

In the case of rational expectations with constant and known natural rates, we compute all model moments and impulse responses

numerically as described in Levin, Wieland, and Williams (1999). In all other cases, we compute approximations of the unconditional moments and impulse responses using simulations of the model.

For model stochastic simulations used to compute estimates of unconditional moments, the initial conditions for each simulation are given by the rational expectations equilibrium with known and constant natural rates. Specifically, all model variables are initialized to their steady-state values, assumed without loss of generality to be zero. The central bank's initial perceived levels of the natural rates are set to their true values, likewise equal to zero. Finally, the initial values of the **c** and **R** matrices describing the private agents' forecasting model are initialized to their respective values, which correspond to the reduced form of the rational equilibrium solution to the structural model assuming constant and known natural rates.

Each period, innovations are generated from Gaussian distributions, with variances reported above. The innovations are serially and contemporaneously uncorrelated. For each period, the structural model is simulated, the private agent's forecasting model is updated (resulting in a new set of forecasts), and the central bank's natural rate estimate is updated. To estimate model moments, we simulate the model for 41,000 periods and discard the first 1,000 periods to mitigate the effects of initial conditions. We compute the unconditional moments from sample root mean squares from the remaining 40,000 periods (10,000 years) of simulation data.[10]

Private agents' learning process injects a nonlinear structure into the model, which may generate explosive behavior in a stochastic simulation of sufficient length for some policy rules that would have been stable under rational expectations. One source of instability stems from the possibility that the forecasting model itself may become unstable. We take the view that private forecasters reject unstable models in practice. Each period of the simulation, we compute the maximum modulus root of the forecasting VAR excluding the constants. If the modulus of this root falls below the critical value of one, the forecasting model is updated as described above; if not, we assume that the forecasting model is not updated and the **c** and **R** matrices are held at their respective previous-period values.[11]

10. Simulations under rational expectations, in which we can compute the moments directly, indicate that this sample size is sufficient to yield very accurate estimates of the unconditional variances. Testing further indicates that 1,000 periods are sufficient to remove the effects of initial conditions on simulated second moments.

11. We chose this critical value so that the test would have a small effect on model simulation behavior while eliminating explosive behavior in the forecasting model.

Stability of the forecasting model is not sufficient to ensure stability in all simulations. We therefore impose a second condition that restrains explosive behavior. In particular, if the inflation rate or the unemployment gap exceeds, in absolute value, five times its respective unconditional standard deviation (computed under the assumption of rational expectations and known and constant natural rates), then the variable that exceeds this bound is constrained to equal the corresponding limit in that period. These constraints on the model are sufficient to avoid explosive behavior for the exercises that we consider in this paper; they are rarely invoked for most of the policy rules we study, particularly for optimized policy rules.

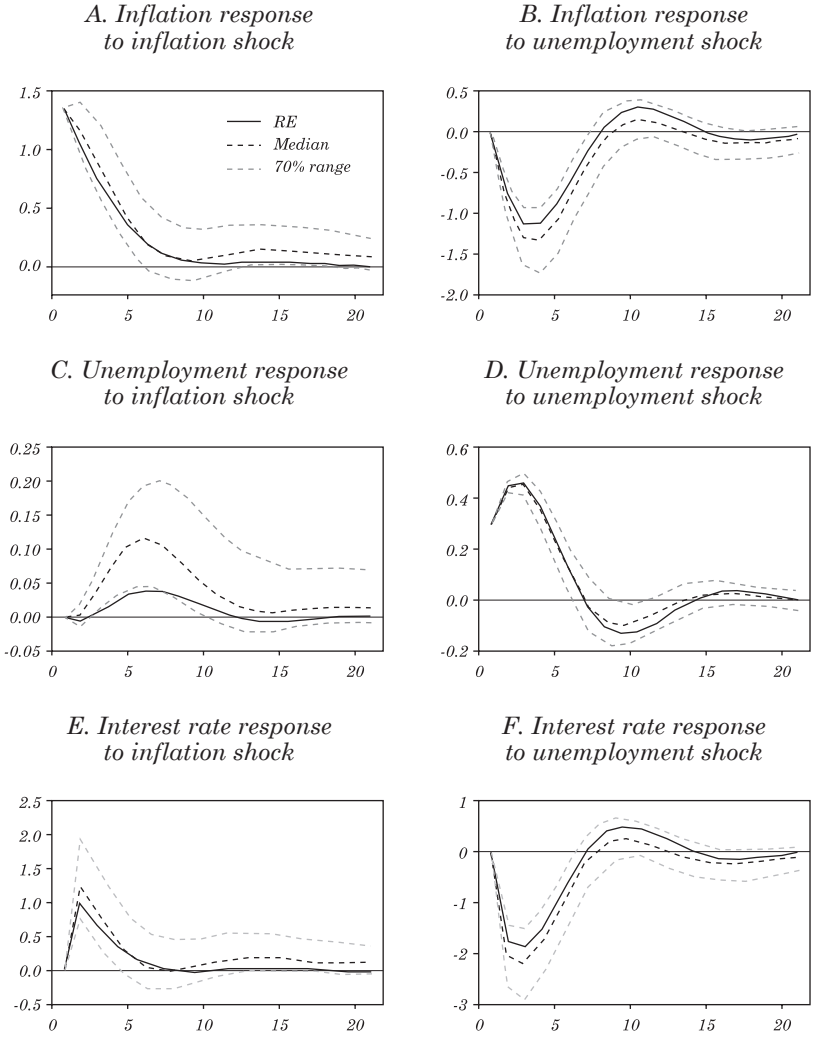
For impulse responses, we first compute an approximation of the steady-state distribution of the model state vector by running a stochastic simulation of 100,000 periods. We then draw 1,001 sample state vectors from this distribution and compute the impulse response function for each of these draws. From these 1,001 impulse response functions, we compute an estimate of the distribution of the model impulse response functions.

3.2 Impulse Responses

We use model impulse responses to illustrate the effects of learning on macroeconomic dynamics. For this purpose, let monetary policy follow a level policy rule similar to that proposed by Taylor (1993), with $\theta_\pi = 0.5$ and $\theta_u = -1$, where the inflation forecast horizon is three quarters ahead ($j = 3$) and that of the unemployment rate is the last observed quarter (that is, $k = -1$).

Figure 1 compares the impulse responses of inflation, the nominal interest rate, and the unemployment rate to one-standard-deviation shocks to inflation and unemployment under perfect knowledge (that is, rational expectations with known natural rates) with the corresponding impulse responses under imperfect knowledge with time variation in the natural rates, $s = 1$, and perpetual learning with gain $\kappa = 0.02$. Each period corresponds to one quarter. Under learning, the impulse responses to a specific shock vary with the state of the economy and the state of beliefs governing the formation of expectations. In other words, the responses vary with the initial conditions, {**X**, **c**, **R**}, at the time the shock occurs. To summarize the range of possible outcomes in the figure, we plot the median and the 70 percent range of the distribution of impulse responses, corresponding to the stationary distribution of {**X**, **c**, **R**}. Under rational expectations, the responses are invariant to the state of the economy.

Figure 1. Impulse Response Functions under the Taylor Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

The dynamic impulse responses to a specific shock exhibit considerable variation under learning. Furthermore, the distribution of responses is not symmetric around the impulse response that obtains under rational expectations. For example, the impulse responses of inflation and unemployment to an inflation shock are noticeably skewed in a direction that yields greater persistence. This persistence may be quite extreme with some probability, indicating that transitory shocks can have very long-lasting effects under learning.

3.3 Macroeconomic Variability and Persistence

Perpetual learning provides a powerful propagation mechanism for economic shocks in the economy, resulting in greater volatility and persistence. We present a summary comparison of the asymptotic variances and persistence for this experiment in table 1, which includes the full range of natural range variation and values of κ considered here. Learning on the part of the public increases the variability and persistence of key macroeconomic variables. Even in the absence of natural rate misperceptions (the case of $s = 0$), shocks to inflation and unemployment engender time variation in private agents' estimates of the VAR used for forecasting. This time variation in the VAR coefficients adds persistent noise to the economy relative to the perfect-knowledge benchmark. As a result, the unconditional variances and the serial correlations of inflation, unemployment, and the interest rate rise under learning. These effects are larger for higher values of κ, for which the sensitivity of the VAR coefficients to incoming data is greater.

The presence of natural rate variation amplifies the effects of private sector learning on macroeconomic variability and persistence. Under rational expectations and the Taylor rule, time-varying natural rates and the associated misperceptions increase the variability of inflation, but have relatively little effect on the variability of the unemployment gap and interest rates. Nevertheless, the combination of private sector learning and natural rate variation (and misperceptions) can dramatically increase macroeconomic variability and persistence. For example, under the Taylor rule, the standard deviation of the unemployment gap rises from 0.87 percent under rational expectations with constant natural rates to 1.11 percent under learning with $s = 1$ and $\kappa = 0.02$. For inflation, the increase in the standard deviation is even more dramatic, from 2.93 percent to 4.35 percent. The first-order autocorrelation of the unemployment gap rises from 0.88 to 0.92 and that of inflation rises from 0.81 to 0.90.

Table 1. Performance under the Taylor Rule

		Standard deviation			*First-order autocorrelation*		
Expectations	*s*	π	$u - u^*$	Δi	π	$u - u^*$	i
Rational expectations	0	2.93	0.87	2.33	0.81	0.88	0.78
	1	3.22	0.88	2.35	0.84	0.88	0.82
	2	3.94	0.89	2.39	0.89	0.88	0.89
$\kappa = 0.01$	0	3.29	0.93	2.57	0.84	0.89	0.81
	1	4.16	1.10	2.89	0.89	0.92	0.86
	2	5.00	1.22	3.10	0.93	0.93	0.89
$\kappa = 0.02$	0	3.66	0.99	2.80	0.86	0.90	0.83
	1	4.35	1.11	3.01	0.90	0.92	0.87
	2	5.21	1.24	3.29	0.93	0.93	0.89
$\kappa = 0.03$	0	3.95	1.04	3.00	0.87	0.91	0.84
	1	4.57	1.15	3.22	0.90	0.92	0.87
	2	5.37	1.29	3.48	0.92	0.93	0.89

Source: Authors' computations.

The presence of natural rate variation and misperceptions interferes with the public's ability to forecast inflation, unemployment, and interest rates accurately. These forecasting errors contribute to a worsening of macroeconomic performance.

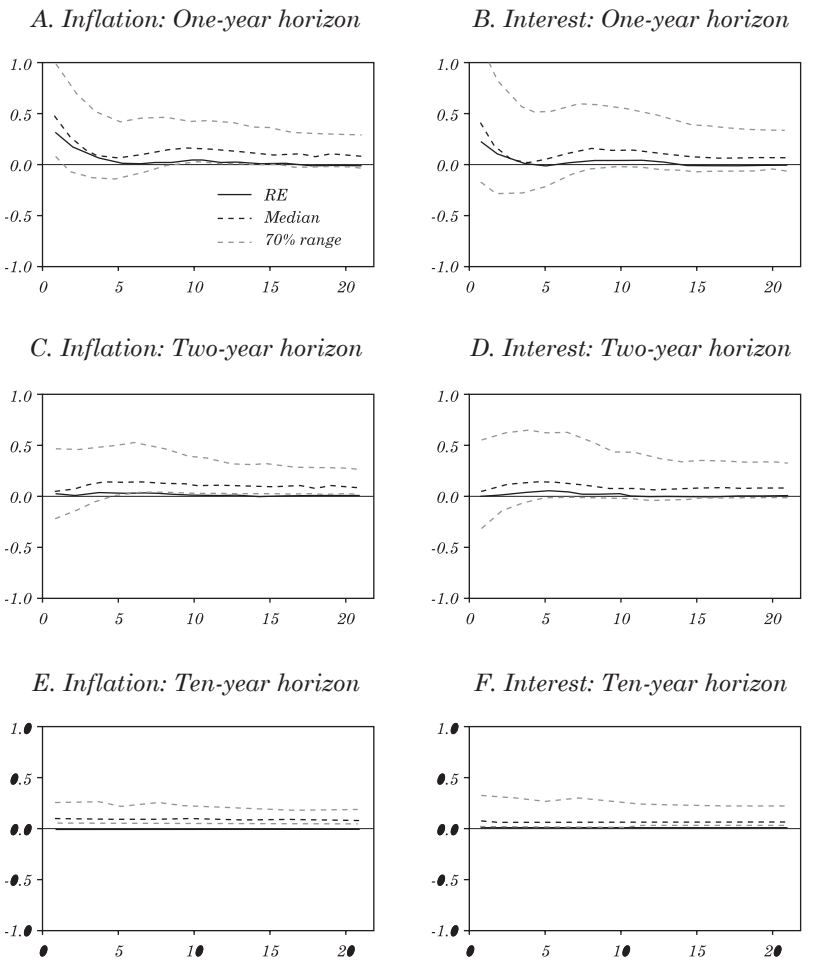
3.4 Excess Sensitivity of Long-Horizon Expectations

The adaptive learning algorithm that economic agents employ to form expectations under imperfect knowledge in our model also allows us to investigate the behavior of long-horizon expectations. This allows examination of the apparent excess sensitivity of yields on long-run government bonds to shocks—a phenomenon that appears puzzling in standard models when knowledge is perfect. Shiller (1979) and Mankiw and Summers (1984) point out that long-term interest rates appear to move in the same direction following changes in short-term interest rates and to overreact relative to what would be expected if the expectations hypothesis held and expectations were assumed to be rational. Changes in the federal funds rate generally cause long-term interest rates to move considerably and in the same direction (Cook and Hahn, 1989, Roley and Sellon, 1995, Kuttner, 2001). Kozicki and Tinsley (2001a, 2001b), Cogley (2005), and Gürkaynak, Sack, and Swanson (2005) suggest that this sensitivity could be attributed to movements in long-run inflation expectations that differ from those implied by standard linear rational expectations macroeconomic models with fixed and known parameters.

Learning-induced expectations dynamics provide a potential explanation for these phenomena.[12] Figure 2 shows the one-, two-, and ten-year-ahead forecasts of the inflation and nominal interest rates from the impulse response to a one-standard-deviation inflation shock, based on the same shocks used in computing figure 1; figure 3 shows the same for a one-standard-deviation shock to the unemployment rate. These measure the annualized quarterly inflation or interest rate expected to prevail n quarters in the future, not the average inflation or interest rate over the next n quarters. These forward rates are computed by projecting ahead using the agents' forecasting model. Under perfect knowledge, inflation is expected to be only a few basis points above baseline two years after the shock, and expectations of inflation ten years in the future are nearly unmoved. The same pattern is seen in forward interest rates.

12. Orphanides and Williams (2005a) and Beechey (2004) analyze the reaction of the term structure of expectations to news in the presence of perpetual learning.

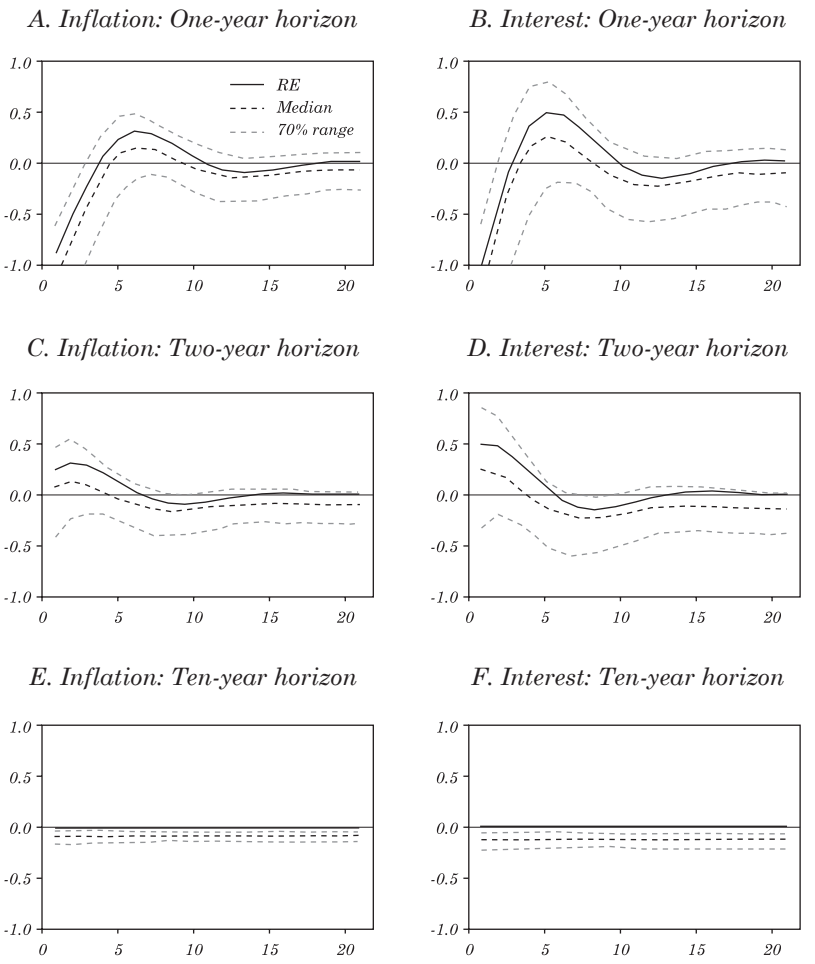
Figure 2. Impulse Response to an Inflation Shock under the Taylor Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

Figure 3. Impulse Response to an Unemployment Shock under the Taylor Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

In contrast to the stability of longer-run expectations found under perfect knowledge, the median response under imperfect knowledge shows inflation and interest rate expectations at the two- and ten-year horizons rising by nearly ten basis points in response to a transitory inflation shock. Moreover, the excess sensitivity of longer-run inflation expectations to transitory shocks exhibited by the median response is on the lower end of the 70 percent range of impulse responses, indicating that the response of longer-run expectations is, on average, even larger and depends crucially on the conditions in which the shock occurs. Indeed, under unfavorable conditions, the inflation expectations process can become unmoored for an extended period. Such episodes correspond to endogenously generated "inflation scares" and are similar to historical episodes for the United States described in Goodfriend (1993). In these episodes, inflation expectations and long-term interest rates appear to react excessively and persistently to some event that would not warrant such a reaction if expectations were well anchored. These results also serve to highlight one of the crucial concerns regarding the behavior of expectations that the practice of inflation targeting attempts to address and that cannot appear in an environment of rational expectations with perfect knowledge. Under perfect conditions, expectations always remain well anchored.

4. Implications for Monetary Policy Design

This section explores the ways in which monetary policy can be improved in an environment of imperfect knowledge. We consider three issues, all of which are closely related key characteristics of inflation targeting. First, we compare the performance of the economy under the level policy rule framework and under the easier-to-communicate and more transparent difference policy framework. As we discuss, the difference rule strategy appears superior for ensuring achievement of the policymakers' inflation objective, especially in an environment with uncertainty regarding natural rates—a situation in which level rules that rely on "gaps" from natural rate concepts for policy implementation run into substantial difficulties. Next, we consider the optimal horizon for expectations of inflation and unemployment rates to which policy reacts in the policy rule, as well as some robustness characteristics of policy under alternative preferences for inflation stabilization versus stabilization of real economic activity. Finally, we turn to the role of communicating an explicit numerical long-run inflation objective to the public for the performance of the economy under alternative policies.

To facilitate comparisons, we compare the performance of the economy using a loss function as a summary statistic. Specifically, we assume that the policymakers' objective is to minimize the weighted sum of the unconditional variances of inflation, the unemployment gap, and the change in the nominal federal funds rate:

$$L = \text{var}(\pi - \pi^*) + \lambda \,\text{var}(u - u^*) + \nu \,\text{var}\left[\Delta(i)\right], \tag{9}$$

where var(x) denotes the unconditional variance of variable x. As a benchmark, we consider $\lambda = 4$ and $\nu = 1$, but we also consider alternatives for the relative weight of real-activity stabilization, λ. (Note that $\lambda = 4 = 2^2$ corresponds to the case of equal weights on inflation and output gap variability—based on Okun's law with a coefficient of 2.)

4.1 Comparing the Level and Difference Rule Approaches

Up to this point, we have assumed that policy follows a specific formulation of the Taylor rule. As emphasized in Orphanides and Williams (2002), such policies are particularly prone to making errors when there is considerable uncertainty regarding natural rates. In particular, persistent misperceptions of the natural unemployment or interest rates translate into persistent deviations of inflation from its target value. Perpetual learning on the part of economic agents amplifies the effect of such errors and further complicates the design of policy. It is thus instructive to also study alternative monetary policy rules that are robust to natural rate misperceptions and are therefore better designed for achieving medium-run inflation stability as in an inflation-targeting framework.

We start by examining more closely the performance of alternative parameterizations of the Taylor rule. Figure 4 presents iso-loss contours, curves that trace out the combinations of the policy rule parameters that yield an identical central bank loss, of the economy with the above loss function for alternative parameterizations of the level rule with $j = 3$ and $k = -1$:

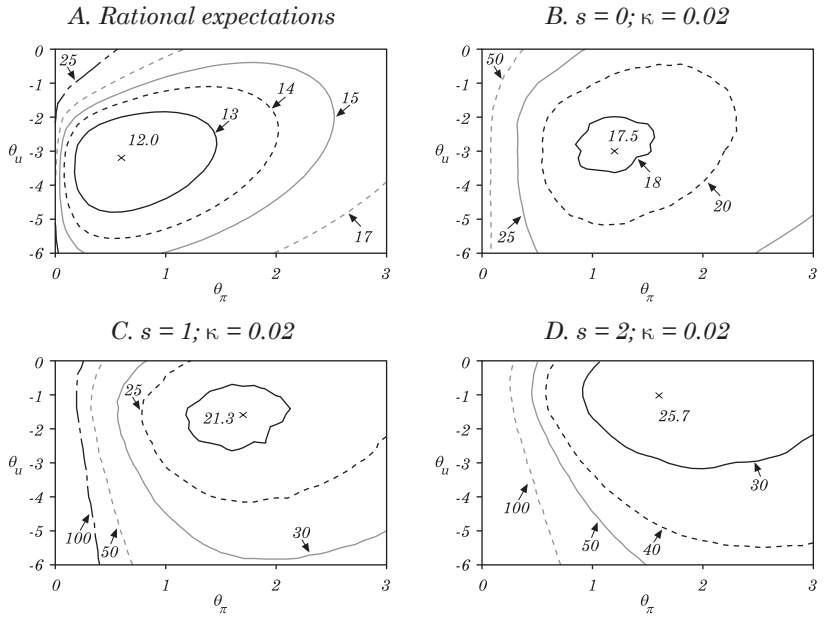
$$i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + \theta_\pi(\overline{\pi}_{t+3}^e - \pi^*) + \theta_u(u_{t-1}^e - \hat{u}_t^*), \tag{10}$$

The top left panel shows the loss under rational expectations with constant natural rates, referred to in this discussion as perfect knowledge, while the other panels show the loss under learning with $\kappa = 0.02$ and time-varying natural rates for values of $s = \{0, 1, 2\}$. In each panel, the

horizontal axis shows the value of the inflation response, θ_π, and the vertical axis shows the value of the unemployment response, θ_u. The contour charts are constructed by computing the loss for each pair of policy rule coefficients along a grid. The contour surface traces the losses corresponding to the values of these response coefficients. The coordinates corresponding to the minimum loss (marked with an *x*) identify the optimal parameters, among the set of values along the grid that we evaluated, for the underlying rule.[13] Thus, from the top-left panel, the optimal level rule under perfect knowledge is given by:

$$i_t = \hat{r}^*_t + \overline{\pi}^e_{t+3} + 0.6\,(\overline{\pi}^e_{t+3} - \pi^*) - 3.2\,(u_{t-1} - \hat{u}^*_t).$$

Figure 4. Performance of the Level Rule[a]

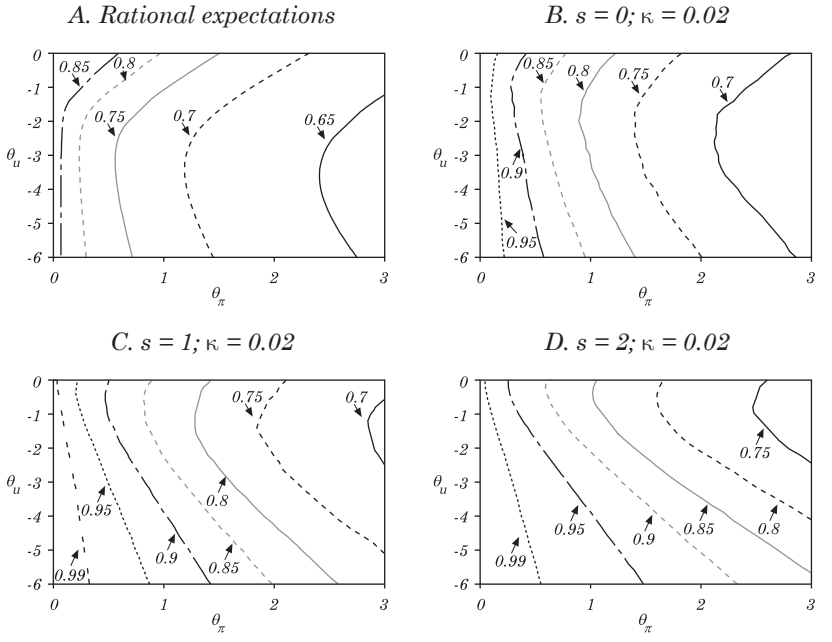


Source: Authors' computations.
a. The level rule is defined as $i_t = \hat{r}^*_t + \overline{\pi}^e_{t+3} + \theta_\pi\left(\overline{\pi}^e_{t+3} - \pi^*\right) + \theta_u\left(u_{t-1} - \hat{u}^*_t\right)$.

13. In constructing the loss contour charts, we only evaluate the losses along the points of the grid. Thus, the minima reported in the charts are approximate and do not correspond precisely to the true minimum values. In cases where the true optimal policy rule coefficients lie near the midpoint between two grid points, the true optimal policy will yield a loss that may be slightly lower than that reported in the chart, even after rounding to one decimal place.

The level rule optimized under the assumption of perfect knowledge is not robust to uncertainty regarding the formation of expectations or natural rate variation. Comparison of the two left panels, for example, indicates that if the optimal level policy under perfect knowledge were implemented when the economy is governed by $s = 1$ and $\kappa = 0.02$, the loss would be very high relative to the loss associated with the best policy under learning. (The same is true for the classic Taylor rule, with $\theta_\pi = 0.5$ and $\theta_u = -1.0$.) One problem with the optimal level rule under perfect knowledge is that policymaker misperceptions of the natural rates of interest and unemployment translate into persistent overly expansionary or contractionary policy mistakes. In such circumstances, the policy rule's rather timid response to inflation is insufficient to contain inflation expectations near the policymakers' target. This is seen in the autocorrelation of inflation, shown in contour plots in figure 5. The combination of private sector learning and natural rate misperceptions yield an autocorrelation of inflation dangerously close to unity when the optimal policy under perfect knowledge is followed.

Figure 5. Autocorrelation of Inflation under the Level Rule[a]



Source: Authors' computations.
a. The level rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + \theta_\pi\left(\overline{\pi}_{t+3}^e - \pi^*\right) + \theta_u\left(u_{t-1} - \hat{u}_t^*\right)$.

Level rules of this type entail a tradeoff between achieving optimal performance in one model specification and being robust to model misspecification. We have shown that the optimal rule under perfect knowledge is not robust to the presence of imperfect knowledge. For our benchmark case with imperfect knowledge, $s = 1$ and $\kappa = 0.02$, a rule with response coefficients close to $\theta_\pi = 1.5$ and $\theta_u = -1.5$ would be best in this family. The greater responsiveness to inflation in this parameterization proves particularly helpful for improving economic stability here, but this policy performs noticeably worse if knowledge is, in fact, perfect.

Next we turn to the alternative policy that avoids gaps from natural concepts altogether. Figure 6 presents comparable iso-loss contours for the difference rule (equation 6) with $j = 3$ and $k = -1$:

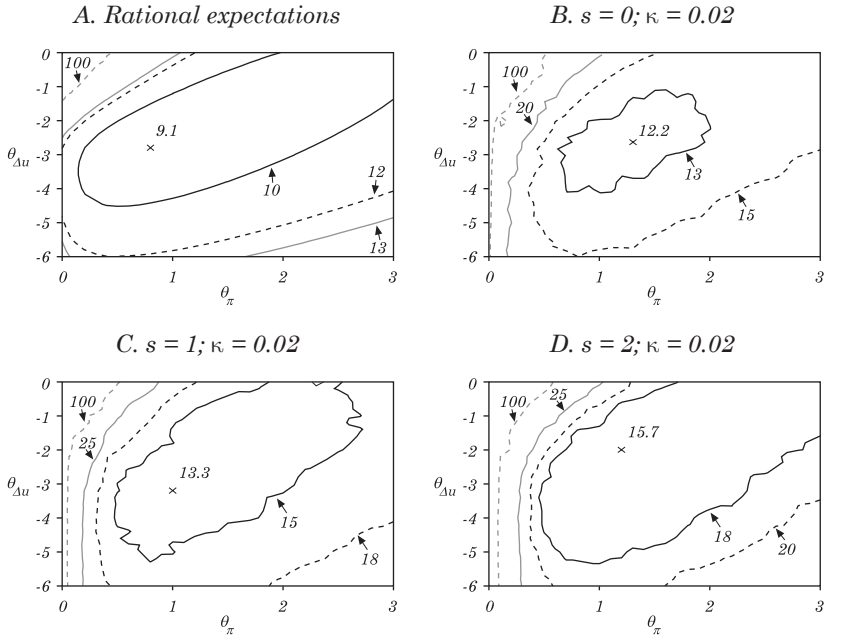
$$i_t = i_{t-1} + \theta_\pi (\overline{\pi}^e_{t+3} - \pi^*) + \theta_{\Delta u} \Delta u_{t-1}. \tag{11}$$

The structure of this figure is comparable to figure 4, except that here, the vertical axis in each panel reflects the responsiveness to the change in unemployment, $\theta_{\Delta u}$. Comparing figure 6 with figure 4 suggests that the difference rule generally yields superior performance, especially when knowledge is imperfect. Furthermore, in sharp contrast to the level rule optimized assuming perfect knowledge, the difference rule optimized assuming perfect knowledge appears to be robust to learning and natural rate variation. A difference rule with a response coefficient to inflation of about 1 and to the change in the unemployment rate of about –3 is nearly optimal under both perfect and imperfect knowledge. Indeed, the loss surface is relatively flat in the region of parameters close to this policy.[14] By avoiding policy mistakes related to natural rate misperceptions, this rule keeps inflation—and thus inflation expectations—under tight control despite the presence of imperfect knowledge.

To demonstrate how the economy behaves under imperfect knowledge with a well-designed difference rule, figures 7, 8, and 9 present impulse responses for the difference rule with $\theta_\pi = 1$ and $\theta_{\Delta u} = -3$. The three figures are directly comparable to the impulse

14. In Orphanides and Williams (2006), we compute the optimal Bayesian policy assuming equal weights across the specifications of learning and natural rate variability considered here. We find that a difference rule with $\theta_\pi = 1.1$ and $\theta_{\Delta u} = 2.6$ is remarkably robust to uncertainty regarding the degree of imperfect knowledge.

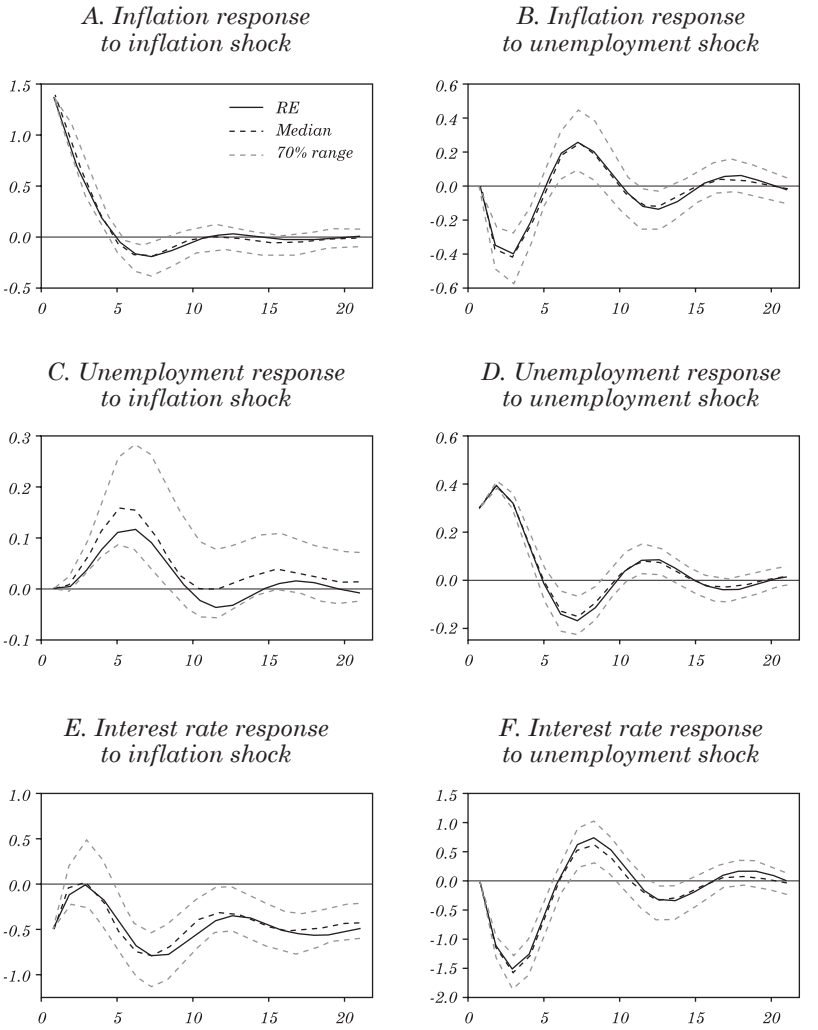
Figure 6. Performance of the Difference Rule[a]



Source: Authors' computations.
a. The difference rule is defined as $i_t = i_{t-1} + \theta_\pi\left(\overline{\pi}^e_{t+3} - \pi^*\right) + \theta_{\Delta u}\Delta u_{t-1}$.

responses for the Taylor rule shown earlier in figures 1, 2, and 3. These responses exhibit some overshooting and secondary cycling, as is typical of difference rules. The resulting loss, however, is significantly lower than that resulting under the level rules that may not exhibit such oscillations. In contrast to the impulse responses under the Taylor rule, the 70 percent range of impulse responses under the difference rule shown in these figures is much tighter and concentrated around the impulse response under perfect knowledge. This serves to demonstrate the relative usefulness of this strategy for mitigating the role of imperfect knowledge in the economy. In particular, figures 8 and 9 show that even without incorporating explicit information about the policymakers' objective in the formation of expectations, this policy rule succeeds in anchoring long-horizon expectations, especially of inflation, under imperfect knowledge.

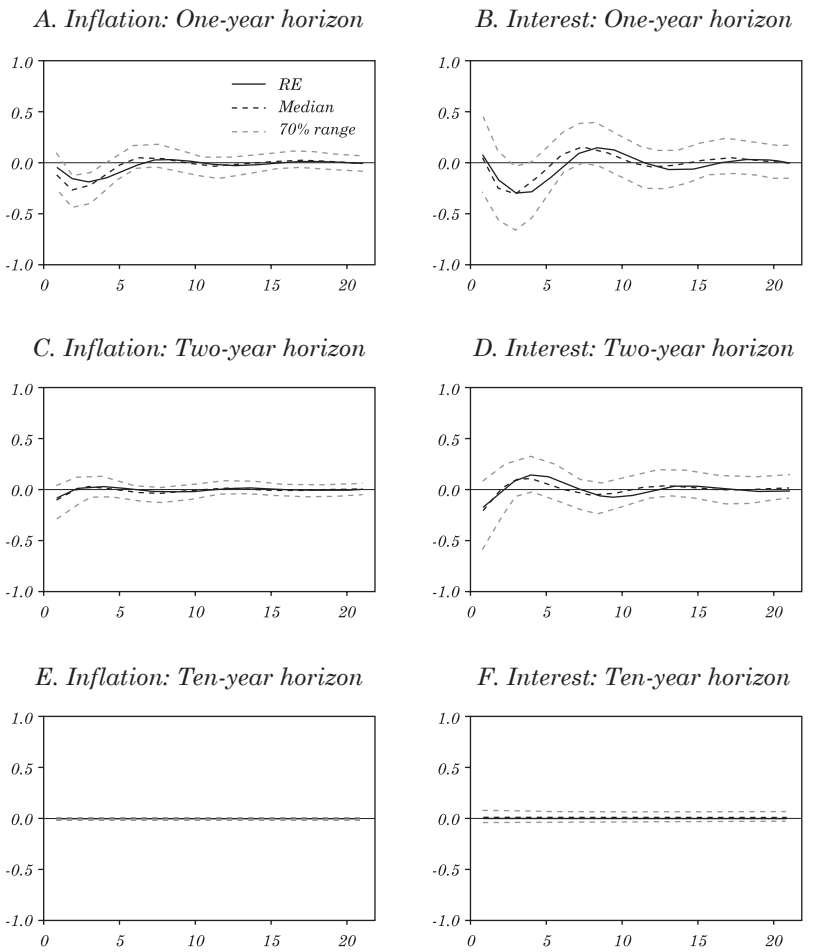
Figure 7. Impulse Response Functions under the Difference Rule[a]



Source: Authors' computations.

a. The difference rule is defined as $i_t = i_{t-1} + 1\left(\pi^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

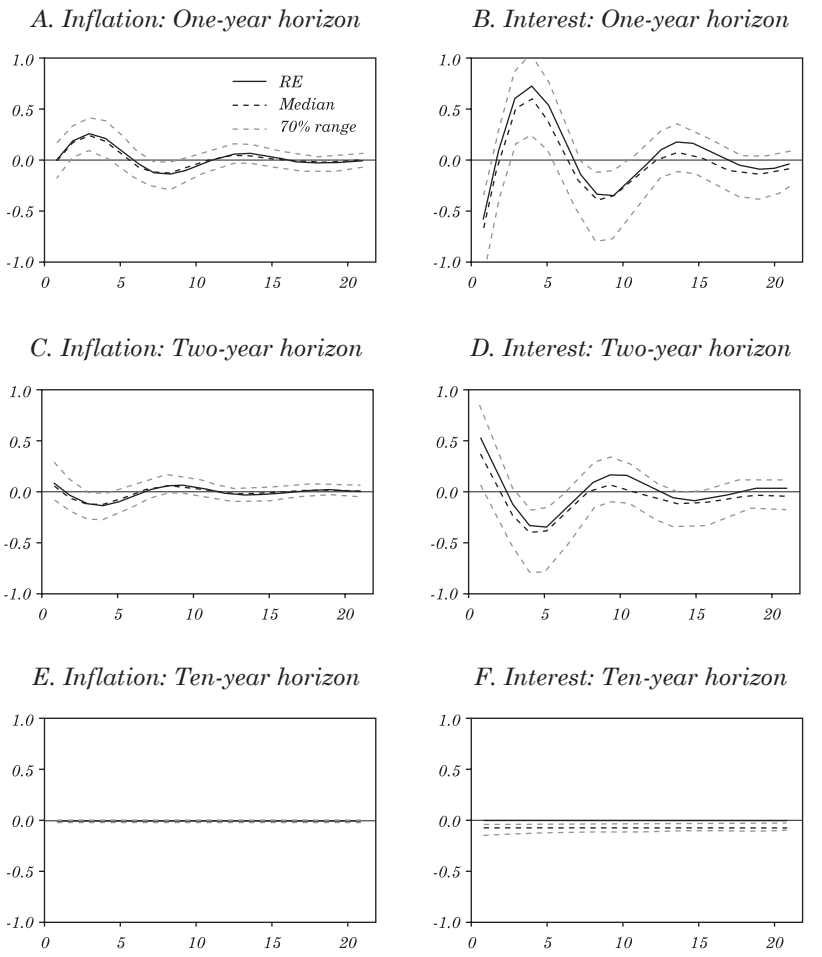
Figure 8. Impulse Response to an Inflation Shock under the Difference Rule[a]



Source: Authors' computations.

a. The difference rule is defined as $i_t = i_{t-1} + 1\left(\bar{\pi}^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

Figure 9. Impulse Response to an Unemployment Shock under the Difference Rule[a]



Source: Authors' computations.

a. The difference rule is defined as $i_t = i_{t-1} + 1\left(\bar{\pi}^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

4.2 Forecast Horizons

Throughout the analysis so far, we have assumed that the policy rule responds to expected inflation at a three-quarter-ahead horizon and to the lagged unemployment rate or the lagged change in the unemployment rate. We also explicitly examine the choice of horizon for the class of difference rules. We find that under perfect knowledge, an outcome-based difference rule that responds to lagged inflation and unemployment performs about as well as forward-looking alternatives, consistent with the findings of Levin, Wieland, and Williams (2003). Under imperfect knowledge, however, an optimized difference rule that responds to the three-quarter horizon for expected inflation outperforms its outcome-based counterpart. As discussed in Orphanides and Williams (2005a), under learning, inflation expectations represent an important state variable for determining actual inflation that is not collinear with lagged inflation. Expected inflation can thus be a more useful summary statistic for inflation in terms of a policy rule.[15]

The inflation forecast horizon in the policy rule should not be too far in the future. Rules that respond to inflation expected two or more years ahead generally perform very poorly. Such rules are prone to generating indeterminacy, as discussed by Levin, Wieland, and Williams (2003). In contrast to inflation, the optimal horizon for the change in the unemployment rate is –1, meaning that policy should respond to the most recent observed change in unemployment (that is, for the previous quarter), as opposed to a forecast of the change in the unemployment rate in subsequent periods.

4.3 Alternative Preferences

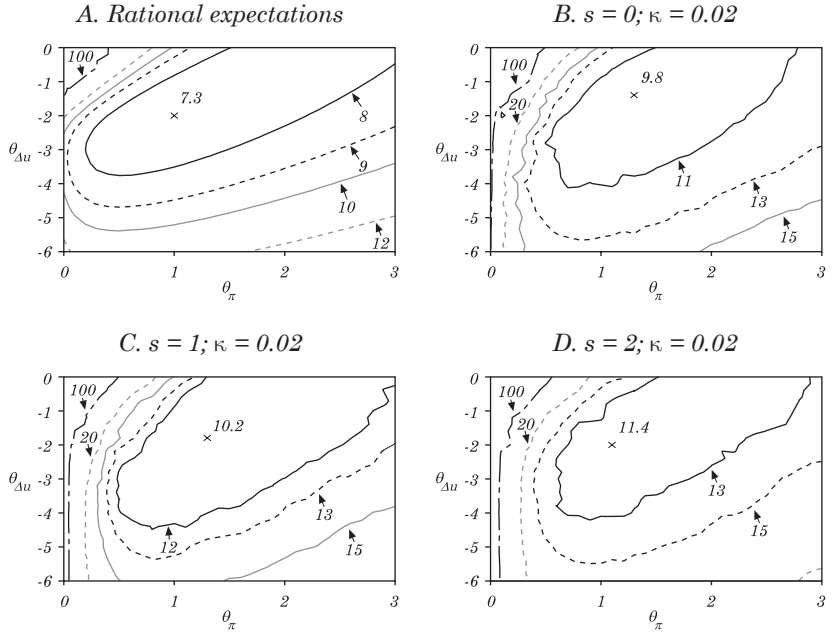
Next, we explore the sensitivity of the simple policy rules we advocate as a benchmark for successful policy implementation to the assumed underlying policymaker preferences. In our benchmark parameterization, we examined preferences with a unit weight on inflation variability and a weight, $\lambda = 4$, on unemployment variability, noting that from Okun's law this implies equal weights on inflation and output gap variability. As with various other aspects of the policy problem we examine, however, it is unrealistic to assume that

15. Using a simpler model, Orphanides and Williams (2005a) show that with certain parameterizations of the loss function, it is best to respond to actual inflation, while in others, it pays to respond to expected inflation. A hybrid rule that responds to both actual and expected inflation outperforms either type of simple rule that responds to one or the other.

policymakers can have much confidence on the appropriate relative weights they should attach to inflation and employment stabilization in the economy from a public welfare perspective. It is therefore important to know whether a policy under consideration performs well across a range of reasonable alternative preferences. Indeed, robustness to such a range of preferences appears to be essential for successful implementation of inflation targeting in practice.

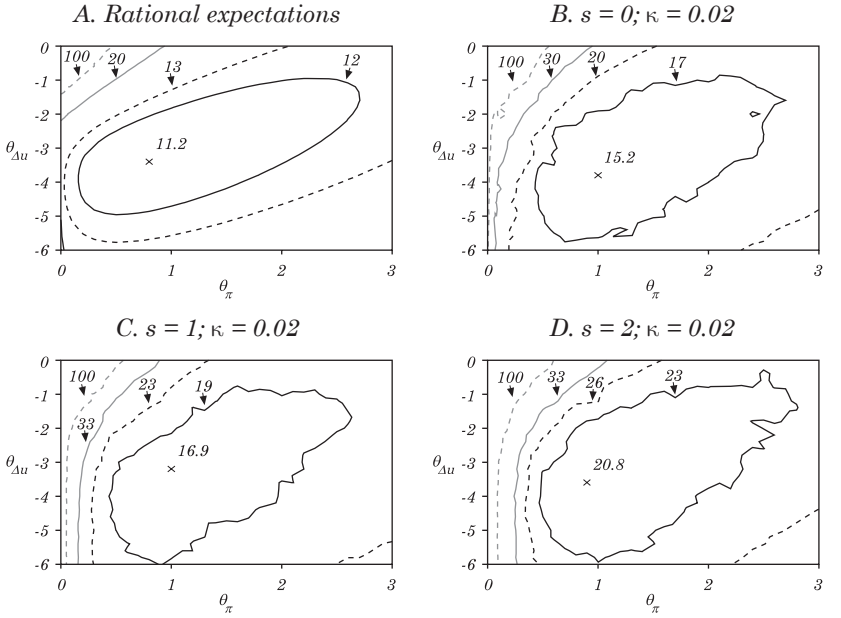
Figures 10 and 11 present the iso-loss contours of the benchmark difference rule with weights $\lambda = 1$ and $\lambda = 8$, respectively, comparable to that in figure 6 with $\lambda = 4$. The iso-loss contours associated with placing greater emphasis on price stability (figure 10) or employment stability (figure 11) suggest that policies derived based on our benchmark loss function would do rather well under either alternative. This speaks well for the robustness of our benchmark difference rules as guides for policy, as a robust policy guide ought to perform well across a range of reasonable alternative preferences.

Figure 10. Performance of the Difference Rule with Greater Emphasis on Inflation Stability ($\lambda = 1$)[a]



Source: Authors' computations.
a. The difference rule is defined as $i_t = i_{t-1} + \theta_\pi\left(\overline{\pi}^e_{t+3} - \pi^*\right) + \theta_{\Delta u}\Delta u_{t-1}$.

Figure 11. Performance of the Difference Rule with Greater Emphasis on Inflation Stability ($\lambda = 8$)[a]



Source: Authors' computations.
a. The difference rule is defined as $i_t = i_{t-1} + \theta_\pi\left(\bar{\pi}^e_{t+3} - \pi^*\right) + \theta_{\Delta u}\Delta u_{t-1}$.

4.4 Explicit Numerical Inflation Objective

The policy features we have described so far may be important not only for characterizing policy under inflation targeting, but also for characterizing policy for non-inflation-targeting central banks that may not have an explicit quantitative inflation target but still recognize the value of price stability and well-anchored inflation expectations for fostering overall economic stability. This section examines what is arguably the most important distinguishing characteristic of inflation targeting, relative to alternative policy frameworks—namely, the specification of an explicit numerical inflation objective.

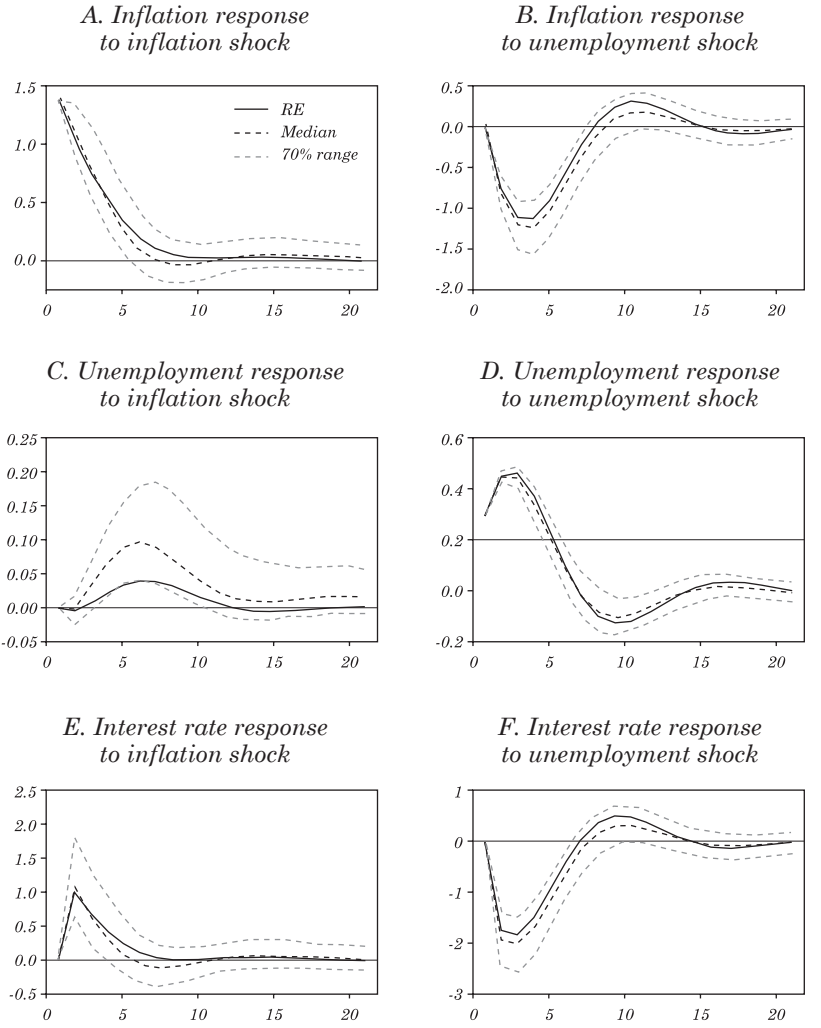
As in Orphanides and Williams (2004, 2005a), we formalize this element of transparency by positing that the announcement of an explicit target is taken at face value by economic agents, who incorporate this information directly into their recursive forecasting algorithm. We implement the idea of a known numerical inflation target by modifying

the learning model that agents use in forecasting to have the property that inflation asymptotically returns to target. No other changes are made to the model or the learning algorithm. In essence, with a known inflation target, agents need to estimate one fewer parameter in their forecasting model for inflation than they would need to do if they did not know the precise numerical value of the central bank's inflation objective. More precisely, we assume that agents estimate reduced-form forecasting equations for the unemployment rate and the inflation rate, just as before. We then solve the resulting two-equation system for its steady-state values of the unemployment rate and the interest rate, assuming that the steady-state inflation rate equals its target value. We modify the forecasting equation for the interest rate by subtracting the steady-state values of each variable from the observed values on both sides of the equation and by eliminating the constant term. This equation is estimated using the constant-gain algorithm. The resulting three-equation system has the property that inflation asymptotically goes to target. This system is used for forecasting as before.

To trace the role of a known target in the economy under alternative policy rules, we compute impulse responses corresponding to the same policy rules examined earlier. Figure 12 shows the impulse responses to the inflation and unemployment shocks for the classic parameterization of the Taylor rule, assuming that the central bank has communicated its inflation objective to the public. Compared with figure 1, the responses of inflation under imperfect knowledge are more tightly centered around the responses under perfect knowledge. The differences are more noticeable when we examine long-run inflation expectations. Figures 13 and 14 show the impulse responses of longer-run inflation and interest rate expectations, following the format of figures 2 and 3. The communication of an explicit numerical inflation objective yields a much tighter range of responses of longer-run inflation expectations, centered around the actual target. Absent here is the upward bias in the response of inflation expectations evident when agents do not know the target. Interestingly, although knowledge of the long-term inflation objective anchors long-term inflation expectations much better, it is unclear whether this translates to a much reduced sensitivity of forward interest rates to economic shocks.[16]

16. These comparisons, however, are based on the assumption that forecasts of these rates are governed by the same learning process governing the expectations for inflation and economic activity at shorter horizons that matter for the determination of economic outcomes in the model. If, instead, the long-horizon interest rate expectations embedded in financial markets reflect additional knowledge, it could result in smaller deviations from the perfect-knowledge benchmark than those presented here.

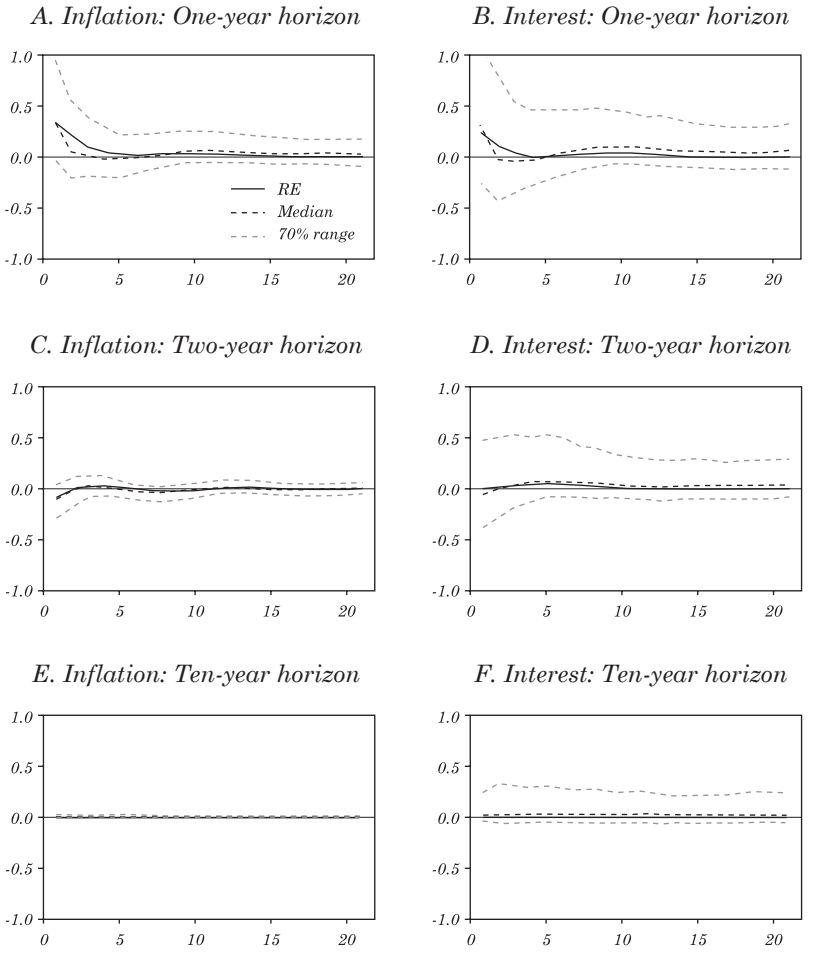
Figure 12. Impulse Response Functions with Known π* under the Taylor Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

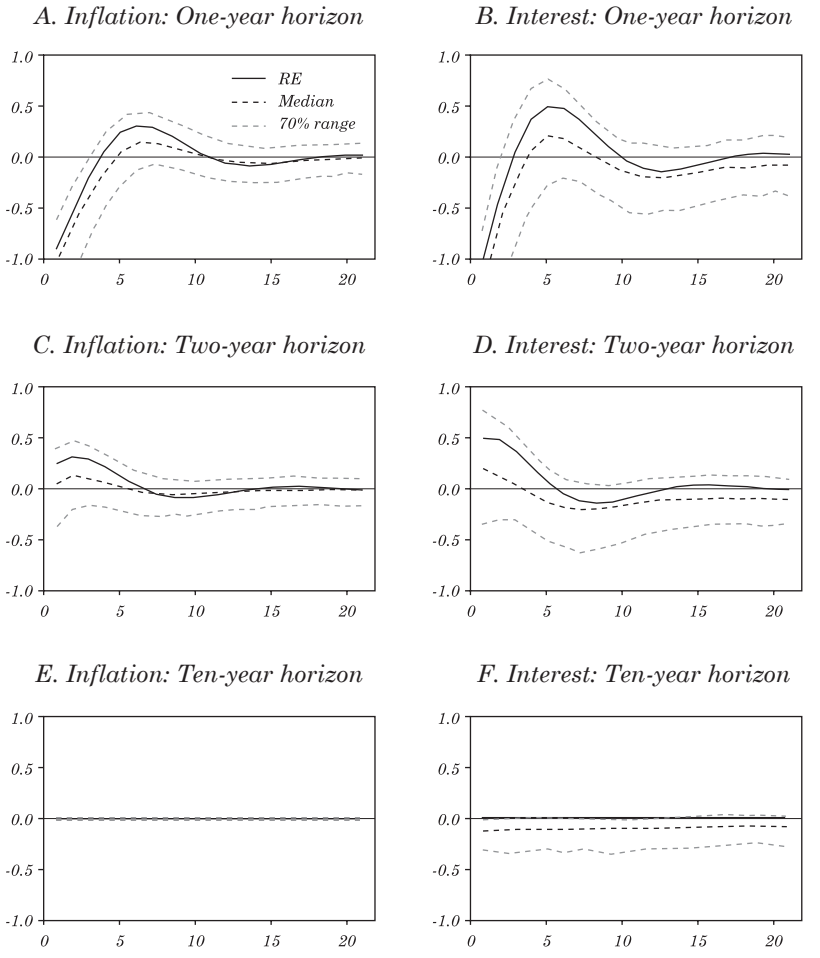
Figure 13. Impulse Response to an Inflation Shock with Known π* under the Taylor Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

Figure 14. Impulse Response to an Unemployment Shock with Known π* under the Taylor Rule[a]



Source: Authors' computations.

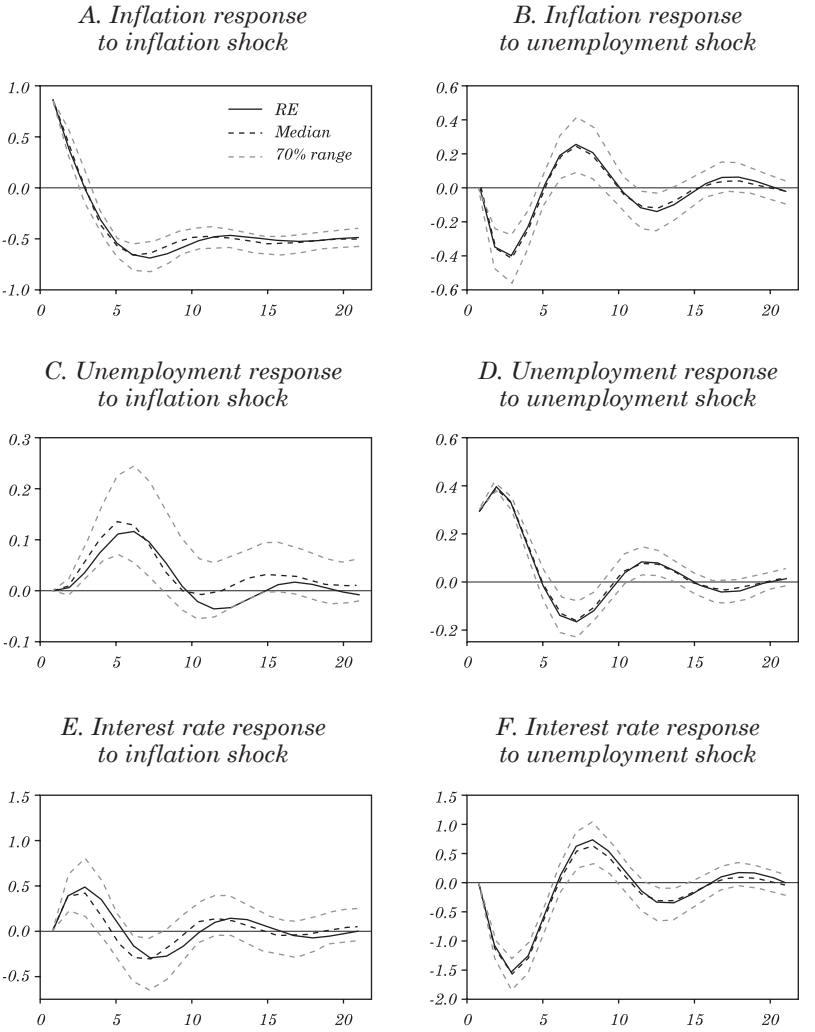
a. The Taylor rule is defined as $i_t = \hat{r}_t^* + \overline{\pi}_{t+3}^e + 0.5\left(\overline{\pi}_{t+3}^e - \pi^*\right) - \left(u_{t-1} - \hat{u}_t^*\right)$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with s = 1 and $\kappa = 0.02$.

Figures 15, 16, and 17 show the impulse responses corresponding to the difference rule specified as above and assuming the central bank has successfully communicated its objective to the public as described above. Short-run expectations tend to cluster around those that obtain under perfect knowledge. The median responses are remarkably close to those under rational expectations, and the 70 percent ranges tend to be quite narrow, especially for inflation. Long-horizon inflation expectations are extremely stable under the difference rule coupled with an explicit numerical inflation objective. For instance, the behavior of ten-year-ahead inflation expectations is virtually indistinguishable from what would be expected under perfect knowledge. Forward interest rates, however, continue to show some small movements.

These impulse responses suggest that the expected benefits of announcing an explicit inflation target may be quite different depending on the policy rule in place. In terms of anchoring long-horizon inflation expectations, for example, the benefits of a known target seem considerably larger if policy follows the classic parameterization of the Taylor rule than if policy is based on a well-designed difference rule. The extent of these benefits also depends on the precise degree of imperfections in the economy (that is, the learning rate, κ, and variation in natural rates, s, in our model). In the limiting case of rational expectations, for instance, the "announcement" of the policymakers' target in our model does not make any difference at all, since agents already know the policymakers' preferences and objectives, by assumption.

To provide a clearer picture of the stabilization benefits of a known inflation target in an environment of imperfect knowledge, we compare the performance of an economy with a known target to that with an unknown target for a given set of policies. Table 2 presents this comparison when expectations are formed with our benchmark learning rate, $\kappa = 0.02$. In the top panel, we present the results for the classic Taylor rule with $\theta_\pi = 0.5$ and $\theta_u = -1.0$, whose properties under learning without a known inflation target were examined in detail in section 3. In the middle panel, we present the results for the Taylor rule with $\theta_\pi = 1.5$ and $\theta_u = -1.5$, which performs best within this family of level rules when $\kappa = 0.02$ and $s = 1$. In the bottom panel, we present comparable results for the difference rule with $\theta_\pi = 1$ and $\theta_{\Delta u} = -3$, which performs well even under learning with an unknown inflation target.

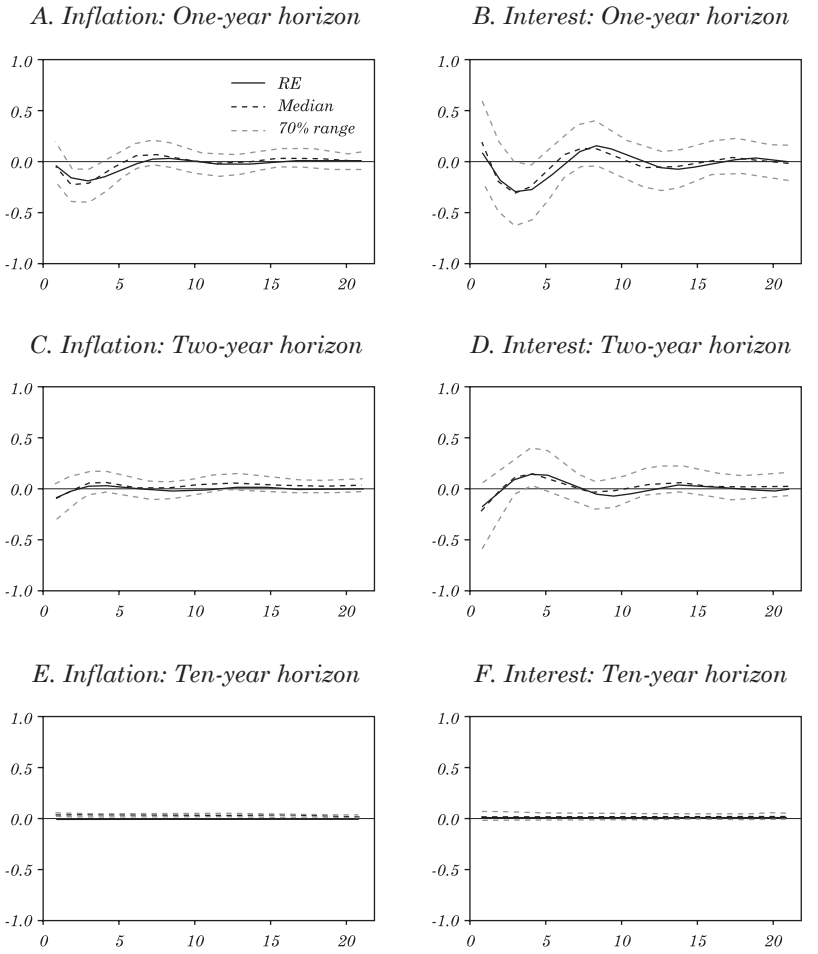
Figure 15. Impulse Response Functions with Known π* under the Difference Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = i_{t-1} + 1\left(\overline{\pi}^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

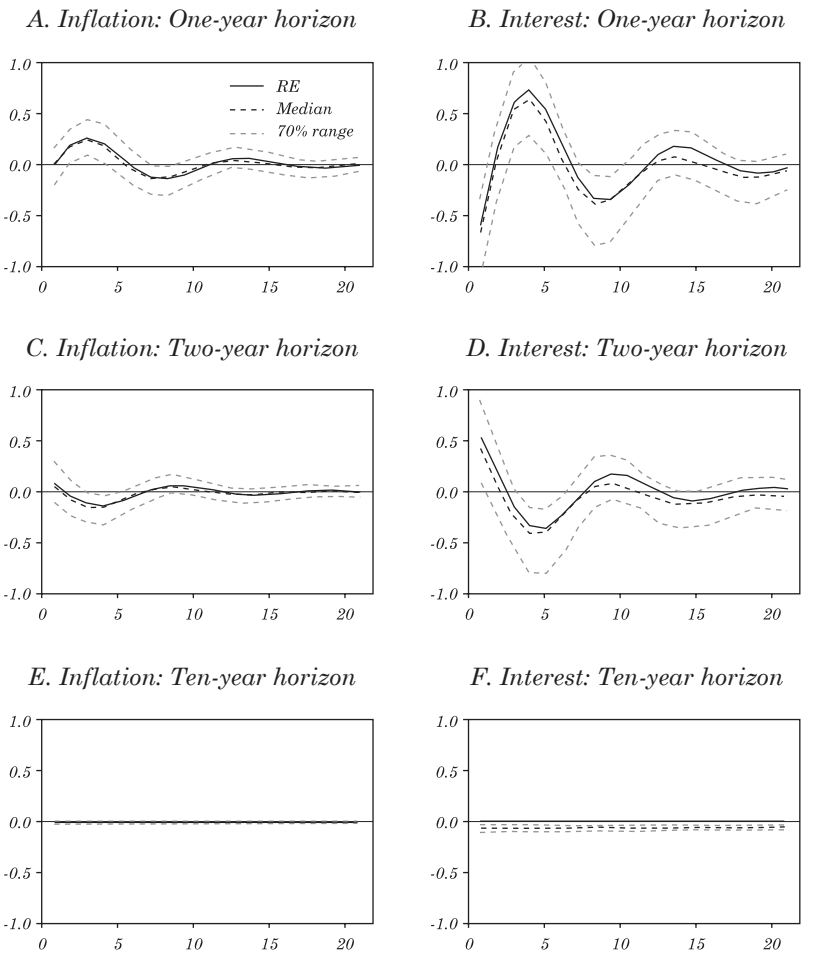
Figure 16. Impulse Response to an Inflation Shock with Known π* under the Difference Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = i_{t-1} + 1\left(\overline{\pi}^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

Figure 17. Impulse Response to an Unemployment Shock with Known π* under the Difference Rule[a]



Source: Authors' computations.

a. The Taylor rule is defined as $i_t = i_{t-1} + 1\left(\overline{\pi}^e_{t+3} - \pi^*\right) - 3\Delta u_{t-1}$. The graphs display rational expectations with perfect knowledge (RE), and median and 70 percent range of outcomes under learning with $s = 1$ and $\kappa = 0.02$.

Table 2. The Role of an Explicit Quantitative Inflation Objective[a]

	Unknown π^*					*Known* π^*				
	Standard deviation					*Standard deviation*				
s	π	$u - u^*$	Δi	*Loss*	*AR*(π)	π	$u - u^*$	Δi	*Loss*	*AR*(π)
				A. Taylor rule ($\theta_\pi = 0.5$; $\theta_u = -1.0$)						
0	3.66	0.99	2.80	25.1	0.86	3.37	0.95	2.67	22.1	0.84
1	4.35	1.11	3.01	32.9	0.90	3.76	1.04	2.80	26.4	0.87
2	5.21	1.24	3.29	44.2	0.93	4.21	1.18	3.02	32.5	0.90
				B. Taylor rule ($\theta_\pi = 1.5$; $\theta_u = -1.5$)						
0	2.43	0.84	3.15	18.6	0.75	2.34	0.82	3.02	17.2	0.72
1	2.62	0.96	3.31	21.5	0.78	2.37	0.89	3.05	18.1	0.74
2	2.93	1.13	3.58	26.5	0.82	2.65	1.08	3.29	22.5	0.79
				C. Difference rule ($\theta_\pi = 1.0$; $\theta_{\Delta u} = -3.0$)						
0	2.15	0.89	2.20	12.6	0.67	2.03	0.80	2.08	11.0	0.64
1	2.20	0.98	2.26	13.7	0.68	2.08	0.90	2.11	12.0	0.65
2	2.35	1.18	2.36	16.6	0.72	2.26	1.13	2.23	15.2	0.70

Source: Authors' computations.

a. All evaluations are for the case of learning with $\kappa = 0.02$. The loss function corresponds to equation (9) with $\lambda = 4$ and $v = 1$. *AR*(π) denotes the first-order serial correlation of inflation.

The economy's stabilization performance uniformly improves with a known inflation target under all three rules. Successful communication of an inflation target results in a modest reduction in the persistence of inflation. In addition, for each rule, the variability of inflation, real activity, and interest rates is smaller when the central bank successfully communicates its numerical inflation objective to the public. The extent of this improvement varies considerably, however. The gains of making the target known appear substantial under the classic Taylor rule. A more modest reduction in volatility is evident for the more aggressive level rule, while the gains associated with a known target are quite small when policy is based on the more robust difference rule. These results suggest that the improvement associated with successfully communicating a target can be rather small, compared with the improvement that could be expected from adopting the other elements of robust policies. For example, abandoning policy based on even the best parameterization of the level Taylor rule in favor of the robust difference rule yields a larger benefit than communicating a numerical inflation objective while continuing to follow a level rule.

5. Conclusion

Inflation targeting has been a very popular strategy among central banks, particularly in small open economies. Researchers have struggled, however, to pin down exactly what inflation targeting means in terms of an implementable policy rule. To some, the Taylor rule, or any monetary policy rule with a fixed long-run inflation target, is a form of inflation targeting; to others, inflation targeting is identified with solving a central bank optimization problem in a rational expectations model. One shortcoming of these approaches is that they abstract from the very cause that gave rise to inflation targeting in the first place: the loss of a nominal anchor that transpired under previous policy regimes in many countries.

This paper has attempted to put inflation-targeting strategy back into the context in which it was born— namely, one in which inflation expectations can endogenously drift away from the central bank's goal. We assume that private agents and the central bank have imperfect knowledge of the economy; in particular, private agents attempt to infer the central bank's goals and reactions through past actions. In such an environment, key characteristics of inflation targeting in practice—including transparency, a commitment to price stability, and

close attention to inflation expectations—can influence the evolution of inflation expectations and the economy's behavior.

The problem of imperfect knowledge may be especially acute in small open economies and transition economies that have been drawn to inflation targeting. Many of these countries have undergone dramatic structural change over the past few decades. Consequently, conclusions regarding the characteristics of optimal monetary policy rules that are based on rational expectations models with perfect knowledge cannot provide trustworthy guidance. Our analysis suggests that policies formulated and communicated in terms of gaps from natural rate concepts that are fundamentally unknowable may be particularly problematic. A more reliable approach to successfully implementing inflation targeting is to search for monetary policy strategies that are robust to imperfect knowledge.

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Optimal Inflation Stabilization in a Medium-Scale Macroeconomic Model

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What is the optimal monetary policy, and how can the central bank implement it? Both questions have been extensively studied, but always in the context of simple theoretical structures, which by design are limited in their ability to account for actual observed business cycle fluctuations. This article seeks to characterize optimal monetary policy and its implementation using a medium-scale, empirically plausible model of the U.S. business cycle.

The model we consider is the one developed in Altig and others (2005). This model has been estimated econometrically and shown to account fairly well for business cycle fluctuations in the postwar United States. The theoretical framework emphasizes the importance of combining nominal as well as real rigidities in explaining the propagation of macroeconomic shocks. Specifically, the model features four nominal frictions (sticky prices, sticky wages, a transactional demand for money by households, and a cash-in-advance constraint on the wage bill of firms) and four sources of real rigidities (investment adjustment costs, variable capacity utilization, habit formation, and imperfect competition in product and factor markets). Aggregate

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fluctuations are driven by three shocks: a permanent neutral productivity shock, a permanent investment-specific technology shock, and temporary variations in government spending. Altig and others (2005) and Christiano, Eichenbaum, and Evans (2005) argue that the model economy for which we seek to design optimal monetary policy can indeed explain the observed responses of inflation, real wages, nominal interest rates, money growth, output, investment, consumption, labor productivity, and real profits to neutral and investment-specific productivity shocks and monetary shocks in the postwar United States.

In our characterization of optimal monetary policy, we depart from the widespread practice in the neo-Keynesian literature on optimal monetary policy of limiting attention to models in which the nonstochastic steady state is undistorted. This approach usually involves assuming the existence of a battery of subsidies to production and employment aimed at eliminating the long-run distortions originating from monopolistic competition in factor and product markets. The efficiency of the deterministic steady-state allocation is assumed for purely computational reasons, as it allows the use of first-order approximation techniques to evaluate welfare accurately up to second order (see Rotemberg and Woodford, 1997).

This practice has two potential shortcomings. First, the instruments necessary to bring about an undistorted steady state (for example, labor and output subsidies financed by lump-sum taxation) are empirically uncompelling. Second, it is not clear ex ante whether a policy that is optimal for an economy with an efficient steady state will also be optimal for an economy in which the instruments necessary to engineer the nondistorted steady state are unavailable. For these reasons we refrain from making the efficient steady-state assumption and instead work with a model whose steady state is distorted.

Departing from a model whose steady state is Pareto efficient has a number of important ramifications. One is that to obtain an accurate second-order measure of welfare it no longer suffices to approximate the equilibrium of the model up to first order. We solve the equilibrium of the model up to second order using the methodology and computer code developed in Schmitt-Grohé and Uribe (2004d) for second-order accurate approximations to policy functions of dynamic, stochastic models. One advantage of this numerical strategy is that because it is based on perturbation arguments, it is particularly well suited to handle economies with a large number of state variables, such as the one studied here.

We address the question of what business cycle fluctuations should look like under optimal monetary policy by characterizing the Ramsey equilibrium associated with our model. The central policy problem faced by the monetary authority is the need to stabilize prices in order to minimize price dispersion stemming from nominal rigidities while minimizing and stabilizing the opportunity cost of holding money to avoid transactional frictions. The task of characterizing Ramsey-optimal policy is challenging, because the model is large and highly distorted. A methodological contribution of the research project to which this article belongs is the development of computational procedures to derive and characterize the Ramsey equilibrium for a general class of dynamic rational expectations models.[1]

We find that the policy tradeoff faced by the Ramsey planner is resolved in favor of price stability. In effect, the Ramsey-optimal inflation rate is -0.4 percent a year, with a standard deviation of only 0.1 percentage points. The optimality of near-zero inflation, however, is highly sensitive to the assumed degree of price stickiness. Estimates of the degree of price stickiness vary between two and five quarters. Within this range the optimal rate of inflation increases from a deflation of about 4 percent a year when prices are reoptimized every two quarters to a mild deflation of less than 0.5 percent a year when prices are reoptimized every five quarters. Depending on what estimate of price rigidity one chooses, the Ramsey-optimal policy can range from close to the Friedman rule to close to price stability.

Quite independent of the precise degree of price stickiness, the optimal inflation target is below zero. In light of this robust result, it is puzzling that all countries that self-classify as inflation targeters set inflation targets that are positive. Annual inflation targets in developed countries range from 2 percent to 4 percent. Somewhat higher targets are observed in developing countries. An argument often raised in defense of positive inflation targets is that negative inflation targets imply nominal interest rates that are dangerously close to the zero lower bound and hence may impair the central bank's ability to conduct stabilization policy. We find, however, that this argument is of no relevance in the context of the medium-scale estimated model within which we evaluate policy. The reason is that under the optimal policy regime, the mean of the nominal interest rate is about 4.5 percent a year, with a standard deviation of only 0.4

1. The Matlab code to replicate the quantitative results reported in this article is available at www.econ.duke.edu/~uribe.

percent. This means that for the zero lower bound to pose an obstacle to monetary policy, the economy must suffer an adverse shock that forces the interest rate to be more than 10 standard deviations below target. The likelihood of such an event is practically nil.

We address the question of implementation of optimal monetary policy by characterizing optimal, simple, and implementable interest rate feedback rules. We restrict attention to what we call operational interest rate rules, by which we mean an interest rate rule that satisfies three requirements. First, the operational rule prescribes that the nominal interest rate be set as a function of a few readily observable macroeconomic variables. In the tradition of Taylor (1993), we focus on rules whereby the nominal interest rate depends on measures of inflation, aggregate activity, and possibly its own lag. Second, the operational rule must induce an equilibrium satisfying the zero lower bound on nominal interest rates. Third, the operational rule must render the rational expectations equilibrium unique. This restriction closes the door to expectations-driven aggregate fluctuations.

Our numerical findings suggest that in the model economy we study, the optimal operational interest rate rule responds aggressively to deviations of price and wage inflation from the target. The price-inflation coefficient is about 5 and the wage-inflation coefficient about 2. In addition, the optimal interest rate rule prescribes a mute response to deviations of output growth from target. In this sense the implementation of optimal policy calls for following a regime of inflation targeting. The parameters of the optimized rule are robust to using a conditional or unconditional measure of welfare.

Remarkably, the optimal operational interest rate rule delivers a welfare level that is virtually identical to the one obtained under the Ramsey-optimal policy. Specifically, the welfare cost associated with living in an economy in which the monetary authority follows the optimal operational rule as opposed to living in the Ramsey economy is only 23 cents a year per person (or 0.001 percent of 2006 annual per capita consumption).

The remainder of the article is organized in five sections. The next section presents the theoretical economy and derives nonlinear recursive representations for the price and wage Phillips curves as well as for the state variables summarizing the degree of wage and price dispersion. Section 2 describes the calibration of the model and discusses the solution method. Section 3 characterizes the steady state of the Ramsey equilibrium. Section 4 examines the dynamics induced by the Ramsey monetary policy. Section 5 computes the

optimal operational interest rate rule. The last section provides concluding remarks.

1. The Model

The skeleton of the model economy used here for policy evaluation is a standard neoclassical growth model driven by neutral productivity shocks, investment-specific productivity shocks, and government spending shocks. The economy features four sources of nominal frictions and five real rigidities. The nominal frictions include price and wage stickiness à la Calvo (1983) and Yun (1996) with indexation to past inflation and money demands by households and firms. The real rigidities originate from internal habit formation in consumption, monopolistic competition in factor and product markets, investment adjustment costs, and the variable costs of adjusting capacity utilization.

To evaluate monetary policy, we are forced to approximate the equilibrium conditions of the economy to an order higher than linear. Toward that end we derive the exact nonlinear recursive representation of the complete set of equilibrium conditions. Of particular interest is the recursive nonlinear representation of the equilibrium Phillips curves for prices and wages. These representations depart from most of the existing literature, which restricts attention to linear approximations to these functions. Another byproduct of deriving the exact nonlinear set of equilibrium conditions is the emergence of two state variables measuring the degree of price and wage dispersion in the economy induced by the sluggishness in the adjustment of nominal product and factor prices. We present a recursive representation of these state variables and track their dynamic behavior.

1.1 Households

The economy is assumed to be populated by a large representative family with a continuum of members. Consumption and hours worked are identical across family members. The household's preferences are defined over per capita consumption, c_t, and per capita labor effort, h_t. They are described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t - bc_{t-1}, h_t), \tag{1}$$

where E_t denotes the mathematical expectations operator conditional

on information available at time, t, $\beta \in (0,1)$ represents a subjective discount factor, and U is a period utility index assumed to be strictly increasing in its first argument, strictly decreasing in its second argument, and strictly concave. Preferences display internal habit formation, measured by the parameter $b \in [0,1]$. The consumption good is assumed to be a composite made up of a continuum of differentiated goods c_{it} indexed by $i \in [0,1]$ via the aggregator

$$c_t = \left[\int_0^1 {c_{i,t}}^{1-1/\eta} di \right]^{1/(1-1/\eta)}, \tag{2}$$

where the parameter $\eta > 1$ denotes the intratemporal elasticity of substitution across different varieties of consumption goods.

For any level of consumption of the composite good, purchases of each individual variety of goods $i \in [0,1]$ in period t must solve the dual problem of minimizing total expenditure, $\int_0^1 P_{i,t} c_{i,t} di$, subject to the aggregation constraint (2), where $P_{i,t}$ denotes the nominal price of a good of variety i at time t. The demand for goods of variety i is then given by

$$c_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\eta} c_t, \tag{3}$$

where P_t is a nominal price index defined as

$$P_t \equiv \left[\int_0^1 P_{i,t}^{1-\eta} di \right]^{1/1-\eta}. \tag{4}$$

This price index has the property that the minimum cost of a bundle of intermediate goods yielding c_t units of the composite good is given by $P_t c_t$.

Labor decisions are made by a central authority within the household (a union), which supplies labor monopolistically to a continuum of labor markets of measure 1 indexed by $j \in [0,1]$. In each labor market j, the union faces a demand for labor given by $(W_t^j / W_t)^{-\eta} h_t^d$, where W_t^j denotes the nominal wage charged by the union in labor market j at time t, W_t is an index of nominal wages prevailing in the economy, and h_t^d is a measure of aggregate labor demand by firms. We postpone a formal derivation of this labor demand function until we consider the firm's problem. In each labor market,

the union takes W_t and h_t^d as exogenous.[2] Given the wage it charges in each labor market $j \in [0,1]$, the union is assumed to supply enough labor, h_t^j, to satisfy demand. That is,

$$h_t^j = \left(\frac{w_t^j}{w_t}\right)^{-\bar{\eta}} h_t^d, \tag{5}$$

where $w_t^j \equiv W_t^j/P_t$ and $w_t \equiv W_t/P_t$. In addition, the total number of hours allocated to the different labor markets must satisfy the resource constraint

$$h_t = \int_0^1 h_t^j dj.$$

Combining this restriction with equation (5), we obtain

$$h_t = h_t^d \int_0^1 \left(\frac{w_t^j}{w_t}\right)^{-\bar{\eta}} dj. \tag{6}$$

Our set-up of imperfectly competitive labor markets departs from most expositions of models with nominal wage inertia (for example, Erceg, Henderson, and Levin, 2000). These models assume that each household supplies a differentiated type of labor input. This assumption introduces equilibrium heterogeneity across households in the number of hours worked. To avoid this heterogeneity from spilling over into consumption heterogeneity, it is typically assumed that preferences are separable in consumption and hours and that financial markets exist that allow agents to fully insure against employment risk. Our formulation avoids the need to assume both separability of preferences in leisure and consumption and the existence of such insurance markets. As we explain below in more detail, our specification gives rise to a wage-inflation Phillips curve with a larger coefficient on the wage mark-up gap than the model with employment heterogeneity across households.

The household is assumed to own physical capital, k_t, which accumulates according to the following law of motion

$$k_{t+1} = (1-\delta)k_t + i_t\left[1 - S\left(\frac{i_t}{i_{t-1}}\right)\right], \tag{7}$$

2. The case in which the union takes aggregate labor variables as endogenous can be interpreted as an environment with highly centralized labor unions. Higher-level labor organizations play an important role in some European and Latin American countries. They are less prominent in the United States.

where i_t denotes gross investment and δ is a parameter denoting the rate of depreciation of physical capital. The function S introduces investment adjustment costs. It is assumed that in the steady state, the function S satisfies $S = S' = 0$ and $S'' > 0$. These assumptions imply the absence of adjustment costs up to first-order in the vicinity of the deterministic steady state.

Like Fisher (2005) and Altig and others (2005), we assume that investment is subject to permanent investment-specific productivity shocks. Fisher argues that this type of shock is needed to explain the observed secular decline in the relative price of investment goods in terms of consumption goods. More important, he shows that investment-specific technology shocks account for about 50 percent of aggregate fluctuations at business cycle frequencies in the postwar U.S. economy. (As we discuss below, Altig and others 2005 find smaller numbers in the context of the model studied here.)

We assume that investment goods are produced from consumption goods by means of a linear technology whereby $1/\Upsilon_t$ units of consumption goods yield one unit of investment goods, where Υ_t denotes an exogenous, permanent technology shock in period t. The growth rate of Υ_t is assumed to follow an AR(1) process of the form $\hat{\mu}_{\Upsilon,t} = \rho_{\mu_\Upsilon} \hat{\mu}_{\Upsilon,t-1} + \varepsilon_{\mu_{\Upsilon,t}}$, where $\hat{\mu}_{\Upsilon,t} \equiv \ln(\mu_{\Upsilon,t} / \mu_\Upsilon)$ denotes the percentage deviation of the gross growth rate of investment specific technological change and μ_Υ denotes the steady-state growth rate of Υ_t.

Owners of physical capital can control the intensity at which this factor is used. Formally, we let u_t measure capacity utilization in period t. We assume that using the stock of capital with intensity u_t entails a cost of $\Upsilon_t^{-1} a(u_t) k_t$ units of the composite final good. The function a is assumed to satisfy $a(1) = 0$, and $a'(1), a''(1) > 0$.

The specification of both capital adjustment and capacity utilization costs are somewhat peculiar. More standard formulations assume that adjustment costs depend on the level of investment rather than its growth rate, as is assumed here. The costs of capacity utilization typically take the form of a higher rate of depreciation of physical capital. The modeling choice here is guided by the need to fit the response of investment and capacity utilization to a monetary shock in the U.S. economy. (For further discussion of this issue, see Christiano, Eichenbaum, and Evans, 2005 and Altig and others, 2005.)

Households rent the capital stock to firms at the real rental rate r_t^k per unit of capital. Total income stemming from the rental of capital is given by $r_t^k u_t k_t$. The investment good is assumed to be a composite good made with the aggregator function shown in equation (2). Thus the

demand for each intermediate good $i \in [0,1]$ for investment purposes, $i_{i,t}$, is given by $i_{i,t} = \Upsilon_t^{-1} i_t (P_{i,t}/P_t)^{-\eta}$.

As in our earlier work (Schmitt-Grohé and Uribe 2004a,b), we motivate a demand for money by households by assuming that purchases of consumption goods are subject to a proportional transactions cost that is increasing in consumption-based money velocity. Formally, the purchase of each unit of consumption entails a cost given by $\ell(v_t)$. The ratio of consumption to real money balances held by the household, which we denote by m_t^h, is given by

$$v_t \equiv \frac{c_t}{m_t^h}. \tag{8}$$

The transactions cost function ℓ satisfies the following assumptions: $\ell(v)$ is nonnegative and twice continuously differentiable; there exists a level of velocity $\underline{v} > 0$, which we refer to as the satiation level of money, such that $\ell(\underline{v}) = \ell'(\underline{v}) = 0$; $(v - \underline{v})\ell'(v) > 0$ for $v \neq \underline{v}$; and $2\ell'(v) + v\ell''(v) > 0$ for all $v \geq \underline{v}$. The first assumption implies that the transaction process does not generate resources. The second assumption ensures that the Friedman rule (that is, a zero nominal interest rate) need not be associated with an infinite demand for money. It also implies that both the transactions cost and the associated distortions in the intra- and intertemporal allocation of consumption and leisure vanish when the nominal interest rate is zero. The third assumption guarantees that in equilibrium money velocity is always greater than or equal to the satiation level $\underline{v}$. As will become clear shortly, the fourth assumption ensures that the demand for money is decreasing in the nominal interest rate. This assumption is weaker than the more common assumption of strict convexity of the transactions cost function.

Households are assumed to have access to a complete set of nominal state-contingent assets. Specifically, each period $t \geq 0$, consumers can purchase any desired state-contingent nominal payment X_{t+1}^h in period $t + 1$ at the dollar cost $E_t r_{t,t+1} X_{t+1}^h$. The variable $r_{t,t+1}$ denotes a stochastic nominal discount factor between periods t and $t + 1$. Households pay real lump-sum taxes in the amount τ_t per period. The household's period-by-period budget constraint is given by

$$\begin{aligned} &E_t r_{t,t+1} x_{t+1}^h + c_t[1 + \ell(v_t)] + \Upsilon_t^{-1}[i_t + a(u_t)k_t] + m_t^h + \tau_t = \\ &\frac{x_t^h + m_{t-1}^h}{\pi_t} + r_t^k u_t k_t + \int_0^1 w_t^j \left(\frac{w_t^j}{w_t}\right)^{-\bar{\eta}} h_t^d dj + \phi_t. \end{aligned} \tag{9}$$

The variable $x_t^h/\pi_t \equiv X_t^h/P_t$ denotes the real payoff in period t of nominal state-contingent assets purchased in period $t-1$. The variable ϕ_t denotes dividends received from the ownership of firms; $\pi_t \equiv P_t/P_{t-1}$ denotes the gross rate of consumer price inflation.

We introduce wage stickiness in the model by assuming that each period the household (or unions) cannot set the nominal wage optimally in a fraction $\tilde{\alpha} \in [0,1)$ of randomly chosen labor markets. In these markets the wage rate is indexed to average real wage growth and to the previous period's consumer price inflation according to the rule

$$W_t^j = W_{t-1}^j(\mu_{z^*}\pi_{t-1})^{\tilde{\chi}},$$

where $\tilde{\chi} \in [0,1]$ is a parameter measuring the degree of wage indexation. When $\tilde{\chi}$ equals 0, there is no wage indexation. When $\tilde{\chi}$ equals 1, there is full wage indexation to long-run real wage growth and past consumer price inflation.

The household chooses processes for c_t, h_t, x_{t+1}^h, w_t^j, k_{t+1}, i_t, u_t, and m_t^h so as to maximize the utility function (1) subject to expressions (6)–(9), the wage stickiness friction, and a no Ponzi game constraint, taking as given the processes w_t, r_t^k, h_t^d, $r_{t,t+1}$, π_t, ϕ_t, and τ_t and the initial conditions x_0^h, k_0, and m_{-1}^h. The household's optimal plan must satisfy constraints (6)–(9). In addition, letting, $\beta^t\lambda_t w_t\tilde{\mu}_t$, $\beta^t\lambda_t q_t$, and $\beta^t\lambda_t$ denote the Lagrange multipliers associated with constraints (6), (7), and (9), respectively, the Lagrangian associated with the household's optimization problem is

$$\begin{aligned}
L = E_0\sum_{t=0}^{\infty}\beta^t\Bigg\langle & U(c_t - bc_{t-1}, h_t) \\
& + \lambda_t\Bigg\{h_t^d\int_0^1 w_t^i\left(\frac{w_t^i}{w_t}\right)^{-\tilde{\eta}}di + r_t^k u_t k_t + \phi_t - \tau_t \\
& - c_t\left[1+\ell\left(\frac{c_t}{m_t^h}\right)\right] - \Upsilon_t^{-1}[i_t + a(u_t)k_t] - r_{t,t+1}x_{t+1}^h - m_t^h + \frac{m_{t-1}^h + x_t^h}{\pi_t}\Bigg\} \\
& + \frac{\lambda_t w_t}{\tilde{\mu}_t}\left[h_t - h_t^d\int_0^1\left(\frac{w_t^i}{w_t}\right)^{-\tilde{\eta}}di\right] \\
& + \lambda_t q_t\left\{(1-\delta)k_t + i_t\left[1 - S\left(\frac{i_t}{i_{t-1}}\right)\right] - k_{t+1}\right\}\Bigg\rangle.
\end{aligned}$$

The first-order conditions with respect to c_t, x^h_{t+1}, h_t, k_{t+1}, i_t, m^h_t, u_t, and w^i_t, in that order, are given by

$$U_c(c_t - bc_{t-1}, h_t) - b\beta E_t U_c(c_{t+1} - bc_t, h_{t+1}) = \lambda_t[1 + \ell(v_t) + v_t\ell'(v_t)], \quad (10)$$

$$\lambda_t r_{t,t+1} = \beta\lambda_{t+1}\frac{P_t}{P_{t+1}}, \quad (11)$$

$$-U_h(c_t - bc_{t-1}, h_t) = \frac{\lambda_t w_t}{\tilde{\mu}_t}, \quad (12)$$

$$\lambda_t q_t = \beta E_t\lambda_{t+1}\left[r^k_{t+1}u_{t+1} - \Upsilon^{-1}_{t+1}a(u_{t+1}) + q_{t+1}(1-\delta)\right], \quad (13)$$

$$\begin{aligned}\Upsilon^{-1}_t\lambda_t = {} & \lambda_t q_t\left[1 - S\left(\frac{i_t}{i_{t-1}}\right) - \left(\frac{i_t}{i_{t-1}}\right)S'\left(\frac{i_t}{i_{t-1}}\right)\right] \\ & + \beta E_t\lambda_{t+1}q_{t+1}\left(\frac{i_{t+1}}{i_t}\right)^2 S'\left(\frac{i_{t+1}}{i_t}\right),\end{aligned} \quad (14)$$

$$v_t^2\ell'(v_t) = 1 - \beta E_t\frac{\lambda_{t+1}}{\lambda_t\pi_{t+1}}, \quad (15)$$

$$r^k_t = \Upsilon^{-1}_t a'(u_t), \text{ and} \quad (16)$$

$$w^i_t = \begin{cases} \tilde{w}_t & \text{if } w^i_t \text{ is set optimally in } t \\ w^i_{t-1}(\mu_{z^*}\pi_{t-1})^{\tilde{\chi}}/\pi_t & \text{otherwise} \end{cases}, \quad (17)$$

where $\tilde{w}_t$ denotes the real wage prevailing in the $1 - \tilde{\alpha}$ labor markets in which the union can set wages optimally in period t. Let $\tilde{h}_t$ denote the level of labor effort supplied to those markets. Because the labor demand curve faced by the union is identical across all labor markets and the cost of supplying labor is the same for all markets, one can assume that wage rates, $\tilde{w}_t$, and employment, $\tilde{h}_t$, are identical across all labor markets updating wages in a given period. By equation (5), $\tilde{w}^{\tilde{\eta}}_t\tilde{h}_t = w^{\tilde{\eta}}_t h^d_t$.

It is useful to track the evolution of real wages in a particular labor market. In any labor market j where the wage is set optimally in

period t, the real wage in that period is $\tilde{w}_t$. If in period $t+1$ wages are not reoptimized in that market, the real wage is $\tilde{w}_t(\mu_z * \pi_t)^{\tilde{\chi}}/\pi_{t+1}$. This is because the nominal wage is indexed by $\tilde{\chi}$ percent of the sum of past price inflation and long-run real wage growth. In general, s periods after the last reoptimization, the real wage is $\tilde{w}_t \prod_{k=1}^{s}(\mu_z * \pi_{t+k-1})^{\tilde{\chi}} / \pi_{t+k}$. To derive the household's first-order condition with respect to the wage rate in those markets where the wage rate is set optimally in the current period, it is convenient to reproduce the parts of the Lagrangian given above that are relevant for this purpose,

$$L^w = E_t \sum_{s=0}^{\infty} (\tilde{\alpha}\beta)^s \lambda_{t+s} h_{t+s}^d w_{t+s}^{\tilde{\eta}} \prod_{k=1}^{s} \left(\frac{\pi_{t+k}}{(\mu_z * \pi_{t+k-1})^{\tilde{\chi}}} \right)^{\tilde{\eta}} \times \left[\tilde{w}_t^{1-\tilde{\eta}} \prod_{k=1}^{s} \left(\frac{\pi_{t+k}}{(\mu_z * \pi_{t+k-1})^{\tilde{\chi}}} \right)^{-1} - \frac{w_{t+s}}{\tilde{\mu}_{t+s}} \tilde{w}_t^{-\tilde{\eta}} \right].$$

The first-order condition with respect to $\tilde{w}_t$ is

$$0 = E_t \sum_{s=0}^{\infty} (\beta\tilde{\alpha})^s \lambda_{t+s} w_{t+s}^{\tilde{\eta}} h_{t+s}^d \prod_{k=1}^{s} \left(\frac{\pi_{t+k}}{(\mu_z * \pi_{t+k-1})^{\tilde{\chi}}} \right)^{\tilde{\eta}} \times \left[\frac{\tilde{\eta}-1}{\tilde{\eta}} \frac{\tilde{w}_t}{\prod_{k=1}^{s} \pi_{t+k} / (\mu_z * \pi_{t+k-1})^{\tilde{\chi}}} - \frac{w_{t+s}}{\tilde{\mu}_{t+s}} \right].$$

Using equation (12) to eliminate $\tilde{\mu}_{t+s}$, we obtain that the real wage $\tilde{w}_t$ must satisfy

$$0 = E_t \sum_{s=0}^{\infty} (\beta\tilde{\alpha})^s \lambda_{t+s} \left(\frac{\tilde{w}_t}{w_{t+s}} \right)^{-\tilde{\eta}} h_{t+s}^d \prod_{k=1}^{s} \left(\frac{\pi_{t+k}}{(\mu_z * \pi_{t+k-1})^{\tilde{\chi}}} \right)^{\tilde{\eta}} \times \left[\frac{\tilde{\eta}-1}{\tilde{\eta}} \frac{\tilde{w}_t}{\prod_{k=1}^{s} \left(\pi_{t+k} / (\mu_z * \pi_{t+k-1})^{\tilde{\chi}} \right)} - \frac{-U_{ht+s}}{\lambda_{t+s}} \right].$$

This expression states that in labor markets in which the wage rate is reoptimized in period t, the real wage is set so as to equate

the union's future expected average marginal revenue with the average marginal cost of supplying labor. The union's marginal revenue s periods after its last wage reoptimization is given by $\left[(\tilde{\eta}-1)/\tilde{\eta}\right]\tilde{w}_t\prod_{k=1}^{s}(\mu_{z^*}\pi_{t+k-1})^{\tilde{\chi}}/\pi_{t+k}$. Here $\tilde{\eta}/(\tilde{\eta}-1)$ represents the mark-up of wages over the marginal cost of labor that would prevail in the absence of wage stickiness. The factor $\prod_{k=1}^{s}(\mu_{z^*}\pi_{t+k-1})^{\tilde{\chi}}/\pi_{t+k}$ in the expression for marginal revenue reflects the fact that as time goes by without a chance to reoptimize, the real wage declines as the price level increases when wages are imperfectly indexed. In turn, the marginal cost of supplying labor is given by the marginal rate of substitution between consumption and leisure, $-U_{ht+s}/\lambda_{t+s}=w_{t+s}/\tilde{\mu}_{t+s}$. The variable $\tilde{\mu}_t$ is a wedge between the disutility of labor and the average real wage prevailing in the economy. Thus $\tilde{\mu}_t$ can be interpreted as the average mark-up that unions impose on the labor market. The weights used to compute the average difference between marginal revenue and marginal cost are decreasing in time and increasing in the amount of labor supplied to the market.

In order to write the wage-setting equation in recursive form, we define

$$f_t^1=\left(\frac{\tilde{\eta}-1}{\tilde{\eta}}\right)\tilde{w}_tE_t\sum_{s=0}^{\infty}(\beta\tilde{\alpha})^s\lambda_{t+s}\left(\frac{w_{t+s}}{\tilde{w}_t}\right)^{\tilde{\eta}}h_{t+s}^d\prod_{k=1}^{s}\left(\frac{\pi_{t+k}}{(\mu_{z^*}\pi_{t+k-1})^{\tilde{\chi}}}\right)^{\tilde{\eta}-1},\ \text{and}$$

$$f_t^2=-\tilde{w}_t^{-\tilde{\eta}}E_t\sum_{s=0}^{\infty}(\beta\tilde{\alpha})^s w_{t+s}^{\tilde{\eta}}h_{t+s}^d U_{ht+s}\prod_{k=1}^{s}\left(\frac{\pi_{t+k}}{(\mu_{z^*}\pi_{t+k-1})^{\tilde{\chi}}}\right)^{\tilde{\eta}}.$$

We can express f_t^1 and f_t^2 recursively as

$$f_t^1=\left(\frac{\tilde{\eta}-1}{\tilde{\eta}}\right)\tilde{w}_t\lambda_t\left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}}h_t^d+\tilde{\alpha}\beta E_t\left(\frac{\pi_{t+1}}{(\mu_{z^*}\pi_t)^{\tilde{\chi}}}\right)^{\tilde{\eta}-1}\left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}-1}f_{t+1}^1, \tag{18}$$

$$f_t^2=-U_{ht}\left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}}h_t^d+\tilde{\alpha}\beta E_t\left(\frac{\pi_{t+1}}{(\mu_{z^*}\pi_t)^{\tilde{\chi}}}\right)^{\tilde{\eta}}\left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}}f_{t+1}^2. \tag{19}$$

The wage-setting equation then becomes

$$f_t^1 = f_t^2. \tag{20}$$

The household's optimality conditions imply a liquidity preference function featuring a negative relation between real balances and the short-term nominal interest rate. To see this, first note that the absence of arbitrage opportunities in financial markets requires that the gross risk-free nominal interest rate, denoted by R_t, be equal to the reciprocal of the price in period t of a nominal security that pays one unit of currency in every state of period $t + 1$. Formally, $R_t = 1/E_t r_{t,t+1}$. This relation, together with the household's optimality condition (11), implies that

$$\lambda_t = \beta R_t E_t \frac{\lambda_{t+1}}{\pi_{t+1}}, \tag{21}$$

which is a standard Euler equation for pricing nominally risk-free assets. Combining this expression with equations (10) and (15), we obtain

$$v_t^2 \ell'(v_t) = 1 - \frac{1}{R_t}.$$

The right-hand side of this expression represents the opportunity cost of holding money, which is an increasing function of the nominal interest rate. Given the assumptions regarding the form of the transactions cost function ℓ, the left-hand side is increasing in money velocity. Thus this expression defines a liquidity preference function that is decreasing in the nominal interest rate and unit elastic in consumption.

1.2 Firms

Each variety of final goods is produced by a single firm in a monopolistically competitive environment. Each firm $i \in [0,1]$ produces output using as factor inputs capital services, $k_{i,t}$, and labor services, $h_{i,t}$. The production technology is given by $F(k_{i,t}, z_t h_{i,t}) - \psi z_t^*$, where the function F is assumed to be homogenous of degree one, concave, and strictly increasing in both arguments. The variable z_t denotes an aggregate, exogenous, and stochastic neutral productivity shock. The parameter $\psi > 0$ introduces fixed costs of operating a firm in each period. In turn, the presence of fixed costs implies that the production function exhibits increasing returns to scale. We model fixed costs to ensure a realistic profit to output ratio in steady state. Finally, we follow Altig and others (2005) and assume that fixed costs are subject

to permanent shocks, z_t^*, with $z_t^* / z_t = \Upsilon_t^{\theta/1-\theta}$. This formulation of fixed costs ensures that along the balanced growth path, fixed costs do not vanish. Let $\mu_{z,t} \equiv z_t / z_{t-1}$ denote the gross growth rate of the neutral technology shock. By assumption, in the nonstochastic steady state, $\mu_{z,t}$ is constant and equal to μ_z. Let $\hat{\mu}_{z,t} = \ln(\mu_{z,t} / \mu_z)$ denote the percentage deviation of the growth rate of neutral technology shocks. Then the evolution of $\mu_{z,t}$ is assumed to be given by $\hat{\mu}_{z,t} = \rho_{\mu_z} \hat{\mu}_{z,t-1} + \varepsilon_{\mu_{z,t}}$, with $\varepsilon_{\mu_{z,t}} \sim (0, \sigma^2_{\mu_z})$. Aggregate demand for good i, which we denote by $y_{i,t}$, is given by $y_{i,t} = (P_{i,t}/P_t)^{-\eta} y_t$, where

$$y_t \equiv c_t[1 + \ell(v_t)] + g_t + \Upsilon_t^{-1}[i_t + a(u_t)k_t], \tag{22}$$

denotes aggregate absorption. The variable g_t denotes government consumption of the composite good in period t.

We rationalize a demand for money by firms by imposing that wage payments be subject to a working capital requirement that takes the form of a cash-in-advance constraint. Formally, we impose

$$m_{i,t}^f = \nu w_t h_{i,t}, \tag{23}$$

where $m_{i,t}^f$ denotes the demand for real money balances by firm i in period t and $\upsilon \geq 0$ is a parameter indicating the fraction of the wage bill that must be backed with monetary assets.

Firms incur financial costs in the amount $(1 - R_t^{-1}) m_{i,t}^f$, stemming from the need to hold money to satisfy the working capital constraint. Letting the variable $\phi_{i,t}$ denote real distributed profits, the period-by-period budget constraint of firm i can then be written

$$E_t r_{t,t+1} x_{i,t+1}^f + m_{i,t}^f - \frac{x_{i,t}^f + m_{i,t-1}^f}{\pi_t} = \left(\frac{P_{i,t}}{P_t}\right)^{1-\eta} y_t - r_t^k k_{i,t} - w_t h_{i,t} - \phi_{i,t},$$

where $E_t r_{t,t+1} x_{i,t+1}^f$ denotes the total real cost of one-period state-contingent assets that the firm purchases in period t in terms of the composite good.[3] We assume that the firm must satisfy demand at

3. Implicit in this specification of the firm's budget constraint is the assumption that firms rent capital services from a centralized market. This is a common assumption in the related literature (for example, Christiano and others, 2005; Kollmann, 2003; Carlstrom and Fuerst, 2005; and Rotemberg and Woodford, 1992). A polar assumption is that capital is firm specific, as in Woodford (2003) and Sveen and Weinke (2003). Both assumptions are clearly extreme. A more realistic treatment of investment dynamics would incorporate a mix of firm-specific and homogeneous capital.

the posted price. Formally, we impose

$$F(k_{i,t}, z_t h_{i,t}) - \psi z_t^* \geq \left(\frac{P_{i,t}}{P_t}\right)^{-\eta} y_t. \tag{24}$$

The objective of the firm is to choose contingent plans for $P_{i,t}$, $h_{i,t}$, $k_{i,t}$, $x_{i,t+1}^f$, and $m_{i,t}^f$ so as to maximize the present discounted value of dividend payments, given by $E_t \sum_{s=0}^{\infty} r_{t,t+s} P_{t+s} \phi_{it+s}$, where $r_{t,t+s} \equiv \prod_{k=1}^{s} r_{t+k-1,t+k}$, for $s \geq 1$, denotes the stochastic nominal discount factor between t and $t + s$, and $r_{t,t} \equiv 1$. Firms are assumed to be subject to a borrowing constraint that prevents them from engaging in Ponzi games.

Clearly, because $r_{t,t+s}$ represents both the firm's stochastic discount factor and the market pricing kernel for financial assets and the firm's objective function is linear in asset holdings, it follows that any asset accumulation plan of the firm satisfying the no Ponzi game constraint is optimal. Without loss of generality, suppose that the firm manages its portfolio so that its financial position at the beginning of each period is nil. Formally, assume that $x_{i,t+1}^f + m_{i,t}^f = 0$ at all dates and states. Note that this financial strategy makes $x_{i,t+1}^f$ state noncontingent. In this case distributed dividends take the form

$$\phi_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{1-\eta} y_t - r_t^k k_{i,t} - w_t h_{i,t} - (1 - R_t^{-1}) m_{i,t}^f. \tag{25}$$

For this expression to hold in period zero, we impose the initial condition $x_{i,0}^f + m_{i-1}^f = 0$. The last term of the right-hand side of the expression for dividends represents the firm's financial costs associated with the cash-in-advance constraint on wages. This financial cost is increasing in the opportunity cost of holding money, $1 - R_t^{-1}$, which in turn is an increasing function of the short-term nominal interest rate R_t.

Letting $r_{t,t+s} P_{t+s} mc_{i,t+s}$ denote the Lagrange multiplier associated with constraint (24), the first-order conditions of the firm's maximization problem with respect to capital and labor services are

$$mc_{i,t} z_t F_2(k_{i,t}, z_t h_{i,t}) = w_t \left[1 + \nu \frac{R_t - 1}{R_t}\right], \text{ and} \tag{26}$$

$$mc_{i,t} F_1(k_{i,t}, z_t h_{i,t}) = r_t^k. \tag{27}$$

It is clear from these optimality conditions that the presence of a working capital requirement introduces a financial cost of labor that is increasing in the nominal interest rate. Moreover, because all firms

face the same factor prices and have access to the same production technology, with the function F being linearly homogeneous, marginal costs, $mc_{i,t}$, are identical across firms. Indeed, because the first-order conditions hold for all firms independently of whether they are allowed to reset prices optimally, marginal costs are identical across all firms in the economy.

Prices are assumed to be sticky à la Calvo (1983) and Yun (1996). Specifically, each period $t \geq 0$, some fraction $\alpha \in [0,1)$ of randomly picked firms are not allowed to optimally set the nominal prices of the good they produce. Instead, these firms index their prices to past inflation according to the rule $P_{i,t} = P_{i,t-1}\pi_{t-1}^{\chi}$. The interpretation of the parameter χ is similar to that of its wage counterpart $\tilde{\chi}$. The remaining $1-\alpha$ firms choose prices optimally. Consider the price-setting problem faced by a firm that has the opportunity to reoptimize the price in period t. This price, denoted by $\tilde{P}_t$, is set so as to maximize the expected present discounted value of profits. That is, $\tilde{P}_t$ maximizes the following Lagrangian:

$$
\begin{aligned}
L = E_t \sum_{s=0}^{\infty} r_{t,t+s} P_{t+s} \alpha^s \Bigg\{ & \left(\frac{\tilde{P}_t}{P_t} \right)^{1-\eta} \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}} \right)^{1-\eta} y_{t+s} - r_{t+s}^{k} k_{i,t+s} \\
& - w_{t+s} h_{i,t+s} [1 + \nu (1 - R_{t+s}^{-1})] \\
& + mc_{i,t+s} \left[F(k_{i,t+s}, z_{t+s} h_{it+s}) - \psi z_{t+s}^{*} - \left(\frac{\tilde{P}_t}{P_t} \right)^{-\eta} \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}} \right)^{-\eta} y_{t+s} \right] \Bigg\}.
\end{aligned}
$$

The first-order condition with respect to $\tilde{P}_t$ is

$$
\begin{aligned}
& E_t \sum_{s=0}^{\infty} r_{t,t+s} P_{t+s} \alpha^s \left(\frac{\tilde{P}_t}{P_t} \right)^{-\eta} \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}} \right)^{-\eta} y_{t+s} \\
& \times \left[\frac{\eta - 1}{\eta} \left(\frac{\tilde{P}_t}{P_t} \right) \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}} \right) - mc_{i,t+s} \right] = 0.
\end{aligned}
\tag{28}
$$

According to this expression, optimizing firms set nominal prices so as to equate average future expected marginal revenues to average future expected marginal costs. The weights used in calculating these averages are decreasing with time and increasing in the size of the demand for the good produced by the firm. Under flexible prices ($\alpha = 0$), the above optimality condition reduces to a static relation equating marginal costs to marginal revenues period by period.

It is useful to express this first-order condition recursively. To that end, let

$$x_t^1 \equiv E_t \sum_{s=0}^{\infty} r_{t,t+s} \alpha^s y_{t+s} mc_{i,t+s} \left(\frac{\tilde{P}_t}{P_t} \right)^{-\eta-1} \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}^{(1+\eta)/\eta}} \right)^{-\eta}$$

and

$$x_t^2 \equiv E_t \sum_{s=0}^{\infty} r_{t,t+s} \alpha^s y_{t+s} \left(\frac{\tilde{P}_t}{P_t} \right)^{-\eta} \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1}^{\chi}}{\pi_{t+k}^{\eta/(\eta-1)}} \right)^{1-\eta}.$$

Express x_t^1 and x_t^2 recursively as

$$x_t^1 = y_t mc_t \tilde{p}_t^{-\eta-1} + \alpha\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}} \right)^{-\eta-1} \left(\frac{\pi_t^{\chi}}{\pi_{t+1}} \right)^{-\eta} x_{t+1}^1, \tag{29}$$

$$x_t^2 = y_t \tilde{p}_t^{-\eta} + \alpha\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\pi_t^{\chi}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}} \right)^{-\eta} x_{t+1}^2. \tag{30}$$

We can then write the first-order condition with respect to $\tilde{P}_t$ as

$$\eta x_t^1 = (\eta - 1) x_t^2. \tag{31}$$

The labor input used by firm $i \in [0,1]$, denoted $h_{i,t}$, is assumed to be a composite made up of a continuum of differentiated labor services, $h_{i,t}^j$ indexed by $j \in [0,1]$. Formally,

$$h_{i,t} = \left[\int_0^1 {h_{i,t}^j}^{1-1/\tilde{\eta}} dj \right]^{1/(1-1/\tilde{\eta})}, \tag{32}$$

where the parameter $\tilde{\eta} > 1$ denotes the intratemporal elasticity of substitution across different types of activities. For any given level of $h_{i,t}$, the demand for each variety of labor $j \in [0,1]$ in period t must solve the dual problem of minimizing total labor cost, $\int_0^1 W_t^j h_{i,t}^j dj$, subject to the aggregation constraint (32), where W_t^j denotes the nominal wage rate paid to labor of variety j at time t. The optimal demand for labor of type j is then given by

$$h_{i,t}^j = \left(\frac{W_t^j}{W_t} \right)^{-\tilde{\eta}} h_{i,t}, \tag{33}$$

where W_t is a nominal wage index given by

$$W_t \equiv \left[\int_0^1 W_t^{j^{1-\bar{\eta}}} dj\right]^{1/1-\bar{\eta}}. \tag{34}$$

This wage index has the property that the minimum cost of a bundle of intermediate labor inputs yielding h_{it} units of the composite labor is given by $W_t h_{i,t}$.

1.3 The Government

Each period the government consumes g_t units of the composite good. Assume that the government minimizes the cost of producing g_t. As a result, public demand for each variety $i \in [0,1]$ of differentiated goods $g_{i,t}$ is given by $g_{i,t} = (P_{i,t}/P_t)^{-\eta} g_t$.

We assume that along the balanced growth path, the share of government spending in value added is constant, that is, we impose $\lim_{j \to \infty} E_t g_{t+j}/y_{t+j} = s_g$, where s_g is a constant indicating the share of government consumption in value added. To this end we impose $g_t = z_t^* \bar{g}_t$, where $\bar{g}_t$ is an exogenous stationary stochastic process. This assumption ensures that government purchases and output are cointegrated. We impose the following law of motion for $\bar{g}_t$:

$$\ln\left(\frac{\bar{g}_t}{\bar{g}}\right) = \rho_{\bar{g}} \ln\left(\frac{\bar{g}_{t-1}}{\bar{g}}\right) + \varepsilon_{\bar{g},t}.$$

The government issues money given in real terms by $m_t \equiv m_t^h + \int_0^1 m_{i,t}^f di$. For simplicity, we assume that government debt is zero at time zero and that the fiscal authority levies lump-sum taxes, τ_t, to bridge any gap between seignorage income and government expenditures, that is, $\tau_t = g_t - (m_t - m_{t-1}/\pi_t)$. As a consequence, government debt is nil at all times. We postpone the presentation of the monetary policy regime until after we characterize a competitive equilibrium.

1.4 Aggregation

We limit attention to a symmetric equilibrium in which all firms that have the opportunity to change their price optimally at a given time choose the same price. It then follows from expression (4) that the aggregate price index can be written as $P_t^{1-\eta} = \alpha(P_{t-1}\pi_{t-1}^{\chi})^{1-\eta} + (1-\alpha)\tilde{P}_t^{1-\eta}$. Dividing

this expression through by $P_t^{1-\eta}$, we obtain

$$1 = \alpha \pi_t^{\eta-1} \pi_{t-1}^{\chi(1-\eta)} + (1-\alpha)\tilde{p}_t^{1-\eta}. \tag{35}$$

1.5 Market Clearing in the Final Goods Market

Naturally, the set of equilibrium conditions includes a resource constraint. Such a restriction is typically of the type $F(k_t, z_t h_t) - \psi z_t^* = c_t[1 + \ell(v_t)] + g_t + \Upsilon_t^{-1}[i_t + a(u_t)k_t]$. In the model presented here, however, this restriction is not valid, because the model implies relative price dispersion across varieties. This price dispersion, which is induced by the assumed nature of price stickiness, is inefficient and entails output loss.

To see this, consider the following expression stating that supply must equal demand at the firm level:

$$F(k_{i,t}, z_t h_{i,t}) - \psi z_t^* = \left\{[1 + \ell(v_t)]c_t + g_t + \Upsilon_t^{-1}[i_t + a(u_t)k_t]\right\}\left(\frac{P_{i,t}}{P_t}\right)^{-\eta}.$$

Integrating over all firms and taking into account that the capital-labor ratio is common across firms; the aggregate demand for the composite labor input, h_t^d, satisfies $h_t^d = \int_0^1 h_{i,t}di$; and that the aggregate effective level of capital, $u_t k_t$ satisfies $u_t k_t = \int_0^1 k_{i,t}di$, we obtain

$$z_t h_t^d F\left(\frac{u_t k_t}{z_t h_t^d}, 1\right) - \psi z_t^* = \left\{[1 + \ell(v_t)]c_t + g_t + \Upsilon_t^{-1}[i_t + a(u_t)k_t]\right\} \times \int_0^1 \left(\frac{P_{it}}{P_t}\right)^{-\eta} di.$$

Let $s_t \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t}\right)^{-\eta} di$. Then we have

$$
\begin{aligned}
s_t &= \int_0^1 \left(\frac{P_{i,t}}{P_t}\right)^{-\eta} di \\
&= (1-\alpha)\left(\frac{\tilde{P}_t}{P_t}\right)^{-\eta} + (1-\alpha)\alpha\left(\frac{\tilde{P}_{t-1}\pi_{t-1}^{\chi}}{P_t}\right)^{-\eta} + (1-\alpha)\alpha^2\left(\frac{\tilde{P}_{t-2}\pi_{t-1}^{\chi}\pi_{t-2}^{\chi}}{P_t}\right)^{-\eta} + \ldots \\
&= (1-\alpha)\sum_{j=0}^{\infty}\alpha^j\left(\frac{\tilde{P}_{t-j}\prod_{s=1}^{j}\pi_{t-j-1+s}^{\chi}}{P_t}\right)^{-\eta} \\
&= (1-\alpha)\tilde{p}_t^{-\eta} + \alpha\left(\frac{\pi_t}{\pi_{t-1}^{\chi}}\right)^{\eta} s_{t-1}.
\end{aligned}
$$

Summarizing, the resource constraint in the model is given by the following two expressions

$$
F(u_t k_t, z_t h_t^d) - \psi z_t^* = \left\{[1+\ell(v_t)]c_t + g_t + \Upsilon_t^{-1}[i_t + a(u_t)k_t]\right\} s_t, \text{ and} \quad (36)
$$

$$
s_t = (1-\alpha)\tilde{p}_t^{-\eta} + \alpha\left(\frac{\pi_t}{\pi_{t-1}^{\chi}}\right)^{\eta} s_{t-1}, \quad (37)
$$

with s_{-1} given. The state variable s_t summarizes the resource costs induced by the inefficient price dispersion featured in the Calvo model in equilibrium.

Three observations are in order about the price dispersion measure s_t. First, s_t is bounded below by 1. That is, price dispersion is always a costly distortion in this model. To see that s_t is bounded below by 1, let $v_{it} \equiv (P_{it}/P_t)^{1-\eta}$. It follows from the definition of the price index given in equation (4) that $\left[\int_0^1 v_{i,t}\right]^{\eta/(\eta-1)} = 1$. By definition we have $s_t = \int_0^1 v_{i,t}^{\eta/(\eta-1)}$. Taking into account that $\eta/(\eta-1) > 1$, Jensen's inequality implies that

$$
1 = \left[\int_0^1 v_{it}\right]^{\eta/(\eta-1)} \leq \int_0^1 v_{it}^{\eta/(\eta-1)} = s_t .
$$

Second, in an economy in which the nonstochastic level of inflation is nil (that is, $\pi = 1$) or prices are fully indexed to any variable ω_t

with the property that its deterministic steady-state level equals the deterministic steady-state value of inflation (that is, $\omega = \pi$), the variable s_t follows, up to first order, the univariate autoregressive process $\hat{s}_t = \alpha \hat{s}_{t-1}$. In these cases the price dispersion measure s_t has no first-order real consequences for the stationary distribution of any endogenous variable of the model. This means that studies that restrict attention to linear approximations to the equilibrium conditions are justified in ignoring the variable s_t if the model features no price dispersion in the deterministic steady state. But s_t matters up to first order when the deterministic steady state features movements in relative prices across goods varieties. More important, the price dispersion variable s_t must be taken into account if one is interested in higher-order approximations to the equilibrium conditions, even if relative prices are stable in the deterministic steady state. Omitting s_t in higher-order expansions would amount to leaving out certain higher-order terms while including others. Finally, when prices are fully flexible, $\alpha = 0$, $\tilde{p}_t = 1$, and thus $s_t = 1$. (Obviously, in a flexible-price equilibrium there is no price dispersion across varieties.)

As discussed above, equilibrium marginal costs and capital-labor ratios are identical across firms. Therefore, one can aggregate the firm's optimality conditions with respect to labor and capital, equations (26) and (27), as

$$mc_t z_t F_2(u_t k_t, z_t h_t^d) = w_t \left[1 + \nu \frac{R_t - 1}{R_t}\right] \tag{38}$$

and

$$mc_t F_1(u_t k_t, z_t h_t^d) = r_t^k. \tag{39}$$

1.6 Market Clearing in the Labor Market

It follows from equation (33) that the aggregate demand for labor of type $j \in [0,1]$, which we denote by $h_t^j \equiv \int_0^1 h_{i,t}^j di$, is given by

$$h_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\bar{\eta}} h_t^d, \tag{40}$$

where $h_t^d \equiv \int_0^1 h_{i,t} di$ denotes the aggregate demand for the composite

labor input. Taking into account that at any point in time the nominal wage rate is identical across all labor markets at which wages are allowed to change optimally, labor demand in each of those markets is

$$\tilde{h}_t = \left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} h_t^d.$$

Combining this expression with equation (40), describing the demand for labor of type $j \in [0,1]$, and with the time constraint (6), which must hold with equality, we can write

$$h_t = (1-\tilde{\alpha}) h_t^d \sum_{s=0}^{\infty} \tilde{\alpha}^s \left(\frac{\tilde{W}_{t-s} \prod_{k=1}^{s} (\mu_{z^*} \pi_{t+k-s-1})^{\tilde{\chi}}}{W_t} \right)^{-\tilde{\eta}}.$$

Let $\tilde{s}_t \equiv (1-\tilde{\alpha}) \sum_{s=0}^{\infty} \tilde{\alpha}^s (\tilde{W}_{t-s} \prod_{k=1}^{s} (\mu_{z^*} \pi_{t+k-s-1})^{\tilde{\chi}} / W_t)^{-\tilde{\eta}}$ The variable $\tilde{s}_t$ measures the degree of wage dispersion across different types of labor. The above expression can be written as

$$h_t = \tilde{s}_t h_t^d. \tag{41}$$

The state variable $\tilde{s}_t$ evolves over time according to

$$\tilde{s}_t = (1-\tilde{\alpha}) \left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} + \tilde{\alpha} \left(\frac{w_{t-1}}{w_t}\right)^{-\tilde{\eta}} \left(\frac{\pi_t}{(\mu_{z^*} \pi_{t-1})^{\tilde{\chi}}} \right)^{\tilde{\eta}} \tilde{s}_{t-1}. \tag{42}$$

Because all job varieties are identical ex ante, any wage dispersion is inefficient, as reflected in the fact that $\tilde{s}_t$ is bounded below by 1. The proof of this statement is identical to that offered earlier for the fact that s_t is bounded below by unity. To see this, note that $\tilde{s}_t$ can be written as $\tilde{s}_t = \int_0^1 (W_{it}/W_t)^{-\tilde{\eta}} di$. This inefficiency introduces a wedge that makes the number of hours supplied to the market, h_t, larger than the number of productive units of labor input, h_t^d. In an environment without long-run wage dispersion, the deadweight loss created by wage dispersion is nil up to first order. Formally, a first-order approximation of the law of motion of $\tilde{s}_t$ yields a univariate autoregressive process of the form

$\hat{\tilde{s}}_t = \tilde{\alpha}\,\hat{\tilde{s}}_{t-1}$ as long as there is no wage dispersion in the deterministic steady state. When wages are fully flexible, $\tilde{\alpha} = 0$, wage dispersion disappears, and $\tilde{s}_t$ equals 1.

It follows from our definition of the wage index given in equation (34) that in equilibrium the real wage rate must satisfy

$$w_t^{1-\tilde{\eta}} = (1-\tilde{\alpha})\tilde{w}_t^{1-\tilde{\eta}} + \tilde{\alpha} w_{t-1}^{1-\tilde{\eta}} \left(\frac{(\mu_{z^*}\pi_{t-1})^{\tilde{\chi}}}{\pi_t} \right)^{1-\tilde{\eta}}. \tag{43}$$

Aggregating the expression for firm's profits given in equation (25) yields

$$\phi_t = y_t - r_t^k u_t k_t - w_t h_t^d - \nu(1 - R_t^{-1}) w_t h_t^d. \tag{44}$$

In equilibrium, real money holdings can be expressed as

$$m_t = m_t^h + \nu w_t h_t^d, \tag{45}$$

and the government budget constraint is given by

$$\tau_t = g_t - (m_t - m_{t-1}/\pi_t). \tag{46}$$

1.7 Functional Forms

We use the following standard functional forms for utility and technology:

$$U = \frac{\left[(c_t - bc_{t-1})^{1-\phi_4} (1-h_t)^{\phi_4} \right]^{1-\phi_3} - 1}{1-\phi_3}, \quad \text{and} \quad F(k,h) = k^{\theta} h^{1-\theta}. \tag{47}$$

The functional form for the investment adjustment cost function is taken from Christiano, Eichenbaum, and Evans (2005):

$$S\left(\frac{i_t}{i_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{i_t}{i_{t-1}} - \mu_I\right)^2,$$

where μ_I is the steady-state growth rate of investment.

Following Schmitt-Grohé and Uribe (2004a, b), we assume that the transactions cost technology takes the form

$$\ell(v) = \phi_1 v + \phi_2/v - 2\sqrt{\phi_1\phi_2}. \tag{48}$$

The money demand function implied by the above transaction technology is of the form

$$v_t^2 = \frac{\phi_2}{\phi_1} + \frac{1}{\phi_1}\frac{R_t - 1}{R_t}.$$

Note the existence of a satiation point for consumption-based money velocity, $\underline{v}$, equal to $\sqrt{\phi_2/\phi_1}$. The implied money demand is unit elastic with respect to consumption expenditures. This feature is a consequence of the assumption that transactions costs, $c\ell(c/m)$, are homogenous of degree one in consumption and real balances and independent of the particular functional form assumed for $\ell(\bullet)$. Furthermore, as the parameter ϕ_2 approaches zero, the transactions cost function $\ell(\bullet)$ becomes linear in velocity and the demand for money adopts the Baumol-Tobin square root form with respect to the opportunity cost of holding money, $(R-1)/R$. That is, the log-log elasticity of money demand with respect to the opportunity cost of holding money converges to 1/2, as ϕ_2 vanishes.

The costs of higher capacity utilization are parameterized as follows:

$$a(u) = \gamma_1(u-1) + \frac{\gamma_2}{2}(u-1)^2.$$

1.8 Inducing Stationarity

This economy features two types of permanent shocks. As a result a number of variables, such as output and the real wage, will not be stationary along the balanced growth path. We therefore perform a change of variables in order to obtain a set of equilibrium conditions that involves only stationary variables. To this end we note that the variables $c_t, m_t^h, m_t, w_t, \tilde{w}_t, y_t, g_t, \phi_t, x_t^1, x_t^2$, and τ_t are cointegrated with z_t^*. Similarly, the variables k_{t+1} and i_t are cointegrated with $\Upsilon_t z_t^*$, the variable λ_t is cointegrated with $z_t^{*(1-\phi_3)(1-\phi_4)-1}$, the variables q_t and r_t^k are cointegrated with $1/\Upsilon_t$, and the variables f_t^1 and f_t^2 are cointegrated with $z_t^{*(1-\phi_3)(1-\phi_4)}$. We therefore divide these variables by the appropriate

cointegrating factor and denote the corresponding stationary variables with capital letters.

1.9 Competitive Equilibrium

A stationary competitive equilibrium is a set of stationary processes u_t, C_t, h_t, I_t, K_{t+1}, v_t, M_t^h, M_t, Λ_t, π_t, W_t, $\tilde{\mu}_t$, Q_t, R_t^k, Φ_t, F_t^1, F_t^2, $\tilde{W}_t$, h_t^d, Y_t, mc_t, X_t^1, X_t^2, $\tilde{p}_t$, s_t, $\tilde{s}_t$, and T_t satisfying expressions (7), (8), (10), (12)–(22), (29)–(31), (35)–(39), and (41)–(46) written in terms of the stationary variables, given exogenous stochastic processes $\mu_{\Upsilon,t}$, $\mu_{z,t}$, and $\bar{g}_t$; the policy process, R_t; and initial conditions c_{-1}, w_{-1}, s_{-1}, $\tilde{s}_{-1}$, π_{-1}, i_{-1}, and k_0. A complete list of the competitive equilibrium conditions in terms of stationary variables is given in the appendix (Schmitt-Grohé and Uribe, 2006).

1.10 Ramsey Equilibrium

We assume that at $t = 0$ the benevolent government has been operating for an infinite number of periods. In choosing the optimal policy, the government is assumed to honor commitments made in the past. This form of policy commitment has been referred to as "optimal from the timeless perspective" (Woodford, 2003).

Formally, we define a Ramsey equilibrium as a set of stationary processes u_t, C_t, h_t, I_t, K_{t+1}, v_t, M_t^h, M_t, Λ_t, π_t, W_t, $\tilde{\mu}_t$, Q_t, R_t^k, Φ_t, F_t^1, F_t^2, $\tilde{W}_t$, h_t^d, Y_t, mc_t, X_t^1, X_t^2, $\tilde{p}_t$, s_t, $\tilde{s}_t$, T_t, and R_t for $t \geq 0$ that maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left(z_0^* \prod_{s=1}^{t} \mu_{z^*,s} \right)^{(1-\phi_4)(1-\phi_3)} \left[\left(C_t - bC_{t-1}/\mu_{z^*,t} \right)^{1-\phi_4} (1-h_t)^{\phi_4} \right]^{1-\phi_3} - 1}{1-\phi_3}$$

subject to the competitive equilibrium conditions (7), (8), (10), (12)–(22), (29)–(31), (35)–(39), and (41)–(46) written in stationary variables and $R_t \geq 1$, for $t > -\infty$, given exogenous stochastic processes $\mu_{z,t}$, $\mu_{\Upsilon,t}$, and $\bar{g}_t$; values of the variables listed above for $t < 0$; and values of the Lagrange multipliers associated with the constraints listed above for $t < 0$.

Technically, the difference between the usual Ramsey-equilibrium concept and the one employed here is that here the structure of the optimality conditions associated with the Ramsey equilibrium is

time invariant. By contrast, under the standard Ramsey-equilibrium definition, the equilibrium conditions in the initial periods are different from those applying to later periods.

Our approach to analyzing the business cycle properties of Ramsey-optimal policy is comparable to that in the literature under the standard definition of Ramsey optimality (for example, Chari, Christiano, and Kehoe, 1995). The reason is that studies of business cycles under the standard Ramsey policy focus on the behavior of the economy in the stochastic steady state (that is, they limit attention to the properties of equilibrium time series, excluding the initial transition).

2. Calibration

The time unit is meant to be one quarter. For most of the calibration, we draw on Altig and others (2005) (hereafter ACEL). We assign most of the parameter values from the "high mark-up" case of the ACEL estimation results, in which the steady-state mark-up in product markets is 20 percent ($\eta = 6$) (table 1).

Following ACEL we assume that in the deterministic steady state of the competitive equilibrium, the rate of capacity utilization equals one ($u = 1$) and profits are zero ($\phi = 0$). ACEL calibrate the discount factor, β, to be $1.03^{-1/4}$; the depreciation rate, δ, to be 0.025; and the capital share, θ, to be 0.36. They assume that preferences are separable in consumption and leisure and logarithmic in habit-adjusted consumption ($\phi_3 = 1$). Their assumed functional form for the period utility function implies a unit Frisch elasticity of labor supply. ACEL assume a steady-state mark-up of wages over the marginal rate of substitution between leisure and consumption of 5 percent (or $\tilde{\eta} = 21$).

ACEL estimate the degree of nominal wage stickiness at slightly more than three quarters ($\tilde{\alpha} = 0.69$). They estimate the degree of habit formation, measured by the parameter b, at 0.69; the elasticity of the marginal capital adjustment cost, κ, at 2.79; the elasticity of the marginal cost of capacity utilization, γ_2/γ_1, at 1.46; and the annualized interest semi-elasticity of money demand by households, $(1/4)\partial \ln(m_t^h)/\partial(R_t)$, at -0.81. They estimate the parameters of the exogenous stochastic processes for the investment-specific and neutral technology shocks $\mu_{\Upsilon,t}$ and $\mu_{z,t}$ at $(\mu_\Upsilon, \sigma_{\mu_\Upsilon}, \rho_{\mu_\Upsilon}) = (1.0042, 0.0031, 0.20)$ and $(\mu_z, \sigma_{\mu_z}, \rho_{\mu_z}) = (1.00213, 0.0007, 0.89)$, respectively. They estimate the degree of price stickiness at five quarters (or $\alpha = 0.8$) when capital is not firm specific, which is the assumption maintained in this paper.

Table 1. Structural Parameters of the Model

Parameter	*Description*	*Value*
β	Subjective discount factor (quarterly)	$1.03^{-1/4}$
θ	Share of capital in value-added	0.36
ψ	Fixed cost parameter	0.25
δ	Depreciation rate (quarterly)	0.025
υ	Fraction of wage bill subject to a cash-in-advance constraint	0.6011
η	Price elasticity of demand for a specific good variety	6
$\tilde{\eta}$	Wage elasticity of demand for a specific labor variety	21
α	Fraction of firms not setting prices optimally each quarter	0.8
$\tilde{\alpha}$	Fraction of labor markets not setting wages optimally each quarter	0.69
b	Degree of habit persistence	0.69
ϕ_1	Transactions cost parameter	0.0459
ϕ_2	Transactions cost parameter	0.1257
ϕ_3	Preference parameter	1
ϕ_4	Preference parameter	0.5301
κ	Parameter governing investment adjustment costs	2.79
$\gamma 1$	Parameter of capacity utilization cost function	0.0412
$\gamma 2$	Parameter of capacity utilization cost function	0.0601
χ	Degree of price indexation	0
$\tilde{\chi}$	Degree of wage indexation	1
μ_γ	Quarterly growth rate of investment-specific technological change	1.0042
σ_{μ_γ}	Standard deviation of the innovation to the investment-specific technology shock	0.0031
ρ_{μ_γ}	Serial correlation of the log of the investment-specific technology shock	0.20
μ_z	Quarterly growth rate of neutral technology shock	1.00213
σ_{μ_z}	Standard deviation of the innovation to the neutral technology shock	0.0007
ρ_{μ_z}	Serial correlation of the log of the neutral technology shock	0.89
$\bar{g}$	Steady-state value of government consumption (quarterly)	0.2141
σ_{ε^g}	Standard deviation of the innovation to log of government consumption	0.008
ρ_g	Serial correlation of the log of government spending	0.9

Source: Altig and others (2005); Cogley and Sbordone (2005); Levin and others (2005); Chistiano and others (2005); Ravn (2005).

We do not draw on the work of ACEL to calibrate the degree of indexation in product prices or wages, because they do not estimate the parameters governing the degree of indexation but simply assume full indexation of all prices to past product price inflation. We draw from the econometric work of Cogley and Sbordone (2005) and Levin and others (2005), who find no evidence of indexation in product prices. We therefore set $\chi = 0$ Levin and others (2005) estimate a high degree of indexation in nominal wages. We therefore assume that $\tilde{\chi} = 1$, which happens to be the value assumed in ACEL.

Following Christiano, Eichenbaum, and Evans (2005), hereafter CEE, we set the steady-state share of money held by households, m^h/m, to 0.44. Using postwar U.S. data, we measure the average money to output ratio as the ratio of M1 to GDP and set it equal to 17 percent a year. Neither ACEL nor CEE impose this calibration restriction. Instead, they assume that all of the wage bill is subject to a cash-in-advance constraint—that is, $\upsilon = 1$. By contrast, our calibration implies that only 60 percent of wage payments must be held in money ($\upsilon = 0.6$).

In calibrating the model, we assume that in the deterministic steady state of the competitive equilibrium, the rate of inflation equals 4.2 percent a year. This value coincides with the average growth rate of the U.S. postwar GDP deflator.

ACEL do not consider government purchases shocks. One study that estimates the process for government purchases in the context of a model similar to ours is Ravn (2005), whose findings we use to calibrate this process. Ravn estimates $\rho_g = 0.9$ and $\sigma_{\varepsilon^g} = 0.008$. Finally, we impose that the steady-state share of government consumption in value-added is 17 percent, the average value observed in the United States over the postwar period.

3. The Ramsey Steady State

In this section we characterize the long-run state of the Ramsey equilibrium in an economy without uncertainty. We refer to this state as the Ramsey steady state. The Ramsey steady state is in general different from the allocation/policy that maximizes welfare in the steady state of a competitive equilibrium.

In most studies on optimal monetary policy in economies with neo-Keynesian features, characterizing the Ramsey steady state is trivial, because they assume the existence of a single nominal distortion—namely, sluggish adjustment in nominal product or factor prices or both. In this case the optimal rate of inflation in the

Ramsey steady state is nil. By contrast, the economy studied here features additional nominal frictions in the form of money demand by households and firms. This feature complicates the computation of the Ramsey steady state.

Two exceptions to the common practice of abstracting from money demand in analyzing optimal monetary policy in the neo-Keynesian model are Khan, King, and Wolman (2003) and Schmitt-Grohé and Uribe (2004a). In both studies the computation of the Ramsey steady state is relatively straightforward because of the simplicity of the theoretical structures considered. In particular, neither study features wage stickiness, capital accumulation, habit formation, variable capacity utilization, or factor adjustment costs. When all of these complications are added, it becomes virtually impossible to characterize the Ramsey steady-state conditions analytically. A contribution of the research project to which this paper belongs is the development of a general algorithm to characterize and numerically solve the Ramsey equilibrium in medium-scale macroeconomic models. This algorithm yields an exact numerical solution for the Ramsey steady-state equilibrium.

3.1 Price Stickiness and the Optimal Inflation Rate

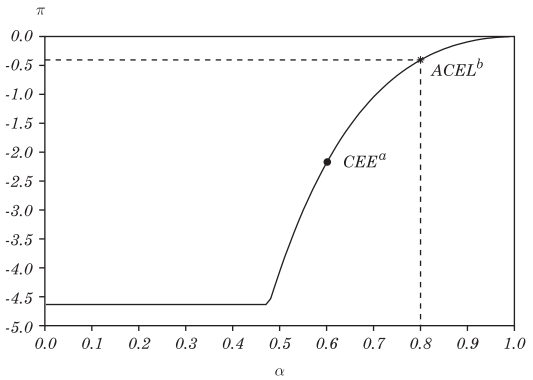
The most striking characteristic of the Ramsey steady state is the high sensitivity of the optimal rate of inflation to the parameter governing the degree of price stickiness, α, for the range of values of this parameter that is empirically relevant. Empirical estimates of the degree of price rigidity using macroeconomic data vary from two to five quarters, or $\alpha \in [0.5,0.8]$. In the context of a model similar to ours, CEE estimate α to be 0.6. By contrast, using a model identical to ours, ACEL estimate a marginal cost gap coefficient in the Phillips curve that is consistent with a value of α of about 0.8 when the market for capital is assumed to be centralized, as is maintained in our formulation.[4] Both CEE and ACEL use an impulse-response matching technique to estimate α. Bayesian estimates of this parameter include Del Negro and others (2004) and Levin and others (2005), who report posterior means of 0.67 and 0.83, respectively, and 90 percent probability intervals of (0.51, 0.83) and (0.81, 0.86), respectively. Evidence on price stickiness based on microeconomic data suggests a much higher

4. If, instead, capital accumulation is assumed to be firm specific, then ACEL's estimate of the Phillips curve is consistent with a value of α of about 0.7.

frequency of price changes than the evidence based on macro data. The findings reported in Bils and Klenow (2004) and Golosov and Lucas (2003), for example, suggest values of α of about one-third, or a degree of price stickiness of about 1.5 quarters.

Figure 1 displays the relationship between the degree of price stickiness, α, and the optimal rate of inflation in percent a year, π. When α equals 0.5, the lower range of the empirical evidence using macro data, the optimal rate of inflation is -4 percent, virtually equal to the level called for by the Friedman rule. For our baseline value of $\alpha = 0.8$, which is near the upper range of the empirical evidence using macro data, the optimal level of inflation rises to -0.4 percent, which is close to price stability. Also evident from figure 1 is the fact that values of α based on microeconomic evidence, of about one-third, imply that the Friedman rule is Ramsey optimal in the long run.

Figure 1. Degree of Price Stickiness and the Optimal Rate of Inflation



Source: Authors' computations.
* Benchmark parameter value
a. CEE = parameter values estimated by Christiano, Eichenbaum, and Evans (2005).
b. ACEL = parameter values estimated by Altig and others (2005). All parameters other than α take their baseline values, given in table 1.

In addition to the uncertainty surrounding the estimation of the degree of price stickiness, a second aspect of the apparent difficulty in reliably establishing the long-run level of inflation has to do with the shape of the relationship linking the degree of price stickiness to the optimal level of inflation. The problem resides in the fact that this relationship becomes significantly steep precisely for that range of values of α that is empirically most compelling. The problem would not arise if

the steep portion of the relationship took place at values of α below 0.33 or above, say, 0.8. It turns out that an important factor determining the shape of the function relating the optimal level of inflation to the degree of price stickiness is the underlying fiscal policy regime.

3.2 Fiscal Policy and the Optimal Inflation Rate

We follow the widespread practice in the literature on optimal monetary policy in the neo-Keynesian framework of ignoring fiscal considerations by implicitly or explicitly assuming the existence of lump-sum, nondistorting taxes that balance the government budget at all times under all circumstances. This assumption is clearly unrealistic and usually maintained on the sole basis of simplicity. We argue that taking the fiscal side of the optimal policy problem explicitly into account has crucial consequences for the optimal long-run level of inflation.

Fiscal considerations fundamentally change the long-run tradeoff between price stability and the Friedman rule. To see this, we briefly consider an economy in which lump-sum taxes are unavailable and the fiscal authority must finance government purchases through proportional capital and labor income taxes. The social planner jointly sets monetary and fiscal policy in a Ramsey-optimal fashion. The details of this environment are described in Schmitt-Grohé and Uribe (2006).

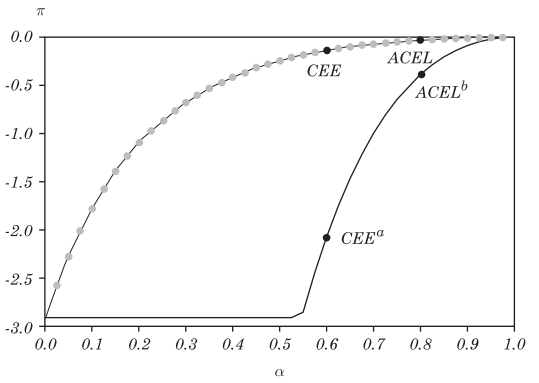
Figure 2 displays the relationship between the degree of price stickiness, α, and the optimal rate of inflation, π. The solid line corresponds to the baseline case considered here (featuring lump-sum taxes).[5] The solid-circled line corresponds to the economy with optimally chosen income taxes analyzed in Schmitt-Grohé and Uribe (2006).[6] In stark contrast to what happens under lump-sum taxation, under optimal distortionary taxation the function linking

5. In producing the solid line shown in figure 2, we assign all structural parameters the baseline values shown in table 1, except for the long-run growth rates of the two productivity shocks, which are set to zero. This deviation from the baseline calibration is necessary to preserve comparability with the model in Schmitt-Grohé and Uribe (2006), which features no long-run growth. The solid line looks essentially like the one shown in figure 1—the only difference is that at the Friedman rule, the inflation rate is -2.9 percent, whereas in figure 1 it is -4.6 percent. This difference is explained by the lack of growth in the model used to produce the solid line in figure 2.

6. In producing the solid-circled line shown in figure 2, we set all structural parameter values to those shown in table 1, except for those governing long-run growth, which are set to zero. The model economy features proportional labor, capital, and profit taxes. The profit tax rate is constrained to be equal to the capital income tax rate. Government transfers are set to zero.

π and α is flat and very close to zero for the entire range of macro data–based empirically plausible values of α, namely 0.5–0.8. In other words, when taxes are distortionary and optimally determined, price stability emerges as a prediction that is robust to the existing uncertainty about the exact degree of price stickiness. Even if one focuses on the evidence of price stickiness stemming from micro data, the model with distortionary Ramsey taxation predicts an optimal long-run level of inflation that is much closer to zero than to the level predicted by the Friedman rule.

Figure 2. Price Stickiness, Fiscal Policy, and Optimal Inflation



Source: Authors' computations.
a. CEE = parameter values estimated by Christiano, Eichenbaum, and Evans (2005).
b. ACEL = parameter values estimated by Altig and others (2005).

Our intuition for why price stability arises as a robust policy recommendation in the economy with optimally set distortionary taxation runs as follows. Consider the economy with lump-sum taxation. Deviating from the Friedman rule (by raising the inflation rate) reduces the price dispersion that originates in the presence of price stickiness. Consider next the economy with Ramsey-optimal income taxation and no lump-sum taxes. In this economy deviating from the Friedman rule reduces price dispersion. In addition, raising inflation increases seignorage revenue, allowing the social planner to lower distortionary income tax rates. The tradeoff between the Friedman rule and price stability is thus tilted in favor of price stability.

It follows from this intuition that what is essential in inducing the optimality of price stability is that at the margin the fiscal authority

trades off the inflation tax for regular taxation. Indeed, it can be shown that if distortionary tax rates are fixed, even at the level that is optimal in a world without lump-sum taxes, and the fiscal authority has access to lump-sum taxes at the margin, the optimal rate of inflation is much closer to the Friedman rule than to zero. In this case increasing inflation no longer has the benefit of reducing distortionary taxes. As a result the Ramsey planner has less incentive to inflate.

3.3 Price Indexation and the Optimal Inflation Rate

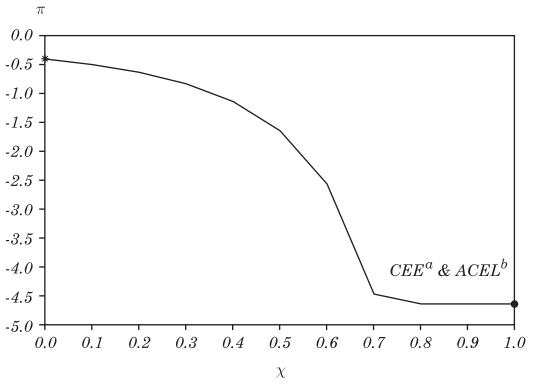
The parameter χ, measuring the degree of price indexation, is crucial in determining the optimal level of long-run inflation, because when prices are fully indexed ($\chi = 1$), price dispersion disappears in the deterministic steady state. As a result the social planner no longer faces a tradeoff between minimizing price dispersion and minimizing the opportunity cost of holding money. In such an environment the Friedman rule is Ramsey optimal. In the absence of perfect indexation ($\chi < 1$), any deviation from zero inflation will entail price dispersion; the lower the degree of indexation, the higher the price dispersion associated with a given level of inflation. Consequently, the Ramsey-optimal deflation rate is increasing in the degree of price indexation.

Figure 3 shows that the Ramsey-optimal inflation rate is indeed a decreasing function of the indexation parameter χ. CEE and ACEL assume that prices are perfectly indexed to lagged inflation—they calibrate the parameter χ to be unity. Under this assumption the Friedman rule is optimal in the deterministic Ramsey steady state. However, the few studies that attempt to estimate the indexation parameter χ find little empirical support for price indexation. For example, using Bayesian methods, Levin and others (2005) report a tight estimate of χ of 0.08. Using a different empirical strategy, Cogley and Sbordone (2005) also find virtually no evidence of price indexation in U.S. data. These two empirical studies motivate our setting $\chi = 0$.

3.4 Money Demand and the Optimal Inflation Rate

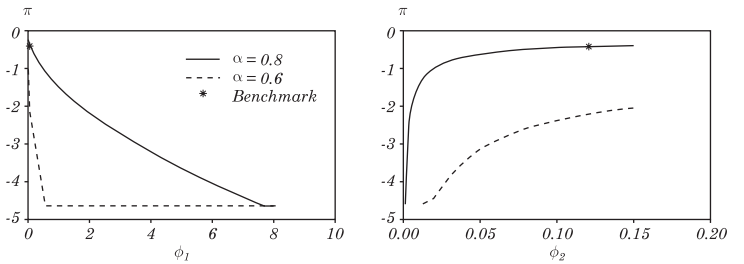
Given the long-run policy tradeoffs present in the model—namely, minimizing the opportunity cost of holding money (by setting $R_t = 1$) versus minimizing price dispersion (by setting $\pi_t = 1$)—one should expect that the larger the money demand friction, the closer the optimal rate of inflation to the one prescribed by the Friedman rule.

Figure 3. Degree of Price Indexation and the Optimal Rate of Inflation



Source: Authors' computations.
* Benchmark Parameter Value
a. CEE = parameter values estimated by Christiano, Eichenbaum, and Evans (2005).
b. ACEL = parameter values estimated by Altig and others (2005). All parameters other than χ take their baseline values, given in table 1.

Figure 4. Money Demand and the Optimal Rate of Inflation



Source: Authors' computations.
Note: In each panel all parameters other than the one shown take their baseline values, given in table 1.

Figure 4 displays the optimal rate of inflation as a function of the two structural parameters defining the demand for money by households, ϕ_1 and ϕ_2. It suggests that the optimal rate of inflation is rather insensitive to changes in these two parameters. At the baseline value of 0.05 for the parameter ϕ_1, the optimal rate of inflation is -0.4 percent a year and money demand is 17 percent of GDP. If one increases ϕ_1 by a factor of 10, to 0.5, the optimal rate of deflation is still small, at only 1 percent, but the demand for money doubles to 35 percent of GDP. One must increase ϕ_1 by a factor of more than 150, to about 8, to induce an

optimal inflation rate close to the Friedman rule. At this value of ϕ_1, the demand for money is larger than annual GDP.

The reason for the implied low sensitivity of the Ramsey inflation rate to the parameters defining the demand for money is the assumed high degree of price stickiness. This distortion is so dominant in this model that optimal policy is overwhelmingly geared toward price stability. As a result, low inflation survives as the overriding goal of monetary policy, even for economically large values of the money demand distortion. If one lowers the degree of price stickiness, the optimal rate of inflation becomes much more sensitive with respect to the transactions cost parameter, ϕ_1. Figure 4 displays with a dashed line the relationship between the optimal rate of inflation and the parameters ϕ_1 and ϕ_2 when the sticky-price parameter α takes the value 0.6. In this case the optimal rate of inflation falls from near price stability to the Friedman rule much more rapidly as one increases ϕ_1 than in the baseline case, in which $\alpha = 0.8$.

A similar message emerges as one varies the other transactions cost parameter, ϕ_2. Only for economically implausible values of ϕ_2 (values implying extremely high interest rate elasticities of money demand) does the Friedman rule emerge as Ramsey optimal.

3.5 Implications for Inflation Targeting

A robust implication of the ACEL model studied here is that the central bank should target mild deflation. This implication is at odds with the observed inflation goals among the large number of industrial and emerging market countries that self-identify their monetary policy as inflation targeting. In industrial countries, inflation targets typically lie in the rage of 2–3 percent a year. Inflation targets are somewhat higher in developing countries.

It is therefore a challenge for monetary policy to square theoretically optimal inflation targets with actual ones. One reason often offered for why the inflation target should be positive is that too low an inflation target (in particular, zero or negative targets) would leave the central bank too close to the zero bound on nominal interest rates, thereby impairing the monetary authority's ability to steer the economy out of recession. Our analysis thus far is necessarily mute on this point, because we have limited attention to a characterization of the Ramsey steady state. In order to ascertain whether the zero bound will indeed be frequently visited under the Ramsey- optimal stabilization policy, a dynamic equilibrium analysis must be carried out.

4. Ramsey Dynamics

We approximate the Ramsey equilibrium dynamics by solving a first-order approximation to the Ramsey equilibrium conditions. There is evidence that first-order approximations to the Ramsey equilibrium conditions deliver dynamics that are fairly close to those associated with the exact solution. In Schmitt-Grohé and Uribe (2004b), we compute the exact solution to the Ramsey equilibrium in a flexible-price dynamic economy with money, income taxes, and monopolistic competition in product markets. In Schmitt-Grohé and Uribe (2004a), we compute the solution to the same economy using a first-order approximation to the Ramsey equilibrium conditions. We find that the solution is not significantly different from the one based on a first-order approximation. In the context of optimal taxation in the standard real-business-cycle model, Benigno and Woodford (2005) show that the first-order approximation to the Ramsey equilibrium conditions implies second moments that are similar to those computed from an approximation based on a minimum-weighted-residual method reported in Chari and others (1995).

4.1 Is the Zero Bound an Impediment to Optimal Policy?

One argument against setting a zero or negative inflation target, as recommended by our model, is that at zero or negative rates of inflation the risk of hitting the zero lower bound on nominal interest rates would severely restrict the central bank's ability to conduct successful stabilization policy. We compute the standard deviations of the nominal interest rate as well as other key macroeconomic variables under the Ramsey-optimal stabilization policy (table 2).

In computing these second moments, we assign all structural parameters of the model the values shown in table 1. We find that the annual standard deviation of the nominal interest rate is only 0.4 percentage points, while the Ramsey steady-state level of the nominal interest rate is 4.4 percent (see table 2). Taken together these figures imply that for the nominal interest rate to hit the zero bound, it must fall more than 10 standard deviations below its target level. The probability of this happening is so small that in the context of the estimated medium-scale model studied here, the zero bound on nominal interest rates does not impose an economically important constraint on the conduct of optimal monetary policy. This

conclusion appears to be robust to changes in the degree of price or wage stickiness within the range of available empirical estimates for the parameters determining the degree of nominal sluggishness (see columns 2 and 3 of table 2).

4.2 Optimality of Inflation Stability

The Ramsey authority faces a three-way tradeoff in determining the optimal degree of inflation volatility. The sticky price distortion in isolation calls for minimizing inflation volatility. The money demand distortion calls for stabilizing the opportunity cost of holding money, that is, minimizing the standard deviation of R_t. The sticky wage distortion renders stabilization of wage inflation (in the absence of indexation) or stabilization of wage inflation net of lagged price inflation (under full indexation to past price inflation) Ramsey optimal. Table 2 indicates that this three-way tradeoff is resolved overwhelmingly in favor of inflation stability.

To see how sensitive the inflation stability goal is to the size of the sticky wage distortion, consider the case of $\tilde{\alpha} = 0.9$, which implies that unions reoptimize wages only every 10 quarters. The optimal volatility of price inflation increases and that of wage inflation falls. The optimal standard deviation of price inflation is now 0.4 percent a year and the optimal standard deviation of wage inflation 1.0 percent. Yet price inflation continues to be significantly smoother over the business cycle than wage inflation. We conclude that a central characteristic of optimal stabilization policy is smooth inflation rates. In this sense one could say that the Ramsey planner pursues a policy of inflation targeting.

4.3 Ramsey Optimal Impulse Responses and Variance Decomposition

Optimal stabilization policy will in general be shaped by the number and nature of exogenous shocks generating aggregate fluctuations. There is considerable debate in the empirical literature about the identification of the main sources of business cycle fluctuations. One branch of the literature uses structural vector autoregression analysis to identify specific structural shocks. Examples of this approach are Altig and others (2005) and Fisher (2005). The work of Fisher suggests that investment-specific technology shocks may explain as much as 50 percent of variations in hours worked. Altig and others identify monetary policy shocks and investment-specific as well as neutral

Table 2. Ramsey Optimal Stabilization Policy: Second Moments

Variable	$\alpha = 0.8$ $\tilde{\alpha} = 0.69$	$\alpha = 0.8$ $\tilde{\alpha} = 0.9$	$\alpha = 0.6$ $\tilde{\alpha} = 0.69$
Standard deviation (percentage points per year)			
Nominal interest rate	0.4	0.4	0.3
Price inflation	0.1	0.4	0.2
Wage inflation	1.2	1.0	1.2
Output growth	0.8	0.8	0.8
Consumption growth	0.5	0.5	0.5
Investment growth	1.3	1.5	1.3
Serial correlation			
Nominal interest rate	0.9	0.8	0.9
Price inflation	0.8	0.9	0.8
Wage inflation	0.7	0.5	0.6
Output growth	0.4	0.5	0.5
Consumption growth	0.9	0.9	0.9
Investment growth	0.8	0.7	0.8
Correlation with output growth			
Nominal interest rate	0.4	0.0	0.3
Price inflation	-0.3	-0.5	-0.4
Wage inflation	0.6	0.4	0.6
Output growth	1.0	1.0	1.0
Consumption growth	0.4	0.4	0.4
Investment growth	0.4	0.5	0.4

Source: Authors' computations.

technology shocks. They find that investment-specific shocks play a smaller role in generating business cycles. Specifically, they estimate that neutral and investment-specific technology shocks together explain only about one-third of the fluctuations in hours, output, and consumption.

Some recent literature uses Bayesian methods to estimate the entire data-generating process of a dynamic stochastic general equilibrium model. Smets and Wouters (2004) is a key example of this

line of research. The authors estimate a model with 10 shocks. One might consider using all of those 10 estimated shocks in the optimal policy problem. However, in econometrically estimated versions of the model studied here (or variations thereof), many of these shocks are often difficult to interpret economically. To a large extent, these shocks represent simple econometric residuals reflecting the distance between model and data rather than true sources of business cycle fluctuations.

A case in point are shocks to Euler equations or mark-up shocks. Before incorporating this type of residual as driving forces, it is our position to first give theory a chance to get closer to the data. We therefore do not attempt to build a model that includes all sources of fluctuations. Instead, we focus on three shocks that have been shown in the empirical literature to explain a significant fraction of aggregate fluctuations: neutral shocks, investment-specific technology shocks, and government purchases shocks.

Variations in output growth are explained in equal parts by government purchases shocks and neutral technology shocks, which each account for 45 percent of output growth variance (table 3). Investment-specific productivity shocks play a minor role in driving fluctuations in output growth, but they are important in explaining movements in hours worked (47 percent), wage inflation (37 percent), and investment growth (61 percent). Fluctuations in consumption growth, the nominal interest rate, inflation, and wage inflation are driven mainly by neutral productivity shocks, with a small contribution by government purchases shocks.

Table 3. Fraction of Variance Explained by Exogenous Disturbances in the Ramsey Equilibrium

Variable	$\mu_{\gamma,z}$	$\mu_{z,t}$	g_t
$\ln y_t/y_{t-1}$	0.11	0.44	0.45
$\ln c_t/c_{t-1}$	0.10	0.80	0.10
$\ln I_t/I_{t-1}$	0.61	0.33	0.06
$\ln R_t$	0.21	0.62	0.17
$\ln \pi_t$	0.13	0.83	0.04
$\ln \pi_t^W$	0.37	0.63	0.00
$\ln h_t^d$	0.47	0.44	0.09

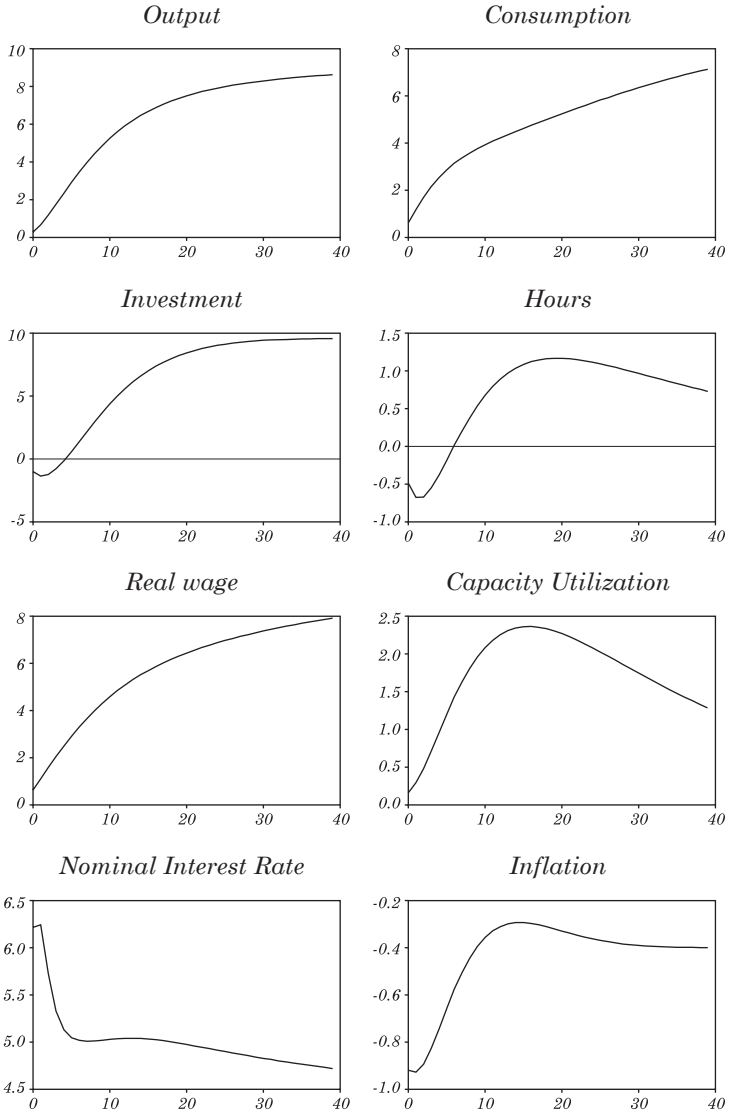
Source: Authors' computations.

In response to a 1 percentage increase in the growth rate of the neutral technology shock ($\ln(\mu_{z,0}/\mu_z) = 1\%$), the Ramsey planner raises nominal interest rates by 175 basis points on impact and allows inflation to fall 45 basis points (figure 5). This monetary tightening is short lived, however: after six quarters the nominal interest rate is back at 5 percent, or 50 basis points above its long-run target. We conjecture that the reason for this tightening is as follows. The Ramsey planner aims to replicate the real allocation associated with the flexible-price/ flexible-wage economy. In such an economy, the real interest rate would rise at least temporarily in response to a positive shock to the growth rate of technology. With sluggish nominal price adjustment, the Ramsey planner would like to induce a rise in the real interest rate without relying on costly movements in the inflation rate. Because the real interest rate equals the risk-free nominal interest rate minus the inflation rate, it follows that the Ramsey-optimal policy is to raise nominal interest rates roughly by the amount that real interest rates would rise in the flexible-price economy. Interestingly, nominal interest rates are tightened not to avoid inflation but to avoid deflation.

An active debate is ongoing over the estimated effects of neutral technology shocks on hours. Galí (1999) finds that hours decline on impact, whereas ACEL find that hours increase. Consistent with the findings of Galí, our model predicts that under the Ramsey policy, hours decline on impact in response to a positive innovation in the neutral technology shock. Our intuition for the initial decline in hours is as follows. Because monetary policy induces a sharp increase in real interest rates on impact, the wealth effect on consumption is initially muted. In addition, due to the presence of adjustment costs in investment, investment spending does not increase much on impact. As a result the positive wealth effect generated by the increase in productivity growth materializes in an expansion of the consumption of leisure.

A 1 percent increase in government consumption raises output by 0.15 percent (figure 6). Given that in the model the share of public consumption in GDP is assumed to be 17 percent, it follows that the government spending multiplier implied by the model is slightly below unity. The model predicts that the government should increase interest rates in response to a positive government spending shock, which is in line with conventional wisdom.

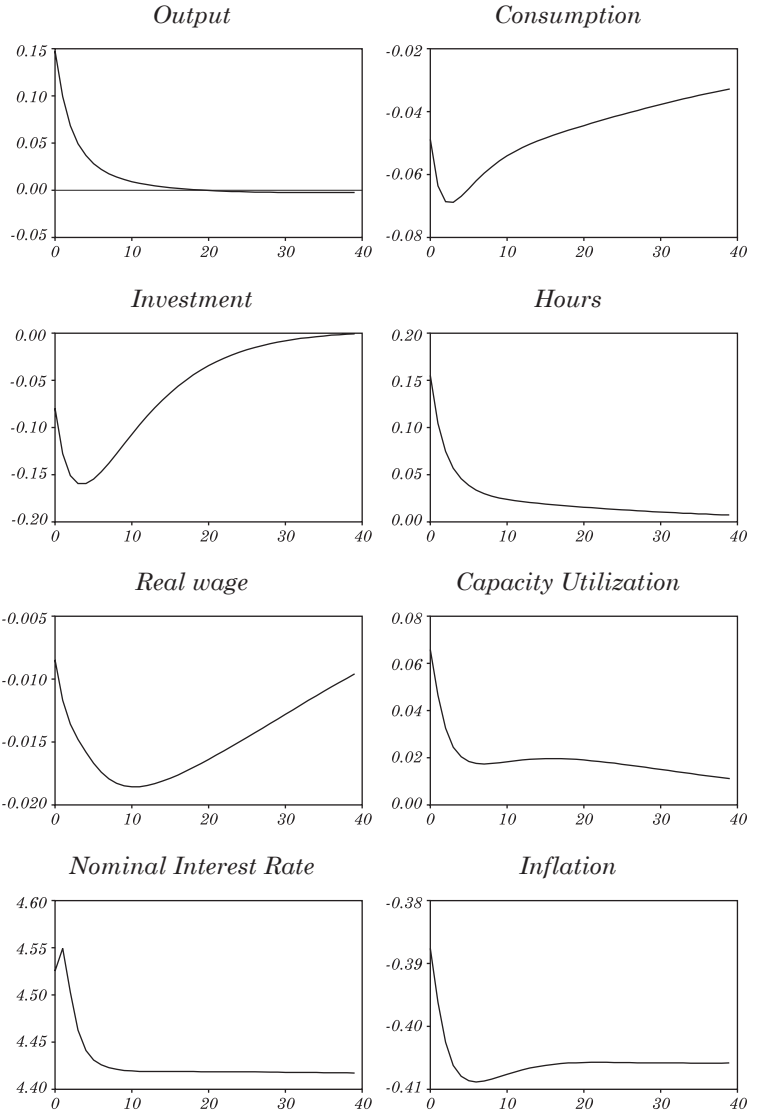
Figure 5. Ramsey Response to a Neutral Productivity Shock



Source: Authors' computations.

Note: The size of the initial innovation to the neutral technology shock is 1 percent, $\ln(\mu_{z,0}/\mu_z) = 1\%$. The nominal interest rate and the inflation rate are expressed in levels in percent a year. Output, wages, investment, and consumption are expressed in cumulative growth rates in percent. Hours and capacity utilization are expressed in percentage deviations from their respective steady-state values.

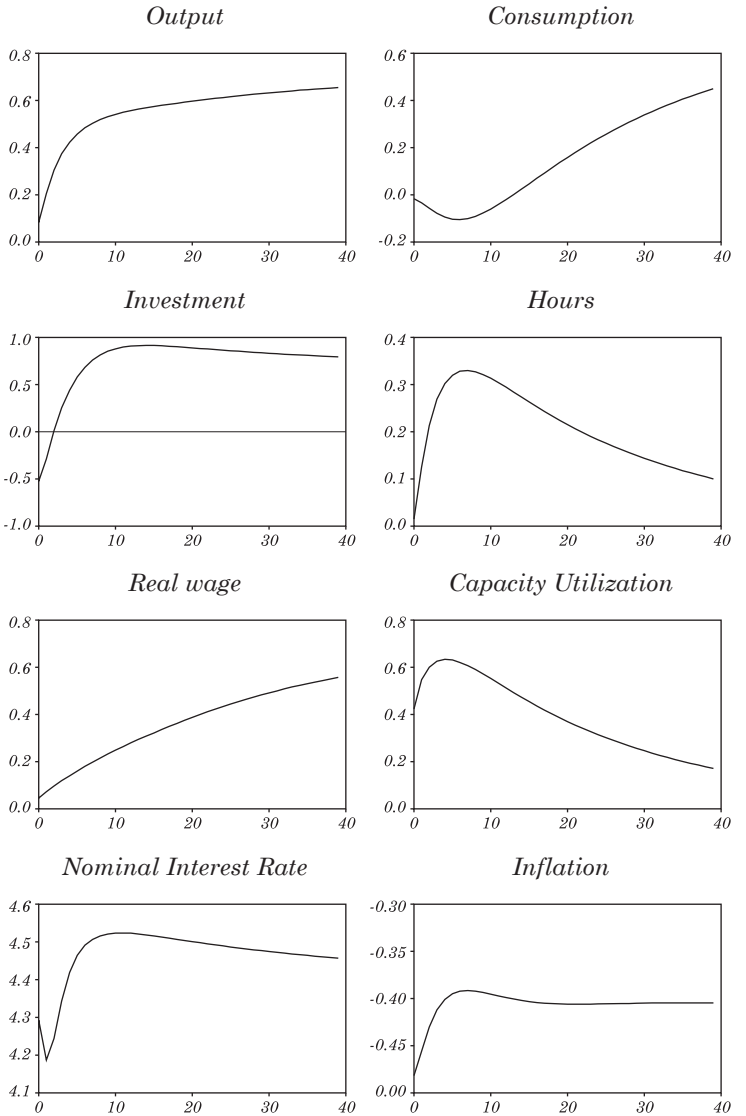
Figure 6. Ramsey Response to a Government Purchases Shock



Source: Authors' computations.

Note: The size of the initial innovation to government purchases is 1 percent of its steady-state value, $\ln(\overline{g}_0 / \overline{g}) = 1\%$. The nominal interest rate and the inflation rate are expressed in levels in percent at an annual rate. Output, wages, investment, and consumption are expressed in cumulative growth rates in percent. Hours and capacity utilization are expressed in percentage deviations from their respective steady-state values.

Figure 7. Ramsey Response to an Investment-Specific Productivity Shock



Source: Authors' computations.
Note: The size of the initial innovation to the neutral technology shock is one standard deviation, $\ln(\mu_{z,0}/\mu_z) = 1\%$. The nominal interest rate and the inflation rate are expressed in levels in percent a year. Output, wages, investment, and consumption are expressed in cumulative growth rates in percent. Hours and capacity utilization are expressed in percentage deviations from their respective steady-state values.

In response to a 1 percentage point increase in the growth rate of investment-specific technological change, Ramsey policy calls for an easing of money market conditions (figure 7). Our intuition is that the Ramsey planner tries to mimic the flexible-price equilibrium. In the absence of price stickiness, real interest rates would fall. Hence the Ramsey planner lowers nominal rates in order to reduce real rates without putting upward pressure on inflation.

5. Optimal Operational Interest Rate Rules

Ramsey outcomes are mute on the issue of what policy regimes can implement them. The information on policy one can extract from the solution to the Ramsey problem is limited to the equilibrium behavior of policy variables such as the nominal interest rate, information that is in general of little use for central banks seeking to implement the Ramsey equilibrium. Specifically, the equilibrium process of policy variables in the Ramsey equilibrium is a function of all of the states of the Ramsey equilibrium. These state variables include all of the exogenous driving forces and all of the endogenous predetermined variables. Among this second set of variables are past values of the Lagrange multipliers associated with the constraints of the Ramsey problem. Even if the policymaker could observe the state of all of these variables, using the equilibrium process of the policy variables to define a policy regime would not guarantee the Ramsey outcome as the competitive equilibrium. The problem is that such a policy regime could give rise to multiple equilibria.

A simple interest rate feedback rule implements the Ramsey equilibrium in the medium-scale model under study. Specifically, we focus on finding parameterizations of interest rate rules that satisfy the following four conditions: they are simple, in the sense that they involve only a few observable macroeconomic variables; they guarantee local uniqueness of the rational expectations equilibrium; the associated path of the nominal interest rate does not violate the zero bound;[7] and they maximize the expected lifetime utility of the representative household conditional on the initial state of the economy being the deterministic steady state of the Ramsey economy. We refer to rules that satisfy the first three criteria as operational

7. We approximate this constraint by requiring that in the competitive equilibrium, two standard deviations of the nominal interest rate be less than the steady-state level of the nominal interest rate.

rules. We refer to operational rules that satisfy the fourth criterion as optimal operational rules.

The family of rules that we consider consists of interest rules whereby the nominal interest rate depends linearly on its own lag, the rates of price and wage inflation, and the growth rate of output. Formally, the interest rate rule is given by

$$\ln\left(\frac{R_t}{R^*}\right) = \alpha_\pi \ln\left(\frac{\pi_t}{\pi^*}\right) + \alpha_W \ln\left(\frac{\pi_t^W}{\pi^{W^*}}\right) + \alpha_y \ln\left(\frac{y_t}{y_{t-1}\mu_y^*}\right) + \alpha_R \ln\left(\frac{R_{t-1}}{R^*}\right). \quad (49)$$

The target values R^*, π^*, π^{W^*} and μ_y^* are assumed to be the Ramsey steady-state values of their associated endogenous variables. (The steady-state growth of output is indeed exogenous and given by μ_z*.) The variable π_t^W denotes nominal wage inflation; in the nonstochastic steady state $\pi^{W^*} \equiv \mu_z * \pi^*$. It follows that in our search for the optimal operational policy rule, we choose the four policy parameters (α_π, α_W, α_y, α_R) so as to maximize welfare, $V_t \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(c_t - bc_{t-1}, h_t)$, where expectations are taken conditional on the initial state being the nonstochastic steady state of the Ramsey equilibrium. Given the complexity of the model, an exact numerical solution does not exist. We therefore approximate our conditional welfare measure to second-order accuracy using the numerical method developed in Schmitt-Grohé and Uribe (2004d).

5.1 The Optimal Operational Rule

The optimal operational interest rate is given by

$$\ln\left(\frac{R_t}{R^*}\right) = 5.0 \ln\left(\frac{\pi_t}{\pi^*}\right) + 1.6 \ln\left(\frac{\pi_t^W}{\pi^{W^*}}\right) - 0.1 \ln\left(\frac{y_t}{y_{t-1}\mu_y^*}\right) + 0.4 \ln\left(\frac{R_{t-1}}{R^*}\right).$$

It is active in both price and wage inflation, because both coefficients are greater than unity. In addition, the rule prescribes virtually no response to output growth. In this sense the optimized interest rate rule can indeed be interpreted as a pure inflation targeting rule. According to the rule, policymakers react positively to lagged nominal interest rates. Because the interest rate coefficient is less than unity, the rule is inertial but not superinertial. Thus policymakers are backward looking in their response to inflation deviations from target.

To quantify the difference between the level of welfare under the Ramsey policy and the optimal operational rule, we compute the

welfare costs of the optimal operational interest rate rules relative to the time-invariant equilibrium process associated with the Ramsey policy. We assume that at time zero all state variables of the economy equal their respective Ramsey steady-state values. Because the nonstochastic steady state is the same across all policy regimes we consider, computing expected welfare conditional on the initial state being the nonstochastic steady state ensures that the economy begins from the same initial point under all possible polices.

We denote the contingent plans for consumption and hours under the Ramsey policy by c_t^r and h_t^r. We denote the contingent plans under the alternative policy regime by c_t^a and h_t^a. Let λ^c denote the welfare cost of adopting policy regime a instead of the Ramsey policy conditional on a particular state in period zero. We define λ^c as the fraction of regime r's consumption process that a household would be willing to give up to be as well off under regime a as under regime r. It follows that λ^c is implicitly defined by[8]

$$E_0 \sum_{t=0}^{\infty} \beta^t U((c_t^a - bc_{t-1}^a), h_t^a) = E_0 \sum_{t=0}^{\infty} \beta^t U((1-\lambda^c)(c_t^r - bc_{t-1}^r), h_t^r).$$

One can derive an unconditional welfare cost measure in a similar manner. That is, one can ask what fraction of consumption under the Ramsey policy are agents willing to give up to attain the same unconditional expectation of lifetime utility as under the alternative policy. Let λ^u denote this unconditional welfare cost measure. Then λ^u is implicitly given by

$$E\left\{\sum_{t=0}^{\infty} \beta^t U((c_t^a - bc_{t-1}^a), h_t^a)\right\} = E\left\{\sum_{t=0}^{\infty} \beta^t U((1-\lambda^u)(c_t^r - bc_{t-1}^r), h_t^r)\right\}.$$

We restrict attention to approximations of λ^c and λ^u that are accurate up to second order (see the appendix for a derivation).

The welfare costs of following the optimal operational interest rate rule rather than the Ramsey policy are virtually zero; agents are willing to give up less than 0.001 percent of the Ramsey consumption

8. For analytical convenience we apply the factor $(1 - \lambda^c)$ to c_{-1}, even though this variable is predetermined at the time of the policy evaluation. In Schmitt-Grohé and Uribe (2004d), we show that if one were not to apply the factor $(1 - \lambda^c)$ to c_{-1}, one would obtain a welfare cost measure that is slightly smaller than the one obtained here. However, because the alternative welfare cost measure is proportional to the one used here, the welfare rankings would be unchanged. Our conclusion that the optimal operational rule yields virtually the same level of welfare as the Ramsey policy would only be strengthened.

Table 4. Welfare under the Optimal Operational Rules

Parameterization	α_{π}	α_{W}	α_{y}	α_{R}	$(100\times\lambda^{c})$	$(100\times\lambda^{u})$	$c_{2006}\lambda^{c}$	$c_{2006}\lambda^{u}$
Optimized rules (equation 48)								
Baseline calibration	5.0	1.6	-0.1	0.4	0.001	0.001	$0.23	$0.19
High wage stickiness ($\tilde{\alpha}$ = 0.9)	0.4	1.9	0.1	2.3	0.008	0.005	$2.50	$1.41
Ad hoc rule								
Taylor rule—output level	1.5	0.0	0.5	0.0	0.14	0.16	$41.81	$48.06

Source: For consumption in 2006, Bureau of Economic Analysis (www.bea.gov).
Note. The variable $c_{2006} \equiv \$30{,}441$ denotes nominal U.S. per capita personal consumption expenditures seasonally adjusted at annual rates in the first quarter of 2006.

stream (less than 23 cents a year) to be as well off under the optimal operational rule as under the Ramsey policy (table 4).

A central characteristic of the optimal rule is that its response to output is mute. Forcing the output coefficient, α_y, to be zero, increases the welfare cost by less than 1 cent a year. This finding has an important policy implication. Central banks need not respond to a measure of output in order to implement an equilibrium that provides virtually the same level of welfare as the Ramsey policy.

While it is true that responding to output has virtually zero welfare gains, it may have significant welfare costs. In table 4 we consider a Taylor rule with a coefficient of 0.5 on deviations of output from trend ($\ln(Y_t/Y)$) and an inflation coefficient of 1.5. This rule is associated with welfare costs of almost $50 a year per person ($200 a year per four-person household).

Interest rate smoothing is not essential from a welfare point of view in this economy. Under the optimal rule, the interest rate smoothing coefficient is 0.4. If one eliminates interest rate smoothing by setting $\alpha_R = 0$ while keeping the other rule coefficients at $\alpha_\pi = 5$, $\alpha_y = 0$, and $\propto_{\pi W} = 1.6$, the welfare costs of the rule increase by 3 cents a year to 26 cents a year, which we regard as negligible.[9]

Next we address the question of how important it is for the central bank to respond to both wage and price inflation rather than to just price inflation. Setting $\propto_{\pi W} = \alpha_y = \alpha_R = 0$ and leaving α_π at the optimized value of 5 increases welfare costs to 81 cents a year per person (0.003 percent of annual consumption). This is still a fairly small number, which leads us to conclude that a simple policy prescription—namely, responding aggressively to price inflation only—can bring about an equilibrium in which agents are virtually as well off as under the Ramsey policy. In this sense we can interpret our findings as supportive of inflation targeting policies.

Table 4 also presents the optimal operational rule coefficients when wages are reoptimized every 10 quarters ($\tilde{\alpha} = 0.9$). In the baseline calibration, we draw from the work of ACEL and assume that wage contracts are reoptimized about every third quarter ($\tilde{\alpha} = 0.69$). ACEL adopt the Erceg, Henderson, and Levin (2000) model of nominal wage stickiness. Under this formulation, wage dispersion generates heterogeneity in work intensity across households. In our formulation,

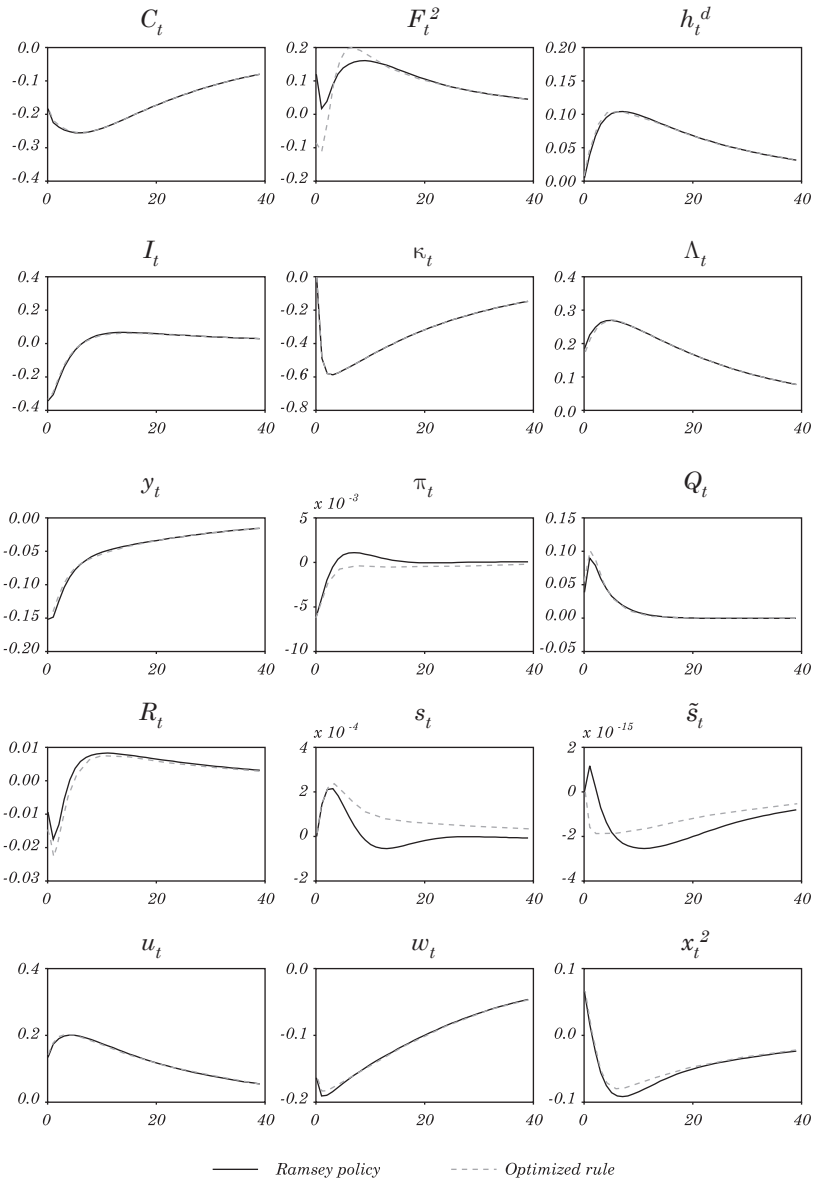
9. In Schmitt-Grohé and Uribe (forthcoming), we study a simpler model without nominal wage rigidity or growth. We find that the optimal interest rate rule delivers virtually the same level of welfare as the Ramsey policy, that the optimal response to output is nil, that responding to output can entail significant welfare costs, and that the welfare gains from interest rate smoothing are negligible.

all households supply the same amount of labor. In equilibrium these two modeling strategies result, up to first order, in a different labor mark-up coefficient in the wage Phillips curve. Specifically, the log-linear approximation to the wage inflation Phillips curve in the ACEL model can be written as $\hat{\pi}_t^W - \hat{\pi}_{t-1} = \beta(E_t\hat{\pi}_{t+1}^W - \hat{\pi}_t) - \gamma\hat{\tilde{\mu}}_t$, where $\gamma = \left[1/(1-\tilde{\eta})\right] \times \left[(1-\tilde{\alpha})(1-\beta\tilde{\alpha})/\tilde{\alpha}\right]$. In our model, under the assumption of full wage indexation, $\tilde{\chi} = 1$ (as maintained in ACEL and in our baseline calibration), the wage Phillips-curve is given by $\hat{\pi}_t^W - \hat{\pi}_{t-1} = \beta(E_t\hat{\pi}_{t+1}^W - \hat{\pi}_t) - (1+\tilde{\eta})\gamma\hat{\tilde{\mu}}_t$. This means that the coefficient on the labor market mark-up differs in the two models by a factor of $(1+\tilde{\eta})$. Given the estimated value for γ reported by ACEL and given our baseline values for $\tilde{\eta}$ and β of 21 and $1.03^{-0.25}$, respectively, the implied value of $\tilde{\alpha}$ in the context of our model is about 0.9. With this degree of wage stickiness, the optimized interest rate rule calls for a more aggressive response to wage inflation and a less aggressive response to price inflation. In addition, the optimal rule now displays a superinertial response to lagged interest rates. The rule continues to call for a mute response to output variations. The welfare differences between the optimal operation rule and the Ramsey policy are still small, at 0.005 percent of the Ramsey consumption stream.

In computing the coefficients of the optimized policy rule, we have restricted attention to maximizing lifetime utility of the representative household conditional on a particular initial the initial state of the economy being the nonstochastic Ramsey steady state. Alternatively, one could pick policy-rule coefficients so as to maximize an unconditional measure of lifetime utility. Our results are robust to adopting this alternative. Specifically, under the unconditional welfare objective, we obtain $\alpha_\pi = 5.1$, $\alpha_W = 1.6$, $\alpha_y = -0.1$, $\alpha_R = 0.4$, $100 \times \lambda^c = 0.001$, and $100 \times \lambda^u = 0.001$.

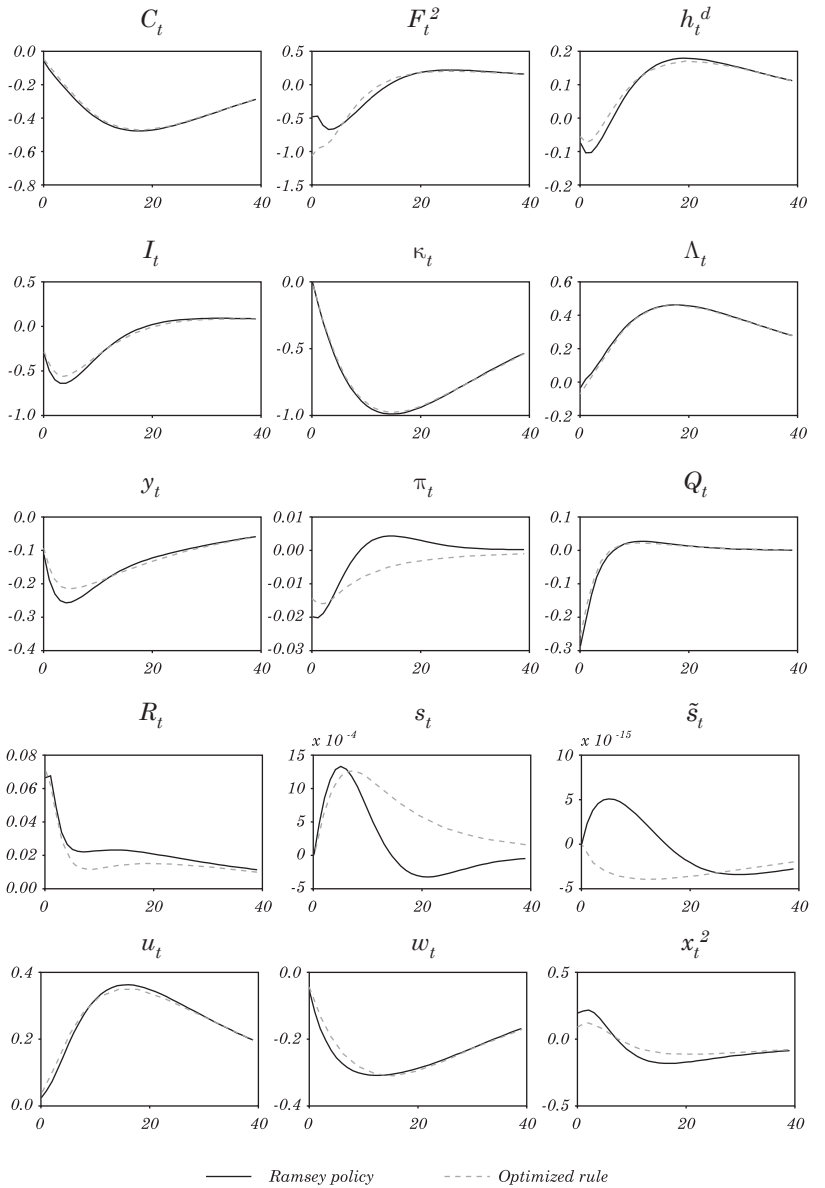
Figures 8, 9, and 10 compare the impulse responses of all variables of the model to the three shocks driving aggregate fluctuations under the Ramsey-optimal policy (solid lines) and under the optimized operational interest rate rule (broken lines). Inflation and the nominal interest rate are shown in percent per quarter deviations from their steady-state values. All other variables are expressed in percent deviations from their deterministic steady state. Variables in capital letters are stationarity-inducing transformations of the corresponding variables in lowercase letters. The figures suggest a remarkable match between the Ramsey responses and the impulse responses associated with the optimized operational interest rate rule.

Figure 8. Ramsey and Optimized Responses to an Investment-Specific Productivity Shock



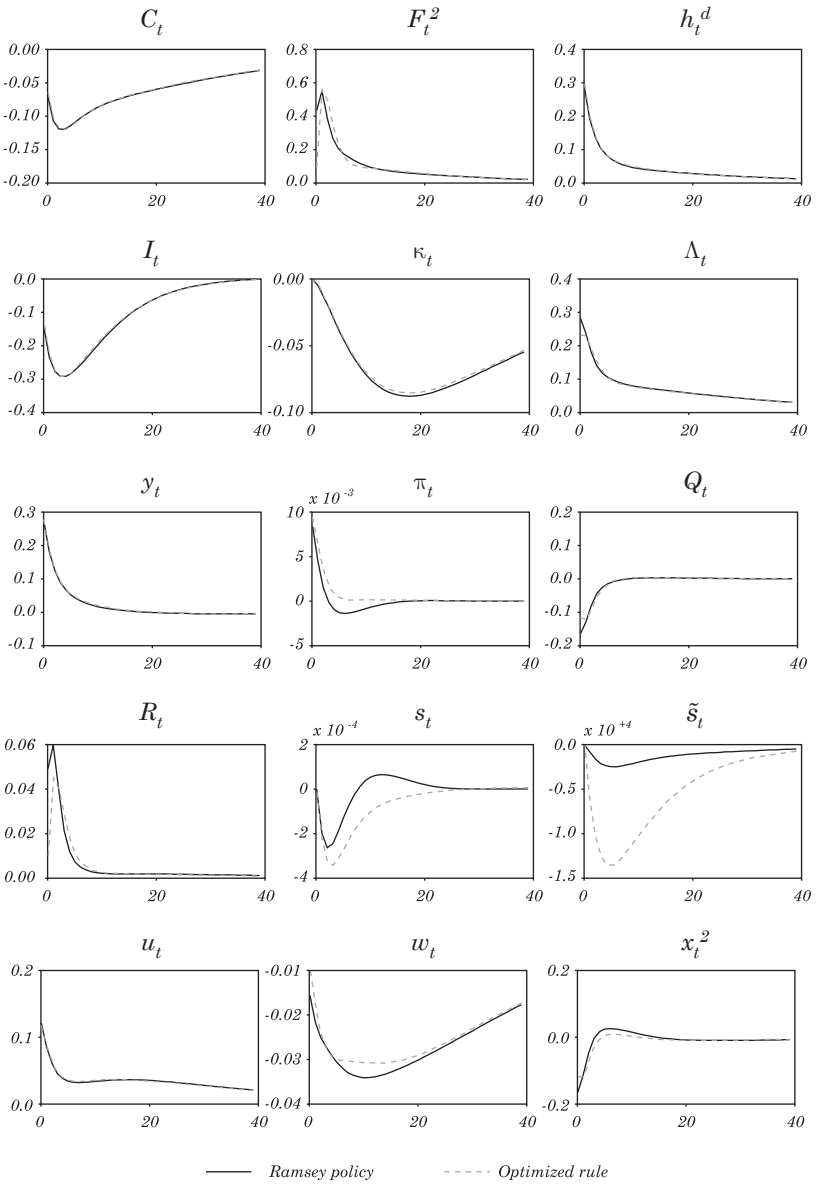
Source: Authors' computations.

Figure 9. Ramsey and Optimized Responses to a Neutral Productivity Shock



Source: Authors' computations.

Figure 10. Ramsey and Optimized Responses to a Government Purchases Shock



Source: Authors' computations.

5.2 Interest Rate Rules and Equilibrium Determinacy

For an interest rate feedback rule to be operational, we require that it induce a locally determinate rational expectations equilibrium. A natural question is what restrictions this requirement imposes on the values that the parameters defining the interest rate rule can take.

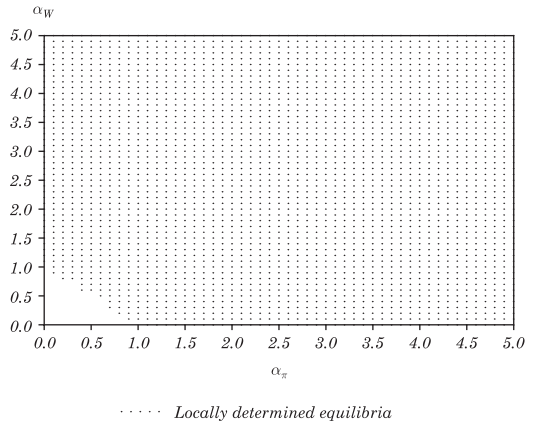
Figure 11 displays the values of the price- and wage-inflation coefficients (α_π and α_W) in the interest rate rule (49) for which the equilibrium is locally determinate. The remaining two policy parameters, α_y and α_R, associated with output growth and the lagged interest rate, are set to zero. To a first approximation, a condition for determinacy is that the sum of the price- and wage-inflation coefficients be greater than unity. The result that the inflation coefficient must be greater than unity for the equilibrium to be unique is easily established in small models with few frictions (see, for example, Leeper, 1991). It is of interest that the same principle applies to a much richer theoretical structure, such as the one studied here. Also noteworthy is the apparent perfect substitutability at the margin between the price- and wage-inflation coefficients in ensuring local uniqueness. In effect, at the southwest frontier of the uniqueness area the coefficients satisfy $\alpha_\pi + \alpha_W \approx 1$.

Local uniqueness of equilibrium is related to the long-run values of the inflation coefficients of the interest rate rule. In the example, the inertial term of the policy rule, α_R, is assumed to be nil. As a result, the short- and long-run values of the price- and wage-inflation coefficients coincide and are equal to α_π and α_W, respectively. Increasing the value of α_R to its optimal level of 0.4 results in a local-determinacy area defined by the relation $\alpha_\pi + \alpha_W > 0.6$. This result appears to generalize to other values of the interest rate coefficient. Thus the pattern that appears to emerge implies roughly a determinacy area defined by the relation $[\alpha_\pi + \alpha_W]/(1 - \alpha_R) > 1$. In other words, the long-run value of the price- and wage-inflation coefficients of the interest rate rule must add up to a number larger than unity for the equilibrium to be locally unique.

6. Discussion and Conclusion

The central focus of this study is the characterization and implementation of optimal monetary policy in the context of a rich model of the macroeconomy with parameters and sources of uncertainty estimated to fit observed fluctuations at business cycle frequency. The

Figure 11. Interest-Rate Feedback Rules and Equilibrium Determinacy



Source: Authors' computations.
Note: The policy parameters α_y and α_R are set to zero. All structural parameters take their baseline values, given in table 1.

central recommendation that emerges from the solution of the Ramsey optimization problem is that the central bank should aim at a low and highly stable rate of inflation. This prescription is very much in line with those proposed by advocates of inflation targeting.

At a deeper level, however, the inflation predictions of the Ramsey equilibrium are neither robust nor coincidental with inflation targeting principles. With respect to robustness, the Ramsey-optimal inflation target varies widely with the parameter determining the degree of price stickiness. For empirically plausible values of this parameter, the optimal inflation target ranges from the Friedman rule (that is, minus the real interest rate) to price stability. This apparent hypersensitivity of the optimal rate of inflation calls for an increased effort at obtaining tighter estimates of the amount of nominal sluggishness present in the economy.

An important difference between the predictions of the Ramsey equilibrium and the observed behavior of central banks adhering to inflation targeting regimes is that the Ramsey-optimal rate of inflation is negative (although possibly close to zero) whereas inflation targeters around the world set targets for the inflation rate that are significantly above zero. In the context of the estimated medium-scale model studied here, fear of confronting the zero bound on nominal interest rates can

hardly represent an impediment to adopting the Ramsey-optimal rate of inflation. In effect, in the Ramsey equilibrium the nominal interest rate takes an average value of about 4.5 percent a year, with a standard deviation of about 0.05 percent. It follows that the chances that a shock would push the nominal interest rate to zero are negligible.

This result poses a challenge for future researchers to find a theoretical explanation for the optimality of positive inflation targets. Some have argued that the presence of downward inflexibility in nominal prices and wages may provide a justification for setting positive inflation targets. Formalizations of this idea have been limited to highly stylized models. It remains to be seen whether medium-scale models incorporating a realistic degree of nominal downward rigidities can generate optimal inflation targets similar in magnitude to those observed across inflation-targeting countries.

The hypersensitivity of the optimal inflation target to the degree of price stickiness may disappear under certain fiscal arrangements. This is the case, for instance, when fiscal policy is also set optimally and the fiscal authority has access only to distortionary income taxes. Under alternative fiscal scenarios, however, the hypersensitivity may be exacerbated. This is the case, for instance, when the fiscal authority has access to a combination of distortionary and nondistortionary taxes but distortionary taxes are fixed (even if at the level prescribed by the Ramsey steady state), so that lump-sum taxes are used at the margin to achieve intertemporal solvency. The interaction between optimal fiscal and monetary policy in the context of medium-scale models requires much more research.

We limit attention to an economy driven by three shocks that have been shown to account for a sizable fraction of business cycles in the U.S. economy: neutral productivity shocks, investment-specific productivity shocks, and government spending shocks. Ideally, the study of optimal monetary policy would incorporate all of the sources of uncertainty that are important drivers of business cycles in the real world. This study is far from this theoretical desideratum.

Better models are needed, but there are no clear guidelines on how to create them. We are skeptical of the approach—recently adopted in some studies—of using the estimation residuals obtained from econometric estimations of the dynamic general equilibrium model as structural economic sources of uncertainty. In many instances, these estimation errors are hardly interpretable as structural economic shocks and are more likely a reflection of the fact that theory lags behind business cycles. The dimension of the challenge that the

presence of these "nonstructural" errors poses for macroeconomic theory is demonstrated by the fact that in most of the estimates of relatively large macroeconomic models, this class of shocks explains the majority of observed business cycle fluctuations.

Appendix
Deriving the Welfare Costs Measure

Consider the Ramsey policy, denoted by r, and an alternative policy regime, denoted by a. We define the welfare associated with the time-invariant equilibrium implied by the Ramsey policy conditional on a particular state of the economy in period 0 as $\tilde{V}_0^r = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^r - b c_{t-1}^r, h_t^r)$, where c_t^r and h_t^r denote the contingent plans for consumption and hours under the Ramsey policy. Using the particular functional form for the period utility function given in equation (47) and setting ϕ_3 to its baseline value of one, we can express the above expression in terms of the stationary transformation of consumption, C_t^r,

$$\tilde{V}_0^r = E_0 \sum_{t=0}^{\infty} \beta^t (1-\phi_4) \ln z_t^* + E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^r - b C_{t-1}^r / \mu_{z^*,t}, h_t^r).$$

Similarly, we define the conditional welfare associated with policy regime a as

$$\tilde{V}_0^a = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^a - b c_{t-1}^r, h_t^a),$$

which can be written in terms of the stationary transformation of consumption as follows

$$E_0 \sum_{t=0}^{\infty} \beta^t (1-\phi_4) \ln z_t^* + E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^a - b C_{t-1}^a / \mu_{z^*,t}, h_t^a).$$

Let $V_0^r \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^r - b C_{t-1}^r / \mu_{z^*,t}, h_t^r)$ so that

$$\tilde{V}_0^r = E_0 \sum_{t=0}^{\infty} \beta^t (1-\phi_4) \ln z_t^* + V_0^r, \text{ and let}$$

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^a - b C_{t-1}^a / \mu_{z^*,t}, h_t^a),$$

so that $\tilde{V}_0^a = E_0 \sum_{t=0}^{\infty} \beta^t (1-\phi_4) \ln z_t^* + V_0^a$.

Let λ^c denote the welfare cost of adopting policy regime a instead of the Ramsey policy, conditional on a particular state in period zero. We define λ^c as the fraction of regime r's consumption process that a

household would be willing to give up to be as well off under regime a as under regime r. It follows that λ^c is implicitly defined by

$$\tilde{V}_0^a = E_0 \sum_{t=0}^{\infty} \beta^t U((1-\lambda^c)(c_t^r - bc_{t-1}^r), h_t^r).$$

Using the definitions given above, this expression can be written as

$$V_0^a = V_0^r + \frac{(1-\phi_4)}{(1-\beta)} \ln(1-\lambda^c). \tag{50}$$

We restrict attention to an approximation of λ^c that is accurate up to second order. In equilibrium, V_0^a and V_0^r are functions of the initial state vector x_0 and the parameter σ_ε scaling the standard deviation of the exogenous shocks (see Schmitt-Grohé and Uribe, 2004c). Therefore, we can write $V_0^a = V^{ac}(x_0, \sigma_\varepsilon)$ and $V_0^r = V^{rc}(x_0, \sigma_\varepsilon)$. This implies that λ^c must be a function of x_0 and σ_ε as well $\lambda^c = \Lambda^c(x_0, \sigma_\varepsilon)$.

Consider a second-order approximation of the function Λ^c around the point $x_0 = x$ and $\sigma_\varepsilon = 0$, where x denotes the deterministic Ramsey steady state of the state vector. Because we wish to characterize welfare conditional on the initial state being the deterministic Ramsey steady state, in performing the second-order expansion of Λ^c only its first and second derivatives with respect to σ_ε have to be considered. Formally, we have

$$\lambda^c \approx \Lambda^c(x,0) + \Lambda^c_{\sigma_\varepsilon}(x,0)\sigma_\varepsilon + \left(\frac{\Lambda^c_{\sigma_\varepsilon\sigma_\varepsilon}(x,0)}{2}\right)\sigma_\varepsilon^2.$$

Because the deterministic steady-state level of welfare is the same across all monetary policies belonging to the class defined in equation (49), it follows that λ^c vanishes at the point $(x_0, \sigma_\varepsilon) = (x, 0)$. Formally, $\Lambda^c(x,0) = 0$. Totally differentiating equation (50) with respect to σ_ε, evaluating the result at $(x_0, \sigma_\varepsilon) = (x, 0)$, and using the result derived in Schmitt-Grohé and Uribe (2004c) that the first derivatives of the policy functions with respect to σ_ε evaluated at $(x_0, \sigma_\varepsilon) = (x, 0)$ are nil ($V^{ac}_{\sigma_\varepsilon} = V^{rc}_{\sigma_\varepsilon} = 0$), it follows immediately that $\Lambda^c_{\sigma_\varepsilon}(x,0) = 0$. $(x,0) = 0$. Totally differentiating (50) twice with respect to σ_ε and evaluating the result at $(x_0, \sigma_\varepsilon) = (x, 0)$ yields $\Lambda^c_{\sigma_\varepsilon\sigma_\varepsilon}(x,0) = (1-\beta/1-\phi_4)[V^{rc}_{\sigma_\varepsilon\sigma_\varepsilon}(x,0) - V^{ac}_{\sigma_\varepsilon\sigma_\varepsilon}(x,0)]$. Thus the conditional welfare cost measure is given by

$$\lambda^c \approx \left(\frac{1-\beta}{1-\phi_4}\right)[V^{rc}_{\sigma_\varepsilon\sigma_\varepsilon}(x,0) - V^{ac}_{\sigma_\varepsilon\sigma_\varepsilon}(x,0)]\frac{\sigma_\varepsilon^2}{2}. \tag{51}$$

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Optimal Inflation Targeting: Further Developments of Inflation Targeting

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Inflation targeting was first introduced in 1990, in New Zealand. Since then it has been adopted by more than twenty countries. This period of fifteen years has seen major progress in practical monetary policy. In particular, the practice of inflation targeting has led to a more systematic and consistent internal decision process (Brash, 2000; Sims, 2002; Svensson 2001a); much more transparent communication with the private sector (Blinder and others, 2001; Fracasso, Genberg, and Wyplosz, 2003; Leeper, 2003); and an unprecedented degree of accountability. The monetary and real stability achieved is exceptional from a historical perspective (King, 2002).

Given this progress, many might think that further improvement is hardly possible, and that monetary policy bliss, or something very close to it, may have been reached. I believe that there is still room for further development and improvement, even though past achievements by inflation-targeting central banks have been very impressive. This paper provides a very selective discussion of points on which I believe further improvements are both possible and desirable.

Good inflation targeting shares these characteristics:

- An explicit monetary policy objective in the form of a numerical inflation target, now with an increasingly explicit concern not

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only about stability of inflation around the target but also about stability of the real economy. The target variables under inflation targeting include both inflation and a real variable, such as the output gap.[1]

- An internal decision process—"forecast targeting"—in which projections of the target variables have a prominent role and the central bank sets the instrument rate such that the forecast of the target variables "looks good" relative to the monetary policy objective.[2]
- A very high degree of transparency and accountability, with the central bank typically publishing its internal projections and providing detailed motivations of them and of its instrument-rate decisions, in order to both implement the policy effectively and allow detailed external scrutiny of the bank's performance.

I believe that further improvements are possible and desirable on all three points. With regard to the first point, the monetary policy objective—that is, the inclusion of not only an inflation stability objective but also an objective of stabilizing the real economy—has been called "flexible" inflation targeting.[3] Inflation-targeting central banks normally acknowledge in different ways that they are flexible inflation targeters.[4] However, they are not very explicit and transparent and probably not very consistent about the relative weight they attach to stability of variables other than inflation. They may not be very consistent about intertemporal substitution between the target variables either. Some refer to a fixed horizon, such as eight quarters, by which the inflation target shall be met, but a fixed horizon is easily shown not to be appropriate for most circumstances (Faust and Henderson, 2004). I believe specifying operational objectives in terms of an explicit intertemporal loss function—initially for internal use within the central bank, later, after a trial period, to be published—is an easy way to make substantial progress in this regard.

1. By *target variables*, I mean the variables that are arguments of the central bank's explicit or implicit loss function.

2. By *instrument rate*, I mean the short-term nominal interest rate that the central bank is using as an instrument or operating target.

3. The terms *flexible* and *strict* inflation targeting were to my knowledge first introduced in a paper of mine presented at a conference at the Bank of Portugal in 1996, later published as Svensson (1999).

4. Norges Bank (the Bank of Norway) is a model of transparency in this respect (and many others): Each Inflation Report contains the statement "Norges Bank operates a flexible inflation targeting regime, so that weight is given to both variability in inflation and variability in output and employment." Norges Bank also puts the inflation forecast and the output gap forecast in the same graph, in order to emphasize both.

With regard to the second point, the internal decision process, the instrument-rate assumption under which projections of the target variables are made has received considerable attention. Several central banks have used the assumption of a constant instrument rate during the entire forecast horizon. This assumption is very problematic for several reasons (see Archer, 2004; 2005; Bean, 2003; Goodhart, 2001; Heikensten, 2005; Honkapohja and Mitra, 2005; Leitemo, 2003; Lomax, 2005; Svensson, 2003a; Woodford, 2005). A few central banks have shifted to the assumption of an instrument-rate path given by market expectations of future instrument rates. This is a considerable improvement but is arguably not the best alternative.

Furthermore, central banks normally make explicit decisions and announcements only about the current instrument rate (the instrument rate for the next month or two) and its level during the period until the next monetary policy decision. However, the current instrument rate matters very little for the central banks' internal projections. What matters for those projections is the entire instrument-rate path assumed.

Similarly, the current instrument rate matters very little for private sector decisions and the economy. What matter are private sector expectations about the entire future path of the instrument rate. These expectations feed into the yield curve and thereby longer-term interest rates and asset prices, which do affect private sector decisions. The current central bank decision and announcement actually matter only to the degree that they affect private sector expectations of the path of future instrument rates. This means that when the central bank decides on a particular current instrument-rate level, it implicitly decides on and announces an expected future instrument-rate path, an instrument-rate plan. For these reasons I believe that substantial progress can be made if central banks explicitly think in terms of entire instrument-rate plans and corresponding projections of target variables and develop a decision process in which the central bank explicitly chooses such an instrument plan. Indeed, the decision process should be designed so as to end with an optimal instrument-rate plan and a corresponding optimal projection of the target variables—a projection of the instrument rate and the target variables that minimizes the central bank's loss function.

With regard to the third point, the high degree of transparency and accountability, inflation-targeting central banks typically publish their internal projections of their target variables (although some may publish projections of output or output growth rather than the

output gap). Since these projections are normally based on an assumed instrument-rate path that differs from the optimal instrument-rate plan (especially if there is no explicit optimal instrument-rate plan), the resulting projections are not the best forecasts, in the sense of minimizing expected squared forecast errors. The projections are biased one way or another. Hence they are not the best information for the private sector. Since monetary policy has an impact on the economy via the private sector expectations of inflation, output, and interest rates that it gives rise to, announcing the optimal projection (including the instrument-rate projection) and the analysis behind it would have the greatest impact on private sector expectations and be the most effective way to implement monetary policy. Since the optimal projection is the best forecast, in the sense of minimizing expected squared forecast errors, it also provides the private sector with the best aggregate information for making individual decisions. Announcing the optimal projection also allows the most precise and sophisticated external evaluation of the monetary policy framework and decisions. For these reasons I believe that substantial progress can be made if inflation-targeting central banks publish and explain optimal projections, including the optimal instrument-rate plan. The Reserve Bank of New Zealand has been doing this since 1997; Norges Bank, the central bank of Norway, has been doing so since 2005.

In short, I believe that inflation-targeting central banks can make substantial progress by being more specific, systematic, and transparent about their operational objectives (by using an explicit intertemporal loss function), their forecasts (by deciding on optimal projections of the instrument rate and the target variables), and their communication (by announcing optimal projections of the instrument rate and target variables).

Substantial progress can also be made regarding the systematic use of central bank judgment—that is, information, knowledge, and views beyond the scope of a particular model. Although formal models are very useful in practical monetary policy, they are drastic simplifications of a complex economy. Judgment will always be necessary. The challenge is to apply good judgment in a disciplined and systematic way rather than in a completely discretionary and ad hoc way. Svensson (2005b) discusses in greater detail how central bank judgment can be incorporated into optimal projections in a consistent way. Svensson and Tetlow (2005) describe a practical way to do so, the method of optimal policy projections, which is to some extent in use at the Federal Reserve Board.

Monetary policy is always conducted under substantial uncertainty. As long as the uncertainty is mainly in the form of exogenous additive shocks, the combination of linear models and quadratic loss functions implies that certainty equivalence holds and that projections in the form of probability means are sufficient for optimal policy. When certainty equivalence is violated—for instance, because the uncertainty is multiplicative and not just additive—mean projections are no longer sufficient for optimal policy. In this case the entire probability distribution of future random target variables matters. Svensson and Williams (2005) develop a flexible and powerful but still tractable framework for optimal monetary policy under quite general form model uncertainty that allows simple multiplicative uncertainty as well as more complex structural model uncertainty. Although certainty equivalence is violated, forecast targeting can still be undertaken, with the projections probability distributions rather than mean projections. The decision process can then be seen as distribution forecast targeting rather than mean forecast targeting.[5] A systematic approach to model uncertainty and distribution forecast targeting is another area in which substantial progress in inflation targeting can be made.

The next section discusses how an explicit intertemporal loss function can be introduced and used by a central bank. Section 2 discusses the instrument-rate assumption. Section 3 discusses transparency and communication issues. Section 4 discusses how central bank judgment can be incorporated in a systematic way. Section 5 discusses model uncertainty and distribution forecast targeting. Section 6 briefly examines optimization under commitment, the timeless perspective, and discretion. Section 7 briefly examines the output gap, the potential output, the interest-rate gap, and the neutral interest rate. Section 8 presents some conclusions. The appendix contains technical material on the loss function and the interest-rate gap.

1. The Loss Function

All real world inflation targeting is flexible. Flexible inflation targeting means that monetary policy objectives include not only stability of inflation around the inflation target but also stability of the real economy, such as the stability of the output gap.[6]

5. The terms mean forecast targeting and distribution forecast targeting were, to my knowledge, introduced in Svensson (2001b).

6. "Strict" inflation targeting, when the central bank is concerned exclusively about inflation, is an abstraction that is sometimes used in pedagogical examples.

Although inflation-targeting central banks normally acknowledge that they are flexible inflation targeters, they are normally not very explicit or transparent—and probably not very consistent— about the relative weights they attach to the stability of variables other than inflation. They may not be very consistent about the intertemporal substitution between the target variables either. Some central bankers refer to a fixed horizon, such as eight quarters, over which the inflation target shall be met, but a fixed horizon is easily shown to be inappropriate for most circumstances (Faust and Henderson, 2004). Some state that they have a medium-term objective, without specifying what this means.

The most direct way to resolve this ambiguity and lack of transparency is to specify an explicit intertemporal loss function as the operational objective for the central bank. This clarifies what the target variables are and what relative weights they have. It clarifies both intra- and intertemporal substitution between levels and stability of the target variables and allows an unambiguous ranking of alternative projections of the target variables.

Flexible inflation targeting implies that the central bank is not concerned exclusively about stabilizing inflation around the inflation target but is also concerned with the stability of the real economy, as represented by the output gap, the employment gap, or the unemployment gap.[7] This can conveniently be expressed as a conventional quadratic loss function,

$$L_t \equiv (\pi_t - \pi^*)^2 + \lambda x_t^2, \tag{1}$$

where L_t denotes the period loss in period t (where the period may be a quarter, for instance); π_t denotes a measure of inflation in period t; π^* denotes the inflation target; x_t denotes a measure of the output gap in period t; and $\lambda > 0$ denotes the relative weight on output-gap stabilization relative to inflation stabilization.[8] The central bank may also be concerned about the variability of instrument-rate changes or exchange-rate changes, which would correspond to additional terms $\lambda_{\Delta i}(i_t - i_{t-1})^2$ or $\lambda_{\Delta i}(s_t - s_{t-1})^2$, where i_t denotes the instrument rate

7. I use the output gap (the difference between output and potential output) as the generic variable representing the business cycle status of the economy. The unconditional mean of the output gap is taken to be zero.

8. The index of inflation, π_t, can be quarterly inflation, four-quarter inflation, or an average of inflation over a longer period (Nessén and Vestin, 2005).

and s_t denotes the (log) exchange rate in period t. In this case the instrument rate or the exchange rate are also target variables.[9]

The corresponding intertemporal loss function in period t can then be written as the sum of current and expected discounted future losses,

$$\mathrm{E}_t \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau}, \tag{2}$$

where E_t denotes central bank expectations conditional on information available in period t and δ is a discount factor that fulfills $0 < \delta \leq 1$.[10] Whereas the period loss function and the weight λ express the substitution between inflation and output-gap variability within a given period, the intertemporal loss function and the discount factor δ express the substitution between expected losses in different periods.

Let $\pi_{t+\tau,t}$ and $x_{t+\tau,t}$ for $\tau \geq 0$ denote (mean) projections in period t of inflation and the output gap τ periods ahead, respectively, and let $\pi^t \equiv (\pi_{t,t}, \pi_{t+1,t}, \ldots)$ and $x^t \equiv (x_{t,t}, x_{t+1,t}, \ldots)$ denote (mean) projections in period t of the current and future inflation and output gaps, respectively. That is, $\pi_{t+\tau,t}$ and $x_{t+\tau,t}$ denote the projection in period t of inflation and the output gap in period $t + \tau$, whereas π^t and x^t denote the entire projection paths of current and future inflation and output gap.

Let $L_{t+\tau,t}$ denote the period loss associated in period t with the projections $\pi_{t+\tau,t}$ and $x_{t+\tau,t}$ of inflation and the output gap for period $t + \tau$,

$$L_{t+\tau,t} \equiv (\pi_{t+\tau,t} - \pi^*)^2 + \lambda x_{t+\tau,t}^2, \tag{3}$$

and let $\mathcal{L}(\pi^t, x^t)$ denote the intertemporal loss associated in period t with the entire projection paths π^t and x^t of inflation and output gap,

$$\mathcal{L}(\pi^t, x^t) = \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau,t}\ . \tag{4}$$

Once the two parameters δ and λ have been determined, the intertemporal loss function $\mathcal{L}(\pi^t, x^t)$ provides a convenient and consistent way to rank different inflation and output-gap projections. Suppose that the central bank staff presents the monetary policy committee with two different instrument-rate plans, which result in

9. Rudebusch (2005) surveys recent work on instrument-rate smoothing. Woodford (2003) and Svensson (2003c) provide further discussion of interest rates as target variables.

10. When $\delta = 1$, the loss function (2) should be interpreted as the limit (from below) $\lim_{\delta \to 1} (1-\delta) E_t \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau}$ in order to ensure convergence (see appendix).

two different projections of inflation and the output gap.[11] Suppose that the first instrument-rate plan results in the projection (π^{t1}, x^{t1}) and that the second instrument-rate plan results in the projection (π^{t2}, x^{t2}). Which instrument plan should the monetary policy committee choose? If the parameters δ and λ correspond to the monetary policy committee's preferences, it should simply choose the instrument plan that results in the inflation and output-gap projection with the lowest loss. Suppose that $\mathcal{L}(\pi^{t1}, x^{t1}) < \mathcal{L}(\pi^{t2}, x^{t2})$. Then the monetary policy committee should choose the first instrument-rate plan and associated inflation and output projections.

How can the monetary policy committee determine the parameters δ and λ? A discount factor δ equal to one implies that the loss in future periods has the same weight as current losses. My guess is that most committee members would agree that a discount factor equal to or close to one is appropriate, given the frequent emphasis on the medium and long run and a desire to avoid myopia. Then only λ remains to be determined.

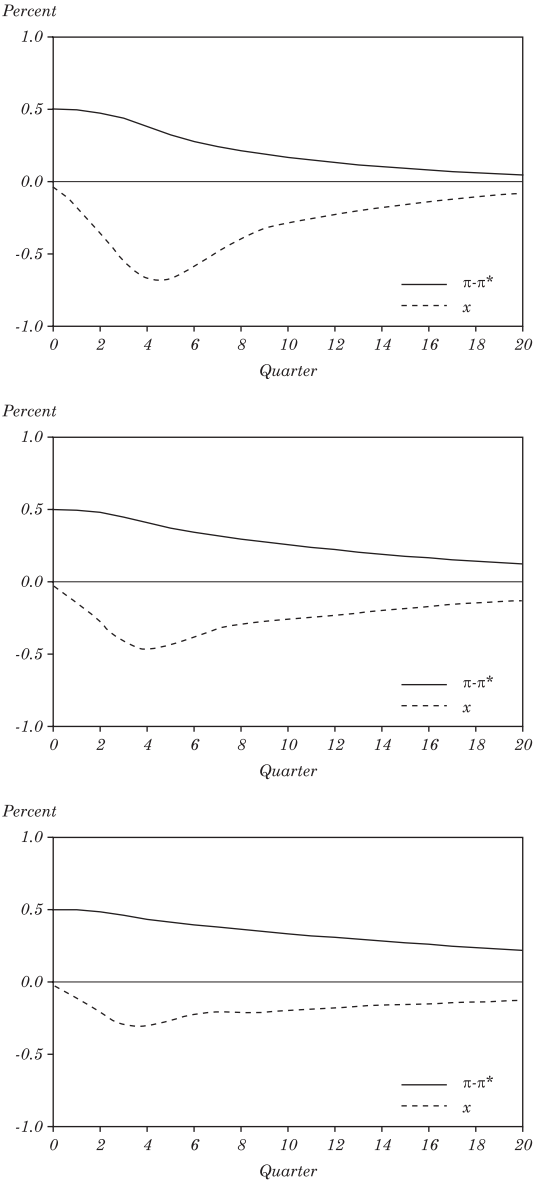
The monetary policy committee can determine λ explicitly or implicitly in several ways. It can determine λ explicitly by majority voting. In this case, by the median voter theorem, the resulting λ will be the median of the distribution of the committee members' individual λs. This is a convenient and practical way of aggregating the committee members' preferences. Majority voting has the general advantage that single extreme views do not affect the outcome, since outliers normally do not affect the median.

If committee members need help determining their individual λs, the λs can be determined implicitly through revealed preference experiments. For instance, suppose a committee member chooses the preferred combination of inflation and output-gap projections among a few alternatives. This choice then reveals the range of implicit λs for which that choice is preferred. Suppose that committee members are presented with the three alternative combinations of inflation gap and output-gap projections shown in figure 1 (where the inflation gap is the deviation from a fixed inflation target) and asked to choose the alternative they prefer. This choice would narrow the range of λs consistent with their choice.[12]

11. I use *monetary policy committee* as the generic term for the monetary policy decisionmaking body of the central bank, including when the bank has a single decisionmaker.

12. The figures are plotted for the Rudebusch-Svensson model in Svensson (2005b), with the same initial situation of a steady zero output gap, a steady 0.5 percentage point inflation gap, and three different values of λ. For two given policy alternatives, (π^{t1}, x^{t1}) and (π^{t2}, x^{t2}), if the monetary policy committee prefers one alternative, one can determine the range of λs for which that alternative gives lower intertemporal loss.

Figure 1. Projected Inflation and Output Gaps Given Alternative Weights on Output-Gap Stabilization



Source: Svensson (2005b).
Note: The solid line shows the inflation gap ($\pi - \pi^*$). The dashed line shows the output gap (x).

The λ can also be determined implicitly over time, revealed by the policy decisions the committee makes. To many committee members, this may be the most natural way to determine λ. If the central bank staff present the monetary policy committee with a few policy alternatives at each decision point (where each policy alternative consists of an inflation path, an output-gap path, and an interest rate path), the selected policy alternatives will over time narrow the range of λs consistent with the committee's decisions. It will also reveal whether the λs seem to be constant over time or time varying.

If the central bank puts weight on instrument-rate smoothing or exchange rate smoothing, the parameters $\lambda_{\Delta i}$ and $\lambda_{\Delta s}$ also need to be determined. If the committee members do not agree that the discount factor δ is equal to unity, they can vote about the discount factor, too, in which case the resulting discount factor will be the median of their individual discount factors.

Using an explicit intertemporal loss function such as (4) has several advantages:

- An explicit intertemporal loss function clarifies what the target variables are and resolves in an unambiguous way the intra- and intertemporal substitution between them. One projection of inflation and the output gap may have a negative output gap in the near future and lower inflation in the more distant future, whereas another may have a less negative output gap in the near future and higher inflation in the more distant future. The intertemporal loss function provides a consistent ranking of the two projections. The loss function makes clear that the entire projection path of the target variables matters, not just the projections at some particular horizon. It thus avoids the tendency to put weight on a particular horizon, such as eight quarters (see Faust and Henderson, 2004 and Heikensten, 1999).
- A loss function clarifies the unnecessary and unhelpful distinction between a "dual" and a "hierarchical" mandate (see Meyer, 2004 and Svensson, 2004); removes any ambiguity about the degree of flexibility in inflation targeting (for instance, in the debate on inflation targeting for the Federal Reserve; Kohn, 2003), and clarifies the appropriate role of asset prices and concerns about bubbles in inflation targeting (Bean, 2003).
- The monetary policy committee has to make choices between different projection combinations in any case; using an intertemporal loss function avoids other inconsistent and ad hoc ways of making such choices.

- It is important to realize that a loss function does not require that projections be made with a model; the loss function can be used to rank purely judgmental projections.
- The loss function can be seen as a necessary operational interpretation of a legislative mandate or government instruction, which is usually too vague to provide precise guidance to consistent policy in particular policy situations. Such an operational interpretation is already needed for the inflation target in some countries (such as Sweden and countries in the euro zone), where the institutional arrangement for monetary policy leaves the central bank in charge of deciding on the number and index for the inflation target.
- The parameters of the loss function have clear intuitive meaning. The discount factor δ represents the substitution between period losses in different periods: the weight of a period loss in one period relative to the period loss one period earlier. The weight λ can be interpreted as the weight on variability of the output gap relative to variability of inflation, so $\lambda = 1$ implies that the monetary policy committee is equally concerned with the variability of the output gap as with the variability of inflation (see the appendix).
- The monetary policy committee can add any target variables that it is concerned about with corresponding weights. Thus, it can include instrument-rate and/or exchange-rate smoothing and/or stabilization; unemployment-gap stabilization; or output-growth gap stabilization. (Mentioning these possibilities does not imply that I endorse them.)
- The monetary policy committee can use a loss function of other forms than the quadratic if it believes another loss function better represents its objectives.[13] (However, the quadratic loss function has many advantages. It can be seen as a second-order approximation to a more general loss function, its symmetry seems natural in an era in which both inflation and deflation are undesirable, and it is easy to use in optimization exercises.)
- If the monetary policy committee would prefer not to specify a loss function for some time, the staff can still provide it with optimal projections for a reasonable set of alternative parameters of the loss function. This set of optimal projections for different parameters then forms the set of efficient feasible projections from

13. Bray and Goodhart (2002) and Svensson (2003b) discuss other functional forms. Ruge-Murcia (2003) discusses inflation targeting with asymmetric preferences.

which the monetary policy committee should choose its preferred alternative.

- The monetary policy committee can experiment with internal uses of alternative loss functions and go public about any loss function at a later stage, when it has decided which loss function to use and the approach has proved useful.
- Eventually going public about the loss function will increase the transparency of monetary policy, improve precision and consistency in the evaluation of monetary policy, and increase accountability. It may also bring better public understanding of the substitutions and tradeoffs involved.

Consequently, I believe that specifying operational objectives in terms of an explicit intertemporal loss function is an easy way to significantly improve inflation targeting.[14]

2. The Instrument-Rate Projection

Because of lags in the transmission mechanism between monetary policy actions and effects on the economy and the target variables, good monetary policy must be forward looking and rely on projections of the target variables. Before it makes its instrument-rate decision, the monetary policy committee is normally presented with a number of alternative projections of the target variables,

14. Mishkin (2004) summarizes his arguments against central banks announcing a loss function—and implicitly also against central banks using one. (My counterarguments in parentheses.) Argument: It may be difficult for monetary policy committee members to specify a loss function, let alone to agree on a loss function. (I have already mentioned simple procedures to specify and agree on a loss function.) Argument: It is far from clear who should decide on the loss function. (The loss function can always be seen as a necessary operationalization of the central bank's mandate.) Argument: It may be difficult to communicate a loss function to the public. (Even a very precise statement like "a weight on output gap stabilization equal to half the weight on inflation stabilization" does not seem incomprehensible for an educated general public.) Argument: Announcing a positive weight on output gap stabilization may lead to more aggressive private sector price and wage increases. (There is no evidence of such increases after Norges Bank became more explicit about output gap stability, and Norway has powerful trade unions!) Argument: Announcing a positive weight on output gap stabilization will require the central bank to publish estimates of the output gap and potential output, and a conceptually correct estimation of potential output is difficult. (True, but such estimation is necessary for good policy. Difficulty is not a good argument in this context. It is difficult to provide inflation forecasts. This is no longer—if it ever was—a valid argument against publishing them. Before the introduction of inflation targeting in New Zealand, I am sure almost every central banker thought that the current standard of transparency would be impossible to achieve, and many probably thought it would be potentially harmful even if it could be achieved.)

conditional on alternative assumptions about the state of the economy, the development of various exogenous variables, the transmission mechanism, and so forth. These projections are conditional on some assumption about the instrument-rate path.

The decision process results in a decision about the level of the instrument rate for the immediate future. Implicitly or explicitly, however, this decision is actually about an instrument-rate plan. The optimal instrument-rate plan is the plan that results in an optimal projection of the target variables, the projection that minimizes the intertemporal loss function. This projection is also the best forecast, in the sense of minimizing expected squared forecast errors.[15]

2.1 The Instrument-Rate Assumption Underlying Projections of the Target Variables

Traditionally, several inflation-targeting central banks have used projections based on an assumption of a constant instrument rate over the forecast horizon. If, everything else equal, the inflation projection is higher (lower) than the inflation target at some given horizon, usually about eight quarters, this has been interpreted as indicating that sooner or later the instrument rate needs to be raised (lowered).

There are numerous problems with the constant instrument-rate assumption.[16] These include:

- A constant instrument rate is often unrealistic. This implies that the resulting projection of inflation and the output gap is unrealistic and not the best forecast of future inflation and the output gap. This in turn makes it difficult and misleading to compare these

15. I use the following terminology: *Feasible projections* (or the set of feasible projections) are the (mean) projections of the instrument rate and the target variables that are consistent with the central bank's information, more specifically, its estimate of the state of the economy, view of the transmission mechanism, and forecast of exogenous variables. The *optimal projection* is the central bank's preferred feasible projection of the instrument rate and the target variables—that is, the feasible projection that best achieves the central bank's objective. More specifically, the optimal projection is the feasible projection that minimizes the central bank's intertemporal loss function. The best forecast is the projection that best predicts the actual future path of the variables in question, more precisely, the projection that minimizes expected squared forecast errors. A *conditional forecast* is a projection that minimizes expected squared forecast errors subject to some particular assumption, such as a particular path of the instrument rate. The *unconditional forecast* is the best projection given available information, including information about monetary policy. The unconditional forecast is the best forecast.

16. See Archer (2004, 2005); Bean (2004); Goodhart (2001); Heikensten (2005); Honkapohja and Mitra (2005); Leitemo (2003); Lomax (2005); Svensson (2003a); and Woodford (2005) for discussions of these problems.

projections to those of other forecasters, which normally assume more realistic underlying instrument-rate paths. It also makes it difficult and misleading to compare the projections to actual outcomes and in this way to assess the forecast performance of the central bank.

- A constant instrument rate often differs from market expectations of future interest rates. Current asset prices (exchange rates, stock market prices, bond prices, housing prices, and so forth) depend on these market expectations. Typically, the current market prices of these assets are used as inputs in central bank projections rather than the hypothetical asset prices that would result if market participants actually expected a constant instrument rate. Hence the central bank projections end up using many inputs that are inconsistent with the constant instrument rate, making the projections inherently inconsistent and misleading. Put differently, they are not consistent constant instrument-rate projections but a mixture of projections based partly on the constant instrument rate, partly on market expectations of future interest rates.
- When market expectations of future interest rates differ from the constant instrument rate, central banks typically would not like market expectations of future interest rates to adjust toward the constant instrument rate. If that happens, it may result in drastic and unwelcome changes in asset prices. Hence central banks using constant instrument-rate projections would normally not like the private sector to take the constant instrument-rate assumption seriously.
- For a constant instrument rate, most projection models are unstable, and the inflation and output-gap projections tend to increase or decrease at an increasing rate with a longer horizon, making longer-term projections more or less useless. This has induced central banks to avoid plotting such projections for longer horizons, in order not to display the problems with constant instrument-rate projections too openly. Projection models with forward-looking variables are normally not even determinate for a constant instrument rate. Determinacy is restored by the assumed shift to some endogenous instrument setting in the form of an ad hoc reaction function beyond the forecast horizon. That shift is often associated with a drastic and awkward jump in the instrument rate, and the projection for shorter horizons depends on the assumed future endogenous policy. Alternatively, the projection model assumes that the instrument rate follows some determinacy-

inducing ad hoc reaction function, but unanticipated shocks to the instrument rate make it constant for many quarters.[17]

For these reasons the constant instrument-rate assumption for projections is inherently problematic and confusing. Since there are better alternatives, it should be abandoned sooner rather than later. Several central banks, including Norges Bank, the Bank of England, Sveriges Riksbank, and the European Central Bank, have abandoned the constant instrument-rate assumption. The Reserve Bank of New Zealand has used projections based on a time-varying instrument rate since 1997.

A first alternative to a constant instrument rate is market expectations of future instrument rates, normally identified with forward interest rates implied by the yield curve. The Bank of England, the Riksbank, and the European Central Bank use market expectations of future interest rates for their projections. Market expectations of future interest rates are usually more realistic than the constant instrument rate, depending on the market's understanding and prediction of future instrument-rate decisions. This makes projections based on them better forecasts of future instrument-rate decisions than constant instrument-rate projections. Moreover, since current asset prices are conditional on market expectations of future interest rates, using current asset prices as inputs in the projections does not cause any apparent inconsistency, in contrast to the case for constant instrument-rate projections.

Using market expectations of future interest rates may be problematic, however, if these expectations are peculiar in some way or deviate substantially from the central bank's preferred instrument plan—a situation that would indicate either a credibility problem or differences between the private sector's and the central bank's views of the state of the economy or the transmission mechanism. In such situations the central bank may want to use ad hoc adjustments of the instrument-rate projection implied by market expectations of future interest rates. Furthermore, market expectations of future interest rates would not normally be identical to the central bank's explicit or implicit instrument plan; the projections based on them would therefore normally not be the best forecast, the forecast that minimizes

17. See Leeper and Zha (forthcoming) for a formalization of this idea with an estimated reaction function. In practice the shocks are assumed to be unanticipated and not to affect market expectations, although they will be serially correlated for many quarters.

expected squared forecast errors.[18] Woodford (2005) provides more detailed criticism of market expectations of future interest rates.[19]

A second alternative for the instrument-rate assumption is an ad hoc reaction function for the instrument rate, such as a Taylor-type rule. Such an assumption results in projections in which inflation eventually approaches the inflation target and the output gap eventually approaches zero. The resulting instrument-rate projections will generally differ from market expectations of future interest rates. (To the extent that the projections are published and interpreted by the private sector as good forecasts of future instrument rates, they may bring market expectations of future interest rates closer to that instrument-rate projection.) The resulting projections of the target variables will generally not minimize an intertemporal loss function, and there is no reason why the instrument-rate projections will be good forecasts of the central bank's actual instrument-rate setting. The resulting projections are to some extent arbitrary.[20] However, if the reaction function used is an estimate of previous policy by the central bank, the resulting projections can be interpreted as those

18. Although private sector expectations are a natural and important input in central bank projections, it is important that they be only one set of inputs among many and that the central bank does not respond mechanically to private sector expectations that in turn depend on the central bank's response. As Woodford (1994) and Bernanke and Woodford (1997) show, a mindless and mechanical response to private sector expectations may lead to indeterminacy and a loss of the nominal anchor.

19. One particular problem emphasized by Woodford (1994) is that an exogenous instrument-rate path—whether it is constant, given by market expectations, or the optimal path—may imply multiple or unstable equilibria in models with forward-looking variables. The technical reason for such a problem is that the set of reduced-form eigenvalues violates the so-called saddlepoint property, namely that the set of eigenvalues with modulus above unity must be exactly equal to the number of nonpredetermined variables. The usual solution to this problem is to specify a reduced-form reaction function in which the instrument rate responds to endogenous variables and the corresponding reduced-form eigenvalues satisfy the saddlepoint property. However, as Svensson and Woodford (2005) show, any such exogenous instrument-rate path can be combined with a commitment to a specific "out-of-equilibrium" response by the central bank to restore a unique and stable equilibrium. For instance, if inflation deviates ex post from and exceeds the equilibrium value consistent with the instrument-rate projection, the instrument rate would be increased more than one-to-one with inflation. More generally, these out-of-equilibrium commitments can be constructed in the form of an instrument-rate response to violations of the first-order condition for optimal policy, the optimal targeting rule. This can be done so that the right reduced-form eigenvalue configuration is created. In this case, in equilibrium no out-of-equilibrium response will be observed, and the instrument rate and the equilibrium will be consistent with the exogenous instrument-rate path.

20. See Svensson (2003a) for a more general critique of simple instrument rules such as Taylor rules.

resulting from "policy as usual" (Berg, Jansson, and Vredin, 2004; Jansson and Vredin, 2003). Essentially, the projections would be analogous to vector autoregression forecasts.[21] The Reserve Bank of New Zealand uses an ad hoc reaction function in its forecast and policy system (discussed in Archer, 2004, 2005; Svensson, 2001a). However, the resulting instrument-rate path is subject to considerable adjustment that reflects judgment and policy preferences and makes it for practical purposes similar to an optimal instrument-rate plan (Archer, 2005).[22]

A third alternative is to use optimal instrument-rate projections, that is, instrument-rate projections for which the resulting projections of the target variables minimize an intertemporal loss function. The staff can present optimal projections of target variables and the instrument rate for alternative parameter values of the loss function and alternative scenarios. This can be done in several ways, incorporating judgment, as discussed in Svensson (2005b). Svensson and Tetlow (2005) describe the method of optimal policy projections, a variant of which is being used by the Federal Reserve Board.[23] If the monetary policy committee agrees on an intertemporal loss function, the staff can present it with optimal projections for that loss function for different scenarios (different assumptions about the state of the economy, forecasts of exogenous variables, and the transmission mechanism, for instance). If the monetary policy committee does not agree on a loss function or does not use a particular loss function, the staff can still present the relevant tradeoffs for different policy choices—the set of efficient feasible projections—by presenting projections for a few different parameters of the loss function. If the monetary policy committee chooses policy in line with this, the resulting projection will be the best forecast, in the sense of minimizing expected squared forecast errors.

As mentioned, since 1997 the Reserve Bank of New Zealand has relied on a time-varying instrument-rate projection that can be interpreted as an optimal instrument-rate projection. Norges Bank first published a time-varying instrument-rate projection that can be interpreted as an optimal instrument-rate path in March 2005. The

21. Blinder (2006) suggests using an empirical reaction function.

22. The particular reaction function used before any judgmental and policy adjustments, a variant of a so-called forecast-based Taylor rule originating with Bank of Canada's quarterly projection model, has some particular problems, discussed in Svensson (2001c).

23. By central bank judgment, I mean information, knowledge, and views beyond the scope of a particular model.

presentation of optimal projections of inflation, the output gap, the exchange rate, and the interest rate has been refined, with fan charts, extensive discussion, and cross-checking, in consecutive inflation reports (see Qvigstad, 2005 and Svensson, 2005a for a discussion of the Norwegian example).

2.2 The Instrument-Rate Decision

The assumption about the current instrument rate matters very little for the central bank's projections. What matters is the assumption about the entire future instrument-rate path. Similarly, the current instrument rate matters very little for private sector economic decisions. What matters is the private sector expectations about future instrument rates. These expectations feed into the yield curve and affect longer-term interest rates and asset prices, which do affect private sector decisions.

The current instrument rate and central bank announcement have an effect on the economy essentially only through the private sector expectations they give rise to about future instrument rates and future inflation and output. Indeed, it is paradoxical that so much attention and discussion is focused on current instrument-rate settings and levels, when what matter are the related plans and expectations about future instrument rates. As is becoming increasingly well known, and as Woodford (2004) and Svensson and Woodford (2005) emphasize, modern monetary policy is essentially the management of private sector expectations.

Since the current instrument rate has very little importance and it is the entire future instrument-rate path that matters, explicitly or implicitly the central bank instrument decision is really a decision about the future path of the instrument rate, about an instrument-rate plan. To some extent this is becoming increasingly recognized. A good example is the increased attention paid to some key words in Federal Open Market Committee statements (www.federalreserve.gov/fomc/) indicating future instrument-rate setting: "policy accommodation can be maintained for a *considerable period*," "[the Committee] can be *patient* in removing its policy accommodation," and "policy accommodation can be removed at a *pace that is likely to be measured*"(italics added).[24]

24. Imagine how much more transparent this communication would have been if the Federal Open Market Committee instead had plotted an instrument-rate projection, as the Reserve Bank of New Zealand and Norges Bank are already doing.

My conclusion from this is that central banks should be more specific, systematic, and transparent about instrument-rate paths and plans. Since the decision about the instrument rate is in effect a decision about the instrument-rate path, it is better that this be explicitly acknowledged. Maintaining that the decision is one about the current instrument-rate levels alone is both misdirected and misleading. Indeed, throughout the decision process, it should be natural to think in terms of alternative instrument-rate paths and plans, not about the instrument rate during the next month or two. Similarly, it should be natural to think in terms of entire projection paths of future target variables, not just the current level, the target variables, or the projection at some particular horizon, such as eight quarters. Furthermore, the discussion of the intertemporal loss function above makes clear that the loss function induces a ranking of entire projection paths, not projections at particular horizons. Indeed, the monetary policy transmission mechanism should be seen as a mapping from an instrument-rate path to target variable paths, not as a mapping from an instrument-rate level to a level of the target variables at some particular horizon.

Goodhart (2001, 2005) and Mishkin (2004) argue that it is too difficult for a monetary policy committee to agree on a path (a sequence of numbers) rather than a current instrument-rate decision (a single number). I argue that doing so is neither necessary nor too difficult and that it is already being done. Monetary policy committees all over the globe decide on projections of inflation and output all the time. Projections are paths, sequences of numbers. Why would there be a big difference between agreeing on an instrument-rate path and an inflation path? Moreover, some central banks, such as the Reserve Bank of New Zealand and Norges Bank, are already explicitly deciding on instrument-rate paths.[25]

In particular, majority voting about paths is completely feasible. One possibility is that the staff prepare two or three alternative sets of projections, each with a particular instrument-rate path and corresponding projections of the inflation and the output gap (perhaps

25. At the Reserve Bank of New Zealand, the governor is the single decisionmaker and is advised by an internal monetary policy committee. The single decisionmaker is sometimes said to simplify the decision about the interest rate path (Goodhart 2001, 2005). My information about monetary policy committee meetings, gained especially during my review of monetary policy in New Zealand (Svensson 2001a), indicates that decisions are normally made in a very collegial manner, similar to a majority voting monetary policy committee. Archer (2005) provides more specific and recent information supporting this impression. Norges Bank has a seven-member board that makes monetary policy decisions. Two members (the governor and deputy governor) are from the bank, and five are external.

but not necessarily minimizing a loss function for alternative λs). The instrument-rate paths might, for instance, differ in the speed at which they return to a common normal level. The monetary policy committee could then vote on these two or three alternative sets of projections, in the same way that it would vote on two or three alternative current instrument-rate settings (if there are three alternatives, perhaps by first eliminating one alternative as least preferred and then voting between the remaining two).

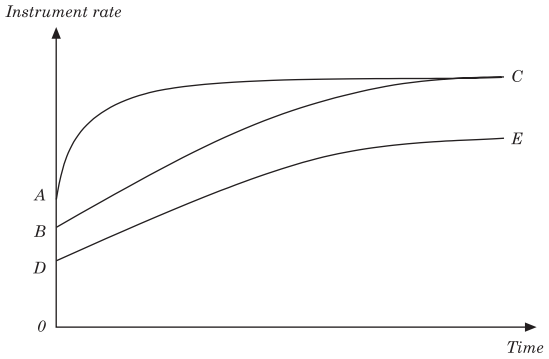
I have suggested a somewhat more general procedure (Svensson 2003a). Suppose that each monetary policy committee member has a preferred instrument-rate plan for the current and future instrument rate in the form of a path. All of these paths could be plotted in a graph with time on the horizontal axis and the instrument rate on the vertical axis. For each future date on the horizontal axis, the committee would pick the median instrument-rate level. Recall the Median-Voter Theorem: The outcome of majority voting about a single variable is the level preferred by the median voter. This is the median-voter theorem applied to a path, as if the monetary policy committee members were simultaneously voting about the instrument rate at the current and future dates. The procedure results in the median instrument-rate plan. This median instrument-rate plan could serve as the starting point for a new round of voting, with each monetary policy committee member suggesting some modification of the median instrument-rate plan. The median of these suggestions, corresponding to majority voting about the modifications, would be chosen as the instrument-rate plan. I would be very surprised if this procedure did not converge to a reasonably consistent compromise within a couple of rounds.[26]

Figure 2 illustrates a situation with three monetary policy committee members. One member prefers instrument-rate plan AC, where A corresponds to the preferred current instrument-rate setting. A second member prefers instrument-rate plan BC. The two members agree on the instrument rate far into the future but disagree on the time to get to that level and on the current instrument-rate level. A third member prefers instrument-rate plan DE, with a lower current level and a lower future level than the other two. The median instrument rate for each date is the instrument rate BC. For

26. Relying on the median instrument-rate plan also has the attractive property that outliers are disregarded: extreme monetary policy committee members will have little or no influence on the resulting instrument-rate plan.

this simple configuration of individual instrument-rate plans, the procedure converges in one step.[27]

Figure 2. Voting on Instrument-Rate Plans



Source: Author.

3. Transparency and Communication Issues

The internal forecast/decision process and the bank's announcement and communication process are distinct, although the appropriate announcement and communication is an important part of managing private sector expectations and thereby implementing monetary policy. From a transparency and accountability point of view, it is desirable that the central bank's reporting be a correct representation of the internal forecast/decision process and its results. However, I see no problem with the bank trying out different internal procedures for some time and announcing them later, once the bank has decided which procedures to follow.

Since monetary policy has an impact on the economy via the private sector expectations of inflation, output, and instrument rates it gives rise to, announcing the optimal projection—including the instrument-rate projection—and the analysis behind it would

27. For a monetary policy committee with an even number of members, the median curve can be defined as the average of the two middle curves. If one member (the governor) has the decisive vote in case of a tie, the governor's vote would decide which of the two middle curves is the median. If the committee members' individual instrument-rate plans intersect, the median curve may consist of segments of different members' plans. In this case a few rounds may be required before a reasonably smooth and consistent median plan is chosen.

have the greatest impact on private sector expectations and be the most effective way to implement monetary policy. Since the optimal projection is the best projection, in the sense of minimizing expected squared forecast errors, it also provides the private sector with the best aggregate information for making individual decisions. Announcing the optimal projections also allows for the most precise and sophisticated external evaluation of the monetary policy framework and decisions.

Morris and Shin (2002) present a result indicating that more public information may reduce social welfare. This result has received considerable attention and been interpreted as arguing against transparency (Amato, Morris, and Shin, 2002; Amato and Shin, 2003; Economist, 2004). However, Svensson (2006) shows that some scrutiny of the result reveals that it has been misinterpreted and is actually pro transparency: except in very special circumstances (when the precisions of private information is more than eight times higher than that of public information), more public information increases social welfare. In particular, for a conservative benchmark of equal precision in public and private information, social welfare is higher than it is without public information.[28]

The announcement of the optimal instrument-rate projection could include fan charts to emphasize that the projection is a probability distribution conditional on current information and judgment and that only with probability zero would future decisions be exactly equal to the central projection. Goodhart (2005) and Mishkin (2004) have warned that the instrument-rate projection might be interpreted as an unconditional commitment. Some special explanation may indeed be required to emphasize that the instrument-rate projection is not a commitment but only the best forecast, the best plan, conditional on current information and judgment and that future decisions and future projections would normally change to reflect new information and judgment. Experience from New Zealand indicates that the market and private sector have no problem understanding that projections are conditioned on current information and will change with new information (Archer, 2004, 2005; Svensson, 2001a). Furthermore, educating the market and the general public about monetary policy is a natural part of successful inflation targeting.

28. Woodford (2005) shows that a slight change in the social welfare measure, such that it is proportional to individual welfare, makes social welfare always increasing in transparency.

This discussion concerns conveying the bank's optimal projection of inflation, the output gap, and the instrument rate to the private sector. It does not attempt to convey the bank's reaction function, that is, how current instrument setting depends on current information and judgment. This reaction function is, in my view, too complex to ever be explicitly expressed, even within the bank. The optimal instrument-rate decision depends in a complex way on all the information and judgment used in the forecasting process. The reaction function is, in my view, best left implicit. (For more detail on this issue, see Svensson 2003c, 2005b.) Fortunately, the decision process proposed above does not require that central bank's reaction function be explicit.[29]

In short, I believe that the best instrument-rate decisions, the most effective implementation of monetary policy, and the most satisfactory degree of transparency and accountability can be achieved with the moderately formal framework discussed above. Let me now discuss a few additional points.

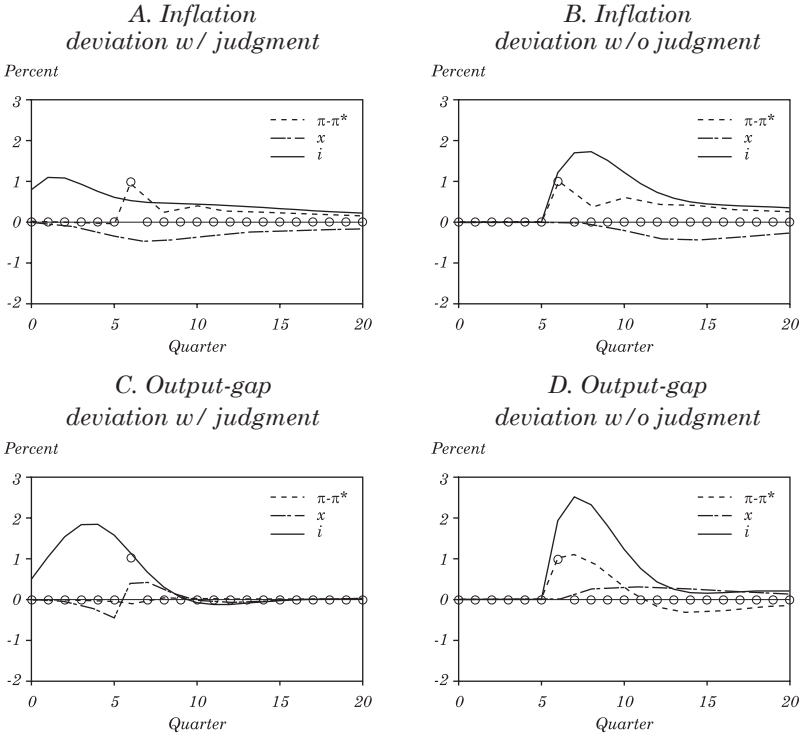
4. Incorporating Judgment

The framework proposed above can be used with projections that are largely judgmental, with projections that are largely model based, or any combination of the two. Svensson (2005b) discusses in greater detail how central bank judgment—information, knowledge, and views beyond the scope of a particular model—can be incorporated into optimal projections in a consistent way. Svensson and Tetlow (2005) describe a practical way of doing so, the method of optimal policy projections, which is in use at the Federal Reserve Board.

My view is that models are very useful in practical monetary policy, but a substantial amount of judgment always needs to be applied. I doubt that good monetary policy can ever be conducted without a substantial amount of judgment. Any model is always a drastic simplification of a complex economy; judgment, in the form of information, knowledge, and views outside the scope of a particular model, will always be necessary. The challenge is to apply good judgment in a disciplined and systematic way rather than in a completely discretionary and ad hoc way.

29. Although it is in principle true that inflation targeting can be described as an ex ante inflation target and an optimal instrument-rate response to observable shocks, as King (1996) notes, in practice the number of potential shocks is so large that the optimal response to all possible observable shocks cannot be made explicit.

Figure 3. Monetary Policy with and without Central Bank Judgment



Source: Svensson (2005b).

Figure 3 shows a situation discussed in Svensson (2005b), based on the empirical model of the U.S. economy of Rudebusch and Svensson (1999).[30] The inflation and output gaps have been equal to their steady-state levels, zero, up to quarter 0. In panel a, the central bank receives new information in quarter 0 about a shock to inflation, the inflation deviation, in quarter 6 with a mean of 1 percentage point and possibly a large variance; the anticipated mean deviation of inflation equals zero for other future quarters. The central bank's judgment in quarter 0, the mean inflation deviations, is marked by circles with no connecting line.

30. Svensson (2005b) also provides an example with an empirical forward-looking model of the U.S. economy by Lindé (2002).

It is important to realize that this example of central bank judgment does not amount to the assumption that the central bank has perfect foresight about future shocks. On the contrary, judgment about future inflation deviations is in the form of probability means. Behind these means would normally be a perceived probability distribution of inflation deviations with considerable uncertainty. The variance of this distribution could be very large. However, under the assumptions made, it is only the mean of the distribution that matters for policy.

Panel a shows the optimal policy projection in quarter 0, $(\pi^0 - \pi^*, x^0, i^0)$, of the inflation gap, $\pi - \pi^*$ (the dashed line); the output gap, x (the dashed-dotted line); and the instrument rate, i (the solid line).[31] The panel shows that when the central bank expects a 1 percentage point inflation deviation in quarter 6, it chooses an optimal instrument-rate projection such that the instrument rate is raised to about 1 percentage point during the first few quarters and then gradually lowered back to its steady-state level. As a result, the projected output gap gradually falls to about -0.5 percentage points in quarter 7 and then very gradually rises back toward zero. The inflation projection shows inflation falling slightly before it is hit by the inflation deviation in quarter 6, then rising to almost 1 percentage point before finally falling back toward its steady-state level after quarter 6. Thus the optimal policy projection is a clear example of preemptive monetary policy: the instrument rate is raised and the output gap reduced well before the expected inflation deviation shock, in order to efficiently control inflation and bring it back to target after the shock. The optimal policy projection in quarter 0 results in an expected intertemporal loss of 4.2 units.[32]

Panel b shows the projection of the same variables for the same expected inflation deviation. However, in this panel the central bank disregards judgment in each quarter while still responding optimally to the predetermined variables (current and past inflation and output gaps). The central bank responds in the same way to the predetermined variables as in the optimal policy, but it does not respond to any expected future deviation. It behaves as if it believes that the deviation

31. The optimal projection is calculated for a period loss function defined over projections as $L_{t+\tau,t} = (\pi_{t+\tau,t} - \pi^*)^2 + \lambda x^2_{t+\tau,t} + \nu(i_{t+\tau,t} - i_{t+\tau-1,t})^2$, with $\lambda = 1$, $\upsilon = 0.2$, and a discount factor $\delta = 1$.

32. Given how the target variables are measured, with the given loss function and $\delta = 1$, an expected difference of inflation from target of one (two) annualized percentage point(s) for a single quarter gives rise to an intertemporal loss of one (four) units.

is a serially uncorrelated zero-mean process, so its expected future deviations are zero. The central bank then keeps the instrument rate at its steady-state level through quarter 5. Accordingly, inflation and the output gap remain at the steady-state levels through quarter 5. In quarter 6 the inflation shock hits and inflation jumps to 1 percentage point, while the predetermined output gap remains at zero. In this situation, once the inflation shock has hit, the optimal monetary policy response is to raise the instrument rate substantially, to more than 1.5 percentage points above the steady-state level during the following few quarters. This reduces the output gap to almost -0.5 percentage points during the next eight to nine quarters. The instrument rate is gradually lowered back to the steady-state level, and inflation and the output gap return to their steady-state levels very slowly. The absence of any preemption requires a larger instrument-rate response when the shock occurs; the output gap is nevertheless reduced, with a considerable lag, and inflation stays above target for a long time. The resulting intertemporal loss is 6.3 units—2.1 units higher than when monetary policy relies on judgment. (Panels c and d illustrate analogous experiments for an expected output deviation in quarter 6; for more detail, see Svensson, 2005b.)

This example shows a substantial difference between monetary policy with and without judgment, with significant differences in the development of the target variables and corresponding intertemporal losses. It indicates the importance of taking central bank judgment into account.

5. Uncertainty, "Mean" Forecast Targeting, and "Distribution" Forecast Targeting

Monetary policy is always conducted under substantial uncertainty. The projections discussed above can be interpreted as mean projections of future random variables, and the procedures discussed above can be called *mean forecast targeting*. Strictly speaking, mean projections are sufficient for optimal policy only under certainty equivalence, which requires a known linear model and a quadratic loss function and only additive uncertain shocks.

When certainty equivalence is violated—because uncertainty is multiplicative and not just additive, for instance—mean projections are not sufficient for optimal policy. In this case, the entire distribution of future random target variables matters.

Svensson and Williams (2005) develop a flexible and powerful but still tractable framework for optimal monetary policy under model uncertainty. Their framework extends the so-called Markov jump linear-quadratic framework to include forward-looking variables.[33] In principle, the forecast targeting procedure discussed here can be carried out using projections of probability distributions—distribution projections—rather than mean projections. In this case the procedures can be called *distribution forecast targeting*. It is too early to tell whether in most situations for monetary policy the difference between mean forecast targeting and distribution forecast targeting is large enough to matter for policy.

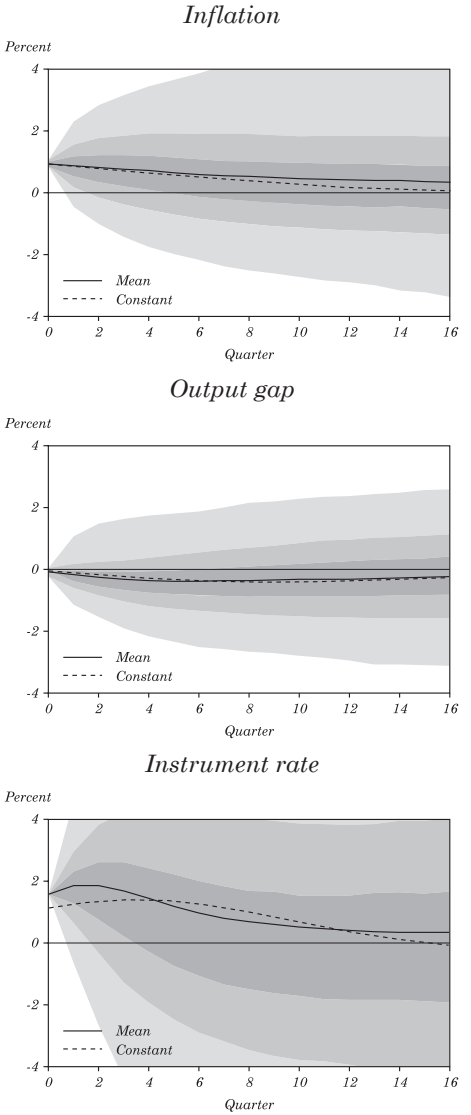
In both mean and distribution forecast targeting, the uncertainty of the projections can conveniently be illustrated with fan charts. The methods of Svensson and Williams (2005) allow the convenient construction and plotting of theoretically and empirically consistent fan charts under both certainty equivalence and certainty nonequivalence.

Figure 4 shows the probability distribution of an optimal projection of inflation, the output gap, and the instrument rate for a three-mode version of the Lindé (2002) empirical neo-Keynesian model of the U.S. economy. This model is used as one example in Svensson and Williams (2005) (another example used there is a three-mode version of the Rudebusch and Svensson, 1999 model). Model uncertainty is modeled as a Markov process that jumps among three alternative modes, with each mode having a different set of model coefficients (that is, a three-mode regime-switching model). The modes are not directly observed by the central bank. The central bank then conducts optimal policy conditional on its subjective probability distribution of the modes—in this case, the stationary distribution of the modes. Svensson and Williams (2005) provide details of the Bayesian method used to estimate the mode-dependent model parameters, the transition probabilities of the modes, and the variance of the mode-dependent additive shocks.

The figure shows the optimal projection of inflation (measured as the difference from the inflation target), the output gap, and the instrument rate starting from an initial situation in quarter 0, when inflation exceeded the inflation target by 1 percentage point and the instrument rate was equal to 1 percentage point the previous quarter, quarter -1. From quarter 0, the economy is subject to unobserved jumps between model modes with estimated transition probabilities, as well

33. Zampolli (2005) uses a Markov jump linear-quadratic framework to examine optimal policy with switching exchange rate dynamics.

Figure 4. Optimal Projection of Inflation, the Output Gap, and the Instrument Rate with Model Uncertainty and Additive Shocks



Source: Svensson and Williams (2005)
Note: Solid lines show the mean projection. Dashed lines show the optimal mean projection for constant coefficients. The dark shading shows the 30 percent probability band. The medium shading shows the 60 percent probability band. The light shading shows the 90 percent probability band.

as additive shocks with estimated mode-dependent variance. Thus, the simulation takes into account both additive and multiplicative uncertainty, with empirical distributions for both kinds of uncertainty. The probability distribution was simulated with 10,000 realizations of the Markov chain.

The light gray bands (90 percent probability) show that the projection's probability distribution has relatively wide tails; the medium (60 percent probability) and dark gray (30 percent probability) shades show that most of the probability mass is relatively concentrated for the inflation and output-gap projection. The probability distribution for the instrument-rate projection is wider than for inflation and the output gap. It is also somewhat asymmetric. This is apparent since the median projection, which will be within the dark gray band, differs from the mean projection, shown by the solid line. The probability distribution seems to converge to a stationary distribution after about 12 quarters.

The Markov jump linear-quadratic framework approach to model uncertainty can be combined with the "additive" central bank judgment discussed in Svensson (2005b). Furthermore, it allows the introduction of "multiplicative" central bank judgment, such as the judgment that model uncertainty is temporarily "high," "normal," or "low." Optimal policy projections can then be computed for these alternative levels of perceived model uncertainty. Svensson and Williams (2005) provide further discussion of these and other extensions.

6. Optimization under Commitment, the Timeless Perspective, and Discretion

When forward-looking private sector expectations are important, optimization under commitment differs from optimization under discretion. The behavior of some central banks is probably better described as optimization under discretion, where each new decision is made from scratch, regardless of previous promises and statements. Indeed, some observers who are opposed to the idea of publishing instrument-rate projections have referred to the undesirability of such projections, because they might be interpreted by the private sector as commitments and thereby restrict the bank's freedom to act (Mishkin, 2004).

From a normative point of view, and when policy advice is given, optimization under commitment is the obvious standard, since policy under commitment, when commitment is possible, results in better

outcomes. Furthermore, the issue of consistent reoptimization under commitment can be handled with optimization under commitment in the timeless perspective (Woodford, 2003; Svensson and Woodford, 2005). Svensson (2005b) provides details under certainty equivalence; Svensson and Williams (2005) examine the case of noncertainty equivalence.

7. The Output Gap, Potential Output, the Interest-Rate Gap, and the Neutral Interest Rate

The output gap—the difference between output and potential output—has been used as a generic variable indicating the state of the business cycle. However, in modern views of the transmission mechanism, the output gap is an import variable and far from arbitrary. In this regard, the theoretically most satisfactory concept of potential output is the hypothetical output level that would result in the economy if all prices and wages were completely flexible. This means that potential output is time varying, shock dependent, and not a simple trend.

Because the output gap and potential output gap are crucial variables in the transmission mechanism, it makes sense for central banks to devote a fair amount of resources to estimating potential output, constructing projections of potential output and the output gap, and publishing those estimates and projections, especially if the output gap is an implicit or explicit target variable. The fact that estimates and projections of potential output and the output gap are quite uncertain does not diminish their importance and is not a reason not to publish them (contrary to what Mishkin, 2004 argues). Generally, a simple principle for transparency is that the central bank should publish projections of all its target variables. If a central bank sets the employment or unemployment gap (defined as the difference between employment [unemployment] and "potential" employment [unemployment]), as a target variable, it should publish estimates and projections of these measures as well. (The theoretically most satisfactory definition of "potential" is the hypothetical level in an economy with completely flexible prices and wages.)

In modern views of the transmission mechanism, the most appropriate measure of monetary policy stance is the projection of the current and future interest-rate gap—the difference between the real instrument rate and the neutral real interest rate. The neutral real interest rate (the Wicksellian natural real interest rate) is the

hypothetical real short-term interest rate that would result in the economy if prices and wages were completely flexible. It is time varying, shock dependent, and not a simple average of past real interest rates. The neutral real interest rate and potential output are related. In the simplest case, the neutral real interest rate is the sum of the rate of time preference and a term equal to expected growth of potential output divided by the intertemporal elasticity of consumption. The most appropriate measure of monetary policy stance is then given by the projection of the current and future interest-rate gap (see appendix). Given the importance of this concept in modern views of the transmission mechanism, it makes sense that central banks estimate, use, and publish estimates of it.

8. Conclusions

Inflation-targeting central banks can improve their targeting by being more specific, systematic, and transparent about their operational objectives (by using an explicit intertemporal loss function), their forecasts (by deciding on optimal projections of the instrument rate and the target variables), and their communication (by announcing optimal projections of the instrument rate and target variables). Progress can also be made by incorporating central bank judgment and model uncertainty in a systematic way in the forecasting and decisionmaking process. In particular, incorporating model uncertainty allows the central bank to target based on more general distribution forecast rather than on the more restrictive mean forecasts under the assumption of approximate certainty equivalence.

Appendix
The Loss Function and the Interest-Rate Gap

A. The Loss Function

Let the period loss function be as shown in expression (1). Assume that δ is arbitrary close to unity. Note that the limit of the intertemporal loss when δ approaches unity satisfies

$$\begin{aligned}
&\lim_{\delta \to 1}(1-\delta)\mathrm{E}_t\sum_{\tau=0}^{\infty}\delta^{\tau}L_{t+\tau} = \mathrm{E}\left[L_t\right] \\
&= \left(\mathrm{E}\left[\pi_t\right]-\pi^*\right)^2 + \mathrm{Var}\left[\pi_t\right]^2 + \lambda\left(\mathrm{E}\left[x_t\right]^2 + \mathrm{Var}\left[x_t\right]\right) \\
&= \left(\mathrm{E}\left[x_t\right]-\pi^*\right)^2 + \mathrm{Var}\left[\pi_t\right] + \lambda\mathrm{Var}\left[x_t\right],
\end{aligned} \tag{A.1}$$

under the assumption that $\mathrm{E}\left[x_t\right] = 0$. Then the intertemporal loss is given by the sum of three terms. The first is the squared deviation from the inflation target of the unconditional (that is, long-run) mean of inflation. The second is the unconditional variance of inflation. The third is the product of λ and the long-run variance of the output gap. Hence λ can be interpreted as the weight on variance of the output gap relative to the weight on variance of inflation (or squared long-run deviations of inflation from the inflation target).

B. The Interest-Rate Gap

That the projection of the current and future interest-rate gap is an appropriate indicator of the monetary policy stance can most easily be demonstrated in a simple neo-Keynesian model of aggregate demand. Let aggregate demand be given by

$$y_t = y_{t+1|t} - \sigma(r_t - \rho_t), \tag{A.2}$$

where y_t denotes (log) output in period t, $z_{t+\tau|t}$ denotes $\mathrm{E}_t z_{t+\tau}$ (the rational expectation in period t of the realization of variable $z_{t+\tau}$ in period $t+\tau$), $\sigma > 0$ denotes the intertemporal elasticity of substitution, r_t denotes a short-term (one-period) real interest rate, and ρ_t denotes the rate of time preference between period t and period $t+1$ and is

an exogenous stochastic process. The short-term real interest rate is defined by

$$r_t \equiv i_t - \pi_{t+1|t}, \tag{A.3}$$

where i_t is a short-term (one-period) nominal interest rate and $\pi_{t+1|t}$ denotes the rational expectation in period t of inflation between period t and period $t + 1$. Equation (A.2) follows from a first-order condition for optimal intertemporal consumption choice with an additively separable utility function for a representative consumer with constant elasticity of intertemporal substitution σ and a stochastic subjective discount factor whose logarithm is ρ_t.

Let $\bar{y}_t$ denote (log) potential output, and assume that it is an exogenous stochastic process. Define the neutral real interest rate, $\bar{r}_t$, as the real interest rate for which output in (A.2) equals potential output. This gives

$$\bar{r}_t \equiv \rho_t + \frac{1}{\sigma}\left(\bar{y}_{t+1|t} - \bar{y}_t\right), \tag{A.4}$$

so the neutral interest rate equals the sum of the rate of time preference and expected potential output growth divided by the intertemporal elasticity of substitution.

Define the output gap as the difference between (log) output and (log) potential output,

$$x_t = y_t - \bar{y}_t. \tag{A.5}$$

Using expressions (A.4) and (A.5) in (A.2) results in

$$x_t = x_{t+1|t} - \sigma(r_t - \bar{r}_t). \tag{A.6}$$

The output gap in period t depends on the expected output gap in period $t + 1$ and the current interest-rate gap, $r_t - \bar{r}_t$. (The nominal and the real interest-rate gaps are the same, if we identify $\bar{r}_t + \pi_{t+1|t}$ with the nominal neutral interest rate, since $r_t - \bar{r}_t = r_t + \pi_{t+1|t} - \bar{r}_t - \pi_{t+1|t} = i_t - (\bar{r}_t + \pi_{t+1|t})$).

Solving (A.6) forward T periods gives

$$x_t = x_{t+T|t} - \sigma \sum_{\tau=0}^{t-1}\left(r_{t+\tau|t} - \bar{r}_{t+\tau|t}\right). \tag{A.7}$$

Assume that the expected output gap far into the future approaches zero ($x_{t+T|t} \to 0$ when $T \to \infty$), and assume that the sum in (A.7) converges when $T \to \infty$ (that is, that $r_{t+T|t} - \bar{r}_{t+T|t} \to 0$ sufficiently fast when $T \to 0$). Then we can let $T \to 0$ in (A.7), yielding $x_t = -\sigma \sum_{\tau=0}^{\infty} \left(r_{t+\tau|t} - \bar{r}_{t+T|t} \right)$.

The output gap depends on the accumulated projected current and future interest-rate gaps, $\sum_{\tau=0}^{T-1} \left(r_{t+\tau|t} - \bar{r}_{t+\tau|t} \right)$. The projection of the current and future interest-rate gap, $r^t - \bar{r}^t = \left(r_t - \bar{r}_t, r_{t+1|t} - \bar{r}_{t+1|t}, \ldots \right)$, contains all the information about the monetary policy stance.

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Transparency, Flexibility, and Inflation Targeting

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Three parallel and certainly not independent changes have occurred in central bank practices over the past fifteen years. The first is the spread of central bank independence, which is tied to the notion that even when the government plays a role in setting the goals of monetary policy, central banks should be free from political interference as they pursue those goals. A second trend is the adoption of inflation targeting. Beginning with New Zealand in December 1989, and followed by Chile in January 1991, over twenty countries have adopted some version of inflation targeting. Finally, the third trend among both inflation-targeting and non-targeting central banks is the adoption of greater transparency in the conduct of monetary policy. In fact, transparency is increasingly viewed as a standard and important component of best practices in central banking.

These three trends are closely related. In democratic societies, independence needs to be underpinned by accountability. Greater transparency is commonly viewed as an important means for achieving this accountability. It is also a natural outcome of the wide-spread adoption of inflation targeting by central banks in both developed and developing economies, since, at a minimum, inflation targeting involves the formal announcement of a target for the inflation rate. Even central banks that have not formally adopted inflation targeting have become more transparent in recent

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years. Eijffinger and Geraats (2006) provide an index of transparency for a set of developed economies that includes both inflation targeters (Australia, Canada, New Zealand, Sweden, and the United Kingdom) and non-targeters (Japan, Switzerland, and the United States). They find that between 1998 and 2002, transparency increased for virtually all the central banks they studied. Even the Federal Reserve, which has so far resisted calls to establish a formal inflation target, has moved to make its policy practices more transparent.

Recently, however, new questions have been raised about the value of having central banks provide more and better information to the public. Morris and Shin (2002) argue that providing more accurate public information can carry a cost when private agents have individual sources of information and must base decisions partly on what they expect others are expecting. In their model, private agents must forecast an underlying shock and attempt to forecast the forecasts of others. This creates a role for higher-order expectations (expectations of expectations of expectations...).[1] Agents may then overreact to public information, increasing the economy's sensitivity to any forecast errors in the public information.

The possibility that the private sector may overreact to central bank announcements captures a concern expressed by policymakers. For example, in discussing the release of Federal Open Market Committee (FOMC) minutes, Janet Yellen expresses the view that "financial markets could misinterpret and overreact to the minutes" (Yellen, 2005). Svensson (2006), however, argues that the Morris-Shin result is not a general one. He shows that welfare is increased by more accurate public information in the Morris-Shin model for all but unreasonable parameter values (and he therefore concludes that their message supports transparency after all).

Unfortunately, the existing research on the role of higher-order expectations and the welfare costs of public information does not employ the types of models that are standard in monetary policy analysis. In this paper, I employ a simple new Keynesian framework to investigate the role of transparency in the presence of private and diverse information. The framework can be used to address such questions as how the public information provided by interest rate movements alters the effectiveness of monetary policy; what benefits

1. Woodford (2003) also investigates the role of higher-order expectations in inducing persistent adjustments to monetary shocks in the Lucas-Phelps islands model. See also Hellwig (2002).

(and potential costs) are associated with releasing additional public information such as a short-run inflation target; whether it is always advantageous to announce targets; and whether central banks should widely publicize their targets.

My results show that a policy's impact on inflation is significantly affected by the way policy actions alter each individual price setter's expectations about the state of the economy. In the absence of central bank announcements, the direct impact on inflation of a contractionary policy move can be offset if private information is poor or the central bank's information is very precise. For example, firms may interpret an interest rate hike as a signal that the central bank believes the economy has been hit by a positive cost shock; inflation may rise as firms adjust their own beliefs about the cost shock. Announcements allow price setters to distinguish policy actions designed solely to offset demand shocks (which therefore should not affect inflation) from those actions designed to partially offset the inflation effects of cost shocks. Announcements can thereby prevent demand shocks from affecting inflation, but expectations can become more volatile in reaction to announcements. Inflation variability can increase when targets are announced.

If formal announcements heighten inflation variability, it may be advantageous for the central bank to make partial announcements of the type analyzed by Cornand and Heineman (2004). Partial announcements include, for example, speeches about the economy that may not be as widely reported as formal policy announcements. Speeches and other means of providing partial information play an important role in central banking practices, and these means of communication long predate the publication of inflation reports. The optimal degree of partial announcement depends on the relative weight the central bank places on inflation and output gap objectives. If the central bank's information about the aggregate economy is more accurate than the private information of price setters, neither inflation "nutters" (that is, strict targeters who focus exclusively on stabilizing inflation, even to the detriment of economic growth) nor central banks that place a large weight on output objectives will find it optimal to make any announcements. Central banks that are flexible inflation targeters will, however, find it optimal to be completely transparent. This may be why inflation targeters (who are not inflation nutters) are likely to implement highly transparent policy regimes.

I focus on the role of transparency for a central bank that already behaves as an inflation targeter and whose objectives are known and

understood by the public. When a central bank has credibly established its reputation for maintaining low and stable inflation, the release of forecasts, output targets, and other information is a means of providing greater transparency about the central bank's assessment of the state of the economy. The next section briefly reviews the related literature; given the excellent survey by Geraats (2002), I focus on work that investigates issues of public information and transparency. Section 2 then discusses the role of the central bank's instrument as a public signal. I show how the behavior of inflation depends on the quality of both the central bank's and the private sector's information. Section 3 considers the case in which the central bank announces its target for the output gap, which provides a second source of public information. Partial announcement of the central bank's target are analyzed in section 4. This section also considers how announcements affect the optimal policy responses to cost and demand disturbances, as well as the optimal degree of transparency. Section 5 presents some extensions and explores lessons, while the appendix provides details of the model and derivations.

1. Policy and Public Information

As Issing notes, "Transparency is not an end in itself: a central bank is not established with the primary objective of communicating with the public" (Issing, 2005). Instead, the arguments in favor of greater transparency rest on two pillars—accountability and efficiency. The first stresses the importance of transparency for ensuring the public can hold policymakers accountable. This rationale for transparency resonates strongly among supporters of central bank independence. With independence comes accountability, and accountability requires transparency.

The second argument for transparency is that it improves economic efficiency, in terms of either the operation of financial markets or the implementation of policy. For example, in remarks at a 2001 conference on transparency in monetary policy held at the Federal Reserve Bank of St. Louis, Alan Greenspan expressed the view that transparency aids the functioning of financial markets: "Simply put, financial markets work more efficiently when their participants do not have to waste effort inferring the stance of monetary policy from diffuse signals generated in the day-to-day implementation of policy" (Greenspan, 2002).

Transparency may also improve the ability of monetary policy to achieve its goals by ensuring that private market expectations are consistent with the aims of central bank policy. In the forward-looking

new Keynesian model that is widely used for monetary policy analysis, for example, the effectiveness of monetary policy depends on the policy's ability to affect expectations about the future path of interest rates (Woodford, 2003). A transparent policy—one that reduces uncertainty about future policy actions—can improve the trade-off between output and inflation objectives. According to King (2005), "Because inflation expectations matter to the behavior of the households and firms, the critical aspect of monetary policy is how decisions of the central bank affect those expectations." This focus on the public's expectations is mirrored in the detailed policy reports produced by many inflation-targeting central banks. The Central Bank of Chile, for example, states that one of the objectives of its Monetary Policy Report is "to provide information that can help guide economic agents' expectations regarding future inflation and output trends" (Central Bank of Chile, 2005, preface).

Both arguments in favor of transparency have been challenged. Critics of formal inflation targeting argue that any regime that holds a central bank accountable for a single objective—such as achieving an inflation target—may lead the central bank to ignore the effects of its actions on broader measures of economic welfare. This is a general problem in designing incentive mechanisms; a high powered incentive scheme works best when actions can be monitored closely.[2] Furthermore, some analysts argue that transparency may actually reduce the central bank's ability to engage in stabilization policies. This last argument is, perhaps, not surprising. Much of the academic literature examining transparency uses models in which monetary policy has real effects only to the extent that it can surprise the public. By creating an inflation surprise, the central bank is able to stimulate real output. Since the public cannot be systematically surprised under rational expectations, the attempt to engineer an economic expansion only leads to an average inflation bias. If transparency reduces the central bank's ability to generate surprises, it weakens the central bank's incentive to engage in expansionary policy and, as a result, lowers the equilibrium rate of inflation. Transparency would seem to be unambiguously advantageous (Faust and Svensson, 2002). However, if the central bank's scope for engaging in stabilization policies is also a function of its ability to generate surprise inflation, transparency reduces that ability.

2. See Walsh (2003) for an application of this principle to inflation targeting.

This limits the potential for policy to reduce economic fluctuations. Transparency may leave the central bank unable to cushion the real economy from macroeconomic shocks, a cost emphasized by Cukierman (2001).

Economists now have a great appreciation for the role that systematic, predictable policy can have on the real economy. It is not just surprises that matter. The effects of transparency may differ considerably when the predictability of policy, rather than its unpredictability, is important in determining its real impact on the economy.[3]

Morris and Shin (2002) develop a different argument for why providing public information can carry a cost. They show that the provision of more accurate public information can, in some circumstances, have a detrimental effect by leading private agents to rely too little on private sources of information.[4] Just as the earlier literature focuses on the role of monetary surprises rather than systematic policy actions to analyze issues of transparency, the Morris-Shin analysis is conducted within a framework that fails to capture important aspects of actual monetary policy. Thus, any potential limits to transparency need to be reexamined in a setting that better captures important aspects of monetary policy and its implementation. For example, the public information in the Morris-Shin study is a signal on an exogenous disturbance. In fact, most of the monetary policy debate on transparency focuses on the endogenous signals a central bank might release. By announcing its inflation forecast, the central bank provides a public signal, but the signal is dependent on policy objectives, as well as on the central bank's assessment of economic conditions. That is, how strongly (or weakly) the central bank reacts to its estimate of an inflation shock affects the information about the central bank's assessment of the economy that can be gleaned from any policy action.

Even in the absence of explicit policy announcements about targets or forecasts, central banks that employ a short-term interest rate as their policy instrument automatically provide public information, as markets can see and react immediately to any change in the policy

3. The reliance on models in which surprises are the key to the real effects of monetary policy may be one reason that Carpenter (2004) finds only a limited set of lessons for policymakers to learn from the academic literature on transparency.

4. As noted previously, Svensson (2006) argues that the Morris-Shin result is not a general one, a conclusion supported by Hellwig (2004).

rate.[5] In addition to the direct impact on spending, the interest rate setting signals to firms the central bank's beliefs about the state of the economy. A rise in the interest rate may imply that the central bank is forecasting a rise in the Wicksellian real rate, or it may signal the forecast of a positive cost shock. Thus, the efforts of private agents to infer what the central bank knows and what other agents think the central bank might know can play a role, even if explicit announcements are not made.

Amato and Shin (2003) cast the Morris-Shin analysis in a more standard macroeconomic model. In their model, the central bank has perfect information about the underlying shocks. This ignores the uncertainty that policymakers themselves face in assessing the state of the economy. Similarly, Amato and Shin do not allow the private sector to use observations on the policy instrument to draw inferences about the central bank's information. In fact, market speculation about policy actions often focuses on what a policy change says about the central bank's assessment of the economy; the nominal interest rate may be the primary public signal about monetary policy that a central bank provides. In this case, the information in the public signal is a direct function of the central bank's policy actions.

Amato and Shin (2003) further assume one-period price setting and represent monetary policy by a price-level targeting rule. In Hellwig (2004), prices are flexible and policy is given by an exogenous stochastic supply of money; private and public information consists of signals on the nominal quantity of money. In contrast, I employ a standard Calvo-type model of imperfect price flexibility, with the modification that firms adjusting each period must do so before observing the actual aggregate price level. The need to infer what other firms are doing is thus present, as in Amato and Shin and in Hellwig, but the approach is consistent with standard new Keynesian models.

Hellwig provides a more microeconomic-based analysis and shows that this can be important for assessing the welfare effects of better information. My interest is in investigating the role of announcements, not just the provision of less noisy exogenous signals. I focus on the

5. In Faust and Svensson (2002) and Jensen (2002), an exogenous control error is present in the link between the central bank's instrument and the output gap. They assume that the central bank is unable to affect or react to this control error, but it can provide the public with accurate information on some fraction of the actual control error. Transparency is then interpreted as a decrease in the volatility of the unannounced component.

implications for inflation and output gap volatility, as these are the most common measures used to assess macroeconomic performance. Some comments on how results might differ if a welfare-based measure were used are discussed in the concluding section.

2. The Policy Instrument as a Source of Public Information

To study the informational role of policy instruments and announcements, I employ a simple new Keynesian model. The details of the model are spelled out in the appendix. The model features a continuum of firms of measure one, each producing a differentiated product using an identical technology. Firms face a Calvo-type fixed probability of adjusting their price each period. In the standard new Keynesian model, firms have complete and common information about current shocks and about current aggregate equilibrium endogenous variables when setting prices. I assume instead that firms do not observe current shocks or the prices set by other firms until the period is over. Since any firm that is setting its price is concerned with its price relative to those of other firms, it needs to form expectations about the factors that determine its optimal relative price and about the behavior of other firms. This need to forecast the behavior of others introduces the role for public information stressed by Morris and Shin. Each period, private firms and the central bank receive noisy signals on aggregate shocks. Each firm's signal is private information to that firm, so individual firms have different information. The central bank sets its policy instrument and may make an announcement about its output gap target.[6] I assume that firms that do adjust their price in period t do so after observing the central bank's instrument.

Suppose firm j is setting its price in period t. Let $p_{j,t}^*$ denote the log price it chooses. It is convenient to treat $\Pi_{j,t}^* \equiv p_{j,t}^* - p_{t-1}$ as the choice variable, where p_{t-1} is last period's aggregate log price level. Let $\bar{\pi}_t^*$ be the average of $\Pi_{j,t}^*$ across the firms adjusting in period t, and let Π_t be the aggregate inflation rate. As shown in the appendix, the firm's decision depends on its expectations regarding $\bar{\pi}_t^*$, the output gap (denoted x_t), future inflation, and a cost shock (s_t). Specifically,

6. In the model, this is equivalent to announcing an inflation target. Give the structure of the model, it is somewhat more straightforward to view any announcement as an announcement about the output target.

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)\kappa E^j_t x_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1} + (1-\omega\beta)E^j_t s_t\,, \quad (1)$$

where E^j_t denotes the expectation at time t based on firm j's information, ω is the fraction of firms that do not adjust their price in a given period, and β is a discount factor.[7] The parameter κ is the output elasticity of marginal cost. The cost shock, s_t, arises as a result of stochastic fluctuations in the wedge between flexible-price output and the economy's efficient level of output (see Benigno and Woodford, 2004). Since a fraction of all firms $(1 - \omega)$ adjusts their prices, while the fraction ω does not, aggregate inflation is given by

$$\pi_t = (1-\omega)\bar{\pi}^*_t\,.$$

I represent monetary policy by the central bank's choice of an instrument, x^I_t, and by any announcements the central bank might make. I assume that x^I_t is observed at the start of the period, so that any firm that sets its price in period t can condition its choice on x^I_t. Because the most interesting policy trade-offs are generated by cost shocks and not by demand shocks, I model the monetary transmission mechanism from the central bank's instrument to the output gap in the simplest way possible. Specifically, let

$$x_t = x^I_t + v_t\,, \quad (2)$$

where v_t is a demand shock.

The model includes two primitive shocks: s, representing cost factors that generate inefficient inflation fluctuations for a given output gap and expectations of future inflation, and v, an aggregate demand disturbance. Each is assumed to be serially and mutually uncorrelated, and the central bank and price-setting firms must act before learning the actual realizations of the shocks. However, each firm receives an idiosyncratic private signal about s_t:

$$s_{j,t} = s_t + \phi_{j,t}\,.$$

The noise term, ϕ_j, is identically and independently distributed across firms. These signals are private in the sense that they are

7. In the case of common information, the appendix shows that equation (1) leads to the standard new Keynesian inflation adjustment relation.

unobserved by any other agent. The central bank receives private signals on the two disturbances:

$$s_{cb,t} = s_t + \phi_{cb,t} \text{ and}$$

$$v_{cb,t} = v_t + \xi_{cb}\,.$$

The noise terms, ϕ_{cb} and ξ_{cb}, are assumed to be independently distributed and to be independent of ϕ_j for all j and t. All stochastic variables are assumed to be normally distributed.[8]

I consider optimal policy in section 4. For now, I assume the central bank sets policy in a manner that would be optimal in the standard new Keynesian model if the central bank's objective is to minimize, under discretion, a standard quadratic loss function in inflation and the output gap. In this case, the optimal policy insulates x_t from any predictable demand shocks, while allowing the output gap and inflation to fluctuate in response to cost shocks. In particular, the central bank sets

$$x_t^I = \alpha E_t^{cb} s_t - E_t^{cb} v_t\,, \tag{3}$$

where $\alpha \leq 0$. This implies an output gap target of $x_t^T = \alpha E_t^{cb} s_t$. Equation (1) implies that

$$\pi_t^T \equiv E_t^{cb}\pi_t = \Delta(1+\alpha\kappa)E_t^{cb} s_t\,,$$

where $\Delta = (1-\omega)(1-\omega\beta)/\omega$. The parameter α characterizes the manner in which the central bank is willing to trade off inflation and output gap fluctuations. Thus, α governs the relative volatility of the central bank's targets for the output gap and inflation.

As equation (3) shows, observing the central bank's instrument imperfectly reveals the central bank's forecasts of demand and cost shocks. A rise in x^I could reflect the central bank's belief that a negative cost shock has occurred, or it could indicate that a negative demand shock has occurred. The actual realization of the output gap is

$$x_t = x_t^I + v_t = x_t^T + v_t - E_t^{cb} v_t\,.$$

8. Therefore, if E_t^{cb} denotes the expectations operator based on the central bank's information set at time t, then $E_t^{cb} s_t = \theta_s^{cb} s_t^{cb}$, where $\theta_s^{cb} = \sigma_s^2/(\sigma_s^2 + \sigma_{cb}^2)$ and σ_{cb}^2 is the variance of $\phi_{cb,t}$. Similarly, $E_t^{cb} v_t = \theta_v^{cb} v_t^{cb}$, where $\theta_v^{cb} = \sigma_v^2/(\sigma_v^2 + \sigma_\xi^2)$.

Price-setting behavior by firm j depends on four factors: the firm's expectations of what other firms are doing ($E_t^j \pi_t^*$); what the firm thinks the central bank believes is the current cost shock, since that affects the firm's expectation of the output gap; the firm's expectation of future inflation; and the firm's expectation of the current cost shock. Thus, two new aspects of the decision are present that are missing from previous analysis. Not only must the firm form expectations about what other firms are expecting (as in Amato and Shin, 2003), but it must also form expectations about the central bank's output gap target, which implicitly involves forming expectations about the central bank's expectation of the cost shock (and implicitly, therefore, about what other firms are expecting that the central bank is expecting). Because firm j has private information on the cost shock, its expectation of s may differ from what it thinks the central bank's expectation is; that is, $E_t^j(E_t^{cb} s_t) \neq E_t^j s_t$. The problem is to guess what the central bank thinks, not simply to guess what the cost shock is. Moreover, the firm must be forward-looking in assessing future inflation.[9]

When the public can observe the central bank's instrument, but no announcements are made by the central bank, the relevant information set of firm j consists of its private signal, $s_{j,t}$, and the central bank's instrument setting, x_t^I. Given that the firm must assess the likely value of the output gap (since that is related to real marginal cost), observing x_t^I provides a noisy signal on x_t^T and therefore on x_t. It also provides information relevant for forecasting the cost shock itself. The informational content of this signal depends on the policy parameter α. This contrasts with Amato and Shin (2003) and Hellwig (2004), who model the public signal as exogenous. Here, the setting of the policy instrument is the public signal, and it depends on the policymaker's preferences.

Firm j's expectations of s_t and x_t conditional on $s_{j,t}$ and x_t^I can be written as $E_t^j s_t = \Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I$ and $E_t^j x_t = \Gamma_{21} s_{j,t} + \Gamma_{22} x_t^I$. In Morris and Shin, Amato and Shin, and Hellwig, the weights placed on private and public information in the individual firm's forecast are independent of any aspect of the central bank's policy decisions. This is not the case here, as the public signal is the central bank's instrument; $\Gamma_{i,j}$ generally depends on α. For example, if α is very small, then movements in x_t^I are due primarily to the central bank's attempt to offset demand

9. The presence of a signaling effect of policy will alter the central bank's incentives in setting policy; see Geraats (2002). In this and the next section, I ignore this by simply taking equation (3) as the description of policy. Section 4 considers optimal policy.

shocks. Private firms therefore place little weight on x_t^I in forming their expectations about the cost shock.

An equilibrium strategy for firm j is a linear function of its private signal and the policy instrument. This strategy is derived in the appendix. Aggregating over all adjusting firms and multiplying by $1 - \omega$ to obtain the aggregate inflation rate, equilibrium inflation can be written as

$$\pi_t = (1-\omega)\bar{\pi}_t^* = \gamma_1 s_t + \gamma_2 x_t^I . \tag{4}$$

The appendix shows that

$$\gamma_1 = (1-\omega)\left[\frac{(1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}}\right]$$

and

$$\gamma_2 = \frac{(1-\omega)(1-\omega\beta)\kappa\Gamma_{22}}{\omega} + \frac{(1-\omega)(1-\omega\beta)\Gamma_{12}}{\omega} + \frac{(1-\omega)^2\gamma_1\Gamma_{12}}{\omega} . \tag{5}$$

Equation (5) divides γ_2, the impact of the policy instrument on inflation, into three distinct terms, each of which represents a different channel through which the policy instrument affects inflation. The first term is the direct (and standard) effect of the instrument on the expected output gap and, therefore, on inflation. Because firms must set prices before they know the current level of production, it is the expected output gap that affects inflation.[10] A unit increase in x_t^I causes firms to expect a rise in the output gap of Γ_{22}, and the output gap elasticity of inflation is $(1-\omega)(1-\omega\beta)\kappa/\omega$. The second term arises when a change in the central bank's instrument leads firms to alter their own expectations of the cost shock. A rise in the instrument will be interpreted (partially) as indicating a negative cost shock ($\Gamma_{12} \leq 0$ because $\alpha \leq 0$). This tends to reduce inflation, partially offsetting the direct positive impact that a rise in xtI has on inflation. Finally, the third term captures the Morris-Shin effect. The public nature of the instrument causes the firm to alter not only its assessment of the cost shock, but also its expectations of what other firms expect.

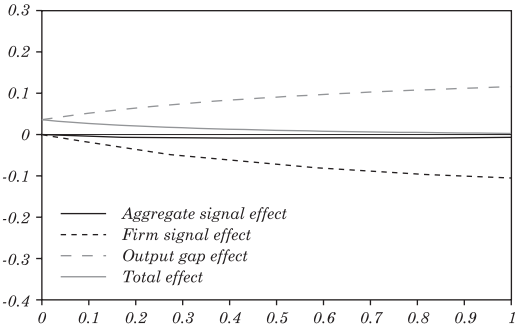
10. In the absence of demand shocks, $x_t^I = x_t$ and $\Gamma_{22} = 1$, so that $\gamma_2 = (1-\omega)(1-\omega\beta)\kappa/\omega$. One thus obtains the standard result in the literature that the output gap elasticity of inflation is $(1-\omega)(1-\omega\beta)\kappa/\omega$.

To assess the components of γ_2 and how they vary with the quality of private and public information, I numerically solve the model. To do so, I set $\omega = 0.5$, $\kappa = 2.0$, and $\beta = 0.99$. A value of 0.5 for ω is consistent with evidence on the frequency of price adjustment in the United States (Bils and Klenow, 2004). In microeconomic-founded models, κ is the sum of the coefficient of relative risk aversion and the inverse of the wage elasticity of labor supply. Values of one for each of these parameters are not uncommon, yielding $\kappa = 2.0$. The value chosen for the discount factor, β, is typical when dealing with quarterly data. In the standard common-information case, optimal policy under discretion would imply that $\alpha = -(\kappa\Delta)^2/[(\kappa\Delta)^2 + \lambda]$, so I use this value for α. For the variances of the different stochastic shocks, I set the variances of the cost and demand shocks equal to each other and normalize so that $\sigma_s^2 = \sigma_v^2 = 1$. Following Amato and Shin, I assume for the benchmark case that the private sector noise variance is equal to 0.2. While Amato and Shin assume the central bank has perfect information on the shocks, I assume the noise variances in the central bank's signals also equal 0.2, so for the baseline case, $\sigma_{\phi,j}^2 = \sigma_{\phi,cb}^2 = \sigma_{\xi}^2 = 0.2$.

Figure 1 illustrates how the quality of the private sector's information affects the net impact of the policy instrument on inflation. The curve labeled "total effect" gives the effect of a one-unit increase in the policy instrument on inflation as a function of the variance of the noise in the private signal on the cost shock. A rise in x_t^I that reflects a rise in x_t^T is associated with an increase in the output gap and would be expected to increase inflation. When $\sigma_{\phi,j}^2 = 0$, firms are able to observe the cost shock without error; observing the central bank's instrument setting conveys no further information about s_t. In this case, policy operates on inflation only through the standard direct effect on the output gap. As the quality of private information deteriorates, however, firms increasingly use x_t^I in forming expectations about the cost shock. The line labeled "firm signal effect" shows the impact on inflation when firm's alter their own expectations about the cost shock once they observe x_t^I (operating through the second term in equation (5)). Recall that x_t^I is decreasing in the central bank's signal on the cost shock. Firms interpret an increase in x_t^I as partly reflecting a decrease in the central bank's forecast of the cost shock. Firms, lower prices in anticipation of a negative cost shock. The direct output gap effect becomes larger for a parallel reason: changes in x_t^I generate larger changes in firms' expectations of the cost shock and, therefore, of the expected output gap.[11]

11. The firm signal effect and the output gap effect essentially cancel each other, because $\kappa\alpha \approx -1$ in the simulations.

Figure 1. The Quality of Private Sector Information and the Policy Instrument's Impact on Inflation[a]



Source: Author's computations.
a. The impact on inflation of a change in the central bank's policy instrument declines as the quality of the private sector's information falls.

The line in the figure labeled "aggregate signal effect" is the contribution of the Morris-Shin effect—the channel working through the firm's expectations of other firms' expectations. Consistent with Svensson's finding in the original Morris-Shin model, this effect contributes little to the overall impact on inflation of a change in the central bank's instrument.

By expressing x_t^I in terms of the underlying shocks, one can express aggregate inflation as

$$\pi_t = (\gamma_1 + \gamma_2 \alpha \theta_s^{cb}) s_t + \gamma_2 \alpha \theta_s^{cb} \phi_{cb,t} - \gamma_2 \theta_v^{cb} (v_t + \xi_t), \tag{6}$$

and the output gap as

$$x_t = \alpha \theta_s^{cb} (s_t + \phi_{cb,t}) - (1 - \theta_v^{cb}) v_t - \theta_v^{cb} \xi_t . \tag{7}$$

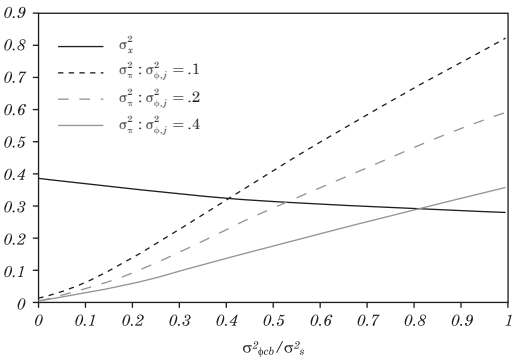
If the central bank has complete information on the demand shock, so that $\xi_t \equiv 0$ and $\theta v^{cb} = 1$, the output gap is insulated from the demand shock. Nevertheless, demand shocks do affect inflation, because equation (6) contains the term $-\gamma_2 v_t$, arising from the effects of demand shocks on the central bank's instrument. If the central bank observes a positive v_t, it lowers x_t^I. Private firms interpret this fall in the policy instrument as reflecting the central bank's belief that the economy has experienced a positive cost shock. Individual firms that are adjusting their price then increase their estimate of the cost shock and believe that other firms will do the same. Lack of transparency

about the central bank's estimate of demand shocks causes inflation to fluctuate in response to demand shocks, even though the central bank has prevented these shocks from affecting the output gap.

In the literature building on Morris and Shin, the precision of the central bank's announcements is often treated as a policy choice. While x_t^I is not an announcement but rather a policy action observed by all firms, its informational content is affected by the precision of the signals received by the central bank. Before examining the role of announcements, I explore the effects on output and inflation variability of more precise central bank information, in the form of a decline in the variance in the central bank's signal on either the cost shock or the demand shock. Morris and Shin argue that an increase in the precision of the public signal could lower welfare, essentially by making the economy more sensitive to public forecast errors. Amato and Shin (2003) find that the variance of the price level increases as the public signal becomes more accurate.

Figure 2 plots the variances of annualized inflation and the output gap as functions of the quality of the central bank's signal on the cost shock. Amato and Shin's result does not hold when the public signal is the central bank's instrument and the central bank's forecast of the cost shock becomes more accurate. As $\sigma^2_{\phi,cb}$ falls, so too does the variance of inflation. Because the central bank's forecast errors affect inflation, an improvement in the central bank's ability to forecast leads

Figure 2. The Accuracy of the Central Bank's Forecast and the Volatility of Inflation and the Output Gap[a]



Source: Author's computations.

a. As the central bank's forecast becomes less accurate, inflation becomes more volatile and the output gap becomes less volatile.

to more stable inflation. Inflation is also more stable if private sector information is less accurate (higher $\sigma^2_{\phi,j}$). When the quality of private information is low, private sector expectations—and thus the prices firms set—are less sensitive to private information. The volatility of the output gap does increase somewhat as $\sigma^2_{\phi,cb}$ falls. When the central bank can forecast more accurately, it responds more aggressively to its signal on the cost shock, leading to greater output gap movements.

Standard quadratic loss functions used to represent the objectives of monetary policy typically include both inflation and output gap volatility. Because more accurate central bank information makes the output gap more volatile while reducing the volatility of inflation, the net gain from the perspective of the central bank depends on the relative weight placed on these two objectives. Figure 2 suggests that only a central bank that placed little weight on its inflation objective would want less accurate forecasts.

3. Central Bank Announcements about Its Targets

While the impact of policy can depend on the informational content of the policy action, discussions of transparency generally focus on actions by the central bank that are designed explicitly to provide information. For example, the publication of the central bank's inflation or output forecasts or its announcement of short-run targets for inflation increase transparency. As noted earlier, a key objective of policymakers is to influence private sector expectations. The market, however, uses central bank announcements for two purposes. Private agents use announcements to better understand and forecast the intentions of the central bank, and they also try to infer from any announcement something about the central bank's assessment of the state of the economy. This means that errors in the central bank's assessment of the economy will infect private sector forecasts and expectations. This may introduce undesirable volatility into private sector expectations.

Suppose the central bank announces its target for the output gap.[12] Since the central bank's target for the output gap depends solely on its forecast of the cost shock, the announcement of x^T reveals $E_t^{cb}s_t$, and firms no longer need to infer the central bank's cost shock forecast from its instrument setting. The announcement of x_t^T does affect each firm's

12. As noted previously, this is equivalent to announcing an inflation target.

estimate of the cost shock itself, and it therefore also affects individual firm's beliefs about the actions that other firms will undertake. Firms can also use the observation of x^I and the announcement of x^T to infer the central bank's forecast of the demand disturbance.[13] However, this information is not relevant for their pricing decision (in the present model), since private forecasts of the output gap simply equal x_t^T.[14]

Intuitively, one would expect that announcing the target would improve economic outcomes. Since private firms are now able to distinguish between interest rate movements that are simply designed to offset demand disturbances from those reflecting the central bank's estimate of the cost shock, demand shocks will no longer cause fluctuations in the inflation rate. At the same time, releasing information on x_t^T in no way hampers the central bank's ability to achieve its output gap target. Greater transparency should thus improve welfare.

This intuition, however, is not necessarily correct, for reasons similar to those discussed by Morris and Shin. While greater transparency about the central bank's output gap target ensures that instrument changes designed to offset demand shocks no longer lead to fluctuations in inflation expectations, private sector expectations become more sensitive to the announced target than they were to the instrument. Consequently, the central bank's forecast errors in estimating the cost shock generate greater volatility in the inflation rate than they did prior to the introduction of announcements. If this channel dominates the reduction in volatility that occurs because demand shocks no longer affect inflation, loss can actually rise when targets are announced. Whether transparency reduces or increases loss depends on the quantitative characteristics of the economy.

When all firms observe x_t^T, equation (1) becomes (again, assuming serially uncorrelated shocks)

$$\pi_{j,t}^* = (1-\omega)E_t^j\bar{\pi}_t^* + (1-\omega\beta)(\kappa x_t^T + E_t^j s_t).$$

In this case, firm j no longer needs to infer the central bank's estimate of the cost shock. Instead, it must only assess what it

13. Recall that $x_t^T - x_t^I = E_t^{cb}v_t$. The information structure here differs from that employed in Geraats (2005), who studies a model in which the public is uncertain about the central bank's inflation target, as well as the underlying demand and supply shocks. Simply announcing an output gap target was not sufficient, in her model, to reveal the central bank's information about the underlying shocks.

14. This follows because $E_t^j x_t = E_t^j(x_t^I + v_t) = x_t^T + E_t^j(v_t - E_t^{cb}v_t) = x_t^T$.

believes the cost shock is and what it expects other adjusting firms will do. The announcement of the target output gap, which reveals the central bank's estimate of the cost shock, also provides information that the firm may wish to combine with its private signal in forming an estimate of s_t.

Let π_t^A denote the equilibrium inflation rate when x_t^T is announced. The appendix shows that

$$\pi_t^A = \bar{\gamma}_1 s_t + \bar{\gamma}_2 x_t^T = (\bar{\gamma}_1 + \alpha\bar{\gamma}_2\theta_s^{cb})s_t + \alpha\bar{\gamma}_2\theta_s^{cb}\phi_{cb,t}\,. \tag{8}$$

The output gap is given by

$$x_t = x_t^T + v_t - E^{cb}v_t = \alpha\theta_s^{cb}(s_t + \phi_{cb,t}) + (1 - \theta_v^{cb})v_t - \theta_v^{cb}\xi_{cb,t}\,. \tag{9}$$

Comparing these with equations (6) and (7) reveals that the behavior of the output gap is unaffected by the central bank's announcement. The announcement has no effect on the central bank's information set and therefore does not affect either the instrument choice or the behavior of the output gap. This follows from the assumption that the central bank directly controls the gap (up to a forecast error). Hence, the more interesting comparison is between equations (6) and (8).

Inflation is insulated from demand shocks when the central bank announces its output target. This does not necessarily mean, however, that inflation will be more stable. Because the information provided by the central bank is no longer contaminated by demand shocks, public expectations about the cost shock will respond more strongly to the announced value of x_t^T. As a consequence, $|\bar{\gamma}_2| > |\gamma_2|$, so that inflation is affected more by any errors the central bank makes in forecasting the cost shock; the coefficient on $\phi_{cb,t}$ is larger in absolute value in equation (8), the equilibrium expression for inflation with a target announcement, than it is in equation (6), the equilibrium inflation rate without announcements.

Table 1 shows the percent change in the variance of inflation that results from announcing the output gap target as a function of the noise variances in both the private and central bank signals on the cost shock. When private information is very accurate ($\sigma^2_{\phi,j} = 0.1$), announcements cause inflation to become more variable unless the central bank's information is equally accurate. With private sector information quite precise, the central bank's instrument contains little useful information in the absence of the announcement of an output gap target, so γ_2 is very small. The central bank's forecast errors thus have little impact on inflation. When the target is announced, however, more weight is assigned to it, since it now provides direct information

on the central bank's forecast of s_t. If central bank forecast errors have a large variance, inflation volatility increases.

Table 1. Effect of announcing x_t^T
Percent change in inflation variance

	$\sigma^2_{\phi,cb}$				
$\sigma^2_{\phi,j}$	*0.1*	*0.3*	*0.5*	*0.8*	*1.0*
0.1	–18.08	25.32	32.41	30.87	28.55
0.3	–40.95	–30.42	–17.07	–7.41	–4.23
0.5	–26.49	–41.50	–31.65	–21.48	–17.26
0.8	7.08	–41.47	–38.17	–29.98	–25.79
1.0	32.27	–37.06	–38.47	–32.18	–28.34

Source: Author's computations.

The other situation in which announcements can raise inflation variability occurs when the central bank has relatively precise forecasts of the cost shock, while private information is very noisy. When private information is poor, price-setting firms place a very large weight on the central bank's announcement, particularly if the central bank has accurate information. Even though $\sigma^2_{\phi,cb}$ is small, the announcement has such a large weight on private expectations that inflation becomes more volatile.

4. Partial Announcements

In the previous section, I assumed that everyone receives (and uses) the central bank's announcement about its output gap target. As noted in the introduction, however, central banks often release information through speeches and other public venues that reach a selective, rather than a universal, audience. Financial markets closely follow and monitor central bank announcements, but this is unlikely to be the case for the wider public audience. Central banks renowned for their transparency, such as the Bank of England, the Reserve Bank of New Zealand, or the Swedish Rijksbank, produce glossy publications that explain their policy framework and forecasts in great detail, yet the readership of these materials is unlikely to extend very far. Even though mass newspapers report on central bank policies and forecasts, I suspect that only the broad contours of policy reach the proverbial person on the street.

Using a framework similar to the Morris-Shin model, Cornand and Heinemann (2004) demonstrate that the partial release of information can be useful. The basic intuition for Cornand and Heinemann's result is straightforward. The wide release of public information serves to coordinate expectations, and this can make the economy sensitive to noise in the public information; this is the cost of announcements. The gain is that announcements provide information that helps the public form more accurate expectations. When the general announcement of the central bank's information may be costly, it may still pay to release information to some members of the public. If only a few agents receive the central bank's information, private sector expectations will, on average, be more accurate. Since only a few agents receive the information, however, it has little effect on the typical agent's expectations of what others are expecting.

To consider the partial release of information, suppose the central bank announces x_t^T in a manner such that only a fraction, P, of all firms receive the information.[15] As $P \rightarrow 1$, and all firms learn x_t^T, the effects of expected demand shocks on inflation are eliminated, but inflation becomes more responsive to $\phi_{cb,t}$. This may limit how widely the central bank wants to broadcast an announcement of x^T.

This creates three classes of firms in each period: those that do not receive an opportunity to adjust their price, those that do adjust but do not receive the central bank's announcement, and those that adjust and receive the announcements. Consider first the adjusting firms that receive information about x_t^T, corresponding to P. For these firms, their expectation of the current cost shock depends on their private information, $s_{j,t}$, and on the announced target output gap.[16] For the adjusting firms that do not observe x_t^T (corresponding to $1 - P$), expectations can be based only on private signals and the central bank's instrument. These firms must also forecast the central bank's output gap target. Firms that adjust prices in period t must form expectations about what other firms are expecting, and this now

15. This partial release of information can be interpreted in terms of the notion of rational inattention emphasized by Mankiw and Reis (2002): perhaps all firms observe the announcement, but only a fraction, P, actually incorporate the new information into their decisions. The assumption here is not that the central bank selectively provides information to some firms but not others; all firms have an equal probability of obtaining the information.

16. Given the assumptions about policy, the instrument x_t^I provides no relevant information once x_t^T is known. This follows because $x_t = x_t^T v_t - E_t^{cb} v_t$, and x_t^I provides no information about $v_t - E_t^{cb} v_t$. The equilibrium strategy of a firm that observes x_t^T depends on x_t^I, since the firm's expectations about what other firms expect must take into account the behavior of firms that do not observe x_t^T.

depends on the fraction of firms that receive information about the central bank's output gap target. The resulting equilibrium inflation rate with partial announcements, π_t^P, takes the form

$$\pi_t^P = \mu_s(P)s_t + \mu_I(P)x_t^I + \mu_T(P)x_t^T,$$

where the coefficients μ_j depend on P. These coefficients also depend on the policy rule followed by the central bank.

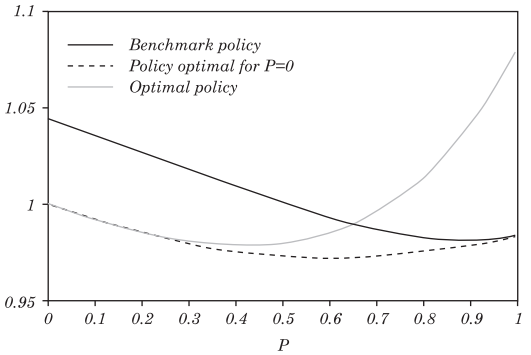
At this point, it is useful to assume a loss function that allows one to assess the effects of partial announcements and to derive optimal policy. I assume the central bank's objective is to minimize a standard quadratic loss function that depends on inflation variability and output gap variability.[17] Specifically, let loss be given by

$$L = \sigma_\pi^2 + \lambda\sigma_x^2, \tag{10}$$

where σ_i^2 denotes the variance of i. For the benchmark simulations, I set $\lambda = 1$ when the inflation rate is expressed at an annual rate.

The solid line in figure 3 shows loss as a function of P for the benchmark policy rule of equation (3). Loss is lower when $P = 1$ (complete announcements) than when $P = 0$ (no announcement), but not fully announcing the output target still generates a small gain. For this policy rule, the minimum loss occurs when $P = 0.9$.

Figure 3. Loss as a Function of *P* for Different Policy Rules



Source: Author's computations.
a. Loss is relative to the optimal policy with P = 0.

17. In section 5 I discuss how conclusions might be affected by using a loss function that is directly related to the welfare costs of fluctuations in the model. Hellwig (2004) provides a welfare-based analysis of the accuracy of public information.

While a policy rule of the form assumed in equation (3) is optimal in a standard new Keynesian model of monetary policy (under discretion), the standard framework assumes symmetric information on the part of firms and the central bank. The central bank's policy instrument thus plays no role in affecting expectations. When the policy instrument also conveys information about the central bank's assessment of the state of the economy, the central bank's incentives are altered. The central bank must now take into account the informational impact its policy choice has on private sector behavior. This incentive effect of information can distort policy. In the context of the model of the previous section, for example, the central bank may not fully adjust its instrument to offset demand shocks, since the movements in x^I necessary to do so would cause the private sector to alter their expectations about the cost shock. Greater transparency in the form of an explicit announcement about the central bank's output gap target would allow the central bank to fully offset demand shocks without affecting private sector expectations about the cost shock. Greater transparency thus improves policy flexibility.[18]

The desirability of announcements depends critically on the policy rule followed by the central bank. For example, suppose the central bank implements a policy rule of the form

$$x_t^I = \alpha_1 E_t^{cb} s_t^{cb} + \alpha_2 E_t^{cb} v_t^{cb}. \tag{11}$$

This rule allows the central bank to let demand shocks affect the output gap target if $\alpha_2 \neq -1$. Suppose further that it chooses α_1 and α_2 to be optimal in the absence of announcements (that is, when $P = 0$).[19] Loss as a function of P with this policy rule is shown by the line labeled "policy optimal for $P = 0$." In this case, loss is lower when no announcements are made than it is with a complete announcement. The optimal P for this rule is 0.42; that is, the output gap target should be conveyed to less than half the private sector. Failure to adjust policy when announcements are made can lead to significant deterioration in loss, as illustrated by the large increase in loss for $P = 1$ when the policy that was optimal in the absence of announcements continues to be followed (see the dashed line). The

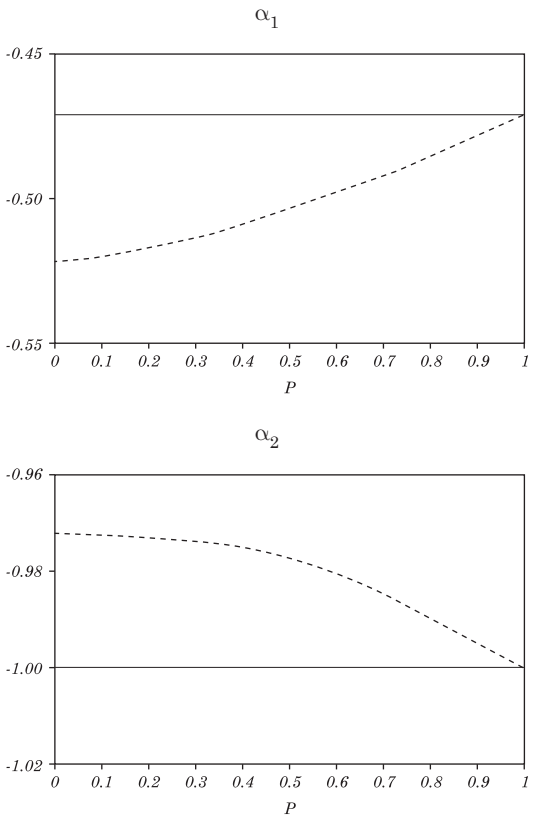
18. Walsh (1999) and Geraats (2005), among others, explore the incentive effect of announcements in different monetary policy contexts. See Geraats (2002) for further references.

19. For the benchmark parameter values, this involves $\alpha_1 = -0.5221$ and $\alpha_2 = -0.9726$.

line labeled "optimal policy" shows the relation between the extent of announcements and loss when policy adjusts to be optimal for each *P*. The lowest loss is now achieved with $P = 0.6$; the announcement of the output gap target should be made to reach most but not all firms.

Figure 4 shows how the policy coefficients vary with the extent of the announcement. The horizontal solid line in each panel shows the value of the coefficient for the standard optimal discretionary policy. The top panel shows that the central bank should react more strongly to a cost shock (α_1 is larger in absolute value) when the bank is less transparent (when P is smaller). The lower panel, in turn, shows that demand shocks should be fully offset in the standard case ($\alpha_2 = -1$).

Figure 4. Optimal Policy Coefficients as a Function of *P*



Source: Author's computations.

In contrast, the central bank's optimal response to its estimate of the demand shock is muted when $P < 1$. This reflects the incentive effect that arises when the central bank is not fully transparent (Geraats, 2002). This is easiest to understand when $P = 0$. Private agents observe only the policy instrument in this case, and they attempt to infer the central bank's cost shock estimate from the instrument. Reacting more strongly to demand shocks adds more noise to the signal provided to the private sector. Errors in the central bank's demand forecast influence inflation, and this also leads to a more muted response to $E_t^{cb} v_t$. As $P \rightarrow 1$, the central bank can adjust its policy instrument to fully offset demand shocks, since private agents are able to distinguish between movements in the instrument stemming from cost shocks and those stemming from demand shocks.

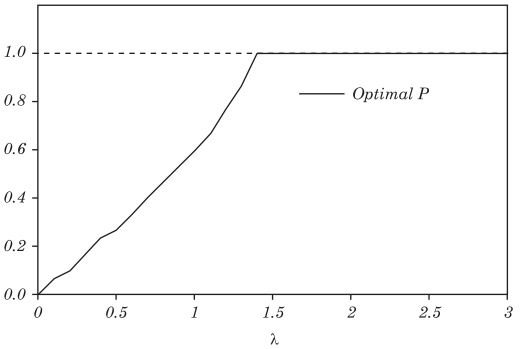
The discussion so far has held λ, the relative weight on the output gap objective in the loss function, fixed. A standard exercise is to vary this weight to map out an efficiency frontier that identifies the minimum inflation variance associated with a given output gap variance. By comparing this frontier for $P = 0$ and for $P = 1$, one can assess the effects of announcing the output gap target on the trade-off faced by the central bank. One can also examine how the frontier for the optimal P compares to the trade-offs for $P = 0$ and $P = 1$ for each λ.

Figure 5 shows the optimal P as a function of λ for the benchmark parameters.[20] Complete transparency ($P = 1$) is only optimal for central banks that place a large weight on output gap volatility relative to inflation volatility. With $P = 1$, the central bank can set $\alpha_2 = -1$; that is, it will completely insulate the output gap from any forecasted demand shock. The gain from setting $\alpha_2 = -1$ is larger for central banks that place a correspondingly large weight on stabilizing the output gap. However, if λ is small, so that the central bank cares primarily about inflation stability, then the optimal P is less than one. By setting $P < 1$, the central bank ensures that private firms do not overreact to its instrument or to the announcement. It will be optimal, in this case, not to fully offset demand shocks, but the resulting increase in output gap volatility leads to only a small impact on the loss function when λ is small.

For the benchmark value of $\sigma^2_{\phi,j}$, the critical value of λ at which it becomes optimal to fully announce targets decreases as the quality of the central bank's information about the cost shock rises. With more accurate information on the cost shock, the central bank is less concerned that its forecast errors will create excessive inflation

20. The values of λ are based on inflation being expressed at annual rates.

Figure 5. The Optimal Extent of Announcements as a Function of λ: $\sigma^2_{\phi,j} = \sigma^2_{\phi,cb} = 0.2$

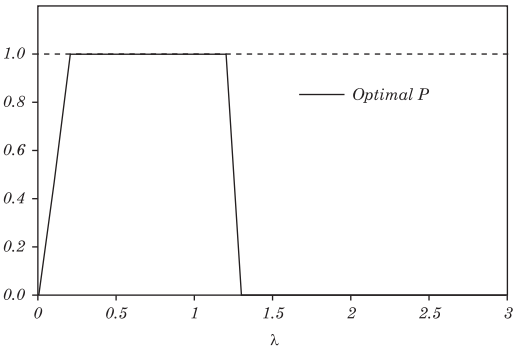


Source: Author's computations.

volatility. As suggested by table 1, however, if private information is very poor, announcements can increase inflation volatility and the optimal *P* will fall.

As discussed earlier, the benchmark calibration, in which the firm's private information and the central bank's information about the aggregate cost shock are equally noisy, may overstate the accuracy of the private information that an individual firm is likely to have about aggregate conditions. Figure 6 shows the effects of

Figure 6. The Optimal Extent of Announcements as a Function of λ: $\sigma^2_{\phi,j} = 0.4,\ \sigma^2_{\phi,cb} = 0.1$



Source: Author's computations.

instead assuming $\sigma^2_{\phi,j} = 0.4$ and $\sigma^2_{\phi,cb} = 0.1$. When the central bank has relatively more accurate information about any aggregate cost shock, then it is optimal to widely announce the output gap target as long as some weight (but not a large weight) is placed on output gap volatility in the loss function. The figure offers an interesting perspective on the rise of central bank transparency. If inflation-targeting central banks are viewed as focusing primarily on inflation objectives while still caring about output fluctuations, such that λ is small but still positive, they are most likely to find a policy of complete transparency to be optimal.

5. Lessons and Extensions

In this paper, I have investigated the role of transparency when private information is diverse and the central bank provides public information either implicitly, by setting its policy instrument, or explicitly, by making announcements about its short-run targets. In the absence of explicit announcements, the impact the policy instrument has on inflation depends critically on the information the instrument conveys to the public about the state of the economy. By announcing its short-run output gap target (equivalently, its short-run inflation target), the central bank reveals information on its forecast of demand and cost shocks. This provides more accurate public information to price-setting firms, but it also makes private sector decisions more sensitive to the central bank's forecast errors. As a result, inflation may become more volatile when the central bank announces its short-run target. For most combinations of the relative accuracy of private and central bank information, however, the net result of making announcements is to reduce inflation variability. When no announcement is made, the central bank will not fully neutralize the impact of demand shocks on the output gap and inflation. The signaling effect of policy actions constrains the central bank's response to its forecasts of demand shocks. By making announcements, the central bank can respond more flexibly and stabilize the output gap from demand disturbances.

Being transparent is seldom an all-or-nothing proposition. Partial announcements provide one means of investigating how widely central banks should disseminate information about their targets. If central banks have more accurate information about aggregate disturbances than private firms do (that is, $\sigma^2_{\phi,j} > \sigma^2_{\phi,cb}$), then inflation targeters

should be very transparent (that is, $P = 1$). Only inflation nutters or central banks that place a large weight on output gap stability would find it optimal to make no announcements.

By assuming serially uncorrelated shocks, I was able to ignore the role of expectations about future inflation, considering only the case in which the private sector observes the central bank's current instrument setting, while some (or all) private firms may observe the current output gap target. The basic framework, however, can be used to consider the implications of announcements about future instrument values or targets. First, consider a situation in which the central bank announces its expected future output gap target.[21] If disturbances are serially uncorrelated, expected future targets and instruments would all equal zero, and their announcement would convey no further information to the public. Assume then that cost and demand shocks do display some degree of persistence. Unless the central bank has additional information that would help it forecast future innovations, the announcements of the future target conveys no additional information, once the current target is announced.

The Federal Reserve has, in recent years, phrased its press releases after FOMC meetings to give markets a strong signal about the likely future direction of interest rates. In terms of the present model, this can be interpreted as providing information about $x^I_{t+1} + 1$. Suppose the central bank announces its expected future instrument setting. In this case, the public obtains information on

$$x^I_t = \alpha_1 \theta^{cb}_s s^{cb}_t + \alpha_2 \theta^{cb}_v v^{cb}_t \text{ and}$$

$$E^{cb}_t x^I_{t+1} = \alpha_1 E^{cb}_t s^{cb}_{t+1} + \alpha_2 E^{cb}_t v^{cb}_{t+1}.$$

As long as cost and demand disturbances are characterized by differing degrees of serial correlation, the private sector is able to infer both central bank signals, s_t^{cb} and v_t^{cb}, from the announced information. Announcing the future path of the policy instrument thus represent an alternative to announcing the policy targets.

An important future extension of the analysis will be to examine the case of unobservable state variables. The estimation problem facing both the private sector and the central bank is greatly complicated when shocks are serially correlated and unobserved. Svensson and

21. This is equivalent in the present model to announcing a future inflation target.

Woodford (2004) consider the case of optimal policy with unobserved states and asymmetric information between the private sector and the central bank. As in the standard literature, however, they assume that all private sector information is common information, and they further assume that the private sector has full information about aggregate states.

While some of the effects of transparency could be assessed by examining the implications for inflation volatility, a loss function was required to determine the optimal extent to which information should be made public. I employed a standard quadratic loss function. This can be misleading, as Hellwig (2004) demonstrates, and it tends to undervalue the gains from transparency. The reason is based on the underlying distortion that makes inflation costly in new Keynesian models. The welfare costs of inflation are due to the increase in price dispersion across firms that inflation generates. When firms have private information, this introduces a new source of price dispersion and exacerbates the welfare costs of inflation. The central bank can reduce the extent of price dispersion by providing information that is common to all firms. This represents a welfare gain and increases the advantages of adopting a transparent policy regime. In terms of the model of partial announcements, employing an explicit welfare criterion is likely to increase the optimal degree of transparency.

Appendix

This appendix provides details of the model underlying the discussion in the text The probability that a firm does not have the opportunity to adjust its price is ω. The log price of firm i in period t is $p_{i,t}$, and p_t is the aggregate log price level. Denote by $p_{i,t}$* the price chosen by firm i if it adjusts its price in period t. Then,

$$p_t = (1-\omega)\bar{p}_t^* + \omega p_{t-1}\,, \tag{12}$$

where $\bar{p}_t^* = \int_0^1 p_{i,t}^* di$. Equation (12) implies that $\bar{p}_t^* - p_t = \omega(\bar{p}_t^* - p_{t-1})$ and

$$\pi_t = p_t - p_{t-1} = (1-\omega)(\bar{p}_t^* - p_{t-1}) = \left(\frac{1-\omega}{\omega}\right)(\bar{p}_t^* - p_t). \tag{13}$$

Let φ denote real marginal cost, and assume a steady-state inflation rate of zero. If firm j can adjust its price in the period, it sets its current price equal to the expected discounted value of current and future nominal marginal cost, φ + p. Future marginal cost is discounted by the probability that the firm has not received another opportunity to adjust ω and by the discount factor, β. In addition, I assume price is affected by a mean zero aggregate cost shock, s_t, that alters the firm's desired price. Hence,

$$p_{j,t}^* = (1-\omega\beta)\sum_{i=0}^{\infty}(\omega\beta)^i\,(E_t^j\varphi_{t+i} + E_t^j p_{t+i} + E_t^j s_{t+i}). \tag{14}$$

where E_t^j denotes the expectations based on the information available to firm j. The key assumption in equation (14) is that prior to setting its price, the firm does not observe the aggregate price level or the realization of either the current marginal cost or the cost shock.

Individual firms may set different prices because they base their expectations on different information sets. To simplify, I assume that all information is revealed at the end of each period. This implies that

$$E_t^j p_{j,t+1}^* = E_t^j \bar{p}_{t+1}^*\,.$$

Each firm expects that if it can adjust in t + 1, it will set the same price as other adjusting firms.

Using equation (13) and defining $\pi_{j,t}$* = $p_{j,t}$* − p_{t-1} one obtains, after some manipulation,

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)E^j_t\varphi_t + (1-\omega\beta)E^j_t s_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1}, \qquad (15)$$

where $\bar{\pi}^*_t = \bar{p}^*_t - p_{t-1}$. Hence, firm j adjusts its price based on its expectations of what other adjusting firms are choosing ($E^j_t\bar{\pi}^*_t$), its expectations about current marginal costs and the cost shock, and its forecast of next-period aggregate inflation. Assume real marginal cost is linearly related to an output gap measure, x_t: $\varphi_t = \kappa x_t$. Then,

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)\kappa E^j_t x_t + (1-\omega\beta)E^j_t s_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1}. \qquad (16)$$

It is interesting to contrast this equation with the standard case in which all firms have identical information sets and are able to observe the current disturbances. In the standard Calvo model, $\pi^*_{j,t} = \bar{\pi}^*_t$ for all j, so equation (15) becomes

$$\pi^*_t = \left(\frac{1-\omega\beta}{\omega}\right)\kappa x_t + \left(\frac{1-\omega\beta}{\omega}\right)s_t + \left(\frac{\beta}{1-\omega}\right)E_t\pi_{t+1}.$$

Then, using equation (13), this becomes

$$\pi_t = (1-\omega)\pi^*_t = \left[\frac{(1-\omega)(1-\omega\beta)}{\omega}\right](\kappa x_t + s_t) + \beta E_t\pi_{t+1},$$

which differs from the standard from only in the coefficient on the cost shock. This is due to the fact that I include the shock in the equation for the firm's optimal price (equation 14), rather than just adding it on at the end.

No Announcements

In the absence of announcements, the information available to firm j is derived from its private signal, $s_{j,t}$, and from observing the policy instrument, x^I_t. These are related to the cost shock innovation and the output gap according to

$$\begin{bmatrix} s_t \\ x_t \end{bmatrix} = \begin{bmatrix} s_{j,t} \\ x^I_t \end{bmatrix} + \begin{bmatrix} \phi_{s,t} \\ v_t \end{bmatrix}.$$

Let $\Gamma = V_{ou}V_{oo}^{-1}$, where V_{ou} is the covariance matrix between the observed signals [$s_{j,t}$, x^I_t] and the unobserved variables [s_t, x_t] and

V_{oo} is the covariance matrix of the observed signals. Then, firm j's expectation of $[s_t\ x_t]$ conditional on $s_{j,t}$ and x_t^I is

$$E_t^j \begin{bmatrix} s_t \\ x_t \end{bmatrix} = \Gamma \begin{bmatrix} s_{j,t} \\ x_t^I \end{bmatrix}.$$

Let $\Gamma_{i,j}$ denote the i,j^{th} element of Γ. Then $E_t^j s_t = \Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I$, and $E_t^j x_j^T = \Gamma_{21} s_{j,t} + \Gamma_{22} x_t^I$. Generally, $\Gamma_{i,j}$ depends on the policy parameter, α (see equation (3)).

Firm j's price setting is now given by

$$\begin{aligned} \pi_{j,t}^* &= (1-\omega) E_t^j \bar{\pi}_t^* + (1-\omega\beta)\kappa (\Gamma_{21} s_{j,t} + \Gamma_{22} x_t^I) \\ &\quad + (1-\omega\beta)(\Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I), \end{aligned} \tag{17}$$

where the assumption of serially uncorrelated shocks has been used to set $E_t^j \pi_{t+1} = 0$. An equilibrium strategy for firm j will take the form

$$\pi_{j,t}^* = \tilde{\gamma}_1 s_{j,t} + \tilde{\gamma}_2 x_t^I. \tag{18}$$

In forming expectations about the pricing behavior of other firms adjusting in the current period, firm j's expectation of $\bar{\pi}_t^*$ is given by

$$E_t^j \bar{\pi}_t^* = \tilde{\gamma}_1 E_t^j s_{j,t} + \tilde{\gamma}_2 x_t^I = \tilde{\gamma}_1 \Gamma_{11} s_{j,t} + (\tilde{\gamma}_1 \Gamma_{12} + \tilde{\gamma}_2) x_t^I.$$

Substituting this into equation (17) yields

$$\begin{aligned} \pi_{j,t}^* &= \left[(1-\omega)\tilde{\gamma}_1 \Gamma_{11} + (1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})\right] s_{j,t} \\ &\quad + \left[(1-\omega)(\tilde{\gamma}_1 \Gamma_{12} + \tilde{\gamma}_2) + (1-\omega\beta)(\Gamma_{12} + \kappa\Gamma_{22})\right] x_t^I. \end{aligned}$$

When I equate coefficients in this expression to those in equation (18), it follows that

$$\tilde{\gamma}_1 = \frac{(1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}} \text{ and}$$

$$\tilde{\gamma}_2 = \frac{(1-\omega)\tilde{\gamma}_1 \Gamma_{12}\,(1-\omega\beta)(\Gamma_{12} + \kappa\Gamma_{22})}{\omega}. \tag{19}$$

Aggregating over all adjusting firms yields equation (4) of the text:

$$\pi_t = (1-\omega)\bar{\pi}_t^* = \gamma_1 s_t + \gamma_2 x_t^I ,$$

where $\gamma_1 = (1-\omega)\tilde{\gamma}_1$ and $\gamma_2 = (1-\omega)\tilde{\gamma}_2$.

Announcements

When the central bank announces x_t^T,

$$E_t^j \begin{bmatrix} s_t \\ x_t \end{bmatrix} = \bar{\Gamma}_1 s_{j,t} + \bar{\Gamma}_2 x_t^T$$

where $\bar{\Gamma} = \bar{\mathbf{V}}_{ou}\bar{\mathbf{V}}_{oo}^{-1}$, in which $\bar{\mathbf{V}}_{oo}$ is the covariance matrix of the observed signals $[s_{j,t}, x_t^T]$, and is the covariance matrix between the observed and unobserved signals, s_t and x_t.

The equilibrium is derived following the same steps as in the previous section. Let $\bar{\Gamma}_{i,j}$ denote the j^{th} element of $\bar{\Gamma}_i$. Then equilibrium inflation is

$$\pi_t^A = \tilde{\gamma}_1 s_{j,t} + \tilde{\gamma}_2 x_t^T , \tag{20}$$

where

$$\tilde{\gamma}_1 = \frac{(1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}} \text{ and}$$

$$\tilde{\gamma}_2 = \frac{(1-\omega)\tilde{\gamma}_1\Gamma_{12}\,(1-\omega\beta)(\Gamma_{12}+\kappa)}{\omega}.$$

Partial Announcements

This subsection provides the solution in the general case of partial announcements and a policy that reacts to both cost and demand shocks. Specifically, assume

$$x_t^I = \alpha_1 E_t^{cb} s_t + \alpha_2 E_t^{cb} v_t ,$$

so that

$$x_t^T = \alpha_1 E_t^{cb} s_t + (1+\alpha_2) E_t^{cb} v_t .$$

In the previous sections, $\alpha_2 = -1$, so that the target gap was independent of the central bank's expected demand disturbance.

Consider first those adjusting firms that receive information about x_t^T (or π_t^T). There are a fraction, P, of such firms; let j index such firms. For these firms, $E_t^j s_t = H_1 s_{j,t} + H_2 x_t^T$ and $E_t^j x_t = x_t^T$. The pricing decision of such a firm satisfies

$$\pi_{j,t}^* = (1-\omega)E_t^j \bar{\pi}_t^* + (1-\omega\beta)\kappa x_t^T + (1-\omega\beta)(H_1 s_{j,t} + H_2 x_t^T). \tag{21}$$

Assume the equilibrium strategy for such a firm is

$$\pi_{j,t}^* = \alpha_1 s_{j,t} + \alpha_2 x_t^I + \alpha_3 x_t^T. \tag{22}$$

The instrument x_t^I appears because it provides information to firms observing x_t^T that is useful in assessing the expectations of firms that do not observe x_t^T.

For the $1 - P$ fraction of adjusting firms who do not observe x_t^T, expectations can be based only on private signals and the central bank's instrument. Let h index these firms. In addition, these firms must forecast both the cost shock and the output gap. Hence,

$$E_t^h s_t = \Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I, \text{ and}$$

$$E_t^h x_t = \Gamma_{21} x_{j,t} + \Gamma_{22} x_t^I.$$

The pricing decision of such a firm satisfies

$$\begin{aligned}\pi_{h,t}^* = {} & (1-\omega)E_t^h \bar{\pi}_t^* + (1-\omega\beta)\kappa(\Gamma_{21} s_{h,t} + \Gamma_{22} x_t^I) \\ & + (1-\omega\beta)(\Gamma_{11} s_{h,t} + \Gamma_{12} x_t^I).\end{aligned} \tag{23}$$

Assume the equilibrium strategy for such a firm is

$$\pi_{h,t}^* = \alpha_1' s_{h,t} + \alpha_2' x_t^I. \tag{24}$$

Given the strategies of equations (22) and (24), for firms that observe x_t^T,

$$E_t^j \bar{\pi}_t^* = P(a_1 E_t^j s_t + a_2 x_t^I + a_3 x_t^T) + (1-P)(a_1' E_t^j s_t + a_2' x_t^I),$$

implying that

$$E_t^j \bar{\pi}_t^* = \left[Pa_1 + (1-P)a_1'\right]H_1 s_{j,t} + \left[Pa_2 + (1-P)a_2'\right]x_t^I + \left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right]x_t^T.$$

Substituting this expression into equation (21) yields

$$\begin{aligned}\pi_{j,t}^* &= (1-\omega)\left\{\left[Pa_1 + (1-P)a_1'\right]H_1 s_{j,t}\right\} + (1-\omega)\left[Pa_2 + (1-P)a_2'\right]x_t^I \\ &\quad + (1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right]x_t^T \\ &\quad + (1-\omega\beta)\kappa x_t^T + (1-\omega\beta)(H_1 s_{j,t} + H_2 x_t^T) \\ &= \left\{(1-\omega)\left[Pa_1 + (1-P)a_1'\right]H_1 + (1-\omega\beta)H_1\right\}s_{j,t} \\ &\quad + (1-\omega)\left[Pa_2 + (1-P)a_2'\right]x_t^I \\ &\quad + \left\{(1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right] + (1-\omega\beta)(\kappa + H_2)\right\}x_t^T.\end{aligned}$$

Equating coefficients with those in equation (22),

$$a_1 = (1-\omega)\left[Pa_1 + (1-P)a_1'\right]H_1 + (1-\omega\beta)H_1; \tag{25}$$

$$a_2 = (1-\omega)\left[Pa_2 + (1-P)a_2'\right]; \text{ and} \tag{26}$$

$$a_3 = (1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right] + (1-\omega\beta)(\kappa + H_2). \tag{27}$$

For firms that do not observe x_t^T,

$$E_t^h \bar{\pi}_t^* = P(a_1 E_t^h s_t + a_2 x_t^I + a_3 E_t^j x_t^T) + (1-P)(a_1' E_t^h s_t + a_2' x_t^I),$$

implying that

$$E_t^h \bar{\pi}_t^* = \left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11}\right]s_{h,t} + \left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + (1-P)a_2'\right]x_t^I + Pa_3 E_t^h x_t^T.$$

For these firms, $E_t^h x_t^T = E_t^h x_t$. Hence,

$$E_t^h \bar{\pi}_t^* = \left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11} + Pa_3\Gamma_{21}\right]s_{h,t} + \left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + (1-P)a_2' + Pa_3\Gamma_{22}\right]x_t^I.$$

Substituting this expression into equation (23) yields

$$\begin{aligned} E_t^h \bar{\pi}_t^* &= (1-\omega)\left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11} + Pa_3\Gamma_{21}\right]s_{h,t} \\ &\quad + (1-\omega)\left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + Pa_3\Gamma_{22}\right]x_t^I \\ &\quad + (1-\omega\beta)\kappa\left(\Gamma_{21}s_{h,t} + \Gamma_{22}x_t^I\right) + (1-\omega\beta)\left(\Gamma_{11}s_{h,t} + \Gamma_{12}x_t^I\right). \end{aligned}$$

Equating coefficients with equation (24),

$$a_1' = (1-\omega)\left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11} + Pa_3\Gamma_{21}\right] + (1-\omega\beta)(\kappa\Gamma_{21} + \Gamma_{11}); \quad (28)$$

$$\begin{aligned} a_2' &= (1-\omega)\left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + (1-P)a_2' + Pa_3\Gamma_{22}\right] \\ &\quad + (1-\omega\beta)(\kappa\Gamma_{22} + \Gamma_{12}). \end{aligned} \quad (29)$$

Equations (25)–(27) and (28)–(29) can be solved jointly for $\alpha 1$, α_2, α_3, α'_1, and α'_2, and actual inflation is

$$\begin{aligned} \pi_t^P &= (1-\omega)P\left(a_1 s_t + a_2 x_t^I + a_3 x_t^T\right) + (1-\omega)(1-P)\left(a_1' s_t + a_2' x_t^I\right) \\ &= (1-\omega)\left\{\left[Pa_1 + (1-P)a_1'\right]s_t + \left[Pa_2 + (1-P)a_2'\right]x_t^I + Pa_3 x_t^T\right\}. \end{aligned}$$

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Inflation Targeting versus Price-Path Targeting: Looking for Improvements

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The world's central banks have undergone dramatic changes in the past fifteen years. Increases in independence and transparency have been coupled with a shift in focus. Price stability is now the paramount objective for the vast majority of modern central bankers. Combined, these changes in central bank structure and policy framework have yielded substantial benefits. Low and stable inflation has brought with it high and stable growth.

Taking recent successes as a starting point, we look at the possibility for further improvements. Could countries benefit by shifting from inflation targeting to price-path targeting? The answer depends on the structure of each country's economy—specifically, on how slowly output growth returns to its sustainable growth rate after moving away from the target. If deviations of output from its potential are relatively persistent, a country is likely to benefit from a shift to price-path targeting. As Svensson (1999b) argues, if the output gap is persistent, focusing on the price level rather than the inflation rate will contribute to reducing fluctuations in output and inflation under a discretionary rule.

Numerous authors (including some in this volume) discuss the benefits associated with implementing a pure inflation-targeting regime. Taking the seminal work of Svensson (1999b) as a starting

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point, we study the relative merits of price-level targeting versus inflation targeting. A number of authors examine this comparison and come to various conclusions. For example, Barnett and Engineer (2000) argue that eliminating price-level drift does a better job than inflation targeting in allowing relative prices to allocate resources and in reducing tax-related distortions and the unintended transfers of wealth between savers and debtors. Chadha and Nolan (2002) employ a representative-agent general equilibrium model to compare the performance of price-level versus inflation targeting for the United Kingdom. Consistent with Svensson's results, they find that the volatility of inflation, output, and interest rates is lower under a price-level target than under an inflation target. Eggertsson and Woodford (2003) and Svensson (2003) show that under certain conditions, price-level targeting contributes toward avoiding the problems associated with the zero nominal interest floor. If the economy experiences either deflation or inflation that is lower than its target for one period, then price-level targeting implies that the inflation rate must be higher in future periods, thereby assisting the economy in countering a liquidity trap.

Pure inflation targeting can create nominal indeterminacy because of its forward-looking nature. Carlstrom and Fuerst (2002) note that forward-looking private agents will sometimes set prices in anticipation of monetary policy that validates their expectations at any level of inflation. By contrast, price-level targeting has a backward-looking feature that eliminates this problem. Dittmar and Gavin (2005) employ a flexible-price real business cycle model to show that pure inflation targeting leads to multiple equilibria, whereas targeting a price-level path can eliminate this indeterminacy.

Price-path and inflation targeting are not the only choices, however. Combinations are also possible. While inflation targeting implies that the (log) price level will be a random walk, and price-path targeting means that prices will quickly revert to their target and be as close to white noise as possible, hybrid rules imply a specific level of persistence. Hybrid or average rules that combine the two extremes are, in fact, optimal in most cases, as shown by Nessén and Vestin (2005).

Our discussion in this paper focuses on these hybrids, with the goal of deriving an optimal rule for a broad set of countries. We build on the earlier work of Cecchetti and Kim (2005) as we study the horizon over which price-path or inflation targets should be evaluated. Following the intuition first provided in King (1999), we examine the

equivalence between a rule with a high weight on inflation targeting that is evaluated only infrequently and one with a high weight on the price-path that is evaluated often. For each country, we are able to derive a horizon for target evaluation that would result in optimal policy.[1] The general result is that when deviations of output from its potential are less persistent, the optimal horizon for target evaluation will be shorter.

The remainder of the paper is developed in five sections. Section 1 provides the theoretical framework that is the basis for our empirical examination. Here we discuss the policymaker's problem and derive the optimal inflation/price-path hybrid targeting rule. We then show how this has implications for the horizon at which the target should be evaluated. Section 2 presents the basic empirical results of the paper. We have thirty-one years of annual data for seventy countries; for eighteen of these countries, we also have twenty-four years of quarterly data. While the larger data set provides some insights, structural changes in the 1973–2003 period lead us to focus on the quarterly results. Taken together, our results suggest little difference between developed and emerging market countries, but the methods of detrending the data matter. When we employ filtering techniques that allow for time variation in mean growth rates, we (unsurprisingly) estimate less persistence in both output and the price level. In sections 3 and 4, we look at certain aspects of the results in more detail. First, we examine time variation in the estimates. Overall, we find that output persistence has not changed much over time, but price-level persistence has fallen. Moreover, the declines are larger in countries that have adopted publicly announced inflation targets. That is, price paths are more stable in these countries. A country's monetary policy regime does matter. Finally, in section 5 we provide some concluding remarks.

1. The Theoretical Framework

We begin with a bit of theory that is based on Cecchetti and Kim (2005). Following Svensson (1999b), that paper examines the case in which society cares about the weighted average of inflation and

1. The horizon for target evaluation is in addition to the time it takes for a policy action to have an impact on the central bank's objectives, usually inflation and the output gap.

output variability. If it were possible to bind central bankers to react to shocks in specific ways—that is, to enforce a commitment to a specific reaction function—then policymakers should be held accountable for minimizing society's loss function. As Svensson shows, however, given discretion over the instrument rule, it may be better to hold policymakers accountable for minimizing a different loss function.[2] The appropriate loss function depends on the degree to which output is persistent, and Svensson concludes that if the choice is between inflation targeting and price-path targeting, then the critical cut-off occurs when the autocorrelation of output deviations from potential equals one-half.[3] Cecchetti and Kim generalize this result, noting that inflation and price-path targeting are the limiting cases of a continuum of possibilities. That is, many hybrid targeting regimes lie between these two options. The mix depends on output persistence.

Cecchetti and Kim (2005, sect. 4.1) present a model derived in two distinct steps. First, they derive the solution to the policymaker's problem (under discretion) assuming that the objective function is known. Second, given this solution, they find the targeting regime that is best from the society's point of view. To present the results, we start by assuming that the central bank minimizes the following function:

$$L^{CB} = E\left\{\sum_t \beta^t \left[\lambda (p_t - p_t^*)^2 + (1-\lambda)(y_t - y_t^*)^2\right]\right\}, \tag{1}$$

where L^{CB} is the central bank's loss function; E is the expectation operation, p is the log of the actual price level; p^* is the desired (target) price level; y is log of current output; y^* is the log of potential or desired output; and β is a discount factor. The targeting regime—whether it is inflation targeting, price-path targeting, or something in between—depends on the definition of p^*. To see this, note that inflation targeting occurs when

$$p_t^*(\mathrm{IT}) = p_{t-1} + \pi^*, \tag{2}$$

where π^* is the inflation target. By contrast, price-path targeting is when

2. Price-level or hybrid targeting can be justified under commitment, as well. In models with forward-looking components where the social and central bank loss functions coincide, such as those described in Woodford (2003) and Giannoni and Woodford (2005), various versions of price-level and hybrid targeting are optimal. The results in the appendix to Cecchetti and Kim (2005), where inflation targeting is optimal under commitment when agents are purely backward looking, are a special case of these.

3. Dittmar and Gavin (2000) and Vestin (2006) also discuss this result.

$$p_t^* \text{ (PPT)} = p_{t-1}^* + \pi^*. \tag{3}$$

Under inflation targeting, the current target is last period's realized level of prices plus the increment π^*, while under price-path targeting, the increment is added to last period's target. In the language of the literature on money-growth targeting, inflation targeting allows for "base drift" whereas price-path targeting does not.

It is only a small step from considering equations (2) and (3) in isolation to studying a weighted average. This is what Batini and Yates (2003) refer to as the hybrid case, in which the price level is allowed to drift somewhat after moving away from the target. We can write this as

$$\begin{aligned} p_t^* \text{ (Hybrid)} &= \eta(p_{t-1} + \pi^*) + (1-\eta)(p_{t-1}^* + \pi^*) \\ &= \eta p_{t-1} + (1-\eta)p_{t-1}^* + \pi^*, \end{aligned} \tag{4}$$

where η is the relative weight placed on inflation targeting. The two extremes, $\eta = 0$ and $\eta = 1$, represent price-path and inflation targeting, respectively.

Normalizing both π^* and y^* to zero (so that both the price path and output are measured as deviation from the targets), we can now rewrite the objective function (equation 1) as

$$L^{CB} = E\left\{\sum_t \beta^t \left[\lambda(p_t - \eta p_{t-1})^2 + (1-\lambda)y_t^2\right]\right\}. \tag{5}$$

Following Svensson (1999b), Cecchetti and Kim close the model with an open economy neoclassical Phillips curve:

$$y_t = \rho y_{t-1} + \alpha(p_t - p_t^e) + \varphi p_t^F + \varepsilon_t, \tag{6}$$

where y_t is now the output gap; p_t^e is the expectation of the log price level (p) at t; p_t^F is the foreign price level denominated in domestic currency; ρ, α, and φ are constants; and ε is an independent and identically distributed shock with variance σ_ε^2.

The role of central bank policymakers is to choose a path for the price level, p_t, that minimizes the objective function (equation 5) subject to the constraint imposed by the dynamics in equation (6). As Cecchetti and Kim show, the rational expectations solution for this problem yields expressions of the form

$$p_t = \eta p_{t-1} + b y_{t-1} + c\,(\varphi p_t^F + \varepsilon_t) \text{ and} \tag{7}$$

$$y_t = \rho y_{t-1} + (1 + \alpha c)(\varphi p_t^F + \varepsilon_t), \tag{8}$$

where b and c are complex functions of the structural parameters ρ and α and the preference parameters λ and β.[4]

A number of authors, including Parkin (2000), note a technical restriction for the existence of a solution to this problem. The condition is that λ has to be sufficiently large relative to ρ. In other words, if output is highly persistent and central bankers care sufficiently about output variability, then the solution will not exist.[5] Policymakers will generate infinite price-level volatility in an attempt to meet their output stabilization goals. The condition is extremely interesting, as it depends on the absolute size of the numbers. That is, it depends on the relative importance of inflation and output variability in the objective—something that has no time units—and a persistence parameter that critically depends on the frequency of the data. The lower the data frequency, the smaller ρ will presumably be, and the less likely the condition is to bind. We return to the issue of data frequency shortly.

To complete the derivation, we move to society's problem. We assume that the social loss is written in terms of output and inflation variability. If we further assume that the preference parameter λ in the central bank's objective and the one in society's are the same, the social loss function is[6]

$$L^S = \lambda \sigma_\pi^2 + (1 - \lambda)\sigma_y^2 . \tag{9}$$

4. Equations (7) and (8) are later estimated using annual data. Following Cecchetti and Kim (2005), the results for the quarterly data analysis come from estimating the following equations:

$$p_t = \eta p_{t-1} + \sum_{i=1}^{4} b_i y_{t-i} + \phi_p p_t^F + e_{1t} \text{ and} \tag{7′}$$

$$y_t = \rho y_{t-1} + \sum_{i=1}^{4} \gamma_i \Delta y_{t-i} + \phi_y p_t^F + e_{2t} . \tag{8′}$$

5. See Cecchetti and Kim (2005, p. 179) for the complex formulas.

6. The two lambdas do not need to match. Following Rogoff (1985), the central banker's weight on output and inflation stabilization could deviate from that of society. Cecchetti and Kim (2005) examine this possibility, showing when it might be reasonable for society to find an inflation-averse central banker. They show that as ρ increases for a fixed social level of λ, there is reason to find a central banker with an increasingly high value for λ.

Cecchetti and Kim show that the value of η that minimizes equation (9)—which constitutes the optimal hybrid—satisfies the following condition:

$$\eta^* = \frac{1-\rho}{2\rho}. \tag{10}$$

As output becomes more persistent (ρ increases toward one), η^* goes to zero, and the optimal hybrid targeting regime thus approaches pure price-path targeting.

In his discussion of Cecchetti and Kim, Mankiw (2005) notes a problem that arises when taking this model to the data. What, Mankiw asks, should the frequency of the data be? Cecchetti and Kim focus on quarterly data. Is this appropriate? Mankiw suggests pinning down the answer to the question by looking at the frequency over which expectations are formed and wages are set. Since the crucial parameter in the model is the persistence of the output gap (ρ), and the output gap results from expectation errors, Mankiw reasons that this is where to determine whether quarterly data are appropriate. He concludes that the answer is no, and that the model should be applied to annual data.

Mankiw comes to this conclusion by focusing on wages. The answer might be different if we instead direct our attention to prices. The rationale for including prices (or inflation) in the social and central bank loss functions is that nominal price changes are inefficient. We would like nominal prices to stay fixed for as long as possible. The sooner prices return to their target, the better. The implication is that the data frequency should match the frequency of price changes.[7]

The most recent evidence indicates that the median duration of price spells (at the retail level) is 10.6 months in the euro area and 4.6 months in the United States (see Dhyne and others, 2005). The distribution of price spells is positively skewed, so the mean is substantially higher than the median. For the euro area, the mean exceeds a year, and it is over six months for the United States. This leads us to conclude that the appropriate frequency is somewhere between one quarter and one year.

We come to a more informative answer if we pose the problem somewhat differently. Instead of asking what the data frequency should be for the computation of the optimal hybrid targeting rule,

7. We thank Gauti Eggertsson for clarifying this argument.

we can look for a joint estimate of η and the horizon over which the central bank is trying to achieve this goal. Both are then measured in the units of the data. For example, if we use annual data, then we have the optimal hybrid rule at an annual frequency, and it is to be evaluated over the horizon computed from annual data.

Here is how it works. First, the ρ and η in equations (7) and (8) have no natural time units; nor does the η in the central bank's objective (equation 5). Equation (8), however, shows that if ρ is measured over quarterly data—call this ρ(quarterly)—then the corresponding annual persistence estimate is approximately $\rho(\text{annual}) = \rho(\text{quarterly})^4$, because the system in equations (7) and (8) is recursive. That is, the annual ρ is the quarterly ρ raised to the fourth power. Equation (7) reveals that the behavior of η is exactly analogous: $\eta(\text{annual}) = \eta(\text{quarterly})^4$.

We now turn to the solution for the optimal hybrid, where η is a function of ρ. For values of η and ρ, we can compute the implied horizon, h, from the following expression:

$$\eta^h = \frac{1-\rho^h}{2\rho^h}. \tag{11}$$

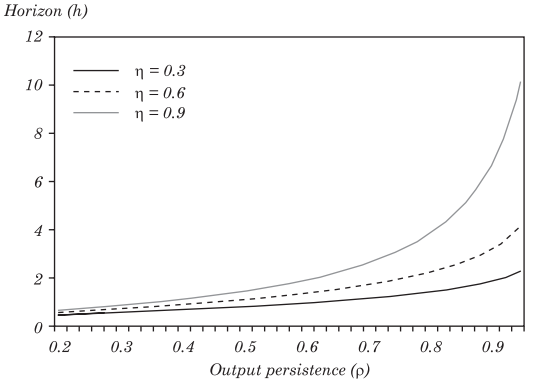
For a given persistence in the price level and the output gap, equation (11) provides an estimate of the horizon at which a central bank that is behaving optimally evaluates its hybrid target. As a practical matter, the h that solves equation (11) has to be added to the lag that it takes for policy actions to influence the central bank's objectives.

Figure 1 provides a sense of the relationship between output gap persistence (ρ), price-level persistence (η), and the implied horizon (h).[8] As either η or ρ increases, so does h. That is, more persistence in either the price level or the output gap implies a longer interval between target evaluations. For example, if $\eta = 0.6$, then as ρ rises from 0.7 to 0.8, h increases from 1.7 to 2.2.

The properties of h are related to the conclusions in King (1999) and Nessén and Vestin (2005): as the evaluation horizon lengthens, the practical difference between inflation and price-path targeting disappears. Politicians are likely to hold an inflation-targeting central bank accountable for meeting inflation targets over horizons that are sufficiently long to make the regime behave similarly to targeting a

8. The natural time units of h are the same as those used to measure the persistence parameters.

Figure 1. Relation between the Optimal Horizon, Price-Level Persistence, and Output Persistence[a]



Source: Own computations based on IFS and OECD Economic Outlook data.
a. The relation is based on equation (11) in the text. The optimal horizon is denoted by h, price-level persistence by η, and output persistence by ρ.

price path. The lower the price-level persistence (η) and the implied horizon (h), the closer the economy is to pure price-path targeting. In a sense, a low (η, h) pair is equivalent to a high one—that is, they can both yield the same value of η^h. For example, (η, h) = (0.4, 1.5) is equivalent to (η, h) = (0.8, 6.1); in both cases $\eta^h = 0.253$. As King's logic implies, short-horizon price-path targeting is equivalent to long-horizon inflation targeting.[9]

2. Empirical Results

Our objective is to estimate the hybrid rule and the implied horizon for the policy regime in as broad a cross-section of countries as possible. To that end, we have assembled annual data on gross domestic product (GDP), the aggregate price level, and import prices for seventy countries. Moreover, we also have quarterly data for eighteen of the

9. A second way to approach this problem is to look for the approximate horizon over which inflation targeting yields the same variability of the price-level gap. Under the hybrid, the variance is proportional to $(1 - \eta^2) - 1$. Alternatively if the inflation target is reset every T periods, then the variance over those intervals is proportional to T. Setting these two equal, and given that our estimates of η are in the range of 0.7 to 0.9, we estimate the horizon T to lie between two and five (in the same time units as the data).

OECD countries in the larger sample. (See the data appendix for a list of sources.) A full set of results for the annual data are shown in table A1 in the appendix. Table 1 provides a summary.

The estimates are somewhat sensitive to the manner in which we estimate the output and price-path gaps. We present two sets of results: one based on assuming a simple linear trend and a send that uses a Hodrick-Prescott (HP) filter with the parameter set to 400. Based on the results for the full sample of seventy countries estimated over the 1973–2003 period, the average estimated horizon, h, equals 3.65 years when we use linear detrending and only 2.35 years when we apply the HP filter. We interpret these horizon estimates as being in addition to the time that it normally takes for monetary policy actions to have an impact on inflation and the output gap. That is, h is the horizon in addition to the policy lag, which is 1.5 to 2.0 years in industrialized countries.

Table 1 reports estimates for four groups of countries: the full sample of seventy countries, forty-five non-OECD countries, twenty-five OECD countries, and twelve euro-area countries. Overall, the groupings are not all that different. They all show some range in the estimates, and the persistence and implied horizon estimates all fall when we use the HP filter. The reason for the drop in the estimated horizon is straightforward. The HP filter essentially removes a time-varying mean from the growth rate—in other words, it allows for a linear trend that is moving around. As many authors note, allowing for time variation in the mean of data reduces estimates of persistence.[10] For example, if the mean of a time series shifts once and for all on a specific date, the mean shift is, by assumption, very persistent. If one were to estimate an autoregressive parameter like ρ or η in equations (7) and (8) ignoring the mean shift, the estimates would be high. Explicitly accounting for the shift unambiguously lowers the estimate of persistence. Now consider what happens to the estimate of h if we reduce both ρ and η. For example, if $\rho = 0.8$ and $\eta = 0.8$, then h is roughly 3.0. If ρ and η both fall to 0.7, this reduces the estimate of h to 2.0. The estimate of h will also drop if the estimate of ρ falls, but η does not.

Fortunately, the qualitative picture painted by the data is not all that different when we shift between the two methods of detrending. For the annual data, horizons for policy evaluation after the effect on inflation and output are two to three years, with estimates of η

10. See, for example, Cecchetti and Debelle (2006).

Table 1. Estimates of Hybrid Inflation Target, Annual Data, 1973–2003[a]

	All 70 countries		*45 non-OECD countries*		*25 OECD countries*		*12 euro area countries*	
Hybrid rule and horizon	η	*h*	η	*h*	η	*h*	η	*h*
Linear trend								
Mean	0.80	3.65	0.80	3.85	0.81	3.31	0.86	4.20
75th percentile	0.90	4.14	0.92	4.45	0.90	3.85	0.90	3.88
Median	0.84	3.00	0.82	3.18	0.85	2.52	0.85	2.77
25th percentile	0.71	1.83	0.69	1.89	0.74	1.51	0.80	1.51
HP filter								
Mean	0.75	2.35	0.72	2.23	0.81	2.54	0.84	2.79
75th percentile	0.88	2.66	0.87	2.47	0.91	2.97	0.92	3.39
Median	0.78	2.00	0.73	1.86	0.84	2.49	0.86	2.34
25th percentile	0.64	1.31	0.60	1.27	0.68	1.49	0.60	1.06

Source: Summary of estimates reported in table A1.
a. Horizon *h* is measured in years.

in excess of 0.7 for more than fifty countries. These countries are behaving as if they were near pure inflation targeting. Based on the quarterly data, estimates of the horizon (after the full effect of policy) are substantially shorter at one-half to one year, but again the economies are close to targeting inflation, presenting estimates of η between 0.6 and 0.8. (To facilitate comparison, we quote all estimates of h in years, regardless of the frequency of the data from which they are computed.)

In the end, we find the analysis of annual data unsatisfactory. It seems wrong to assume that economies have been stable over the turbulent decades of the 1970s, 1980s, and 1990s. We therefore turn to the smaller set of eighteen countries for which we have quarterly data beginning in 1980. Again, we present two sets of results: one based on linear detrending and the second using the HP filter (with a smoothing parameter of 1,600). Tables 2 and 3 report the complete results, while table 4 contains a brief summary. Each table includes results for two time periods: 1980–91 and 1992–2003. They also report bootstrap standard errors.[11]

For the period from 1980 to 1991, linear detrending yields an average estimated implied horizon of 1.35 years, while the HP-filtered estimates are half that, at 0.68 years. For the more recent sample, from 1992 to 2003, the average estimate of the horizon obtained using HP-filtered data is half what we get from linear detrended data. The quarterly estimates are uniformly lower than the ones we obtain using annual data. That is, we find both lower price-persistence and a smaller implied horizon for target evaluation. This almost surely reflects the sample period we are studying. The annual data includes the much more turbulent 1970s—a period in which inflation was generally higher and more variable than in recent years, while growth tended to be lower and more volatile. All in all, this leads us to be more confident in the higher-frequency estimates.

With regard to the precision of the estimates, we note two things. First, using the 1980–91 data, the estimates of the implied horizon

11. The parametric recursive bootstrap (Freedman and Peters, 1984) used here assumes that the estimated model for each country in equations (7′) and (8′) is correctly specified, and that the corresponding error terms are independent but not identically distributed. We resample with replacement from the matrix consisting of both estimated residuals from both equations. This allows us to generate 1,000 "pseudo"-samples for each country, which are then used to compute replications of the estimate of the horizon. The reported standard errors are obtained from computing the standard deviation of these replications.

Table 2. Quarterly Data Estimates: Linear Trend[a]

	1980–91			*1992–2003*		
Country	ρ	η	*h*	ρ	η	*h*
Australia	0.88	0.98	1.89	0.86	0.97	1.71
	(0.09)	(0.07)	(1.63)	(0.10)	(0.08)	(1.82)
Belgium	0.88	0.69	0.88	0.73	0.60	0.46
	(0.06)	(0.07)	(0.31)	(0.13)	(0.11)	(0.16)
Canada	0.88	1.07	3.94	0.88	0.83	1.20
	(0.07)	(0.08)	(7.17)	(0.07)	(0.11)	(0.56)
Denmark	0.82	0.94	1.16	0.76	0.69	0.57
	(0.10)	(0.08)	(0.51)	(0.10)	(0.13)	(0.16)
Finland	0.71	0.82	0.59	0.90	0.96	2.12
	(0.08)	(0.07)	(0.09)	(0.07)	(0.07)	(0.94)
France	0.90	0.92	1.73	0.91	0.77	1.22
	(0.05)	(0.09)	(0.71)	(0.05)	(0.12)	(0.43)
Germany	0.95	0.78	1.64	0.78	0.91	0.90
	(0.10)	(0.11)	(0.65)	(0.13)	(0.06)	(0.46)
Italy	0.77	0.93	0.90	0.72	0.92	0.71
	(0.10)	(0.05)	(0.37)	(0.12)	(0.03)	(0.40)
Japan	0.86	0.69	0.79	0.72	0.79	0.58
	(0.07)	(0.11)	(0.35)	(0.16)	(0.09)	(0.26)
Korea, Rep. (S)	0.41	0.99	0.31	0.80	0.72	0.68
	(0.14)	(0.05)	(0.17)	(0.06)	(0.06)	(0.13)
Netherlands	0.80	0.89	0.95	0.97	0.89	2.99
	(0.09)	(0.05)	(0.33)	(0.06)	(0.09)	(2.26)
New Zealand	0.54	1.05	0.47	0.62	0.81	0.45
	(0.15)	(0.06)	(0.29)	(0.14)	(0.09)	(0.17)
Norway	0.85	1.01	1.73	0.81	0.54	0.53
	(0.07)	(0.07)	(1.16)	(0.09)	(0.16)	(0.16)
Portugal	0.83	0.74	0.77	0.89	0.75	1.04
	(0.06)	(0.10)	(0.22)	(0.06)	(0.11)	(0.29)
Spain	0.76	1.07	1.20	0.83	0.81	0.90
	(0.11)	(0.11)	(0.59)	(0.06)	(0.12)	(0.28)
Sweden	0.80	0.84	0.83	0.90	0.70	0.94
	(0.13)	(0.08)	(0.34)	(0.06)	(0.08)	(0.24)
United Kingdom	0.97	0.88	3.04	0.81	0.57	0.56
	(0.07)	(0.11)	(1.97)	(0.09)	(0.14)	(0.21)
United States	0.83	1.01	1.49	0.82	0.74	0.75
	(0.06)	(0.06)	(0.58)	(0.07)	(0.09)	(0.27)

Source: Own computations based on IFS and OECD Economic Outlook data.
a. Horizon is measured in years. Standard deviations are in parentheses.

Table 3. Quarterly Data Estimates: HP Filter[a]

	1980–91			*1992–2003*		
Country	ρ	η	*h*	ρ	η	*h*
Australia	0.82	0.87	0.97	0.65	0.88	0.54
	(0.11)	(0.07)	(0.65)	(0.13)	(0.07)	(0.46)
Belgium	0.81	0.78	0.78	0.59	0.46	0.29
	(0.12)	(0.06)	(0.43)	(0.15)	(0.12)	(0.24)
Canada	0.81	1.07	1.70	0.80	0.71	0.67
	(0.09)	(0.08)	(2.42)	(0.08)	(0.14)	(0.20)
Denmark	0.55	0.49	0.27	0.64	0.28	0.25
	(0.15)	(0.14)	(0.13)	(0.13)	(0.16)	(0.07)
Finland	0.80	0.80	0.78	0.84	0.74	0.79
	(0.06)	(0.11)	(0.29)	(0.07)	(0.12)	(0.63)
France	0.87	0.79	1.04	0.82	0.47	0.49
	(0.09)	(0.07)	(0.61)	(0.09)	(0.14)	(0.23)
Germany	0.65	0.56	0.36	0.64	0.74	0.43
	(0.15)	(0.16)	(0.17)	(0.11)	(0.10)	(0.45)
Italy	0.77	0.86	0.79	0.65	0.85	0.52
	(0.12)	(0.07)	(0.50)	(0.12)	(0.06)	(0.25)
Japan	0.67	0.62	0.41	0.45	0.57	0.24
	(0.12)	(0.12)	(0.15)	(0.17)	(0.14)	(0.14)
Korea, Rep. (S)	0.36	0.91	0.25	0.74	0.37	0.34
	(0.15)	(0.06)	(0.14)	(0.06)	(0.15)	(0.11)
Netherlands	0.61	0.84	0.46	0.89	0.80	1.17
	(0.14)	(0.07)	(0.26)	(0.09)	(0.10)	(1.54)
New Zealand	0.28	1.10	0.23	0.58	0.73	0.37
	(0.17)	(0.08)	(0.55)	(0.12)	(0.07)	(0.20)
Norway	0.70	0.87	0.62	0.32	0.38	0.16
	(0.10)	(0.11)	(0.26)	(0.15)	(0.17)	(0.08)
Portugal	0.84	0.79	0.89	0.81	0.74	0.72
	(0.10)	(0.08)	(0.71)	(0.09)	(0.13)	(0.39)
Spain	0.60	0.75	0.41	0.77	0.70	0.59
	(0.14)	(0.12)	(0.15)	(0.09)	(0.14)	(0.28)
Sweden	0.63	0.92	0.53	0.82	0.45	0.47
	(0.13)	(0.07)	(0.37)	(0.05)	(0.11)	(0.24)
United Kingdom	0.87	0.83	1.15	0.78	0.40	0.39
	(0.08)	(0.09)	(0.55)	(0.07)	(0.14)	(0.11)
United States	0.71	0.89	0.66	0.80	0.70	0.66
	(0.07)	(0.07)	(0.19)	(0.10)	(0.09)	(0.22)

Source: Own computations based on IFS and OECD Economic Outlook data.
a. Horizon is measured in years. Standard deviations are in parentheses.

Table 4. Estimates of Hybrid Inflation Target, Quarterly Data[a]

	Linear trend				*HP filter*			
	Mean		*Median*		*Mean*		*Median*	
Period and sample	η	*h*	η	*h*	η	*h*	η	*h*
1980–91								
18 OECD countries	0.91	1.35	0.92	1.05	0.82	0.68	0.84	0.64
8 euro area countries	0.85	1.08	0.85	0.92	0.77	0.69	0.79	0.78
1992–2003								
18 OECD countries	0.78	1.01	0.78	0.82	0.61	0.50	0.70	0.48
8 euro area countries	0.83	1.29	0.86	1.27	0.69	0.62	0.74	0.55

Source: Own computations based on IFS and OECD Economic Outlook data.
a. Horizon *h* is measured in years.

are not only high, but also imprecise. We see many fewer estimates above four in 1992–2003, using the linear trend. Second, allowing for a time-varying mean has a dramatic effect: our estimates of persistence and the implied horizon both fall substantially, and precision is increased (see table 3).

A complete analysis would build uncertainty directly into the optimization problem. In the setup we use here, the important source of uncertainty is the imprecision in the model parameter estimates—that is, the uncertainty about η and ρ. In the elementary framework described by Brainard (1967), policymakers should act cautiously when they are unsure of something like the elasticity of their inflation or output objective with respect to their interest rate instrument; in particular, they should not react strongly to observed shocks.[12] More recently, Onatski and Stock (2002) describe circumstances under which uncertainty can lead to bigger, not smaller, reactions. Theirs is a risk-management result: policymakers need to avoid very bad outcomes. If, for example, inflation might be a random walk, then a policymaker who cares about inflation variability should react more aggressively to any possibility of inflation changing. Balancing these two results—one advocating smaller reactions and the other larger—is a daunting task for policymakers.

Returning to our results, we note that uncertainty about persistence in both output and price-path gaps fell in the last decade. This clearly makes life easier for policymakers.

3. Time Variation

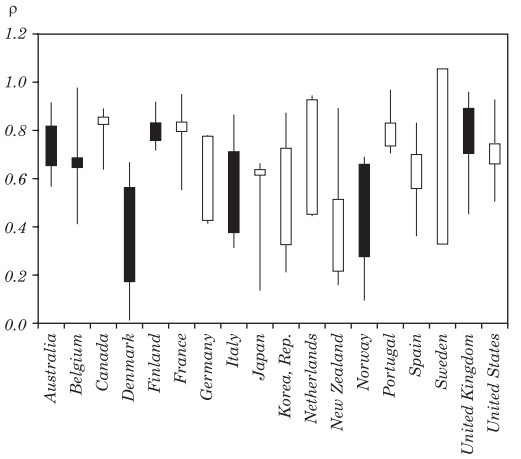
While interesting, the estimates of the previous section are clearly unsatisfactory. Substantial evidence indicates that persistence in output and prices varies over time.[13] This, combined with the known changes in monetary policy regime, suggests that both η and h may undergo important changes during our sample. Unfortunately, thirty years of annual data—the size of the sample for our large cross-section of seventy countries—is insufficient to study time variation. Instead, we focus on the twenty-four years of quarterly data covering eighteen countries.

12. Data uncertainty—that is, imprecise estimates of the state of the economy—does not influence the problem in the same way, as recently proved by Svensson and Woodford (2003).

13. For an examination of time variation in output persistence, see Cecchetti, Flores-Lagunes, and Krause (2005); for inflation persistence, see Cecchetti and Debelle (2006).

We have split the sample in half, creating subperiods for 1980 to 1991 and 1992 to 2003. The results using linear detrending are in table 2, while those using the HP filtered data are in table 3. With regard to output persistence, our estimate of ρ falls in nine of the eighteen countries when we use constant linear detrending, and in eleven when we allow for time variation in mean growth. To provide a closer look at the second case, figure 2 plots the range of estimates of ρ obtained using a five-year moving window. The general pattern is that output persistence increased between the early to mid-1980s and the eight years ending in 2003. Persistence also tends to be higher in the early 1990s than either before or after, although this is not evident in the figure. For all but two countries (Denmark and New Zealand), the output persistence estimates tend to lie primarily above one-half.

Figure 2. Range of Output Persistence for Eighteen OECD Countries[a]

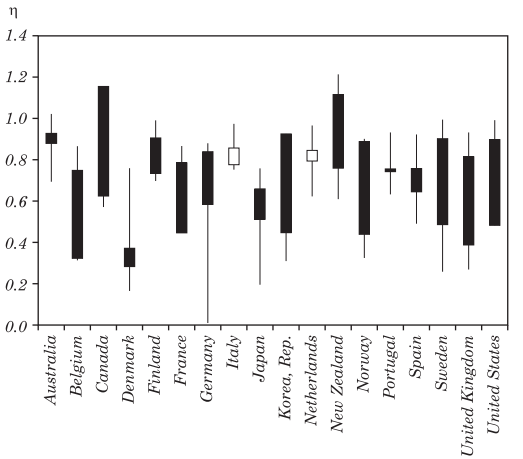


Source: Own computations based on IFS and OECD Economic Outlook data.
a. For each country, the thin vertical line represents the overall range of the estimates, while the top and bottom of the bar is the estimate at the beginning and the end of the sample period. A solid bar indicates that estimated persistence fell between the early to mid-1980s and the 1996–2003 period, while a white bar represents an increase.

The persistence in the deviation of prices from trend has tended to decline substantially over time. When we use linear detrending, persistence falls in thirteen of the eighteen countries; applying an HP filter results in estimated declines in sixteen countries (see table 2). This shift toward price-path targeting is confirmed by

the more flexible time-variation estimates reported in figure 3. Comparing the early 1980s with the most recent five-year period reveals that the estimated degree of price-level persistence declined in sixteen of the eighteen countries. Moreover, the increases were very modest in the two countries where the estimates rise (Italy and the Netherlands).

Figure 3. Range of Price Persistence for Eighteen OECD Countries[a]

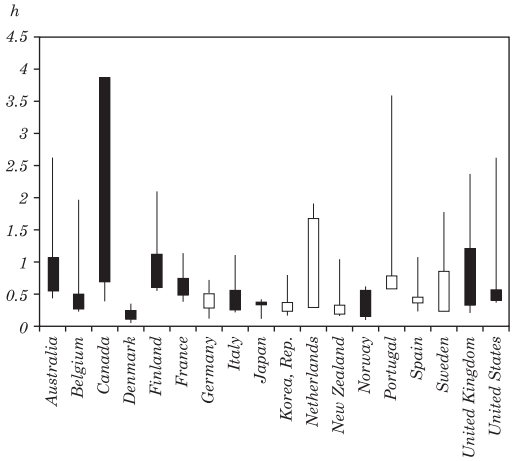


Source: Own computations based on IFS and OECD Economic Outlook data.
a. For each country, the thin vertical line represents the overall range of the estimates, while the top and bottom of the bar is the estimate at the beginning and the end of the sample period. A solid bar indicates that estimated persistence fell between the early to mid-1980s and the 1996–2003 period, while a white bar represents an increase.

Estimates of the implied horizon for target evaluation show less of a tendency to vary (see figure 4). When we use linearly detrended data, five countries show an increase in h; the number rises to seven with HP filtering. Most of the increases are relatively small, however, at one-quarter or less. By contrast, where we estimate reductions, they are large.

The horizon h is the value that equates price-level persistence with optimal price level persistence. It thus equates the optimal convex combination of inflation and price-path targeting with that in the data. This means that the horizon, plus the lag with which policy affects inflation and the output gap, is an indicator of the timeframe policymakers should have in mind in order to achieve the minimum loss.

Figure 4. Range of Horizon Estimates for Eighteen OECD Countries[a]



Source: Own computations based on IFS and OECD Economic Outlook data.
a. For each country, the thin vertical line represents the overall range of the estimates, while the top and bottom of the bar is the estimate at the beginning and the end of the sample period. A solid bar represents a decrease in the optimal horizon between the first and last period; a white bar represents an increase in the horizon. h is measured in years.

4. Inflation Targeters versus Nontargeters

The data in tables 2 and 3 provide the basis for exploring whether there are any systematic differences between countries that publicly state that they target inflation and those that do not. For this comparison, we run a fixed-effects regression to establish whether countries that adopted inflation targeting in the 1990s experienced a significantly different behavior of output and price persistence (ρ and η) or the implied horizon for target evaluation (h) than nontargeters.

The regressions are of the following form:

$$y_{i,t} = a_i + b\text{Target}_{i,t} + u_{i,t}\,, \tag{12}$$

where $y_{i,t}$ is ρ, η, or h for country i in period t; $\text{Target}_{i,t}$ is a dummy variable that takes the value of one if country i is targeting inflation in period t; and a_i is a country-specific fixed effect. For each country we take the difference in equation (12) across the two subperiods of our quarterly data. We report estimates of b, the impact of publicly announced inflation targeting, in table 5.

We might expect inflation targeting countries to experience higher output volatility.[14] However, there is no reason to think that the monetary policy regime would have a direct impact on the persistence of output, and this is what we find. The first column of table 5 reports that inflation targeters experience slightly higher output persistence than nontargeters, but the differences are small in magnitude and not statistically significantly different from zero.

Table 5. Fixed-Effects Regression: Inflation Targeters versus Nontargeters[a]

Method and explanatory variable	*Output persistence* (ρ)	*Price persistence* (η)	*Horizon* (h)
HP filtering			
Inflation targeting (b)	0.06	–0.25	–1.10
	(0.42)	(0.01)	(0.07)
Linear detrending			
Inflation targeting (b)	0.04	–0.15	–2.33
	(0.47)	(0.04)	(0.17)

Source: Own computations based on IFS and OECD Economic Outlook data.
a. Regressions use HP detrending; p values are in parentheses.

It is both reassuring and unsurprising to find that the adoption of inflation targeting changes a country's price-level persistence. Our results show inflation targeting is correlated with large declines in η (regardless of the detrending procedure we use). The fall in the estimates is quite large—between 0.15 and 0.25. This means that the price process in inflation-targeting countries is substantially closer to price-path targeting than to inflation targeting. The implied horizon for target evaluation falls by more in these countries, as well—between one and two quarters.

5. Conclusion

The details of a country's monetary policy regime should depend on that country's economic structure. Whether the optimal approach pure inflation targeting, pure price-path targeting, or some hybrid depends on the country's output persistence. Once policymakers realize that the horizon for target evaluation can vary, any hybrid rule can be optimal.

14. Cecchetti and Ehrmann (2002) report that inflation-targeting countries tend to experience more output volatility than countries that do not target inflation.

For example, a rule that is weighted heavily toward inflation targeting but is evaluated over a long horizon will be equivalent to a rule that grants priority to the price-path but employs a shorter horizon.

This result bears a striking resemblance to Svensson's (1999a) important observation that the speed at which a central bank strives to bring inflation back to its target level depends on the weight of output fluctuations in its objective function. The higher the weight on output variability, the slower the path back. The same thing is happening here. The more persistent output, the more output variability is created by explicitly targeting inflation, and the longer the time horizon for policy evaluation. Thus, the more policymakers care about output variability or the more prone the economy is to prolonged movements away from potential output, the longer the time horizon over which policymakers should be operating.

Turning to our empirical results, we find that countries vary quite a bit in the degree to which output and the price-level are persistent. While developed and emerging market countries present few differences, inflation-targeting countries show a distinctly lower degree of price-level persistence. Moreover, our estimates of persistence generally fall when we adopt methods that allow for potential output growth to vary over time. Our comparison of the 1980s and the 1990s (based on the more reliable quarterly data) indicates that output persistence has not changed, but price-level persistence has fallen. This is surely, in part, a consequence of the adoption of formal inflation targets. Finally, our results imply that the optimal horizon for target evaluation has gotten shorter. There is a sense in which countries are closer to price-path targeting than they are to inflation targeting.

Appendix

Our data sources are as follows. Annual data on GDP, the consumer price index (CPI), and import prices data were obtained from the International Monetary Fund's *International Financial Statistics* CD-ROM (December 2004). Quarterly data for seasonally adjusted GDP, CPI, and import prices were obtained from the *OECD Economic Outlook* 76 (December 2004). Data on inflation targeting were taken from Mishkin and Schmidt-Hebbel (2002).

Table A1 provides our results by country, based on the annual data from 1973 to 2003, using linear detrending and the Hodrick-Prescott filter.

Table A1. Annual Data, 1970–2003

	Linear detrending			*HP filtering*		
Country	ρ	η	*h*	ρ	η	*h*
Algeria	0.91	0.94	8.76	0.82	0.87	3.92
Argentina	0.75	0.93	3.23	0.63	0.80	1.83
Australia	0.48	0.82	1.28	0.48	0.80	1.24
Austria	0.54	0.84	1.51	0.46	0.64	1.06
Belgium	0.50	0.86	1.38	0.35	0.62	0.82
Bolivia	0.90	0.49	2.58	0.91	0.50	2.81
Burkina Faso	0.24	0.66	0.65	0.04	0.63	0.32
Burundi	0.85	0.60	2.56	0.76	0.48	1.68
Cameroon	0.87	0.78	3.90	0.84	0.62	2.56
Canada	0.79	0.57	2.03	0.75	0.75	2.41
Chile	0.80	0.51	1.92	0.60	0.55	1.28
Colombia	0.92	0.73	4.44	0.76	0.73	2.42
Congo, Dem. Rep.	0.91	0.68	3.84	0.79	0.44	1.71
Costa Rica	0.97	0.67	5.86	0.84	0.55	2.33
Côte d'Ivoire	0.84	0.82	3.79	0.81	0.64	2.45
Denmark	0.52	0.89	1.50	0.53	0.86	1.49
Dominican Republic	0.84	0.85	4.06	0.68	0.94	2.59
Ecuador	0.45	0.69	1.06	0.43	0.72	1.06
Egypt, Arab Rep.	0.82	1.02	5.89	0.74	1.03	3.89
El Salvador	0.79	0.99	4.45	0.79	0.96	4.19
Finland	0.87	0.78	3.86	0.82	0.70	2.82
France	0.71	0.85	2.46	0.70	0.92	2.69
Gabon	0.49	0.82	1.33	0.43	0.65	0.98
Gambia, The	0.50	0.79	1.29	0.41	0.92	1.16
Germany	0.71	0.85	2.52	0.63	0.87	2.01
Ghana	0.91	0.58	3.13	0.65	0.47	1.29
Greece	0.88	1.08	14.87	0.69	1.34	9.35
Guatemala	0.91	0.93	8.04	0.98	0.90	16.08
Haiti	0.84	0.89	4.47	0.73	0.81	2.45
Honduras	0.78	1.04	4.90	0.74	0.88	2.85
Hungary	0.88	0.74	3.85	0.83	0.64	2.62

Table A1. (continued)

	Linear detrending			*HP filtering*		
Country	ρ	η	*h*	ρ	η	*h*
Iceland	0.85	0.87	4.46	0.76	0.87	3.06
India	0.58	0.56	1.25	0.28	0.48	0.63
Indonesia	0.91	0.71	4.14	0.83	0.62	2.53
Ireland	0.93	0.94	10.18	0.80	0.85	3.39
Italy	0.48	0.90	1.38	0.28	0.91	0.83
Japan	0.90	0.48	2.50	0.74	0.43	1.50
Kenya	0.86	0.84	4.25	0.71	0.83	2.38
Korea, Rep.	0.84	0.53	2.26	0.70	0.68	1.89
Lesotho	0.47	0.77	1.21	0.42	0.37	0.77
Luxembourg	0.82	0.79	3.23	0.75	0.62	1.98
Madagascar	0.55	0.85	1.57	0.27	0.78	0.74
Malaysia	0.75	0.51	1.68	0.57	0.44	1.08
Mexico	0.74	0.99	3.65	0.75	0.87	2.97
Morocco	0.40	0.87	1.10	0.13	0.71	0.48
Netherlands	0.83	0.85	3.88	0.77	0.78	2.67
New Zealand	0.74	0.93	3.10	0.74	0.90	2.94
Nicaragua	0.89	0.86	5.50	0.53	0.88	1.53
Nigeria	0.75	0.88	2.99	0.47	0.84	1.26
Norway	0.76	0.86	2.97	0.73	0.91	2.88
Pakistan	0.87	0.70	3.32	0.69	0.74	1.99
Paraguay	0.62	1.00	2.34	0.70	0.86	2.42
Peru	0.78	0.80	2.82	0.65	0.84	2.03
Philippines	0.81	0.92	4.13	0.74	0.34	1.31
Portugal	0.64	0.87	2.07	0.57	0.95	1.82
Rwanda	0.60	0.72	1.55	0.55	0.67	1.31
Senegal	0.69	0.77	2.07	0.42	0.63	0.96
Sierra Leone	0.85	0.96	5.79	0.54	0.92	1.66
South Africa	0.59	1.03	2.15	0.47	1.00	1.45
Spain	0.81	0.77	3.01	0.81	0.91	4.08
Swaziland	0.88	1.00	8.49	0.77	0.55	1.89
Sweden	0.78	0.90	3.45	0.75	1.00	3.88
Switzerland	0.62	0.84	1.89	0.58	0.84	1.68
Thailand	0.85	0.52	2.27	0.78	0.64	2.22
Togo	0.59	0.89	1.80	0.51	0.89	1.47
Trinidad and Tobago	0.99	0.90	18.85	0.81	0.64	2.46
United Kingdom	0.69	0.67	1.81	0.80	0.69	2.56
United States	0.52	0.52	1.07	0.58	0.71	1.44
Uruguay	0.81	1.08	6.78	0.65	1.12	3.18
Venezuela, RB	0.80	0.80	3.12	0.73	0.82	2.48

Source: Own computations based on IFS and OECD Economic Outlook data.

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Does Inflation Targeting Make a Difference?

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Since New Zealand adopted inflation targeting in 1990, a steadily growing number of industrial and emerging economies have explicitly adopted an inflation target as their nominal anchor. Eight industrial countries and thirteen emerging economies had full-fledged inflation targeting in place in early 2005. Many other emerging economies are planning to adopt inflation targeting in the near future. This trend has triggered an intensifying debate over whether inflation targeting makes a difference. Opinions diverge widely over whether central banks are better off after they adopt inflation (forecast) targeting as an explicit and exclusive anchor for conducting monetary policy. Analysts are demanding hard evidence that inflation targeting improves macroeconomic performance relative to countries without explicit inflation targeting.

Empirical evidence on the direct link between inflation targeting and particular measures of economic performance generally provides some support for the view that inflation targeting is associated with

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an improvement in overall economic performance.[1] This conclusion is derived from the following four results:

—Inflation levels, inflation volatility, and interest rates have declined after countries adopted inflation targeting.

—Output volatility has not worsened after the adoption of inflation targeting; if anything, it has improved.

—Exchange rate pass-through seems to be attenuated by the adoption of inflation targeting.

—The fall in inflation levels and volatility, interest rates, and output volatility is part of a worldwide trend in the 1990s, and inflation targeters have not done better in terms of these variables or in terms of exchange rate pass-through than nontargeting industrialized countries such as Germany or the United States.[2]

Although these results suggest that inflation targeting is beneficial, they are less conclusive than first appears. Ball and Sheridan (2005), in one of the few empirical papers critical of inflation targeting, argue that inflation targeting does not make a difference in industrial countries. They claim that the apparent success of inflation targeting countries simply reflects regression toward the mean: that is, inflation will fall faster in countries that start with high inflation than in countries with an initially low inflation rate. Since the countries that adopted inflation targeting generally had higher initial inflation rates, their larger decline in inflation merely reflects a general tendency of all countries, both targeters and nontargeters, to achieve better inflation and output performance in the 1990s, when inflation targeting was adopted.

Ball and Sheridan's findings are heavily disputed by Truman (2003), Hyvonen (2004), Vega and Winkelried (2005), IMF (2005), and Batini and Laxton (in this volume), who provide evidence—based on using samples that include emerging countries and different specifications and estimation techniques—that inflation

1. Roger and Stone (2005) reach this conclusion.

2. For evidence supporting these first four results, see Bernanke and others (1999), Corbo, Landerretche, and Schmidt-Hebbel (2002), Neumann and von Hagen (2002), Hu (2003), Truman (2003), and Ball and Sheridan (2005). There is also some mildly favorable evidence on the impact of inflation targeting on sacrifice ratios. Bernanke and others (1999) do not find that sacrifice ratios in industrialized countries fell with the adoption of inflation targeting, while Corbo, Landerretche, and Schmidt-Hebbel (2002) conclude, based on a larger sample of inflation targeters, that inflation targeting did lead to an improvement in sacrifice ratios. Cohen, Gonzalez, and Powell (2003) also find that inflation targeting leads to nominal exchange rate movements that are more responsive to real shocks than nominal shocks. This might indicate that inflation targeting can help the nominal exchange rate act as a shock absorber for the real economy.

levels, persistence, and volatility are lower in inflation-targeting countries than in nontargeters. However, Ball and Sheridan's paper does raise a serious issue about the empirical literature on inflation targeting. The adoption of inflation targeting is clearly an endogenous choice, as is pointed out by Mishkin and Schmidt-Hebbel (2002) and Gertler (2005). The finding that better performance is associated with inflation targeting thus may not imply that inflation targeting causes this better performance.

The fourth result above—namely, that the inflation and output performance of inflation-targeting countries improves but does not surpass countries like Germany and the United States—also suggests that what really matters for successful monetary policy is establishing a strong nominal anchor. While inflation targeting is one way to achieve this, it is not the only way. Germany was able to create a strong nominal anchor with its monetary targeting procedure (see Bernanke and Mishkin, 1992; Mishkin and Posen, 1997; Bernanke and others, 1999; Neumann and von Hagen, 2002). In the United States, the strong nominal anchor has been Alan Greenspan (see, for example, Mishkin, 2000). It is not at all clear that inflation targeting would have improved performance during the Greenspan era, although it might well do so in the future if the United States is not as fortunate with choices of Fed chairmen like Greenspan and Bernanke (Mishkin, 2005). Furthermore, as emphasized in Calvo and Mishkin (2003) and Sims (2005), an inflation target alone is not capable of establishing a strong nominal anchor if the government pursues irresponsible fiscal policy or inadequate prudential supervision of the financial system, which might then be prone to a financial crisis.

Empirical evidence that focuses on whether inflation targeting strengthens the nominal anchor may be even more telling about the possible benefits of inflation targeting. Recent research has found the following additional results:

—Evidence that the adoption of inflation targeting leads to an immediate fall in inflation expectations is not strong.[3]

—Inflation persistence, however, is lower for countries that have adopted inflation targeting than for countries that have not.

—Inflation expectations appear to be more anchored for inflation targeters than nontargeters: that is, inflation expectations react less to

3. For example, Bernanke and others (1999) and Levin, Natalucci, and Piger (2004) do not find that inflation targeting leads to an immediate fall in expected inflation, but Johnson (2002, 2003) finds some evidence that expected inflation falls after the announcement of inflation targets.

shocks to actual inflation for targeters than nontargeters, particularly at longer horizons.[4]

These results suggest that once inflation targeting has been in place for a while, it does make a difference by anchoring inflation expectations and thus strengthening the nominal anchor. Inflation targeting could therefore strengthen the nominal anchor in the United States even beyond what was achieved under "maestro" Greenspan. Recent theory on optimal monetary policy, sometimes called the new neoclassical synthesis (Woodford, 2003; Goodfriend and King, 1997), shows that establishing a strong nominal anchor is a crucial element in successful monetary policy. Consequently, the evidence on anchoring inflation expectations bolsters the case for the adoption of inflation targeting.

Our survey of the debate on whether inflation targeting matters indicates that open questions remain, particularly with regard to other dimensions of comparative macroeconomic performance in inflation-targeting countries, both over time and in comparison with nontargeting countries. Are the inflation level and the volatility of inflation and output lower in inflation-targeting countries? Do monetary policy and macroeconomic performance variables respond differently to shocks under inflation-targeting than under other monetary policy regimes? Is monetary policy efficient under inflation-targeting? Are inflation-targeting central banks more accurate in hitting their targets than nontargeters in maintaining or achieving stable inflation?

This paper addresses these questions systematically by applying a common methodological approach, across issues and throughout the paper, based on four methodological choices. First, we look for empirical evidence in a sample of twenty-one industrial and emerging inflation-targeting countries before and after their adoption of inflation targeting, and we compare their performance to a control group of thirteen industrial countries without inflation targeting (termed nontargeters). The macroeconomic and monetary policy performance of the nontargeters in this control group is among the best in the world, raising the odds against finding evidence of better performance among inflation-targeting countries. Second, we distinguish between two types of inflation-targeting regimes, one in which inflation targets are still converging to the long-run goal for inflation and one in which the inflation target is stationary. This distinction is important because the strength of the nominal anchor may vary depending on whether inflation

4. Gürkaynak, Levin, and Swanson (in this volume); Levin, Natalucci, and Piger (2004); Castelnuovo, Nicoletti-Altimari, and Palenzuela (2003).

targets are stable. Third, we test for differences in the group behavior of inflation targeters and nontargeters—and for changes between pre- and post-targeting periods among targeters—making statistical inferences from panel data estimations, panel vector autoregressive models, and panel impulse responses. Finally, to exploit the rich available data and identify dynamic patterns, we use a high-frequency sample of quarterly data, covering the 1989–2004 period and subperiods.

Section 1 of the paper describes more closely the two samples of inflation targeters and nontargeters and presents comparative descriptive statistics on their inflation and growth performance. The following sections test for differences in performance between targeters and nontargeters and (for targeters) between pre- and post-targeting periods, along four dimensions. Section 2 revisits the question about differences in inflation behavior among country groups, extending previous research on the same issue to a country panel and considering alternative estimation methods and control groups. Section 3 tests for differences in the country groups' dynamic response of inflation to oil price and exchange rate shocks and of domestic interest rates to international interest rate shocks. Section 4 measures differences in macroeconomic performance (output and inflation volatility) and monetary policy efficiency. Section 5 reports differences between country groups in meeting inflation targets or objectives. Section 6 offers concluding remarks.

1. Descriptive Inflation and Output Statistics

Inflation targeting was started by New Zealand in 1990, with several industrial countries and emerging economies following in subsequent years. Our sample of inflation-targeting countries comprises eight industrial countries and thirteen emerging economies that had full-fledged inflation targeting in place in late 2004.[5]

Dating the adoption of inflation targeting is not uncontroversial, particularly in emerging economies that started a version of inflation targeting termed partial inflation targeting. Under partial inflation targeting, countries often maintained an additional nominal anchor (typically an exchange rate band), did not satisfy key preconditions for inflation targeting, and did not put in place formal features of inflation targeting (such as formalizing monetary policy decisions or publishing

5. We therefore exclude Finland and Spain, which adopted inflation targeting in 1993 and 1995, respectively, before adopting the euro in 1999.

an inflation report with inflation forecasts). In contrast, under full-fledged inflation targeting, the inflation target is the only nominal anchor (although exchange rate interventions could be present), and the central bank pursues most formal policy and transparency features observed under best-practice inflation targeting.

Here we follow much of the previous literature (for example, Corbo, Landerretche, and Schmidt-Hebbel, 2002; Mishkin and Schmidt-Hebbel, 2002; Roger and Stone, 2005) in dating the adoption of inflation targeting with the start of either partial or full-fledged inflation targeting, in opposition to work that considers inflation targeting as starting only with full-fledged targeting (for example, IMF, 2005; Batini, and Laxton, in this volume). For the reasons mentioned above, however, we identify two distinct post-adoption periods, based on the stationarity of the inflation target itself. During target convergence, inflation targets are adjusted downward, typically for calendar years, and they are based on annual or multi-annual announcements. During target stationarity, inflation targets are fixed at a constant level or range for an indefinite future, although some countries occasionally make slight adjustments to the target.[6] An important advantage of using converging versus stationary targets to identify relevant post-targeting periods is that this distinction is based on an observable feature that is precisely dated, whereas the partial/full-fledged dichotomy is based on more subjective characteristics and dating.

Table 1 summarizes the information on inflation-targeting countries for the world population of inflation targeters. The data sample used in this paper starts with the first quarter of 1989 and extends through the fourth quarter of 2004. Pre-targeting sample periods range from one year (New Zealand, the most senior inflation targeter) to twelve years (Iceland, Norway, Hungary, and the Philippines, the most recent targeters). Target convergence periods also vary significantly in extension, from no convergence (for example, Australia and Thailand) to eleven years of convergence (Israel). The length of the stationary-target period is also heterogeneous, extending from one year (Poland) to twelve years (New Zealand).

Our most recent data on inflation target levels (or midpoints of target ranges) show little country variation. For the eight stationary industrial countries, the average inflation target level was 2.2 percent in 2005. Among emerging economies, the average inflation

6. Countries that have exceptionally and only marginally adjusted their stationary target levels or ranges include New Zealand and the United Kingdom.

Table 1. Inflation-Targeting Periods and 2005 Target Levels in Twenty-One Inflation-Targeting Countries

		Inflation-targeting period		
Country	*Pre-targeting period*	*Converging-target period*	*Stationary-target period*	*2005 inflation target level (%)*
Industrial Economies				
Australia	1989:1–1994:2		1994:3–2004:4	2–3
Canada	1989:1–1990:4	1991:1–1994:4	1995:1–2004:4	1–3
Iceland	1989:1–2000:4	2001:1–2002:4	2003:1–2004:4	2.5
New Zealand	1989:1–1989:4	1990:1–1992:4	1993:1–2004:4	1–3
Norway	1989:1–2000:4		2001:1–2004:4	2.5
Sweden	1989:1–1994:4		1995:1–2004:4	2 (+/–1)
Switzerland	1989:1–1999:4		2000:1–2004:4	<2
United Kingdom	1989:1–1991:4		1992:1–2004:4	2
Group average				2.2

Table 1. (continued)

Country	*Pre-targeting period*	*Inflation-targeting period*		*2005 inflation target level (%)*
		Converging-target period	*Stationary-target period*	
Emerging Economies				
Brazil	1989:1–1998:4	1999:1–2004:4		4.5 (+/–2.5)
Chile	1989:1–1990:4	1991:1–2000:4	2001:1–2004:4	2–4
Colombia	1989:1–1998:4	1999:1–2004:4		5 (+/–0.5)
Czech Republic	1989:1–1997:4	1998:1–2004:4		3 (+/–1)
Hungary	1989:1–2000:4	2001:1–2004:4		3.5 (+/–1)
Israel	1989:1–1991:4	1992:1–2002:4	2003:1–2004:4	1–3
Korea	1989:1–1997:4	1998:1–1998:4	1999:1–2004:4	2.5–3.5
Mexico	1989:1–1998:4	1999:1–2002:4	2003:1–2004:4	3 (+/–1)
Peru	1989:1–1993:4	1994:1–2001:4	2002:1–2004:4	2.5 (+/–1)
Philippines	1989:1–2000:4	2001:1–2004:4		5–6
Poland	1989:1–1997:4	1998:1–2003:4	2004:1–2004:4	2.5 (+/–1)
South Africa	1989:1–1999:4		2001:1–2004:4	3–6
Thailand	1989:1–1999:4		2000:1–2004:4	0–3.5
Group average, eight stationary-target countries				3.0
Group average, five converging-target countries				3.6

Source: Authors' calculations, based on data from central bank websites.

target level that year was 3.0 percent for the subsample of eight inflation targeters with a stationary target and 3.6 percent for the subsample of inflation targeters that were still converging toward future stationary target levels in 2004.

Figure 1 depicts inflation targets since the adoption of inflation targeting and twelve-month consumer price index (CPI) inflation rates for every inflation targeter, based on quarterly data for 1989–2004. Visual inspection of the absolute differences between inflation and target levels suggests that inflation-targeting countries have been successful in meeting their targets. Section 5 tests this hypothesis more systematically and compares the finding with a control group of nontargeters.

Figure 1. Annual Inflation Rates and Targets in Inflation-Targeting Countries, 1990–2004

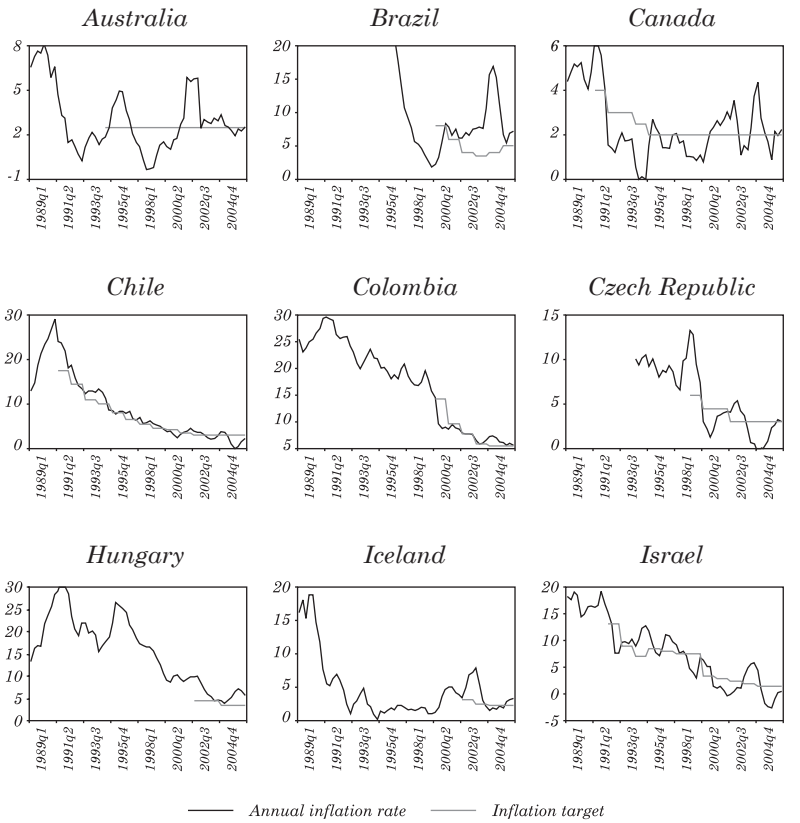
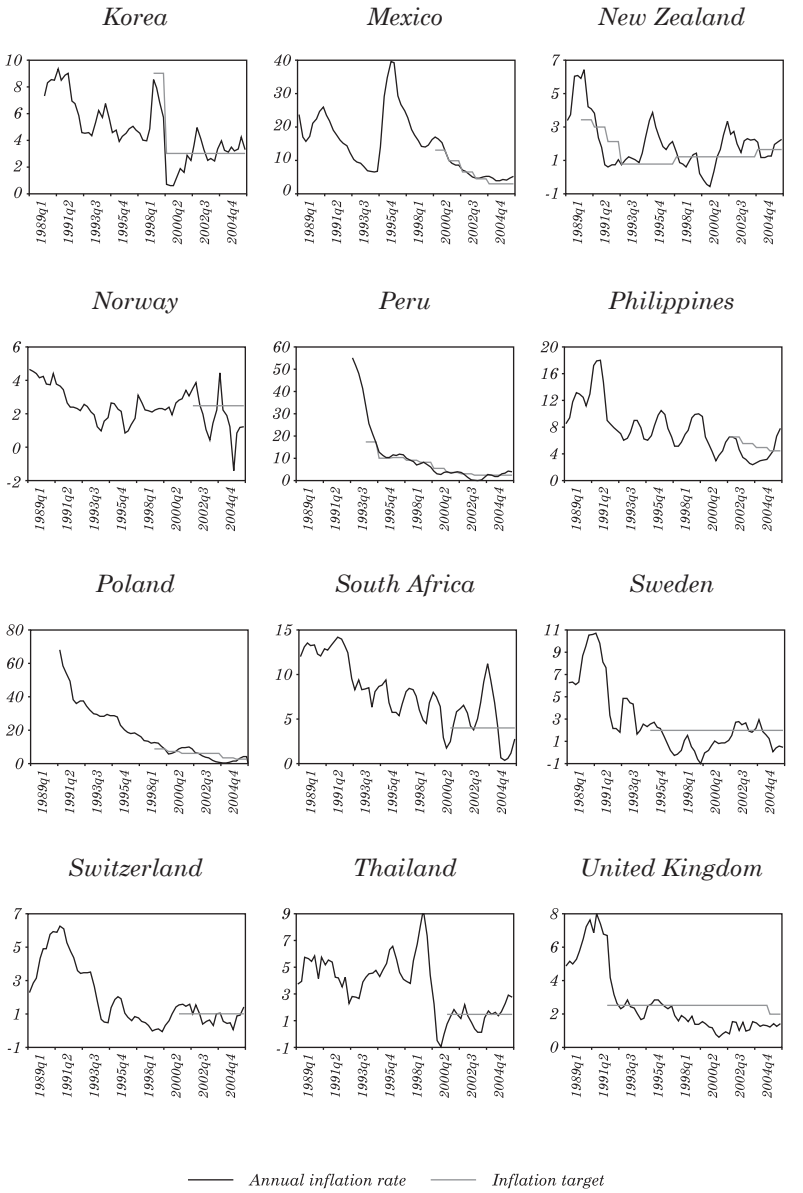


Figure 1. (continued)

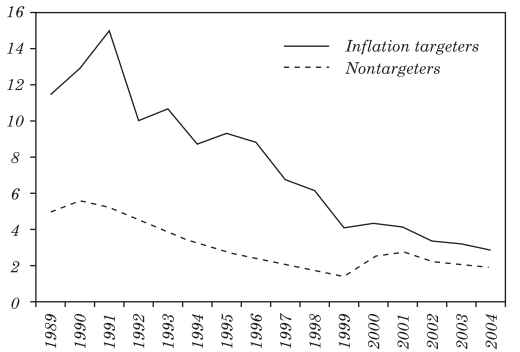


Source: Authors' calculations, based on data from the IMF's *International Financial Statistics* and central bank websites.

Our control group of nontargeters comprises a selective set of thirteen industrial countries that are at the international frontier of macroeconomic management and performance: Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, Portugal, and the United States. In choosing this control group, we reduce the probability of finding evidence of better comparative performance under inflation targeting, considering that the world population of twenty-one inflation targeters encompasses a more heterogeneous country set in terms of past performance, current macroeconomic institutions, and income levels.[7]

Figure 2 shows that inflation targeters and nontargeters had very different annual inflation rates in the late 1980s and early 1990s.[8] However, as time passed and inflation targeting was adopted in the 1990s, the inflation gap between inflation targeters and nontargeters fell almost monotonically and was almost closed by 2004. This inflation convergence is largely due to the massive decline in inflation among inflation-targeting emerging economies (figure 3).

Figure 2. Average Annual CPI Inflation Rates in Inflation Targeters and Nontargeters, 1989–2004[a]

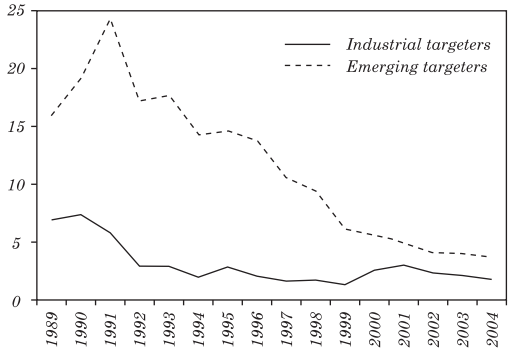


Source: Authors' calculations, based on data from the IMF's *International Financial Statistics* (IFS).
a. Annual averages of inflation rates for twenty-one inflation-targeting countries and thirteen nontargeting countries, identified in the text. Inflation rates are averages of four-quarterly twelve-month CPI inflation rates for the corresponding year.

7. Ten of the thirteen countries in the control group joined the euro area in 1999 and therefore do not pursue an independent monetary policy for a significant part of our 1989–2004 sample period. While this may be a disadvantage, we think it is of less concern than the problems—and less relevant results—that would arise if our control group was made up of developing countries.

8. The country sample of inflation targeters depicted in figure 2 is held fixed, including all years before the adoption of inflation targeting in each of the twenty-one countries.

Figure 3. Average Annual CPI Inflation Rates in Industrial and Emerging Inflation Targeters, 1989–2004[a]



Source: Authors' calculations based on data from the IMF's International Financial Statistics (IFS).
a. Annual averages of inflation rates for nine industrial and twelve emerging inflation-targeting countries, identified in the text. Inflation rates are averages of four-quarterly twelve-month CPI inflation rates for the corresponding year.

Comparative descriptive statistics on inflation performance confirm these facts (table 2). Inflation targeters reduced their average inflation rates from 12.6 percent before the adoption of inflation targeting to 4.4 percent after the adoption. Inflation declined to 6.0 percent in the post-adoption convergence and then to 2.3 percent after attaining stationary targets. Inflation-targeting emerging economies have recorded 6.0 percent inflation since adopting inflation targeting, while the corresponding figure is only 2.2 percent in inflation-targeting industrial countries. The latter figure is very close to the average 2.1 percent inflation recorded among nontargeters since 1997. We observe a similar pattern for inflation volatility (measured by the standard deviation of inflation). While inflation volatility in industrial inflation targeters is twice the level recorded in nontargeters, inflation persistence is slightly lower in industrial targeters than in nontargeters. The next section more systematically tests for significant differences in inflation performance between inflation targeters and nontargeters, controlling for possible endogeneity of the inflation-targeting regime.

Comparative descriptive statistics on the volatility and persistence of output growth and the output gap reflect the following trends (table 3). Emerging inflation targeters—in contrast to industrial inflation targeters—have achieved a significant reduction in output growth volatility and output gap volatility. Nontargeters

Table 2. Descriptive Statistics on Inflation Levels, Volatility, and Persistence of Inflation Targeters and Nontargeters, 1989–2004[a]

Sample group and statistic	*Pre-targeting period[b]*	*Post-targeting period[c]*
Nontargeting countries		
Mean	4.01	2.07
Standard deviation	1.37	0.79
Persistence	0.91	0.83
All inflation-targeting countries		
Mean	12.63	4.37
Standard deviation	3.91	2.63
Persistence	0.83	0.81
Industrial inflation-targeting countries		
Mean	4.73	2.24
Standard deviation	2.16	1.40
Persistence	0.79	0.76
Emerging inflation-targeting countries		
Mean	18.56	5.97
Standard deviation	5.23	3.55
Persistence	0.87	0.85
Converging-target inflation-targeting countries		
Mean	—	6.04
Standard deviation	—	3.11
Persistence	—	0.78
Stationary-target inflation-targeting countries		
Mean	—	2.32
Standard deviation	—	1.29
Persistence	—	0.71

Source: Authors' calculations, based on data from the IMF's IFS.
a. Persistence is measured as the estimated coefficient of an AR(1) equation for inflation.
b. For nontargeters, the corresponding period is 1989–1996.
c. For nontargeters, the corresponding period is 1997–2004.

also achieved a significant reduction in both volatility measures after 1997, to levels that are below those recorded by industrial inflation targeters. However, output persistence, like inflation persistence, is lower in stationary-target inflation targeters than in nontargeters after 1997.

Table 3. Descriptive Statistics on GDP Growth and Output Gap Volatility and Persistence of Targeters and Nontargeters, 1989–2004[a]

Sample group and statistic	*Pre-targeting period[b]*	*Post-targeting period[c]*
Nontargeting countries		
Standard deviation of GDP growth	4.01	2.07
Standard deviation of output gap	1.37	0.79
Persistence of GDP growth	0.73	0.74
Persistence of output gap	0.71	0.68
All inflation-targeting countries		
Standard deviation of GDP growth	3.04	2.23
Standard deviation of output gap	1.87	1.36
Persistence of GDP growth	0.75	0.74
Persistence of output gap	0.65	0.75
Industrial inflation-targeting countries		
Standard deviation of GDP growth	2.01	2.15
Standard deviation of output gap	1.36	1.29
Persistence of GDP growth	0.75	0.74
Persistence of output gap	0.69	0.72
Emerging inflation-targeting countries		
Standard deviation of GDP growth	3.81	2.30
Standard deviation of output gap	2.26	1.41
Persistence of GDP growth	0.75	0.76
Persistence of output gap	0.63	0.78
Converging-target inflation-targeting countries		
Standard deviation of GDP growth	—	2.43
Standard deviation of output gap	—	1.50
Persistence of GDP growth	—	0.68
Persistence of output gap	—	0.76
Stationary-target inflation-targeting countries		
Standard deviation of GDP growth	—	1.52
Standard deviation of output gap	—	1.15
Persistence of GDP growth	—	0.55
Persistence of output gap	—	0.61

Source: Authors' calculations, based on data from the IMF's IFS.
a. Persistence is measured as the estimated coefficient of an AR(1) equation for GDP growth and the output gap.
b. For nontargeters, the corresponding period is 1989–1996.
c. For nontargeters, the corresponding period is 1997–2004.

2. Comparative Inflation Performance

Comparing inflation performance in inflation-targeting countries and nontargeting countries has recently received increased attention (Truman, 2003; Ball and Sheridan, 2005; Vega and Winkelried, 2005; IMF, 2005). All these works are based only on cross-section evidence, but they differ significantly in the choice of control groups of nontargeters and in estimation techniques. Not surprisingly, results also differ significantly, as summarized below. In this section we focus on the comparative performance of inflation levels, extending the previous literature by considering alternative control groups, a panel data set, and alternative estimation techniques.

In line with previous research, we specify inflation as a weighted average of its long-term or underlying mean and its recent past represented by its lagged value, consistent with a standard partial-adjustment specification:

$$\pi_{i,t} = \lambda\pi^{*}_{i,t} + (1-\lambda)\pi_{i,t-1} + \varepsilon_{i,t}, \tag{1}$$

where π is the observed twelve-month CPI inflation rate, π^{*} is the unobserved long-term average twelve-month CPI inflation rate, parameter λ is the weight attached to long-term inflation, and ε is a stochastic disturbance term. Consistent with a panel sample, subindexes i and t denote country units and time periods.

The unobserved long-term inflation rate is allowed to differ between inflation targeters and nontargeters, according to the following specification based on an inflation-targeting-regime dummy variable and controlling for country- and time-specific effects:

$$\pi^{*}_{i,t} = \beta D_{i,t} + \alpha_i + \delta_t, \tag{2}$$

where D is the inflation-targeting-regime dummy, β is its coefficient, α is a country fixed effect, and δ is a time fixed effect. For inflation-targeting countries, $D_{i,t}$ is set equal to 0 for periods before inflation-targeting adoption and 1 for periods of inflation targeting; for nontargeters, $D_{i,t}$ is equal to 0 for all periods.

Substituting equation (2) into equation (1) yields the following expression:

$$\pi_{i,t} = \lambda\beta D_{i,t} + (1-\lambda)\pi_{i,t-1} + \lambda\alpha_i + \lambda\delta_t + \varepsilon_{i,t}. \tag{3}$$

By subtracting lagged inflation from both sides of equation (3) and taking t and t–1 as the periods before and after the inflation-targeting adoption date, we arrive at the following difference-in-difference cross-section specification, which is used by Ball and Sheridan (2005) and IMF (2005) to test for inflation performance differences between inflation targeters and nontargeters:

$$\pi_{i,post} - \pi_{i,pre} = \gamma_1 + \gamma_2 D_i - \gamma_3 \pi_{i,pre} + \mu_i , \tag{4}$$

where $\pi_{i,post}$ ($\pi_{i,pre}$) is average observed inflation in the period after (before) the inflation-targeting adoption date; γ_1, γ_2, and γ_3 are reduced-form coefficients; and μ_i is a stochastic disturbance term.

Table 4 summarizes the cross-section results on comparative inflation performance reported by the previous literature. Ball and Sheridan (2005) reject any long-term differences between inflation targeters and nontargeters regarding inflation mean, volatility, and persistence, for a sample of seven industrial inflation targeters and thirteen industrial nontargeters. They attribute inflation performance improvement in inflation-targeting industrial countries over time to reversion to the mean after the low performance of the 1980s, as reflected by their reported significance of lagged inflation ($\pi_{i,pre}$).[9]

IMF (2005) comes to the opposite conclusion using a similar ordinary least squares (OLS) cross-section estimation technique. The treatment and control groups differ radically from those used by Ball and Sheridan, however: the study compares inflation performance in thirteen developing inflation targeters to a control group of twenty-two developing countries. They find that inflation targeting has helped developing inflation targeters reduce annual long-term inflation rates by 4.8 percent and lower long-term inflation volatility by 3.6 percent.

Finally, Vega and Winkelried (2005) use a matching (propensity score) technique applied to cross-country data for a treatment sample of twenty-three industrial and developing inflation targeters and a control group of eighty-six industrial and developing nontargeters. They report that targeters have lower long-term annual inflation rates ranging from 2.6 percent to 4.8 percent and lower long-term inflation volatilities by 1.5 percent to 2.0 percent. The similarity of Vega and Winkelried's results to those reported in the IMF suggests that

9. Hyvonen (2004) disputes this interpretation by reporting strong evidence for inflation divergence among industrial countries in previous decades. In earlier work—based on panel data estimations for 68 inflation-targeting and nontargeting countries—, Truman (2003) finds that inflation rates are 2.4 percent lower in inflation-targeting countries.

Table 4. Difference in Inflation between Inflation Targeters and Nontargeters in Previous Literature

Study	*Sample*	*Estimation technique*	*Difference in long-term inflation level*	*Difference in long-term inflation volatility*	*Difference in long-term inflation persistence*
Ball and Sheridan (2005)	Targeters: 7 industrial economies; nontargeters: 13 industrial economies	Cross-section, OLS	Zero	Zero	Zero
IMF (2005)	Targeters: 13 emerging economies; nontargeters: 22 emerging economies	Cross-section, OLS	4.8%	3.6%	n.a.
Vega and Winkelried (2005)	Targeters: 23 industrial and emerging economies; nontargeters: 86 industrial and emerging economies	Cross-section, propensity score matching	2.6–4.8%	1.5–2.0%	Ambiguous

Source: References cited herein.

sample differences weigh more heavily than differences in estimation techniques in the results reported by the three cited studies.

Next we extend the tests for differences in inflation performance reported by previous studies along three dimensions. We add the time dimension of the data to the cross-country dimension, focusing on a large panel sample of quarterly data for sixteen years and thirty-four countries. We check the robustness of our results by reporting results based on different estimation techniques (OLS and IV estimations). Finally, we report different results by varying the composition of our inflation-targeting treatment group (separating industrial and emerging-market inflation targeters and stationary-target and converging-target inflation targeters) and of our nontargeting control group (considering different combinations of the nontargeting sample and the pre-targeting sample).

To facilitate comparison with previous studies, we start by estimating equation (4), using quarterly data from 1989–2004 for our full sample of twenty-one developing and industrial inflation targeters and thirteen industrial nontargeters.[10] The results suggest that inflation has been 1 percent higher in inflation-targeting countries than in nontargeters, on average, as reflected by the coefficient of the contemporaneous inflation-targeting dummy variable (table 5). Given the estimated coefficient on pre-targeting (pre-1997) inflation in inflation targeters (nontargeters), equal to –0.85, the long-term average difference in inflation between inflation targeters and nontargeters is estimated at 1.2 percent.[11] This finding of 1 percent higher inflation in inflation-targeting countries is estimated conditional on the inclusion of the highly significant pre-targeting (pre-1997) inflation rate. This estimate is much smaller than the unconditional inflation difference between inflation targeters and nontargeters for the inflation-targeting (post-1997) period, equal to 2.3 percent (the difference between 4.37 percent and 2.07 percent reported in table 2).

Our result stands in contrast with the negative inflation differences between inflation targeters and nontargeters found by Vega and Winkelried (for developing and industrial countries) and the IMF (for developing countries only) and the zero differences in

10. For inflation targeters, the pre-and post-adoption periods are identified in table 2. For nontargeters, we follow the convention of previous studies in using an arbitrary cut-off date that is consistent with the targeters' average adoption date. In our sample, this date is the fourth quarter of 1996.

11. This result must be qualified, however, because of the omission of country fixed effects and the possible endogeneity of the inflation-targeting-regime dummy, addressed below.

Table 5. Inflation Difference between Targeters and Nontargeters: Cross-Section OLS Estimation[a]

Explanatory variable	*Coefficient*
Inflation-targeting dummy	1.007
	(0.093)*
Pre-targeting (pre-1997) inflation	–0.850
	(0.000)***
Constant	1.468
	(0.002)**
R^2	0.973
No. observations	34
No. countries	34

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. P values are reported in parentheses.

Ball and Sheridan (for industrial countries only). This suggests that differences in results are mostly a reflection of inflation-targeting and nontargeting country group composition. Of all the reported studies, our sample composition is the most stringent against finding favorable effects of the inflation-targeting regime, because our inflation targeters comprise the world population of industrial and developing countries, while our control group encompasses only high-achieving industrial nontargeters. Not surprisingly, we find a significantly higher average inflation level in inflation-targeting countries, conditional on their pre-targeting (or pre-1997) inflation levels.

We now proceed to extend the above cross-country studies by exploiting both the country and time dimensions of our full panel sample, using both OLS and instrumental variables (IV) estimation techniques. We start by focusing on our full treatment sample comprising all inflation targeters, but considering three different data sets with alternative control groups. Control group 1 includes all 1989–2004 observations for our thirteen nontargeting countries and the pre-targeting observations of all subsequent inflation targeters, implying a large panel dataset of 1,942 quarterly observations for the full sample. Control group 2 covers all 1989–2004 observations for our thirteen nontargeting countries but excludes the pre-targeting observations of all subsequent inflation targeters; this implies a

smaller panel of 1,420 quarterly observations for the full sample. Finally, control group 3 encompasses all pre-targeting observations of all subsequent inflation targeters and excludes nontargeting countries; this generates a panel of 1,183 observations.

We turn back to equation (3), which is the relevant specification for our panel sample. In contrast to equation (4) and the corresponding results reported in table 5, the regressors now include inflation lagged by one quarter and exclude inflation in the pre-targeting (pre-1997) period. For reference, we start by reporting pooled OLS results with time dummies, with one for each of the three control groups (columns 1, 3, and 5 in table 6). All subsequent results on inflation differences between country groups are conditional on the inclusion of lagged inflation and thus are not directly comparable to the differences in unconditional inflation means reported in table 2.

The results for control group 1 (first column in table 6) show that the impact of the inflation-targeting regime is to reduce inflation by 0.1 percent per year, with a long-term effect (considering the coefficient estimate of lagged inflation) of –1.9 percent. Recall, however, that we include high pre-targeting inflation levels among subsequent inflation targeters in control group 1. Dropping this subsample yields the results reported for control group 2 in column 3, which show no significant inflation difference between inflation targeters and nontargeters. The estimation presented in column 5 reinforces these results: inflation targeters' long-term inflation is a significant 5 percent lower than their pre-targeting long-term inflation level.

These OLS results may be biased because of endogeneity of the inflation-targeting regime to inflation. As shown by our previous research using a cross-section sample of inflation targeters and nontargeters (Mishkin and Schmidt-Hebbel, 2002), the adoption of inflation targeting is determined by country-specific variables, including central bank independence, the fiscal surplus, and initial inflation.

Given the lack of adequate instruments for the inflation-targeting regime variable for our full panel sample, we estimate a parsimonious first-stage specification for the inflation-targeting dummy as a function of its own lag and average pre-targeting (pre-1997) inflation for inflation targeters (nontargeters).[12] The results for various panel

12. Some determinants of an inflation-targeting regime (like central bank independence measures) included in the Mishkin and Schmidt-Hebbel cross-section probit estimation for inflation targeting are not available for time series, while other determinants (such as the ratio of fiscal balance to GDP and trade openness measures) were found to be insignificant in our current panel data sample.

Table 6. Difference in Inflation between Inflation Targeters and Nontargeters: Panel Sample[a]

	Control group 1		*Control group 2*		*Control group 3*	
Explanatory variable	*Pooled OLS (1)*	*Panel IV (2)*	*Pooled OLS (3)*	*Pooled IV (4)*	*Pooled OLS (5)*	*Panel IV (6)*
Inflation-targeting dummy	–0.115	–0.457	–0.010	–0.010	–0.338	–0.491
	(0.047)**	(0.000)***	(0.827)	(0.827)	(0.001)***	(0.002)***
Lagged inflation	0.939	0.904	0.908	0.908	0.932	0.901
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Constant	0.596	0.660	0.568	0.160	0.590	1.023
	(0.004)*	(0.002)***	(0.009)***	(0.465)	(0.082)*	(0.003)
No. observations	1942	1942	1420	1420	1183	1183
No. countries	34	34	34	34	21	21

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. Control group 1 includes all nontargeters and pre-targeters; control group 2 includes all nontargeters; control group 3 includes pre-targeters. Control group 2 regressions cannot be estimated using panel data techniques since country fixed effects are perfectly collinear with inflation targeting. Instruments used in control group 1 and 3 are the lagged inflation-targeting dummy and initial inflation; the instrument used in control group 2 is initial inflation. Time dummies are included for every quarter, and p values are reported in parentheses.

samples of inflation targeters and nontargeters show that both variables are useful instruments of the inflation-targeting-regime dummy; we therefore use them in our subsequent IV estimations.[13]

Returning to table 6, we report IV results for the preceding specification of the inflation difference in columns 2, 4, and 6.[14] This exercise confirms the qualitative results of columns 1, 3, and 5. When we use control group 1 (which includes the inflation targeters' pre-targeting observations since 1989), inflation is lower among inflation targeters. The corresponding estimations for control group 2 show that this result vanishes, yielding no significant difference. With control group 3, however, the lower inflation among inflation targeters is magnified.

We find for control groups 1 and 3 that both the contemporaneous and long-term effects of the inflation-targeting dummy on inflation differentials in inflation-targeting countries is larger for the IV estimations than for the OLS estimations (comparing columns 1 and 2 and columns 5 and 6). This suggests that the absolute size of the inflation-targeting dummy coefficient is biased downward in the OLS estimations, because it fails to take into account the endogeneity of inflation targeting to inflation. When we use IV, the estimated effect of inflation targeting is to lower long-run annual inflation by 4.8 percent (compared to control group 1) and by 5 percent (compared to control group 3). However, there is no significant inflation difference between inflation targeters and nontargeters (control group 2).

To explore whether these results for our full treatment sample (including all industrial and emerging-market inflation targeters) are robust to considering different subsamples of inflation targeters, we divide the full treatment sample first into industrial and emerging-market inflation targeters and then into converging-target and stationary-target inflation targeters. Tables 7 and 8 report the corresponding results for our three control groups, using only IV panel estimation techniques. As above, we infer that estimated inflation differences between inflation targeters and nontargeters depend largely on which control group is used. However, they also vary significantly with treatment groups—that is, across different subsamples of inflation targeters.

13. Results of the first-stage regressions are available on request.

14. We use time dummies in all IV specifications. For control groups 1 and 3, we also use country-specific dummies (fixed effects). We use a within-estimation technique to eliminate the bias that may arise from the correlation between the fixed effects and the regressors owing to the lags of the dependent variable. Finally, we do not use fixed effects for control group 2, since the inflation-targeting dummy would be perfectly correlated with the fixed effects. We therefore apply a standard pooled IV procedure to control for endogeneity in control group 2.

Table 7. Difference in Inflation between Inflation Targeters and Nontargeters, Disaggregated by Industrial and Emerging Targeters[a]

	Control group 1 (Panel IV)		*Control group 2 (Pooled IV)*		*Control group 3 (Panel IV)*	
Explanatory variable	*Industrial Economies* (1)	*Emerging Economies* (2)	*Industrial Economies* (3)	*Emerging Economies* (4)	*Industrial Economies* (5)	*Emerging Economies* (6)
Inflation-targeting dummy	–0.071	–0.806	–0.061	0.103	–0.142	–0.745
	(0.579)	(0.000)***	(0.098)*	(0.118)	(0.490)	(0.002)***
Lagged inflation	0.889	0.892	0.947	0.902	0.878	0.884
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Constant	0.940	0.953	–0.070	0.196	1.497	0.824
	(0.000)***	(0.000)***	(0.652)	(0.404)	(0.002)***	(0.096)***
No. observations	1590	1613	1080	1099	831	854
No. countries	34	33	22	25	21	20

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. Control group 1 includes all nontargeters and pre-targeters; control group 2 includes all nontargeters; control group 3 includes pre-targeters. Control group 2 regressions cannot be estimated using panel data techniques since country fixed effects are perfectly collinear with inflation targeting. Instruments used in control group 1 and 3 are the lagged inflation-targeting dummy and initial inflation; the instrument used in control group 2 is initial inflation. Time dummies are included for every quarter, and p values are reported in parentheses.

Table 8. Difference in Inflation between Inflation Targeters and Nontargeters, Disaggregated by Stationary and Converging Targeters[a]

	Control group 1 (Panel IV)		*Control group 2 (Pooled IV)*		*Control group 3 (Panel IV)*	
Explanatory variable	*Stationary targeters* (1)	*Converging targeters* (2)	*Stationary targeters* (3)	*Converging targeters* (4)	*Stationary targeters* (5)	*Converging targeters* (6)
Inflation-targeting dummy	–0.197	–0.858	0.020	0.021	–0.148	–0.929
	(0.093)*	(0.000)***	(0.607)	(0.750)	(0.462)	(0.001)***
Lagged inflation	0.905	0.893	0.950	0.909	0.900	0.887
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Constant	–0.085	0.864	–0.097	0.557	0.055	1.122
	(0.698)	(0.002)***	(0.560)	(0.011)**	(0.901)	(0.138)
No. observations	1636	1567	1118	1050	877	808
No. countries	34	34	24	27	21	21

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. Control group 1 includes all nontargeters and pre-targeters; control group 2 includes all nontargeters; control group 3 includes pre-targeters. Control group 2 regressions cannot be estimated using panel data techniques since country fixed effects are perfectly collinear with inflation targeting. Instruments used in control group 1 and 3 are the lagged inflation-targeting dummy and initial inflation; the instrument used in control group 2 is initial inflation. Time dummies are included for every quarter, and p values are reported in parentheses.

The results for industrial inflation targeters show that inflation is numerically, but not significantly, lower in industrial inflation targeters than in control groups 1 and 3 (results in columns 1 and 5 of table 7). While this result may be surprising, recall that our econometric results are conditional on including the highly significant lagged inflation variable. In contrast, we find weak evidence (significant at the 10 percent level) that inflation in industrial inflation targeters is significantly lower than in nontargeters for control group 2—by 0.06 percent on impact and by 1.1 percent in the long run. Considering its weak significance, this result is similar to Ball and Sheridan's (2005) finding of no significant inflation difference for industrial countries, based on OLS cross-section results.

The results for emerging inflation targeters point to a considerable gain in inflation. Compared with control groups 1 and 3, emerging inflation targeters record a large and significant reduction of inflation (table 7, columns 2 and 6), which is close to 0.8 percent on impact and 7.0 percent in the long term. However, when compared with nontargeters only (control group 2 in column 4), emerging inflation targeters do not record inflation gains.

The results for converging-target and stationary-target inflation targeters also confirm that the choice of treatment and control groups is crucial (see table 8). Our general result on control groups is upheld: inflation differences tend to favor inflation targeters only in comparison with control groups 1 and 3. Inflation differences in favor of inflation targeters are found to be highly significant in converging inflation targeters and not significant in stationary targeters.

The evidence on the comparative inflation performance of inflation targeters and nontargeters reported both here and in the previous literature thus shows that the effect of inflation targeting on inflation can go either way. Our findings suggest that the source of these differences lies in the use of heterogeneous control groups. The failure to use panel data techniques in previous studies prevents the separation of control groups across countries and time. By exploiting both the cross-section and time dimensions of our sample, we found that the largest difference in inflation performance between inflation targeters and nontargeters occurs when the treatment group is compared with its own pre-targeting experience. This effect declines when nontargeting experiences are added to the control group, but it is still statistically significant. When the control group is restricted to nontargeting countries, however, we find no systematic, significant difference in inflation between inflation targeters and nontargeters.

Further disaggregation of the treatment group into industrial and emerging inflation targeters, and into converging-target and stationary-target inflation targeters, yields mixed results. They confirm that results are highly dependent on the choice of control groups. They also suggest that emerging and converging-target inflation targeters record the largest gains in inflation reduction. Finally, industrial inflation targeters exhibit a statistically weak reduction in inflation relative to nontargeting industrial countries.

3. Inflation and Policy Response to Shocks

If inflation targeting improves the credibility of monetary policy and the anchoring of inflation expectations, then we would expect that inflation would respond less to oil price shocks under inflation targeting and there would be less of a pass-through effect from exchange rate shocks. As a result of increased credibility and reduced devaluation to inflation pass-through, inflation targeting may also reinforce monetary policy independence (that is, it may weaken the reaction of domestic interest rates to shocks in foreign rates).

We therefore want to assess whether inflation targeters differ from nontargeters—and whether targeters differ pre- and post-targeting—in the response of inflation to shocks in oil prices and the exchange rate and the response of domestic interest rates to innovations in international interest rates. To test for differences, we adopt a comparative analysis of impulse response functions in different country samples, depending on whether a country has inflation targeting in place (in the spirit of the difference-in-differences approach). However, instead of using traditional country vector autoregressive (VAR) models, we use a panel VAR that allows us to use the larger data set on inflation targeters and nontargeters employed in this paper.

Our approach to assessing the impact of inflation targeting on the responses described above is based on the analysis and comparison of aggregated impulse response functions in the following five groups of countries and periods: inflation targeters before the adoption of inflation targets; inflation targeters after the adoption of inflation targeting; inflation targeters after achieving stationary targets; nontargeters before 1997; and nontargeters after 1997. The first group—namely, inflation targeters in the period before they implemented inflation targeting—is characterized by a heterogeneous sample period, since it starts at the beginning of our sample (first quarter of 1989) but ends according to the date of adoption of inflation targeting in each

country. The second group presents the opposite situation, in which the sample period is heterogeneous at the beginning but ends at the same period (fourth quarter of 2004). The third group, which is made up of inflation targeters that have achieved stationary targets, is a subsample of the full inflation-targeting group. The results for this subsample might differ from the full sample because the convergence period from the adoption of inflation targeting to a stationary target may not be characterized by high credibility. The full benefits of inflation targeting in achieving a strong nominal anchor might only be obtained after inflation targets become stationary. The fourth and fifth groups both encompass our sample of countries without inflation targeting, but they differ in their sample period.

Once we have estimated the responses to shocks for each group (as described below), we compare those responses between different pairs of groups. Specifically, we are looking for significant differences (that is, statistically different from zero) between the responses before and after the adoption of inflation targeting in inflation targeters (group 1 versus group 2), before the adoption of inflation targeting and after the achievement of a stationary target (group 1 versus group 3), before and after 1997 in nontargeters (group 4 versus group 5), after inflation targeting in inflation targeters and after 1997 in nontargeters (group 2 versus group 5), and after the achievement of a stationary target and after 1997 in nontargeters (group 3 versus group 5). We also split our treatment group sample (inflation targeters) into industrial and emerging economies to check for possible differences in their performance.

We use panel VAR techniques to estimate the impulse response functions for each group described above. This technique combines a traditional VAR approach with panel data. It allows us to exploit our rich information set and gain efficiency in the estimation. This methodology also allows for unobserved country heterogeneity and facilitates the exposition and analysis of aggregate results.[15] To our knowledge, this technique has not been used in studies of inflation targeting.

Following Love and Zicchino (2002), we allow for individual heterogeneity by introducing fixed effects. Since fixed effects are correlated with the regressors due to lags of the dependent variable, we use forward mean differencing (the Helmert procedure) to remove the mean of all the future observations available for each country. This technique supports the use of lagged regressors as instruments and

15. For applied studies using panel VAR estimation, see Holtz-Eakin, Newey, and Rosen, 1988; Love and Zicchino, 2002; Miniane and Rogers, 2003.

estimates the coefficients by system generalized method of moments (GMM). Finally, we identify the responses to innovations in the system using the Choleski decomposition of the variance-covariance matrix of residuals, and we apply bootstrap methods to construct their confidence intervals. Since we cannot assume independence among our samples, we also use bootstrap methods to construct confidence intervals for differences in impulse response functions instead of simply taking their differences.[16]

Our VAR system contains the following six variables (in this order): international oil price, international interest rate, output gap, inflation, interest rate, and nominal exchange rate. As is usual in any VAR estimation, the most exogenous variables enter first in the VAR. Since the model yields similar impulse response functions using two or more lags, we selected a lag order of two for reasons of parsimony.

We start by discussing the impulse responses of inflation to oil price shocks (figures 4, 5, and 6) and exchange rate shocks (figures 7, 8, and 9), and end with the impulse responses of domestic to international interest rates (figures 10, 11, and 12).[17] Each figure shows the dynamic response of one selected variable to a shock in another variable of the system. For example, the first cell (first row and first column) of figure 4 depicts the dynamic response of domestic inflation to an international oil price shock in inflation-targeting countries before they adopted inflation targeting. The response of domestic inflation to an oil price shock equivalent to one standard deviation is 0.18 percent in quarter 0 (contemporaneous effect) and peaks at 0.40 percent in quarter 2 (after the shock).[18]

Each row of cells in the figure focuses on a different comparison between the dynamic response of two sample groups. The first three rows report before-and-after comparisons—rows 1 and 2 for inflation targeters before and after they adopted inflation targeting, and row 3 for nontargeters before and after 1997. Rows 4 and 5 report comparisons across country groups: inflation targeters after adopting inflation targeting or after achieving a stationary target, respectively,

16. If we were simply to assume sample independence, the corresponding confidence intervals for differences would be narrower.

17. We estimated impulse responses for other shocks (including inflation and output gap responses to interest rate shocks and interest rate responses to exchange-rate shocks) and tested for their differences across country groups, but the results were not relevant.

18. The three shocks considered in this section—namely, shocks to the international price of oil, the domestic interest rate, and the international interest rate—are measured as one standard deviation of the residual of the corresponding equation.

are compared to nontargeters after 1997. For instance, the first row of figure 4 compares the response of inflation targeters before they adopted inflation targeting (first column) to the response of inflation targeters after they did so (second column). The third column reports the difference between the preceding responses—that is, the response in the second column minus the response in the first column.

Figure 4. Response of Inflation to an Oil Price Shock: All Inflation Targeters

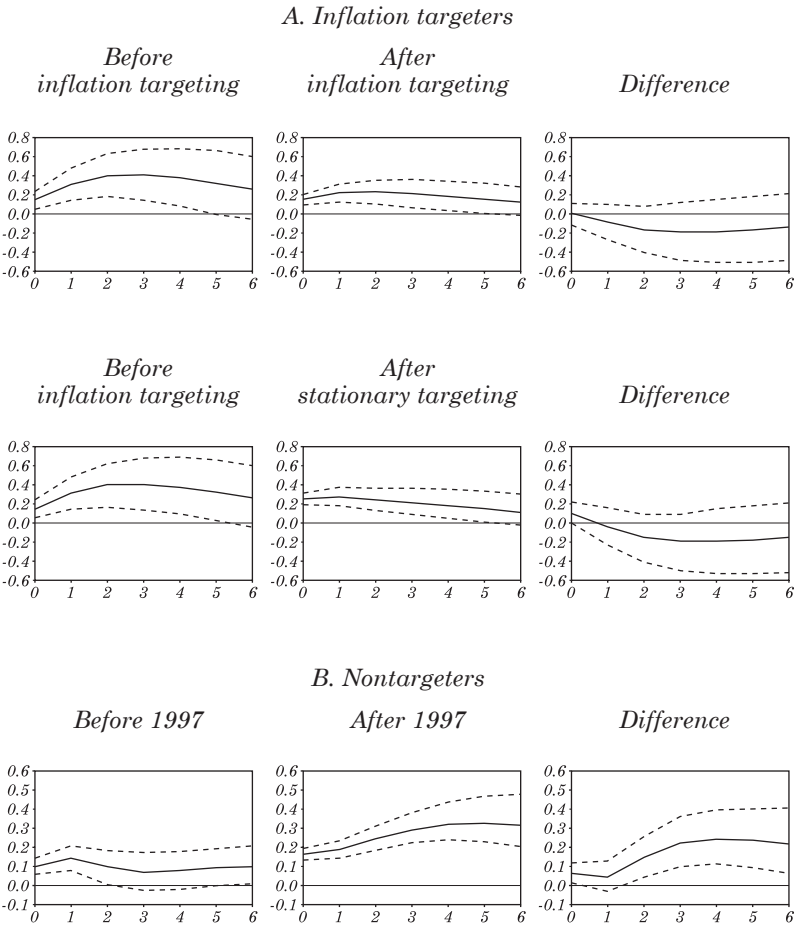
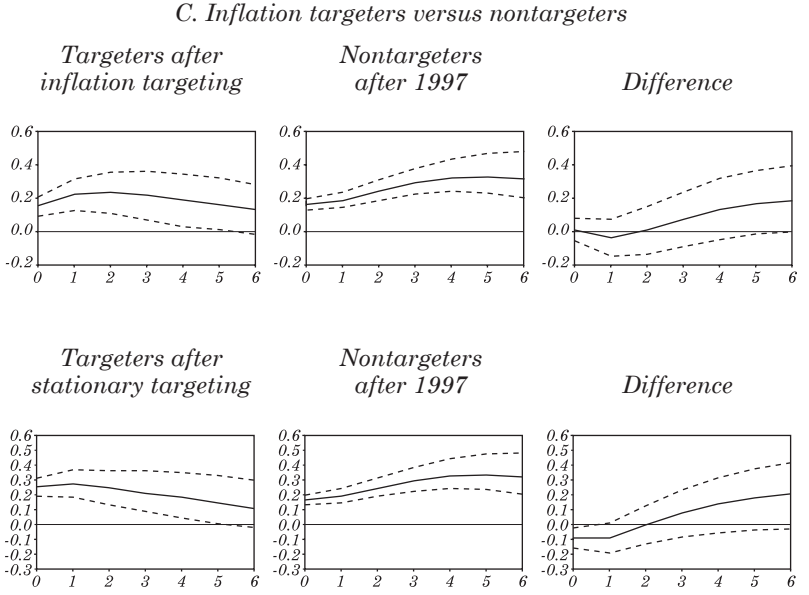


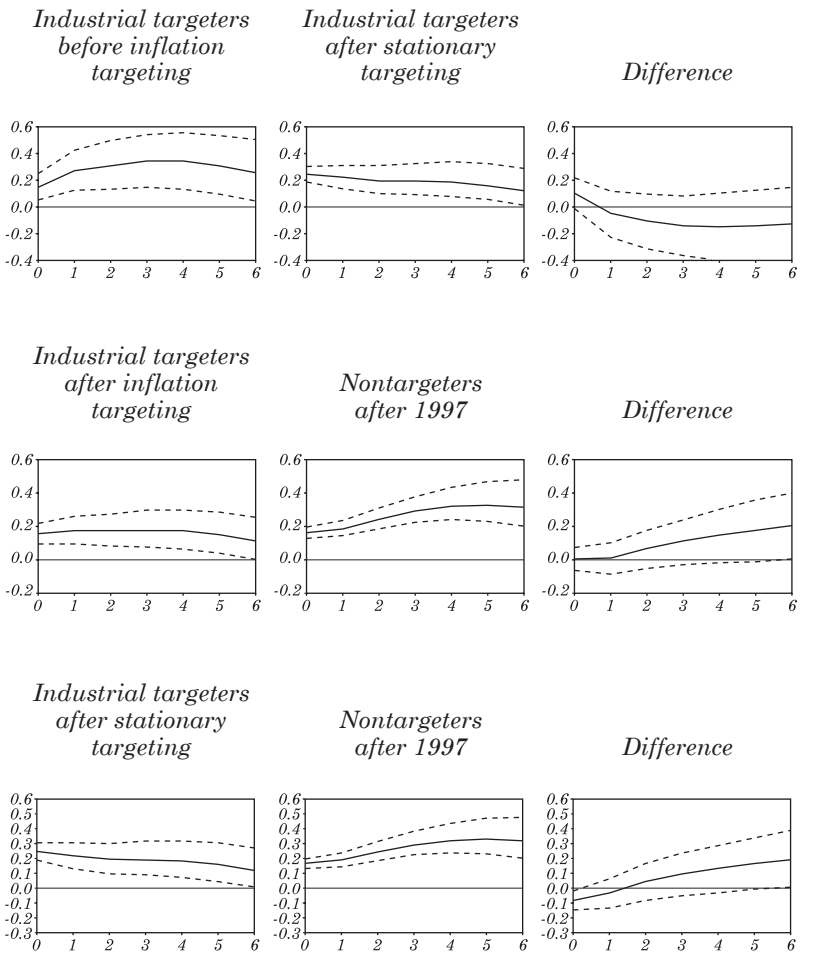
Figure 4. (continued)



Source: Authors' estimations.

The (positive) response of inflation to oil price shocks is smaller in inflation targeters after adopting inflation targeting and after achieving stationarity than before the adoption of inflation targeting (first and second rows of figure 4, respectively). These differences are not statistically different from zero, however, as reflected by the confidence intervals in column three. The opposite result is observed for nontargeters (third row, figure 4). The reaction of inflation to oil prices in nontargeters is larger after 1997 than before 1997, and this difference is statistically different from zero starting in the second quarter after the oil price shock. When we compare all inflation targeters with nontargeters after 1997 (fourth row, figure 4) and stationary inflation targeters with nontargeters after 1997 (fifth row, figure 4), we find that both inflation targeters and stationary inflation targeters react slightly more than nontargeters to oil price shocks on impact and in the first quarter after the shock, but less in the following quarters. While the differences are generally not statistically significant, the short-term response to an oil price

Figure 5. Response of Inflation to an Oil Price Shock: Industrial Inflation Targeters

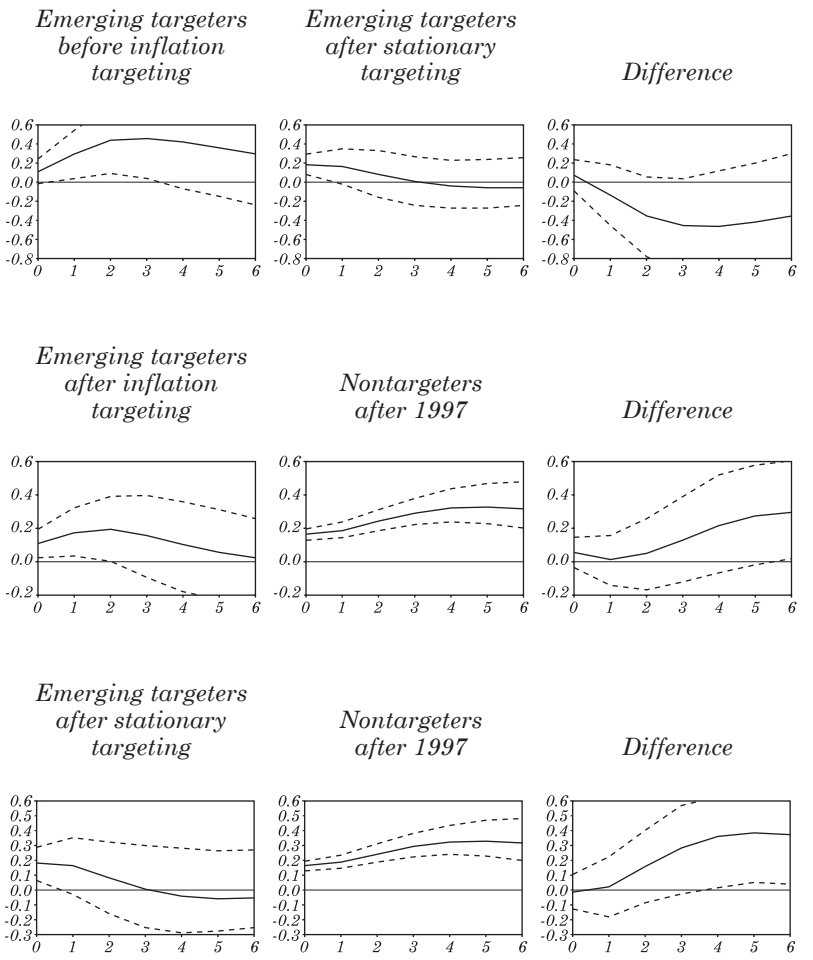


Source: Authors' estimations.

shock in inflation-targeting countries is somewhat larger than in nontargeters, but it is smaller from the third quarter onward.

To take into account the sample heterogeneity in our full treatment group of inflation targeters, we divide the group first

Figure 6. Response of Inflation to an Oil Price Shock: Emerging Inflation Targeters



Source: Authors' estimations.

into industrial and emerging-market inflation targeters and then further into inflation targeters before the start of inflation targeting and stationary-target inflation targeters. Figures 5 and 6 depict the response of inflation to a shock in oil prices, separately for industrial

and emerging inflation targeters. The first row of each figure reports the comparison of inflation targeters before they adopted inflation targeting and after they achieved a stationary target; this is equivalent to the before-and-after comparison reported for all inflation targeters in the second row of figure 4. In rows 2 and 3 of each figure, we report comparisons across country groups (inflation targeters after they adopted inflation targeting and nontargeters in row 2 and inflation targeters after they achieved a stationary target and nontargeters in row 3); this is equivalent to the comparisons reported for all inflation targeters in rows 4 and 5 of figure 4, respectively.

In both industrial and emerging economies, inflation responds less to oil price shocks under a stationary target than before the adoption of inflation targeting (first rows of figures 5 and 6), but the differences are not statistically significant. However, the inflation response to an oil price shock is larger in industrial inflation targeters with a stationary target than in emerging-market inflation targeters with a stationary target. While the inflation reaction is positive and significant during the seven quarters after the oil price shock in industrial stationary inflation targeters, it is significant only until the first quarter in emerging-market stationary inflation targeters.

We now turn to the comparison of inflation targeters and nontargeters (the second and third rows of figures 5 and 6). In all inflation-targeting treatment groups, inflation responds less to oil price shocks than it does in nontargeters (after 1997), and this difference is significant by the sixth quarter, at the latest. In the case of emerging-market stationary inflation targeters, this difference is larger, earlier, and more significant than in the other inflation-targeting treatment groups: it is significant from the fourth to the sixth quarters (last row in figure 6). This last result shows that the performance in emerging stationary inflation targeters is the main force behind the results found for the full sample of inflation targeters (figure 4).

This comparative evidence on the inflation consequence of oil price shocks leads us to two main conclusions. First, inflation targeting helps all inflation targeters to reduce the domestic inflation response to an oil price shock relative to their own pre-targeting experience, although this reduction is not statistically different from zero. Second, in all inflation-targeting treatment groups, the inflation response to oil price shocks is smaller than in nontargeting countries after 1997. The difference in favor of inflation targeters is statistically significant, on average, at later quarters, reflecting smaller and less persistent effects of an oil shock on domestic inflation in inflation-targeting

than in nontargeting countries. This result is particularly strong in emerging-market stationary inflation targeters, where the response of inflation to an oil price shock is the smallest and least persistent of all our subsamples.

The response of inflation to innovations in the exchange rate provides a measure of the dynamics of devaluation-inflation pass-through. The positive response of inflation to exchange rate depreciation shocks is not much different before and after the adoption of inflation targeting in the full sample of inflation targeters (first row, figure 7). However, stationary-target inflation targeters show a larger decline in the response of inflation to exchange rate shocks, and this reduction is statistically significant in the first and second quarters after the shock. We observe a smaller response of inflation to exchange rate shocks in nontargeters after 1997 than in all inflation targeters and in stationary inflation targeters (fourth and fifth rows, figure 7). This result is statistically different from zero until the fourth quarter after the shock.

Figure 7. Response of Inflation to an Exchange Rate Shock: All Inflation Targeters

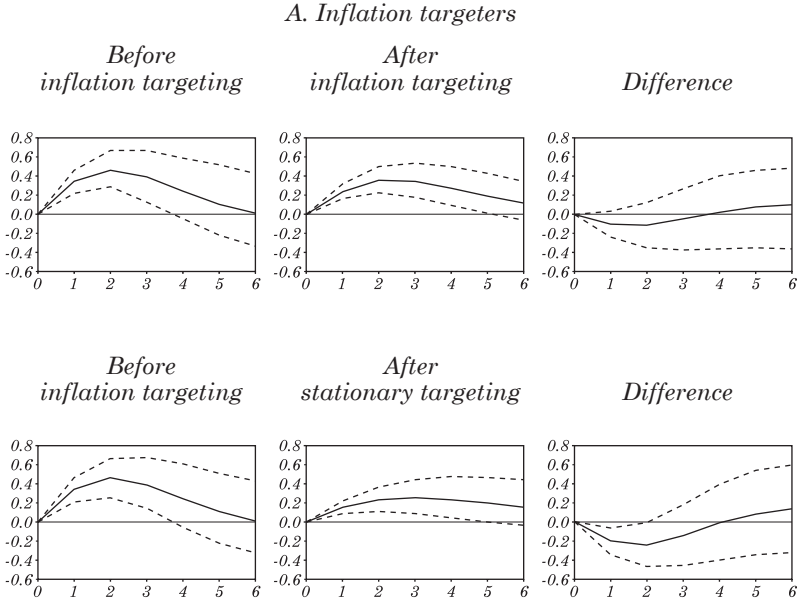
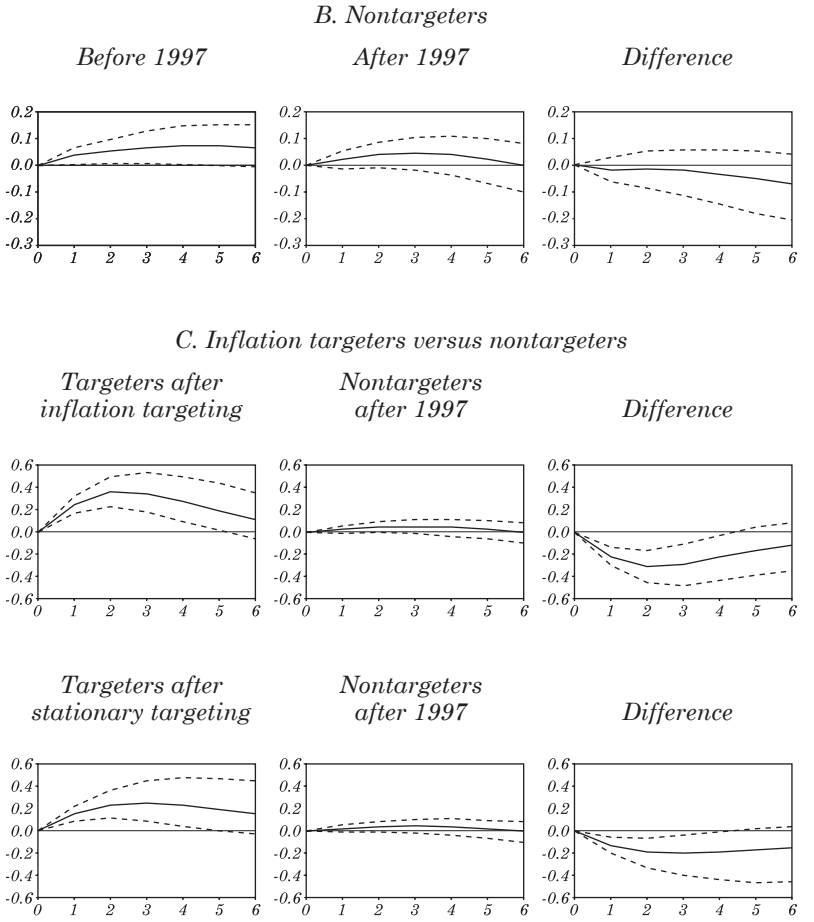


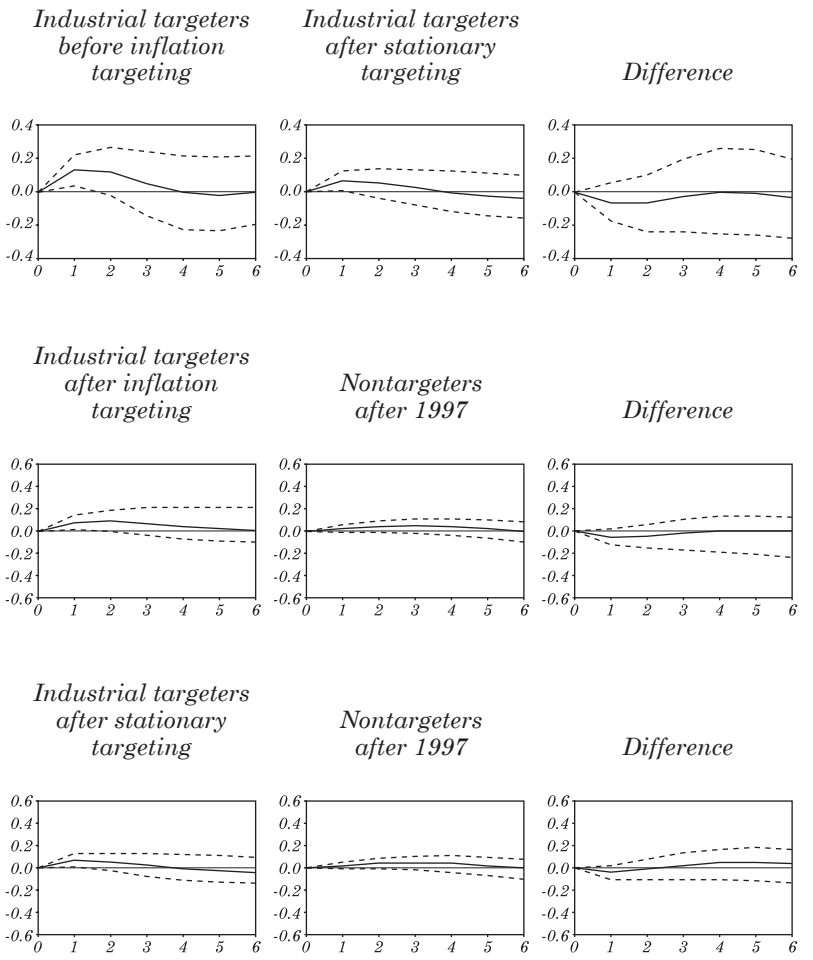
Figure 7. (continued)



Source: Authors' estimations.

Next, we separate our treatment group into industrial and emerging inflation targeters (figures 8 and 9). Industrial inflation targeters (after inflation targeting) and industrial stationary inflation targeters exhibit a significantly smaller inflation response to exchange rate shocks than either emerging-market inflation targeters (after inflation targeting) or emerging stationary inflation targeters. Both industrial treatment groups (that is, all inflation targeters and

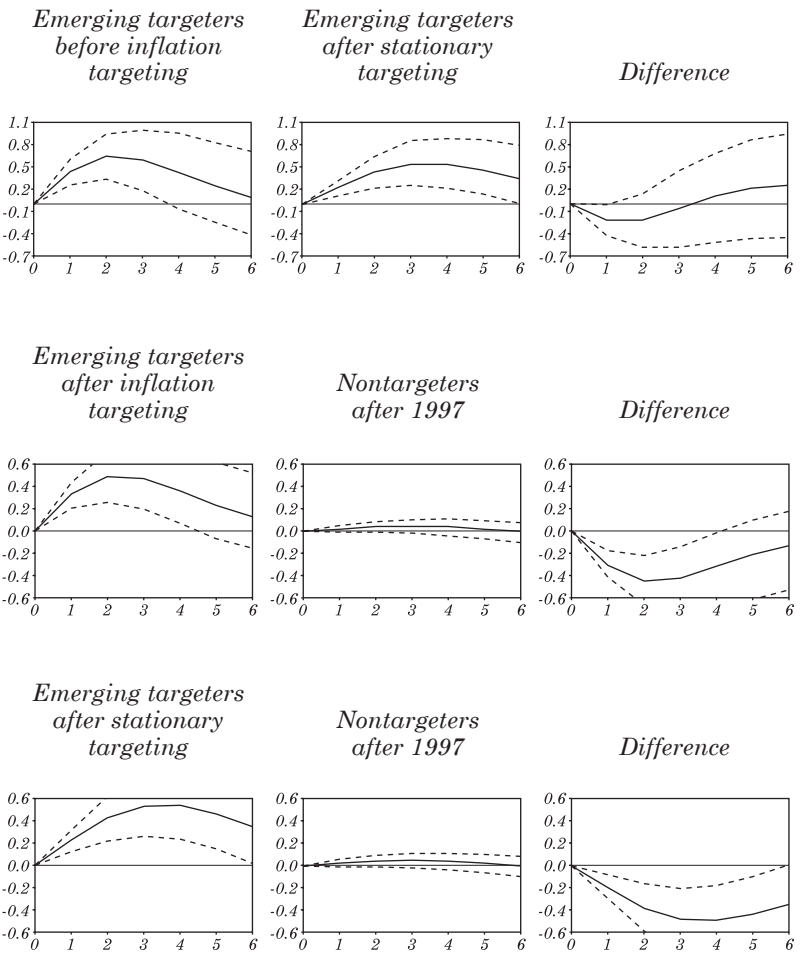
Figure 8. Response of Inflation to an Exchange Rate Shock: Industrial Inflation Targeters



Source: Authors' estimations.

stationary inflation targeters) display pass-through coefficients that are close to zero and insignificant in most periods. Both emerging-market treatment groups, in turn, register pass-through coefficients that are positive and significant at least until the fourth quarter

Figure 9. Response of Inflation to an Exchange Rate Shock: Emerging Inflation Targeters



Source: Authors' estimations.

after the shock. In industrial inflation targeters, the adoption of both inflation targeting and stationary-target inflation targeting has not made any difference to their pass-through coefficients, in comparison with both their own pre-targeting experience and in comparison with

nontargeters after 1997 (figure 8). In emerging-market economies, however, the comparisons yield very different results (figure 9). Short-term pass-through effects declined after the adoption of stationary targets in emerging economies, and the difference is significant in the first quarter after the exchange rate shock. Nevertheless, this reduction has not been sufficient to bring pass-through coefficients down to zero, as occurred among nontargeters after 1997. In fact, emerging-market inflation targeters and stationary inflation targeters exhibit much larger pass-through effects than nontargeters, and the differences are significant from quarters one through four (for all inflation targeters) and quarters one through six (for stationary inflation targeters).

We reach two conclusions from our comparison of the dynamics of pass-through effects from exchange rate shocks to domestic inflation. First, the adoption of inflation targeting has helped reduce the short-term pass-through somewhat under stationary-target inflation targeting, relative to the sample's own pre-targeting experience. This result, however, is entirely driven by emerging-market inflation targeters, where the pass-through coefficients fell somewhat after the countries achieved a stationary target but remain positive and significantly different from zero. Pass-through effects have been close to zero in industrial inflation targeters before and after inflation targeting and in nontargeters. Second, when comparing all inflation targeters and all stationary-target inflation targeters to nontargeters after 1997, the pass-through effects are significantly larger in both groups of targeters than in the nontargeters. This result is due to emerging-market inflation targeters, which exhibit much larger pass-through coefficients than nontargeters after 1997—and the differences are statistically significant from quarters one through five, on average. In contrast, industrial inflation targeters and nontargeters do not exhibit any significant differences in pass-through performance.

Finally, we consider the issue of comparative monetary independence, reflected by the response of domestic interest rates to shocks in international interest rates. In the pre-targeting period of inflation-targeting countries, the response of domestic interest rates to a shock in the international interest rate is very large, rises over time, and is statistically significant from impact through quarter six (first cell, figure 10). The positive response of the domestic interest rate to international interest rate shocks falls substantially in inflation targeters after they adopt inflation targeting and after they achieve stationary inflation targeting. In both cases, the decline in interest rate

sensitivity is very large and statistically different from zero. Among nontargeters, interest rates react more strongly to international interest rates after 1997 than before, which may reflect the inclusion of a large number of euro area members in our control group. This difference is statistically significant only for the first two quarters after the shock. Interest rate sensitivity to foreign interest rate shocks is larger in inflation targeters and in stationary inflation targeters than in nontargeters after 1997; this difference is statistically different from zero in the case of all inflation targeters. This suggests that in the period of convergence, inflation targeting is not sufficient to achieve the level of monetary independence attained by nontargeters. However, interest rates in stationary inflation targeters respond to international interest rates at a similar magnitude as in nontargeters, since the difference in their impulse response functions is not statistically different from zero. Monetary independence under stationary inflation targeting has thus converged to the levels observed among nontargeters.

Figure 10. Response of the Domestic Interest Rate to an International Interest Rate Shock: All Inflation Targeters

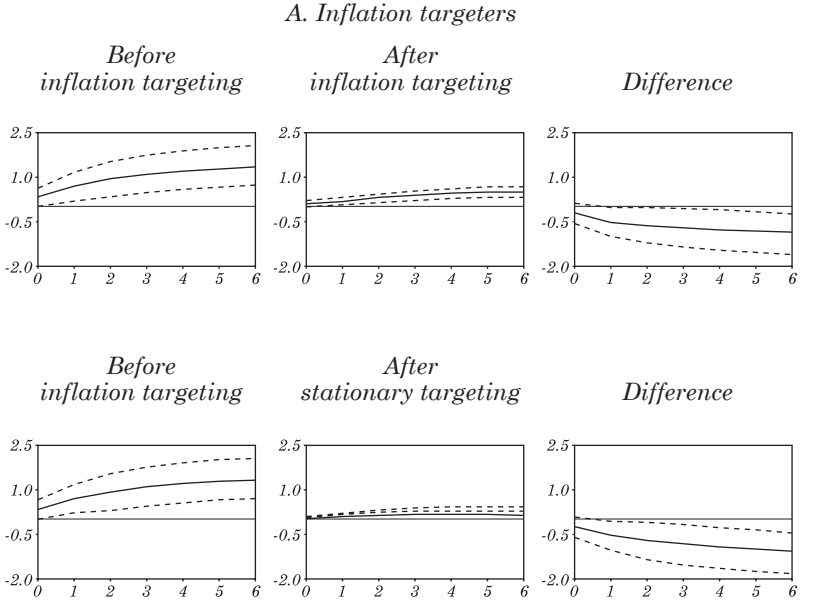
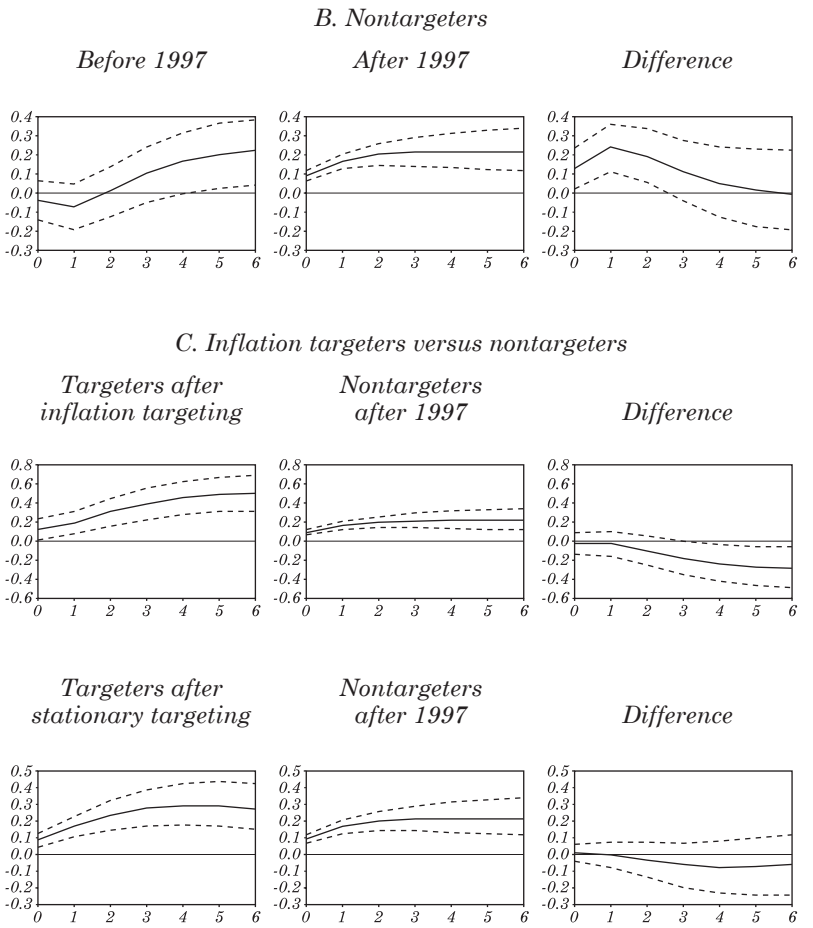


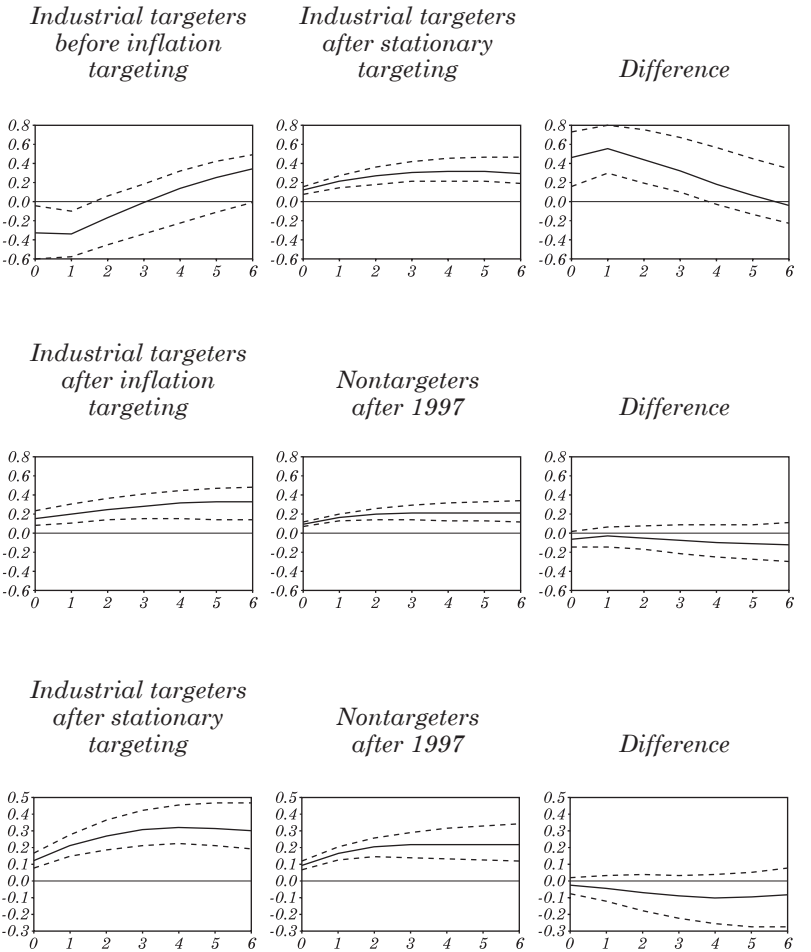
Figure 10. (continued)



Source: Authors' estimations.

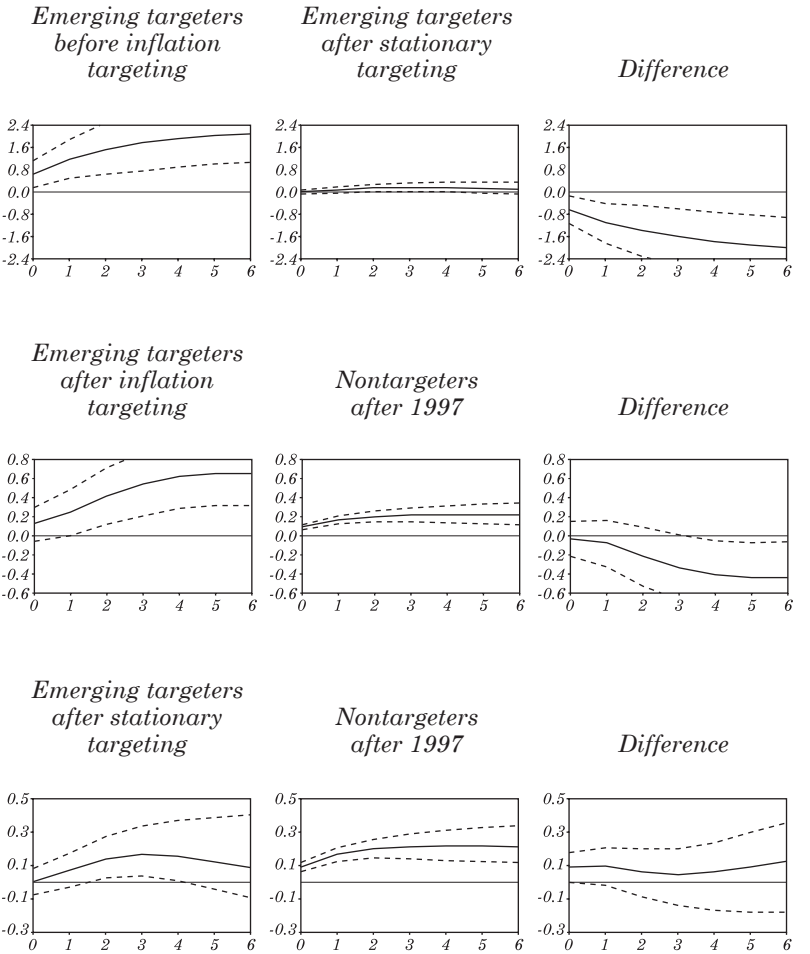
Our next task is to disaggregate industrial and emerging inflation targeters, since these two groups exhibit large and significant differences in monetary independence (see figures 11 and 12). The contrast in the domestic interest rate reaction to foreign interest rate shocks is striking in the pre-targeting period. While the response is negative and significant in the first quarters after the shock in the industrial pre-targeting experience, the response is positive, huge,

Figure 11. Response of the Domestic Interest Rate to an International Interest Rate Shock: Industrial Inflation Targeters



Source: Authors' estimations.

Figure 12. Response of the Domestic Interest Rate to to an International Interest Rate Shock: Emerging Inflation Targeters



Source: Authors' estimations.

increasing, and statistically significant in emerging-market countries. This points to a significant lack of monetary independence in the latter group before they adopted inflation targeting.

The results are quite different after the adoption of inflation targeting. In industrial stationary inflation targeters, the domestic interest rate sensitivity turns positive and is significantly larger in the first four quarters after the shock than it was before inflation targeting. This makes industrial inflation targeters more similar to nontargeters: there is no statistical difference in monetary independence between industrial inflation targeters (and industrial stationary inflation targeters) and nontargeters after 1997. In emerging inflation targeters, however, the adoption of inflation targeting massively reduces their interest rate sensitivity to foreign interest rate shocks. The size of the interest rate response declines by one order of magnitude after the start of inflation targeting, but it remains positive and significant from quarters one through six. Emerging-market inflation targeters attain a further reduction in interest rate sensitivity on achieving a stationary target: the response is now barely positive and only significant in quarters two to four after the foreign interest rate shock. Comparing emerging inflation targeters with post-1997 nontargeters yields a larger interest rate sensitivity (that is, significantly different from zero in quarters three to six) in the former group. Once emerging-market economies reach their stationary targets, their interest sensitivity declines further to levels that are numerically smaller but statistically not different from those observed among nontargeters after 1997.

We conclude two points from our comparisons of dynamic responses of domestic interest rates to a shock in the international interest rate, which serves as a measure of monetary independence. First, the adoption of inflation targeting brought down interest rate sensitivity estimates for the full sample of inflation-targeting countries. However, this aggregate result hides two opposite changes. In industrial countries, interest rate sensitivity increased from negative to positive and significant with the adoption of inflation targeting. In contrast, in emerging-market inflation targeters, interest rate sensitivity declined from huge before inflation targeting to moderate during converging-target inflation targeting and to small under stationary-target inflation targeting. Second, inflation targeters are more similar to nontargeters as a result of these changes. While the sensitivity of interest rates to foreign interest rate shocks is slightly larger in industrial stationary inflation targeters than in nontargeters, and slightly smaller in emerging-market stationary inflation targeters

than in nontargeters, the differences are not statistically significant. Our measure of monetary independence thus reflects a convergence of inflation-targeting countries that have achieved stationary targets to the levels exhibited by nontargeters.

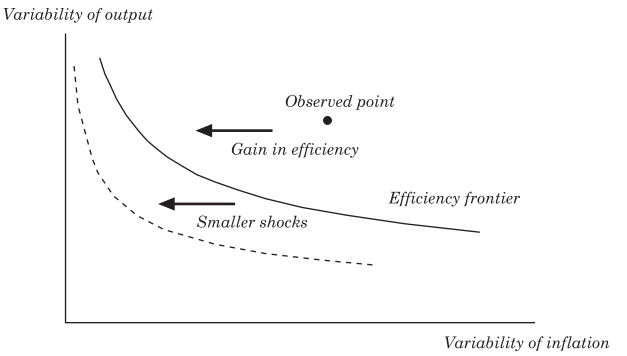
4. Inflation Volatility, Output Volatility, and Monetary Policy Efficiency

One way of gauging macroeconomic performance is to focus on the stability of inflation and real growth. The evidence reported in tables 2 and 3 shows that standard deviations of inflation and the output gap are larger in inflation targeters than in nontargeters. One possible explanation is that nontargeters are hit by smaller shocks. Alternatively, nontargeters' central banks may be more efficient at implementing policies to meet their stabilization objectives. In this section, we compute performance measures to identify the contribution of different monetary policy strategies to the observed differences in macroeconomic performance between inflation targeters and nontargeters. Following Cecchetti and Krause (2002) and Cecchetti, Flores-Lagunes, and Krause (2006), we estimate an inflation and output variability efficiency frontier that allows us to derive measures of economic performance and monetary policy efficiency.

The performance of monetary policy can be assessed using the inflation and output variability trade-off faced by the policymaker. This trade-off allows us to construct an efficiency frontier known as the Taylor curve (Taylor, 1979). The inflation-output variability frontier is understood by considering an economy that is hit by two types of disturbances: aggregate demand and aggregate supply shocks. Aggregate supply shocks move output and inflation in opposite directions, forcing the monetary authority to face a trade-off between inflation and output variability. The position of the efficiency frontier therefore depends on the intensity of aggregate supply shocks: the smaller the shocks, the closer is the frontier to the origin (see figure 13).

The efficiency frontier is also an indicator of the degree of optimality of monetary policy. When monetary policy is suboptimal, the economy will exhibit large output and inflation volatility and will be located at a significant distance from the frontier. Movements toward the efficiency frontier indicate improved monetary policy (figure 13). These features of the efficiency frontier allow us to construct measures of economic and monetary policy performance to examine the contribution of policy efficiency and the variability of shocks to the observed differences in

Figure 13. Monetary Policy Efficiency Frontier and Performance Point



Source: Authors.

macroeconomic performance between different samples of nontargeters and inflation targeters.

We closely follow the methodology derived by Cecchetti, Flores-Lagunes, and Krause (2006). We do not apply their method to individual countries, however, but rather to inflation-targeting and nontargeting country groups. We start by obtaining a measure of an economy's performance in terms of output and inflation variability. Specifically, we derive a standard conventional central bank objective, which is to minimize the following loss function determined by quadratic inflation and output deviations:

$$L = \lambda(\pi_t - \pi_t^*)^2 + (1-\lambda)(y_t - y_t^*)^2, \tag{5}$$

where π_t is the inflation rate, π_t^* is the inflation target or objective, y_t is the log level of output, y_t^* is the target or trend level of output, and λ is the policymaker's weight attached to inflation. Hence our measure of macroeconomic performance, L, is a weighted average of observed variability of inflation and output with respect to their target levels.

The difference between the observed performance measures of nontargeters (L_{NIT}) and inflation targeters (L_{IT}) reflects differences in macroeconomic outcomes. If $\Delta L = L_{\text{NIT}} - L_{\text{IT}}$ is negative, then nontargeters present a better macroeconomic performance than inflation targeters. We similarly interpret the comparison of inflation targeters before and after they adopted inflation targeting.

If $\Delta L = L_{\text{post-IT}} - L_{pre\text{-IT}}$ is negative, then inflation targeters recorded a performance gain after the adoption of inflation targeting.

This change in performance can reflect either a change in the position of the efficiency frontier (that is, a better performance is explained only by smaller supply shocks) or a change in monetary policy efficiency or both. The change in performance due to the change in the size of shocks is derived from the following combination of the optimal variances of output and inflation:

$$S = \lambda\overline{(\pi_t - \pi_t^*)^2} + (1-\lambda)\overline{(y_t - y_t^*)^2}, \tag{6}$$

where $\overline{(\pi_t - \pi_t^*)^2}$ and $\overline{(y_t - y_t^*)^2}$ are the deviations of inflation and output from their targets under an optimal policy, respectively. S is the measure of supply shocks variability. Therefore, the smaller the variability of the disturbances that hit the economy, the closer is the efficiency frontier to the origin and the smaller is the latter measure. For example, a negative difference of this measure between nontargeters and inflation targeters, $\Delta S = S_{\text{NIT}} - S_{\text{IT}}$, indicates that the shocks hitting nontargeters are smaller. Alternatively, a negative value of $\Delta S = S_{\text{post-IT}} - S_{pre\text{-IT}}$ implies that inflation targeters face smaller shocks after the adoption of inflation targeting.

Finally, we evaluate the efficiency of monetary policy by measuring how close actual performance is to performance under optimal policy (that is, the distance to the efficiency frontier). We label this measure E and define it as follows:

$$E = \lambda\left[(\pi_t - \pi_t^*)^2 - \overline{(\pi_t - \pi_t^*)^2}\right] + (1-\lambda)\left[(y_t - y_t^*)^2 - \overline{(y_t - y_t^*)^2}\right]. \tag{7}$$

Hence, the smaller the value of E, the closer monetary performance is to optimal policy. Differences in policy efficiency between nontargeters and targeters are obtained by computing $\Delta E = E_{\text{NIT}} - E_{\text{IT}}$; a negative value of ΔE implies that nontargeters' policy is more efficient. Similarly, the change in policy efficiency of inflation targeters over time is computed as $\Delta E = E_{\text{post-IT}} - E_{pre\text{-IT}}$, which is negative if inflation targeters improved their policy efficiency.

Computation of these performance measures requires empirical estimates of the output-inflation variability frontier. We first need to derive a policy reaction function from minimization of the loss function, subject to the constraints imposed by the structure of the economy. Given this solution and a value for the weight of inflation in

the policymaker's loss function (λ), we are able to plot a point on the efficiency frontier. Varying the weight assigned to the variability of inflation allows us to trace the entire efficiency frontier. We proceed in two main steps: we estimate a simple dynamic aggregate demand and supply model, and we then use this estimate to construct the efficiency frontier.

We consider a simple dynamic panel aggregate demand and supply model similar to the one used in Rudebusch and Svensson (1999). The model consists of the following two equations:

$$y_{i,t} = \sum_{j=1}^{p} \phi_{1,j} i_{i,t-j} + \sum_{j=1}^{p} \phi_{1,p+j} y_{i,t-j} + \sum_{j=1}^{p} \phi_{1,2p+j} \pi_{i,t-j} + \sum_{i=j}^{p} \phi_{1,3p+j} px_{i,t-j} + \sum_{i=j}^{p} \phi_{1,4p+j} \text{oil}_{t-j} + v_{1,i} + \varepsilon_{1,i,t}; \tag{8}$$

$$\pi_{i,t} = \sum_{j=1}^{p} \phi_{1,j} y_{i,t-j} + \sum_{j=1}^{p} \phi_{1,p+j} \pi_{i,t-j} + \sum_{i=j}^{p} \phi_{1,2p+j} px_{i,t-j} + \sum_{i=j}^{p} \phi_{1,3p+j} \text{oil}_{t-j} + v_{2,i} + \varepsilon_{2,i,t}. \tag{9}$$

The first equation reflects an aggregate demand function, where detrended output ($y_{i,t}$) for country i at time t is explained by p own lags, p lags of the nominal interest rate ($i_{i,t}$), and inflation deviations from targets or objectives ($\pi_{i,t}$). We also include p lags of two exogenous variables, the deviation of the oil price from trend (oil_t) and external price inflation ($px_{i,t}$), as well as a country fixed effect ($v_{1,t}$).[19] The second equation represents a Phillips curve, in which inflation deviations from its target or objective are a function of p own lags, p lags of detrended output, p lags of the deviation of the oil price from trend, p lags of the deviation of external inflation from trend, and a country fixed effect. Finally, $\varepsilon_{1,i,t}$ and $\varepsilon_{2,i,t}$ represent the error terms. We estimate both equations for a group of countries (for example, nontargeters and targeters) using the generalized method of moments (GMM) for dynamic panels (Arellano and Bond, 1991).

Having estimated the dynamics of the economy, we proceed to obtain the optimal monetary policy function. The central bank selects

19. External inflation is defined as the sum of the annualized nominal exchange rate devaluation and the annual inflation rate of the United States.

a path for the interest rate from the minimization of its loss function subject to the dynamics of the economy:

$$\min \widehat{E}(L) = \widehat{E}\left[(\pi_t - \pi_t^*)^2 + (1-\lambda)(y_t - y_t^*)^2\right] = \widehat{E}(\mathbf{Y}_t' \, \mathbf{\Lambda} \mathbf{Y}_t), \tag{10}$$

subject to

$$\mathbf{Y}_t = \mathbf{B}\mathbf{Y}_{\mathbf{t\text{-}1}} + \mathbf{c}i_{t-1} + \mathbf{D}\mathbf{X}_{t-1} + \mathbf{v}_t, \tag{11}$$

where $\mathbf{Y}_t = (i_{t-1}, y_t, y_{t-1}, \pi_t, \pi_{t-1})'$, $\mathbf{X}_t = (px_t, \text{oil}_t)'$, $\mathbf{v}_t = (0, \varepsilon_{1,t}, 0, \varepsilon_{2,t}, 0)'$, **B** and **D** are matrices of the estimated coefficients of the aggregate demand and supply equations, Λ is a matrix of the weights attached to output and inflation variability, and $\hat{E}$ is the expectation conditional on information available at time t. The solution to this optimal control problem yields an optimal path for the interest rate:

$$i_t = \mathbf{\Gamma}\mathbf{Y}_t + \Psi, \tag{12}$$

where $\Gamma = -(\mathbf{c}'\mathbf{H}\mathbf{c})^{-1}\mathbf{c}'\mathbf{H}\mathbf{B}$ with $\mathbf{H} = \Lambda + (\mathbf{B} + \mathbf{c}\Gamma)'\mathbf{H}(\mathbf{B} + \mathbf{c}\Gamma)$, and ψ is a constant term that depends on **B**, **c** and **D**. Using this result, we calculate the optimal variances of output and inflation, obtaining a point on the efficiency frontier for each value of λ.

With the estimated efficiency frontier at hand, we determine the optimal variances of inflation and output that are required to compute performance measures. We calculate the ratio of the observed volatilities of output and inflation and then identify the point on the frontier that implies this variability ratio. This is similar to performing a homothetic shift of the frontier so that it passes through the data point determined by the observed variances of output and inflation.

Consistent with our measures in the other sections of the paper, here our measures of inflation volatility are based on the deviation of CPI inflation from the inflation target for inflation targeters and from a Hodrick-Prescott (HP) trend for nontargeters. For both county groups, output volatility is based on the output gap or deviation from an HP trend.

We are now able to compute the performance measures presented above in order to disentangle the contribution of changes in monetary policy efficiency and supply shocks to the observed differences in macroeconomic performance between different country groups. As in other sections of the paper, we compare the performance between five groups of countries: inflation targeters before and after the adoption

of inflation targeting; inflation targeters before they adopted inflation targeting and after they achieved a stationary target; nontargeters before and after the mean inflation-targeting adoption date (first quarter of 1997); inflation targeters vis-à-vis nontargeters after the first quarter of 1997; and stationary inflation targeters versus nontargeters after the first quarter of 1997. As above, we also present results for all inflation targeters and for industrial and emerging inflation targeters.

Table 9 reports the estimated comparative measures of economic performance, L, monetary policy efficiency, E, and the variability of supply shocks, S, for each pair of country groups. Figures 14 through 26 depict actual performance points, L, and efficiency frontiers consistent with E for each pair of country groups. We follow Cecchetti, Flores-Lagunes, and Krause (2006) in using a value of λ—that is, the weight attached to inflation deviations in the loss function—equal to 0.80. This value is consistent with the empirical estimates for inflation-targeting and nontargeting countries reported by Cecchetti and Ehrmann (2002) and Corbo, Landerretche, and Schmidt-Hebbel (2002).

Row 1a of table 9 reports the estimated measures for all inflation targeters, before and after the adoption of inflation targeting. Figure 14 depicts the corresponding positions or observed combinations of output and inflation variability, as well as the efficiency frontiers observed before and after inflation-targeting adoption. Macroeconomic performance improved between these periods, as inflation and output volatility shrank. This is reflected by the inward shift of observed points or positions before and after inflation-targeting adoption in figure 14. The corresponding performance gain is reflected by a negative value of $\Delta L = L2 - L1$, at –3.817, in row 1a. The latter improvement disaggregates into a gain in efficiency, $\Delta E = E2 - E1$ (by –0.882, equivalent to a 23.1 percent contribution to the overall performance gain), which is reflected in a movement closer to the efficiency frontier, and a reduction in the variability of shocks hitting the economy, $\Delta S = S2 - S1$ (by –2.935, equivalent to a 76.9 percent contribution), which is reflected in a shift of the efficiency frontier. Another way to confirm the contribution of shocks and policy efficiency to the initial and final positions, $L1$ and $L2$, is to quantitatively decompose the latter position, summarized in the second line of row 1a in table 9. Efficiency ($E1$) explains 35.3 percent of pre-targeting performance ($L1$), a share that rises to 45.7 percent after the adoption of inflation targeting.

Table 9. Changes in Performance and Policy Efficiency over Time and between Targeters and Nontargeters

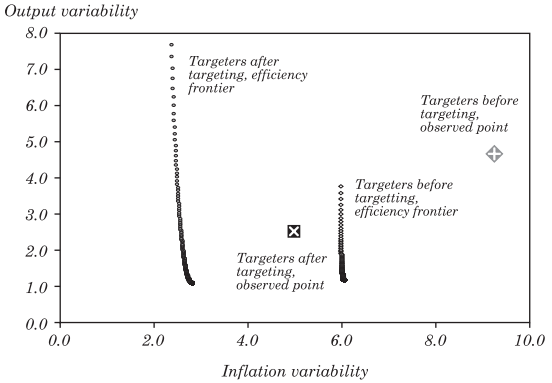
Sample Group 1				*Sample Group 2*				*Change*		
	L1	*E1*	*S1*		*L2*	*E2*	*S2*	*L2–L1*	*E2–E1*	*S2–S1*
1a. Targeters before targeting	8.302	2.931	5.371	Targeters after targeting	4.485	2.048	2.436	−3.817	−0.882	−2.935
(as % of L)		35.3	64.7	(as % of L)		45.7	54.3		23.1	76.9
1b. Industrial targeters before targeting	1.952	0.398	1.553	Industrial targeters after targeting	1.752	0.786	0.966	−0.199	0.388	−0.587
(as % of *L*)		20.4	79.6	(as % of L)		44.9	55.1		−194.3	294.3
1c. Emerging targeters before targeting	11.863	5.308	6.555	Emerging targeters after targeting	6.657	3.098	3.559	−5.206	−2.211	−2.995
(as % of *L*)		44.7	55.3	(as % of L)		46.5	53.5		42.5	57.5
2a. Targeters before targeting	8.302	2.931	5.371	Stationary targeters	2.007	0.780	1.227	−6.296	−2.151	−4.145
(as % of L)		35.3	64.7	(as % of L)		38.9	61.1		34.2	65.8
2b. Industrial targeters before targeting	1.952	0.398	1.553	Industrial stationary targeters	1.358	0.524	0.834	−0.593	0.126	−0.719
(as % of *L*)		20.4	79.6	(as % of L)		38.6	61.4		−21.3	121.3
2c. Emerging targeters before targeting	11.863	5.308	6.555	Emerging stationary targeters	3.547	1.850	1.697	−8.316	−3.459	−4.857
(as % of *L*)		44.7	55.3	(as % of L)		52.1	47.9		41.6	58.4
3. Nontargeters before 1997	0.869	0.129	0.740	Nontargeters after 1997	0.571	0.268	0.303	−0.298	0.139	−0.437
(as % of L)		14.9	85.1	(as % of L)		47.0	53.0		−46.9	146.9

Table 9. (continued)

Sample Group 1				*Sample Group 2*				*Change*		
	L1	*E1*	*S1*		*L2*	*E2*	*S2*	*L2–L1*	*E2–E1*	*S2–S1*
4a. Targeters after targeting	4.485	2.048	2.436	Nontargeters after 1997	0.571	0.268	0.303	–3.913	–1.780	–2.134
(as % of L)		45.7	54.3	(as % of L)		47.0	53.0		45.5	54.5
4b. Industrial targeters after targeting	1.752	0.786	0.966	Nontargeters after 1997	0.571	0.268	0.303	–1.181	–0.517	–0.663
(as % of *L*)		44.9	55.1	(as % of L)		47.0	53.0		43.8	56.2
4c. Emerging targeters after targeting	6.657	3.098	3.559	Nontargeters after 1997	0.571	0.268	0.303	–6.086	–2.829	–3.257
(as % of *L*)		46.5	53.5	(as % of L)		47.0	53.0		46.5	53.5
5a. Stationary targeters	2.007	0.780	1.227	Nontargeters after 1997	0.571	0.268	0.303	–1.435	–0.511	–0.924
(as % of L)		38.9	61.1	(as % of L)		47.0	53.0		35.6	64.4
5b. Industrial stationary targeters	1.358	0.524	0.834	Nontargeters after 1997	0.571	0.268	0.303	–0.787	–0.3	–0.5
(as % of *L*)		38.6	61.4	(as % of L)		47.0	53.0		32.5	67.5
5c. Emerging stationary targeters	3.547	1.850	1.697	Nontargeters after 1997	0.571	0.268	0.303	–2.976	–1.581	–1.395
(as % of *L*)		52.1	47.9	(as % of L)		47.0	53.0		53.1	46.9

Souerce: Authors' estimations.

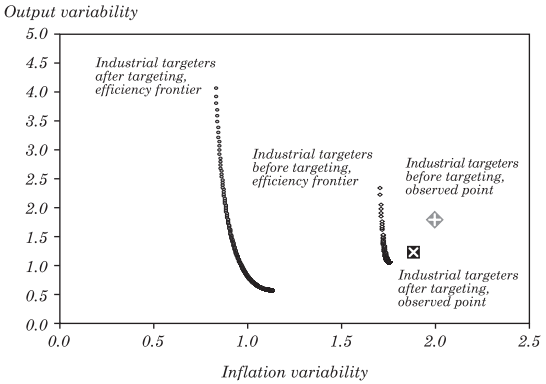
Figure 14. Estimated Efficiency Frontiers and Observed Performance Points: All Targeters before and after Inflation Targeting



Source: Authors' estimations.

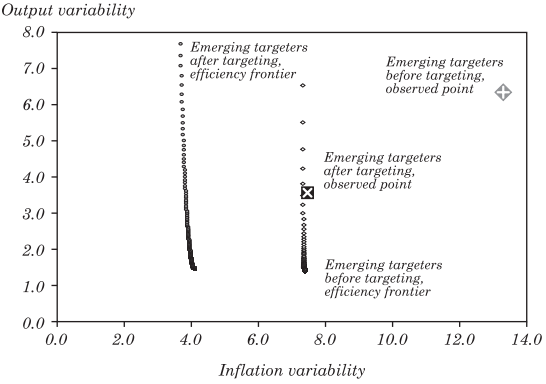
Rows 2a and 2b report the corresponding before-and-after comparisons for industrial and emerging inflation targeters. The variability of inflation and output is much larger in emerging than in industrial inflation targeters both before and after adoption of inflation targeting. For example, position $L2$ (after the adoption of inflation targeting) reflects a combination of inflation and output variability of 6.657 for emerging inflation targeters, versus 1.752 for industrial inflation targeters. Similar differences are observed in the efficiency frontier positions of industrial and emerging inflation targeters: the former are much closer to the origin than the latter (compare figures 15 and 16). In both country groups, however, macroeconomic performance improved with the adoption of inflation targeting. Industrial inflation targeters observed a small improvement, with ΔL equaling –0.199. This change results from two counteracting processes: a reduction in policy efficiency that deteriorated macroeconomic performance (lowering the observed gain by 194.3 percent) and a reduction in the variability of shocks that shifted the efficiency frontier significantly inward (which explains 294.3 percent of the performance gain). In contrast, emerging inflation targeters experienced a much larger macroeconomic improvement following the adoption of inflation targeting (ΔL is –5.206). This reflects both increased policy efficiency (contributing 42.5 percent) and a lower exposure to shocks (contributing 57.5 percent).

Figure 15. Estimated Efficiency Frontiers and Observed Performance Points: Industrial Targeters before and after Inflation Targeting



Source: Authors' estimations.

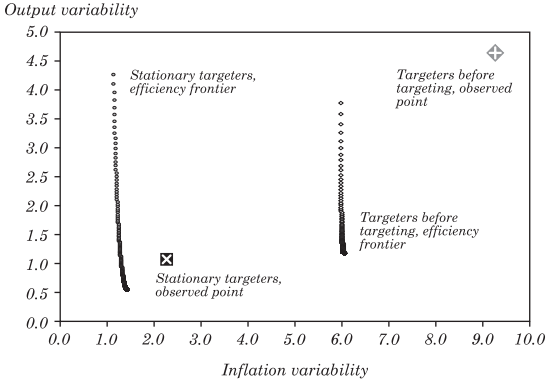
Figure 16. Estimated Efficiency Frontiers and Observed Performance Points: Emerging Targeters before and after Inflation Targeting



Source: Authors' estimations.

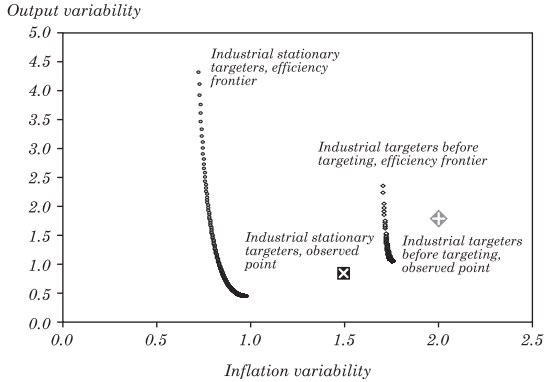
The next comparison is between pre-targeting and stationary-targeting performance (rows 2a, 2b, and 2c in table 9 and figures 17, 18, and 19). We find that inflation targeters reap a much larger improvement in macroeconomic performance once they achieve stationary inflation targets. The efficiency frontier position of stationary targeters has shifted much closer to the origin than was

Figure 17. Estimated Efficiency Frontiers and Observed Performance Points: All Targeters before Inflation Targeting and Stationary-Target Targeters



Source: Authors' estimations.

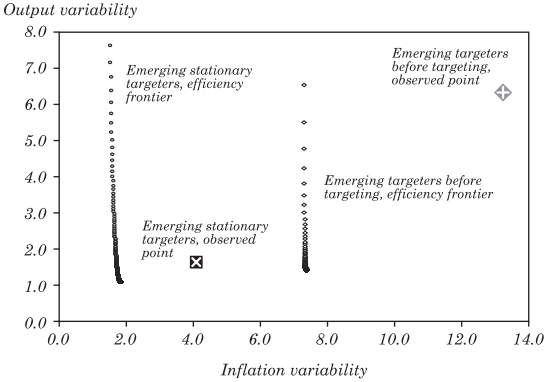
Figure 18. Estimated Efficiency Frontiers and Observed Performance Points: Industrial Targeters before Inflation Targeting and Industrial Stationary-Target Targeters



Source: Authors' estimations.

the case for all inflation targeters (both converging and stationary) discussed above (figure 17). Moreover, the relative contribution of efficiency improvements to the performance gain when adopting stationary inflation targeting is larger (34.2 percent) than the corresponding contribution of efficiency improvements when adopting

Figure 19. Estimated Efficiency Frontiers and Observed Performance Points: Emerging Targeters before Inflation Targeting and Emerging Stationary-Target Targeters



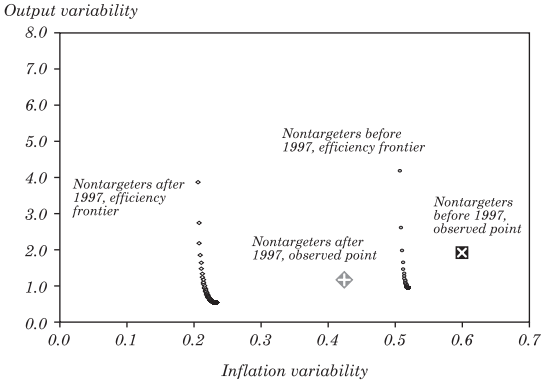
Source: Authors' estimations.

inflation targeting in general (23.1 percent). As in the case of the full inflation-targeting sample, emerging stationary inflation targeters register a much larger gain than industrial stationary inflation targeters (rows 2b and 2c of table 9 and figures 18 and 19). The benefits reaped by emerging economies, however, are much larger for the sample of stationary targeters than for the full sample.

The third comparison is for nontargeters before and after the first quarter of 1997 (see row 3 in table 9 and figure 20). As in our previous comparisons, nontargeters record an improvement in macroeconomic performance in the later period. The reduction in their output and inflation volatility, however, is more than fully explained by a decrease in the size of shocks, while monetary policy efficiency deteriorated. This pattern parallels that seen for industrial targeters above. Therefore, both inflation-targeting and nontargeting industrial economies display a common feature: supply shocks weakened significantly after the adoption of inflation targeting or after 1997, which explains more than 100 percent of their observed macroeconomic performance gains. This stands in contrast to emerging inflation targeters, where both weaker supply shocks and improved policy efficiency contributed to their (much larger) performance gains.

Next we compare inflation targeters after the adoption of inflation targeting and nontargeters after 1997. We use the performance

Figure 20. Estimated Efficiency Frontiers and Observed Performance Points: Nontargeters before and after 1997

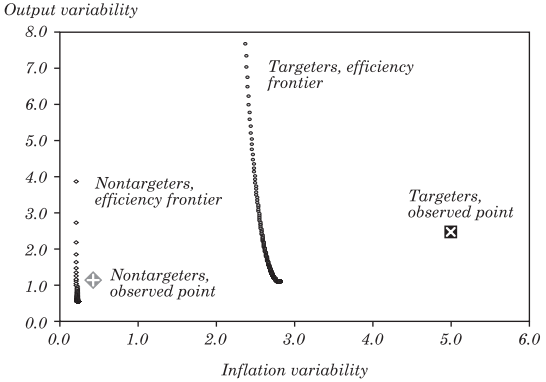


Source: Authors' estimations.

changes over time observed for our treatment and control groups separately to compare macroeconomic performance across our treatment and control groups. We compare the performance of all inflation targeters (including both converging and stationary inflation targeters) and nontargeters (rows 4a, 4b, and 4c in table 9 and figures 21, 22, and 23) and of stationary inflation targeters and nontargeters (rows 5a, 5b, and 5c in table 9 and figures 24, 25, and 26). A general result is that the full sample of inflation targeters (both converging and stationary targeters) exhibit actual performance levels, efficiency frontier positions, and policy efficiency levels that are worse than those of nontargeters. However, stationary inflation targeters are much closer to the performance and efficiency levels of nontargeters than is the full sample. The difference in performance between nontargeters and stationary targeters (–1.435; see row 5a) is primarily due to larger shocks in stationary inflation targeters (explaining 64.4 percent of the performance difference) and, to a lesser degree, to less efficient policy among inflation targeters (explaining 35.6 percent).

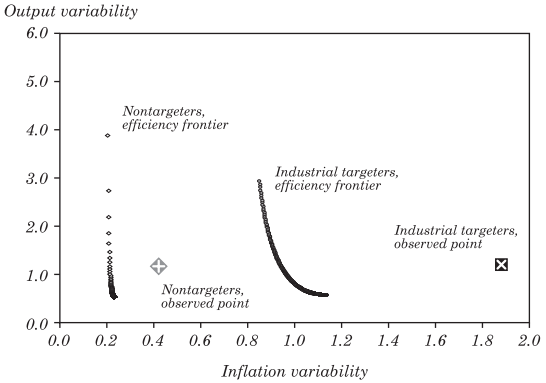
When we disaggregate the inflation targeters into emerging and industrial countries, we find that the difference between nontargeters and inflation targeters is largely due to a significantly worse performance by emerging economies. Emerging inflation targeters (both converging and stationary) not only exhibit larger supply shocks, but are also further away from their efficiency frontiers (figure 23). However, the large difference between nontargeters and all emerging

Figure 21. Estimated Efficiency Frontiers and Observed Performance Points: All Targeters and Nontargeters after 1997



Source: Authors' estimations.

Figure 22. Estimated Efficiency Frontiers and Observed Performance Points: Industrial Targeters and Nontargeters after 1997

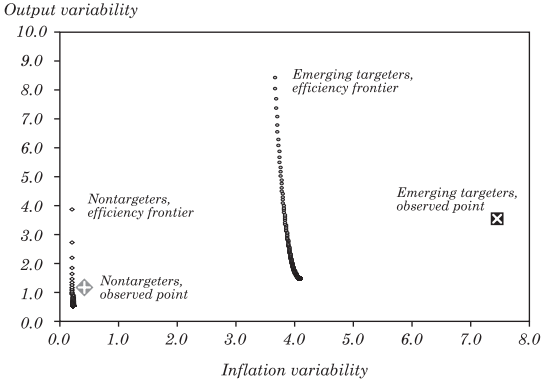


Source: Authors' estimations.

inflation targeters (ΔL equals –6.086; row 4c), declines by half once emerging inflation targeters attain stationary inflation targets (ΔL is –2.976; row 5c).

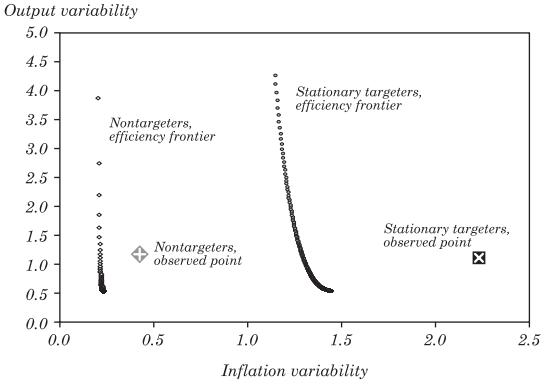
Industrial inflation targeters are much closer in performance to our control group of nontargeters, and the difference narrows further when

Figure 23. Estimated Efficiency Frontiers and Observed Performance Points: Emerging Targeters and Nontargeters after 1997



Source: Authors' estimations.

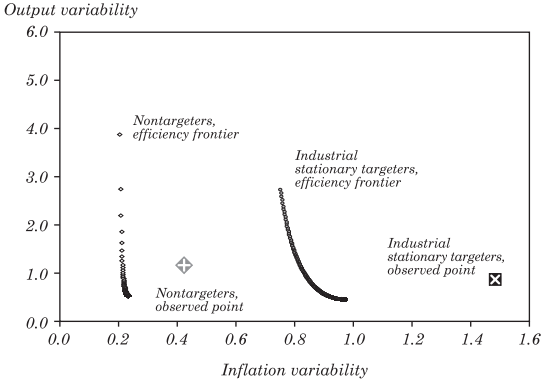
Figure 24. Estimated Efficiency Frontiers and Observed Performance Points: Stationary Targeters and Nontargeters after 1997



Source: Authors' estimations.

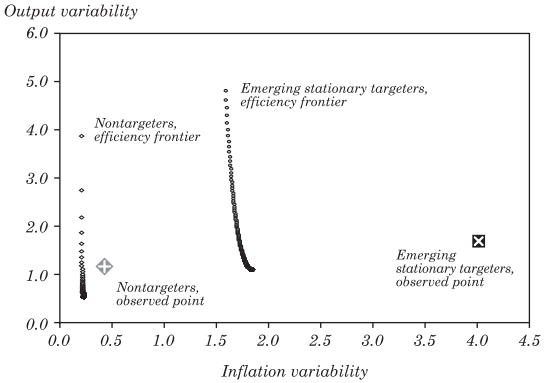
we compare stationary industrial inflation targeters to nontargeters (row 5b and figure 25). The relatively small difference in performance (ΔL is –0.787) is due mainly to the supply shocks faced by industrial stationary inflation targeters (explaining 67.5 percent of the difference) and less to less efficient policy (explaining 32.5 percent of the difference).

Figure 25. Estimated Efficiency Frontiers and Observed Performance Points: Industrial Stationary Targeters and Nontargeters after 1997



Source: Authors' estimations.

Figure 26. Estimated Efficiency Frontiers and Observed Performance Points: Emerging Stationary Targeters and Nontargeters after 1997



Source: Authors' estimations.

Based on the evidence in this section, we conclude that countries adopting inflation targeting have substantially improved the efficiency of their monetary policy. Furthermore, the gains in efficiency are larger for stationary inflation targeters than for inflation targeters in general. Relevant differences in performance levels and gains are

apparent when disaggregating inflation targeters into industrial and emerging economies. Observed macroeconomic performance is much better in industrial inflation targeters than in emerging inflation targeters both before and after the adoption of inflation targeting (or stationary inflation targeting). However, the improvement that comes with the adoption of inflation targeting is much larger in emerging economies than in industrial countries. Convergence toward stationary inflation targeting is particularly beneficial to emerging economies. These countries record major reductions in output and inflation volatility after adopting stationary inflation targeting, both because they face smaller supply shocks and because they improve their monetary policy efficiency. In contrast, industrial inflation targeters improve their macroeconomic performance only because they face smaller supply shocks; their monetary policy efficiency levels (which were already high before the adoption of inflation targeting, compared with emerging countries) actually deteriorate somewhat after the adoption of inflation targeting.

The likely source of the overall macroeconomic improvement that comes with inflation targeting is the credibility that inflation targeters gain when they finally achieve sufficient disinflation to stabilize their inflation targets. Increased credibility helps shift monetary policy outcomes closer to the efficiency frontier. This is particularly the case of emerging countries, where the pre-targeting gap between actual and desirable macroeconomic performance is the largest and where pre-targeting credibility is weak.

Although inflation targeting improves monetary performance over time, our control group of nontargeters still exhibits better macroeconomic performance and higher levels of monetary policy efficiency than our different treatment groups of inflation targeters. The differences between industrial nontargeters and emerging inflation targeters have narrowed massively under inflation targeting, but they remain large. Nontargeters also display better macroeconomic performance than industrial inflation targeters, but this difference is small and has narrowed under inflation targeting. Most of the remaining performance differences between industrial inflation targeters and nontargeters—in favor of the latter—stems from the smaller supply shocks faced by nontargeters, while monetary policy is only marginally more efficient in nontargeters than in industrial inflation targeters.

5. Inflation Accuracy

How accurate are inflation-targeting central banks in hitting their official targets? And how does their accuracy compare to the success of nontargeting countries in achieving a stable inflation rate? The first question is addressed by Calderón and Schmidt-Hebbel (2003), Albagli and Schmidt-Hebbel (2005), and Roger and Stone (2005). The first two of these studies also identify the determinants of success in hitting inflation targets, showing that institutional variables (such as central bank independence) and credibility measures (including investment risk measures and country risk spreads) are significant factors in reducing target misses among inflation targeters.

We address the second question in this section. Our results are tentative because they involve comparing easily measured deviations of actual inflation from target levels in inflation-targeting countries with the deviations of actual inflation from inflation objectives in nontargeting countries, which are not easily measured since they are not announced in nontargeting countries. We construct proxies for implicit inflation objectives in the form of inflation trends obtained using the Hodrick-Prescott filter. These proxies are likely to underestimate the true measures of inflation deviations in nontargeting countries because the HP-filtered trend could react excessively to temporary inflation deviations. The size of the potential bias is likely to be inversely correlated with the degree of smoothing applied by the HP filter. We therefore conduct robustness tests of our results along two dimensions: the assumption about inflation deviations in inflation-targeting countries and the degree of HP smoothing of the actual inflation series.

For the first dimension, we compute two measures of inflation deviations for inflation-targeting countries. The first inflation deviation measure (ID1) computes the deviation of actual inflation from actual inflation targets, while the second inflation deviation measure (ID2) provides the deviation of actual inflation from HP trends for inflation-targeting countries, to maximize comparability with our measure of inflation deviation for nontargeting countries. All measures are absolute values of inflation deviations.

We report on both measures for several country groups and for the full 1989—2004 period and subperiods in table 10 and figure 27. For ID1, the median absolute inflation deviation is 1.03 percent for inflation targeters and 0.54 percent for nontargeters. For ID2, the median absolute inflation deviation is lower for inflation targeters,

at 0.84 percent, and unchanged for nontargeters, at 0.54 percent. The inflation deviation measure based on actual inflation targets (ID1) for inflation targeters is systematically larger than the one based on HP-filtered inflation trends (ID2) across all subgroups of inflation-targeting countries. This suggests that the use of HP-filtered inflation trends as a proxy for implicit inflation objectives for nontargeters and for inflation targeters during the pre-targeting period may, in fact, bias downward the inflation deviation measures in inflation targeters and thus bias upward the reported differences of deviations between inflation targeters and nontargeters.

Figure 27 depicts the time pattern of median absolute inflation deviations for inflation targeters and nontargeters, using both measures. Nontargeters exhibit systematically lower inflation deviations than inflation targeters. However, inflation targeters' median inflation deviations show a negative trend in 1989–2004, whereas the median inflation deviations of nontargeters are stationary.[20]

Our subsamples of inflation targeters display large differences in hitting targets. According to the ID1 measure, the median absolute inflation deviation is 0.77 percent in industrial economies, versus 1.28 percent in emerging economies (table 10). The difference is even larger when we divide inflation targeting experiences according to periods of converging targets, when median absolute inflation deviations are 1.49 percent, and stationary targets, when deviations decline by half to reach 0.77 percent. As expected, the largest difference is observed between two very heterogeneous nontargeting experiences: before the adoption of inflation targeting (or before 1997 for nontargeters), median absolute inflation deviations were 1.12 percent among inflation targeters and 0.36 percent among nontargeters.

However, the latter prima facie evidence of poorer inflation accuracy in inflation-targeting countries is far from conclusive. Many large inflation-target misses could be explained by idiosyncratic country or time-period shocks, and these could be correlated with the adoption of inflation targeting, particularly in emerging economies. We thus test for significant differences in inflation deviations between inflation targeters and nontargeters, controlling for potential determinants of inflation shocks.

Following previous work on differences in inflation deviations among inflation targeters (Calderón and Schmidt-Hebbel, 2003;

20. We reject the presence of nonstationarity in all series at the 1 percent confidence level using the augmented Dickey-Fuller and Phillips-Perron unit root tests.

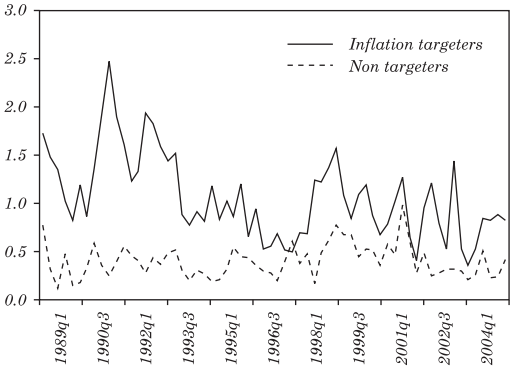
Table 10. Absolute Deviation of the Inflation Rate from Target or Trend in Inflation Targeters and Nontargeters[a]

	ID1 Percentile			*ID2 Percentile*		
Sample group	*25*	*50*	*75*	*25*	*50*	*75*
Inflation Targeters	0.46	1.03	1.99	0.33	0.84	1.74
Industrial Economies (7)	0.40	0.77	1.39	0.23	0.50	1.13
Emerging Economies (14)	0.49	1.28	2.42	0.50	1.14	2.00
Stationary (16)	0.38	0.77	1.46	0.24	0.56	1.16
Converging (14)	0.63	1.49	2.77	0.70	1.42	2.17
Nontargeters	0.24	0.54	1.20	0.24	0.54	1.20
Always nontargeters (13)	0.18	0.36	0.67	0.18	0.36	0.67
Targeters before targeting (21)	0.41	1.12	2.38	0.41	1.12	2.38

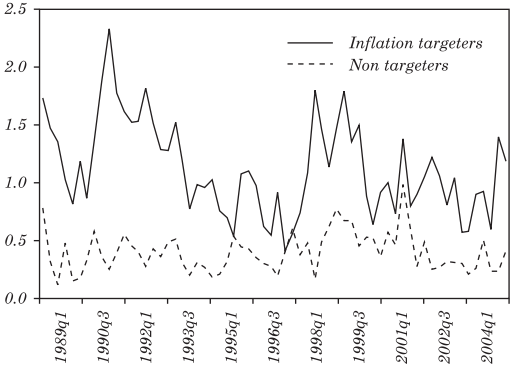
Source: Authors' calculations, based on data from Organization for Economic Cooperation and Development, Main Economic Indicators; IMF; and central banks.
a. For inflation-targeting countries, ID1 is defined as the absolute deviation of actual inflation from inflation targets, and ID2 is the absolute deviation of actual inflation from its HP trend. For nontargeting countries, ID1 and ID2 are defined as the absolute deviation of actual inflation from its HP trend. Number of countries is in parentheses.

Figure 27. Median Absolute Deviations of Inflation Rate from Inflation Target or from Trend in Inflation Targeters and Nontargeters, 1989–2004[a]

A. First inflation deviation measure (ID1)



B. Second inflation deviation measure (ID2)



Source: Authors' calculations, based on data from Organization for Economic Cooperation and Development, Main Economic Indicators; IMF; and central banks.
a. See the text for definitions of inflation deviation measures ID1 and ID2.

Albagli and Schmidt-Hebbel, 2005), we specify the following panel data specification for the absolute value of deviations of inflation $|\pi_{i,t} - \pi^*_{i,t}|$:

$$\left|\pi_{i,t} - \pi^*_{i,t}\right| = \sum_{j=1}^{r} \phi_j \left|\pi_{i,t} - \pi^*_{i,t}\right| + \alpha \mathrm{IT}_{i,t} + \mathbf{X}_{i,t}\beta + c_i + e_{i,t}\,, \tag{13}$$

as a function of its own lag, a vector of relevant inflation-shock controls ($\mathbf{X}_{i,t}$), a dummy variable ($IT_{i,t}$) that takes a value of one if the country has an inflation-targeting regime in place and zero otherwise, and country- and time-specific effects. The inflation deviation is defined as the absolute value of the difference between the twelve-month CPI inflation rate ($\pi_{i,t}$) and the annual inflation target ($\pi^*_{i,t}$). The vector of control variables comprises two domestic shocks (absolute nominal exchange rate shocks and the output gap or the absolute deviation of output growth from trend) and two external shocks (the lagged absolute deviation of the Federal funds rate from trend and the absolute deviation of the international oil price from trend).

We estimate our model for absolute inflation deviations in equation (13) using an unbalanced panel sample of twenty-one inflation-targeting and twelve nontargeting countries, with quarterly observations for 1989–2004.[21] As in preceding sections, we consider two alternative control groups: control group 1 includes the full nontargeting sample of both industrial nontargeting countries and the pre-targeting observations of all subsequent inflation targeters, while control group 2 encompasses only the industrial nontargeting countries. Furthermore, we control for possible endogeneity of the choice of the inflation-targeting regime (the inflation-targeting dummy variable) and the two domestic shocks, using as instruments the variables listed at the bottom of tables 11 and 12 and making use of panel data IV estimation. For control group 1, we obtain the fixed-effects estimator, but we are unable to estimate a fixed-effects model for control group 2 owing to the presence of time-invariant variables. To tackle this problem, we follow Plümper and Troeger (2004), who obtain a modified Hausman-Taylor IV estimator to compute the coefficients of time-invariant variables.[22]

The results are reported in table 11 (using the ID1 measure as the dependent variable) and table 12 (using the ID2 measure as the

21. To avoid endogeneity problems with the Federal funds rate variable, we excluded the United States from our standard control group of thirteen nontargeting countries.

22. This procedure can be summarized in three steps. First, we estimate a panel fixed-effects model excluding time-invariant right-hand-side variables. Second, we regress the fixed-effects vector on the time-invariant explanatory variables and obtain its unexplained part. Finally, we estimate a pooled IV model including all explanatory time-variant and time-invariant variables, as well as the unexplained part of the fixed-effects vector. Using Monte Carlo experiments, Plümper and Troeger (2004) find that their estimation technique performs better than pooled OLS and random-effects models in the estimation of the coefficients of time-invariant variables.

Table 11. Inflation Deviation from Target or Trend in Targeting and Nontargeting Countries: ID1[a]

Explanatory variable	*Control group 1* *(1)*	*Control group 2* *(2)*	*Control group 1* *(3)*	*Control group 2* *(4)*	*Control group 1* *(5)*
Abs [Deviation from target (t–1)]	0.537	0.490	0.537	0.511	0.537
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Inflation-targeting dummy	–0.181	–0.447			
	(0.063)*	(0.275)			
Abs [NER depreciation]	0.047	0.013	0.048	0.021	0.047
	(0.000)***	(0.039)**	(0.000)***	(0.007)***	(0.000)***
Abs [Output gap (t–1)]	0.033	0.035	0.038	0.075	0.029
	(0.443)	(0.393)	(0.394)	(0.245)	(0.503)
Abs [Oil gap]	0.003	0.002	0.003	0.002	0.003
	(0.069)*	(0.123)	(0.075)*	(0.192)	(0.062)*
Abs [Fed funds rate (t–4)]	0.033	0.020	0.035	0.030	0.034
	(0.014)**	(0.197)	(0.009)***	(0.063)*	(0.011)**
Stationary targeters			–0.133	–0.348	
			(0.257)	(0.489)	

Table 11. (continued)

Explanatory variable	*Control group 1* *(1)*	*Control group 2* *(2)*	*Control group 1* *(3)*	*Control group 2* *(4)*	*Control group 1* *(5)*
Converging targeters			–0.232	–0.118	
			(0.065)*	(0.924)	
Emerging targeters					–0.245
					(0.039)**
Industrial targeters					–0.077
					(0.610)
Constant	–0.105	1.063	–0.123	0.629	–0.111
	(0.358)	(0.012)**	(0.288)	(0.496)	(0.333)
No. observations	1861	1375	1865	1391	1861
No. countries	33	33	33	33	33

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. The dependent variable is absolute inflation deviation, given by our ID1 measure. For inflation-targeting countries, ID1 is defined as the absolute deviation of actual inflation from inflation targets; for nontargeting countries, ID1 is defined as the absolute deviation of actual inflation from its HP trend. The regressions are based on panel IV estimations. The instrument set includes lagged values of inflation deviation from target, an inflation-targeting dummy, nominal exchange rate depreciation, the output gap, and contemporaneous observations of the oil gap and the Federal funds rate. Control group 1 includes all nontargeters and pre-targeters; control group 2 includes only all nontargeters. P values are reported in parentheses.

Table 12. Inflation Deviation from Target or Trend in Targeting and Nontargeting Countries: ID2[a]

Explanatory variable	*Control group 1* *(1)*	*Control group 2* *(2)*	*Control group 1* *(3)*	*Control group 2* *(4)*	*Control group 1* *(5)*
Abs [Deviation from target (t–1)]	0.527	0.502	0.528	0.451	0.527
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Inflation-targeting dummy	–0.270	–0.205			
	(0.002)***	(0.668)			
Abs [NER depreciation]	0.038	0.005	0.038	0.007	0.038
	(0.000)***	(0.309)	(0.000)***	(0.212)	(0.000)***
Abs [Output gap (t–1)]	0.091	0.121	0.091	0.134	0.091
	(0.021)**	(0.002)***	(0.026)**	(0.005)***	(0.023)**
Abs [Oil gap]	0.003	0.002	0.003	0.002	0.003
	(0.033)**	(0.078)*	(0.033)**	(0.133)	(0.032)**
Abs [Fed funds rate (t–4)]	0.026	0.005	0.026	0.010	0.026
	(0.034)**	(0.716)	(0.031)**		(0.033)**
Stationary targeters			–0.264	–0.408	
			(0.012)**	(0.408)	

Table 12. (continued)

Explanatory variable	*Control group 1* *(1)*	*Control group 2* *(2)*	*Control group 1* *(3)*	*Control group 2* *(4)*	*Control group 1* *(5)*
Converging targeters			−0.258	−0.121	
			(0.023)**	(0.907)	
Emerging targeters					−0.280
					(0.008)***
Industrial targeters					−0.252
					(0.061)*
Constant	−0.051	0.684	−0.060	0.730	−0.052
	(0.615)	(0.177)	(0.562)	(0.390)	(0.608)
No. observations	1861	1390	1865	1391	1861
No. country	33	33	33	33	33

Source: Authors' estimations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. The dependent variable is absolute inflation deviation, given by our ID2 measure. For both inflation-targeting and nontargeting countries, ID2 is defined as the absolute deviation of actual inflation from its HP trend. The regressions are based on panel IV estimations. The instrument set includes lagged values of inflation deviation from target, an inflation-targeting dummy, nominal exchange rate depreciation, the output gap, and contemporaneous observations of the oil gap and the Federal funds rate. Control group 1 includes all nontargeters and pre-targeters; control group 2 includes only all nontargeters. P values are reported in parentheses.

dependent variable). Each table presents results for the two alternative nontargeting control groups and for alternative inflation-targeting dummies (one for all inflation-targeting country experiences and others that capture a heterogeneous effect of inflation targeting for converging and stationary inflation-targeting periods and for emerging and industrial inflation-targeting countries).

Inflation deviations exhibit systematic persistence, as reflected by the significant coefficient of the lagged dependent variable. Its point estimate is close to 0.5 across the ten results reported in tables 11 and 12, which shows that the long-term effects of all other variables are close to twice their contemporaneous effects. All control variables exhibit the expected positive signs, and most are significant at conventional levels.

Our variable of interest—namely, the inflation-targeting dummy—exhibits a robust negative coefficient across all regressions, but it is only significant when we use the first control group. For example, the first column of table 11 reports that the contemporaneous effect of inflation targeting is to reduce absolute inflation deviations by 0.18 percent, when using the ID1 measure and the full sample of nontargeting country experiences (control group 1). Moreover, the contemporaneous impact of inflation targeting on absolute inflation deviations rises in magnitude from –0.18 to a long-term effect of –0.40 percent, that is, 0.18 percent / (1–0.54). The effect of inflation targeting increases to –0.45 percent, but it is insignificant when we exclude pre-targeting experiences in inflation-targeting countries (column 2). The latter result is the relevant one for comparing inflation-targeting experiences to those of countries that never had inflation targeting in place.

The result in column 1, based on ID1, increases to –0.27 percent when we use the ID2 measure, as reported in column 1 of table 12. This confirms that inflation target deviations from actual targets lead to higher deviations than those measured as deviations from HP-filtered trends. It suggests that comparing actual deviations from observable targets in inflation-targeting countries with HP-filter-inferred deviations from unobservable inflation objectives in nontargeting countries leads to an upward bias in inflation targeters' deviations relative to nontargeters' deviations. The reported coefficients for the inflation-targeting regime based on the ID1 measures are thus likely to be lower-bound estimates, while those based on the ID2 measure might be closer to the unobservable regime difference.

Columns 3, 4, and 5 in tables 11 and 12 report coefficients for separate inflation-targeting dummy variables for converging-target

and stationary-target inflation-targeting periods and for emerging and industrial inflation targeters. For both cases, the coefficients exhibit the expected negative sign, but they vary in significance and magnitude. The results in column 3 show that converging inflation targeters exhibit about 0.24 percent lower absolute deviations of inflation, while the results for stationary inflation targeters vary from –0.13 percent to –0.26 percent. When we restrict the control group to the nontargeting countries that never had inflation targeting in place, the results remain negative but lose statistical significance (see column 4). Column 5 presents the coefficients that capture separate effects of inflation targeting on emerging and industrial economies. Only emerging countries show a significantly lower inflation deviation than that observed in control group 1. When we use the ID2 measure, however, the results suggest that both emerging and industrial inflation targeters observe lower absolute inflation deviations (of similar magnitude) than those observed in control group 1.

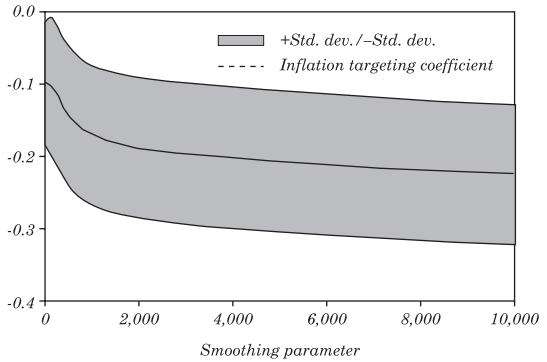
To check the robustness of our results to the underlying assumptions on the Hodrick-Prescott filtering procedure to obtain inflation trends as proxies for inflation objectives, we ran the regressions reported in column 1 of tables 11 and 12 on alternative absolute inflation deviation series based on different values of the HP filter smoothing parameter used in obtaining trend inflation series.[23] Figure 28 depicts the estimated coefficient of the inflation-targeting dummy variable for alternative smoothing parameter values ranging from 100 to 10,000. The figure suggests that the inflation-targeting coefficient estimates of –0.18 and –0.27 in column 1 of tables 11 and 12 are robust to wide ranges of alternative HP smoothing parameters.

We conclude the following from the results reported in this section. Prima facie, inflation deviations from inflation targets or trends are larger in inflation-targeting than in nontargeting countries. However, this evidence is based on simple sample statistics that do not control for country- and time-specific shocks that affect inflation deviations and that could be correlated with inflation-targeting experiences (across countries and over time). When we control for the latter shocks, our econometric findings point toward a much more differentiated performance regarding inflation accuracy under inflation targeting. First, when comparing all inflation targeters (and also the emerging/industrial and converging/stationary subsamples)

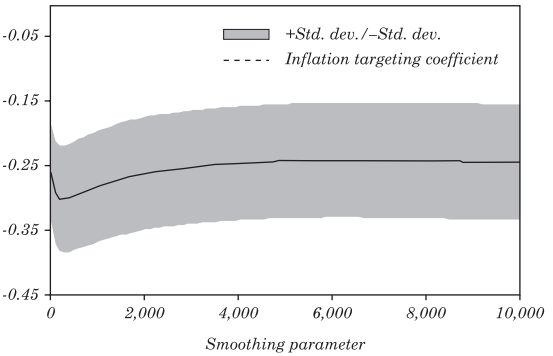
23. The coefficient used in all HP-filtered trends discussed in this paper is the standard lambda equal to 1,600 for quarterly data.

Figure 28. Estimated Coefficient of Inflation Targeting for Alternative Values of the HP Filter Smoothing Parameter[a]

A. First inflation deviation measure (ID1)



B. Second inflation deviation measure (ID2)



Source: Authors' estimations.
a. The reported coefficients correspond to the IT dummy coefficients from the regressions reported in column 1 of tables 11 and 12.

to all nontargeting experiences (including nontargeting countries and pre-targeting experiences, represented by control group 1), inflation deviations are smaller in inflation-targeting than in nontargeting countries. The point estimates for the inflation-targeting gain in inflation deviations ranges from 0.18 percent to 0.45 percent (and roughly twice the latter range for the long-term inflation-targeting

gain) for the full experience of inflation-targeting countries and periods. However, this result is not robust to using the alternative control group 2, comprising only nontargeting countries. While inflation deviations are still smaller in inflation-targeting countries, the corresponding coefficients are no longer significantly different from zero. When we use our preferred inflation deviation measure, ID2, and disaggregate all inflation targeters into different subgroups, we find that inflation targeting lowers absolute inflation deviations by similar amounts in emerging and industrial targeters and in converging and stationary targeters.

6. Conclusions

A steadily growing number of industrial and emerging countries have explicitly adopted an inflation target as their nominal anchor. Eight industrial countries and thirteen emerging economies had full-fledged inflation targeting in place in early 2005. Many other emerging economies are planning to adopt inflation targeting in the near future. This paper has explored whether inflation targeting makes a difference after central banks adopt the regime as an explicit and exclusive anchor for conducting monetary policy.

Previous empirical evidence on the direct link between inflation targeting and particular measures of economic performance provides some support for the view that inflation targeting is associated with an improvement in overall economic performance. However, the ongoing debate on whether inflation targeting matters indicates that open questions remain, particularly on the comparative macroeconomic performance in inflation targeting countries, both over time and relative to nontargeting countries. Are inflation levels and inflation and output volatilities lower in inflation-targeting countries? Do monetary policy and macroeconomic performance variables respond differently to shocks under inflation targeting? Is monetary policy more efficient under inflation targeting? Are inflation-targeting central banks more accurate in hitting their targets than nontargeting countries are in maintaining or achieving stable inflation?

We have addressed these questions by systematically applying a common methodological approach, across issues and throughout the paper. We have looked for empirical evidence in the world sample of twenty-one industrial and emerging-economy inflation-targeting countries, before and after their adoption of inflation targeting, and compared their performance to a control group of thirteen

industrial nontargeters. We have distinguished between two types of inflation-targeting regimes, one in which inflation targets are still converging to the long-run goal for inflation and one in which the inflation target is stationary. We have tested for differences in group behavior of inflation targeters and nontargeters and for changes between pre- and post-targeting changes among inflation targeters, making statistical inferences from panel data estimations, panel vector autoregressive models, and panel impulse responses. Finally, to exploit the rich available data and identify dynamic patterns, we have used a high-frequency sample of quarterly data, covering 1989–2004 and subperiods.

Comparative descriptive statistics on inflation performance confirm that inflation targeters reduced their average inflation rates from 12.6 percent before the adoption of inflation targeting to 4.4 percent thereafter. Inflation declined to 6.0 percent in the post-adoption convergence period and then to 2.3 percent after the achievement of stationary targets. Emerging-economy inflation targeters recorded an average 6.0 percent inflation after they adopted inflation targeting, while the corresponding figure is only 2.2 percent for industrial-economy inflation targeters. The latter figure is very close to the average 2.1 percent inflation recorded among nontargeters since 1997. A similar pattern is observed for inflation volatility. Inflation volatility in industrial inflation targeters is twice the level recorded in nontargeters, but inflation persistence is slightly lower in industrial inflation targeters than in nontargeters. Emerging inflation targeters, in turn, achieved a significant reduction in output growth volatility and output gap volatility under inflation targeting. Nontargeters also achieved a significant reduction in both volatility measures after 1997, to levels that are below those recorded by industrial inflation targeters. However, output persistence, like inflation persistence, is lower in stationary-target inflation targeters than in nontargeters.

Moving beyond unconditional inflation comparison, we follow previous research by testing for systematic differences in inflation levels between inflation-targeting and nontargeting countries, controlling for past inflation. The evidence on the comparative inflation performance of inflation targeters and nontargeters reported both here and in the previous literature shows that the effect of inflation targeting on inflation can go either way. Our findings suggest that the source of such differences lies in the use of heterogeneous control groups. The absence of panel data techniques in the earlier literature prevents the disaggregation of control groups across countries and time.

We have extended the earlier research, exploiting both the cross-section and time dimensions of our sample. We find that the largest difference in inflation performance is observed when the treatment group is compared to its own pre-targeting experience. When nontargeting countries are added to the control group, this effect declines but is still statistically significant. However, when we restrict the control group to nontargeting countries, we find no systematic, significant difference in inflation between inflation targeters and nontargeters. Further disaggregation of the treatment group into industrial and emerging inflation targeters and into converging-target and stationary-target inflation targeters yields mixed results. They confirm that results are highly dependent on the choice of control groups. They also suggest that emerging-economy and converging-target inflation targeters record the largest gains in inflation reduction. Industrial inflation targeters exhibit a statistically weak reduction in inflation in comparison with industrial nontargeting countries.

If inflation targeting improves the credibility of monetary policy and strengthens the anchoring of inflation expectations, we would expect inflation targeting to reduce inflation's response to oil price shocks and lessen the pass-through effect from exchange rate shocks. As a result of increased credibility and reduced devaluation to inflation pass-through, inflation targeting may also strengthen monetary policy independence (that is, weaken the reaction of domestic interest rates to foreign interest rate shocks). We have therefore assessed whether inflation targeters differ from nontargeters—and whether post-targeting differs from pre-targeting among inflation targeters—in the response of inflation to shocks in oil prices and the exchange rate and the response of domestic interest rates to innovations in international interest rates. Our results are as follows.

We reach two conclusions on the inflation consequence of oil price shocks. First, inflation targeting helps all inflation targeters reduce the domestic inflation response to an oil price shock relative to their own pre-targeting experience, although this reduction is not statistically different from zero. Second, in all inflation-targeting treatment groups, the inflation response to oil price shocks is smaller than in nontargeting countries after 1997. The difference in favor of inflation targeters is statistically significant, on average, for later quarters, because the effects of an oil shock on domestic inflation are smaller and less persistent in inflation-targeting countries than in nontargeters. Surprisingly, this result is particularly strong in emerging-market

stationary-target inflation targeters, where the response of inflation to the oil price is the smallest and least persistent.

We also present two conclusions based on our comparison of the dynamics of the pass-through effects from exchange rate shocks to domestic inflation. First, the adoption of inflation targeting helped reduce the short-term pass-through under stationary-target inflation targeting, vis-à-vis their own pre-targeting experience. This result, however, is entirely driven by emerging-market inflation targeters, where pass-through coefficients fell somewhat after a stationary target was achieved but remained positive and significantly different from zero. In industrial inflation targeters and nontargeters, the pass-through effects were close to zero before and after inflation targeting (or before and after 1997, in the case of nontargeters). Second, when we compare all inflation targeters and all stationary inflation targeters to nontargeters after 1997, the pass-through coefficients are significantly larger in the former groups than in the latter. This result is due to emerging-market inflation targeters, which exhibit much larger pass-through coefficients than nontargeters after 1997; the differences are statistically significant from quarters 1 through 5, on average. In contrast, industrial inflation targeters and nontargeters do not exhibit any significant differences in pass-through performance.

To measure monetary independence, we compared the dynamic responses of domestic interest rates to a shock in the international interest rate, and we again arrived at two conclusions. First, the adoption of inflation targeting has brought down interest sensitivity estimates for the full group of inflation-targeting countries. This aggregate result hides two opposing changes, however. The adoption of inflation targeting in industrial countries has increased interest rate sensitivity from negative to positive and significant. In contrast, in emerging-market inflation targeters, interest sensitivity has declined from huge before inflation targeting to moderate during converging-target inflation targeting and to small under stationary-target inflation targeting. Second, these changes made inflation targeters more similar to nontargeters. While interest rate sensitivity to foreign rate shocks is slightly larger in industrial stationary inflation targeters than in nontargeters and slightly smaller in emerging-market stationary inflation targeters than in nontargeters, the differences are not statistically significant. Our measures of monetary independence thus reveal a convergence of inflation-targeting countries that have achieved stationary targets to the levels exhibited by nontargeters.

Next we investigated the potential gains associated with inflation targeting in terms of improving macroeconomic performance (that is, the reduction in inflation and output volatilities), which can be attributed to smaller supply shocks and more efficient monetary policy. The comparative results for inflation-targeting countries over time (that is, before and after the adoption of inflation targeting) and relative to nontargeting countries are as follows. Adopting inflation targeting led to substantial improvement in the efficiency of monetary policy; these gains are larger for stationary inflation targeters than for inflation targeters in general. Observed macroeconomic performance is much better in industrial inflation targeters than in emerging inflation targeters, both before and after the adoption of inflation targeting (or stationary inflation targeting). However, emerging economies recorded a much greater improvement following the adoption of inflation targeting than industrial countries. Emerging economies registered major reductions in output and inflation volatility after adopting stationary inflation targeting, both because they faced smaller supply shocks and because they improved their monetary policy efficiency. In contrast to emerging inflation targeters, industrial targeters improved their macroeconomic performance only because they faced smaller supply shocks; their monetary policy efficiency levels (which were already high before the adoption of inflation targeting, compared with emerging countries) actually deteriorated somewhat after the adoption of inflation targeting.

Although inflation targeting improves monetary performance over time, our control group of nontargeters still exhibits better macroeconomic performance and higher levels of monetary policy efficiency than our different treatment groups of inflation targeters. The differences between industrial nontargeters and emerging inflation targeters narrowed massively under inflation targeting, but they still remain large after the achievement of stationary inflation targeting. Nontargeters also exhibited better macroeconomic performance than industrial inflation targeters, but this difference was small and narrowed under inflation targeting. Most of the remaining performance difference between industrial inflation targeters and nontargeters—in favor of the latter—is explained by the smaller supply shocks faced by nontargeters, while monetary policy efficiency is only marginally better in nontargeters than in industrial inflation targeters.

We ended our research by comparing the success of inflation-targeting central banks in hitting their official targets (or maintaining inflation levels close to their inflation trends) to the success of

nontargeting central banks in maintaining inflation levels close to their inflation trends. Prima facie, inflation deviations from inflation targets or trends are larger in inflation-targeting than in nontargeting countries. However, this evidence is based on simple sample statistics that do not control for country- and time-specific shocks that affect inflation deviations and that could be correlated with inflation-targeting experiences (across countries and over time). When we control for such shocks, our findings point to a more differentiated performance regarding inflation accuracy under inflation targeting. First, when comparing the full sample of inflation targeters (and also the emerging/industrial and converging/stationary subsamples) to all nontargeting experiences (including nontargeting countries and pre-targeting experiences), inflation deviations are significantly smaller in inflation-targeting than in nontargeting experiences. This result is not robust, however, when the control group includes only nontargeting countries. Inflation deviations are still numerically smaller in inflation-targeting countries relative to nontargeting countries, but the differences are not statistically significant from zero. This holds for both the aggregate treatment group comprising all inflation targeters and the different inflation-targeting subgroups (emerging and industrial targeters and converging and stationary targeters): inflation deviations are numerically lower than in nontargeting countries, but the difference is not statistically significant.

We conclude that our evidence supports inflation targeting. Inflation targeting seems to help countries achieve lower inflation in the long run, reduce their response to oil price and exchange rate shocks, strengthen monetary policy independence, improve monetary policy efficiency, and obtain inflation outcomes that are closer to target levels. Furthermore, some benefits of inflation targeting increase when inflation targeters achieve disinflation and are able to implement a stationary inflation target. This may suggest that the credibility of an inflation-targeting regime improves once it becomes a stationary regime.

Inflation targeting thus seems to be the natural monetary regime choice, especially for emerging-market economies, where the gains from inflation targeting are found to be the largest. Not surprisingly, a large number of developing countries are currently planning to adopt inflation targeting in the near future.

Despite the favorable results attained by inflation-targeting countries over time, our evidence generally does not suggest that countries that adopt inflation targeting have improved their monetary policy performance beyond that of our control group of nontargeters,

all of which are industrial countries with a successful monetary policy. However, inflation targeting does seem to help countries converge toward the performance of our very demanding control group, particularly during the mature phase of stationary targeting.

Indeed, obtaining a strong nominal anchor is the key to successful monetary policy. Our evidence suggests that some industrial countries have been able to obtain a strong nominal anchor without resorting to inflation targeting. The Federal Reserve's policies under Alan Greenspan, for example, may not have been very different or any better if the Federal Reserve had adopted inflation targeting (Mishkin, 2005). It is therefore not entirely surprising that we did not find much evidence that inflation targeters do better than our control group of industrialized nontargeters.

Nevertheless, we feel that the adoption of inflation targeting has advantages even for industrial countries. Industrialized countries that have not adopted inflation targeting face four problems (see Bernanke and others, 1999; Mishkin, 2005). First, the strong nominal anchor that produced a successful monetary policy is often based on individuals, and their replacements may not be strongly committed to the nominal anchor. Second, the focus on the long run exhibited by successful nontargeters may weaken in the future. Third, the lack of transparency about the goals of monetary policy increases uncertainty. Fourth, the lack of accountability in the absence of inflation targeting could undermine central bank independence in the future, thereby weakening the nominal anchor. Inflation targeting has the potential to ensure that the successful monetary policy performance of our control group of industrial nontargeters in recent years continues in the future.

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The Relationship between Exchange Rates and Inflation Targeting Revisited

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For decades, the exchange rate was at the center of macroeconomic policy debates in emerging markets. Many countries used the nominal exchange rate to bring down inflation; –others—mostly in Latin America—used the exchange rate to implicitly tax the export sector.[1] Currency crises were common and usually resulted from acute real exchange rate overvaluation. In the 1990s, academics and policymakers debated the merits of alternative exchange rate regimes for emerging economies. Many authors drew on credibility-based theories to argue that developing and transition countries should have hard peg regimes, preferably currency boards or dollarization. One of the main arguments in favor of rigid exchange rate regimes was that emerging economies exhibited a fear of floating.[2] After the currency crashes of the late 1990s and early 2000s, however, a growing number of emerging economies moved away from exchange rate rigidity and adopted a combination of flexible exchange rates and inflation targeting. Because of this move, the exchange rate

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1. Argentina is perhaps the best example of a country that has used the nominal exchange rate to achieve alternative policy objectives. In the 1960s and 1970s, the real exchange rate was deliberately kept at an overvalued level to implicitly tax the agriculture sector (Díaz-Alejandro, 1970). In the early 1980s, the exchange rate was devalued at a slow, predefined rate to bring down inflation; this was the so-called *tablita* episode. In the 1990s, Argentina had a fixed exchange rate and a currency board. For a historical view of Argentina's exchange rate policies, see Della Paolera and Taylor (2003).

2. See Calvo (1999); Calvo and Reinhart (2002).

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has become less central in economic policy debate in most emerging markets, although it certainly has not disappeared altogether. Indeed, the adoption of inflation targeting has raised a number of important exchange-rate-related questions, many of them new.

This paper addresses three broad policy issues related to inflation targeting and exchange rates. These issues have become increasingly important in analyses on monetary policy in emerging countries.[3] First, I examine the effectiveness of the nominal exchange rate as a shock absorber in inflation-targeting regimes. This issue is related to the extent of the pass-through from the exchange rate to domestic prices. Much of the literature on pass-through misses the important connection between pass-through and the exchange rate's effectiveness as a shock absorber.

Second, I analyze whether the adoption of inflation targeting has had an impact on exchange rate volatility. Many authors point out that since inflation targeting requires some degree of exchange rate flexibility, it necessarily results in higher exchange rate volatility.[4] This, however, is not a very interesting statement. A more useful analysis would separate the effects of inflation targeting, on the one hand, and of a more flexible exchange rate regime, on the other, on exchange rate volatility. This is what I do in section 2 of the paper.

Third, I discuss whether the exchange rate should affect the monetary policy rule in an inflation-targeting regime. This issue remains unresolved from an analytical perspective. At the policy level, very few inflation-targeting central banks openly recognize using the exchange rate as a separate term in their policy rules (that is, Taylor rules). Existing empirical evidence suggests, however, that almost every central bank takes exchange rate behavior into account when undertaking monetary policy.[5]

Much has been written about these three topics, yet recent policy debates miss some of the finer aspects of the problems. In this paper, therefore, I take a new look at the issues. In sections 1 and 2, on pass-through and volatility, I perform comparative empirical analyses for a group of seven countries—two advanced and five emerging—that

3. On inflation targeting, see Bernanke and others (1999); Bernanke (2004); Mishkin and Schmidt-Hebbel (2001); Jonas and Mishkin (2005); Mishkin and Savastano (2001); Corbo and Schmidt-Hebbel (2003); Schmidt-Hebbel and Werner (2002).

4. See Mishkin and Savastano (2001) for a discussion of the requirements for an inflation-targeting regime to work.

5. See the discussion in section 3.

have adopted inflation targeting.[6] In section 3, I discuss the possible role of the exchange rate in determining the monetary policy stance in an inflation-targeting system. Section 4 concludes.

1. The Effectiveness of the Nominal Exchange Rate as a Shock Absorber in Inflation-Targeting Regimes

Economists have long been concerned with the effectiveness of nominal exchange rate changes as shock absorbers. This issue has been related with structuralists' rejection of devaluations and the historical skepticism regarding the benefits of flexible exchange rates. From a policy perspective, this issue can be decomposed into three topics: the effects of nominal exchange rate changes on the real exchange rate; the effects of real exchange rate changes on the external position of a country; and the collateral effects of nominal exchange rate changes on balance sheets and aggregate economic activity.

This section addresses the first topic—namely, the effects of nominal exchange rate changes on real exchange rates—in the context of inflation-targeting regimes. This question is directly related to the issue of the pass-through from exchange rates to domestic prices. Much of the recent literature on the pass-through ignores the question of the exchange rate's effectiveness, focusing instead on the inflationary effects of exchange rate changes. If the inflationary effects of exchange rate changes are large, the authorities will have to implement monetary and fiscal policies that offset the inflationary consequences of exchange rate changes. Historically, pass-through has tended to be large in emerging countries and, in particular, in countries that experience a currency crisis. Borensztein and De Gregorio (1999), for example, examine forty-one countries and find that after one year, 30 percent of a nominal devaluation was passed through to inflation; after two years, the pass-through was a very high 60 percent, on average. They also find that the degree of pass-through was significantly smaller in advanced countries.

A number of recent papers show that the degree of pass-through has declined substantially since the 1990s; particularly telling examples include the United Kingdom and Sweden after their currency crises in

6. I chose these countries for two reasons: I wanted countries representing different regions and different stages of development, and I needed fairly long time series to perform the empirical analysis.

the early 1990s, and Brazil after the 1999 devaluation of the real. Taylor (2000) argues that this lower pass-through was the result of a decline in the level and volatility of inflation. He holds that one of the positive consequences of a strong commitment to price stability is that the extent of pass-through declines significantly, creating a virtuous circle in which lower inflation reduces pass-through, and this, in turn, helps maintain low inflation. Campa and Goldberg (2002) test Taylor's proposition using data on domestic prices of imports for member countries of the Organization for Economic Cooperation and Development (OECD); their results suggest that monetary conditions are only mildly related to the degree of pass-through. Gagnon and Ihrig (2004) use a sample of advanced nations to analyze this issue; they conclude that the decline in the pass-through is related to changes in monetary policy procedures and, in particular, the adoption of inflation targeting.

1.1 Two Notions of Pass-Through

Most authors argue—either implicitly or explicitly—that a decline in the degree of pass-through is a positive development; after all, a lower pass-through will reduce inflationary pressures from abroad. This inflation-centered view is too simplistic, however, and it tends to ignore the role of relative prices and the real exchange rate.[7]

Once relative prices are introduced into the analysis, it is clear that the pass-through problem not only affects inflation, but is also related to the effectiveness of the nominal exchange rate as a shock absorber. In this context, it is important to make a distinction between the pass-through of exchange rate changes into the price of nontradabales and into the domestic price of tradables. While a high pass-through into nontradables will reduce the nominal exchange rate's effectiveness, a high pass-through into tradables will enhance it.

To illustrate this point, I use the standard definition of the real exchange rate, ρ, as the (domestic) relative price of tradable to nontradable goods:

$$\rho = \frac{P_T}{P_N}, \tag{1}$$

7. Edwards and Levy-Yeyati (2005) analyze the effectiveness of alternative exchange rate regimes in accommodating external shocks. For the exchange rate to act as a shock absorber, changes in the nominal exchange rate must be translated into real exchange rate changes. See also Hochreiter and Siklos (2002).

where P_T is the domestic price of tradables and P_N is the price of nontradables. For the nominal exchange rate to be an effective shock absorber—under either an adjustable or a flexible exchange rate regime—a depreciation of the nominal exchange rate (E) will have to generate an increase in ρ; if this happens, the change in ρ will help generate an expenditure switching effect. Traditional models ensure this result through three assumptions: (1) the law of one price holds for tradables;[8] (2) P_N is the result of the clearing conditions in the nontradables market; and (3) economic authorities pursue tight monetary and fiscal policies and nominal wages do not adjust automatically as a result of the nominal depreciation. The first two assumptions are summarized in equations (2a) and (2b):

$$P_T = EP_T^*; \tag{2a}$$

$$N^S\left(\frac{W}{P_N}\right) = N^D(\rho, A), \tag{2b}$$

where E is the nominal exchange rate (an increase in E is a nominal depreciation); P_T* is the international price of tradables; N^S and N^D are the supply and demand for nontradables, W is nominal wages, and A is absorption. Absorption is affected by fiscal policy and monetary policy; both expansive fiscal and monetary will result in a higher A.

In this setting, and assuming that the international price of tradables does not change,

$$\frac{d\log\rho}{d\log E} = 1 - \left(\alpha_1 + \alpha_2\frac{d\log W}{d\log E} + \alpha_3\frac{d\log A}{d\log E}\right). \tag{3}$$

where $\alpha_1 = \eta/(\eta - \varepsilon)$, $\alpha_2 = -\varepsilon/(\eta - \varepsilon)$, $\alpha_3 = \phi/(\eta - \varepsilon)$, and $\eta \geq 0, \varepsilon \leq 0, \phi \geq 0$ are elasticities. According to the traditional monetary model, the pass-through from the exchange rate to the domestic price of tradables will be unitary, and the pass-through to the domestic price of nontradables will depend on wage rate behavior and absorption policies. Under the classical case, $d\log W = d\log A = 0$, and the pass-through to P_N will be equal to $0 < (1 - \alpha_1) \leq 1$. A nominal depreciation will result in a real exchange rate depreciation—that is, $(d\log\rho)/(d\log E) > 0$—and the nominal exchange rate will play a role as a shock absorber.

8. This assumption is often referred to as producer-currency pricing.

The assumptions of the traditional monetarist model do not necessarily hold in the real world, however. Indeed, in the presence an automatic backward-looking wage indexation mechanism, the pass-through to the price of nontradables will be equal to one, and $(d\log\rho)/(d\log E) = 0$. Moreover, if the monetary authorities have low credibility and labor unions expect inflationary pressures in the future, then $(d\log W)/(d\log E) > 0$, and the effectiveness of the nominal exchange rate as a shock absorber will decline, as shown in Edwards (1998).

A number of analysts question the validity of the law of one price for tradables (equation 2a), even in small economies. If export firms have some monopolistic power, they will set prices in a way that maximize profits. In this case, they will price to market—that is, they will not alter their domestic prices in a particular market in proportion to exchange rate changes.[9] The easiest way to visualize this is to consider the optimal pricing strategy for a monopoly operating in country *j*. Equation (2a) for the domestic price of tradables is replaced with the following:

$$P_T^j = \mu \mathrm{MC}^j, \tag{2c}$$

where μ is the markup; and MC is the marginal cost of operating in country *j* (in domestic currency), which depends on production costs, the cost of transportation, and distribution costs. The markup depends on the price elasticity of demand for *T* in country *j* (ϑ) and is given by $\mu = \vartheta / (1+\vartheta)$, where $\vartheta < 0$. The elasticity, in turn, depends on a number of variables, including income growth and the degree of price instability in the economy. Under most circumstances, a change in the nominal exchange rate will not be translated into a one-for-one change in the domestic price of tradables, for two reasons. First, MC does not necessarily remain constant when *E* changes. Second, the mark-up is affected when the exchange rate depreciates; indeed, it is likely to decline.[10] This means that the magnitude of the pass-through from exchange rate to the price of tradables is likely to be less than one. When the pass-through into importable goods is zero, the market is said to be characterized by local currency pricing.

Although the framework developed here could be made more complex (by assuming that nontradables use tradable inputs, for example), the main points would still be valid. In particular, once the role of the real exchange rate is explicitly introduced into the analysis, it is important to distinguish between two notions of exchange rate

9. See Atkenson and Burstein (2005) for a recent survey and results.
10. This is the case under many forms of the demand curve.

pass-through: pass-through into nontradables and pass-through into tradables. From a policy perspective, pass-through coefficients for tradables and nontradables should be different, with the pass-through for tradable goods being higher than that for nontradables.

In this section, I use data from seven inflation-targeting countries to investigate whether the adoption of this monetary policy regime affected the magnitude of the pass-through; see table 1 for a list of countries and the date when inflation targeting was enacted. One of the main objectives of this analysis is to investigate whether the adoption of inflation targeting has altered the effectiveness of nominal exchange rates as shock absorbers. As pointed out above, this would be the case if the pass-through from exchange rates to nontradable prices has declined or if the pass-through to tradables goods has increased (or, at least, has not declined).

Table 1. Selected Inflation-Targeting Countries

Country	*Start date of inflation-targeting regime*
Australia	April 1993
Brazil	June 1999
Canada	February 1991
Chile	June 1991, June 1994
Israel	December 1991
Korea	January 1998
Mexico	January 1999

Source: Corresponding central bank's monetary policy reports and press releases; IMF research papers.

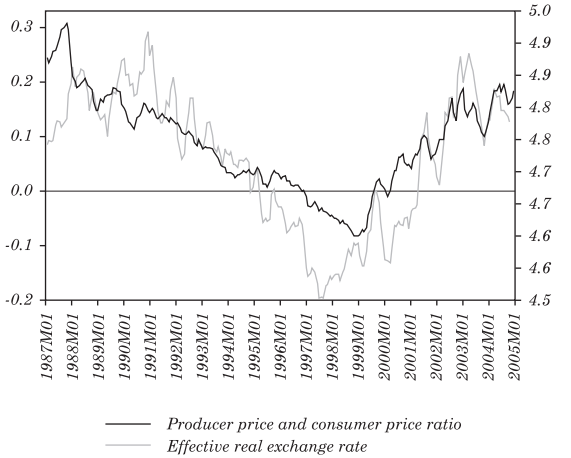
1.2 Empirical Model

An empirical analysis of the pass-through that focuses on inflation and the real exchange rate must consider the way in which changes in nominal exchange rates affect the domestic prices of nontradable and tradable goods. Most countries, however, have important data limitations, especially with regard to nontradables prices. Data limitations are most severe in emerging countries, where long series of domestic prices of importable goods are rarely available.[11] I therefore use the CPI index as a proxy for the domestic price of nontradables (P_N) and the PPI as a proxy

11. In the International Monetary Fund's *International Financial Statistics* (IFS), unit import prices for industrialized countries are expressed in domestic currency. For most emerging countries, however, they are expressed in U.S. dollars.

for the domestic price of tradables (P_T). This means that I am using the PPI-to-CPI ratio as a proxy for the real exchange rate in equation (1). This provides a fairly good proxy for the (effective) real exchange rate in many countries, as illustrated in figure 1 for the case of Chile.

Figure 1. Effective and Proxied Real Exchange Rates: Chile[a]



Source: IMF, International Financial Statistics.
a. The proxy used for the real exchange rate is the ratio of the producer price index to the consumer price index.

Most empirical studies on pass-through estimate variants of the following equation (Campa and Goldberg, 2002; Gagnon and Ihrig, 2004):

$$\Delta \log P_t = \beta_0 + \beta_1 \Delta \log E_t + \sum \beta_{2i} \mathbf{x}_{it} + \beta_3 \Delta \log P_t^* + \beta_4 \Delta \log P_{t-1} + \omega_t, \quad (4)$$

where P_t is a price index (of either importable, tradable, or nontradable goods), E is the nominal exchange rate, P^* is the an index of foreign prices, the betas are parameters to be estimated, $\mathbf{x}_{it}$ is a vector of other controls expected to capture changes in the markup, and ω_t is an error term with standard characteristics. The short-run pass-through is given by β_1, and the long term pass-through is $\beta_1/(1-\beta_4)$.[12]

12. Campa and Goldberg (2002) use the sum of four lagged coefficients of the change in the exchange rate to compute the long-run pass-through. Most other authors also follow this distributed-lags approach.

Many analysts impose the constraint $\beta_1 = \beta_3$. In this paper, however, I consider the more general case, and I allow for different coefficients for the nominal exchange rate and international prices.[13]

From an empirical perspective, the question of interest is whether the coefficients β_1 and β_4 experience a structural change at (approximately) the time of the adoption of inflation targeting. I investigate this by adding two interactive terms to equation (4), so the equation I actually estimate is

$$\begin{aligned}\Delta \log P_t = \beta_0 + \beta_1 \Delta \log E_t + \sum \beta_{2i} \mathbf{x}_{it} + \beta_3 \Delta \log P_t^* + \beta_4 \Delta \log P_{t-1} \\ + \beta_5 \Delta \log E_t \cdot \mathrm{DIT} + \beta_6 \Delta \log P_{t-1} \cdot \mathrm{DIT} + \omega_t,\end{aligned} \tag{4a}$$

where DIT is a dummy variable that takes the value of one since (approximately) the time inflation targeting is adopted, and zero otherwise. The short-term pass-through in the post-inflation-targeting period is $\beta_1 + \beta_5$. In contrast with other studies, in equation (4a) I allow the coefficient of lagged $\Delta \log P$ in the post-inflation-targeting period to be different from the pre-inflation-targeting coefficient. This is important for two reasons: first, it allows me to investigate whether a more inflationary-focused policy reduces inflationary inertia, as argued by Taylor (2000). Second, it provides an alternative channel through which the long-run pass-through may decline. Indeed, since the long-run pass-through in the post-inflation-targeting period is $(\beta_1 + \beta_5)/[1 - (\beta_4 + \beta_6)]$, it could be lower than the pre-inflation-targeting coefficient because either β_5 or β_6 may be significantly negative in equation (4a).

Estimating equation (4a) presents several challenges. The most important has to do with potential endogeneity problems: $\Delta \log E$ may not be exogenous, and it may be correlated with the error term. In principle, there are several ways to deal with this issue, but none of these methods is particular satisfactory in practice. For example, simultaneous equations methods, such as two-stage least squares or generalized method of moments, are limited by the difficulty of finding good instruments for $\Delta \log E$. However, in the vast majority of countries with floating exchange rates, most exogenous variables are not highly correlated with changes in the nominal exchange rate.[14] In the case of structural vector autoregressions (VARs),

13. Some studies, such as Gagnon and Ihring (2004), analyze how different monetary regimes affect the extent of pass-through.

14. This difficulty was first pointed out by Meese and Rogoff (1983).

identification conditions require making unconvincing assumptions about the timing of the effects of the exchange rate on prices. For these reasons, most recent studies on pass-through, including Campa and Goldberg (2002) and Gagnon and Ihrig (2004), rely on least squares methods. An additional challenge in estimating equation (4a) is that many countries do not have data on the (possible) determinant of the markup or the additional controls, **x**.

1.3 Data and Empirical Results

To estimate equation (4a), I use quarterly data for the period 1985–2005 for two advanced and five emerging countries that adopted inflation targeting at some point in the last fifteen years (see table 1).[15] Chile adopted inflation targeting in an evolutionary fashion, so table 1 provides two adoption dates: 1991, when an inflation target range was first announced, and 1994, when a specific inflation rate was adopted as a target.[16] Unless otherwise indicated, the results reported in this section were obtained using mid-1994 date as the launch date for inflation targeting in Chile. The results were similar using the 1991 launch date.

I estimated two equations for each country: one for the rate of change of the CPI (which, as mentioned, is a proxy for nontradables inflation) and one for the rate of change of the PPI (a proxy for domestic tradables inflation). All data are expressed as quarterly percentage changes. The exchange rate is the effective (multilateral) exchange rate, defined as the domestic price of a basket of currencies. Thus, an increase in E is a (multilateral) nominal depreciation.[17] To the extent that it takes time for the public to understand a new policy regime, the structural change in the pass-through coefficients will not be instantaneous, but rather will take place some quarters after the new policy is adopted. In the estimation of equation (4a), I considered alternative lags for DIT; most of the results reported in table 2 are for four lags. The rate of change of the U.S. producer price index was used as a proxy for world inflation. In the basic results reported in table 2, I follow Gagnon and Ihrig (2004) and do not include the additional controls, **x**. See, however, the discussion below.

15. The time period was slightly shorter in some countries.

16. Another relevant date is March 2000, when the first Monetary Policy Report was published.

17. For the majority of countries, I took the multilateral effective exchange rate from the IFS. For countries for which the IFS does not provide the effective rate, I constructed a multilateral exchange rate index.

Table 2. SURE Estimates: Exchange Pass-through, Selected Countries[a]

	Australia		*Brazil*		*Canada*		*Chile*	
Explanatory variable	*CPI*	*PPI*	*CPI*	*PPI*	*CPI*	*PPI*	*CPI*	*PPI*
dlog E	0.054	0.070	0.719	0.759	0.039	0.085	0.137	0.207
	(2.34)	(1.31)	(24.76)	(22.30)	(0.79)	(0.79)	(2.88)	(2.08)
dlog P^*	0.184	0.481	0.117	0.404	0.128	0.070	0.028	0.254
	(3.13)	(3.65)	(0.22)	(1.66)	(2.69)	(0.66)	(0.26)	(1.10)
dlog P_{-1}	0.548	0.060	0.300	0.284	0.499	0.404	0.355	0.194
	(4.09)	(0.30)	(10.38)	(8.67)	(3.99)	(1.83)	(3.43)	(1.77)
Constant	0.006	0.011	0.011	–0.013	0.004	0.003	0.003	0.016
	(2.27)	(2.51)	(0.55)	(0.54)	(2.75)	(1.24)	(3.88)	(1.66)
DIT* dlog E	–0.057	–0.054	–0.663	–0.524	–0.066	0.032	–0.132	–0.162
	(1.55)	(0.60)	(4.95)	(3.28)	(1.20)	(0.28)	(2.27)	(1.32)
DIT* dlog P_{-1}	–0.344	–0.011	0.866	0.379	–0.488	–0.054	–0.090	–0.120
	(1.76)	(0.05)	(1.51)	(1.41)	(2.77)	(0.19)	(0.79)	(0.66)
Summary statistic								
R^2	0.467	0.234	0.974	0.964	0.349	0.220	0.667	0.169
Durbin-Watson.	2.11	2.17	2.39	2.41	2.14	2.06	2.13	1.74
Determinant residual covariance	–	4.85e–9	–	4.13e–6	–	1.49e–9	–	3.73e–8

Table 2. (continued)

	Israel		*Korea*		*Mexico*	
Explanatory variable	*CPI*	*PPI*	*CPI*	*PPI*	*CPI*	*PPI*
dlog E	0.624	0.627	0.020	0.055	0.191	0.246
	(12.18)	(5.95)	(1.20)	(2.10)	(4.85)	(5.98)
dlog P^*	0.017	0.202	0.006	0.137	0.184	0.313
	(0.18)	(1.54)	(0.07)	(0.88)	(0.64)	(1.29)
dlog P_{-1}	0.132	0.121	0.200	0.213	0.635	0.584
	(2.84)	(2.92)	(2.07)	(2.15)	(10.49)	(10.06)
Constant	0.024	0.018	0.013	0.003	0.026	0.021
	(4.78)	(4.33)	(4.59)	(0.94)	(1.96)	(1.79)
DIT* dlog E	–0.427	–0.430	–0.031	–0.063	–0.176	–0.053
	(5.23)	(6.42)	(0.43)	(0.77)	(1.05)	(0.31)
DIT* dlog P_{-1}	0.120	–0.064	–0.097	–0.039	–0.454	–0.362
	(0.92)	(0.54)	(0.43)	(0.51)	(2.02)	(1.74)
Summary statistic						
R^2	0.866	0.880	0.210	0.110	0.793	0.790
Durbin-Watson.	2.46	2.10	2.15	2.32	2.31	2.37
Determinant residual covariance	–	2.98e–8	–	7.19e–9	–	5.23e–8

Source: Author's elaboration.
a. Quarterly data from 1986:1 to 2005:1, except for Chile, which is 1988:1 to 2005:1. E is nominal effective exchange rate, P^* is the U.S. producer price index, P_{-1} is one lag of domestic producer or consumer price index, and DIT is a dummy for periods with inflation targeting. Absolute value of t statistics is reported in parentheses.

Since, for each country, the errors in the CPI and PPI equations are likely to be correlated, I estimated the two equations for each country simultaneously, using Zellner's seemingly unrelated regressions (SURE) procedure.[18] The results obtained are presented in table 2. Table 3 presents a summary of the pass-through coefficients in the pre-inflation-targeting and post-inflation-targeting periods. The main results may be summarized as follows.

—The pre-inflation-targeting short-term pass-through coefficient in the CPI equation is positive in all countries. It is significantly so in six out of the seven countries; the only exception is Canada, whose coefficient is positive but not significant.[19] However, the estimated coefficients show a significant degree of variability across countries. The pre-inflation-targeting short-term pass-through coefficient into nontradable prices (CPI) ranges from a low of 0.020 in Korea to a very high 0.719 in Brazil. A simple inspection at these estimates suggests that the CPI pass-through coefficient has historically been much higher in countries with a tradition of high and chronic inflation (such as Brazil), than in countries with traditional price stability (such as Korea).

—The short term pass-through coefficient in the PPI (or tradables) equation is significantly positive in six out of the seven countries. There is also a significant variability across countries.

—The point estimate of the pre-inflation-targeting short term pass-through coefficient is higher for tradables (PPI) than for nontradables (CPI) in all countries.

—In the pre-inflation-targeting period, the long-run point estimate for the PPI pass-through is higher than for the CPI pass-through in most countries.

—The estimated coefficient of ($d\log E \cdot \mathrm{DIT}$) is negative in all cases. It is significantly so in most cases. This indicates that the short-run pass-through declined in every country in the sample following the adoption of inflation targeting. Moreover, in most cases the decline was larger in the CPI (or nontradables) equation than in the PPI equation, indicating that the short-run effectiveness of the nominal exchange rate rose.

—The decline in the short-run CPI pass-through in the post-IT period was particularly dramatic in the case of Brazil, where the short-run coefficient declined from 0.719 to 0.056. Chile, Israel, and Mexico

18. All equations also include a time trend and, in the case of Brazil, two dummy variables for the 1989 and 1999 currency crises.

19. In the analysis that follows, I consider coefficients with a p value of 20 percent or less to be significant. In most cases, however, the p values are less than 5 percent.

Table 3. Short- and Long-Run Exchange Rate Pass-through, Selected Countries[a]

	CPI equations				*PPI equations*			
	Short-run pass-thorough		*Long-run pass-thorough*		*Short-run pass-thorough*		*Long-run pass-thorough*	
Country	*Pre-IT*	*Post-IT*	*Pre-IT*	*Post-IT*	*Pre-IT*	*Post-IT*	*Pre-IT*	*Post-IT*
Australia	0.054	0.000	0.120	0.000	0.070	0.070	0.070	0.070
Brazil	0.719	0.056	1.027	—	0.759	0.235	1.060	0.697
Canada	0.039[a]	0.000	0.078[a]	0.000	0.085	0.085[a]	0.143[a]	0.143
Chile	0.137	0.005	0.212	0.008	0.207	0.045	0.257	0.056
Israel	0.624	0.197	0.718	—	0.627	0.197	0.713	0.224
Korea	0.020	0.020	0.025	0.025	0.055	0.055	0.070	0.070
Mexico	0.191	0.015	0.523	0.018	0.246	0.246	0.591	0.316

Source: Author's elaboration, based on estimations reported in table 2.
a. Quarterly data from 1986:1 to 2005:1.

also display a major reduction in the pass-through coefficient. At the other extreme, the change in the degree of CPI (or nontradables) pass-through in Korea is not statistically significant, as the CPI pass-through was already very low when inflation targeting was adopted (0.020).

—The pre-inflation-targeting period was characterized by a considerable degree of inflation inertia in most countries, measured by the coefficient of lagged $\Delta \log P$ (see table 2). In most cases, however, inertia was higher for CPI (or nontradables) inflation than for PPI (or tradables) inflation.

—The estimated coefficients of ($\Delta \log P_{-1} \cdot$ DIT) are negative in the vast majority of the countries, with the exception of Brazil for both definitions of inflation and Israel for CPI. The estimated coefficient for ($\Delta \log P_{-1} \cdot$ DIT) is negative and statistically significant for Australia (CPI), Canada (CPI), and Mexico (CPI and PPI), indicating that inflation inertia declined significantly after those countries adopted inflation targeting.

—The post-inflation-targeting long-run pass-through depends on the behavior of both ($\Delta \log P_{-1} \cdot$ DIT) and ($\Delta \log E \cdot$ DIT). As table 3 shows, the long-run pass-through coefficient declined in the post-inflation-targeting period in most countries in the sample (see table 3). This is the case for both the CPI (or nontradables) and the PPI (or tradables) pass-through coefficients.

To explore whether the differences in the pass-through coefficients for the CPI (nontradables) and PPI (tradables) equations reported in tables 2 and 3 are statistically significant, I computed Wald chi-squared statistics to test for cross-equation restrictions. The results are reported in table 4. The null hypothesis that the pass-through coefficients in the CPI and PPI equations are equal is rejected at conventional levels in four of the seven countries.[20] In Brazil, the null hypothesis was rejected both in the short- and long-run in the pre- inflation-targeting period, but it is only rejected in the short-run in the post- inflation-targeting period. Finally, I also tested the joint hypothesis that the short- and long-run pass-through coefficients were equal in both the pre- and post-inflation-targeting periods. The results (which are available on request) indicate that the null hypothesis is rejected for Brazil, Canada, and Mexico.

The estimates reported in table 2 include few controls. To check for the robustness of the results and, in particular, to check for possible omitted variables bias, I also estimated equation (4a) with

20. In most cases, the rejection is not across all time runs and time periods.

Table 4. Wald Tests for Cross-Equation Restrictions[a]

	Short-Run		*Long-Run*	
Country	*Pre-inflation-targeting*	*Post-inflation-targeting*	*Pre-inflation-targeting*	*Post-inflation-targeting*
Australia	0.078	0.131	0.209	0.132
	(0.78)	(0.72)	(0.65)	(0.72)
Brazil	4.240*	3.966*	6.216*	0.543
	(0.04)	(0.04)	(0.01)	(0.46)
Canada	0.189	11.189**	0.085	8.219*
	(0.66)	(0.01)	(0.77)	(0.00)
Chile	0.721	0.251	0.140	0.214
	(0.39)	(0.61)	(0.71)	(0.64)
Israel	0.007	0.010	0.025	0.523
	(0.93)	(0.87)	(0.87)	(0.46)
Korea	3.466**	0.030	2.840**	0.051
	(0.05)	(0.91)	(0.09)	(0.92)
Mexico	23.523*	14.846*	3.824*	6.235*
	(0.00)	(0.00)	(0.05)	(0.01)

Source: Author's elaboration, based on estimations reported in table 2 and 3.
* statistically significant at the 5 percent level.
** statistically significant at the 10 percent level.
a. The test statistics are chi-squared with one degree of freedom. The null hypothesis is that the pass-through coefficients in the CPI and PPI equations are equal in each country. *P* values are reported in parentheses.

the following controls: deviations of GDP from a stochastic trend, lagged one or two periods (in some regressions this variable was also interacted with the nominal depreciation); deviations of U.S. GDP, lagged one or two periods; the change in the degree of volatility of inflation, lagged one or two periods (in some regressions this variable was also interacted with the nominal depreciation); and a time trend. The results are very similar to those presented in table 2 and confirm that most countries display breakpoints in the short-run pass-through, the degree of inertia, and the long-run pass-through coefficient.[21]

1.4 Further Results and Comments on Chile's Experience

Chile has been a pioneer in the implementation of inflation targeting in emerging economies. The country suffered high and chronic inflation for decades. Starting in the 1940s, inflation increased significantly and became a major political and economic problem, and repeated efforts to quell it proved unsuccessful (Meller, 1996). Pazos (1972) refers to Chile as the premier case of an economy in which inflation tended to perpetuate itself. Numerous scholars have analyzed the historical behavior of inflation in Chile, concluding that fiscal largesse, low Central Bank credibility, and widespread indexation practices (for both wages and the nominal exchange rate) were behind Chile's historical high rates of inflation. In the 1990s, however, Chile's monetary policy underwent important changes: the Central bank was granted independence, and it formally adopted an inflation-targeting approach (Corbo, 1998; Schmidt-Hebbel and Tapia, 2002; Morandé, 2002). Since then, inflation has declined significantly; it has not been considerably different from world inflation in the last few years.

The results presented in tables 2 and 3 tend to confirm this story: after adopting inflation targeting in the early 1990s, Chile experienced a decline in the degree of pass-through, in the case of both CPI and PPI inflation (see also De Gregorio and Tokman, 2004). This section provides additional results on Chile that shed further light on the relation between inflation and exchange rates. Table 5 presents new estimates for equation (4a) for CPI (or nontradables) and PPI (or tradables) inflation using three stages least squares (3SLS), which deals with the potential endogeneity of exchange rate changes.[22] Although

21. Results are available on request.

22. I used the following instruments: lagged first difference in the U.S. CPI, the commodity price index, and first difference of the U.S. PPI.

the point estimates are somewhat different, the overall results tend to confirm the conclusions reached above. The 3SLS estimations generally show that the degree of both CPI and PPI pass-through declined in the post-inflation-targeting period. Interestingly, and in contrast with the cases of Australia, Canada and Mexico, I find no evidence of a decline in the degree of inflationary inertia in Chile in the post-inflation-targeting period. Moreover, the level of inertia in Chile is similar for CPI and PPI inflation. From a comparative perspective, however, inflationary inertia is not higher in Chile than in countries with a long tradition of price stability, such as Australia and Canada (see table 2).

Table 5. 3SLS Estimates: Exchange Rate Pass-Through, Chile

Explanatory variable	*CPI*	*PPI*
dlog E_{-1}	0.228	0.530
	(1.55)	(2.21)
dlog P_{-1}	0.375	0.281
	(2.53)	(1.62)
dlog P^*	–0.035	0.213
	(0.26)	(0.72)
C	0.024	0.000
	(1.69)	(0.00)
DIT* dlog E	–0.214	–0.446
	(1.47)	(2.00)
DIT* dlog P_{-1}	–0.105	–0.189
	(0.62)	(0.70)
Summary statistic		
R^2	0.647	0.056
Durbin-Watson	2.05	1.72
Determinant residual covariance	4.31e–0.8	

Source: Author's elaboration.
a. Quarterly data from 1988:1 to 2005:2. E is nominal effective exchange rate, P^* is the U.S. producer price index, P_{-1} is one lag of domestic producer or consumer price index, and DIT is dummy for periods with inflation targeting. Instruments are the lagged first difference of the U.S. CPI, the first difference of commodity price index, and the first difference of the U.S. PPI. Absolute value of t statistics is reported in parentheses.

2. Inflation Targeting and Exchange Rate Volatility: Some Empirical Tests

As a number of authors point out, a floating exchange rate system is a requirement for a well-functioning inflation-targeting

regime (Mishkin and Savastano, 2001).[23] In a world of capital mobility, independent monetary policy cannot coexist with a pegged exchange rate regime—this is the so-called impossibility of the holy trinity. This connection between inflation targeting and floating exchange rates has led some analysts to argue that one of the costs of inflation targeting is increased exchange rate volatility. De Gregorio, Tokman, and Valdés (2005) discuss this issue in the Chilean context; they show that (nominal) exchange rate volatility has not been higher in Chile than in other countries with floating exchange rates.

The way in which the adoption of inflation targeting affects exchange rate volatility is an important policy issue, yet recent debates do not address it appropriately. Many analysts compare exchange rate volatility under inflation targeting with volatility under a pegged or administered exchange rate regime. This is not an adequate comparison. Policy evaluation requires separating the selection of the exchange rate regime and the adoption of inflation targeting. The correct question is whether the adoption of inflation targeting increases exchange rate volatility, controlling for the exchange rate regime. Moreover, most volatility analyses are based on comparisons of unconditional volatility measures across countries, or across time in the same country.

In this section, I use two approaches to address these issues. First, I analyze whether the adoption of inflation targeting affects conditional exchange rate volatility in countries that have had a floating exchange rate for a prolonged period, such as Australia and Canada. Second, I estimate regressions that control for the exchange rate regime. The analysis uses monthly data and focuses on the seven countries in table 1. Conceptually, conditioning for the exchange rate regime makes it possible to determine whether inflation targeting alone raises exchange rate volatility. For example, Australia and Canada both have a long tradition of floating rates. Comparing their conditional volatility before and after the implementation of inflation targeting provides information on the effects of the new policy regime on exchange rate behavior.

2.1 The Data and the Empirical Model

Figure 2 displays data on exchange rate volatility, measured as the monthly difference in the log of the nominal effective exchange

23. The authorities do not need to abstain completely from intervention in the foreign exchange market. See the discussion in section 3 of this paper.

rate for the countries in the sample for January 1988 to January 2005. The figure clearly captures the degree of instability—including crises—faced by some of the countries in the period under study. The figure also shows that instability varied significantly in most of the countries.

Figure 2. Exchange Rate Volatility in the Sample Countries[a]

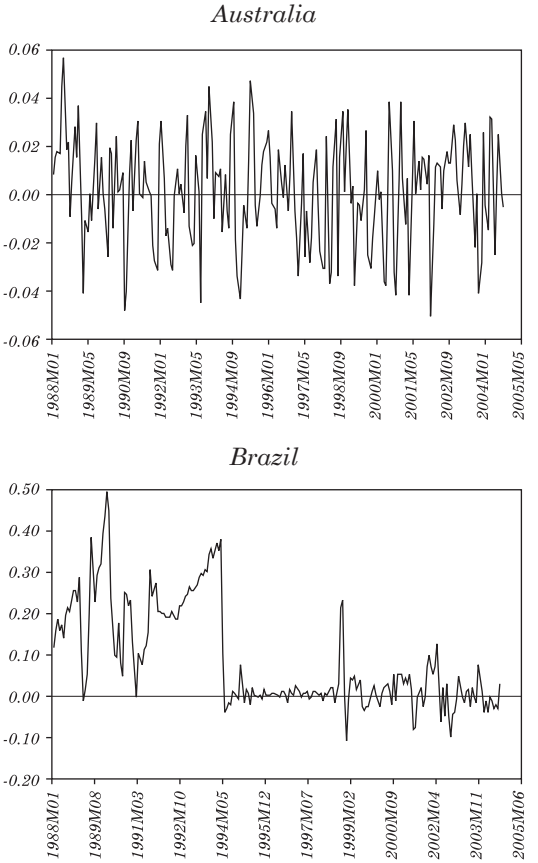


Figure 2. (continued)

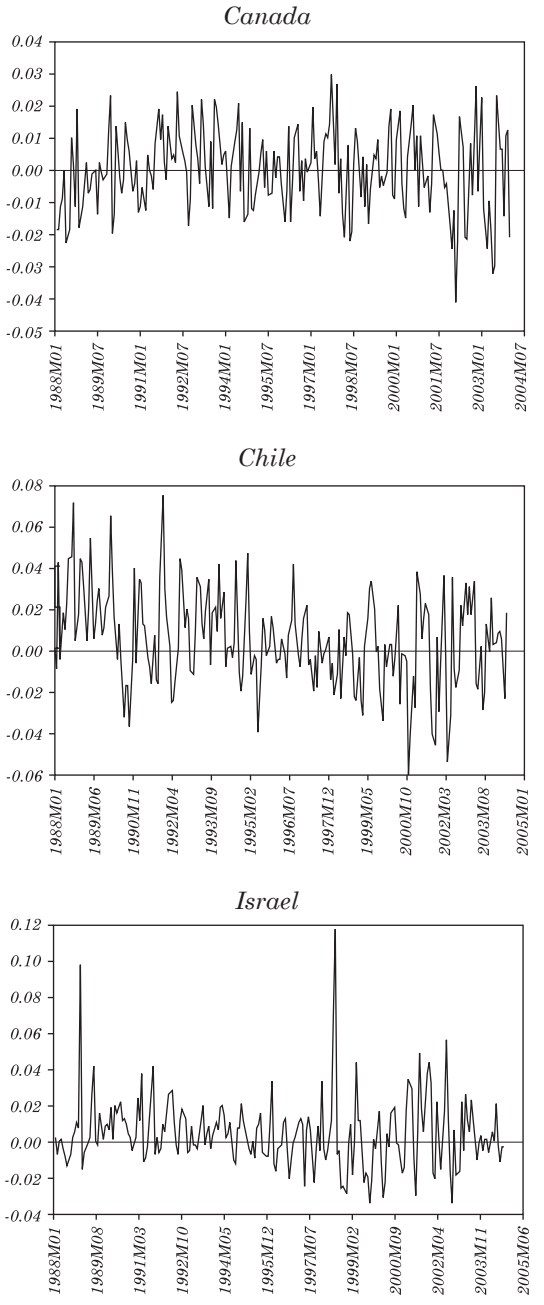
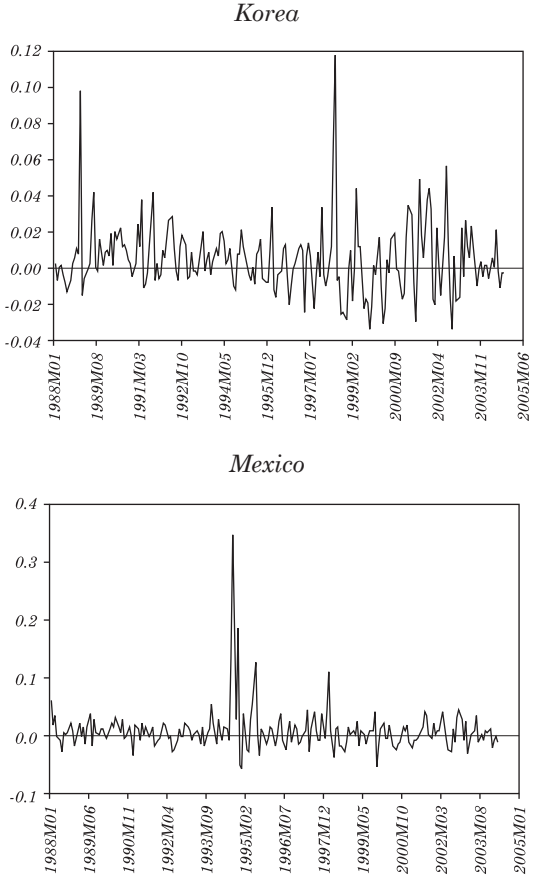


Figure 2. (continued)



Source: Author's elaboration, basedd on data from IMF, International Financial Statistics.
a. Exchange rate volatility is measured as the monthly difference in the log of the nominal effective exchange rate in each country from January 1988 to January 2005.

The changing degree of exchange rate volatility illustrated in figure 2 suggests that, during this period, exchange rate volatility can be explained by models in the generalized autoregressive conditional heteroskedastic (GARCH) tradition. Most GARCH-based empirical work on exchange rate volatility tends to ignore the potential role of alternative monetary regimes, both in the mean and conditional variance equations. Consider the following GARCH model of nominal exchange rates in a particular country:

$$\Delta \log E_t = \theta + \sum \phi_j z_{t-j} + \psi_t \; ; \tag{5}$$

$$\sigma_t^2 = \alpha_1 + \alpha_2 \psi_{t-1} + \sum \gamma_i \sigma_{t-i}^2 + \sum \delta_i y_{t-i} \; , \tag{6}$$

where, as before, E is the nominal effective exchange rate; z is a variable that affects changes in the exchange rate and may include lagged values of $\Delta \log E$, as well as other domestic or international variables; and ψ_t represents innovations to exchange rate changes, with zero mean and conditional variance ${\sigma_t}^2$. In equation (6), y_t, is a variable, other than past squared innovations or lagged forecast variance, that helps explain exchange rate volatility.

This section reports the results from estimating models based on equations (5) and (6) using monthly data for the seven countries in the sample. The time period is January 1988 through January 2005, with the exception of Brazil, for which the period is June 1994 to January 2005.[24] My main objective is to investigate whether the adoption of an inflation-targeting operating procedure for monetary policy affects exchange rate volatility. I am also interested in exploring whether the adoption of a floating exchange rate regime has an effect on volatility. I therefore included two dummy variables as y_t in the conditional variance equation (equation 6): DIT, which takes the value of one if the country has implemented an inflation-targeting regime, and FLOAT, which takes the value of one if the country has a floating exchange rate regime. The variable FLOAT is based on information from a number of sources, including Levy-Yeyati and Sturzenegger (2003), Reinhart and Rogoff (2004), and the IMF. The means equation (equation 5) also includes a time trend and, for Mexico and Korea, dummy variables for their major currency crises.[25]

2.2 Results

In the first step of the analysis, I used ordinary least squares to estimate several versions of equation (5) for the seven countries in the sample.[26] The analysis of the residuals clearly showed the presence of

24. Inflation in Brazil experienced a structural break around mid-1994, when the real plan was adopted.

25. Some of the estimates also include the floating regime dummy in the means equation. Its inclusion does not affect the results, however.

26. As is customary, a preliminary step consists of analyzing stationarity. I used both country-specific and panel techniques.

conditional heteroskedasticity. Engle's Lagrange multiplier (LM) test rejected the null hypothesis of absence of ARCH for every country. In the second step, I identified the order of the GARCH process for each of the countries, and I verified stability. Finally, I estimated the system of equations (5) and (6). The dummy variables for inflation targeting (DIT) and a floating regime (FLOAT) were lagged one period in all cases, although the results were not affected significantly when I used alternative lag structures (including no lags). If the adoption of inflation targeting has indeed resulted in increased nominal effective exchange rate instability, as some critics argue, then the estimated coefficient of DIT would be significantly positive. If floating rates increase exchange rate volatility, as one would expect under most circumstances, then the estimated coefficient of FLOAT would be significantly positive. I did not include the FLOAT variable when estimating the conditional variance equations for Australia and Canada, since both of these countries have had a floating regime since the mid-1970s.

The results are provided in table 6. I only report the order of the GARCH process and the estimated coefficients of DIT and FLOAT. The main results may be summarized as follows. First, the estimated coefficient of the inflation targeting dummy, DIT, is positive and very small in three of the countries—namely, Australia, Canada, and Korea—but it is not significantly different from zero in any of these cases. This indicates that the adoption of inflation targeting did not increase nominal multilateral exchange rate volatility (at least in this sample).

Second, the estimated coefficient of the inflation targeting dummy, DIT, is significantly negative in Brazil, Chile (for both equations), and Israel, and it is negative (but not significant) in Mexico. In the case of Chile, the degree of significance of DIT is higher (in absolute terms) when 1994 is considered as the beginning of the inflation-targeting period. When the FLOAT variable is excluded, the coefficient of DIT becomes positive (but insignificant) in the conditional variance equations for Chile and Brazil. These results suggest that, after controlling for the exchange rate regime, the adoption of inflation targeting has tended to reduce conditional volatility in some countries. The most likely reason for this is that inflation targeting is a transparent and predictable monetary framework that tends to reduce unexpected shocks or news.

Finally, the estimated coefficient of the FLOAT variable is positive in the five equations in which it was included. Moreover, it is significantly positive in three of the five equations—for Brazil, Chile, and Israel.

Table 6. GARCH Estimates: Inflation Targeting, Exchange Rate Regime, and Nominal Exchange Rate Volatility, Selected Countries[a]

Country	*DIT*	*FLOAT*	*DW*	R^2
Australia (1,1)	6.36e–06	–	1.96	0.10
	(0.96)	–		
Brazil (2,2)	–0.001	0.0008	1.97	0.25
	(4.16)	(2.55)		
Canada (1,1)	6.73e–06	–	1.89	0.04
	(0.66)	–		
Chile (1,1)[b]	–7.48e–06	1.71e–07	1.96	0.18
	(1.70)	(3.57)		
Chile (1,1)[c]	–1.57e–05	2.54e–05	1.94	0.22
	(4.20)	(5.97)		
Israel (1,1)	–3.71e–04	3.94e–04	2.30	0.05
	(5.44)	(3.92)		
Korea (1,0)	0.002	0.002	1.73	0.10
	(0.94)	(0.95)		
Mexico (1,1)	–3.67e–04	2.1e–04	2.50	0.14
	(1.06)	(0.63)		

Source: Author's elaboration.
a. Monthly data from January 1988 to January 2005. DIT is a dummy for periods with inflation targeting, and FLOAT is a dummy for periods with floating exchange rate. Absolute value of *z* statistics is reported in parentheses.
b. Inflation targeting assumed to start in June 1991.
c. Inflation targeting assumed to start in June 1994.

The results reported in table 6 are for standard GARCH models. In this setting, the nominal exchange rate reacts in the same way to positive and negative shocks. As a number of authors argue, however, the nominal exchange rate may react asymmetrically to positive and negative shocks. To analyze whether this possibility would affect the main results discussed above, I estimated a series of threshold and exponential GARCH models for the seven countries in the sample. Although I find some evidence of asymmetric responses, the main conclusions on the DIT and FLOAT coefficients discussed above still hold: there is no evidence that, once one controls for the exchange rate regime, the volatility of nominal (multilateral) exchange rates increased following the adoption of inflation targeting.

The results presented above are for nominal multilateral exchange rates. To analyze whether the adoption of inflation targeting affected real effective exchange rate volatility, I estimated equations (5) and (6)

for the four countries with monthly data on real effective exchange rates (namely, Australia, Canada, Chile, and Israel). The results, which are reported in table 7, tend to confirm those obtained for nominal multilateral exchange rate volatility. There is no evidence that the adoption of inflation targeting increased real effective exchange rate volatility. In fact, the evidence indicates that the opposite occurred in Chile and Israel; in both of these countries the coefficient of DIT is negative, with a *z* statistic in excess of 1.2 (in absolute terms). As in table 6, these estimates suggest that the adoption of a floating regime increased real exchange rate volatility: the estimated coefficients of the FLOAT dummy are significantly positive

Table 7. GARCH Estimates: Inflation Targeting, Exchange Rate Regime, and Real Exchange Rate Volatility, Selected Countries[a]

Country	*Mean equation*	*GARCH*	*DIT*	*FLOAT*	*DW*	R^2
Australia	AR(2)	(1,1)	–1.77e–06	–	1.96	0.07
			(0.52)	–		
Canada	AR(3)	(1,3)	–3.67e–05	–	2.03	0.04
			(1.11)	–		
Chile[b]	AR(1)	(2,2)	–8.39e–06	2.50e–06	1.87	0.05
			(1.27)	(4.02)		
Chile[c]	AR(1)	(2,2)	–2.35e–05	4.66e–05	1.89	0.10
			(2.57)	(4.22)		
Israel	AR(1)	(2,2)	–3.47e–05	7.05e–05	1.89	0.09
			(1.43)	(1.75)		

Source: Author's elaboration.
a. Monthly data from January 1988 to January 2005. DIT is a dummy for periods with inflation targeting, and FLOAT is a dummy for periods with floating exchange rate. Absolute value of *z* statistics is reported in parentheses.
b. Inflation targeting assumed to start on June, 1991.
c. Inflation targeting assumed to start on June, 1994.

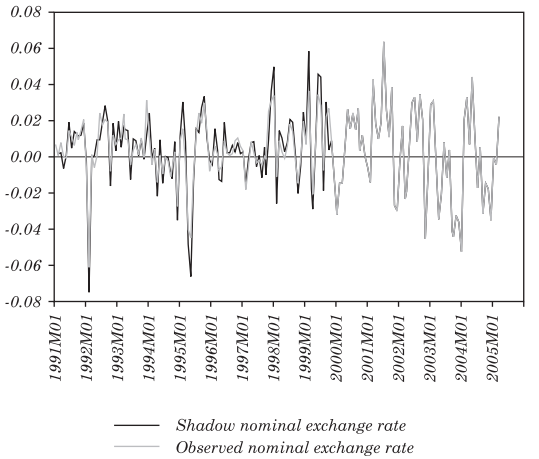
2.3 Extensions for the Case of Chile

The results reported above span a period in which most—but not all—of the countries in the sample underwent important changes in their exchange rate regime. Chile is a case in point.[27] During this

27. This also applies to Mexico, which had a band until late 1994, and Israel, which had a widening crawling band into the 2000s. Korea had a managed exchange rate until 1998; Brazil had a managed rate until 1999.

period, the country evolved from an exchange rate band of varying width to a flexible exchange rate. The extent of exchange rate volatility during the band period may have been limited by the existence of the band itself, even if the actual exchange rate never hit the bands. If this is the case, the results for the emerging countries (though not for Australia or Canada) in table 6 maybe misleading. To address this issue, I used data on Chile's shadow nominal exchange rate—or the exchange rate that would have prevailed in the absence of the bands—to analyze exchange rate volatility in the period 1991–2004. The data on the shadow exchange rate were taken from Edwards and Rigobon (2005). This shadow rate was computed using an iterative procedure based on the behavior of the actual rate, the bands, and the fundamentals. Figure 3 presents the evolution of the monthly change of the nominal observed and nominal shadow exchange rate for the Chilean peso relative to the U.S. dollar.

Figure 3: Monthly Changes in Observed and Shadow Nominal Exchange Rate



Source: Edwards and Rigobon (2005).

The estimation of the conditional variance equation for the shadow exchange rate yielded the following results: the point estimate for the inflation targeting dummy, DIT, was –2.36E–05, with a *z* statistic of –0.406. The point estimate for the floating exchange rate dummy,

FLOAT, was 0.00004, with a z statistic of 1.620.[28] These results, then, confirm those reported in the preceding subsection. Even when a shadow exchange rate is used, there is no evidence suggesting that the adoption of inflation targeting increased nominal exchange rate volatility; there is, however, some evidence that the move from a band to a floating regime did have a small positive effect on volatility.

3. Central Bank Policy and the Exchange Rate under an Inflation-Targeting Policy Regime

Should inflation-targeting central banks intervene in the foreign exchange market? If so, should the intervention be sterilized, where the resulting changes in monetary aggregates are offset through operations involving domestic securities, or nonsterilized, where monetary aggregates are affected?[29] These complex questions have moved to the center of the policy debate in many inflation-targeting countries, especially in Latin America. In this section, I discuss the issue of whether inflation-targeting central banks should explicitly consider the exchange rate in their monetary rule.[30] This question is related to a number of important (and controversial) policy issues, including the costs of real exchange rate misalignment and fear of floating.[31]

3.1 The Issues

From a technical perspective, the discussion of the relation between central bank policy and the exchange rate may be framed in terms of the form of the Taylor rule in a small open economy. Taylor himself poses the problem as follows: "How should the instruments of monetary policy (the interest rate or a monetary aggregate) *react to the exchange rate*?" (Taylor, 2001, p. 263, emphasis added). To address this question formally, consider the following equation:[32]

28. This estimation uses the DIT_{1994} dummy.

29. Questions do not end here, however. For example, if intervention is sterilized, what type of domestic securities should be used in the sterilization? Should purchases and sales of foreign exchange be conducted in the spot or forward market?

30. It is not my intention to provide a comprehensive survey of central bank intervention. The literature is voluminous and country specific, and it continues to grow. See, for example, Domínguez and Frankel (1993); Taylor (2004); Kearns and Rigobon (2005); Neely (2001); Sarno and Taylor (2001). For an excellent analysis of different central bank policies, including Chile, see Tapia and Tokman (2004).

31. On fear of floating, see Calvo and Reinhart (2002).

32. This is the precise equation presented by Taylor in his discussion on the subject.

$$i_t = f\pi_t + gy_t + h_0 e_t + h_1 e_{t-1}, \tag{7}$$

where i_t is the short-term interest rate used by the central bank as a policy tool; π_t is the deviation of the inflation rate from its target level (possibly zero); y_t is the deviation of real GDP from potential real GDP (often called the output gap); e_t is the log of the real exchange rate in year t;[33] and f and g are the traditional Taylor rule coefficients. Finally, h_0 and h_1 are the coefficients of the current and lagged log of the real exchange rates in the expanded Taylor rule, and they are the main interest of this discussion. If $h_0 = h_1 = 0$, then exchange rate developments should not be incorporated in the policy rule, and the Taylor rule reverts to its traditional form.

In principle, the optimal monetary policy rule in a small open economy—that is, the policy that maximizes the authorities' objective function—could conceivably be one in which both h_0 and h_1 are different from zero. Interestingly, if $h_0 > 0$ and $h_0 = -h_1$, then the rule implies that monetary policy should react to changes in the (real) exchange rate. The formulation in equation (7) does not imply that the monetary authorities should defend a certain level of the exchange rate, even when h_0 and h_1 are different from zero. If the optimal policy calls for intervention (that is, for h_0 and h_1 different than zero) and if the monetary authorities follow this policy, a casual observer may conclude that the country in question is subject to fear of floating. This would be an incorrect inference, however, as the country in question would be practicing optimal flotation.

To fully answer this question, it is necessary to specify the policymaker's objective (or loss) function and the model that best captures the functioning of the economy. Most authors assume that the goal of policymakers is to minimize a loss function that combines deviations of GDP (or GDP growth) from trend and deviations of inflation from its target:[34]

$$L = (\pi_t - \hat{\pi}) + \lambda(y_t - \hat{y}), \tag{8}$$

where $\lambda > 0$ and where $\hat{\pi}$ is the inflation target, $\hat{y}$ is potential output, and $(y_t - \hat{y})$ is the output gap. In this case, the exchange rate will

33. In this formulation, an increase in e denotes a real exchange rate appreciation.

34. Medina and Valdés (2002) develop a model in which the authorities also target the current account. They show that the optimal reaction function is significantly different from traditional Taylor rules.

play a role in the monetary policy rule if changes in e (or, in some models, changes in the nominal exchange rate) affect inflation or the output gap (or both). To the extent that the pass-through coefficient is different from zero, exchange rate changes will affect actual inflation—that is, $\partial\pi/\partial e > 0$. If (some) changes in the real exchange rate reflect misalignment, they will affect the output gap. Under these circumstances, the optimal policy will take into account the way in which exchange rate developments affect the two components of the loss function. What is unclear, however, is whether the exchange rate should have an independent role in the monetary policy rule (equation 8). If the authorities have modeled the economy correctly (and, in doing so, have incorporated the effects of e on π and y), there is no need to include an exchange rate term in equation (8). De Gregorio, Tokman, and Valdés (2005) make this point forcefully in their discussion of Chile. If, however, there is a lagged response of both inflation and output to exchange rate changes, the central bank may want to preempt their effect by adjusting the policy stance when the exchange rate change occurs, rather than when its effects on π and y are manifested.

Whether a preemptive strategy is preferable to waiting until π and y begin to reflect the effects of a change in e is, in the final analysis, an empirical issue. Moreover, it is a country-specific issue; the main characteristics of a particular economy—including its inflation dynamics, the size of the pass-through coefficient, and different elasticities—will determine the extent to which macroeconomic volatility (that is, deviations of inflation and growth from targets and trends) is lower when h_0 and h_1 are different from zero.

3.2 A Selective Review of the Literature

Most analytical discussions on inflation targeting implicitly assume that $h_0 = h_1 = 0$, without actually inquiring how the incorporation of e into the policy rule will be affect welfare and macroeconomic performance. Furthermore, most discussions on inflation targeting in the mainstream literature tend to ignore open-economy issues. In the important book, *The Inflation-Targeting Debate,* edited by Ben S. Bernanke and Michael Woodford (2005), the index has no entry for devaluation or pass-through and only one entry for exchange rate. This last corresponds to the paper by Jonas and Mishkin (2005) on inflation targerting in transition economies. Most of the other papers in the volume do not include

explicit discussions on exchange rate behavior when addressing monetary policy issues. Exceptions include Cecchetti and Kim (2005), who develop a section on an open economy, but do not ask formally whether h_0 or h_1 should be equal to zero. King (2005) briefly notes that although the United Kingdom experienced a sharp currency appreciation (in excess of 20 percent), this did not alter the effectiveness of the inflation-targeting-based policy. Finally, Caballero and Krishnamurthy (2005) develop a model of an open economy where the exchange rate plays an important role during a sudden stop; the exchange rate does play an important role in determining optimal monetary policy in their setting.

Woodford (2003) provides firm analytical underpinnings for interest-rate-based monetary policy, yet he does not deal explicitly with exchange rates. The index has no entries for exchange rate(s), devaluation, or pass-through and only one entry for open economy. No open-economy model is presented, and the discussions on optimal policy rule do not consider the (potential) role of open-economy variables.[35]

The pioneering book by Bernanke and others (1999) includes interesting discussions on the role of exchange rates in monetary policy implementation in a number of countries. Canada, for example, explicitly uses a monetary conditions index (MCI) that includes the exchange rate.[36] However, the chapter on design and implementation (chapter 3) does not discuss at the analytical level whether exchange rate considerations should be explicitly incorporated into the policy rule in an inflation-targeting setting. In the chapter on Australia, Israel, and Spain, the authors discuss how Israel and Spain gradually relaxed exchange rate bands when they adopted inflation targeting, and they explain that in both of these countries the authorities decided "not to respond to short-term exchange rate fluctuations" when making monetary policy decisions (Bernanke and others, 1999, p. 205).

Mishkin and Savastano (2001) provide one of the most complete discussions on the issue. They convincingly argue that the discussion on macroeconomic stability in Latin America is not related to the selection of the exchange rate regime. The issue, rather, is how to create an institutional framework for conducting credible monetary

35. To be fair, one could interpret the discussion in section 2.1 of chapter 7, on cost-push shocks, as including shocks stemming from exchange rate depreciation.

36. New Zealand also adopted an MCI in the late 1990s.

policy, and they consider that inflation targeting provides such a framework. Mishkin and Savastano develop a model in which optimality implies a Taylor rule of the following form:

$$i_t = \pi_t + b_1 (\pi - \pi^*) + b_2 y_t + b_3 e_t , \tag{9}$$

where e_t is the log of the real exchange rate, expressed as deviations from its equilibrium value. The authors make a very important point:

> "In Latin America exchange rate fluctuations are likely to have a bigger effect on aggregate demand and aggregate supply (because the pass-through may be larger)... [This] indicates that the weight of the exchange rate in the modified Taylor-rule, b_3, may be relatively large. However, this is in no way inconsistent with inflation targeting." (Mishkin and Savastano, 2001, p. 434).

Ball (1999), Obstfeld and Rogoff (1995), and Svensson (2000) argue that adding the exchange rate as an additional variable in equations like equation (7) will result in more stable macroeconomic outcomes. A simulation exercise undertaken by Svensson (1999, 2000) finds that the optimal values of the exchange rate coefficients are $h_0 = -0.45$ and $h_1 = 0.45$. Ball's (1999) analysis suggests that macroeconomic instability will be reduced if $h_0 = -0.37$ and $h_1 = 0.17$. These results, however, are model specific, and they will change for different parameterizations.

Taylor (2002) reviews nineteen models developed to analyze inflation and monetary issues. Of these, only five assume that the exchange rate affects aggregate demand, and only six assume that exchange rate changes are a factor in the process of price determination. This illustrates quite starkly that many influential researchers continue to think in terms of closed-economy monetary models.

Whether h_0 and h_1 should indeed be different from zero is ultimately a country-specific empirical question that should be dealt with by analyzing country-specific evidence—based on both historical data and simulation exercises. After much reflection, I find it difficult to disagree with Taylor (2001) when he expresses some skepticism on the general merits of adding the exchange rate into the interest rate equation, for at least two reasons. First, as pointed out earlier, in properly specified models, the exchange rate already plays an indirect role through its effect on π_t and y_t; second, adding the exchange rate (or any other asset price, for that matter) into the

Taylor rule is likely to add considerable volatility to monetary policy. This conclusion is similar to that of Mishkin and Schmidt-Hebbel (2001), who provide an extensive discussion on the subject. They find that when implementing policy, central banks should consider the effects of exchange rate fluctuations on inflation and the output gap, but they should not consider an independent role for e_t. As they state, "targeting an exchange rate is likely to worsen the performance of monetary policy."

3.3 What Do Inflation-Targeting Central Banks Actually Do?

The above discussion clearly indicates that the issue of whether monetary policy should react to the exchange rate is not fully resolved. At the analytical level, the answer is likely to depend on each country's structural characteristics and the authorities' loss function. The vast majority of central banks, however, do not openly recognize that they explicitly take exchange rate developments into account when conducting monetary policy. If pressed, most inflation-targeting central bankers would go so far as to say that exchange rate changes play a role in monetary policy because they tend to affect inflation, but they would be reluctant to acknowledge that the exchange rate plays a direct role in the monetary policy rule itself. That is, in terms of equation (7), the vast majority of inflation-targeting central bankers would say that in their policy rules, $h_0 = h_1 = 0$.

As every student of monetary policy knows, however, what central banks say they do often diverges from what they actually do. Mohanty and Klau (2005) estimate monetary policy reaction functions (that is, Taylor rules) for thirteen emerging and transition economies; they find that the real exchange rate coefficient was significant in eleven of them.[37] This provides strong indication that, contrary to what they state, most inflation-targeting central banks take central bank developments into account when determining their monetary policy stance. Table 8 presents a list of the countries with the estimated short- and long-term coefficients in the estimated Taylor rule reaction functions.[38]

37. Hammermann (2005) also estimates central bank reaction functions to analyze whether the exchange rate plays a role.

38. The coefficients in table 7 have positive signs, since in this paper a higher exchange rate represents depreciation. In the Mohanty and Klau (2005) paper, a higher rate represents appreciation, and the coefficients are negative.

Table 8. Interest Rate Response to Changes in Real Exchange Rate[a]

Country	*Short-term*	*Long-term*
India	0.18	0.60
Korea	0.29	0.67
Philippines	0.09	0.13
Taiwan	0.03	0.18
Thailand	0.31	0.74
Brazil	0.10	0.36
Chile	0.00	0.00
Mexico	0.79	1.58
Peru	0.38	2.71
Czech Republic	–0.03	–0.19
Hungary	0.15	0.60
Poland	0.05	0.20
South Africa	0.12	6.00

Source: Mohanty and Klau (2005).
a. Obtained from estimated Taylor rule equations.

The case of Chile is particularly interesting. According to Mohanty and Klau's (2005) base estimates, Chile's Taylor rule may be expressed as follows (t statistics are in parentheses):

$$i_t = \underset{(0.25)}{0.32} + \underset{(4.87)}{0.97}\pi_t + \underset{(1.25)}{0.32}y_t + \underset{(2.78)}{0.35}\Delta xr_t - \underset{(-2.40)}{0.35}\Delta xr_{t-1} + \underset{(4.03)}{0.32}i_{t-1},$$

where Δxr is the change in the real exchange rate. The data are quarterly, and the time period covered is from 1992 to 2002. What is particularly interesting about the Chilean case is that the effect of (real) exchange rate changes on central bank policy appears to last only one quarter. Indeed, the sum of the coefficients for Δxr_t and Δxr_{t-1} add up to zero.

As the results summarized in table 8 show, there is a wide range of values for both the short- and long-run estimated coefficients of the real exchange rate in these Taylor rule reaction functions. (The short run is defined as the sum of the coefficients of Δxr_t and Δxr_{t-1}; the long run is the sum of these two coefficients divided by one minus the coefficient of y_{t-1}). Short-run coefficients, for example,

range from a relatively high 0.79 for Mexico all the way to zero for Chile; long-run coefficients show an even larger dispersion.[39] To examine why monetary policy appears to have been more susceptible to exchange rate changes in some countries than others, I estimated a number of cross-country regressions. The dependent variable is the short-run exchange rate coefficient reported in table 8. The following controls were used: average inflation, 1990–95; standard deviation of quarterly inflation, 1990–95; standard deviation of the real exchange rate, 1990–95; degree of openness of the economy, measured as imports plus exports over GDP; length of time the country has had floating rates; and number of years since inflation targeting was adopted. The results obtained for these six univariate regressions are presented in table 9. Since I only have thirteen observations, I made no attempt to run a multivariate regression with all the regressors. Despite the extremely small sample, the results reported in table 9 are interesting and suggestive. Countries with a history of higher inflation seem to have a higher coefficient for Δxr in their Taylor rules. Also, countries that have historically had a more volatile (real) exchange rate seem to attach a higher coefficient to the exchange rate in their monetary rule. When both variables are included in a bivariate regression their coefficient are still positive and continue to have a relatively high level of significance.

4. Concluding Remarks

The exchange rate is one of the most important macroeconomic variables in emerging and transition economies. It affects inflation, exports, imports, and economic activity. For decades the vast majority of emerging countries had rigid exchange rate regimes—either pegs (adjustable or hard) or a managed rate. This, however, has changed in the last few years, when an increasingly large number of countries have adopted flexible exchange rate regimes. This move away from exchange rate rigidity has occurred while many countries have embraced inflation targeting as a way of conducting monetary policy. The conjunction of inflation targeting and flexible rates has brought a host of new policy issues to the center of the discussion, including issues related to the role of the exchange rate in monetary policy, volatility, and the relation between exchange rate changes and inflation.

39. In the case of long-run coefficients, most of the very high values are the result of a very low estimate for the lagged interest rate. This may be biasing the long-run estimates.

Table 9. Exchange Rate Coefficient in Taylor Rule Equations and Country Characteristics[a]

Explanatory variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Average inflation	0.015					
	(1.74)***					
Std. deviation inflation		0.010				
		(0.71)				
Std. deviation real exchange rate			0.040			
			(1.78)***			
Trade openness				−0.001		
				(0.64)		
Time with floating regime					−0.000	
					(0.11)	
Years since inflation targeting adopted						0.005
						(0.26)
Constant	0.037	0.140	−0.031	0.276	0.207	0.170
	(0.35)	(1.51)	(0.23)	(1.86)	(1.17)	(1.73)
No. observations	13	13	13	13	13	13
R^2	0.22	0.04	0.22	0.04	0.00	0.01

Source: Author's elaboration.
* Statistically significant at the 1 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 10 percent level.
a. Estimated using ordinary least squares. Absolute value of t statistics is reported in parentheses.

In this paper, I have addressed three of these issues: the relation between the pass-through and the effectiveness of nominal exchange rates in inflation-targeting regimes; the effects of inflation targeting on exchange rate volatility; and the role (or potential role) of exchange rate changes on the monetary rule in inflation-targeting countries. The main findings from this analysis may be summarized as follows. First, countries that have adopted inflation targeting have experienced a decline in the pass-through from exchange rate changes to inflation. In many of the countries in the sample, this decline in the pass-through has been different for CPI and PPI inflation. There is no evidence, however, of changes in the degree of effectiveness of the nominal exchange rate as a shock absorber. Second, the adoption of inflation-targeting monetary policy procedures has not resulted in an increase in nominal or real exchange rate volatility. However, the adoption of a floating exchange rate regime increased the degree of volatility of exchange rates in three out of five countries. Finally, there is some evidence that inflation-targeting countries with a history of high and unstable inflation tend to explicitly take developments in the nominal exchange rate into account when conducting monetary policy.

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Inflation Targeting and the Anchoring of Inflation Expectations in the Western Hemisphere

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Many central banks have adopted a formal inflation-targeting framework based on the belief and the theoretical predictions that an explicit and clearly communicated numerical objective for the level of inflation over a specified period would, in itself, be a strong communication device that would help anchor long-term inflation expectations.[1] Empirically verifying the success of inflation-targeting regimes in this dimension has been difficult, however, as survey data on long-term inflation expectations tend to be of limited availability and low frequency.[2]

In compiling the data for this project, we received invaluable assistance from Klaus Schmidt-Hebbel and Mauricio Larraín. The paper also benefited from very helpful discussions, comments, and suggestions from Frederic Mishkin, Eric Parrado, Scott Roger, Brian Sack, Klaus Schmidt-Hebbel, Lars Svensson, and Jonathan Wright. We also appreciate the excellent research assistance of Claire Hausman and Oliver Levine. The views expressed in this paper are solely the responsibility of the authors, and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System, the management of the Federal Reserve Bank of San Francisco, or any other person associated with the Federal Reserve System.

1. See, for example, Leiderman and Svensson (1995); Bernanke and Mishkin (1997); Svensson (1997); Bernanke and others (1999).

2. For an analysis using semiannual survey data on long-run inflation expectations in the 1990s and early 2000s for a panel of countries, see Levin and Piger (2002).

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In this paper, we use daily bond yield data for Canada, Chile, and the United States to investigate whether long-term inflation expectations in these countries are anchored, essentially extending the analysis of Gürkaynak, Sack, and Swanson (2005) and Gürkaynak, Levin, and Swanson (2006) to examine comparable data for Canada and Chile. Of these three countries, Canada and Chile have been formal inflation targeters throughout much of the 1990s and 2000s, while the United States has not had an explicit numerical inflation objective. We test the success of inflation targeting in anchoring long-term inflation expectations by comparing the behavior of long-term nominal and indexed bond yields across these three countries in response to important economic developments. Forward inflation compensation—defined as the difference between forward rates on nominal and inflation-indexed bonds—provides us with a high-frequency measure of the compensation that investors require to cover the expected level of inflation, as well as the risks associated with inflation, at a given horizon. If far-ahead forward inflation compensation is relatively insensitive to incoming economic news, then one could reasonably infer that financial market participants have fairly stable views regarding the distribution of long-term inflation outcomes. This is precisely the outcome one would hope to observe in the presence of an explicit and credible inflation target.

The daily frequency of our bond yield data, together with the frequent release of important macroeconomic statistics and monetary policy announcements, provides a large event-study data set for our analysis. This holds even for samples that span only a few years—the period for which we have inflation-indexed bond data for the United States and long-term nominal bond data for Chile. Thus, in contrast to previous empirical work using quarterly or even semiannual data, we are able to bring to bear thousands of daily observations of the response of long-term bond yields to major economic news releases in Canada, Chile, and the United States.

For the United States, we find that far-ahead forward nominal interest rates and inflation compensation respond significantly and systematically to a wide variety of macroeconomic data releases and monetary policy announcements. These responses are all consistent with a model in which the private sector's view of the central bank's long-run inflation objective is not strongly anchored, as we show. In Canada, far-ahead forward nominal interest rates and inflation compensation display little or no such sensitivity to either domestic

or foreign economic news. Thus, the anchoring of long-run inflation expectations in Canada appears to be stronger than in the United States. Finally, the data for Chile is more limited in terms of the sample period, the depth and breadth of fixed income markets, and the availability of domestic macroeconomic data releases. Despite these limitations, we do not find significant responses of far-ahead inflation compensation in Chile with respect to domestic or foreign macroeconomic news.[3]

The remainder of the paper proceeds as follows. Section 1 presents two reference models of the economy to act as benchmarks for comparison with our empirical results. Section 2 investigates the responses of far-ahead forward interest rates and inflation compensation in the United States to economic news and shows that these rates respond by much more than standard models would predict. Section 3 discusses possible explanations for this finding. Section 4 repeats our empirical analysis for Canada and Chile to investigate the extent to which inflation targeting may help anchor the private sector's views regarding the long-run inflation objective of the central bank. Section 5 concludes. An appendix provides a detailed description of all the data used in our analysis.

1. Long-Run Implications of Macroeconomic Models

To aid the interpretation of our econometric results, it is useful to have a reference model as a benchmark. We consider two standard macroeconomic models: a pure new Keynesian model (taken from Clarida, Galí, and Gertler, 2000) and a modification of that model that allows for a significant fraction of backward-looking or rule-of-thumb agents (taken from Rudebusch, 2001). These two models can be thought of as different parameterizations of the following equations:

$$\pi_t = \mu_\pi E_t \pi_{t+1} + (1-\mu_\pi) A_\pi(L)\pi_t + \gamma y_t + \varepsilon_t^\pi \text{ and} \tag{1}$$

$$y_t = \mu_y E_t y_{t+1} + (1-\mu_y) A_y(L) y_t - \beta(i_t - E_t \pi_{t+1}) + \varepsilon_t^y, \tag{2}$$

where π denotes the inflation rate, y the output gap, and i the short-term nominal interest rate, and ε^π and ε^y are independent

3. Ertürk and Özlale (2005) obtain a similar finding of anchored expectations for Chile using a GARCH specification on monthly Chilean data.

and identically distributed (i.i.d.) shocks.[4] The parameters μ_π and μ_y describe the degree of forward-looking behavior in the model, and the lag polynomials $A_\pi(L)$ and $A_y(L)$ summarize the parameters governing the dynamics of any backward-looking components of the model.

The two models differ in the extent of their forward-looking behavior. The pure new Keynesian model assumes that agents are completely forward looking ($\mu_\pi = \mu_y = 1$), and the parameter values for the equations are taken from Clarida, Galí, and Gertler (2000). A number of authors, however, estimate much smaller values of μ_π (around 0.3) to match the degree of inflation persistence observed in U.S. data (for example, Fuhrer, 1997; Roberts, 1997; Rudebusch, 2001; Estrella and Fuhrer, 2002). Thus, in the second model considered, we set $\mu_\pi = 0.3$ and take parameter values from Rudebusch (2001).[5] Note that Rudebusch's model is among the most persistent of the hybrid new Keynesian models in the literature, owing to the inclusion of several lags of output and inflation in equations (1) and (2) and a particularly low value of μ_y (Rudebusch assumes $\mu_y = 0$) in the income-spending (IS) equation (equation 2).

We close these two models with an interest rate rule of the following form:

$$i_t = (1-c)\left[(1+a)\bar{\pi}_t + by_t\right] + ci_{t-1} + \varepsilon_t^i, \tag{3}$$

where $\bar{\pi}$ denotes the trailing four-quarter moving average of inflation, ε^i is an i.i.d. shock, and a, b, and c are the parameters of the rule.[6] Note that the policy rule is both backward-looking, in that the interest rate responds to current values of the output gap and inflation rather than their forecasts, and inertial, in that it includes the lagged federal funds rate. Both of these characteristics tend to add inertia to the short rate, which, together with the persistence of the Rudebusch model, generally gives the model the best possible chance to explain the term structure evidence we find below. We include an interest rate shock, ε_t^i, for the purpose of generating impulse response functions.

4. These variables are all normalized to have steady-state values of zero.

5. Rudebusch estimates and uses a value of $\mu = 0.29$ in the inflation equation and sets $\mu = 0$ in the output equation, so we use those values as well. There are also some minor timing differences between the specification of Rudebusch's model and equations (1) and (2). To generate the impulse response functions in figure 1, we use the model exactly as specified in Rudebusch (2001), but these differences in specification have no discernible effect on our results.

6. We use the values of a, b, and c estimated by Rudebusch (2002) from 1987:4 to 1999:4: namely, $a = 0.53$, $b = 0.93$, and $c = 0.73$.

The three panels of figure 1 show the response of the short-term nominal interest rate to a one-percent shock to the inflation equation, the output equation, and the interest rate equation, respectively, under our two baseline models.[7] In the pure new Keynesian (Clarida, Galí, and Gertler) model, the effect of the macroeconomic and monetary policy shocks on the short-term interest rate dies out very quickly, generally within a year. The interest rate displays much more persistence in the partially backward-looking (Rudebusch) model. Even in that model, however, the short-term interest rate essentially returns to its steady-state level well within ten years after each shock.

2. The Sensitivity of U.S. Long-Term Interest Rates to Economic News

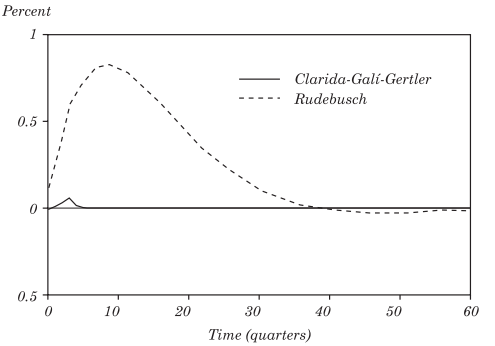
We now turn to how well the above model predictions are matched by U.S. data. The models predict that macroeconomic data releases and monetary policy announcements should affect the path of nominal interest rates only in the short run. To examine whether the U.S. data match the predictions of the models, we must look beyond the response of interest rates in the first few years after a shock and instead focus on the behavior of forward interest rates several years ahead.

Forward rates are often a very useful means of interpreting the term structure of interest rates. For a bond with a maturity of m years, the yield $r_t^{(m)}$ represents the rate of return that an investor requires to lend money today in return for a single payment m years in the future (for the case of a zero-coupon bond). By comparison, the k-year-ahead one-year forward rate $f_t^{(k)}$ represents the rate of return from period $t + k$ to period $t + k + 1$ that the same investor would require to commit today to a one-year loan beginning at time $t + k$ and maturing at time $t + k + 1$. The linkage between these concepts

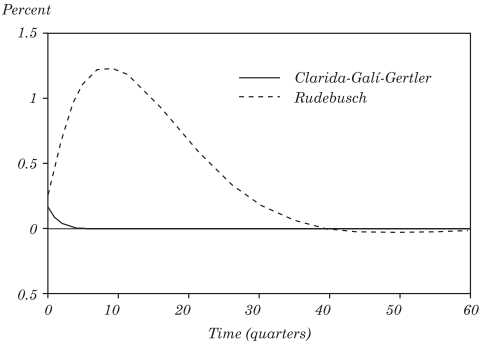
7. In a discussion of our paper at the Central Bank of Chile, Eric Parrado reported impulse response functions using the small open economy international macroeconomic model of Galí and Monacelli (2005), roughly calibrated to match the data in Canada and Chile. The results from those impulse response functions were consistent with our analysis for the standard closed economy new Keynesian models presented here: in particular, short-term interest rates returned to steady state well within ten years of a shock. Indeed, that model returned to steady state even more quickly—within just four or five years, compared to seven or eight years for the Rudebusch model. We believe this difference is due to the persistent parameters of the Rudebusch model, rather than to the lack of an open economy transmission mechanism in that model.

Figure 1. Impulse Response Functions for Standard Macroeconomic Models

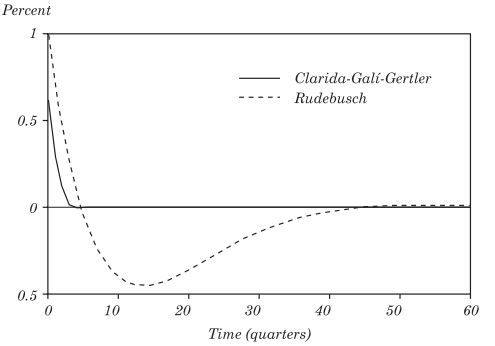
Interest rate response to a 1 percent inflation shock



Interest rate response to a 1 percent output shock



Interest rate response to a 1 percent interest rate shock



Source: Authors' computations.

is simple: an m-year (continuously-compounded) zero-coupon security can be viewed as a sequence of one-year forward agreements over the next m years:[8]

$$f_t^{(k)} = (k+1)r_t^{(k+1)} - kr_t^{(k)}. \quad (4)$$

For our analysis, we use Federal Reserve Board data on forward interest rates for U.S. Treasury securities.[9] Given our interest in measuring long-term expectations, our analysis focuses on the longest maturity for which we have high-quality bond yield data. The liquidity and breadth of the markets for government securities at and around the ten-year horizon thus lead us to focus on the one-year forward rate nine years ahead (that is, the one-year forward rate ending in ten years). The analysis of the previous section shows that this horizon is sufficiently far out for standard macroeconomic models to largely return to their steady states, so that any movements in forward interest rates or inflation compensation at these horizons should not be due to transitory responses of the economy to an economic shock.

To measure the effects of macroeconomic data releases on interest rates, the unexpected (or surprise) component of each macroeconomic data release must be computed, since the expected component of macroeconomic data releases should have no effect in forward-looking financial markets.[10] Using the surprise components of macroeconomic data releases, where expectations are measured just a few days before the actual release, also removes any possible issue of endogeneity arising from interest rates feeding back to the macroeconomy. Any such effects, to the extent that they are systematic or predictable, will be incorporated into the market forecast for the statistical release.

To measure the surprise component of each data release, we compute the difference between the actual release and the median forecast of

8. If we could observe zero-coupon yields directly, computing forward rates would be as simple as this. In practice, however, most government bonds in the United States and abroad make regular coupon payments, and thus the size and timing of the coupons must be accounted for to translate observed yields into the implied zero-coupon yield curve. In the results presented below, we also investigate whether the use of U.S Treasury STRIPS (which are zero-coupon securities that thus do not require fitting a yield curve first) alters the estimated response of far-ahead forward nominal rates in the United States. We find that the STRIPS data yield essentially identical results.

9. The Federal Reserve Board computes implied zero-coupon yields from observed, off-the-run U.S. Treasury yields using the extension of Nelson-Siegel described in Svensson (1994). Details are available in Gürkaynak, Sack, and Wright (2005).

10. Kuttner (2001) tests and confirms this hypothesis for the case of monetary policy announcements.

that release made by professional forecasters just a few days prior to the release date. For the United States, we use data on professional forecasts of the next week's statistical releases, published every Friday by Money Market Services for thirty-nine different macroeconomic data series.[11] Not all thirty-nine of these macroeconomic statistics have a significant impact on interest rates, even at the short end of the yield curve. Thus, to conserve space and reduce the number of exogenous variables in our regressions, we restrict our attention to the macroeconomic variables that Gürkaynak, Sack, and Swanson (2005) identify as having statistically significant effects on the one-year Treasury bill rate over the 1990–2002 period: capacity utilization, consumer confidence, the core consumer price index (CPI), the employment cost index (ECI), the advance (that is, first) release of real GDP, initial claims for unemployment insurance, the National Association of Purchasing Managers (NAPM) / Institute for Supply Management (ISM) survey of manufacturing activity, new home sales, employees on nonfarm payrolls, retail sales, and the unemployment rate.[12]

As with macroeconomic data releases, we must compute the surprise component of monetary policy announcements in each of our countries in order to measure the effects of these announcements on interest rates. We measure monetary policy surprises for the United States using federal funds futures rates, which provide high-quality, virtually continuous measures of market expectations for the federal funds rate (Krueger and Kuttner, 1996; Rudebusch, 1998; Brunner, 2000).[13] The federal funds futures contract for a given month settles at the end of the month based on the average federal funds rate that was realized over the course of that month. Thus, daily changes in the current-month futures rate reflect revisions to the market's expectations for the federal funds rate over the remainder of the month. As explained in Kuttner (2001) and Gürkaynak, Sack, and Swanson (2002), the

11. Several authors find the Money Market Services data to be of high quality (for example, Balduzzi, Elton, and Green, 2001; Andersen and others, 2003; Gurkaynak, Sack, and Swanson, 2005).

12. In addition to these eleven variables, Gürkaynak, Sack, and Swanson (2005) also included leading indicators and the core producer price index in their analysis. We originally included these two variables as well, but they never entered significantly into any of our regressions at even the shortest horizon at even the ten percent level. We therefore omit them from the results below to save space and reduce the number of explanatory variables. Nonetheless, our results are essentially identical whether we include these additional variables in the regressions or not.

13. Gürkaynak, Sack, and Swanson (2002) show that, among the many possible financial market instruments that potentially reflect expectations of monetary policy, federal funds futures are the best predictor of future policy actions.

change in the current month's contract rate on the day of a Federal Open Market Committee (FOMC) announcement, scaled up to account for the timing of the announcement within the month, provides a measure of the surprise component of the FOMC decision.[14] We compute the surprise component associated with every FOMC meeting and intermeeting policy action by the FOMC over our sample.[15]

2.1 The Sensitivity of U.S. Interest Rates to Economic News

Table 1 reports results for nominal interest rates in the United States over the 1994–2005 period.[16] Each column provides results from a regression of daily changes in the corresponding interest rate on the surprise component of the macroeconomic data releases and monetary policy announcements listed at the left.[17] We regress the change in interest rates on all of our macroeconomic and monetary policy surprises jointly to properly account for days on which more than one piece of economic news was released. To facilitate interpreting our coefficient estimates, we normalize each macroeconomic surprise by its standard deviation. Each coefficient in the table thus estimates the interest rate response in basis points per standard deviation surprise in the corresponding macroeconomic statistic. The one exception to this rule is the monetary policy surprises, which we leave in basis points, so that these coefficients represent a basis point per basis point response.

14. To avoid very large scale factors, if the monetary policy announcement occurs in the last seven days of the month, we use the next-month contract rate instead of scaling up the current-month contract rate.

15. The only exception is that we exclude the intermeeting 50 basis point easing on 17 September 2001, because financial markets were closed for several days prior to that action and because that easing was a response to a large exogenous shock to the U.S. economy and financial markets. We would thus have difficulty disentangling the effect of the monetary policy action from the effect of the shock itself on financial markets that day.

16. Our STRIPS data begin in 1994, so we restrict analysis in table 1 to the post-1994 period. Gürkaynak, Sack, and Swanson (2005) report very similar results for the 1990–2002 period using forward rates from a fitted yield curve.

17. Although we have almost one thousand daily observations in each of these regressions, most of the elements of any individual regressor are zero, because any given macroeconomic statistic is only released once a month (or once a quarter in the case of GDP and once a week in the case of initial claims). We restrict attention in all our regressions to those days on which some macroeconomic statistic was released or a monetary policy announcement was made, but our results are not sensitive to this restriction.

Table 1. U.S. Forward Rate Responses to Domestic Economic News, 1994–2005[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward nominal rate ending in ten years, from STRIPS*
Capacity utilization	1.76***	1.24**	0.80
	(3.78)	(2.05)	(1.21)
Consumer confidence	1.36***	1.04*	0.88
	(3.13)	(1.85)	(1.43)
Core CPI	1.92***	1.47*	1.80**
	(3.29)	(1.94)	(2.16)
Employment cost index	1.66**	1.87*	1.24
	(2.28)	(1.98)	(1.20)
Real GDP (advance)	1.37*	0.36	–0.08
	(1.95)	(0.40)	(–0.08)
Initial jobless claims	–0.91***	–0.59**	–0.62**
	(–4.16)	(–2.07)	(–2.00)
NAPM/ISM manufacturing survey	2.40***	2.54***	2.79***
	(5.58)	(4.55)	(4.56)
New home sales	0.77*	0.85	1.01*
	(1.88)	(1.60)	(1.73)
Nonfarm payrolls	4.63***	2.51***	2.62***
	(10.24)	(4.28)	(4.08)
Retail sales (excl. cars)	2.15***	1.69**	1.36*
	(3.75)	(2.26)	(1.66)
Unemployment rate	–1.63***	0.38	–0.52
	(–3.32)	(0.60)	(–0.74)
Monetary policy	0.30***	–0.17**	–0.24***
	(4.78)	(–2.14)	(–2.71)
No. observations	1,371	1,371	1,371
R^2	0.16	0.06	0.05
Joint test p value	0.000***	0.000***	0.000***

Source: Authors' computations.
* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.
a. The sample is from January 1994 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant, a Y2K dummy that takes on the value of 1 on the first business day of 2000, and a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Joint test p value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. t-statistics are reported in parentheses.

The first column of table 1 reports the responses of the one-year Treasury spot rate to the economic releases as a benchmark for comparison. As one might expect from a Taylor-type rule or from casual observation of U.S. financial markets, interest rates at the short end of the term structure exhibit highly significant responses to surprises in macroeconomic data releases and monetary policy announcements. Moreover, these responses are generally consistent with what one would expect from a Taylor-type rule: upward surprises in inflation, output, or employment lead to increases in short-term interest rates, and upward surprises in initial jobless claims (a countercyclical economic indicator) cause short-term interest rates to fall. The magnitudes of these estimates seem reasonable, with a two-standard-deviation surprise leading to about a 3 to 10 basis point change in the one-year rate (depending on the statistic) on average over our sample. Monetary policy surprises lead to about a one-for-three or one-for-two response of the one-year yield to the federal funds rate. This is consistent with the view that a surprise change in the federal funds rate is often not a complete surprise to markets, but rather a moving forward or pushing back of policy changes that were already expected to have some chance of occurring in the future.

The middle column of table 1 shows the response of far-ahead forward interest rates in the U.S. to economic news. If ten years is a sufficient amount of time for the U.S. economy to return largely to steady state following an economic shock, as our simulations above suggest, and if long-term inflation expectations were firmly anchored in the United States, then one would expect to see little or no response of these rates to economic news. This is not the case, however: far-ahead forward nominal rates in the United States respond significantly to nine of the twelve macroeconomic data releases we consider, often with a very high degree of statistical significance, and a test of the joint hypothesis that all coefficients in the regression are zero is rejected with a p value on the order of 10^{-10}. Not only are the estimated coefficients statistically significant, but their magnitudes are large, often more than half as large as the effect on the short-term interest rate. Finally, the signs of these coefficients are not random, but rather they closely resemble the effect on short-term interest rates and the short-term inflation outlook. This resemblance is consistent with markets expecting some degree of pass-through of short-term inflation to the long-term inflation outlook. The case of monetary policy surprises offers perhaps the most striking example of this pattern: the estimated effect of monetary policy surprises on far-

ahead nominal interest rates is opposite to the effect of surprises on the one-year spot rate—that is, a surprise monetary policy tightening causes far-ahead forward nominal rates to fall. This result echoes the finding by Gürkaynak, Sack, and Swanson (2005) for their 1990–2002 and 1994–2002 samples. It is also consistent with financial markets expecting a pass-through of the short-term inflation outlook to long-term inflation, as we demonstrate in section 3, below.

The right-hand column of table 1 reports a robustness check on the above results, in which we computed the response of the one-year forward rate ending in ten years using U.S. Treasury STRIPS rather than the Federal Reserve's smoothed yield curve data.[18] STRIPS are pure zero-coupon securities whose yields provide a direct, market-based measure of forward rates that does not require any yield curve fitting or smoothing. (On the other hand, STRIPS are less liquid than Treasury notes and bonds and thus suffer from larger bid-ask spreads and trading costs, making observed prices a less clean measure of the true shadow value of the securities and introducing some noise into our estimates.) The results in the right-hand column of table 1 are very much in line with those from the middle column: seven of the twelve macroeconomic news releases we consider lead to significant responses of ten-year-ahead forward interest rates, with estimated magnitudes that are very similar to those from our yield-curve-based estimates, and the joint hypothesis that all coefficients are equal to zero is likewise rejected at extremely high levels of statistical significance (p value on the order of 10^{-9}). All of these observations suggest that our results are not due to any artifact of yield-curve fitting involved in computing forward rates from Treasury coupon securities.

2.2 The Sensitivity of U.S. Interest Rates and Inflation Compensation to Economic News

The United States has issued inflation-indexed Treasury securities since 1997. A natural question arising from our estimates above, then, is to what extent the strong responses in far-ahead forward interest rates are due to changes in real interest rates, as opposed to changes

18. U.S. Treasury STRIPS (Separate Trading of Registered Interest and Principal Securities) are created by decoupling the individual coupon and principal payments from U.S. Treasury notes and bonds into pure zero-coupon securities. See Sack (2000) for more details and the potential usefulness of STRIPS for estimating the Treasury yield curve. In this paper, we compute the one-year forward rate ending in ten years using the nine-year STRIPS security and ten-year STRIPS security and applying equation (1).

in inflation compensation—the difference between nominal and real interest rates. Table 2 investigates this interesting question.

The primary shortcoming of U.S. Treasury inflation-indexed securities—commonly referred to as TIPS—is that they were issued for the first time in January 1997 and only annually for the first few years after that date. We therefore cannot compute a far-ahead forward real rate for the United States until January 1998, giving us a sample that covers only about seven and a half years. Nonetheless, the high frequency of the data still leaves us with almost a thousand observations with which to perform our analysis.

We obtained data on the forward real interest rates implied by TIPS from the Federal Reserve Board.[19] We define forward inflation compensation as the difference between the forward nominal rate and forward real rate at each horizon. This measure captures the compensation that investors demand both for expected inflation at the given horizon and for the risks or uncertainty associated with that inflation.[20]

In the first two columns of table 2, we repeat the regressions of the one-year spot rate and the ten-year-ahead one-year rate on our macroeconomic surprises over the sample of TIPS data (1998–2005). Our results over this sample are very similar to those in table 1, although the statistical significance is reduced for our coefficient estimates in both regressions. For example, only five of our twelve coefficients for the ten-year-ahead nominal rate are significant over this shorter sample, compared with nine of twelve in table 1, although the joint hypothesis that all coefficients are zero in that regression is still rejected at very high levels of statistical significance.[21] The signs and magnitudes of the coefficients in these two columns are also very similar to those we estimated over the larger 1994–2005 period.

19. The Federal Reserve Board provides real yield curve estimates beginning in January 1999. We extend the nine- to ten-year forward rate series back to January 1998 by taking the nine- and ten-year TIPS rates and computing the implied forward rate between the two using Shiller, Campbell, and Schoenholtz's (1983) approximation.

20. Forward real rates, nominal rates, and inflation compensation may also be affected by other factors, such as term premiums and premiums for liquidity. We discuss the robustness of all of our results with respect to these types of risk premiums in the next section.

21. The significance of the negative response of forward nominal rates to monetary policy surprises is notably absent over this later sample, perhaps reflecting the fact that these surprises become generally smaller and less frequent in the later part of our sample (Swanson, 2005). Another possible explanation for the smaller number of significant coefficients over the later sample is that long-term interest rates have gradually become better anchored in the United States. We leave this as an interesting question for future research.

Table 2. U.S. Forward Rate Responses to Domestic Economic News, 1998–2005[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
Capacity utilization	1.55***	0.91	0.51	0.40
	(2.92)	(1.33)	(1.31)	(0.66)
Consumer confidence	1.34**	0.50	0.18	0.32
	(2.57)	(0.75)	(0.47)	(0.55)
Core CPI	1.01	1.25	–0.37	1.63**
	(1.58)	(1.53)	(–0.80)	(2.28)
Employment cost index	1.14	1.13	–0.10	1.23
	(1.48)	(1.15)	(–0.17)	(1.43)
Real GDP (advance)	2.37***	1.91*	0.02	1.89**
	(2.92)	(1.84)	(0.04)	(2.08)
Initial jobless claims	–1.06***	–0.74**	–0.20	–0.54*
	(–4.25)	(–2.32)	(–1.09)	(–1.94)
NAPM/ISM manufacturing survey	2.26***	2.96***	1.74***	1.22**
	(4.39)	(4.49)	(4.59)	(2.12)
New home sales	0.23	0.67	–0.32	0.99*
	(0.51)	(1.15)	(–0.94)	(1.93)
Nonfarm payrolls	4.45***	1.79**	1.26***	0.54
	(8.02)	(2.52)	(3.07)	(0.88)

Table 2 (continued)

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
Retail sales (excl. cars)	1.60***	1.52*	0.68	0.84
	(2.55)	(1.88)	(1.46)	(1.18)
Unemployment rate	–1.20*	0.89	0.84*	0.05
	(–1.95)	(1.13)	(1.85)	(0.07)
Monetary policy	0.36***	–0.01	0.01	–0.02
	(4.35)	(–0.13)	(0.18)	(–0.26)
No. 0bservations	950	950	950	950
R^2	0.15	0.06	0.04	0.04
Joint test *p* value	0.000***	0.000***	0.000***	0.010**

Source: Authors' computations.
* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.
a. The sample is from January 1998 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant, a Y2K dummy that takes on the value of 1 on the first business day of 2000, and a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Inflation compensation is the difference between nominal and real rates. Joint test *p* value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. *t*-statistics are reported in parentheses.

In the third and fourth columns of table 2, we decompose the response of forward nominal rates into its constituent real rate and inflation compensation components. We find some evidence that part of the estimated responsiveness of nominal forward rates is actually due to movements in real interest rates, particularly for the NAPM/ISM manufacturing survey and nonfarm payrolls releases.[22] In the majority of cases, however, the responsiveness of long-term nominal interest rates is due at least partially to changes in inflation compensation. Five of our twelve estimated coefficients are statistically significant, and the joint hypothesis that all coefficients are zero is rejected with a p value of about 1 percent.

3. Possible Explanations for the Behavior of U.S. Long-Term Interest Rates

In steady state, the short-term nominal interest rate, i^*, equals the steady-state real interest rate, r^*, plus the steady-state level of inflation, π^*, by Fisher's equation:

$$i^* = r^* + \pi^* . \tag{5}$$

As mentioned above, standard asset-pricing theory indicates that forward rates with sufficiently long horizons—that is, $f_t^{(N)}$ for N large, where $f_t^{(N)}$ is the forward rate ending in N years' time—equal the expected steady-state short-term rate plus a risk premium, ρ:

$$f_t^{(N)} = r^* + \pi^* + \rho . \tag{6}$$

The fact that $f_t^{(N)}$ responds to many macroeconomic data releases and monetary policy surprises indicates that one (or more) of r^*, π^*, and ρ is changing in response to these surprises.

3.1 Some Nonexplanations for the Excess Sensitivity Puzzle: r^* and ρ

In our search for a solution to the excess sensitivity puzzle documented above, we consider, but ultimately discard, two possible causes: changes

22. We do not take a stand on why far-ahead real rates might move in response to economic news, although one possible explanation is that markets view the particular data release as informative about the economy's long-run rate of productivity growth and, hence, about the equilibrium real interest rate.

in r^* (the long-run equilibrium real interest rate) and changes in ρ (the risk premium). Although r^* is a potentially time-varying component of steady-state short-term rates, our results for the nominal forward rates are probably not due to r^* responding to surprises. We have two reasons for ruling out time variance in steady-state real rates as the main culprit. First, TIPS provide a measure of far-ahead forward real rates, and as we showed in table 2, the sensitivity of nominal rates in the United States to economic news was almost always attributable to changes in inflation compensation, rather than to changes in real rates. Second, many of the nominal interest rate responses that we estimate are difficult to interpret in terms of changes in r^*. For example, it is difficult to explain why a surprise uptick in inflation (of either the CPI or the PPI) would lead the market to revise upward its estimate of r^*, the long-run equilibrium real rate of interest.[23] Similarly, a surprise monetary policy tightening is not likely to lead the market to revise its estimate of r^* downward—presumably, a surprise tightening of policy, to the extent that it provides any information about r^*, indicates that the FOMC views r^* as being higher than the market estimate.

This is not to say that changes in the market's perception of r^* are necessarily unimportant. Indeed, changes in r^* may have had some effect on long-term interest rates in our sample, particularly in the late 1990s, when market estimates of the long-run rate of productivity growth in the United States were largely in flux. Relying solely on changes in r^* to explain our empirical results, however, is likely to cause difficulties for precisely the reasons described above.

Alternatively, one might argue that changes in the risk premium, ρ, are the most likely explanation for our findings of excess sensitivity in long-term interest rates. While some authors find little evidence for time-varying risk premiums in the data (for example, Bekaert, Hodrick, and Marshall, 2001), a number of prominent studies (such as Fama and Bliss, 1987; Campbell and Shiller, 1991) document strong violations of the expectations hypothesis for a wide variety of samples and securities, suggesting that the risk premiums embedded in long-term bond yields may, in fact, vary substantially over time. A time-varying risk premium is often offered as an explanation for the excess volatility puzzle and as a likely factor in the failure of the expectations hypothesis for longer maturities.

23. Even if one regards surprises in inflation as being informative about productivity growth in the late 1990s, the usual story that is told is that surprisingly low inflation was indicative of high productivity growth, which would, in turn, be related to a higher equilibrium real rate, r^*.

For our analysis, however, as long as the variation in risk premiums is small enough at the very high frequencies we consider, the change in bond yields over the course of the day will effectively difference out the risk premium at each point in our sample, allowing us to interpret the change in yields as being driven primarily by the change in expectations. While there is no a priori reason why risk premiums should vary only at lower frequencies, the predictors of excess returns on bonds emphasized in the studies above generally have this feature—that is, the variation from one day to the next is very small, while the large variations in premiums that they estimate occur at much lower frequencies, particularly the business cycle (Cochrane and Piazzesi, 2005; Piazzesi and Swanson, 2004). Thus, the failure of the expectations hypothesis alone is not sufficient to call our analysis into question.

Nevertheless, risk premiums are poorly understood, so the fact that previous estimates of time-varying risk have generally found predictability only at lower frequencies does not imply that they could not change appreciably from one day to the next. In order for changes in risk premiums to explain our results, however, one would have to explain why they would move so systematically in the way that we document, being positively correlated with output and inflation news while moving inversely with surprises in monetary policy.[24] Moreover, one would have to explain why we do not find similar movements in risk premiums in the United Kingdom or Sweden, as documented in Gürkaynak, Levin, and Swanson (2006)—if anything, one would expect the importance of risk premiums to be greater in these smaller, less liquid markets—or why the behavior of risk premiums in the United Kingdom would have changed after the Bank of England gained independence from Parliament in 1997 (Gürkaynak, Sack, and Swanson, 2003; Gürkaynak, Levin, and Swanson, 2006).

Given that current theory puts little structure on the behavior of term premiums, one can write an ad hoc model of the term premium that would match our empirical findings. However, the fact that we did not observe a strong response of real interest rates to economic news

24. Cochrane and Piazzesi (2005) and Piazzesi and Swanson (2004) find that risk premiums in Treasury securities and interest rate futures move countercyclically over the business cycle. This is exactly opposite to the direction that would be needed to explain our findings that far-ahead forward interest rates in the United States and in the United Kingdom before central bank independence comove positively with surprises in output and employment.

in the United States suggests that if changes in risk premiums are responsible for the excess sensitivity of the forward nominal rates, any such risk seems to be more closely related to inflation compensation than to real rates. This is in line with our interpretation that it is the perceived *distribution* of future inflation outcomes (and not necessarily only its mean) that is unanchored.

3.2 A Possible Explanation for Excess Sensitivity: Changes in π^*

While we do not wish to discount the importance of changes in market perceptions of r^* or changes in risk premiums that are unrelated to inflation, we find each of them inadequate on its own to explain all of our empirical results. We now show that changes in the market's perception of π^*, the long-run inflation objective of the central bank, helps explain all of our findings. Thus, changes in π^* are not only necessary for explaining at least some of our results, but also sufficient.[25]

Model with time-varying π^* and perfect information

We demonstrate the sufficiency of changes in π^* by augmenting the benchmark model from section 1 to include an additional equation that permits the central bank's inflation objective to vary over time, without taking a stand on why this might be so. In this alternative specification, past values of inflation affect the central bank's inflation target. Our assumed functional form for the time-variance in π^* is

$$\pi_t^* = \pi_{t-1}^* + \theta\left(\bar{\pi}_{t-1} - \pi_{t-1}^*\right) + \varepsilon_t^{\pi^*}, \tag{7}$$

where $\bar{\pi}_{t-1}$ is the trailing four-quarter moving average of inflation. Thus, persistently low (high) inflation will, over time, tend to decrease (increase) the central bank's long-run inflation target.[26] Exogenous changes in the central bank's inflation objective, π^*, are captured by the shock $\varepsilon_t^{\pi^*}$.

25. While the model presented below is based on time variance in the perceived mean of the steady-state inflation distribution, the results would go through if other moments of that distribution were time varying, as well. These would be reflected in the inflation term premium.

26. This has some similarities to the idea of opportunistic disinflation described in Orphanides and Wilcox (2002).

Our benchmark model with time-varying π^* thus takes the form:

$$\pi_t = \mu_\pi E_t \pi_{t+1} + (1-\mu_\pi) A_\pi(L)\pi_t + \gamma y_t + \varepsilon_t^\pi, \tag{8}$$

$$y_t = \mu_y E_t y_{t+1} + (1-\mu_y) A_y(L) y_t - \beta(i_t - E_t \pi_{t+1}) + \varepsilon_t^y, \tag{9}$$

$$i_t = (1-c)\left[\bar{\pi}_t + a(\bar{\pi}_t - \pi_t^*) + b y_t\right] + c\, i_{t-1} + \varepsilon_t^i, \text{ and} \tag{10}$$

$$\pi_t^* = \pi_{t-1}^* + \theta(\bar{\pi}_{t-1} - \pi_{t-1}^*) + \varepsilon_t^{\pi^*}, \tag{11}$$

where equation (10) now explicitly recognizes the existence of a time-varying inflation target. We use the same parameter values for the model as for the Rudebusch specification in section 1, and we select a value for θ to roughly calibrate our impulse response functions to match the estimated responsiveness of long-term forward rates in our data. It turns out that we require relatively small values for θ (the loading of the central bank's inflation target on the past year's inflation) to match the term structure evidence. We thus set θ equal to 0.02 for the simulations below, implying that annual inflation one percentage point above target leads the central bank to raise its target by 2 basis points. This may seem negligibly small, but the persistence of inflation—particularly the four-quarter trailing average that enters into equation (11)—leads to cumulative effects on π^* that are nonnegligible, as we now show.

Figure 2 plots the impulse responses of inflation, the output gap, the short-term interest rate, and π^* to a one percent shock to each of equations (8) through (11).[27] The qualitative features of our empirical findings are reproduced very nicely. For example, after a one percent inflation shock (the first column), the short-term nominal interest rate rises gradually, peaks after a few years, and then returns to a long-run steady-state level that is about 35 basis points higher than the original steady state. This is due to the fact that the higher levels of inflation on the transition path cause the central bank's long-run objective, π^*, to rise. A similar response of short-term nominal interest rates and inflation can be seen in response to a one percent shock

27. The model has no indexation to steady-state inflation, so the central bank's π^* does not enter the private sector's equations directly. Rather, it only enters indirectly through the private sector's forecast of π_{t+1} and y_{t+1}, which depend on the current and expected future path for the interest rate (which depends on π^*).

to output (the second column). For the federal funds rate shock (the third column), as inflation in the economy falls in response to the monetary tightening, the central bank's long-run target π^* gradually falls, as well. In the long run, the short-term nominal interest rate and inflation settle below their initial levels, producing exactly the kind of inverse relation between far-ahead forward rates and short rates that we found in the data.

Model with time-varying π^* and imperfect information

The above model can also be extended to include the case in which the private sector does not directly observe the central bank's inflation objective, π^*, and thus must infer it from the central bank's actions, as in Kozicki and Tinsley (2001), Ellingsen and Soderstrom (2001), and Erceg and Levin (2003). The advantages of a model with imperfect information are threefold. First, it emphasizes that the behavior of the term structure is driven by private sector expectations of future outcomes, which in the case of imperfect information can differ from the actual impulse responses to a particular (unobserved or imperfectly observed) shock. Second, a model with imperfect information provides a more realistic description of long-term interest rate behavior in the United States, since the Federal Reserve's long-term objective for inflation, π^*, is unknown to financial markets. Third, the presence of imperfect information increases the importance and effects of monetary policy shocks in the model, which allows for a better calibration to our empirical results than the model with perfect information can provide.

To consider the case of imperfect information, equations (8) through (11) must be augmented to include a private sector Kalman filtering equation:

$$\hat{\pi}_t^* = \hat{\pi}_{t-1}^* + \theta\left(\bar{\pi}_{t-1} - \hat{\pi}_{t-1}^*\right) - \kappa\left(i_t - \hat{i}_t\right). \tag{12}$$

For simplicity and tractability, we assume that the forms of equations (8) through (11), all parameter values, and the shocks ε^{π} and ε^{y} are perfectly observed by the private sector. Thus, only π^*, ε^{π^*}, and ε^{i} are unobserved. Private agents update their estimate of the central bank's inflation target, denoted $\hat{\pi}_t^*$, using equation (12).[28] In

28. This procedure is optimal under the assumptions of normally distributed shocks and a normally distributed prior for the inflation target. For other shock distributions, the Kalman filter is the optimal linear inference procedure.

Figure 2. Impulse Responses with Time-Varying π^* (Perfect Information)

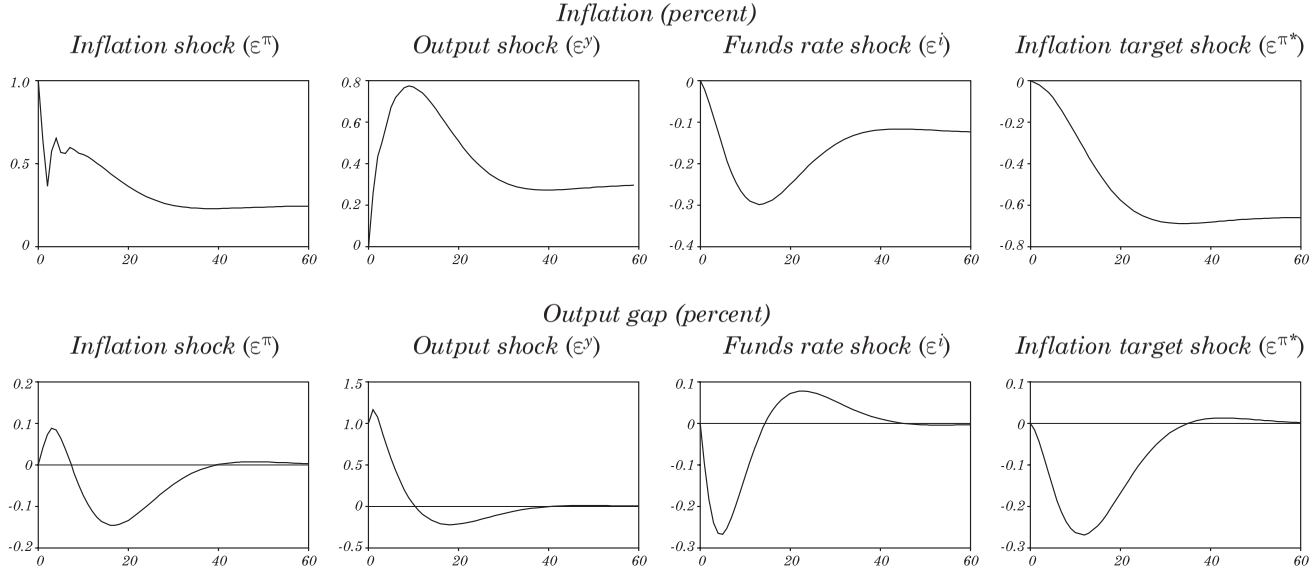
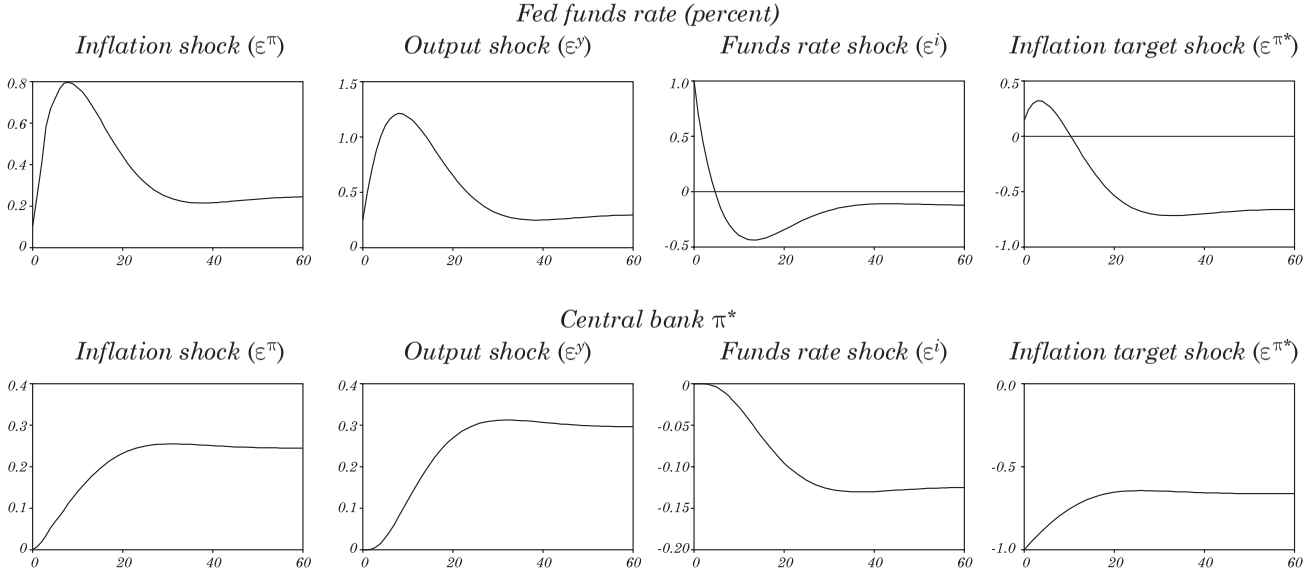


Figure 2 (continued)



Source: Authors' computations.

particular, agents observe the deviation of the interest rate from their expectation, $i_t - \hat{i}_t$, where $\hat{i}_t$ is obtained by substituting $\hat{\pi}^*_t = \hat{\pi}^*_{t-1}$ and $\varepsilon^i_t = 0$ into equation (10), and they revise $\hat{\pi}^*_t$ by an amount determined by the Kalman gain parameter, κ. Again, we choose (rather than estimate) a value for κ of 0.1, which is meant to be illustrative and matches the data.[29]

Figure 3 presents the private sector's expected impulse responses to inflation, the output gap, the short-term interest rate, and the central bank's inflation objective following a shock to each of equations (8) through (11). Because this version of the model features imperfect information, the impulse responses expected by the private sector on impact may differ from the actual impulse responses from a shock. In particular, the private sector is initially unable to distinguish between the temporary shock, ε^i, and the permanent central bank preference shock, ε^{π^*}. The expected impulse responses to those two shocks are therefore identical, up to a scale factor, even though the actual impulse responses to those two shocks play out quite differently over time.[30]

29. Alternatively, one could derive the optimal value for κ from the variance of the shocks to π^* and to *i,* but this value would have to be indirectly inferred anyway since π^* is unobserved. The value of 0.1 that we use for κ corresponds to a ratio of $\sigma_i/\sigma_{\pi^*} = 3$.

30. Expected and actual impulse responses for the case of imperfect information are calculated as follows. If, starting from steady state, the model is hit by a shock to π or to y, then the private sector observes those two shocks, so there is no imperfect information and the impulse responses are just like in the perfect information case. If, instead, there is a shock to i or to the central bank's π^*, then the private sector does not observe the true shock and must estimate what the shock was from the observed change in i. The private sector optimally assigns part of the change in i to ε^i and part of the change in i to ε^{π^*}. Knowing the true structure of the economy, the private sector then projects the economy forward using its above two estimates for the shocks to i and to π^*. This yields the *expected* impulse response functions at time t. This solution also yields the *actual* equilibrium of the model at time t (and time t only). In period t+1, the economy will evolve slightly differently than the private sector had expected the previous period (because the private sector did not observe the true shocks to i and π^*). In particular, i will be a little different again from what the private sector was expecting, so agents will think that their previous estimate of π^* may have been wrong or that there may have been another shock to i or another shock to π^*. (Of course, in an impulse response function, we do not hit the model with any additional shocks, but the private sector does not know this). The private sector thus optimally updates its estimate of π^* again, and projects the economy forward again using the true structure. This solution yields the equilibrium of the model at time $t + 1$ (and time $t + 1$ only). Come period $t + 2$, the economy will evolve slightly differently than the private sector had expected the previous period, and so forth. We repeat this procedure to obtain the entire actual response of interest rates to the shock (which we plot in figure 4). Again, the private sector's estimate of π^* does not enter the private sector's equations directly, but only indirectly through the private sector's forecast of π_{t+1} and y_{t+1}, which depends on the current and expected future path of the interest rate, which in turn depends on the private sector's estimate of π^*.

The expected impulse responses in figure 3 again reproduce the qualitative features of our empirical findings nicely. The responses to an inflation shock (the first column) or an output shock (second column) are identical to the perfect information case in figure 2, because we have assumed that the private sector has perfect information regarding those two variables. For the case of the federal funds rate shock (third column), however, two effects are now present. First, when the private sector sees the surprise tightening in short-term interest rates, they cannot tell whether the shock is purely temporary (ε^i) or reflects a more permanent change in π^*, so they respond to the shock by partially revising downward their estimate of the central bank's π^*. Inflation in the economy thus falls in response to both the monetary tightening and the fall in inflation expectations, leading to larger effects than in the perfect information case. Second, the central bank's long-run objective, π^*, falls over time as inflation comes in below target, as was true in the perfect information case. The effect of the additional channel arising from imperfect information is to increase the relative size and importance of the effects of the interest rate shock on the term structure, allowing for a better calibration to our empirical results and providing a more realistic model of long-term interest rates in the United States.

Note that imperfect information about the central bank's target, π^*, plays a role only in the third and fourth columns of the figure. A model based solely on imperfect information or imperfect credibility, as in Kozicki and Tinsley (2001) or Erceg and Levin (2003), would be unable to reproduce our findings of excess sensitivity of U.S. interest rates to output and inflation surprises as long as shocks to ε^π and ε^y are observed.

For reference, the actual impulse responses of the model (equations 7 through 12) are depicted in figure 4. The figure illustrates how the differing effects of shocks to i and to π^* play out over time. The fifth row depicts the evolution of the private sector's estimate, $\hat{\pi}^*$, in response to each shock. Shocks to inflation or output, about which there is no imperfect information, lead to responses of $\hat{\pi}^*$ that are identical to those of π^*, but the two variables evolve differently for the imperfectly observed cases of shocks to i and π^*.

Finally, our hypothesis that the private sector's expectations of the central bank's long-run inflation objective, π^*, have varied over time is also consistent with measures of these expectations derived from survey data. For example, the median ten-year CPI inflation forecast

Figure 3. Expected Impulse Responses with Time-Varying π^* (Imperfect Information)

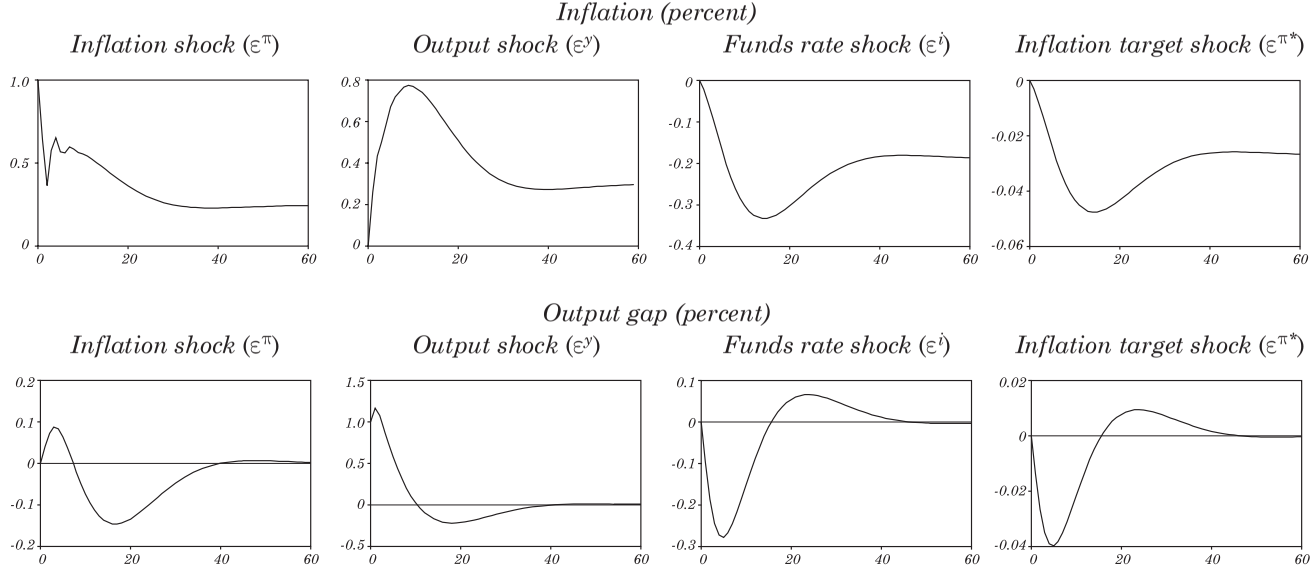
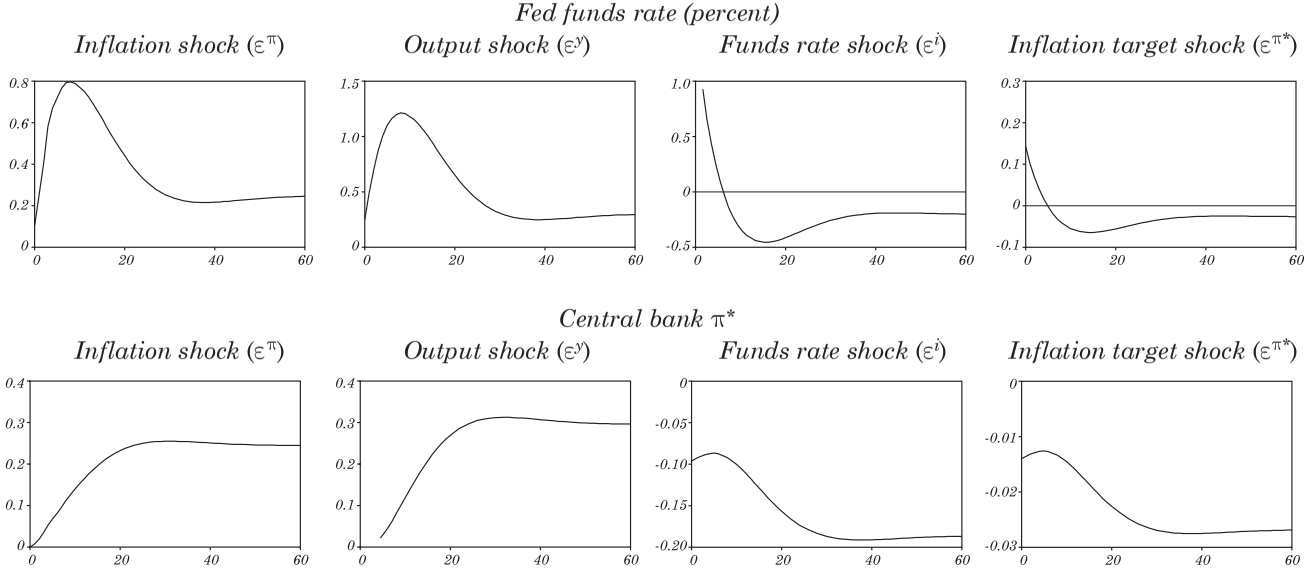


Figure 3 (continued)



Source: Authors' computations.

Figure 4. Actual Impulse Responses with Time-Varying π^* (Imperfect Information)

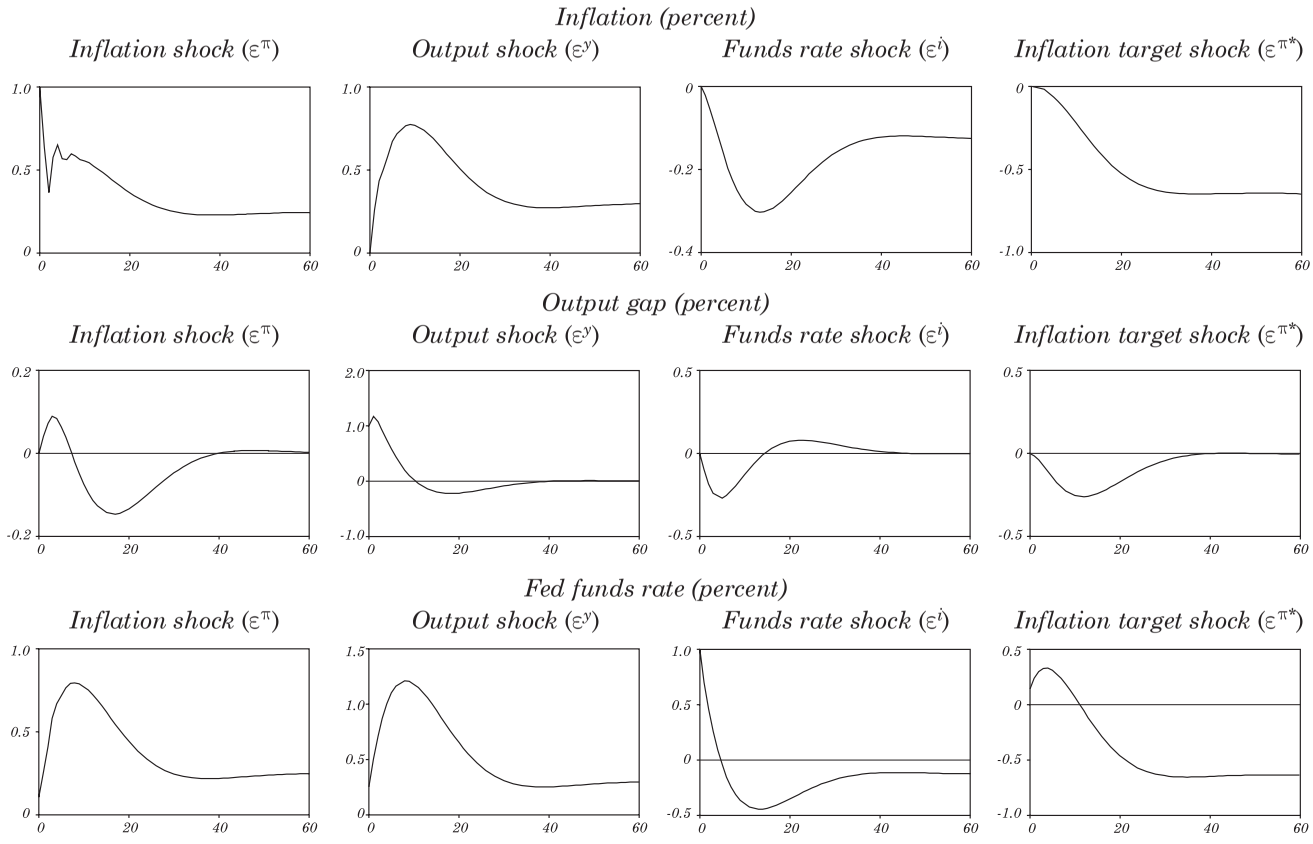
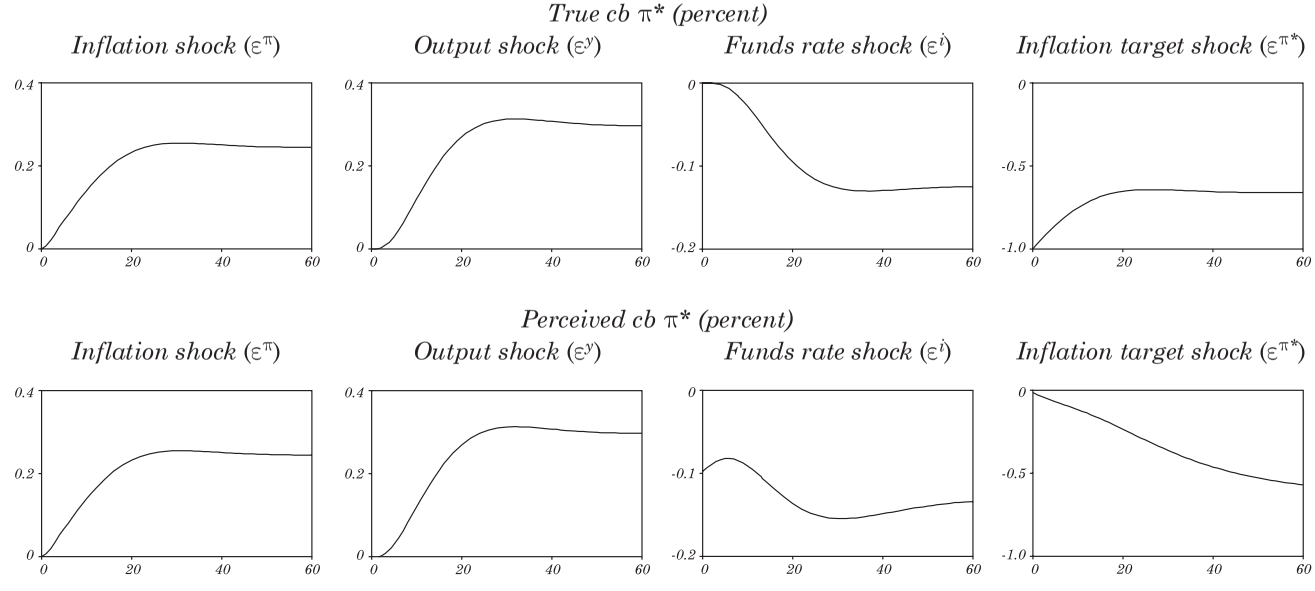


Figure 4 (continued)



Source: Authors' computations.

in the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters fell from 4 percent in the fourth quarter of 1991 (the first time the long-run forecast question was asked) to a little under 2.5 percent by the end of 2002. This decline of about 1.5 percentage points compares with a fall of about 2.5 percentage points in ten-year nominal forward interest rates over the same period.

4. The Sensitivity of Long-Term Interest Rates in Canada and Chile

We have shown that U.S. long-term interest rates are excessively responsive to economic news, and that this responsiveness is well explained by changes in financial market perceptions of a long-run inflation objective in the United States that is not well anchored. We now explore whether long-term interest rates are any more stable in countries that are explicit inflation targeters than in the United States. Gürkaynak, Levin, and Swanson (2006) consider the cases of Sweden and the United Kingdom and find that far-ahead forward interest rates are much better anchored in those two countries than in the United States. In this paper, we extend the comparison to Canada and Chile, which have been formal inflation targeters throughout much of the 1990s and 2000s.[31] Despite these relatively short sample periods, our high-frequency methodology provides us with several hundred to a thousand observations for each of these countries for our analysis.

4.1 The Sensitivity of Long-Term Interest Rates in Canada

We obtained data on Canadian macroeconomic news releases and financial market expectations of those releases from two sources:

31. Both Canada and Chile adopted an inflation-targeting framework in which the target was not firmly anchored at first, but was rather successively lowered during a transition period. Canada adopted its inflation-targeting framework in 1991, but the target was not stabilized at the current level of 1–3 percent until early 1995. Chile, in turn, adopted its inflation-targeting framework in 1991, but the target was not stabilized at the current level of 2–4 percent until early 2001. For our purposes, the latter dates are the more relevant ones. Finally, the adoption of an inflation-targeting range rather than a point makes very little difference in theory, because the optimal monetary policy is always to aim for inflation to lie at the midpoint of the range, as discussed, for example, by Orphanides and Wieland (2000).

Money Market Services and Bloomberg.[32] When those data sets overlap, they agree very closely. Between these two sources, we have data on Canadian capacity utilization, the consumer price index, core consumer price index, employment, real GDP, retail sales, the unemployment rate, and wholesale trade. Most of these series go back to 1996, and a few go back even farther.[33] To measure the surprise component of Canadian monetary policy announcements, we obtained the dates of changes in the Bank of Canada's target overnight interbank rate back to 1995 from the Bank of Canada's web site, and we measured the surprise component of these changes as the change in the three-month Canadian Treasury bill on the dates of these monetary policy changes.

We obtained data on Canadian nominal bond yields from the Bank of Canada's web site and data on real bond yields from Bloomberg. The Bank of Canada provides nominal zero-coupon yield curve estimates extending back to the 1980s. Inflation-indexed bond data for Canada is more limited: Canada issued its first inflation-indexed bond in 1991 and its second in 1996, implying that we cannot compute a forward real rate for Canada until 1996. Moreover, Canada has issued indexed bonds only at the thirty-year maturity. These securities thus have extremely long durations and appeal primarily to pension funds, insurance companies, and individual investors, resulting in low levels of secondary market liquidity, high transactions costs, and observed real interest rates that are noisy, particularly in the earlier years of our sample.[34] Thus, to reduce the noisiness of the data and facilitate

32. Data from Bloomberg were freely available to us through a subscription at the Federal Reserve Board and the Federal Reserve Bank of San Francisco. However, Money Market Services (our source for the U.S. data) had data for a number of Canadian series that were not covered by Bloomberg and that we thought might be important, so we purchased these additional series from Money Market Services. See the appendix for details.

33. Details of the data are provided in the appendix.

34. To compute far-ahead forward real rates in Canada, we use as many of the 2021, 2026, 2031, and 2036 maturity coupon bond yields as are available on any given date and compute the far-ahead forward rates between pairs of securities using Shiller, Campbell, and Schoenholtz's (1983) approximation. We use the average one-day change in these forward rates in our regressions. We use a longer (twenty- to thirty-year-ahead) horizon to proxy for the nine-year-ahead real one-year forward rate in Canada, because we simply do not have nine-year-ahead Canadian indexed bond data. Although we could use a twenty- or thirty-year-ahead horizon for our nominal Canadian forward rates, as well, we judged that the lower liquidity and higher trading costs of these longer-horizon securities would more than offset any gains from having a precise match in maturity.

comparison with the United States, we begin our analysis of Canada in January 1998.[35]

The results of our analysis for Canada are presented in tables 3 and 4. Table 3 investigates the sensitivity of Canadian far-ahead forward interest rates and inflation compensation to domestic economic news. As in previous tables for the United States, the first column reports the response of the one-year Canadian nominal spot rate to domestic news releases. Short rates respond significantly to several of the statistics we consider, with signs and magnitudes that are consistent with our earlier estimates for the United States. In sharp contrast to the United States, however, far-ahead forward nominal rates in Canada (in the second column) respond significantly to almost none of these news releases: only the coefficient on monetary policy surprises is significant at even the 10 percent level, and that result is driven by just one or two observations at the beginning of the sample. We find very similar results when we look at far-ahead forward inflation compensation (the fourth column). Here again, only one coefficient is marginally statistically significant (on the core CPI), and even that coefficient seems to be driven by a puzzling negative relation between far-ahead forward real interest rates and core CPI releases. The joint hypothesis that all coefficients in the regression are equal to zero in these two regressions is not rejected at any standard level of significance.

In table 4, we explore whether Canadian far-ahead forward interest rates and inflation compensation respond to U.S. economic data releases and monetary policy announcements. Because Canada is a relatively small open economy, it is reasonable to think that short-term interest rates and even long-term real rates in Canada might be largely determined by developments in the rest of the world, particularly developments in the United States. We would still expect the long-run values of purely nominal variables, such as inflation and inflation expectations, to be determined primarily by domestic monetary policy, particularly at the far-ahead horizons

35. In 1996 and 1997, there are seven forward real rate changes in Canada of 100 basis points or more in a single day, and seventeen changes of 50 basis points or more. We believe that these observations are due to low trading volumes and low liquidity for these securities, rather than to perceived changes in economic fundamentals. After January 1998, there are no changes of 50 basis points or more. While noise and low liquidity may still be an issue in the indexed bond data after January 1998, we found that problems related to regression outliers were essentially eliminated by restricting attention to the post-1997 period. Moreover, this period matches our sample for the United States, allowing for closer comparability between our U.S. and Canadian results.

Table 3. Canadian Forward Rate Responses to Domestic Macroeconomic News, 1998–2005[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
Capacity utilization	0.19 (0.16)	0.61 (0.39)	0.59 (0.85)	0.02 (0.01)
CPI	1.49* (1.68)	−0.27 (−0.24)	−0.79 (−1.61)	0.53 (0.47)
Core CPI	1.22 (1.58)	−0.23 (−0.23)	−1.07** (−2.49)	0.84 (0.86)
Employment	3.07*** (4.48)	0.65 (0.75)	0.34 (0.90)	0.31 (0.35)
Real GDP	−1.01 (−0.58)	−2.35 (−1.08)	0.25 (0.26)	−2.60 (−1.19)
Retail sales	1.48** (2.28)	−0.29 (−0.36)	0.00 (0.01)	−0.30 (−0.36)
Unemployment rate	0.31 (0.50)	−0.29 (−0.37)	0.11 (0.32)	−0.40 (−0.51)
Wholesale trade	0.09 (0.13)	−0.55 (−0.59)	−0.28 (−0.69)	−0.27 (−0.29)
Monetary policy	0.81*** (5.77)	−0.28 (−1.57)	−0.06 (−0.761)	−0.22 (−1.25)
No. observations	327	327	327	327
R^2	0.19	0.02	0.10	0.03
Joint test *p* value	0.000***	0.806	0.006***	0.732

Source: Authors' computations.
* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.
a. The sample is from January 1998 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant, a Y2K dummy that takes on the value of 1 on the first business day of 2000, and a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Inflation compensation is the difference between nominal and real rates. Joint test *p* value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. *t*-statistics are reported in parentheses.

Table 4. Canadian Forward Rate Responses to U.S. Macroeconomic News, 1998–2005[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
U.S. capacity utilization	1.42**	0.72	0.12	0.60
	(2.13)	(0.81)	(0.26)	(0.63)
U.S. consumer confidence	1.35*	–0.00	0.62	–0.62
	(1.91)	(–0.00)	(1.32)	(–0.61)
U.S. core CPI	0.96	2.07**	–0.30	2.37**
	(1.22)	(1.98)	(–0.59)	(2.10)
U.S. employment cost index	1.11	2.09	0.62	1.47
	(1.13)	(1.60)	(0.96)	(1.04)
U.S. real GDP (advance)	2.40**	0.40	–0.06	0.46
	(2.49)	(0.32)	(–0.09)	(0.34)
U.S. initial jobless claims	–0.99***	–0.72	–0.27	–0.45
	(–2.85)	(–1.56)	(–1.20)	(–0.89)
U.S. NAPM/ISM manufacturing survey	1.72**	1.88*	1.18**	0.69
	(2.18)	(1.79)	(2.27)	(0.61)
U.S. new home sales	–0.66	0.60	–0.52	1.12
	(–1.22)	(0.85)	(–1.47)	(1.46)
U.S. nonfarm payrolls	4.32***	1.66*	1.78***	–0.13
	(6.63)	(1.92)	(4.16)	(–0.14)
U.S. retail sales (excl. cars)	1.12	0.47	0.18	0.29
	(1.39)	(0.44)	(0.35)	(0.25)

Table 4 (continued)

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
U.S. unemployment rate	–1.04 (–1.31)	–1.72 (–1.63)	0.42 (0.80)	–2.13* (–1.87)
U.S. monetary policy	0.37*** (3.52)	–0.20 (–1.45)	0.14** (2.03)	–0.34** (–2.27)
No. observations	939	939	939	939
R^2	0.16	0.03	0.06	0.02
Joint test p value	0.000***	0.148	0.001***	0.361

Source: Authors' computations.
* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.
a. The sample is from January 1998 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant, a Y2K dummy that takes on the value of 1 on the first business day of 2000, and a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported), and Canadian macroeconomic news releases (coefficients not reported since they are very similar to table 3). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Inflation compensation is the difference between nominal and real rates. Joint test p value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. t-statistics are reported in parentheses.

we are considering in this paper. Thus, while short-term rates and perhaps long-term real interest rates in Canada might be expected to respond to U.S. economic news, we would still expect far-ahead forward inflation compensation and perhaps nominal rates to remain largely invariant, if financial markets view the distribution of long-run inflation outcomes in Canada as being well-anchored.

The regressions in table 4 include both Canadian and U.S. macroeconomic data releases and monetary policy announcements, although coefficients on the Canadian releases are not reported to save space (they are very similar to those reported in table 3). The first column of table 4 shows that short-term interest rates in Canada are indeed significantly affected by U.S. monetary policy announcements and by many U.S. macroeconomic data releases. Still, far-ahead forward nominal rates in the second column) are not very responsive to these U.S. economic news releases, with three coefficients exhibiting only a marginal degree of statistical significance. The joint hypothesis that all coefficients are zero in this far-ahead forward nominal rate regression is not rejected at any standard level of statistical significance. The same observations generally remain true when we look at far-ahead forward inflation compensation (the fourth column): although this period includes three U.S. data releases that are significantly related to Canadian far-ahead forward inflation compensation at the 10 percent level or better, the joint test that all coefficients are equal to zero is not rejected at any standard level of significance.

These findings for Canada are reminiscent of those reported by Gürkaynak, Levin, and Swanson (2006) for the United Kingdom and Sweden, which were both inflation targeters over much of the 1990s. In their analysis, the United Kingdom and Sweden displayed a much greater anchoring of far-ahead forward nominal rates and inflation compensation in response to economic news than did the United States. Finally, in the case of the United Kingdom, the Bank of England was granted operational independence from Parliament in 1998. Gürkaynak, Levin, and Swanson show that, while the United Kingdom has had substantially better-anchored long-term inflation expectations than the United States since that date, the data for the early 1990s display a sensitivity of forward nominal rates and inflation compensation that is very similar to what we observe in the United States. All of these findings support the conclusion that a credible inflation-targeting framework significantly helps to anchor the private sector's perception of the distribution of future long-run inflation outcomes.

4.2 The Sensitivity of Long-Term Interest Rates in Chile

Chile has a much less extensive set of monthly macroeconomic data releases than are available in a more industrialized country such as the United States or Canada. We obtained data on Chilean monthly macroeconomic data releases and ex ante private sector forecasts of these releases from the Central Bank of Chile for four macroeconomic statistics: consumer price index inflation, monetary policy announcements, real GDP growth in the current quarter, and real GDP growth in the previous quarter. However, whereas our forecast data for the United States and Canada are at most a few days old on release, the Chilean data can be as much as two or even three weeks old by the time of the actual release, because the private sector macroeconomic forecast is only collected every few weeks. Thus, our measure of macroeconomic surprises for Chile is likely to suffer from measurement error, which will diminish our chances of finding statistically significant effects of releases on interest rates at even the short end of the yield curve.[36]

The Central Bank of Chile also provided us with Chilean real and nominal yield curve data. In contrast to the United States and Canada, there were no long-term nominal government bonds outstanding in Chile until 2002—all long-term government debt issued prior to that date was inflation indexed, at least in the last thirty years. This lack of long-term nominal debt presumably reflects the fact that the Chilean government was unwilling to pay the large risk premiums that investors would have demanded to hold such long-term nominal liabilities during a period in which markets viewed the government and the central bank as being greater credit and inflation risks than they are today. Thus, our sample for Chile is restricted to the 2002–05 period, which, although very short, still provides us with about four hundred observations for our analysis given the high frequency of the data. Moreover, even with ideal data, it would be difficult to extend our sample for Chile further back than 2001: although Chile formally adopted an inflation-targeting framework in 1991, the inflation target itself was revised downward throughout the 1990s and only stabilized at the current range of 2–4 percent in the first quarter of 2001. Finally, the Chilean yield curves are based on a relatively small number of securities, owing to the smaller size of Chilean financial markets,

36. Our data on U.S. macroeconomic data releases remain relatively free of measurement error, however. We consider the response of Chilean interest rates to these U.S. releases, just as we did for Canada in the preceding section.

so that implied forward rates for Chile are generally much noisier than in the United States and Canada, again posing a challenge for empirical analysis.

We report the results of our analysis for Chile in tables 5 and 6. Table 5 reports the response of Chilean interest rates and inflation compensation to domestic economic news. The first column of the table reports the estimated responses of short-term Chilean interest rates to economic news over this period. Only one of our four Chilean macroeconomic data releases—monetary policy announcements—is statistically significant, which is consistent with the idea that measurement error and a shorter sample make estimation difficult. That one statistic is highly significant, however, with a sign and magnitude similar to our estimates for the United States. Moreover, the joint test of the hypothesis that all coefficients in the regression are zero can be rejected at the 1 percent significance level. We thus have evidence that our analysis still has power despite the limitations of the data. Nevertheless, in contrast to the behavior of Chilean short rates, neither far-ahead forward nominal rates nor inflation compensation respond significantly to Chilean monetary policy announcements, which suggests some degree of anchoring. The hypothesis that all of the coefficients in these regressions are zero cannot be rejected at any standard level of significance.

In table 6, we address the response of Chilean interest rates to U.S. macroeconomic and monetary policy announcements. A few U.S. statistics are estimated to have significant effects on Chilean short rates, although some of the coefficients (on U.S. nonfarm payrolls and unemployment) have signs that are perhaps puzzling. The joint hypothesis that all coefficients in the short-rate regression are zero is rejected at the 1 percent level. Again, in contrast to short rates, far-ahead forward nominal rates and inflation compensation in Chile respond to almost no U.S. macroeconomic data releases, with the exception of the U.S. unemployment rate release and perhaps U.S. monetary policy surprises. The hypothesis that all coefficients in the regression are zero is also not rejected at standard significance levels in either case. While the Chilean data are clearly much noisier and more problematic than in the data for more industrialized countries such as Canada, Sweden, the United Kingdom, and the United States, our results for Chile are all consistent with those other countries. The exercise suggests that the commitment of the central bank to a credible long-run inflation objective significantly helps to anchor private sector expectations about long-run inflation outcomes.

Table 5. Chilean Forward Rate Responses to Domestic Macroeconomic News, 2002–05[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in ten years*	*One-year forward real rate ending in ten years*	*One-year forward inflation compensation ending in ten years*
CPI	0.40 (0.64)	1.86 (0.84)	–1.37 (–0.53)	3.23 (0.97)
Real GDP	0.25 (0.30)	1.10 (0.38)	2.13 (0.62)	–1.03 (–0.23)
Real GDP, previous quarter	–0.69 (–0.49)	1.91 (0.39)	2.83 (0.49)	–0.92 (–0.13)
Monetary policy	0.15*** (3.92)	0.22 (1.61)	0.06 (0.37)	0.16 (0.78)
No. observations	98	98	98	98
R^2	0.16	0.04	0.02	0.02
Joint test *p* value	0.005***	0.406	0.703	0.773

Source: Authors' computations.
* Statistically significant at the 10 percent level. ** Statistically significant at the 5 percent level. *** Statistically significant at the 1 percent level.
a. The sample is from August 2002 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant and a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Inflation compensation is the difference between nominal and real rates. Joint test *p* value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. *t*-statistics are reported in parentheses.

Table 6. Chilean Forward Rate Responses to U.S. Macroeconomic News, 2002–05[a]

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in 10 yrs*	*One-year forward real rate ending in 10 yrs*	*One-year forward inflation compensation ending in ten years*
U.S. capacity utilization	–0.16 (–0.23)	2.27 (1.02)	–1.06 (–0.39)	3.33 (0.96)
U.S. consumer confidence	–0.05 (–0.08)	–0.59 (–0.27)	–0.02 (–0.01)	–0.57 (–0.17)
U.S. core CPI	0.86 (1.11)	2.12 (0.85)	–4.19 (–1.39)	6.31 (1.63)
U.S. employment cost index	0.78 (0.81)	0.65 (0.21)	4.00 (1.07)	–3.35 (–0.70)
U.S. real GDP (advance)	–0.44 (–0.32)	–4.92 (–1.14)	2.95 (0.57)	–7.87 (–1.17)
U.S. initial jobless claims	–0.36 (–0.93)	0.80 (0.66)	–0.65 (–0.44)	1.46 (0.76)
U.S. NAPM/ISM manufacturing survey	–0.60 (–0.66)	–0.26 (–0.09)	5.23 (1.50)	–5.49 (–1.22)
U.S. new home sales	0.38 (0.80)	0.38 (0.25)	–2.53 (–1.39)	2.92 (1.24)
U.S. nonfarm payrolls	–1.35* (–1.72)	1.55 (0.62)	–3.50 (–1.16)	5.06 (1.30)
U.S. retail sales (excl. cars)	1.68** (2.20)	–2.46 (–1.01)	0.48 (0.16)	–2.94 (–0.77)

Table 6 (continued)

Explanatory variable	*One-year nominal rate*	*One-year forward nominal rate ending in 10 yrs*	*One-year forward real rate ending in 10 yrs*	*One-year forward inflation compensation ending in ten years*
U.S. unemployment rate	3.78***	–8.70***	2.98	–11.68***
	(4.20)	(–3.03)	(0.86)	(–2.61)
U.S. monetary policy	0.25	–0.81	0.67	–1.48*
	(1.46)	(–1.51)	(1.04)	(–1.77)
No. observations	399	399	399	399
R^2	0.10	0.05	0.03	0.05
Joint test *p* value	0.001***	0.234	0.688	0.167

Source: Authors' computations.
* Statistically significant at the 10 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 1 percent level.
a. The sample is from August 2002 to October 2005, at daily frequency on the dates of macroeconomic and monetary policy announcements. Regressions also include a constant, a year-end dummy that takes on the value of 1 on the first business day of any year (coefficients not reported), and Chilean macroeconomic news releases (coefficients not reported since they are very similar to table 5). Macroeconomic data release surprises are normalized by their standard deviations, so these coefficients represent a basis point per standard deviation response. Monetary policy surprises are in basis points, so these coefficients represent a basis point per basis point response. Inflation compensation is the difference between nominal and real rates. Joint test *p* value is for the hypothesis that all coefficients (other than the constant and dummy variables) are zero. *t*-statistics are reported in parentheses.

4.3 Time-Series Behavior of Forward Rates in Canada, Chile, and the United States

Our analysis in the previous sections focused on the conditional volatility of forward rates in Canada, Chile and the United States, by which we mean the movement of these rates in response to specific data releases. Although we took care to include as many variables as possible and any macroeconomic data release that seemed important, our regressions have nonetheless omitted many factors that influence the daily behavior of interest rates at both the short and long ends of the yield curve. The R^2 values in our regressions are in every case below 20 percent, even for short-term interest rates.[37] Given our argument that the relative responsiveness of forward rates in different countries to macroeconomic data releases and monetary policy announcements is due to different degrees of stability of private sector long-run inflation expectations, one might expect to see that other economically relevant news that we have omitted would lead to a similar contrast in far-ahead forward interest rate behavior across our three countries. In other words, one might expect to see forward rates in the United States that would tend to be more volatile unconditionally as well as conditionally, to the extent that long-run inflation expectations in the United States are unanchored.

Figure 5 presents unconditional time series plots of far-ahead forward nominal rates and inflation compensation for Canada, Chile, and the United States. We find a number of interesting observations. First, far-ahead nominal rates and inflation compensation are not completely stable in any of the three countries. Both high and low frequencies exhibit clear variation, the source of which remains an open question. Possible explanations include the following: high transaction

37. This observation is all the more remarkable in light of the fact that we have restricted our attention in the regression to only those days on which at least one of our right-hand-side variables was nonzero; the R^2 values are even lower (though our coefficient estimates are very similar) if we perform the regression on all days. Thus, even on the days on which important macroeconomic news was released, we can only explain a relatively small fraction of the variance of interest rates at even the short end of the yield curve. One reason for the low R^2 values is that macroeconomic data releases often contain much more information than just the simple headline number that we must focus on in our analysis. For example, monetary policy announcements by the Federal Reserve often contain lengthy statements discussing the motivation for the move and even the future outlook for monetary policy; GDP releases contain information about its various components, which can independently influence private-sector forecasts of future output; and inflation releases contain a detailed breakdown of constituent components, which may independently influence forecasts of future inflation.

costs in Canadian and Chilean markets that drive observed prices away from true shadow values and errors in yield curve estimation resulting from a small number of securities outstanding;[38] time-varying risk or liquidity premiums; variations in financial market perceptions of the central bank's credibility and commitment to its long-run inflation objective; changes in the official inflation target itself (both Canada and Chile lowered their official targets several times in the early 1990s) or perceptions that the central bank's inflation target might change in the future; changes in tax rates or market perceptions that tax rates might change in the future; market perceptions that the central bank's preferred measure of inflation might change in the future; and differences between the consumption deflator of the marginal investor and the price index that is being targeted by the central bank.

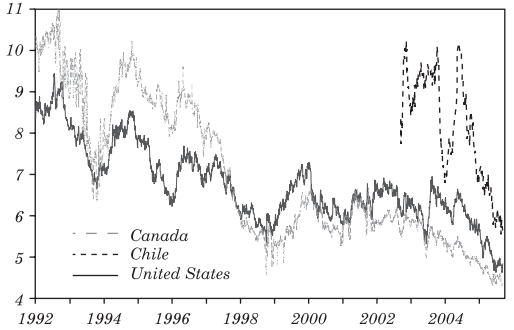
Second, despite the variation in our estimates of far-ahead forward nominal rates and inflation compensation, the Canadian rates have improved spectacularly vis-à-vis the United States. In the first half of the 1990s, far-ahead forward rates in Canada were clearly and consistently higher and more volatile than in the United States. From the late 1990s onward, that situation has completely reversed: far-ahead forward nominal rates and inflation compensation in Canada have been clearly and consistently lower and less volatile than in the United States. This is all the more remarkable considering that liquidity is lower and transaction costs higher in Canada, and the number of outstanding securities with which to estimate a yield curve is much smaller; thus, all else equal, one would tend to expect risk premiums and measurement error to produce more volatile forward rates in Canada. These observations exactly parallel the findings of Gürkaynak, Levin, and Swanson (2006) for the United Kingdom and Sweden. The sample period for our Chilean data is shorter, but it also shows a remarkable fall in these far-ahead forward rates over time, bringing them toward levels that are becoming increasingly comparable to those in the United States.

Third, inflation targeting by itself is not a silver bullet that suddenly lowers and stabilizes far-ahead forward nominal rates

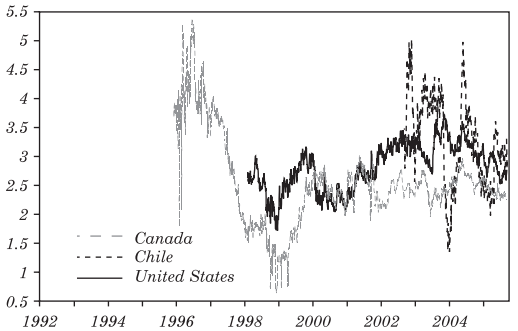
38. As mentioned in the preceding sections, Chile has only a few nominal and indexed government bonds outstanding, and Canada has only a few highly illiquid indexed government securities outstanding. Thus, estimates of forward rates in these two countries can be noisy, particularly in Chile and in the early years of the Canadian indexed market, when there were only two bonds outstanding and their liquidity was very low. (A third Canadian real bond was introduced in 1999 and liquidity in that market has increased steadily over time).

Figure 5. Time Series Plots of Forward Nominal Rates and Inflation Compensation

A. One-year forward nominal rate ending in ten years (percent)



B. One-year forward inflation compensation ending in ten years (percent)



Source: Authors' computations.

and inflation compensation. Canada officially adopted an inflation-targeting framework in February 1991, but the real gains in far-ahead forward rates and inflation compensation seem to have come gradually. Why this is so remains an open question, but it may be due partly to the fact that, although Canada adopted a formal inflation-targeting framework in 1991, the official inflation target was revised lower on several occasions in the early 1990s. One would hardly expect long-term inflation expectations to be anchored around the central bank's target if that target itself were perceived by markets to be in transition to an unspecified long-run level. Thus, the true date of adoption of a

fixed long-run inflation target in Canada might be identified as 1995, the date at which the current range of 1–3 percent was adopted and regarded as likely to persist (Mishkin and Schmidt-Hebbel, in this volume, make this point for a number of inflation-targeting adopters).[39] In addition, the initial announcement of an inflation-targeting regime in Canada and the initial announcement of the 1–3 percent target may have been regarded with some skepticism by financial markets, and only gradually did the feasibility of—and the central bank's commitment to—the new targeting regime become clear. These factors may also help explain why far-ahead forward nominal rates and inflation compensation in Chile remain fairly volatile and have exhibited somewhat of a downward trend in the past few years.

Finally, the figure provides direct evidence against the critique by Ball and Sheridan (2003) that there are no visible benefits from inflation targeting once initial conditions and mean reversion are taken into account. Ball and Sheridan's argument would predict that Canada, which began from high levels of inflation expectations in the early 1990s, would tend to converge back toward the levels in the United States over the 1990s. In contrast to this prediction, however, we find that inflation expectations in Canada actually overtake those in the United States in 1997 and then outperform the United States for the next eight years. This is a much stronger performance than can be accounted for simply by a tendency for reversion to the mean.

5. Conclusions

As in Gürkaynak, Sack, and Swanson (2005) and Gürkaynak, Levin, and Swanson (2006), we find that U.S. long-term forward nominal interest rates and inflation compensation are excessively sensitive to macroeconomic data releases and monetary policy announcements. In contrast, we find that long-term nominal interest rates and inflation compensation in Canada display much less sensitivity to economic news, while the unconditional volatility of these series over the past decade has been markedly lower than in the United States. These results are consistent with the findings of Gürkaynak, Levin, and Swanson (2006) for Sweden and the United Kingdom, two countries that have also maintained explicit inflation targets in recent years

39. The adoption of a target range for inflation (as opposed to a point) is not, in itself, a reason for variability of long-term inflation expectations, since the optimal monetary policy is always to aim for the midpoint of the range, as noted previously in this paper and discussed in detail in Orphanides and Wieland (2000).

In the case of Chile, the available sample period is fairly short and only a limited set of macroeconomic news releases are readily available. Nevertheless, our regression analysis does not indicate any excess sensitivity of far-ahead forward interest rates and inflation compensation, which is consistent with the hypothesis that inflation targeting in Chile has been reasonably successful in anchoring long-run inflation expectations. The unconditional volatility of these series, however, appears to be much higher in Chile than in either Canada or the United States, perhaps underscoring the extent to which the Chilean economy is still in the process of converging to the economic and financial conditions of the more industrialized economies. In particular, only a small number of Chilean government securities are actively traded in bond markets, and the yields on these securities may be quite sensitive to variations in liquidity and other market frictions. While not entirely conclusive, these results suggest that the presence of a transparent and credible inflation objective can play an important role in anchoring long-run inflation expectations in both emerging market economies and industrialized countries.

Our findings suggest that the potential welfare gains from reduced bond market volatility would be an important subject for future research. Although we have not demonstrated any such welfare gains in this paper, existing macroeconomic and finance theory identifies several strong possibilities: for example, less persistent deviations of inflation from target in the short and medium run as a result of firmer anchoring of expectations at the long end (Woodford, 2003); a greater ability of the central bank to control inflation in the short and medium run (ibid.); less volatile long-term nominal interest rates and lower risk premiums on nominal rates, which would improve the efficiency of investment decisions (Ingersoll and Ross, 1992); and a reduced chance of either a 1970s-style expectations trap for inflation (Albanesi, Chari, and Christiano, 2003) or an imperfect-information-driven inflation scare (Orphanides and Williams, 2005). To the extent that these benefits are important in practice as well as in principle, adopting a more explicit inflation objective could improve U.S. economic performance and U.S. monetary policy even beyond the successes of the past twenty years.

Appendix

Data on U.S. macroeconomic statistical releases and forecasts were obtained from Money Market Services (MMS) through July 2003, when that company merged with a larger financial institution. Beginning in December 2003, the same survey was produced again by Action Economics (AE). Both data sets can be obtained from Haver Analytics at www.haver.com. From August through November 2003, we fill in the holes in the MMS/AE survey data using the releases and forecasts reported by Bloomberg Financial Services. For additional details about individual macroeconomic series, see Gürkaynak, Sack, and Swanson (2003).

We obtained data on Canadian macroeconomic news releases and financial market expectations of those releases from two sources: Money Market Services and Bloomberg, as discussed in section 4. When those data sets overlap, they agree very closely. Between these two data sources, we have data on Canadian capacity utilization, the consumer price index, core consumer price index, employment, real GDP, retail sales, the unemployment rate, and wholesale trade. Most of these series go back to 1996, and a few go back even farther. To measure the surprise component of Canadian monetary policy announcements, we obtained the dates of changes in the Bank of Canada's target overnight interbank rate back to 1995 from the Bank of Canada's web site, and we measured the surprise component of these changes using the change in the three-month Canadian Treasury Bill on the dates of these monetary policy changes. The exact statistics we use, including Bloomberg and MMS mnemonics for those series, are reported in table A1.

Table A1. Data Sources for Canada

Series	*Data Source*	*Mnemonic*[a]	*Notes*
Capacity utilization	MMS	{L,D,M}156CU	Level, percent
Consumer price index	Bloomberg	cacpiyoy	Year-on-year change, percent
Core CPI	MMS	{L,D,M}156CPXY	Year-on-year change, percent
Employment	MMS	{L,D,M}156ED	Month-on-month change, thousands
Real GDP	MMS	{L,D,M}156GPA	Quarter-on-quarter change, percent
Retail sales	Bloomberg	carsmom	Month-on-month change, percent
Unemployment rate	Bloomberg	caunemp	Level, percent
Wholesale trade	Bloomberg	cawtmom	Month-on-month change, percent
Monetary policy	Bank of Canada		Authors' calculations from policy change dates and three-month Canadian Treasury bill rate

Source: Authors' computations.
a. This column reports the mnemonic used in the Bloomberg database for series obtained from Bloomberg and from the MMS database for series obtained from Money Market Services.

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Under What Conditions Can Inflation Targeting Be Adopted? The Experience of Emerging Markets

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Inflation targeting has become an increasingly popular monetary policy strategy, with 21 countries (8 industrial and 13 emerging market economies) targeting inflation and others considering following in their footsteps. Numerous studies of inflation targeting in industrial countries have been conducted; much less analysis has been done on its effects in emerging markets.[1]

This article seeks to fill this void. It looks at the experience of the emerging market countries that have adopted inflation targeting since the late 1990s, focusing on both macroeconomic performance and the potential benefits and costs of inflation targeting adoption. It draws on a new and detailed survey of 31 central banks to support the analysis. Particular attention is paid to the implications for institutional change and to the feasibility and success of inflation targeting when specific conditions, such as central bank independence and lack of fiscal dominance, are initially absent.

1. What Is Inflation Targeting and Why Does It Matter?

It is now widely accepted that the primary role of monetary policy is to maintain price stability.[2] Alan Greenspan, former Chairman

1. There is a large body of empirical literature on the performance of inflation targeting in industrial countries. More recently, work has been underway to extend this type of analysis to emerging market countries.

2. See Batini, Laxton and Yates (2003) and Pianalto (2005).

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of the Federal Reserve, has offered an operating definition of price stability that is broadly accepted: "Price stability obtains when economic agents no longer take account of the prospective change in the general price level in their economic decisionmaking" (Greenspan, 2001). This is often thought to correspond to an annual rate of inflation in the low single digits.[3]

Inflation targeting is one of the operational frameworks for monetary policy aimed at attaining price stability. In contrast to alternative strategies—notably money or exchange rate targeting, which seek to achieve low and stable inflation by targeting intermediate variables, such as the growth rate of money aggregates or the level of the exchange rate of an "anchor" currency—inflation targeting involves targeting inflation directly. The literature offers several different definitions of inflation targeting.[4] In practice, however, inflation targeting has two main characteristics that distinguish it from other monetary policy strategies.

First, the central bank is mandated and commits to a unique numerical target in the form of a level or a range for annual inflation. A single target for inflation emphasizes the fact that price stabilization is the primary focus of the strategy; the numeric specification provides a guide to what the authorities intend as price stability.

Second, the inflation forecast over some horizon is the de facto intermediate target of policy. For this reason inflation targeting is sometimes referred to as "inflation forecast targeting" (Svensson, 1997). Since inflation is partially predetermined in the short term because of existing price and wage contracts or indexation to past inflation, monetary policy can influence only expected future inflation. By altering monetary conditions in response to new information, central banks influence expected inflation and bring it in line over time with the inflation target, which eventually leads actual inflation to become better anchored to the target.

The monetary policy strategy followed by 21 countries has these characteristics; these countries are treated here as inflation targeters (table 1).[5] Defining inflation targeting according to these two characteristics makes it clear why, for example, neither the

3. See Bernanke and others (1999); Mishkin and Schmidt-Hebbel (2001); Brook, Karagedikli, and Scrimgeour (2002); Batini (2004); and Burdekin and others (2000).

4. See, among others, Leiderman and Svensson (1995); Mishkin (1999); Bernanke and others (1999).

5. According to these criteria, Chile and Israel are not classified as having adopted inflation targeting until the de-emphasis of their exchange rate targets, in 1999 (in Chile) and 1997 (in Israel).

Federal Reserve nor the European Central Bank is considered an inflation targeter: the Federal Reserve lacks a numerical specification for its price stability objective,[6] and the European Central Bank has traditionally given a special status to a second numerical objective, a "reference value" for the growth of the euro-area M3 broad money aggregate.[7]

Table 1. Emerging Market and Industrial Countries that Target Inflation

Country	*Date inflation targeting adopted*	*Current inflation target (percent)*
Emerging market countries		
Israel	1997Q2	1–3
Czech Rep.	1998Q1	3 (+/- 1)
Korea, Rep. of	1998Q2	2.5–3.5
Poland	1999Q1	2.5 (+/- 1)
Brazil	1999Q2	4.5 (+/- 2.5)
Chile	1999Q3	2–4
Colombia	1999Q3	5 (+/- 0.5)
South Africa	2000Q1	3–6
Thailand	2000Q2	0–3.5
Hungary	2001Q3	3.5 (+/- 1)
Mexico	2002Q1	3 (+/-1)
Peru	2002Q1	2.5 (+/- 1)
Philippines	2002Q1	5–6
Industrial countries		
New Zealand	1990Q1	1–3
Canada	1991Q1	1–3
United Kingdom	1992Q4	2
Australia	1993Q1	2–3
Sweden	1993Q1	2 (+/- 1)
Switzerland	2000Q1	<2
Iceland	2001Q1	2.5
Norway	2001Q1	2.5

Source: International Monetary Fund (IMF) staff calculations.
Note: All countries except Mexico publish forecasts of inflation.

6. See Kohn (2003a, and 2003b), Gramlich (2003), and Bernanke and Woodford (2005).

7. See European Central Bank (1999), Solans (2000), and Issing (2000). However, the European Central Bank has recently de-emphasized the weight attached to this reference value, moving toward a "pure" inflation targeting regime (see European Central Bank, 2003).

Proponents of inflation targeting argue that it yields a number of benefits relative to other operating strategies (see, for example, Truman, 2003):

- *Inflation targeting can help build credibility and anchor inflation expectations more rapidly and durably*. It makes it clear that low inflation is the primary goal of monetary policy and involves greater transparency to compensate for the greater operational freedom that it offers. Inflation targets are also intrinsically clearer and more easily observable and understandable than other targets, since they typically do not change over time and are controllable by monetary means.[8] Inflation targeting can thus help economic agents better understand and evaluate the performance of the central bank, anchoring inflation expectations faster and more permanently than strategies in which the task of the central bank is less clearly defined and more difficult to monitor (IMF, 2005a).

- *Inflation targeting provides more flexibility*. Since inflation cannot be controlled instantaneously, the target on inflation is typically interpreted as a medium-term objective. This implies that central banks pursue the inflation target over a certain horizon, by focusing on keeping inflation expectations at the target.[9] Short-term deviations of inflation from the target are acceptable and do not necessarily translate into losses in credibility.[10] The scope for greater flexibility could reduce variability in the output gap.[11]

8. Money targets, for example, have to be reset yearly and are hard to control, because shifts in money demand or in the money multiplier impair the control of the money supply and alter the long-run relationship between money and inflation. Central bank control over exchange rate targets is also limited, because the level of the exchange rate is ultimately determined by the international demand and supply of the domestic currency vis à vis that of the "anchor" currency. Shifts in sentiment about the domestic currency can thus trigger abrupt changes in its relative value that cannot be offset easily by central bank actions. Many central banks have abandoned money and exchange rate targets on these grounds (see IMF, 2005b).

9. The horizon over which inflation-targeting central banks attempt to stabilize inflation usually varies with the types of shocks that have taken inflation away from the target and with the speed of monetary transmission. See Batini and Nelson (2001) for a discussion of optimal horizons under inflation targeting.

10. Under "full credibility," economic agents under inflation targeting pre-emptively adjust their plans in the face of incipient inflationary pressures, so that the central bank has to move interest rates even less and price stabilization comes at even lower output gap variability costs (see, for example, King, 2005).

11. For an explanation of why some inflation targeting alternatives may imply higher output costs, see IMF (2005a).

- *Inflation targeting involves a lower economic cost in the face of monetary policy failures.* The output costs of policy failure under some alternative monetary commitments, such as exchange rate pegs, can be very large, usually involving massive reserve losses, high inflation, financial and banking crises, and possibly debt defaults.[12] In contrast, the output costs of failing to meet the inflation target are limited to inflation that is temporarily higher than targeted and growth that is temporarily slower, as interest rates are raised to bring inflation back to target.[13]

Critics have argued that inflation targeting has disadvantages and imposes excessive constraints on central banks:

- *Inflation targeting offers too little discretion and thus unnecessarily restrains growth.* Since the success of inflation targeting relies on the establishment of a reputational equilibrium by the central bank interacting with agents in the domestic economy, inflation targeting can work effectively only if the central bank acts consistently and convincingly to attain the inflation target. In other words, for inflation targeting to work well, the central bank must demonstrate its commitment to low and stable inflation through tangible actions. In the initial phases of inflation targeting, demonstrating commitment may require an aggressive response to inflationary pressures, which could temporarily reduce output. More generally, inflation targeting constrains discretion inappropriately: it is too confining in terms of an ex ante commitment to a particular inflation number and a particular horizon over which to return inflation to target.[14] By obliging the central bank to hit the target so restrictively, inflation targeting can unnecessarily restrain growth.[15]

- *Inflation targeting cannot anchor expectations, because it offers too much discretion.* In contrast to those who worry that inflation targeting may be too restraining, some argue that inflation targeting cannot help build credibility in countries that lack it

12. The experience of Argentina in 2001 is an example of this.

13. The experience of South Africa in late 2002 is one such case.

14. The horizon over which inflation targeting central banks attempt to stabilize inflation at target is not always specified and varies from country to country. See Batini and Nelson (2001) for a discussion of optimal horizons under inflation targeting.

15. See, among others, Rivlin (2002) and Blanchard (2003).

because it offers excessive discretion over how and when to bring inflation back to target and because targets can be changed.[16]

- *Inflation targeting implies high exchange rate volatility.* Because it elevates price stability to the status of the primary goal for the central bank, inflation targeting requires benign neglect of the exchange rate. If this is the case, it could have negative repercussions on exchange rate volatility and growth.

- *Inflation targeting cannot work in countries that do not meet a stringent set of preconditions,* making the framework unsuitable for the majority of emerging market economies. Preconditions often considered essential include the technical capability of the central bank to implement inflation targeting, the absence of fiscal dominance, sound financial markets, and an efficient institutional set-up to support and motivate the commitment to low inflation.

2. Inflation Targeting: An Assessment of the Impact

Empirical studies have focused primarily on the experience of industrial economies, because these countries, many of which adopted inflation targeting in the early 1990s, have longer track records.[17] These studies generally suggest that inflation targeting has been associated with performance improvements, although the evidence is typically insufficient to establish statistical significance of these improvements. No study, however, finds that performance has deteriorated under inflation targeting.

The lack of strong evidence from industrial countries may reflect several factors. First, there are only eight inflation targeters to look at and a limited set of nontargeters against which to compare them. Second, the macroeconomic performance of inflation targeters and nontargeters alike improved during the 1990s, for a variety of reasons, including better monetary policy (some aspects of the performance of many nontargeters along some dimensions was improved by preparations for entry into the European Monetary Union, for example). Finally, the fact that most industrial countries entered the 1990s with relatively low and stable inflation makes

16. See, for example, Rich (2000); Genberg (2001); and Kumhof (2002).

17. See, for example, Ball and Sheridan (2003); Levin, Natalucci, and Piger (2003); Truman (2003); and Hyvonen (2005), among others.

it more difficult to discern any incremental improvement due to inflation targeting.

In many ways, the experience of emerging markets offers a richer set of data for assessing the effects of inflation targeting than that of the industrial countries. The time span covered is short—three to seven years—but the sample of inflation targeters and suitable comparison countries is considerably larger. Moreover, because many emerging market targeters experienced relatively high levels of inflation and macroeconomic volatility before adopting inflation targeting, it should be easier to discern the effects of inflation targeting. In addition, looking at the experience of emerging markets can provide more useful information about how inflation targeting performs during periods of economic turbulence. While the global inflation and financial market environment has generally been benign in recent years, a number of emerging market inflation targeters were under substantial stress during the course of their inflation targeting regimes (examples include Brazil and other Latin American countries in the early 2000s, South Africa in late 2002, and Hungary and Poland since 2000.)

For the analysis that follows, we look at 13 emerging market inflation targeters (shown in table 1).[18] We compare them against the remaining 22 emerging market countries that are in the JP Morgan Emerging Markets Bond Index, plus 7 additional countries that are classified similarly.[19]

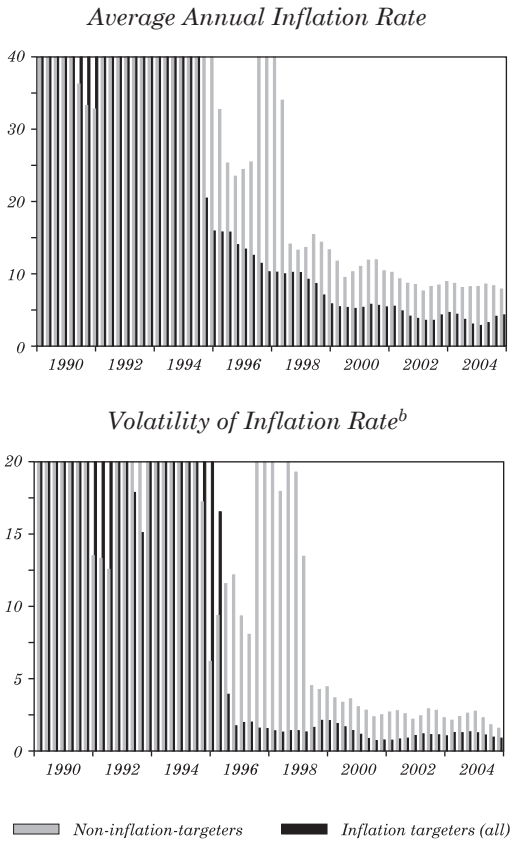
It is useful to begin by reviewing inflation performance of targeters and nontargeters over the past 15 years (figure 1). Inflation in both groups was high in the early to mid-1990s, but as of 1997 it was somewhat higher for the nontargeters, which, as a group had already begun to disinflate by 1995.[20] Inflation fell in both targeting and nontargeting countries, but even into 2004 a sizable wedge of roughly 3.5 percentage points remained. Such a wedge reflects the success of most inflation targeters in keeping actual inflation on average close to target, although targets have been missed, especially

18. All of these countries except the Czech Republic and Israel are included in the JP Morgan Emerging Markets Bond Index.

19. These are Botswana, Costa Rica, Ghana, Guatemala, India, Jordan, and Tanzania. We also experimented with excluding these seven countries from the control group.

20. The hypothesis put forth by Ball and Sheridan (2003) that the countries that chose to adopt inflation targeting were those experiencing a transitory increase in inflation is broadly inconsistent with the data when the country sample is extended to include emerging markets.

Figure 1. Inflation, 1990–2004[a]
(percent)



Source: IMF, *International Financial Statistics;* and IMF staff calculations.
a. Regional average for emerging market and selected developing countries; average inflation rates above 40 percent and volatilities above 20 percent are not shown, to enable clearer illustration of smaller average inflation differences in the recent past.
b. Rolling one-year standard deviation of inflation.

for disinflating countries, which have tended to miss targets more often and by more than countries with stable inflation targets (table 2; Roger and Stone, 2005).

To look at the experience in more detail, we compare the performance of inflation targeters before and after adopting inflation targeting relative with the performance of nontargeters. This approach raises the issue of what to use as the "break date" for nontargeters: while no partitioning of the sample is perfect, we follow Ball and Sheridan (2003) in using the average adoption date for inflation targeters (1999Q4) (dates range from 1997Q2 to 2002Q1). Other partitions of the sample yield similar results, as reported below.

As shown in the first panel of table 2, the level and volatility of inflation before inflation targeting was adopted are high and variable for many countries in the sample (figure 2). The convergence to low and stable inflation following adoption is striking: all countries are clustered in the 1–7 percent range, with a maximum standard deviation of 2 percent. The nontargeters also show improvement along both dimensions, and many succeeded in stabilizing inflation at low levels. As a group, however, their convergence is weaker than the inflation targeters, with many continuing to experience relatively high and volatile inflation. For real output growth and volatility, the pattern is less clear: abstracting from one or two outliers, output volatility is generally lower in the post-adoption period for both groups, with little change in average growth rates.

Table 2. Actual Inflation Relative to Target in Selected Groups of Countries

Item	*Standard deviation from target (RMSE) (percentage points)*[a]	*Frequency of deviations*[b] *(percent)*		
		Total	*Below*	*Above*
All countries	1.8	43.5	24.2	19.3
Industrial countries	1.3	34.8	22.5	12.3
Emerging market countries	2.3	52.2	25.9	26.2
Stable inflation targets	1.3	32.2	21.7	10.6
Disinflation targets	2.2	59.7	27.7	32.0

Source: Roger and Stone (2005).
a. Figures represent equally weighted averages of statistics for individual countries in relevant groups. Individual country statistics are based on monthly (quarterly for Australia and New Zealand) differences between 12-month inflation rates and centers of target ranges.
b. Inflation outcomes relative to edges of target ranges.

2.1 Econometric Analysis

A more formal statistical analysis, along the lines proposed by Ball and Sheridan (2003), yields similar results. Underlying the analysis is the assumption that some gauge of macroeconomic performance—call it X—depends partly on a country's own history and partly on some underlying mean value of the variable in question. In the case of the inflation rate for inflation targeters, this mean should, of course, correspond to the inflation target; for other countries, this would simply be the "normal" level of inflation to which observed inflation reverts. Mathematically, this process can be expressed as follows:

$$X_{i,t} = \phi\,[\alpha^T d_{i,t} + \alpha^N (1 - d_{i,t})\,] + (1 - \phi)\, X_{i,t-1}, \tag{1}$$

where $X_{i,t}$ is the value of a macroeconomic performance indicator X for country i at time t, α^T is the mean to which X reverts for inflation targeters, α^N is the mean to which X reverts for nontargeters, and $d_{i,t}$ is a variable equal to 1 for targeters and 0 for nontargeters. The parameter ϕ represents the speed with which X reverts to its group-specific α: a value of ϕ equal to 1 means X reverts completely after one period, while a value of ϕ equal to 0 implies that X depends only on its history, with no tendency to revert to any particular value.

The regression used by Ball and Sheridan (2003), and in the results reported in tables 3–6, is a version of equation (1), rewritten in terms of the change in X, appending an error term e, and assuming there are two periods, pre and post adoption:

$$X_{i,\text{post}} - X_{i,\text{pre}} = \phi\alpha^T d_i + \phi\alpha^N (1 - d_i) - \phi\, X_{i,\text{pre}} + e_i, \tag{2}$$

or, letting $a_0 = \phi\alpha^N$, $a_1 = \phi(\alpha^T - \alpha^N)$ and $b = -\phi$,

$$X_{i,\text{post}} - X_{i,\text{pre}} = a_0 + a_1\, d_i + bX_{i,\text{pre}} + e_i. \tag{3}$$

The pre-period for inflation targeters is defined as 1985 until the quarter before the adoption of inflation targeting; the post-period runs from inflation targeting adoption through 2004. The break date for nontargeters is 1999Q4, which corresponds to the mean adoption date for emerging-market inflation targeters.

Table 3 reports the baseline results obtained from estimating equation (3) on the full sample of 35 emerging market economies of

the JP Morgan Emerging Markets Bond Index plus the Czech Republic and Israel (which are inflation targeters but not part of the index) plus 7 countries that are often classified as emerging markets. Included in the set of X variables are CPI inflation, inflation volatility, the volatility of real GDP growth, and the output gap.

Table 3. Baseline Results

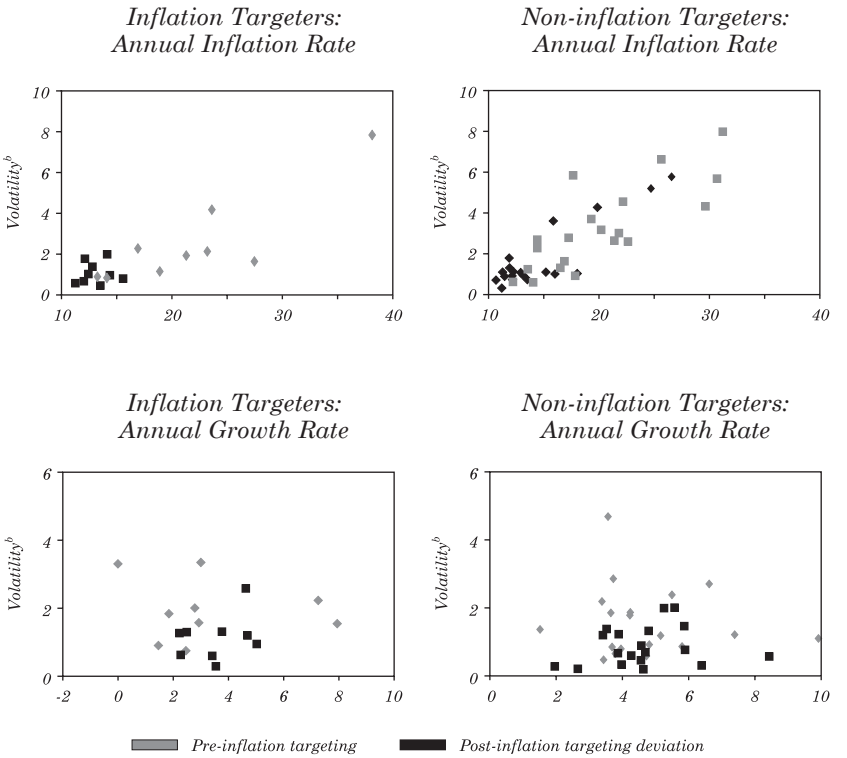
Variables	*IT dummy variable*
CPI inflation	–4.820**
Volatility of CPI inflation	–3.638**
Volatility of real output growth	–0.633
Volatility of output gap	–0.010**

Sources: IMF, *International Financial Statistics;* and IMF staff calculations.
Note: One, two, and three asterisks denote statistical significance at the 10, 5, and 1 percent level, respectively.

In this framework the relevant parameter for gauging the economic impact of inflation targeting is a_1, the coefficient on the inflation targeting dummy variable. This parameter is reported in tables 3–6 (a_0 captures whether there has been a generalized improvement in macroeconomic performance across countries independently of differences in monetary regimes). Consider the row on CPI inflation in table 3, showing estimates of equation (3) when X = CPI inflation. There a_1 = -4.8, implying that in countries that have adopted inflation targeting, the reduction in CPI inflation was on average 4.8 percentage points greater than in countries that did not do so. Note that if ϕ were known to be zero (that is, complete mean reversion), the estimated a_1 would be nothing more than the difference between average $X_{\text{post}} - X_{\text{pre}}$ for inflation targeters and nontargeters; the only advantage of the regression method is that it controls for the initial level of X_{pre}. Furthermore, by focusing on relatively long periods of time, the analysis is largely a comparison of steady states, saying nothing about what happens during the transition to an inflation targeting (or any other) policy framework; doing so would require a very careful control of cyclical conditions to distinguish transition effects from the normal trajectory of the business cycle.

The results in table 3 reaffirm the descriptive statistics and the visual impression from the plots: inflation targeting is associated with a significant 4.8 percentage point reduction in average inflation and a

Figure 2. Inflation and Growth Performance[a]
(1985–2004; percent; average on x-axis)



Source: IMF, *International Financial Statistics;* OECD Analytical Database; and IMF staff calculations.
a. Period average for emerging market and selected developing countries, with pre-inflation targeting average inflation less than 40 percent.
b. Rolling one year standard deviation of inflation.

reduction in its standard deviation of 3.6 percentage points relative to other strategies.[21] The standard deviation of output gap is also slightly lower for the inflation targeters, and the difference between targeters and nontargeters is statistically significant at the 5 percent level.

21. This finding is at odds with arguments raised by Kumhof (2002), Genberg (2001), and Rich (2000), among others, that inflation targeting is too soft or too discretionary to enable central banks to reduce inflation on a durable basis.

Thus there is no evidence that inflation targeters meet their inflation objectives at the expense of real output stabilization.[22]

The result that inflation targeting improves inflation performance more than other regimes is in a sense unsurprising, as the control of inflation is, after all, the central bank's overriding medium-term objective. An interesting question is how performance compares on other dimensions that are not directly related to inflation per se, including survey-based inflation expectations; their volatility; and the volatility of the nominal exchange rate, foreign reserves, and real interest rates. Inflation targeting performance was checked with respect to a proxy for the probability of exchange rate crises, using the exchange market pressure index, based on the seminal work of Girton and Roper (1977) and developed by Eichengreen, Rose, and Wyplosz (1994) and Eichengreen (1995).

Using the same statistical framework as before, we find that inflation targeting leads to a reduction in the level and volatility of inflation expectations, along with inflation itself (table 6). This confirms the notion that inflation targeting has an advantage over other regimes in anchoring expectations and building credibility on a more durable basis, even if inflation targets are missed more frequently in emerging markets than in industrial countries. In the sample used here, the fiscal position before adoption of inflation targeting or the absence of fiscal improvement following adoption does not seem to affect the ability of inflation targeting to deliver lower or more stable inflation (or inflation expectations) relative to other strategies.[23] Nominal exchange rate volatility is lower than in nontargeters, as is the standard deviation of the real interest rate and the volatility of international reserves.[24] Interestingly, there is evidence at the 5 percent significance level that inflation targeting is associated with a lower probability of crises, perhaps in part reflecting the greater de jure, if not de facto, flexibility of the exchange rate regime.

22. This result suggests that concerns raised by, among others, Benjamin Friedman (2001); Baltensperger, Fischer, and Jordan (2002); Meyer (2002); Rivlin (2002); and Blanchard (2003) that inflation targeting is too rigid and constrains discretion inappropriately at the expense of the rate or variability of economic growth may be unwarranted, at least for emerging markets.

23. An event study by Celasun, Gelos, and Prati (2004) over time samples predating the adoption of inflation targeting finds that fiscal improvements may have helped lower inflation expectations in some emerging market countries.

24. Exchange rate volatility in inflation targeting countries is lower than in nontargeters, even when countries with exchange rate targets are dropped from the nontargeting control group.

Robustness Checks

Next, we examined how sensitive the results are to: (i) the way the sample was partitioned into "pre" and "post" periods; (ii) the exclusion of countries whose inflation was high in the "pre" period; (iii) the exclusion of low income countries or of both these and countries that are not "upper middle income" according to the World Bank classification by income; (iv) the exclusion of the seven non-IT countries not included in the JP Morgan EMBI; (v) the exclusion of countries that are severely indebted according to the World Bank classification of country indebtedness; (vi) the exclusion of countries with an exchange rate peg in the "post" period; and, finally, (vii) different degrees of fiscal discipline across countries.

The partitioning of the sample into pre and post periods is somewhat arbitrary, both in determining the starting date for the calculation of the pre-period averages and in the assigning of 1999:Q4 as the hypothetical break date for the nontargeters. In an effort to assess any distortion created by the arbitrariness of the partitioning, we re-estimated equation (3) using two alternative sample partitioning schemes. The first is to start the pre period in 1990 rather than 1985, thus largely removing any effects of the Latin American debt crisis from the sample. The second is to change the break date for nontargeters from 1999:Q4 to the date of the most recent de facto change in monetary policy framework (based on IMF staff calculations and the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions*). Under these schemes and the baseline partitioning, however, the pre and post samples vary across countries. To eliminate any possibility that simple time effects could account for the results, a third partitioning was tried, using a standardized 1994–96 pre period, and a standardized 2002–04 post period.

Several additional checks were performed to ensure that the results are robust to sample selection and to the inclusion of other potentially important factors affecting macroeconomic outcomes. First, to guard against the possibility that a handful of extreme inflation observations might be exerting undue influence on the regression, a control was included for countries whose inflation rate exceeded 40 percent in the pre period; a threshold of 100 percent was also tried. Second, equation (3) was reestimated over a smaller sample that excluded countries defined as low-income by the World Bank, as well also over a sample that excluded the seven countries in the control group that were not listed

in the JP Morgan Emerging Markets Bond Index. Third, on the full sample a control was included for countries that are severely indebted externally, in line with the World Bank classification of countries' external indebtness. Fourth, on the full sample a control for countries with an exchange rate peg during the post period was used. Finally, on the full sample controls were included for the public debt-to-GDP ratio in the pre period and on the change between post and pre periods to rule out the possibility that the observed gains in macroeconomic performance are ascribable not to the introduction of inflation targeting but rather to improvements in fiscal discipline. Results for these two sets of robustness checks are reported in tables 4–6.

The significance, sign, and magnitude of additional controls is reported after the slash next to each estimate of the a_1 coefficient (when nothing is reported it means that the control was not significant). In the first column of the bottom panel of table 6, for example, the significance of a precondition on the debt/GDP ratio is examined. Results indicate that the control is significant only for the volatility of 6- to 10-year inflation expectations, suggesting that having a "bad" debt/GDP ratio before adopting inflation targeting reduced the volatility of inflation expectations usually associated with inflation targeting by 0.018 percentage points relative to nontargeting.

None of these modifications significantly alters the baseline results. Inflation targeting continues to be associated with a statistically significant larger reduction in the level and standard deviation of inflation relative to other regimes and little or no effect on the volatility of output.[25] The main results of the analysis, therefore, appear to be robust, even when the improvement in fiscal performance in the post-targeting period is accounted for. Interestingly, inflation targeting seems to outperform exchange rate pegs, even when only successful pegs are chosen in comparison.

The conclusions of this analysis are subject to two important caveats. First, although the success of inflation targeting in emerging markets to date is encouraging, the time elapsed since these countries adopted inflation targeting is short, making it hard to draw definite

25. The advantages of inflation targeting relative to other strategies are robust independently of the controls used. However, countries with an initial level of inflation of more than 40 percent show smaller reductions in inflation and inflation volatility before and after adopting inflation targeting. When severely indebted countries are excluded, inflation targeting still implies statistically significant macroeconomic improvements relative to not targeting, although the reduction in inflation volatility and output gap volatility is no longer statistically significant.

Table 4. Different Classifications

	World Bank classification by income		*World Bank classification by foreign indebtedness*	*Emerging markets*	*EMBI classification*
Variables	*No low income country*	*No lower middle income country*	*No severely indebted country*		
			IT dummy variable		
CPI inflation	–5.025**	–9.406*	–3.820**	–4.972**	–4.653**
Volatility of CPI inflation	–4.138**	–4.209	–1.842	–4.828**	–3.959**
Volatility of real output growth	–0.898	–3.128*	–0.435	–1.235	–0.937
Volatility of output gap	–0.012**	–0.024**	–0.009	–0.014**	–0.012**

Sources: IMF, *International Financial Statistics;* J.P. Morgan; national sources; World Bank; and IMF staff calculations.
Note: One, two, and three asterisks denote statistical significance at the 10, 5, and 1 percent level, respectively.

Table 5. Robustness Checks

Variables	*Different dates*		
	Starting date 1990	*Actual dates for non-inflation-targeters Starting date: 1985*	*Time periods 1994–96 vs. 2002–04*
	IT dummy variable		
CPI inflation	–4.818**	–6.519***	–4.520***
Volatility of CPI inflation	–3.636**	–4.159***	–2.358**
Volatility of real output growth	–0.653	–1.221	–1.030
Volatility of output gap	–0.009**	–0.013**	–0.010*

Variables	*Control variables*				
	Fiscal discipline		*Inflation*		
	Debt/GDP (Pre)[a]	*Debt/GDP (Change)*[b,c]	*Pre-inflation > 40 percent*[d]	*Pre-inflation >100 percent*[e]	*Exchange rate regime pegs*
	IT dummy/control variables				
CPI inflation	–5.254***	–5.910**	–4.411**/10.036**	–4.758**	–5.829**
Volatility of CPI inflation	–3.461**	–4.084**	–3.498**/7.695**	–3.631**	–3.835**
Volatility of real output growth	–0.595	–0.868	–0.649/2.650**	–0.633	–0.751
Volatility of output gap	–0.010**	–0.011**	–0.011**/0.015**	–0.010**	–0.013**

Sources: IMF, *International Financial Statistics*; national sources; and IMF staff calculations.
Note: One, two, and three asterisks denote statistical significance at the 10, 5, and 1 percent level, respectively. Control variables missing when not significant.
a. Debt in percent of GDP prior to adoption of inflation targeting.
b. Difference in debt in percent of GDP between latest available and prior to adoption of inflation targeting.
c. The sample does not include Argentina and China because fiscal changes in these countries were many times larger than the average in non-inflation targeting countries, and so were biasing the results (showing when included that an improvement in the fiscal stance worsens inflation expectations).
d. Period average inflation prior to adoption of inflation targeting above 40 percent.
e. Period average inflation prior to adoption of inflation targeting above 100 percent.

Table 6. Additional Performance Indicators
(Baseline model robustness checks)

	Starting date		*Actual dates for non-inflation-targeters*	*Time periods*
Variables	*1985*	*1990*	*Starting date: 1985*	*1994–96 vs. 2002–04*
			IT dummy variable	
5-year π forecast 5^{f}	–2.672**	–2.672**	–3.016**	–2.197
Volatility of 5-year π forecast	–2.076**	–2.076**	–1.330**	–1.717**
6–10-year π forecast	–2.185**	–2.185**	–2.558**	–2.184
Volatility of 6–10-year π forecast	–1.737***	–1.737***	–1.232**	–1.596**
Exchange market pressure index	–0.340**	–0.327*	–0.330	–0.494*
Exchange rate volatility	–11.090*	–11.107**	–9.303	–3.654
Reserves volatility	–16.333***	–16.384***	–21.945***	–14.770**
Volatility of real interest rate	–5.025***	–5.025**	–4.695***	–3.020**

Table 6. (continued)

	Control Variables				
	Fiscal discipline		*Inflation*		
Variables	*Debt/GDP (Pre)*[a]	*Debt/GDP (Change)*[b,c]	*Pre-inflation >40 percent*[d]	*Pre-inflation >100 percent*[e]	*Exchange rate regime pegs*
	IT dummy/control variables				
5-year π forecast[f]	−2.906**	−2.901**	−2.578**	−2.726**	−1.721
Volatility of 5-year π forecast	−1.840*	−1.755**	−1.765**	−2.103**	−1.491**
6–10-year π forecast	−2.203*	−2.404*	−2.085**	−2.146*	−1.592*
Volatility of 6–10-year π Forecast	−1.350**/ 0.018***	−1.548***	−1.645***	−1.704**	−1.675*
Exchange market pressure index	−0.328**	−0.384**	−0.339**	−0.340*	−0.519***/ −0.4333*
Exchange rate volatility	−9.510**	−7.958*	−9.721*	−11.927*	−13.240**
Reserves volatility	−15.458**	−20.886***/ 0.186**	−16.072***	−16.328***	−20.109***
Volatility of real interest rate	−4.985**	−6.186**	−5.129** /8.790**	−5.019**	−5.817**

Sources: IMF, *International Financial Statistics;* national sources; and IMF staff calculations.
Note: One, two, and three asterisks denote statistical significance at the 10, 5, and 1 percent level, respectively. Control variables missing when not significant.
a. Debt in percent of GDP prior to adoption of inflation targeting.
b. Difference in debt in percent of GDP between latest available and prior to adoption of inflation targeting.
c. The sample does not include Argentina and China because fiscal changes in these countries were many times larger than the average in non-inflation targeting countries, and were, therefore, biasing the results (showing when included that an improvement in the fiscal stance worsens inflation expectations).
d. Period average inflation prior to adoption of inflation targeting above 40 percent.
e. Period average inflation prior to adoption of inflation targeting above 100 percent.
f. π refers to CPI inflation.

conclusions about its effects. Nevertheless, the observed similarities in the behavior of inflation expectations in emerging market and industrial country inflation targeters over a comparable time span bodes well for what may lie ahead for emerging market targeters (see IMF, 2005a).

Second, in the absence of a counterfactual, it is difficult to resolve definitively whether inflation targeting is causal in generating the observed benefits. In many cases the adoption of inflation targeting coincided with the passage of significant reforms of central banking laws in the early 1990s, which might be interpreted as the manifestation of a shift in preferences toward lower inflation. The fact that these banks still felt the need to install a new monetary framework, however, suggests that a change of heart is not enough without a framework that allows the central bank to follow through on its intention.

3. Do Preconditions Need to Be Met Before Inflation Targeting Is Adopted?

A common objection to inflation targeting is that it is costly in terms of institutional and technical requirements, making the framework unsuitable for some emerging market economies. The most detailed exposition of this point was made by Eichengreen et al. (1999), who argue that technical capabilities and central bank autonomy were severely lacking in most emerging market economies (including several that subsequently adopted inflation targeting).[26] Such countries, the argument goes, would be better off sticking with a conventional policy framework, such as an exchange rate peg or money growth targeting.

"Preconditions" fall into four broad categories:

- *Institutional independence*. The central bank must have full legal autonomy and be free from fiscal and political pressure that create conflicts with the inflation objective.

26. Agénor (2002); Schaechter, Stone, and Zelmer (2000); IMF (2001); Carare, Schaechter, and Stone, (2002); and Khan (2003) also stress the relevance of preconditions. More neutral or benign views on the conceptual relevance of preconditions can be found in Truman (2003), Jonas and Mishkin (2005), Debelle (2001), and Amato and Gerlach (2002).

- *A well-developed technical infrastructure*. The central bank must have inflation forecasting and modeling capabilities and the data needed to implement them.

- *Economic structure*. Prices must be fully deregulated, the economy should not be overly sensitive to commodity prices and exchange rates, and dollarization should be minimal.

- *A healthy financial system*. In order to minimize potential conflicts with financial stabilization objectives and guarantee effective monetary policy transmission, the banking system should be sound and capital markets well developed.

To assess the role of preconditions for the adoption of inflation targeting, we administered a survey to 21 inflation-targeting central banks and 10 nontargeting central banks in emerging markets.[27] The version of the survey given to inflation-targeting central banks focused on how policy was formulated, implemented, and communicated and how various aspects of central banking practice had changed before and during the adoption of targeting.[28] Survey responses were cross-checked with independent primary and secondary sources and in many cases augmented with "hard" economic data (see appendix). Overall, the evidence indicates that no inflation targeter had these preconditions in place before adopting inflation targeting, although—unsurprisingly—industrial economy targeters were generally in better shape than emerging market inflation targeters at least in some dimension (table 7).

Institutional Independence

Most of the central banks enjoyed at least de jure instrument independence at the time they adopted inflation targeting.[29] However,

27. These countries included Botswana, Guatemala, India, Indonesia, Malaysia, Pakistan, Russia, Tanzania, Turkey, and Uruguay.

28. The version for targeters was similar in all respects but focused on change before and after the current monetary regime.

29. Instrument independence, which allows the central bank full control over setting the policy instrument, is by far the more important criterion of central bank independence. Goal independence, or the ability of the central bank to set macroeconomic objectives unilaterally, is rare, even in industrial countries, where goals are typically determined by the elected government or through consultation between the central bank and the government (see Debelle and Fischer, 1994).

Table 7. Preconditions and Current Conditions in Inflation Targeting and Nontargeting Emerging Market and Industrial Countries

	Targeters				*Nontargeters*	
	Emerging markets		*Industrial countries*		*Emerging markets*	
Item	*Pre-adoption*	*Current*	*Pre-adoption*	*Current*	*Pre- adoption of current regime*	*Current*
Technical infrastructure	0.29	0.97	0.74	0.98	0.51	0.62
Data availability	0.63	0.92	0.84	0.94	0.65	0.70
Systematic forecast process	0.10	1.00	1.00	1.00	0.60	0.80
Models capable of conditional forecasts	0.13	1.00	0.38	1.00	0.28	0.35
Financial system health	0.41	0.48	0.53	0.60	0.40	0.49
Bank regulatory capital to risk-weighted assets	0.75	1.00	0.75	1.00	0.71	0.86
Stock market capitalization to GDP	0.16	0.21	0.28	0.44	0.16	0.19
Private bond market capitalization to GDP	0.10	0.07	0.40	0.31	0.29	0.20
Stock market turnover ratio	0.29	0.22	0.28	0.35	0.37	0.45
Currency mismatch	0.92	0.96	1.00	1.00	0.67	0.97
Maturity of bonds	0.23	0.43	0.46	0.52	0.18	0.29

Table 7. (continued)

	Targeters				*Nontargeters*	
	Emerging markets		*Industrial countries*		*Emerging markets*	
Item	*Pre-adoption*	*Current*	*Pre-adoption*	*Current*	*Pre- adoption of current regime*	*Current*
Institutional independence	0.59	0.72	0.56	0.78	0.49	0.64
Fiscal obligation	0.77	1.00	0.75	1.00	0.50	0.70
Operational independence	0.81	0.96	0.63	1.00	0.70	1.00
Central bank legal mandate	0.50	0.62	0.16	0.44	0.40	0.55
Governor's job security	0.85	0.85	1.00	1.00	0.80	0.80
Fiscal balance as percentage of GDP	0.48	0.47	0.45	0.78	0.38	0.42
Public debt as percentage of GDP	0.47	0.47	0.53	0.54	0.35	0.46
Central bank independence	0.26	0.64	0.44	0.72	0.32	0.55
Economic structure	0.36	0.46	0.47	0.55	0.55	0.44
Exchange rate pass-through	0.23	0.44	0.31	0.50	0.33	0.42
Sensitivity to commodity prices	0.35	0.42	0.44	0.56	0.67	0.55
Extent of dollarization	0.69	0.75	1.00	1.00	0.63	0.60
Trade openness	0.18	0.21	0.13	0.16	0.56	0.19

Sources: IMF, *Global Financial Stability Report;* IMF, *International Financial Statistics;* national sources; OECD; Ramon-Ballester and Torsten (2005); World Bank, *Financial Structure and Economic Development Database*; IMF staff calculations.
Note: A value of 1 represents best current practice.

survey responses—corroborated by consulting the relevant central bank laws—indicate that only one fifth[30] of the emerging market targeters contemporaneously satisfied other key indicators[31] of independence at adoption and thus can be characterized as having adopted inflation targeting under a very high degree of legal autonomy.[32] Of course, it is possible that even legal provisions designed to shield the central bank from pressures to monetize might be overwhelmed by a dire fiscal imbalance.

The data suggest that inflation targeters faced a wide variety of fiscal conditions at the time they adopted inflation targeting. Israel and the Philippines, for example, had high public debt/GDP ratios and large fiscal deficits, while Chile was in good fiscal shape. The emerging market inflation targeters did, however, tend to have somewhat higher public debt levels than the industrial country targeters.

Technical Infrastructure

Central bank survey responses indicate that the majority of industrial and emerging market targeters started with little or no forecasting capability and no forecasting model; when a small model was available, most central banks report that it was not suitable to make forecasts conditional on different assumptions for the monetary policy instrument.[33] In addition, although industrial country targeters often had some sort of systematic forecast process in place, most emerging market targeters did not. Key data to generate forecasts and analyze spending and price patterns were missing or of low quality

30. This overall picture is borne out by broader measures of central bank independence, notably by indices prepared by Arnone and others (2005), based in turn on the methods of Grilli, Masciandaro and Tabellini (1991).

31. These include freedom from any obligation for the central bank to purchase government debt, thus preventing monetization; a high degree of job security for the central bank governor (a fixed term and provisions that allow the governor to be fired only with cause); and the presence of an inflation-focused mandate in which price stability is the sole stated objective.

32. Legal autonomy has sometimes been granted concurrently with—or, in one case, after—the adoption of inflation targeting. Many of the central banks in the sample achieved greater independence in the early 1990s (see Jácome, 2001 for a survey of developments in Latin America). Hungary and the Republic of Korea became fully independent just as inflation targeting was being adopted, suggesting a recognition of the close connection between the two phenomena. The Central Bank of Thailand, which adopted inflation targeting in 2000, continues to operate under a charter from 1942 that says almost nothing about monetary autonomy. A new central bank law is reportedly under consideration by the Thai parliament.

33. Exceptions are Canada, Sweden, and the United Kingdom among industrial countries and Poland and South Africa among emerging markets.

at the time inflation targeting was adopted, with emerging market targeters at a disadvantage relative to industrial country targeters.

Economic Structure

None of the targeters enjoyed ideal economic conditions at the time they adopted targeting. Countries were sensitive to changes in exchange rates and commodity prices when they adopted inflation targeting. Dollarization was not a problem for industrial country targeters; the evidence on dollarization from the survey and from data collected by Ramon-Ballester and Wezel (2005) indicate different degrees of dollarization across emerging market targeters, with Peru the most dollarized targeter.[34] Last but not least, the survey indicates that the consumer price index in a number of targeting countries included at the time of adoption (and in most case still includes) a significant share of administered prices.

Healthy Financial and Banking System

At adoption most targeters scored poorly in terms of the risk-weighted capital adequacy ratio; measures of financial market depth (ratios of stock market capitalization to GDP, private bond issuance to GDP, and stock market turnover or the maximum maturity of actively traded government or corporate nominal bonds); and the extent of banks' foreign currency open positions.

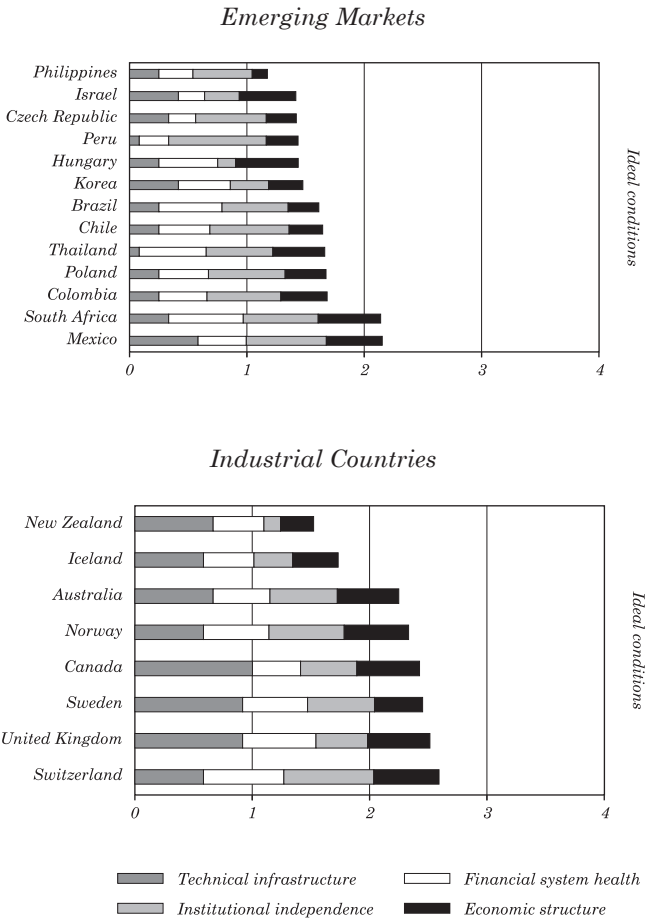
Failure to Meet Preconditions

The fact that none of today's inflation targeters—either individually or on average—met preconditions suggests that failure to meet them is not by itself an impediment to the adoption and success of inflation targeting (figure 3). This finding is confirmed by econometric tests. Using the preconditions listed in table 3 as additional control variables in the regressions from the previous section, we find that no precondition enters significantly in the equations explaining the improvement in macroeconomic performance following the adoption of inflation targeting (table 8).[35]

34. These data are broadly in line with those of Reinhart, Rogoff, and Savastano (2003).

35. The only exception is represented by evidence of greater exchange rate volatility for countries with better developed financial systems before adopting inflation targeting.

Figure 3. Initial Conditions Prior to Adopting Inflation Targeting



Source: IMF staff calculations.
Note: For each of the four categories of initial conditions, 0 = poor and 1 = ideal.

Two other messages emerge from table 7. First, in terms of institutional, technical, and economic characteristics, the gap between inflation targeters (at the time of adoption) and potential emerging market inflation targeting adopters (today) is relatively small, suggesting that these factors should not stand in the way of the successful adoption of inflation targeting in these countries. It is impossible to be completely confident from this analysis that this will be true for other countries that may have much weaker initial conditions than those documented here. But the evidence based on the sample clearly rejects a common view that emerging markets are too fragile and lack the necessary prerequisites to successfully implement an inflation targeting regime.

Second, the evidence and survey responses indicate that the adoption of inflation targeting has been associated with rapid improvements in institutional and technical structures, including developments in data availability and forecasting. Thus even if meeting institutional and technical standards may not be critical before inflation targeting is adopted, a proactive approach to making improvements by the central bank and other parts of government after adopting targeting may be essential to ensure the conditions needed for success.

4. Conclusions

Inflation targeting is a relatively new monetary policy framework for emerging market countries. While the short time period that has elapsed since the adoption of these frameworks means that any assessment must be preliminary, the evidence from the initial years of operation is encouraging, with targeting associated with lower inflation, lower inflation expectations, and lower inflation volatility. There have been no visible adverse effects of targeting on output, and performance along other dimensions—such as the volatility of interest rates, exchange rates, and international reserves—has been favorable. All this may explain the appeal of this strategy for emerging markets in which poor past inflation records have made it difficult to build credibility and minimizing the output costs of reducing inflation is imperative for social and political reasons. It also may explain why no country has yet abandoned inflation targeting.

The evidence suggests that it does not appear to be necessary for emerging market countries to meet a stringent set of institutional, technical, and economic preconditions before successfully adopting

Table 8. Do Preconditions Need To Be Met before Inflation Targeting Is Adopted?

Variable	*Technical infrastructure*	*Financial system health*	*Economic structure*	*Institutional independence*
CPI inflation	5.599	6.553	0.831	–1.517
Volatility of CPI inflation	1.056	–0.260	–2.759	–1.141
Volatility of real output growth	4.288	–0.561	–2.907	–2.275
Volatility of output gap	–.007	–0.006	–0.004	–0.032
5-year inflation forecast	0.358	–1.479	2.193	–0.463
Volatility of 5-year inflation forecast	–0.198	0.192	0.216	–0.064
6- to 10-year inflation forecast	–0.615	–1.778	0.432	–1.719
Volatility of 6–10-year inflation forecast	–0.287	0.507	0.227	–0.077
Exchange market pressure index	0.464	0.599	-0.203	0.796
Exchange rate volatility	22.302	39.792*	–14.650	0.786
Reserves volatility	5.610	2.674	–1.437	–28.867
Volatility of real interest rate	–3.034	–3.169	–1.330	1.011

Source: IMF (2005) and IMF staff calculations.
* Significant at the 5 percent level.

inflation targeting. Instead, the feasibility and success of targeting appears to depend more on the authorities' commitment and ability to plan and drive institutional change after introducing targeting. Consequently, policy advice to countries that are interested in adopting targeting could usefully focus on the institutional and technical goals central banks should strive for during and after adopting targeting in order to maximize its potential benefits.

Appendix
Data from the Survey on Preconditions and Current Conditions

Variable Descriptions and Data Sources

Unless otherwise noted, all data run from 1985:Q1 through 2004:Q4.

- *Inflation rate*. Calculated as the annual growth rate of the consumer price index. Quarterly data were obtained from the IMF's *International Financial Statistics* and data from the Organisation for Economic Co-operation and Development (OECD).

- *Output growth rate*. Annual growth rate of real GDP in local currency. Quarterly data were obtained from the IMF's *International Financial Statistics* and *World Economic Outlook* and from OECD data.

- *Output gap*. Calculated as the residual from a regression of the logarithm of real GDP on a constant term, a linear trend, and a quadratic trend.

- *Nominal short-term interest rate*. Three-month money market interest rate or deposit rate. Quarterly data were obtained from the IMF's *International Financial Statistics* and *World Economic Outlook* and from OECD data.

- *Foreign exchange rate*. Local currency per U.S. dollar. Quarterly data were obtained from the IMF's *International Financial Statistics*.

- *International reserves minus gold*. In U.S. dollars. Quarterly data were obtained from the IMF's *International Financial Statistics*.

- *Broad money*. In local currency, broadest definition available. Quarterly data were obtained from the IMF's *International Financial Statistics* and *World Economic Outlook*.

- *Inflation expectations*. Survey data were obtained from Consensus Economics, Inc. Availability varies by country.

Indicators of Preconditions and Current Conditions

Central Bank Infrastructure

These three survey-based indicators are intended to measure central banks' data resources, modeling, and forecasting capabilities. For the regression analysis, an index of central bank infrastructure was created as the simple average of these three measures.

- *Data availability*. Survey questions 78 and 84 asked whether all essential macroeconomic data were available at the time inflation targeting was adopted. Answers were coded as 1 if all data were available, reliable, and of good quality and as 0 if any data were missing. A value of 0.25 was assigned if all data were available but most were either highly unreliable (because, for example, they were typically subject to large revisions or available only at low frequencies). A value of 0.75 was assigned if all data were available but all were not reliable or of good quality,

- *Systematic forecast process*. Survey questions 47–52 asked about the forecasting capabilities in place at the time of adoption. If a periodic, systematic forecast process was already in place, the variable was set at 1; if no such process was in place, the variable was set to 0.

- *Models capable of conditional forecasts*. Based on responses to survey questions 47–52, a variable was created and set to 1 if forecasting models capable of generating conditional forecasts were available; the variable was set to 0 if no such models were available.

Health of the Financial System

Six indicators measure the degree of development and degree of soundness of the banking and financial system. Two are taken from the survey responses; four are based on nonsurvey data sources. For the regression analysis, an index of banking and financial conditions was created as the simple average of these six measures. In most cases the health of the United Kingdom's financial system was taken as the benchmark in constructing the components of the index itself, on the grounds that the United Kingdom is widely considered to be financially developed and sound from a financial regulatory point of view.

- *Percentage of banks' risk-weighted assets*. Using data compiled and reported in a previous IMF study,[36] a variable was created and set to 1 for countries in which the banking system, in aggregate, had regulatory capital in excess of 10 percent of risk-weighted assets; the variable was set to 0 for countries not meeting this standard.

- *Stock market capitalization*. Using data from the World Bank, the ratio of stock market capitalization to GDP was calculated for each country in the sample and scaled to the ratio for the United Kingdom, so that a value of 1 indicates a degree of stock market capitalization comparable to that of the United Kingdom.[37]

- *Depth of private bond market*. Using the same World Bank data, the ratio of privately issued bonds outstanding to GDP was calculated for each country in the sample and scaled to the ratio for the United Kingdom, so that a value of 1 indicates a degree of private bond market depth comparable to that of the United Kingdom.

- *Stock market turnover*. Using the same World Bank data, the ratio of stock market turnover to GDP was calculated for each country in the sample and scaled to the ratio for the United Kingdom, so that a value of 1 indicates a transaction volume comparable to that of the United Kingdom.

- *Lack of currency mismatch*. Survey question 106 asked central banks to characterize the degree of currency mismatch faced by domestically owned banks. From the responses to this question, a variable equal to 1 was created if the degree of mismatch was described as "none" or "low." The variable was set equal to 0.5 if "some" or "moderate" mismatch was reported. It was set to 0 of the degree of reported mismatch was "high."

- *Maturity of bonds*. Survey question 114 asked central banks to report the maximum maturity of actively traded bonds. The response to this question was converted to years and divided by 30, so that countries with actively traded 30-year bonds were assigned a value of 1 for this variable.

36. IMF (2005), table 22.

37. The underlying data were obtained from the World Bank Financial Structure and Economic Database (http://www.worldbank.org/research/projects/finstructure/database.htm).

Institutional Independence

Six indicators gauge the degree to which the central bank is able to pursue its monetary policy objectives free from conflict with other, competing objectives. Three are based on the responses to the survey administered to central banks (checked for consistency against other central bank sources), three are derived from independent data sources. For the regression analysis, an index of institutional autonomy was created as the simple average of these six measures.

- *Absence of fiscal obligation*. Survey questions 3 and 7 asked central banks whether there was an implicit or explicit obligation to finance government budget deficits. From the responses, a variable was created and set equal 1 if no such obligation existed and 0 otherwise.

- *Operational independence*. Survey questions 4 and 7 asked whether the central bank had full "instrument independence," giving it sole responsibility for setting the monetary policy instrument. A variable was created and set to 1 for countries reporting full instrument independence and 0 otherwise.

- *Inflation-focused mandate*. Survey questions 14 and 18 asked central banks to describe their legal mandate. From these responses, a variable was created and set to 1 if inflation is the only formal objective, to 0.5 if other objectives are specified but inflation takes precedence, and to 0 if other objectives are specified on an equal footing with inflation.

- *Favorable fiscal balance*. Using primary fiscal balance data from the IMF and the OECD, a variable was created indicating a lack of pressure to finance fiscal deficits. For each country in the sample, the ratio of the primary fiscal balance to GDP was calculated and averaged over the two years before the adoption of inflation targeting. (For nontargeters, the most recent two years were used.) This ratio was converted to a score ranging from 0 to 1 using a logistic transformation, scaled in such a way that a budget that was in balance or in surplus was assigned a value of 1 and a budget deficit in excess of 3 percent of GDP was assigned a value of 0.[38]

38. The transformation used is: $\exp(2 \times (\text{balance} + 1.5))/[1 + \exp(2 \times (\text{balance} + 1.5))]$, where "balance" is the fiscal balance, expressed as a percentage of GDP.

- *Low public debt.* Using data from the OECD and the IMF's Fiscal Affairs Department/World Economic Outlook public debt database, the ratio of public debt to GDP was calculated for the year before inflation targeting was adopted. (For nontargeters, the most recent observation was used.) From this, a variable was created equal to the greater of 1 or 1 minus the ratio of debt to GDP. Thus a country with no public debt received a value of 1 and one with a ratio of debt to GDP equal to or greater than 100 received a value of 0.

- *Central bank independence.* This variable is the "overall" measure (the average of political and economic) of central bank independence reported by Arnone and others (2005).[39] These data are available for 1991–92 and 2003. They are scaled so that a value of 1 indicates complete independence while lower values indicate less independence.

Economic Structure

Five indicators capture a variety of economic conditions that are often thought to affect the likelihood of success of inflation targeting. For the regression analysis, an index of economic conditions was created as the simple average of these five measures.

- *Low exchange rate pass-through.* Survey question 96 asked central banks to characterize the degree of exchange rate pass-through. The responses were coded as follows: 1 for "not sensitive," 0.5 for "sensitive," and 0 for "very sensitive."

- *Low sensitivity to commodity prices.* Survey question 97 asked central banks to characterize the degree of sensitivity of inflation to commodity price fluctuations. The responses were coded as follows: 1 for "not sensitive," 0.5 for "sensitive," and 0 for "very sensitive."

- *Extent of dollarization.* Survey question 98 asked central banks to characterize the degree of dollarization in their economies. These responses and data from Ramon-Ballester and Wezel (2005) were used to construct a variable whose value was set to 1 for countries with little or no dollarization, 0.5 for countries with some dollarization, and 0 for countries with a high degree of dollarization.

39. See Arnone and others (2005).

- *Extent of trade openness*. The ratio of exports plus imports to GDP was calculated using data from the IMF's *International Financial Statistics* and *World Economic Outlook* and the OECD. This ratio was then scaled to that of Singapore (the economy with the largest trade share relative to GDP) and subtracted from 1, resulting in an index that equals 1 in the hypothetical case of a completely autarchic economy and 0 for an economy with a degree of trade openness comparable to that of Singapore. Inflation targeters' preconditions were calculated using an average of the trade to GDP ratio over the two years before they adopted inflation targeting; for nontargeters the score was based on the 2004 data.

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New Keynesian Models for Chile in the Inflation-Targeting Period

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Dynamic stochastic general equilibrium (DSGE) models with nominal rigidities have become a popular tool for monetary policy analysis in recent years.[1] The basic sticky price model has been enriched to include additional sources of nominal and real rigidities. These additional elements have been introduced to generate the observed degree of persistence in inflation, real wages, and output.[2] Extensions of these closed economy models to open economies have highlighted the presence of the same types of rigidities.[3]

This paper was written while Felipe Liendo was affiliated with the Central Bank of Chile. The model presented in this paper is a simplified version of the DSGE model currently being developed at the Central Bank of Chile (the MAS project). We thank our discussants, Renzo Rossini and Raphael Bergoeing, and Sebastián Edwards, Douglas Laxton, Andrew Levin, David Rappoport, Claudio Soto, and Rodrigo Valdés for useful suggestions and comments.

1. Prominent examples of monetary business cycle models with price stickiness include Goodfriend and King (1997) and Rotemberg and Woodfoord (1997).

2. Altig and others (2004), Christiano, Eichenbaum, and Evans (2005), and Smets and Wouters (2003b) argue that these ingredients can indeed explain the joint dynamics of inflation, output, real wages, labor, consumption, investment, and nominal interest rates in the U.S. economy.

3. For new open economy models with nominal rigidities, see Adolfson and others (2005a, 2005b); Benigno and Benigno (2003); Galí and Monacelli (2005); Schmitt-Grohé and Uribe (2001), and Smets and Wouters (2003a).

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In this paper, we estimate a small open economy DSGE model for Chile to determine, at the aggregate level, the extent and magnitude of alternative sources of nominal and real rigidities to explain business cycles in Chile. Identifying the level of nominal and real rigidities that are present in the economy is a relevant step toward the efficient design of monetary policy. In particular, the existence (or absence) of certain rigidities may have very different implications for the trade-off between output and inflation stabilization that central banks face. For instance, standard new Keynesian models with nominal price rigidities and flexible wages generate a strong policy prescription: the role of monetary policy is to fully stabilize inflation. In this setup, inflation depends only on expected inflation and the gap between current output and its natural level (that is, the level that would prevail in the absence of nominal stickiness). In this framework, the central bank does not face a trade-off: stabilizing inflation is equivalent to stabilizing output from its natural level.

The absence of a trade-off between output and inflation stabilization is what Blanchard and Galí (2005) call the divine coincidence, and it is a controversial feature of the standard new Keynesian model. A frequently used approach to avoid this coincidence is to introduce a cost push shock to the new Keynesian Phillips curve, so the central bank faces a stabilization trade-off (see Clarida, Galí, and Gerler, 1999). This may seem an ad-hoc solution because, as noted by Blanchard and Galí (2005), conventional supply shocks do not appear as disturbances in the baseline new Keynesian model.

A more structural way of dealing with this coincidence is to remove the assumption that wages are flexible. Erceg, Henderson, and Levin (2000) find two important results when both wage and price decisions are staggered. First, the policymaker's welfare function depends on the variance of output, price inflation, and wage inflation; second, it becomes impossible to set more than one variance to zero in the face of exogenous shocks. They thus demonstrate that, in contrast with the standard new Keynesian model with only price rigidities, there is a trade-off between stabilizing the output gap, price inflation, and wage inflation. In this case, the efficient equilibrium (the one under flexible prices and wages) cannot be reached with monetary policy.

The above result can be explained as follows. On the one hand, staggered wage setting can lead to cross-sectional dispersion in hours worked across households. This dispersion imposes a welfare cost because households dislike variations in their labor supply, given that they have an increasing marginal disutility of labor. The policymaker's

welfare function thus depends not only on the variance of output and inflation (as in the standard new Keynesian model with only price rigidities), but also on the variance of wage inflation, which is directly correlated with the variance of employment. The variances of output, price inflation, and wage inflation have a negative weight on the policymaker's welfare function. On the other hand, the fact that wages are staggered implies that marginal costs depend not only on the output gap, but also on the difference between the observed real wage and the equilibrium real wage (see Blanchard and Galí, 2005). As a consequence, the New Keynesian Phillips curve is a function of both the output and real wage gap. In this context, any shock that moves the equilibrium real wage generates a movement in price inflation (because the observed real wage cannot fully adjust toward its equilibrium level). This movement can only be offset by altering the output gap. Therefore, when both wage and price stickiness are introduced, the divine coincidence no longer holds, and there is a trade-off between stabilizing price inflation and output. In contrast with the ad-hoc supply shocks that are usually introduced to generate a trade-off between price inflation and output gap stabilization, in this case this trade-off arises endogenously.

Blanchard and Galí (2005) consider real rigidities, such as wage indexation, in addition to nominal rigidities, such as price and wage stickiness. In this case, the existence of a stabilization trade-off will depend on both the degree of wage inertia and the nominal rigidities.

A policy rule that seeks to fully stabilize inflation is clearly suboptimal in the presence of wage rigidities. In particular, it can exacerbate the volatility of both output and wage inflation. In this case, an alternative policy rule that seeks to minimize the volatility of a weighted average of wage and price inflation may perform better, as shown by Erceg, Henderson, and Levin (2000) and Blanchard and Gal (2005). In other words, optimal policy prescriptions depend on the set of frictions that the economy faces and, in particular, the importance of nominal and real rigidities in the wage setting process.[4]

Standard reduced-form models, with no explicit microeconomic foundations, are unable to identify, in practice, the source of nominal

4. Additional examples of optimal monetary policy with sticky prices and one or more nominal or real frictions include Adão, Correia, and Teles (2003); Benigno and Woodford (2004); Kahn, King, and Wolman (2003); Lama and Medina (2004); Schmitt-Grohé and Uribe (2004, 2005); and Woodford (2001).

and real frictions. Their contribution to policy analysis is thus rather limited. We lay down a structural model containing both nominal and real frictions and estimate it for Chile. The model features habit formation in the consumer's utility function, introduces wage and price rigidities, and allows for the possibility of imperfect exchange rate pass-through to import prices. We also explore alternative specifications for the monetary policy reaction function, assessing whether the central bank has reacted to expected, contemporaneous, or past inflation. Finally, we also conduct a subsample analysis to determine whether any of the relevant rigidities or policy coefficients changed after 1999, when full-fledged inflation targeting and a free-floating exchange rate regime were introduced.

We use Bayesian techniques to estimate the model. To apply this methodology we combine priors and the likelihood function to obtain the posterior distribution of structural parameters. The likelihood function of the parameters is evaluated using the Kalman filter of a log-linear approximation of the model. We use the Metropolis-Hastings algorithm to approximate the posterior distribution.

We adopt a Bayesian approach for various reasons.[5] First, the Bayesian approach is system-based and fits the dynamic stochastic general equilibrium model to a vector of time series. Second, the estimation is based on the likelihood function generated by the DSGE model, rather than, for instance, the discrepancy between DSGE model responses and vector autoregression (VAR) impulse responses. Third, prior distributions can be used to incorporate additional information into the parameter estimation. Fourth, this approach can cope with potential model misspecification and possible lack of identification of the parameters of interest. In a misspecified model, if the likelihood function peaks at a value that is at odds with the prior information on any given parameter, the posterior probability will be low. The prior density thus allows us to weight information about different parameters according to its reliability. Lack of identification, in turn, may result in a likelihood function that is flat for some coefficient values. Hence, based on the likelihood function alone, it would not be possible to identify the value of the parameters of interest. The Bayesian approach copes with this problem by introducing prior distributions. In fact, a proper prior can introduce curvature into the objective function, the posterior distribution, making it possible to identify the value of

5. See Fernández-Villaverde and Rubio-Ramírez (2004) and Lubik and Schorfheide (2006) for a deeper discussion of the advantages of this approach.

different parameters. Finally, as pointed out by Fernández-Villaverde and Rubio-Ramírez (2004) and Rabanal and Rubio-Ramírez (2005), Bayesian estimation delivers a form for comparing models through, the marginal likelihood. This makes it possible to determine the extent to which additional ingredients of the model help explain the Chilean data. An advantage of using the marginal likelihood to compare models is that it penalizes overparametrization.

In recent years, several macroeconometric models with Keynesian features—for example, a Phillips curve—have been estimated for the Chilean economy to analyze monetary policy.[6] The parameters estimated in this type of model do not have a structural interpretation, however, since they are based on reduced-form equations. In this paper, the parameters estimated do have a structural interpretation. Céspedes, Ochoa, and Soto (2005) similarly estimate a structural Phillips curve for Chile, derived from a new Keynesian model similar to ours. Nevertheless, they make a single equation estimation of that Phillips curve, which can still suffer from identification problems because it does not take into account the cross-correlation between inflation and the rest of the equations in the system.[7] Other studies use general equilibrium models for the Chilean economy, in which the parameters have a structural interpretation. However, the values of the parameters in these models are calibrated and not estimated.[8] Moreover, these models do not consider nominal rigidities such as those emphasized by the new Keynesian literature. Caputo and Liendo (2005) estimate a general equilibrium model for Chile based on Galí and Monacelli (2005), where wages are fully flexible and aggregate consumption is completely smooth.[9] This model also lacks the imperfect pass-through to imported prices considered here.

Our main results are as follows. First, models with both price and wage rigidities fit better the Chilean data. Rabanal and Rubio-Ramírez (2005) highlight the presence of both staggered prices and wage setting as salient features for explaining U.S. data. They also

6. See Corbo and Tessada (2005); García, Herrera, and Valdés (2002); García and others (2005); and Medina and Valdés (2002). Gallego, Schmidt-Hebbel, and Servén (2005) develop a general equilibrium model derived from first principles, but in which some equations (such as the labor supply) are reduced form and not fully consistent with the rest of the model.

7. See Leeper and Zha (2000) for a discussion of identification problems in the estimation of reduced-form equations or partial equilibrium models.

8. See, for example, Bergoeing and Soto (2005); Duncan (2005).

9. This last result is due to the fact that the model displays perfect risk sharing in international financial markets and does not incorporate habit in consumption.

show that the point estimates of price rigidity are higher than those of wages in the U.S. economy.[10] In our case, the degree of rigidity is higher for wages than for prices. Our estimation shows that nominal wages are optimally adjusted every three quarters, on average, while the optimal horizon for price adjustments is every two quarters. The subsample analysis suggests that both prices and wages were adjusted less frequently after 1999 than before. This result is in line with Céspedes and Soto (in this volume), who find that a highly credible inflation-targeting regime leads to less frequent price adjustments. Another relevant feature of the Chilean economy is the imperfect pass-through from the exchange rate to import prices. Our results indicate that import prices are kept fixed for around two years, on average, with a degree of stickiness that does not change over time.

Second, adding wage indexation clearly improves the fit of the model. This level of indexation is comparatively larger than that of domestic and import prices. Wage indexation generates a more persistent response of inflation to shocks, and makes inflation fluctuations more costly in terms of output and labor.[11] It is also, as mentioned above, one of the determinants of the monetary policy trade-off.

Third, real rigidities such as habit formation also deliver a better account of the aggregate data, although the estimated values are quantitatively small. Chari, Kehoe, and McGrattan (2000) point out that models with nominal rigidities do not generate enough persistence in output following a monetary shock as predicted by semi-structural VARs in U.S. The inclusion of habit formation in consumption has helped solve this issue.[12] In the case of Chile, our work confirms the relevance of this type of real rigidity to explain business cycle fluctuations.

Fourth, models with a Taylor rule that reacts to expected inflation better characterize the monetary policy in the sample period. As found by Corbo (2002), Schmidt-Hebbel and Tapia (2002), and Caputo (2005), the policy response to inflation is comparatively larger than the response to output and to exchange rate. On the other hand, the subsample analysis indicates that the degree of interest rate smoothness increased after 1999, while the response to inflation relative to output became less aggressive. This result may be an

10. The calibrated values used by Christiano, Eichenbaum, and Evans (2005) suggest that wages are slightly stickier than prices.

11. See Jadresic (2002).

12. See Fuhrer (2000).

indication that, in a context of greater policy credibility, the inflation target can be achieved with a lower sacrifice ratio.

The rest of the paper is organized as follows. Section 1 describes the structure of a dynamic general equilibrium model for the Chilean economy. Section 2 then explains the econometric strategy to estimate the parameters and compare models. In this section, we also describe the data used and our choice of priors and calibrated parameters to construct the posterior distribution. In section 3, we present the results of the Bayesian estimation. Finally, section 4 concludes.

1. A Simple Small Open Economy Model

In this section, we describe a dynamic stochastic general equilibrium (DSGE) model with nominal and real rigidities. This microfounded model is closely related to the new open economy literature. It is a simplified version of Medina and Soto's (2005) model for the Chilean economy, but to make this paper self-contained, we subsequently describe the structure of the model and the decision problems of the agents.

In this setup, the domestic economy is open to international markets, and it is small for the rest of the world. The last assumption implies that international prices, foreign interest rates, and foreign demand are not affected by domestic agents. The main rigidities of the baseline model are the following: sticky prices and wages, past inflation indexation of prices and wages, and habit formation in consumption. Home goods are sold to domestic and foreign households. We also assume that these goods are an imperfect substitute of the foreign (imported) good.

The economy includes two types of firms: intermediate goods producers and retailers. The first type produces differentiated varieties of intermediate goods. For simplicity, we assume that labor is the only variable input used for production. These firms have monopolistic power over the variety of goods they produce. The second type of firms are competitive retailers that combine intermediate goods to produce home goods.

Households supply a differentiated labor service and receive the corresponding wage compensation. Each household has a monopolistic power over the type of labor service it provides. Furthermore, households are the owners of firms producing intermediate goods, so they receive the income corresponding to the monopolistic rents generated by these firms.

Monetary policy is modeled as a Taylor-type rule that incorporates interest rate inertia. In particular, the interest rate reacts to inflation, GDP growth, and its own lagged value. The rule is augmented to include a response to nominal exchange movements. We also test whether the data support a reaction to expected, contemporaneous, or past inflation.

We assume that labor productivity grows at a rate g_y. Finally, we also assume that in the steady state, the inflation rate is exogenously determined by the monetary authority, and it is nonzero.

1.1 Households

The domestic economy is inhabited by a continuum of households indexed by $j \in [0, 1]$. The expected present value of the utility of household j is given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log\left[C_t(j) - b\left(1+g_y\right) C_t \right] - \zeta_t \frac{\left[l_t(j) \right]^{1+\sigma_L}}{1+\sigma_L} + \frac{\varpi}{u+1} \left(\frac{M_t(j)}{P_t} \right)^{u+1} \right\} \quad , \quad (1)$$

where $l_t(j)$ is labor effort, $C_t(j)$ is total consumption, and $M_t(j)$ corresponds to the total nominal balances held at the beginning of period t. The inverse elasticity of labor supply with respect to real wages is represented by σ_L, while ζ_t is a preference shock that shifts the labor supply. The ϖ coefficient represents the importance of real balances, $M_t(j)/P_t$ in the utility function. Preferences display habit formation, measured by the parameter b. The consumption good is a composite of home and imported goods:

$$C_t(j) = \left\{ (1-\alpha)^{1/\eta} \left[C_{H,t}(j) \right]^{(\eta-1)/\eta} + \alpha^{1/\eta} \left[C_{F,t}(j) \right]^{(\eta-1)/\eta} \right\}^{\eta/(\eta-1)} , \quad (2)$$

where η is the elasticity of substitution between home and imported goods, and α is the share of imported goods in the domestic consumption basket. For any level of consumption, each household purchases a composite of home and imported goods in period t to minimize the total cost of its consumption basket. Each household thus minimizes $P_{H,t}C_{H,t}(j) + P_{F,t}C_{F,t}(j)$, subject to equation (2), where $P_{H,t}$ and $P_{F,t}$ are the price of home and imported goods, respectively. Therefore, the demand for home and imported goods are given by

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \; ; \; C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \tag{3}$$

The price of the consumption good is defined as

$$P_t = \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{1/(1-\eta)}. \tag{4}$$

We detrend and log-linearize expressions (3) and (4) to obtain the following:[13]

$$\hat{c}_{Ht} = \hat{c}_t - \eta\left(\hat{p}_{Ht} - \hat{p}_t\right), \tag{log 1}$$

$$\hat{c}_{Ft} = \hat{c}_t - \eta\left(\hat{p}_{Ft} - \hat{p}_t\right), \text{ and} \tag{log 2}$$

$$\hat{p}_t = \left(1-\alpha\right)\hat{p}_{Ht} + \alpha\left(\hat{p}_{Ft}\right). \tag{log 3}$$

Domestic households have access to three different types of assets: money, $M_t(j)$; one-period noncontingent foreign bonds, $B_t^*(j)$; and one-period domestic contingent bonds $d_{t+1}(j)$, which pay out one unit of domestic currency in a particular state. There are no adjustment costs in the portfolio composition. However, each time a domestic household borrows from abroad, it must pay a premium over the international price of external bonds. This premium is introduced in the model to obtain a well-defined steady state for the economy.[14] The household budget constraint is thus given by

$$\begin{aligned} P_t C_t(j) + E_t\left[q_{t,t+1} d_{t+1}(j)\right] + \frac{e_t B_t^*(j)}{\left(1+i_t^*\right)\Theta\left(\frac{e_t B_t^*}{P_{X,t} X_t}\right)} + M_t(j) = \\ W_t(j) l_t(j) + d_t(j) + e_t B_{t-1}^*(j) + M_{t-1}(j) + \Pi_t + T_t, \end{aligned} \tag{5}$$

where Π_t are profits received by domestic firms, e_t is the nominal exchange rate, $W_t(j)$ is the nominal wage set by household j, and T_t represents per capita lump-sum net transfers from the government.

13. Lowercase variables with ˆ denote log-linear deviation with respect to the steady-state values.

14. See Schmitt-Grohé and Uribe (2003) for different ways to achieve a steady state that is independent of initial conditions in small open economy models.

The term

$$\Theta\left(\frac{e_t B_t^*}{P_{X,t} X_t}\right)$$

corresponds to the premium domestic households have to pay each time they borrow from abroad, where

$$B_t^* = \int_0^1 B_t^*(j)dj$$

is the aggregate net foreign asset position of the economy and $P_{X,t}X_t$ is the nominal value of exports.[15] Also, $q_{t,t+1}$ is the price of domestic contingent bonds in period t, normalized by the probability of the occurrence of the state. Assuming the existence of a full set of contingent bonds ensures that the consumption of all households is the same, independently of the labor income they receive each period.[16]

Our assumption that the premium depends on the aggregate net foreign asset position of the economy implies that households take $\Theta(\cdot)$ as given when deciding their optimal portfolios. In other words, households do not internalize the effect on the premium of changes in their own foreign asset position. In the steady state, the $\Theta(\cdot)$ function is parameterized as

$$\Theta\left(\frac{eB^*}{P_X X}\right) = \Theta \text{ and } \frac{\Theta'(eB^*/P_X X)}{\Theta(eB^*/P_X X)}\frac{eB^*}{P_X X} = \mu .$$

Here B^*corresponds to the steady-state net foreign asset position, while $P_X X$is the steady-state value of exports. When the country as a whole is a net debtor, μ is the elasticity of the upward slopping supply of international funds.

Consumption and saving decisions

Households choose consumption and the composition of their portfolios by maximizing equation (1) subject to equation (5). The optimal conditions can be combined to obtain log-linear expressions for the Euler equation and the uncovered interest parity condition:

15. Since the economy is growing in the steady state, the net asset position is also growing in the long run. Therefore, to have a stationary risk premium, this premium must be a function of the ratio of the net asset position and some variable that grows at the same rate in the steady state. We chose exports, since they could represent a form of international collateral (see Caballero and Krishnamurthy, 2001)

16. This, in turn, motivates the exclusion of index j in expressions (log 1) and (log 2).

$$\hat{c}_t = \frac{1}{1+b} E_t\left(\hat{c}_{t+1}\right) + \frac{b}{1+b}\hat{c}_{t-1} - \frac{1-b}{1+b}\left[\hat{i}_t - E_t\left(\hat{\pi}_{t+1}\right)\right] \text{ and} \qquad \text{(log 4)}$$

$$\hat{i}_t = \hat{i}_t^* + E_t\left(\Delta\widehat{e}_{t+1}\right) + \mu\left[\widehat{rer_t} + \hat{b}_t^* - \left(\widehat{p}_{X,t} - \widehat{p}_t\right) - \hat{x}_t\right], \qquad (6)$$

where $\hat{e}_t$ is the nominal exchange rate and $\widehat{rer_t} = \hat{e}_t + \widehat{p}_{F,t}^* - \widehat{p}_t$ is the real exchange rate (both measured as the log deviation from their steady-state values). Based on the real exchange rate definition, the nominal exchange rate devaluation can be defined as

$$\Delta\hat{e}_t = \widehat{rer}_t - \widehat{rer}_{t-1} - \hat{\pi}_t^* + \hat{\pi}_t\,, \qquad \text{(log 5)}$$

where $\hat{\pi}_t^*$ is foreign inflation (in foreign currency).

Labor supply decisions and wage setting

Each household *j* is a monopolistic supplier of a differentiated labor service. There is a set of perfectly competitive labor service assemblers that hire labor from each household and combine it into an aggregate labor service unit, l_t, that is then used by the intermediate goods producer. The labor service unit is defined as follows:

$$l_t = \left[\int_0^1 l_t(j)^{(\varepsilon_L - 1)/\varepsilon_L}\, dj\right]^{\varepsilon_L/(\varepsilon_L - 1)}. \qquad (7)$$

where ε_L is the elasticity of substitution of different types of labor. The optimal composition of this labor service unit is obtained by minimizing its cost, given the different wages set by different households. In particular, the demand for the labor service provided by household *j* is:

$$l_t(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\varepsilon_L} l_t\,, \qquad (8)$$

where $W_t(j)$ is the wage rate set by household *j* and W_t is an aggregate wage index defined as

$$W_t = \left[\int_0^1 W_t(j)^{1-\varepsilon_L}\, dj\right]^{1/(1-\varepsilon_L)}. \qquad (9)$$

Following Erceg, Henderson, and Levin (2000), we assume that wage setting is subject to a nominal rigidity à la Calvo (1983). In each period, each household faces a constant probability $(1 - \phi_L)$ of being able to re-optimize its nominal wage. We assume there is an updating rule for all households that cannot re-optimize their wages. In particular, if a household cannot optimize during i periods between t and $t+i$, then its wage at time $t+i$ is given by

$$W_{t+i}(j) = \Gamma^{i}_{W,t} W_t(j), \tag{10}$$

where $\Gamma^{i}_{W,t}$ describes an adjustment rule for wages, which is defined as

$$\Gamma^{i}_{W,t} = \prod_{j=1}^{i} (1+\pi_{t+j-1})^{\xi_L} (1+\bar{\pi}_{t+j})^{1-\xi_L} (1+g_y).$$

This "passive" adjustment rule implies that workers who do not optimally reset their wages update them by considering a geometric weighted average of past CPI inflation and the inflation target set by the authority, $\bar{\pi}_t$. The inclusion of $(1+g_y)$ in the above expression prevents large real wage dispersion along the steady-state growth path. Once a household has decided on a wage, it must supply any quantity of labor service that is demanded at that wage. A particular household j that is able to re-optimize its wages at time t solves the following problem:

$$\max_{W_t(j)} = E_t \left\langle \sum_{i=0}^{\infty} \phi_L^i \Lambda_{t,t+i} \left\{ \frac{W_t(j)\Gamma^{i}_{W,t}}{P_{t+i}} \right.\right.$$

$$\left.\left. -\zeta_t \left[l_{t+i}(j) \right]^{\sigma_L} \left[C_{t+i} - b(1+g_y) C_{t+i-1} \right] \right\} \right\rangle l_{t+i}(j),$$

subject to the labor demand (equation 8) and the updating rule for the nominal wage (equation 10). The variable $\Lambda_{t,t+i}$ is the relevant discount factor between periods t and $t+i$; it is given by

$$\Lambda_{t,t+i} = \beta^i \frac{C_t - b(1+g_y)C_{t-1}}{C_{t+i} - b(1+g_y)C_{t+i-1}}.$$

Combining the optimal choice of wages with the updating rule and the definition of the aggregate real wage, we obtain the following log-linear expression for real wages, *wr*:

$$\begin{bmatrix}1+\nu_L\phi_L \\ +\sigma_L\varepsilon_L(\phi_L+\nu_L)\end{bmatrix}\widehat{wr}_t = (1-\nu_L)(1-\phi_L)\left(\sigma_L\hat{l}_t + \frac{1}{1-b}\hat{c}_t - \frac{b}{1-b}\hat{c}_{t-1} + \hat{\zeta}_t\right)$$
$$+(1+\sigma_L\varepsilon_L)\phi_L\widehat{wr}_{t-1} + (1+\sigma_L\varepsilon_L)\nu_L E_t(\widehat{wr}_{t+1}) \qquad (\log 6)$$
$$-(1+\sigma_L\varepsilon_L)(\phi_L+\nu_L\xi_L)\hat{\pi}_t + (1+\sigma_L\varepsilon_L)\phi_L\xi_L\hat{\pi}_{t-1}$$
$$+(1+\sigma_L\varepsilon_L)\nu_L E_t(\hat{\pi}_{t+1}),$$

where $\nu_L = \beta\phi_L$

1.2 Home Goods Sector

There are two types of firms in this sector: retailers and intermediate goods producers. The latter use labor to produce a differentiated good while the former combine these intermediate inputs to produce the home good consumed by domestic and foreign households.

Retailers

Retailers create units of home goods according to a constant-elasticity-of-substitution aggregator of a continuum of intermediate products that are indexed on the unit interval, $z_H \in [0, 1]$. Specifically, retailers produce $Y_{H,t}$ units of home goods using the following constant-return-to-scale technology:

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(z_H)^{(\varepsilon_H-1)/\varepsilon_H}\, dz_H\right]^{\varepsilon_H/(\varepsilon_H-1)} \qquad (11)$$

Retailers then allocate their demands for intermediate goods by minimizing the total cost of production, subject to equation (11), where. ε_H is the elasticity of substitution of differentiated intermediate goods. The optimal combination of intermediate goods determines a demand for each variety, z_H:

$$Y_{H,t}(z_H) = Y_{H,t}\left[\frac{P_{H,t}(z_H)}{P_{H,t}}\right]^{-\varepsilon_H}, \qquad (12)$$

where $P_{H,t}(z_H)$ is the price of the variety z_H and $P_{H,t}$ is the aggregate price level of home goods, which is given by

$$P_{H,t} = \left[\int_0^1 P_{H,t}(z_H)^{1-\varepsilon_H}\, dz_H\right]^{1/(1-\varepsilon_H)}. \tag{13}$$

The total production of home goods is consumed by domestic and foreign households. The foreign demand for home goods is given by the following expression, in log-linear form:

$$\hat{c}^*_{Ht} = \hat{c}^*_t - \eta^*\left[\left(\widehat{p}_{Ht} - \widehat{p}_t\right) - \widehat{rer}_t\right], \tag{log 7}$$

where $\hat{c}^*$ is the aggregate level of foreign consumption and η^* is the elasticity of substitution of the foreign demand.

Intermediate goods producers

The producers of intermediate home inputs are assumed to be monopolistic competitors. We further assume that they face a nominal rigidity that prevents them from adjusting prices optimally in every period. For simplicity, we assume that the only variable input is labor. The production function can thus be expressed as follows:

$$Y_{H,t}(z_H) = A_{H,t}(1+g_y)^t\, l_t(z_H), \tag{14}$$

where $A_{H,t}$ is a productivity shock. The cost of producing is $W_t l_t(z_H)$, which implies that the marginal cost of each intermediate firm is equal to $W_t/[A_{H,t}(1+g_y)^t]$.

Following Calvo (1983), we assume that firms adjust their prices infrequently. In particular, they do so when receiving a signal. In every period, the probability of receiving a signal and adjusting prices is $1-\phi_H$ for all firms, independent of their history. If the firm does not receive a signal, then it follows a simple updating rule defined by the function $\Gamma^i_{H,t}$. Thus, if a firm, z_H, receives a signal in period t, then it will adjust the price of its variety, $P_{H,t}(z_H)$, so as to maximize the following expression:

$$\max_{P_{H,t}(z_H)} E_t\left\langle \sum_{i=0}^{\infty}(\phi_H)^i\, \Lambda_{t,t+i} \times\left\{\frac{\Gamma^i_{H,t}P_{H,t}(z_H) - W_t\Big/\left[A_{H,t}(1+g_y)^t\right]}{P_{t+i}}\right\} Y_{H,t+i}(z_H)\right\rangle, \tag{15}$$

subject to the restrictions imposed by the technology and considering the demand the firm faces for its variety (equation 12). The passive adjustment rule is given by

$$\Gamma^{i}_{H,t} = \prod_{j=1}^{i} (1+\pi_{H,t+j-1})^{\xi_H} (1+\bar{\pi}_{t+j})^{1-\xi_H}, \tag{16}$$

where $1+\pi_{H,t} = (P_{H,t}/P_{H,t-1})$, and where $\bar{\pi}_{t+j}$ corresponds to the inflation target set by the authority. Relative price changes may have a feedback impact through this adjustment rule. Firms that do not optimally adjust take into consideration the inflation target, which is set in terms of consumption goods inflation. The parameter ξ_H captures the degree of indexation in the economy. The larger this parameter, the larger is the weight of past inflation in defining new prices.

Combining the optimal price setting with the automatic updating rule yields a hybrid Phillips curve for home goods inflation:

$$\hat{\pi}_{Ht} = \frac{\beta}{1+\beta\xi_H} E_t\left(\hat{\pi}_{Ht+1}\right) + \frac{\xi_H}{1+\beta\xi_H}\hat{\pi}_{Ht-1} + \frac{(1-\phi_H)(1-\beta\phi_H)}{\phi_H(1+\beta\xi_H)}\left(\widehat{wr}_t + \hat{p}_t - \hat{p}_{Ht} - \hat{a}_{Ht}\right). \tag{log 8}$$

1.3 Imports

The import sector consists of a continuum of firms that buy a homogeneous good in the foreign market. These firms turn the imported good into a differentiated import.[17] Competitive assemblers combine this continuum of differentiated imports in a final imported good, Y_F. The technology of importing assemblers is given by

$$Y_{F,t} = \left[\int_0^1 Y_{F,t}(z_F)^{(\varepsilon_F-1)/\varepsilon_F}\, dz_F\right]^{\varepsilon_F/(\varepsilon_F-1)},$$

where ε_F is the elasticity of substitution of differentiated import goods and $Y_{F,t}(z_F)$ is the quantity of a differentiated import, z_F, used by the assemblers. The optimal mix of the differentiated import is given by the following demand:

17. This differentiating technology can be interpreted as product branding.

$$Y_{F,t}(z_F) = Y_{F,t}\left[\frac{P_{F,t}(z_F)}{P_{F,t}}\right]^{-\varepsilon_F}, \tag{17}$$

where $P_{F,t}(z_F)$ is the price of the import brand, z_F, charged in the domestic market, and $P_{F,t}$ is the aggregate price of imported goods in the domestic market:

$$P_{F,t} = \left[\int_0^1 P_{F,t}(z_F)^{1-\varepsilon_F}\, dz_F\right]^{1/(1-\varepsilon_F)}.$$

The different importing firms buy the homogeneous foreign good abroad at price $P^*_{F,t}$, in foreign currency. Each importing firm possesses monopoly power over the domestic retailing of its variety. We assume local currency price stickiness to allow for incomplete exchange rate pass-through to the import prices. An importing firm adjusts the domestic price of its variety infrequently, when receiving a signal. The signal arrives with probability $1 - \phi_F$ each period. The arrival of the signal is independent of the history of a particular firm and identically distributed across importing firms. As in the case of domestically produced goods, if a firm does not receive a signal, it updates its price following a passive rule. This passive rule is defined through $\Gamma^{i}_{F,t}$ and states that if an importer, z_F, does not receive a signal to optimally adjust its price between time t and $t + i$, then its price at time $t + i$ is given by $\Gamma^{i}_{F,t}P_{F,t}(z_F)$. The updating rule is defined as

$$\Gamma^{i}{}_{F,t,t+i} = \prod_{j=1}^{i}(1+\pi_{F,t+j-1})^{\xi_F}\,(1+\bar{\pi}_{t+j})^{1-\xi_F},$$

where $1 + \pi_{F,t} = P_{F,t}/P_{F,t-1}$.

Hence, when a generic importing firm, z_F, receives a signal, it chooses a new price by maximizing the following expression:

$$\max_{P_{f,t}(z_F)} E_t\left[\sum_{i=0}^{\infty}(\phi_F)^{i}\Lambda_{t,t+i}\,\frac{\Gamma_{F,t,t+i}P_{F,t}(z_F) - e_{t+i}P^*_{F,t+i}(z_F)}{P_{t+i}}Y_{F,t+i}(z_F)\right],$$

subject to the domestic demand for variety z_F (equation 17) and the updating rule. As in the case of home goods, the optimal price setting can be combined with the automatic updating rule to obtain a Phillips curve for the inflation of imported goods in the domestic market:

$$\hat{\pi}_{F,t} = \frac{\beta}{1+\beta\xi_F} E_t\left(\hat{\pi}_{F,t+1}\right) + \frac{\xi_F}{1+\beta\xi_F}\hat{\pi}_{F,t-1} + \frac{(1-\phi_F)(1-\beta\phi_F)}{\phi_F(1+\beta\xi_F)}\left(\hat{e}_t + \hat{p}^*_{F,t} - \hat{p}_{F,t}\right). \quad \text{(log 9)}$$

1.4 Monetary Policy

We assume that monetary policy in Chile could be modeled as a Taylor-type rule:

$$\hat{r}_t = \psi_i \hat{r}_{t-1} + (1-\psi_i)(\psi_\pi \hat{\pi}_t + \psi_y \hat{y}_t + \psi_{\Delta e}\Delta\hat{e}_t) + \nu_t^m \quad \text{(log 10)}$$

To be consistent with monetary policy in Chile during the sample period analyzed, we consider the real interest rate, $\hat{r}_t$, as the monetary policy instrument. In this specification, ψ_π and ψ_y are, respectively, the long run responses of the monetary authority to deviations of inflation and GDP growth from their target levels (steady-state values). We also include a reaction to the nominal devaluation, $\psi_{\Delta e}$, to analyze empirically whether this feature is relevant for Chile. Finally, ψ_i controls for the degree of interest rate smoothing, which has been proved to be important for explaining monetary policy empirically.

This specification has been estimated for Chile in several papers, including Schmidt-Hebbel and Tapia (2002), Caputo (2005), Parrado and Velasco (2002), and Corbo (2002). The evidence generally supports the existence of a Taylor-type policy reaction function that responds to inflation deviations from target, to output, and to real exchange rate misalignments. The papers cited above perform their estimations in a univariate setting. In this paper, the policy rule coefficients are estimated along with the rest of the coefficients that characterize the economy. This allows us to exploit cross-equation restrictions that link agents' decision rules to the policy parameters.

Finally, the real (ex-ante) and nominal interest rates are linked through the following identity:

$$\hat{r}_t = \hat{i}_t - E_t\left(\widehat{\pi}_{t+1}\right) \quad \text{(log 11)}$$

1.5 Aggregate Equilibrium

Using the aggregate equilibrium in the labor market, we can write the market-clearing condition for the home goods sector as,

$$\hat{a}_{H,t} + \hat{l}_t = \left(\frac{C_H}{Y_H}\right)\hat{c}_{H,t} + \left(1 - \frac{C_H}{Y_H}\right)\hat{c}^*_{H,t}, \qquad \text{(log 12)}$$

where C_H/Y_H is the steady-state fraction of home goods production that is consumed by domestic households.[18]

Total GDP is given by

$$Y_t = C_t + P_{X,t}X_t - e_t P^*_{F,t}C_{F,t}.$$

$P_{X,t}X_t$ is the total level of exports, which is given by,

$$P_{X,t}X_t = P_{H,t}C^*_{H,t} + X_{S,t},$$

where $X_{S,t}$ is the level of commodity exports, which represents a significant share of Chilean exports. We treat this component of exports as exogenous and stochastic.[19] We log-linearize the GDP around the steady-state growth path to get

$$\hat{y}_t = \left(1 - \frac{NX}{Y}\right)\hat{c}_t + \left(\frac{C^*_H}{Y}\right)\hat{c}^*_{Ht} + \left(\frac{X}{Y} - \frac{C^*_H}{Y}\right)\hat{x}_{St} - \alpha\left(1 - \frac{NX}{Y}\right)\hat{c}_{F,t}, \qquad \text{(log 13)}$$

where NX/Y is the net exports-to-GDP ratio. The detrended and log-linearized expression for exports is

$$\hat{p}_{X,t} + \hat{x}_t = \left(\frac{C^*_H}{X}\right)(\hat{p}_{H,t} + \hat{c}^*_{H,t}) + \left(1 - \frac{C^*_H}{X}\right)\hat{x}_{S,t}. \qquad (18)$$

18. We do not need to specify the money market equilibrium condition since money is separable in the utility function and the policy instrument is the interest rate.

19. In Chile commodities represent a significant share of total exports. These commodities are produced independently of domestic economic conditions (the interest rate, real wages, and so forth) and they can therefore be considered as exogenous in the short run.

Using this expression for exports, we can write the uncovered interest parity (equation 6) as follows:

$$\hat{i} = \hat{i}_t^* + E_t(\Delta\hat{e}_{t+1}) + \mu\left\{\hat{rer}_t + \hat{b}_t^* - \left(\frac{C_H^*}{Y}\right)\left(\frac{Y}{X}\right)\left(\hat{p}_{H,t} - \hat{p}_t + \hat{c}_{H,t}^*\right) - \left[1 - \left(\frac{C_H^*}{Y}\right)\left(\frac{Y}{X}\right)\right]\hat{x}_t\right\}. \tag{log 14}$$

Since we model an open economy, the net foreign asset evolution is governed by (log-linear form)

$$\begin{aligned}\frac{1-\mu}{\left(1+i^*\right)\Theta}\hat{b}_t^* = &\left[\frac{1}{\left(1+\pi^*\right)\left(1+g_y\right)} - \frac{1-\mu}{\left(1+i^*\right)\Theta} - \left(\frac{M}{Y}\frac{Y}{eB^*}\right)\right]\hat{rer}_t \\ &+ \frac{1}{\left(1+i^*\right)\Theta}\hat{i}_t^* + \frac{1}{\left(1+\pi^*\right)\left(1+g_y\right)}\left(\hat{b}_{t-1}^* - \hat{\pi}_t^*\right) \\ &+ \left[\frac{C_H^*}{Y}\left(\frac{Y}{eB^*}\right) - \frac{\mu}{\left(1+i^*\right)\Theta}\left(\frac{C_H^*}{Y}\right)\left(\frac{Y}{X}\right)\right] \\ &\times\left(\hat{p}_{H,t} - \hat{p}_t + \hat{c}_{H,t}^*\right) \\ &+ \left[\left(\frac{X}{Y} - \frac{C_H^*}{Y}\right)\frac{Y}{eB^*} - \frac{\mu}{\left(1+i^*\right)\Theta}\left(1 - \frac{C_H^*}{Y}\frac{Y}{X}\right)\right] \\ &\times\left[\hat{x}_{S,t} - \left(\frac{M}{Y}\right)\left(\frac{Y}{eB^*}\right)\hat{c}_{F,t}\right].\end{aligned} \tag{log 15}$$

To close the model, we link the change in the real price of home and imported goods with consumption price inflation, as follows:

$$\hat{p}_{H,t} - \hat{p}_t = \hat{p}_{H,t-1} - \hat{p}_{t-1} + \hat{\pi}_{H,t} - \hat{\pi}_t, \text{ and} \tag{log 16}$$

$$\hat{p}_{F,t} - \hat{p}_t = \hat{p}_{F,t-1} - \hat{p}_{t-1} + \hat{\pi}_{F,t} - \hat{\pi}_t. \tag{log 17}$$

1.6 Stochastic Exogenous Process

The economy is subject to seven orthogonal fluctuations: a labor supply shock ($\hat{\zeta}_t$); a foreign interest rate shock ($\hat{i}^*_t$); a foreign inflation shock ($\hat{\pi}^*_t$); a foreign demand shock ($\hat{c}^*_t$); a productivity shock ($\hat{a}_{Ht}$); a monetary policy shock (ν^m_t); and a commodity export shock ($\hat{x}_{St}$). We specify the following stochastic processes for these shocks:

$$\hat{\zeta}_t = \rho_\zeta \hat{\zeta}_{t-1} + \varepsilon_{\zeta,t} \tag{log 18}$$

$$\hat{i}^*_t = \rho_{i^*} \hat{i}^*_{t-1} + \varepsilon_{i^*,t} \tag{log 19}$$

$$\hat{\pi}^*_t = \rho_\pi \hat{\pi}^*_{t-1} + \varepsilon_{\pi^*,t} \tag{log 20}$$

$$\hat{c}^*_t = \rho_{c^*} \hat{c}^*_{t-1} + \varepsilon_{c^*,t} \tag{log 21}$$

$$\hat{a}_{Ht} = \rho_a \hat{a}_{Ht-1} + \varepsilon_{at} \tag{log 22}$$

$$\nu^m_t = \varepsilon_{m,t} \tag{log 23}$$

$$\hat{x}_{St} = \rho_S \hat{x}_{St-1} + \varepsilon_{St} \tag{log 24}$$

where each innovation $\varepsilon_{i,t}$ follows a normal distribution with zero mean and variance $\sigma^2_{i,t}$, for $i = \zeta$, i^*, π^*, c^*, a, m, S, and innovations are uncorrelated with each other.

1.7 Alternative Models

We consider alternative models that reduce the degree of rigidity and modify the specification of the monetary policy rule. In addition to the baseline case, we estimate five models that remove, one by one, some of the nominal and real rigidities for a given policy rule. The first alternative model, M1, removes the assumption that there is incomplete exchange rate pass-through to the import prices; it therefore considers $\phi_F = \xi_F = 0$. The second model, M2, removes the assumption of price indexation of home goods, in addition to incomplete pass-through. That is, in this model, $\phi_F = \xi_F = \xi_H = 0$. The third alternative model, M3, further removes wage indexation, such that $\phi_F = \xi_F = \xi_H = \xi_L = 0$. In this case, inflation is not inertial, and

wages are not indexed to past inflation. The fourth model, M4, removes the assumption that wages are sticky. This means that $\phi_L = 0$, so workers set their wages optimally in each period. As before, $\phi_F = \xi_F = \xi_H = \xi_L = 0$. In this specification, there is no inertial behavior in the inflation equation or in the wage equation. Finally, model M5 assumes no habit formation in the consumers' utility function. As a result, in this specification, $b = 0$ and $\phi_F = \xi_F = \xi_H = \xi_L = \phi_L = 0$. This last case is the standard new Keynesian model with no inertia (inflation and consumption are forward looking) and sticky prices.

For the baseline model (which takes into account the nominal and real rigidities of the economy), we investigate how monetary policy has reacted in the inflation-targeting period. In so doing, we follow Lubik and Schorfheide (2006) and assess the plausibility of alternative policy rule specifications. We are interested in determining what inflation horizon is implicit in the policy reaction function. In particular, we test whether the Central Bank of Chile has been forward- or backward-looking with regard to inflation. In the first case, we modify equation (log 10) by replacing current inflation, $\hat{\pi}_t$, with expected one-period-ahead inflation, $E_t(\hat{\pi}_{t+1})$. In the second case, the target is one-period-past inflation, $\hat{\pi}_{t-1}$.

To compare alternative model specifications, we use the Bayes factor, which enables us to assess which model is more likely to generate the data.

2. Econometric Methodology

Having set up a theoretical model with nominal and real rigidities, we estimate the structural coefficients that characterize the economy. As a previous step, we kept a number of parameters fixed throughout the estimation procedure. Most of these parameters can be related to the steady-state values of the observed variables in the model, and they are therefore calibrated so as to match some long-run statistics. We assume an annual long-run labor productivity growth of 3.5 percent.[20] The long-run annual inflation rate is 3 percent, which is consistent with the target value defined by the Central Bank of Chile in 2001. The subjective discount factor, β, is set close to 0.99 (annual basis) to yield an annual nominal interest rate of 7.0 percent in the steady state. The share of imported goods

20. This is consistent with 5 percent long-run GDP growth and 1.5 percent labor force growth.

in the consumption basket, α, is set at 40 percent, while the share of home goods production in total GDP, Y_H/Y, is set at 90 percent.[21] The ratio of net exports to GDP, NX/Y, in the steady state is equal to 2.0 percent, which is consistent with the average value of this statistic in the sample period analyzed. The remaining shares can be obtained using these values and the steady-state relations (see the appendix). Obtaining direct information on price and wage markups is cumbersome, so we use values in the range used by other studies: $\varepsilon_L = \varepsilon_H = \varepsilon_F = 9$.[22]

We can now estimate the remaining coefficients that characterize the economy. In particular, we want to know the values of $\theta = (\sigma_L, b, \phi_H, \phi_L, \phi_F, \eta, \eta^*, \mu, \xi_L, \xi_H, \xi_F, \psi_i, \psi_\pi, \psi_y, \psi_{\Delta e}, \rho_\zeta, \rho_{i^*}, \rho_{\pi^*}, \rho_{c^*}, \rho_a, \rho_s, \sigma_\zeta, \sigma_{i^*}, \sigma_{\pi^*}, \sigma_{c^*}, \sigma_a, \sigma_s)$. We follow Rabanal and Rubio-Ramírez (2005), Lubik and Schorfheide (2006) and Adolfson and others (2005b) in using Bayesian estimation techniques for both the model estimation and our evaluation.

Simply stated, the Bayesian approach works as follows. First, it places a prior distribution with density $p(\theta)$ on the structural parameters, θ. The data, $\mathbf{Y}^T$, are then used to update the prior distribution through the likelihood function, $L(\theta/\mathbf{Y}^T)$, to obtain the posterior distribution of θ. According to Bayes' theorem, this later distribution, $p(\theta/\mathbf{Y}^T)$, takes the form

$$p\left(\theta/\mathbf{Y}^T\right) = \frac{L\left(\theta/\mathbf{Y}^T\right)p(\theta)}{p\left(\mathbf{Y}^T\right)} \tag{19}$$

Draws from this posterior distribution can be generated through Bayesian simulation techniques. Based on these draws, we can compute the summary statistics (namely, posterior means and standard deviations) that characterize the structural coefficients.

To compare alternative model specifications, we use the marginal likelihood function, which is the probability that the model assigns to having observed the data. It is defined as the integral of the

21. The value-added of natural resources accounts for about 10 percent of total GDP.

22. Christiano, Eichenbaum, and Evans (2005) use $\varepsilon_L = 21$ and $\varepsilon_H = 6$ for a closed economy model calibrated for the United States. Adolfson and others (2005b) use the same values for an open economy model calibrated for the euro area. Brubakk and others (2005) use $\varepsilon_L = 5.5$ and $\varepsilon_H = 6$ for a calibrated model of the Norwegian economy. Jacquinot, Mestre, and Spitzer (2005) calibrate $\varepsilon_L = 2.65$ and $\varepsilon_H = 11$.

likelihood function across the parameter space using the prior as the weighting function:

$$p\left(\mathbf{Y}^T / H_i\right) = \int L\left(\theta / \mathbf{Y}^T, H_i\right) p\left(\theta / H_i\right) d\theta \tag{20}$$

where $p(\mathbf{Y}^T|H_i)$ is the probability of having observed the data under model specification H_i, and $L(\theta/\mathbf{Y}^T,H_i)$ and $p(\theta/H_i)$ are the likelihood function and the prior distribution, respectively, under model specification H_i. A natural way of assessing which model is more plausible is to construct the ratio of the marginal likelihood function under alternative model specifications. This ratio, known as the Bayes factor, takes the following form:

$$B_{i,j} = \frac{p\left(\mathbf{Y}^T / H_i\right)}{p\left(\mathbf{Y}^T / H_j\right)}$$

where $B_{i,j}$ is the Bayes factor of model i over model j. If $B_{i,j} > 1$, model i is more plausible than model j, and vice versa. Since we are unable to obtain the marginal likelihood function in a closed-form, we estimate it as in Geweke (1998) and Rabanal and Rubio-Ramírez (2005), by integrating over the draws used to construct the posterior distribution. These draws are generated through the Metropolis-Hastings algorithm.

2.1 Likelihood Function

To construct the posterior distribution (equation 19), we need to compute the likelihood function. First, we solve the model and write the solution in state-space form. We then use the Kalman filter to evaluate the likelihood of each of the models. In practice we proceed as follows.

Equations (log 1) to (log 24) form a linear rational expectation model in the variables

$$\mathbf{s}_t = \begin{bmatrix} \hat{y}_t, \hat{c}_t, \hat{c}_{H,t}, \hat{c}_{F,t}, \hat{\pi}_t, \hat{\pi}_{H,t}, \hat{\pi}_{F,t}, \hat{r}_t, \hat{i}_t, \Delta\hat{e}_t, \widehat{rer}_t, \widehat{wr}_t, \hat{l}_t, \hat{b}^*_t, \\ \hat{a}_{H,t}, \hat{\zeta}_t, \hat{x}_{S,t}, \hat{c}^*_t, \hat{c}^*_{H,t}, \hat{i}^*_t, \hat{\pi}^*_t, \nu^m_t, \left(\widehat{p}_{H,t} - \widehat{p}_t\right), \left(\widehat{p}_{F,t} - \widehat{p}_t\right) \end{bmatrix}$$

The vector of observables is $\mathbf{y}_t = \left[\hat{y}_t, \hat{\pi}_t, \hat{r}_t, \Delta\hat{e}_t, \widehat{rer}_t, \widehat{wr}_t, \hat{l}_t\right]$ and the rest are endogenous but nonobservable variables. Following Sims (2002), the log-linearized DSGE model can be written as a system of the form

$$\Gamma_0(\theta)\mathrm{s}_t = \Gamma_1(\theta)\mathrm{s}_{t-1} + \Gamma_\varepsilon(\theta)\varepsilon_t + \Gamma_\eta(\theta)\eta_t, \tag{22}$$

where θ is the vector of structural coefficients and Γ_i is a matrix, ε_t stacks the innovations of the exogenous processes, and η_t is composed of rational expectation forecast errors. The solution to equation (22) can be expressed as[23]

$$\mathrm{s}_t = \phi_1(\boldsymbol{\theta})\mathrm{s}_{t-1} + \phi_\varepsilon(\boldsymbol{\theta})\boldsymbol{\varepsilon}_t \tag{23}$$

A measurement equation then relates the model variables, $\mathbf{s}_t$, to the vector of observables, $\mathbf{y}_t$:

$$\mathbf{y}_t = \boldsymbol{A}(\boldsymbol{\theta}) + \boldsymbol{B}\mathbf{s}_t \tag{24}$$

Given $\mathbf{Y}^{\mathrm{T}} = \{\mathbf{y}_1, \ldots, \mathbf{y}_{\mathrm{T}}\}$, we now obtain the likelihood function $L(\theta|\mathbf{Y}^T)$ that can be evaluated, for any given θ, using the Kalman filter.

2.2 Posterior Distribution

We derive the posterior distribution of the coefficients in two steps. First, we find the posterior mode, which is the most likely point in the posterior distribution, and compute the Hessian matrix at the mode using a standard optimization routine.[24] In this case, the likelihood function is computed by first solving the model and then using the Kalman filter. Second, we implement the Metropolis-Hastings algorithm to generate draws from the posterior. The algorithm generates a sequence of draws that is path dependent. It works as follows: (1) Start with an initial value of the parameters—say, θ^0—and compute the product of the likelihood and the prior at this point: $L(\theta^0|\mathbf{Y}^T)p(\theta^0)$; (2) From θ^0, generate a random draw, θ^1, such that $\theta^1 = \theta^0 + \boldsymbol{v}^1$, where v^1 follows a multivariate normal distribution and the variance-covariance matrix of v^1 is proportional to the inverse

23. We use the updated version of Uhlig's (1997) routines to solve the log-linearized model.

24. Namely, the csminwel command in Matlab.

Hessian of the posterior mode, and then, for θ^1, compute $L(\theta^1|\mathbf{Y}^T)p(\theta^1)$. The new draw, θ^1, is accepted with probability R and is rejected with (1-R), where

$$R = \min\left\{1, \frac{L\left(\theta^1 \middle| \mathbf{Y}^T\right) p\left(\theta^1\right)}{L\left(\theta^0 \middle| \mathbf{Y}^T\right) p\left(\theta^0\right)}\right\}.$$

If the draw is accepted, it is possible to generate another draw, $\theta^2 = \theta^1 + v^1$, and assess whether this second draw is accepted. If the draw is rejected, we go back to the initial value, θ^0, and generate another draw. The idea of this algorithm is that, regardless of the starting value, more draws will be accepted from the regions of the parameter space where the posterior density is high. At the same time, areas of the posterior support with low density are less represented, but will eventually be visited. In practice we implement this algorithm with 5,000 draws.

2.3 Data

To estimate the model, we use quarterly data on the Chilean economy for the period 1990:1 to 2005:4. We choose the following seven observables variables: real GDP, the short-term real interest rate, consumer price inflation (CPI), the real exchange rate, nominal exchange rate devaluation, real wages, and labor input. Real GDP, consumer prices, real wages, and labor input are seasonally adjusted using the X-12 method.

We use core inflation as a measure of consumer price inflation. Core inflation is also used to deflate nominal wages and construct the real exchange rate. We demean all variables. In the case of real wages and GDP, we detrend and demean the series using a linear trend in order to work with stationary series.[25] Labor input is constructed as the fraction of total employment over the working-age population. The short-term real interest rate corresponds to the monetary policy rate, which was indexed until July 2001. For the later period, the real interest rate is constructed as the difference between the nominal monetary policy rate and the expected inflation implicit in the main forecast model of the Central Bank.

25. The estimated parameters did not change significantly when we used a Hodrick-Prescott filter.

2.4 Prior Distribution

The priors' density function, its mean, and its standard deviation reflect our beliefs about the potential values that parameters can take. A relatively high standard deviation results in a more diffuse prior distribution; this reflects the uncertainty associated with a specific coefficient. If the standard deviation is low and, in the limit, zero, it means that the coefficient should take a specific value, independent of the actual data. In general, we choose our priors based on evidence presented in previous studies for Chile. When the evidence is weak or nonexistent, we tend to impose more diffuse priors.

Table 1 presents the prior distribution, the mean, and the 90 percent probability interval for the coefficients contained in θ. For the inverse elasticity of labor supply, σ_L, we assume an inverse gamma distribution with mode 1.0 and four degrees of freedom. In practice, this implies that the elasticity of labor supply, σ_L^{-1}, can take values between 0.3 and 1.6, in the 90 percent confidence interval. This is a wide range and reflects our uncertainty with regard to this coefficient. The habit formation coefficient, b, follows a beta distribution with a mean of 0.5 and a standard deviation of 0.25. The 90 percent confidence interval for this coefficient is thus between 0.1 and 0.9. This range is much wider than Adolfson and others (2005b) find for the same coefficient in the euro area. The probability that prices and wages are not reset optimally every quarter, ϕ_H, ϕ_F and ϕ_L, follows a beta distribution with a mean of 0.75 and a standard deviation of 0.10. This prior is similar to that considered by Adolfson and others (2005b) for the euro area and by Rabanal and Rubio-Ramírez (2005) for the United States. The elasticity of substitution between foreign and domestic goods, η, follows an inverse gamma distribution with a mode of 1.5 and four degrees of freedom. We use the same assumption for η^*. In this case, this elasticity can vary between 0.97 and 5.49. This is a wide range, which is in line with that suggested by Adolfson and others (2005b). The supply elasticity of international funds, μ, is assumed to follow an inverse gamma distribution with a mode of 0.1 and four degrees of freedom.

We impose nonnegativity restrictions on the policy rule coefficients. We assume inverse gamma distributions with four degrees of freedom for ψ_π and ψ_y. For ψ_π, we set a mode of 0.75. This implies values for ψ_π that are in the range found in previous estimations.[26] For ψ_y, we

26. See Schmidt-Hebbel and Tapia (2002); Caputo (2005).

Table 1. Prior Distributions

Variable	*Density*	*Mean/mode*[a]	*Std. dev./df*[b]	*90% Interval*
σ_L	Inverse Gamma	1.00	4.00	0.64–3.66
b	Beta	0.50	0.25	0.10–0.90
ϕ_H	Beta	0.75	0.10	0.57–0.90
ϕ_L	Beta	0.75	0.10	0.57–0.90
ϕ_F	Beta	0.75	0.10	0.57–0.90
η	Inverse Gamma	1.50	4.00	0.97–5.49
η^*	Inverse Gamma	1.50	4.00	0.97–5.49
μ	Inverse Gamma	0.10	4.00	0.06–0.37
ξ_H	Beta	0.50	0.25	0.10–0.90
ξ_L	Beta	0.50	0.25	0.10–0.90
ξ_F	Beta	0.50	0.25	0.10–0.90
ψ_i	Beta	0.75	0.20	0.35–0.99
ψ_π	Inverse Gamma	0.75	4.00	0.48–2.74
ψ_y	Inverse Gamma	0.50	4.00	0.32–1.83
$\psi_{\Delta e}$	Inverse Gamma	0.20	5.00	0.13–0.61
ρ_a	Beta	0.70	0.25	0.21–0.99
ρ_s	Beta	0.70	0.25	0.21–0.99
ρ_{c^*}	Beta	0.70	0.25	0.21–0.99
ρ_{i^*}	Beta	0.70	0.25	0.21–0.99
ρ_{π^*}	Beta	0.70	0.25	0.21–0.99
ρ_ζ	Beta	0.70	0.25	0.21–0.99
σ_a	Inverse Gamma	1.00	3.00	0.64–4.89
σ_s	Inverse Gamma	1.00	3.00	0.64–4.89
σ_{c^*}	Inverse Gamma	1.00	3.00	0.64–4.89
σ_{i^*}	Inverse Gamma	0.50	3.00	0.32–2.45
σ_{π^*}	Inverse Gamma	0.25	3.00	0.16–1.22
σ_m	Inverse Gamma	0.20	3.00	0.13–0.98
σ_ζ	Inverse Gamma	1.00	3.00	0.64–4.89

Source: Authors.
a. Mean for beta distributions; mode for inverse gamma distributions.
b. Standard deviation for beta distributions; degrees of freedom for inverse gamma distributions.

set a mode of 0.5, which yields a prior 90 percent probability interval of 0.32 to 1.83 for this coefficient. On the other hand, we assume that $\psi_{\Delta e}$ follows an inverse gamma distribution with a mode of 0.2 and five degrees of freedom. Finally, for the interest rate smoothing coefficient, ψ_i, we assume a beta distribution with a mean of 0.75 and a standard deviation of 0.2. The priors chosen for the policy rule coefficients are in line with the stylized facts found in previous studies.

The autoregressive parameters of the stochastic shocks, ρ_ζ, ρ_{i^*}, ρ_{π^*}, ρ_s, ρ_{c^*}, ρ_a, have beta distributions. This means that their value

should lie in the (0, 1) interval range. We do not impose tight priors on these distributions, so shocks can be either persistent or nonpersistent. Specifically, for all parameters, we set the prior mean at 0.7 and the standard deviation at 0.25. Thus the 90 percent probability interval considers values from 0.21 to 0.99. The standard deviations of the shocks are assumed to have an inverse gamma distribution with three degrees of freedom. The shape of this distribution implies a rather diffuse prior; that is, we do not have strong prior information on those coefficients. In any case, the mean of the distributions are set based on previous single-equation estimations and on trials with weak priors. In particular, σ_a, σ_{c^*}, σ_s, and σ_ζ have a prior mode of 1.0, which implies values for these parameters between 0.64 and 4.89. For σ_{i^*} the mode is set at 0.5, implying values from 0.32 to 2.45, whereas the modes of σ_{π^*} and σ_m are set at 0.25 and 0.20, respectively.

3. Bayesian Estimation Results

Once the priors have been specified, we estimate the model by first computing the posterior mode and then constructing the posterior distribution with the Metropolis-Hastings algorithm. Table 2 presents the posterior mean of each parameter and its standard deviation under alternative model specifications. In order to compare different models, we also report (in the last row) the value of the log marginal density.

In the baseline case (second column), the inverse of the elasticity of labor supply, σ_L, has a posterior mean of 0.80, which is slightly smaller than the value reported for the United States by Rabanal and Rubio-Ramírez (2005). The posterior mean of the habit formation coefficient, b, is 0.14. This is consistent with an autoregressive coefficient for consumption, $b/(1 + b)$, of nearly 0.15. This degree of habit formation is below that found for Europe by Adolfson and others (2005b). The posterior mean of the Calvo probability is 0.53 for home goods prices, ϕ_H, and 0.68 for wages, ϕ_L. This implies that home goods prices are set optimally more frequently than wages: home goods prices are reset every two quarters, on average, whereas wages are kept fixed, on average, for three quarters. Compared with evidence for developed economies, the results for ϕ_H imply less sticky prices in the home goods sector, whereas for ϕ_L they imply similar values. For example, Adolfson and others (2005b) report values for ϕ_H and ϕ_L of 0.89 and 0.70, respectively, for the euro area. This is consistent with an average duration of 9.5 quarters for prices and

Table 2. Posterior Distributions of Models with Different Sources of Rigidities[a]

Variable	*Baseline*	*Model M1*	*Model M2*	*Model M3*	*Model M4*	*Model M5*
σ_L	0.800 (0.202)	1.489 (0.733)	1.168 (0.574)	1.344 (0.701)	1.282 (0.331)	0.746 (0.175)
b	0.139 (0.084)	0.944 (0.016)	0.946 (0.023)	0.952 (0.016)	0.132 (0.073)	— (—)
ϕ_H	0.527 (0.088)	0.075 (0.020)	0.077 (0.014)	0.082 (0.018)	0.090 (0.017)	0.100 (0.018)
ϕ_L	0.677 (0.068)	0.865 (0.028)	0.885 (0.029)	0.872 (0.025)	— (—)	— (—)
ϕ_F	0.911 (0.017)	— (—)	— (—)	— (—)	— (—)	— (—)
η	0.889 (0.190)	0.678 (0.113)	0.564 (0.105)	0.661 (0.131)	0.516 (0.104)	0.633 (0.125)
η^*	0.557 (0.087)	0.511 (0.080)	0.574 (0.078)	0.518 (0.086)	0.474 (0.079)	0.645 (0.080)
μ	0.413 (0.078)	0.113 (0.016)	0.109 (0.021)	0.102 (0.018)	0.191 (0.047)	0.935 (0.045)
ξ_L	0.704 (0.176)	0.675 (0.134)	0.724 (0.137)	— (—)	— (—)	— (—)
ξ_H	0.114 (0.101)	0.023 (0.042)	— (—)	— (—)	— (—)	— (—)
ξ_F	0.079 (0.068)	— (—)	— (—)	— (—)	— (—)	— (—)
ψ_i	0.908 (0.026)	0.911 (0.028)	0.921 (0.021)	0.833 (0.050)	0.853 (0.059)	0.838 (0.074)
ψ_π	1.274 (0.658)	3.295 (1.002)	3.600 (1.364)	2.578 (1.133)	9.331 (4.266)	7.797 (2.803)
ψ_y	0.229 (0.046)	0.270 (0.077)	0.269 (0.064)	0.193 (0.041)	0.308 (0.104)	0.289 (0.084)
$\psi_{\Delta e}$	0.146 (0.031)	0.176 (0.046)	0.211 (0.059)	0.134 (0.030)	0.168 (0.055)	0.182 (0.050)
Log post	−713.07	−778.57	−776.32	−785.40	−831.07	−832.68

Source: Authors' estimations.

a. The table presents posterior means. Standard deviations are in parentheses.

3.5 quarters for wages. In the United States, the average duration of prices and wages is 6.2 and 2.4 quarters, respectively (Rabanal and Rubio-Ramírez, 2005). In a partial equilibrium estimation for Chile, Céspedes, Ochoa, and Soto (2005) find a higher degree of prices stickiness than what we find here, with prices being optimally reset every three to eight quarters. However, they do not estimate the degree of price and wage stickiness simultaneously.

Our estimation of the elasticity of substitution between domestic and foreign goods, η, is 0.89. The estimated value for η^* is 0.56. The values for these elasticities are below the estimates for the euro area in Adolfson and others (2005b). At the same time, our results show the existence of both inflation and wage indexation: the coefficients ξ_L and ξ_H are estimated to be 0.70 and 0.11, respectively. This latter result implies a reduced-form coefficient on lagged inflation, $\xi_H/(1+\beta\xi_H)$, with a value very close to zero. For Chile, Céspedes, Ochoa, and Soto (2005) find a larger value for both ξ_H and $\xi_H/(1+\beta\xi_H)$. We therefore conclude that inflation inertia tends to become less important when we introduce wage indexation. In the next subsection, we test whether ξ_L and ξ_H can be removed from the model and the implications that this would have for the remaining coefficients.

Imperfect pass-through from the exchange rate to import prices is a relevant feature of the Chilean economy. The value of, ϕ_F, indicates that import prices are kept fixed for around two years, on average. The degree of indexation, ξ_F, is quantitatively small in this case, at 0.08.

The results for the policy rule coefficients, ψ_i, ψ_π, ψ_y, and $\psi_{\Delta e}$, tend to confirm the findings of previous research. First, we find an important degree of interest rate smoothing: ψ_i has a posterior mean of nearly 0.9. Second, the response to inflation is relatively more important than the policy response to output and the exchange rate: the posterior mean of ψ_π is 1.27 whereas ψ_y and $\psi_{\Delta e}$ have a posterior mean of 0.23 and 0.15, respectively.

3.1 Posterior Distribution and Model Comparison

What is the relevance of a particular nominal or real rigidity? Is the monetary policy better described by a forward-looking inflation-targeting Taylor rule or by a rule that reacts to contemporaneous inflation? To answer these questions, we assess the plausibility of alternative models in which we remove some of the rigidities. We also consider models with alternative specifications of the Taylor rule.

We begin by considering a model, M1, that removes the imperfect pass-through and import price inertia. That is, $\phi_F = 0$, and $\xi_F = 0$. As shown in table 2, the log marginal probability density is well below the value under the baseline model. Hence, the fit of the model is clearly worse when we remove imperfect pass-through.

Next, we consider a model, M2, that removes inflation inertia, $\xi_H = 0$. The results are shown in the fourth column of table 2. In general, the posterior mean of the coefficients does not change, but this specification has a slightly higher log marginal probability density than M1. Thus, once we remove imperfect pass-through, allowing for $\xi_H = 0$ the fit of the model improves. However, the baseline model still delivers a better fit for the Chilean data than M2. In the third alternative specification, we impose no wage indexation, $\xi_L = 0$ (see table 2, column 5). This causes the marginal probability density to fall, so we can rule out the hypothesis that $\xi_L = 0$. The fourth model we test, M4, additionally removes the assumption that wages are sticky, such that $\phi_L = 0$. The Bayes factor for this specification is less than one. Allowing for flexible wages thus worsens the model's ability to fit the aggregate data. Finally, we consider a specification, model M5, in which we also remove the habit coefficient from the Euler equation, $b = 0$. This model displays a slightly worse fit of the data than model M4. Therefore, although the magnitude of real rigidities is small, empirically it is a relevant feature for explaining the Chilean data.

3.2 Alternative Policy Rules Specifications

Table 3 presents alternative specifications for the policy reaction function. In the baseline case, the Central Bank is reacting to contemporaneous inflation. We test an alternative specification in which the monetary authority is reacting, instead, to expected future inflation (see table 3, column 3). This model fits the data better than the baseline. The Chilean data thus favor a forward-looking behavior by the Chilean Central Bank with respect to inflation. In this case, the values of the nominal and real rigidities do not change significantly, although the policy reaction to expected inflation seems to be higher than in the baseline case. Finally, we test whether a backward-looking specification for the Taylor-type policy rule is preferred and conclude that this model cannot explain the Chilean data better than a model with expected inflation targeting. Forward-looking behavior by the Central Bank is important and consistent with the set of real and nominal rigidities found in the estimation. The presence of real

Table 3. Posterior Distributions of Models with Alternative Monetary Policies[a]

Variable	*Baseline*	*Targeting future expected inflation*	*Targeting past inflation*
σ_L	0.800 (0.202)	0.616 (0.154)	0.673 (0.160)
b	0.139 (0.084)	0.064 (0.045)	0.486 (0.246)
ϕ_H	0.527 (0.088)	0.419 (0.065)	0.752 (0.122)
ϕ_L	0.677 (0.068)	0.644 (0.051)	0.806 (0.074)
ϕ_F	0.911 (0.017)	0.917 (0.018)	0.905 (0.021)
η	0.889 (0.190)	0.823 (0.195)	0.719 (0.140)
η^*	0.557 (0.087)	0.553 (0.079)	0.491 (0.078)
μ	0.413 (0.078)	0.431 (0.071)	0.425 (0.068)
ξ_L	0.704 (0.176)	0.601 (0.161)	0.811 (0.093)
ξ_H	0.114 (0.101)	0.190 (0.080)	0.045 (0.060)
ξ_F	0.079 (0.068)	0.168 (0.136)	0.077 (0.043)
ψ_i	0.908 (0.026)	0.902 (0.023)	0.909 (0.027)
ψ_π	1.274 (0.658)	1.841 (0.643)	0.772 (0.172)
ψ_y	0.229 (0.046)	0.243 (0.060)	0.285 (0.105)
$\psi_{\Delta e}$	0.146 (0.031)	0.136 (0.035)	0.154 (0.049)
Log post	−713.07	−710.10	−712.05

Source: Authors' estimations.
a. The table presents posterior means. Standard deviations are in parentheses.

and nominal rigidities confirms that the effect of monetary policy on inflation occurs with lags. Hence, targeting future expected inflation recognizes that stabilizing current inflation is costly given the presence of real and nominal inertia.

3.3 Subsample Analysis

The inflation-targeting regime in Chile has undergone some changes in the past years. After 1999, Chile embraced a full-fledged inflation-targeting regime with a fixed inflation target and a free-floating exchange rate. To see whether some of the structural coefficients may have changed, we analyze the behavior of the price and wage rigidities in two subsamples: 1990–99 and 2000–05. This exercise is performed for the baseline model. The subsample analysis suggests that both prices and wages were adjusted less frequently after 1999 (see table 4). This result is in line with Céspedes and Soto (in this volume), who find that a credible inflation-targeting regime reduces the incentive to change prices and wages in nominal terms. At the same time, imperfect pass-through from the exchange rate to import prices is a relevant feature of the Chilean economy, with a degree of stickiness that, apparently, does not change over time.

Table 4. Posterior Mode of Price and Wage Rigidities for Subsamples

Variable	*1990–99*	*2000–05*
ϕ_H	0.400	0.907
ϕ_L	0.612	0.805
ϕ_F	0.972	0.913
ξ_L	0.359	0.318
ξ_H	0.137	0.103
ξ_F	0.119	0.070

Source: Authors' estimations.

We also analyze the subsample behavior of the policy itself, using the baseline specification for the policy reaction function (see table 5). This exercise indicates that the degree of interest rate smoothing increased after 1999. The response to inflation and output also became a little more aggressive after 1999. More importantly, the ratio of ψ_π to ψ_y shrank after 1999 (4.11 versus 2.98). This last result may be an

indication that, in a context of increased policy credibility, the inflation target can be achieved with a relatively less aggressive reaction to inflation vis-à-vis output, reducing the sacrifice ratio. Finally, the policy response to exchange rate movements seems less important in the second subperiod, which is clearly consistent with the elimination of the exchange rate bands.

Table 5. Posterior Mode of Policy Rule Coefficients for Subsamples

Variable	*1990–99*	*2000–05*
ψ_i	0.682	0.938
ψ_π	0.649	0.727
ψ_y	0.158	0.244
$\psi_{\Delta e}$	0.321	0.159

Source: Authors' estimations.

4. Conclusions

In this paper, we have derived a microfounded model that features habit formation in the utility function and considers both sticky prices and wages. We also introduced indexation in prices and wages, and we incorporated imperfect pass-through from the exchange rate to import prices.

These nominal and real rigidities may be features that characterize a small open economy like Chile. The main question this paper addresses, then, is the extent to which nominal and real rigidities are important in explaining the behavior of the aggregate data in Chile during the inflation-targeting period. This question is particularly important from a policymaker's perspective. Identifying the level of nominal and real rigidities that are present in the economy is a relevant step toward the efficient design of monetary policy. The existence (or absence) of certain rigidities may have very different implications for the trade-off between output and inflation stabilization that central banks face.

We address this question in the context of a structural model that is estimated using Bayesian techniques. The advantage of this approach is that it is system-based and enables us to incorporate additional information, not contained in the actual data, into the parameter estimation. Moreover, this approach can cope with identification and misspecification problems. In this context, we also investigate how

the Chilean Central Bank has designed its policy in the inflation-targeting period. To do this, we introduce a Taylor-type policy rule in the microfounded model and assess whether this rule has reacted to expected, contemporaneous, or lagged inflation.

Our main results are as follows. First, models with both price and wage rigidities best account for the Chilean data. Notably, the degree of wage rigidities is higher than that of domestic prices. Our results show that nominal wages are adjusted optimally every three quarters, on average. In contrast, prices are re-optimized every two quarters. The subsample analysis suggests that both prices and wages were adjusted less frequently after 1999 than before. This result could reflect the increased credibility of the inflation-targeting regime, which would give price and wage setters less of an incentive to adjust nominal prices and wages. At the same time, imperfect pass-through from the exchange rate to import prices is a relevant feature of the Chilean economy.

Second, adding wage indexation clearly improves the fit of the model. This level of indexation is comparatively larger than that of domestic and import prices. Wage indexation generates a more persistent response of inflation to shocks, and it is one of the determinants of the policy trade-off.

Third, real rigidities such as habit formation also provide a better account of the aggregate data, although the possible values of it are quantitatively small.

Fourth, models with a Taylor rule that reacts to expected inflation characterize monetary policy in the sample period better than models with a Taylor rule that reacts to contemporaneous inflation. As found in previous studies, the policy response to inflation is comparatively larger than the response to output and the exchange rate. Moreover, the subsample analysis indicates that the degree of interest rate smoothness increased after 1999. The response to inflation relative to output also became less aggressive after 1999. In a context of increased policy credibility, the inflation target can be achieved with a smaller trade-off between inflation and output fluctuations, reducing the sacrifice ratio.

Overall, our results confirm the relevance of a wide set of frictions for explaining the behavior of the Chilean economy. These frictions are the key elements that determine the optimality of alternative ways of designing monetary policy. Hence, the results presented here raise two questions: to what extent has the Chilean Central Bank reacted to both price and wage inflation, and what is the optimal response to this type of friction? We leave these questions to future research.

Appendix
The Steady State of the Model

We assume that the long-run income per capita growth rate is g_y, and the steady-state inflation rate is π_C. These assumption imply a nominal interest rate given by $i = (1 + g_y)(1 + \pi_C)/\beta - 1$. The foreign interest rate and inflation rate are i^* and π^*. The arbitrage condition in the steady state implies an external premium equal to

$$\Theta = \frac{1+i}{1+\pi_C}\frac{1+\pi^*}{1+i^*}.$$

In the long-run steady state, the ratio of net exports to GDP is denoted by NX/Y. The share of imported goods in total consumption is α, and the share of domestically produced (H) goods in total GDP is denoted by Y_H/Y. We use these statistics to find

$$\frac{C}{Y} = 1 - \frac{NX}{Y};$$

$$\frac{M}{Y} = \frac{C_F}{Y} = \frac{C_F}{C}\frac{C}{Y} = \alpha\left(1 - \frac{NX}{Y}\right);$$

$$\frac{X}{Y} = \frac{NX}{Y} + \frac{M}{Y} = \frac{NX}{Y}(1-\alpha) + \alpha;$$

$$\frac{C_H}{Y} = \frac{C_H}{C}\frac{C}{Y} = (1-\alpha)\left(1 - \frac{NX}{Y}\right);$$

$$\frac{C_F}{Y} = \frac{C_F}{C}\frac{C}{Y} = \alpha\left(1 - \frac{NX}{Y}\right); \text{ and}$$

$$\frac{C_H^*}{Y} = \frac{Y_H - C_H}{Y} = \frac{Y_H}{Y} - (1-\alpha)\left(1 - \frac{NX}{Y}\right).$$

Finally, using the foreign interest rate and the ratio of net exports to GDP, we derive an expression for the ratio of net foreign assets to GDP:

$$\frac{eB^*}{Y} = \frac{NX}{Y}\left[\frac{1}{(1+i^*)\Theta} - \frac{1}{(1+g_y)(1+\pi^*)}\right].$$

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Credibility and Inflation Targeting in Chile

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After a long history of high and volatile inflation, the Central Bank of Chile began implementing its monetary policy in the early 1990s by announcing yearly targets for inflation. This new framework was the first step toward a full-fledged inflation-targeting setup, although the Central Bank continued to pursue an explicit objective for the exchange rate. One year before the first announced inflation target in 1990, the Central Bank was granted autonomy through a special law that explicitly states that the main objective of monetary policy is to ensure price stability.

Some authors argue that by enhancing the credibility of monetary policy, this new institutional framework contributed fundamentally to lowering inflation to its current level of around 3 percent (Corbo, 1998; Morandé, 2002; Schmidt-Hebbel and Werner, 2002).[1] Credibility affects the dynamics of price adjustments and, in general, the underlying process that determines inflation. Credibility may also determine the tradeoffs faced by the monetary authority when implementing its policy. In particular, a more credible monetary authority should face an improved tradeoff between inflation and output stabilization, making it less costly to carry out a stabilization process.

In this paper, we provide new evidence of changes in the dynamics of the Chilean inflationary process in recent years. Based

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1. Other possible factors in the success of the disinflationary process in Chile include favorable productivity shocks (see, for example, De Gregorio, 2003).

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on a new Keynesian Phillips curve, we show that price rigidity has increased in the last few years, while the degree of indexation in the economy—based on past inflation—has decreased. We also show that the exchange rate pass-through into traded goods inflation has decreased. Our findings are consistent with the idea that the credibility of monetary policy has increased over time. We argue that as monetary policy has become more credible, costly price adjustments have been carried out less frequently, and the prevalence of indexation based on past inflation has decreased.

These changes in the inflationary process, triggered by the enhanced credibility, may have had significant repercussions in the way monetary policy is implemented in Chile. As we show in Céspedes and Soto (2005), when credibility is low, a central bank that is concerned with the sacrifice ratio during a disinflationary process may be less aggressive in implementing its monetary policy in order to avoid large output losses. As it gains credibility, the central bank may fight inflation deviation from target strongly.

This paper presents evidence of a structural change in the policy rule that characterizes the conduction of the monetary policy. Our evidence is consistent with the idea that monetary policy in Chile has been operating in an environment of improved credibility over the last several years. We show that the monetary policy rule has become more forward-looking in terms of inflation and more aggressive in fighting deviations of inflation from the target.

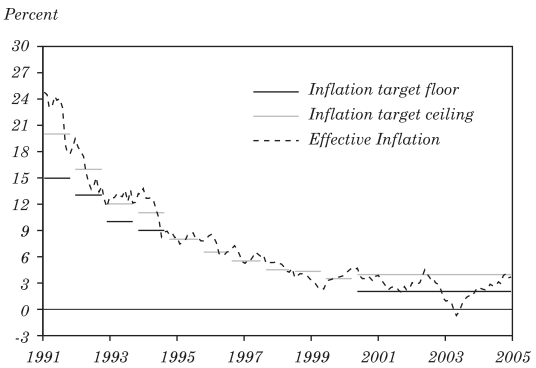
The paper is organized as follows. The next section briefly describes the different phases of the monetary policy regime in Chile since the Central Bank was granted independence, with a focus on the two phases of the inflation-targeting regime that started in 1991. In section 2, we discuss what credibility means and present some preliminary evidence on the change in the Central Bank's degree of credibility. In section 3, we show how this change in the degree of credibility could have affected the inflationary process in Chile by modifying the degree of price stickiness and the extent of indexation to past inflation. The fourth section presents estimated monetary policy rules for different subsamples, and section 5 concludes.

1. Evolution of the Inflation-Targeting Framework in Chile

In the period 1991–2005, the Chilean economy grew at an average rate of 5.7 percent per year. The inflation rate fell from levels close to 30 percent in early 1991 to stationary levels around 3 percent by the

end of the 1990s, and it has fluctuated around that figure since then (see figure 1). During this period, the Central Bank of Chile began to announce an explicit target for inflation, a practice that has been credited with providing a sound guide for conducting monetary policy.[2] Nevertheless, the whole monetary policy framework underwent significant changes along the way. In the first phase (1991–99), the macroeconomic framework included not only inflation targets, but also targets for the current account deficit and a managed exchange rate. In the second phase (2000 to date), the Central Bank implemented a full-fledged inflation-targeting regime in which inflation is the main policy objective, with no other explicit targets.

Figure 1. Effective Inflation and Inflation Targets in Chile, 1991–2005



Source: Authors' calculations based on Central Bank of Chile data.

The Central Bank announced the first target range for inflation in September 1990, after being granted independence in 1989. The initial target, a 15–20 percent target range for December 1991, was defined for consumer price index (CPI) inflation. The initial inflation target was set over a rather short time horizon and represented a strong commitment to reducing inflation. The short-term inflation target reflected the need to generate credibility for the new regime. Previous poor inflation performance had led to a widespread indexation

2. See Corbo (1998) on the effects of inflation targeting on Chilean inflation dynamics in the 1990s.

of the economy and high inflation expectations (see Schmidt-Hebbel and Tapia, 2002). The stabilization process was thus very gradual to avoid high output losses in the context of this widespread indexation and low credibility (Massad, 2003).

In addition to the annual inflation targets, the Central Bank implemented a target band for the exchange rate during the first phase (1991–99). The band was perceived as the appropriate instrument for achieving a normal functioning of the external payments system. The Central Bank also set targets for the current account deficit. To retain the possibility of managing the exchange rate with monetary policy independence, the Bank maintained regulations on the capital account, including a nonremunerated reserve requirement for capital inflows. Exchange rate market interventions were conducted during this period to sustain the exchange rate band. Significant modifications to the exchange rate band were also applied, including adjustments in its width and one-time realignments.

Since 2000, Chile has operated a flexible inflation-targeting regime with the objective of keeping the CPI inflation rate between 2 and 4 percent over a two-year horizon. The move to a full-fledged inflation-targeting framework was seen as the natural step after reaching the steady-state level of inflation and establishing sufficient credibility. It was triggered, in part, by the macroeconomic outcomes of the Asian crisis. GDP growth fell significantly in 1998–99, while the annual inflation rate dropped from 4.6 percent in 1998 to 2.3 percent in 1999. These events led the monetary policy authority to substantially enhance its macroeconomic framework. The main new elements were the adoption of a free-floating exchange rate regime, the deepening of the foreign exchange derivatives market, and the total opening of the capital account (see Morandé, 2002; Céspedes, Ochoa, and Soto, 2005). In addition, transparency increased significantly with the publication of a regular inflation report and the public release of policy meeting minutes.

2. Has Credibility Improved in Chile?

Answering the question of whether credibility has improved in Chile is difficult, as there are no direct measures of credibility. The literature has not yet reached a unanimous definition of the concept of credibility itself, and most of the proposed definitions have an important subjective component. Consequently, practical measures are not readily available.

2.1 What Credibility Means

The academic literature identifies a central bank's credibility as incentive compatibility, precommitment, or strong aversion to inflation. Barro and Gordon (1983) hold that a central bank is credible if it attains higher payoffs (utility) by following its promised actions rather than reneging. Economic agents expect the central bank to do exactly what it promised because that increases its own payoff. This logic is behind Walsh's proposal for an optimal contract design for central bankers that would make the fight against inflation more efficient (Walsh, 1995). By making incentives compatible with the fight against inflation through an explicit contract, this mechanism ensures the credibility of the monetary authority's promises. In the absence of such a contract, credibility could be reached by means of a (credible) precommitment technology, although this could imply having institutional arrangements that are not always available. Finally, credibility has been associated with a strong aversion to inflation. This last definition seems tautological, however: one cannot determine whether the monetary authority really has a strong aversion to inflation unless one can determine how credible the aversion to inflation is. Moreover, having a strong aversion to inflation does not ensure that a central bank has the means to reach its objectives.

Blinder (1999) surveys a group of central bankers and academics to explore why credibility is important and how central banks can enhance their credibility. Although he does not ask participants to define credibility, he asks how close the concept of credibility is to "dedication to price stability." Nearly 90 percent of the respondents answered that the two factors are quite closely related.

The main argument for why the Central Bank of Chile may have gained credibility over the 1990s hinges precisely on this notion of credibility. The new constitutional charter of 1989 not only guaranteed the Central Bank autonomy from the government, but also explicitly established stabilizing the value of the national currency as one of the Bank's two main objectives. In other words, one of the Bank's explicit objectives is price stability.

Autonomy, however, may not be enough to guarantee credibility. Posen (1998) and Fischer (1994), for example, find a positive correlation between the sacrifice ratio and an index of central bank independence. This result seems to suggest that more autonomous central banks are not necessarily more credible. It may be more relevant "to match deeds and words" (Blinder, 1999).

Albagli and Schmidt-Hebbel (2004) undertake an international cross-section comparison of inflation performance for several inflation-targeting central banks. They find that for different measures of inflation deviations from target, Chile ranks among the most accurate inflation targeters in the sample of nineteen countries. At least from an international perspective, the Central Bank of Chile has fulfilled its promises.

The question, then, is whether this behavior has been consistent over time. Figure 2 presents two measures of inflation deviations from target for Chile since 1991. In one of the measures, we consider the center of the target range as the authority's objective, while in the other, we assume that inflation has not deviated from the target if it stays within the target range. In both cases, we report the deviation and the absolute value of the deviation. The figure clearly illustrates that the Central Bank was less accurate in hitting the target in the early 1990s.[3] It improved by the mid-1990s, when the economy entered a phase of sustained growth and low inflation. The Central Bank's performance in terms of hitting the midpoint of the target range worsens after the Russian crisis, when inflation fell more than 2 percent below the target. Over the last several years, however, the Central Bank has generally managed to keep inflation within the target range.

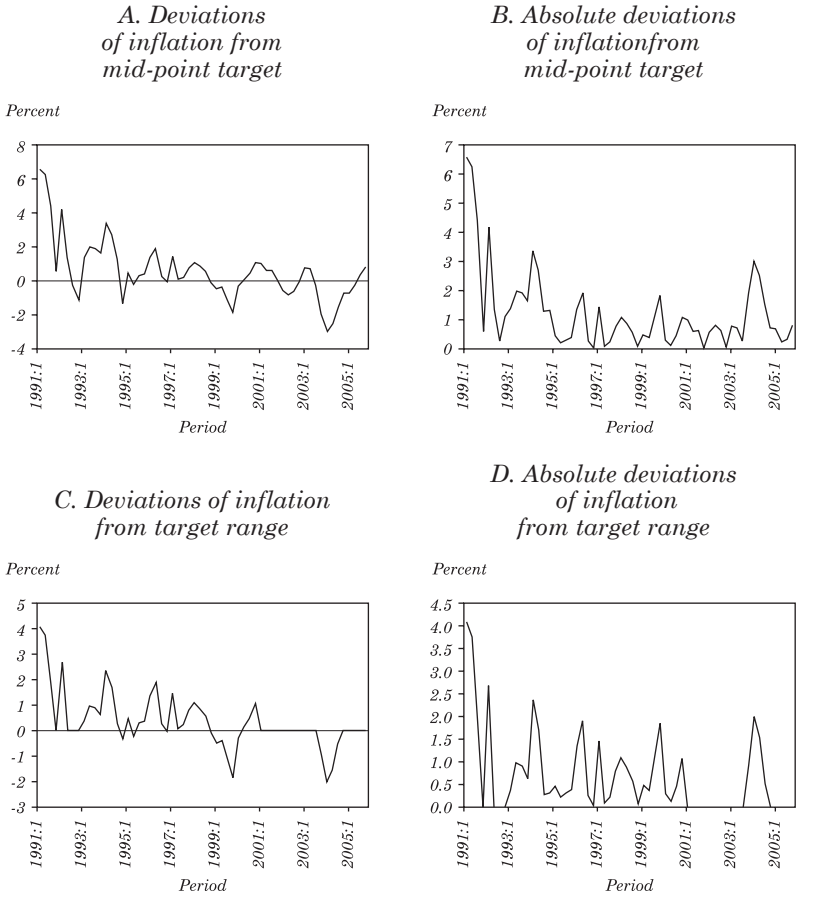
2.2 A Direct Measure of Credibility

One direct measure of credibility is the difference between private inflation expectations and the announced target. This credibility measure is consistent with the measure discussed by Faust and Svensson (2001) and Cukierman and Meltzer (1986). The latter paper defines credibility as the absolute value of the difference between the policymaker's plans and the private sector's beliefs about those plans. The smaller this difference, the higher the credibility of planned monetary policy.

To construct this measure of credibility, we consider two measures of expected inflation. The first is based on nominal-real market interest rate differentials. The second is a measure of expectation taken from survey data. Figure 3 depicts the evolution of the difference between expected inflation constructed using market interest rates and the

3. Some authors normalize the deviation of inflation from target by the inflation target level.

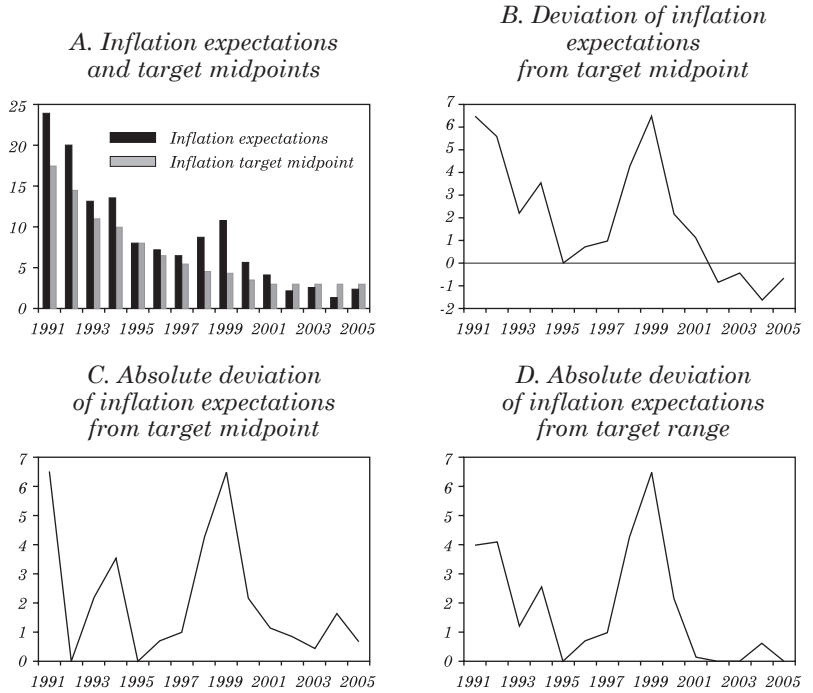
Figure 2. Inflation Deviation from Target in Chile, 1991–2005



Source: Authors' calculations based on Central Bank of Chile data.

announced inflation target. The figure shows that credibility increased in the early 1990s. However, expected inflation was way above the announced target during the Asian crisis, signaling a possible decrease in credibility. Since the end of the 1990s, expected inflation has been lower than the midpoint of the announced target, but inside the target range (except for 2004). In other words, the credibility of the announced target seems to have increased over the last several years.

Figure 3. Inflation Target Credibility in Chile, 1991–2005: Expected Inflation Measured as Nominal-Real Interest Rate Differentials

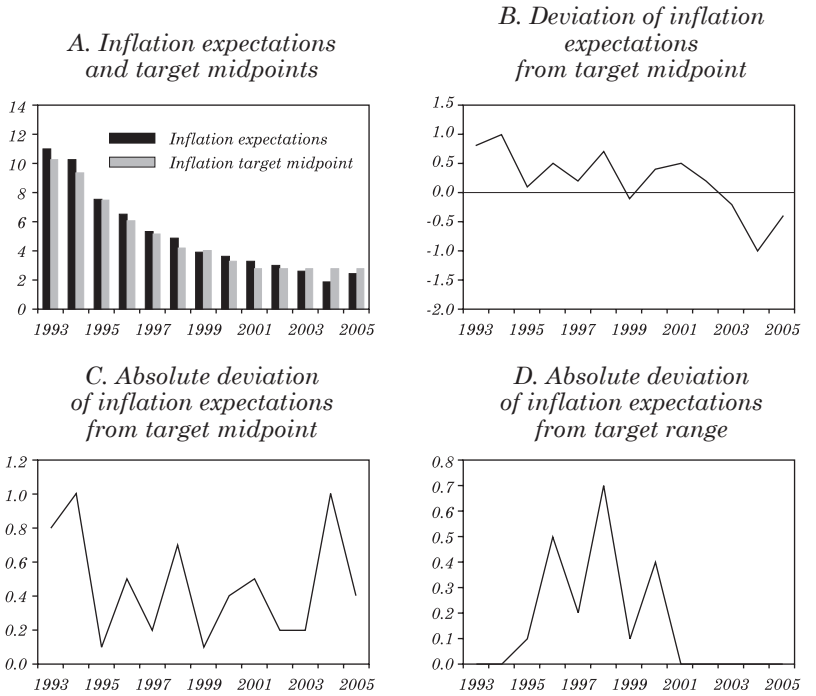


Source: Authors' own calculations.

This credibility measure, based on market expectations extracted from interest rate differentials, is subject to two important criticisms. First, the level and volatility of inflation were much higher in the early 1990s than at the end of the decade. That implies that the expected inflationary premium implicit in the nominal interest rate was also higher in the early 1990s. Consequently, the difference between expected inflation and the announced target may not have decreased over time. Second, although nominal instruments have existed for a long time, the market turnover was pretty low until 2001, when monetary policy was nominalized.[4] In other words, the market for nominal instruments was not very liquid until recently. Therefore,

4. In addition to defining an overnight nominal interest rate as its monetary policy instrument, the Central Bank introduced a set of nominal instruments in August 2001 to help set benchmarks for that market.

Figure 4. Inflation Target Credibility in Chile, 1991–2005: Expected Inflation from Consensus Forecast



Source: Authors' calculations based on Central Bank of Chile and Consensus Forecast data.

prices do not necessarily reflect market expectations on inflation.

Figure 4 charts the difference between private inflation expectations and the announced target using survey data. Survey data on analyst expectations regarding future inflation, drawn from Consensus Forecast, are available for Chile only since 1993. When using this measure of expectations, we observe that expected inflation has generally been much closer to the midpoint of the inflation target. Until 2002, expected inflation was above the midpoint of the target (except in 1999). Since that year, expected inflation has been below the midpoint of the target, but always inside the target range.[5]

5. To facilitate comparison with previous periods, we consider one-year-ahead expected inflation. However, following the introduction of a steady-state inflation target in 2001, the monetary authority explicitly stated that its goal is to keep inflation within the target range in a horizon of twelve to twenty-four months.

3. Frequency of Price Adjustment, Credibility, and Indexation

The preliminary evidence presented in the previous section hints that there may, in fact, have been gains in monetary policy credibility during the disinflationary process carried out by the Central Bank of Chile in the 1990s. In this section, we perform a more detailed analysis of how this change in the macroeconomic environment may have changed the inflationary dynamics. We start by estimating a new Keynesian Phillips curve for Chile and performing some stability tests on some key semistructural parameters. We then evaluate whether the degree of import price rigidity may have changed in a manner consistent with the hypothesis that the credibility of the Chilean monetary policy regime has risen.[6]

3.1 The Phillips Curve and the Persistence of Inflation

We estimate a new Keynesian Phillips curve (NKPC) in which the parameters have a semistructural interpretation. We emphasize that the parameters are not completely structural. In fact, changes in the macroeconomic environment seem to have had an impact on the value of some of the deep parameters that characterize the NKPC (see also Rudd and Whelan, 2003, 2005). The fraction of firms optimally adjusting prices each period decreased at the end of the 1990s, and the weight given to the announced inflation target by the firms that do not optimally adjust prices in a particular period has increased over the last few years. We argue that this evidence is consistent with the view that the Central Bank's higher credibility in its commitment to price stability (low inflation) changed the way in which firms set prices.

The theoretical NKPC comes from a standard model of monopolistic competitive firms that adjust prices infrequently.[7] We extend the basic model in Galí and Gertler (1999) to allow for passive price adjustment for all firms that do not optimize each period. Firms thus change prices every period, either optimally or by following this passive adjustment. The logic behind this dual pricing mechanism is that the menu costs for

6. García and Restrepo (2001) and Schimidt-Hebbel and Werner (2002) document the existence of a change in the pass-through coefficient for the Chilean economy using different setups.

7. See Galí and Gertler (1999) for a full derivation of the NKPC.

price adjustments are not related to the cost of changing prices itself, but rather to all the costs that an optimizing procedure involves (such as collecting information on market conditions, costs, and forecasting). Given those menu costs, firms will go through an optimization process only infrequently (see Christiano, Eichenbaum, and Evans, 2005).

This framework is appropriate for describing Chilean inflationary dynamics for two reasons. First, the notion of a passive adjustment is very plausible in a high-inflation environment—as in Chile in the early 1990s—where it is difficult to extract the information content of prices. Second, the passive adjustment setting allows us to formally introduce an indexation mechanism into the Phillips curve. In the case of Chile, indexation has been a prevalent phenomenon for many years (see Landerretche, Lefort, and Valdés, 2002).

The passive adjustment mechanism for firms that do not optimally adjust their prices consists in upgrading prices in proportion to a geometric average of past inflation and the announced target for inflation. The passive adjustment rule can be expressed as follows:

$$\Gamma_{t,i} = \prod_{j=1}^{i} \left(1 + \pi_{t+j-1}\right)^{\kappa} \left(1 + \pi_{t+j}^{tar}\right)^{1-\kappa}, \tag{1}$$

where $\Gamma_{t,i}$ is the percentage change in price of a firm that is not able to optimally adjust between t and $t + i$, π_{t+j-1} is the inflation rate in $t + j - 1$, and π_{t+j}^{tar} is the inflation target set by the authority for the period $t + j$. This updating rule implies that whenever firms do not receive a signal, they adjust their prices by a geometric average of the inflation target set by the authority and past inflation. Parameter κ is a measure of the degree of persistency of inflation and can be associated with the credibility of the target set by the authority. The larger this parameter, the larger the weight given to past inflation and the lower the weight given to the inflation target—and thus the lower the credibility of the announcement. The Phillips curve with the Calvo model and this updating rule is given by

$$\hat{\pi}_t = \lambda \xi mc_t + \gamma_f E_t \hat{\pi}_{t+1} + \gamma_b \hat{\pi}_{t-1} + \zeta_t, \tag{2}$$

where $\hat{\pi}_t = \pi_t - \pi_t^{tar}$ corresponds to the deviation of inflation from the target, mc_t represents marginal costs, $\lambda(\kappa, \theta, \beta) = (1 - \theta)(1 - \theta\beta)/[\theta(1+\kappa\beta)]$, $\gamma_f(\kappa, \theta, \beta) = \beta/(1+\kappa\beta)$, and $\gamma_b(\kappa, \theta, \beta) = \kappa/(1+\kappa\beta)$. Parameter β is the subjective discount factor and ξ defines whether capital is mobile across firms (ξ=1) or firm specific ($\xi \neq 1$). The term ζ_t is a

function of changes in the inflation target.[8] Notice that parameter κ defines the backward-looking component of the Phillips curve. In other words, this parameter is also a measure of the degree of indexation in the economy.

Parameter θ is the probability that a firm will keep the current price until the next period. It also corresponds to the share of firms that do not optimally adjust prices in a particular period. We assume that this parameter captures, to some extent, the credibility of monetary policy. In the standard Calvo model, the probability of adjusting prices—or the share of firms optimally setting prices each period—has no economic interpretation other than as a measure of the degree of price stickiness. In our case, we assume that firms will adjust prices more often (that is, a larger share of firms will optimally adjust prices each period) when future inflation is more uncertain and the central bank's commitment regarding inflation is perceived to be weak.

Parameters θ, β, and κ are estimated using a generalized method of moments (GMM) estimation with quarterly data from 1991:1 to 2005:4, based on the following orthogonality condition derived from equation (2):

$$E_t\left\{\begin{bmatrix}\theta(1+\kappa\beta)\hat{\pi}_t-(1-\theta)(1-\theta\beta)\xi mc_t\\ -\theta\beta\hat{\pi}_{t+1}-\theta\kappa\hat{\pi}_{t-1}+\theta(1+\kappa\beta)\zeta_t\end{bmatrix}\mathbf{z}_t\right\}=0\,, \tag{3}$$

where $\mathbf{z}_t$ is a vector of instruments that includes three lags of the inflation deviation from target, the real marginal cost deviation from trend, and the output gap (from t – 3 to t – 5).[9]

Benchmark results for the estimated hybrid model are presented in table 1. We give the estimated values of parameters θ, β, and λ under four different specification for the marginal cost—derived from a Cobb-Douglas technology, a technology with labor hoarding, a CES technology and a CES technology for an open economy—, and assuming alternatively that capital is freely mobile and firm specific. We also report the estimated value of parameter κ, which measures the degree to which firms index their prices to past inflation.

8. In the steady state, with a constant inflation target, $\zeta_t = 0$.

9. To check the relevance of the instrument set used in our regressions, we test the null hypothesis that the coefficients on all the instruments are jointly zero in the first stage of the estimation. The F statistic, the associated p value, and the adjusted R^2 from the first stage of these regressions allowed us to reject the null hypothesis that the instruments are jointly irrelevant. The adjusted R^2 is generally over 0.5.

Table 1. Benchmark Phillips Curve Estimation[a]

	Model											
	Cobb-Douglas		*Overhead labor*		*CES, σ=0.5*		*CES, σ=1.5*		*CES for an open economy, σ=0.5*		*CES for an open economy, σ=1.5*	
Parameter	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*
θ	0.910	0.679	0.927	0.721	0.916	0.659	0.930	0.809	0.921	0.669	0.932	0.802
	(0.05)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)
β	0.973	0.973	0.966	0.966	0.973	0.973	0.970	0.970	0.969	0.969	0.951	0.951
	(0.16)	(0.16)	(0.13)	(0.13)	(0.15)	(0.15)	(0.15)	(0.15)	(0.14)	(0.14)	(0.12)	(0.12)
κ	0.776	0.776	0.730	0.730	0.732	0.732	0.760	0.760	0.727	0.727	0.737	0.737
	(0.11)	(0.11)	(0.09)	(0.09)	(0.08)	(0.08)	(0.11)	(0.11)	(0.10)	(0.10)	(0.09)	(0.09)
λ	0.006	0.090	0.005	0.068	0.005	0.108	0.004	0.029	0.005	0.102	0.004	0.034
	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.06)	(0.00)	(0.02)	(0.00)	(0.06)	(0.00)	(0.02)
γ_f	0.554	0.554	0.567	0.567	0.568	0.568	0.558	0.558	0.568	0.568	0.559	0.559
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
γ_b	0.442	0.442	0.428	0.428	0.427	0.427	0.437	0.437	0.426	0.426	0.433	0.433
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
τ_1	0.430	0.430	0.414	0.414	0.416	0.416	0.424	0.424	0.413	0.413	0.412	0.412
	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.06)	(0.06)

Table 1. (continued)

	Model											
	Cobb-Douglas		*Overhead labor*		*CES, σ=0.5*		*CES, σ=1.5*		*CES for an open economy, σ=0.5*		*CES for an open economy, σ=1.5*	
Parameter	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*	*ξ=1*	*ξ≠1*
τ_2	-0.442	-0.442	-0.428	-0.428	-0.427	-0.427	-0.437	-0.437	-0.426	-0.426	-0.433	-0.433
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
D	11.169	3.121	13.674	3.591	12.022	2.937	14.372	5.226	12.693	3.020	14.632	5.056
	(6.75)	(0.38)	(6.86)	(0.44)	(6.39)	(0.35)	(8.98)	(0.10)	(5.93)	(0.33)	(6.70)	(0.90)
J statistic	4.505	4.505	4.060	4.060	4.227	4.228	4.063	4.063	4.487	4.487	4.464	4.464
P value	(0.98)	(0.98)	(0.99)	(0.99)	(0.98)	(0.98)	(0.99)	(0.99)	(0.98)	(0.98)	(0.98)	(0.98)

Source: Authors' calculations.
a. Standard errors based on a Newey-West covariance matrix robust to serial correlation up to twelve lags are in parentheses. Parameter ξ defines whether capital is mobile across firms (ξ=1) or firm specific (ξ≠1). Row D reports the estimated duration of price stickiness. The *J* statistic is the Hansen test of overidentifying restrictions (we report the *p* values in parentheses). The set of instruments includes five lags of inflation deviation from its target and detrended output, three lags of real marginal costs, and five lags of detrended terms of trade.

The estimated share of the backward-looking component, γ_b, is statistically significant in all specifications, and it is about 0.45. This figure is slightly smaller than Agénor and Bayraktar (2003) find for Chile in their study of the inflation dynamics in middle-income countries. These authors estimate a nonstructural Phillips curve that includes both backward- and forward-looking components; they find that the backward-looking component is about 0.52. Unlike our case, Agénor and Bayraktar use several lags of the output gap (up to three for Chile) as the driving force for inflation.

The estimated values for parameter θ under this hybrid specification of the NKPC lie in the range of 0.8 to 0.9. This implies that firms adjust prices every seven quarters, on average. In the case of discount factor, β, our empirical results indicate that the estimated value for this parameter is somewhat low. Our specification for marginal cost with firm-specific capital delivers a lower value for θ, implying shorter average duration of price stickiness, as in Galí, Gertler, and López-Salido (2001). Finally, the overidentifying restrictions are satisfied for all cases. Table 1 also presents the results for the specification for marginal cost that assumes firm-specific capital (the results assuming capital mobility are similar).[10]

Parameter κ is consistently estimated in the range of 0.75 to 0.82, implying that within the sample period, firms gave more weight to past inflation than to inflation targets when passively adjusting their prices. These figures suggest a much stronger role for the backward-looking component of inflation in the Chilean case than is estimated by Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001) for the euro area. They are quite similar, however, to the estimates for the United States in those same two papers.

We turn now to the issue of parameter stability. [11] Following Céspedes, Ochoa, and Soto (2005), we consider a predictive test for structural change with an unknown breakpoint developed by Ghysels and Hall (1990), Ghysels, Guay, and Hall (1997), and Guay (2003). This test consists in estimating the parameter vector for a first subsample and then evaluating the moment conditions for the second subsample

10. We perform a robustness exercise to address the importance of the backward-looking component of the Phillips curve, in which we incorporate additional lags of inflation to the hybrid model. Additional lags of inflation turn out to be insignificant, as does the sum of the three additional lags of inflation.

11. This issue has not been formally analyzed in the literature. Jondeau and Le Bihan (2005) test the stability of their Phillips curve estimates, but they only examine the reduced-form (linear) parameters and use Wald-type tests, which have some important drawbacks (as they point out).

at these parameter values. The subsample is then increased by one observation at the time. Each time, the PR statistic (or predictive test) is constructed.[12]

Table 2 presents the estimated predictive tests (supremum: supPR; average: avgPR; and exponential: expPR), along with the date for which the largest PR test is obtained. The PR-type tests can be divided into a test of structural change for the vector of parameters and a test of the stability of the overidentifying restrictions (Sowell, 1996). We report the PR1-type statistic, which tests both parameter and overidentifying restriction stability, and the PR2-type tests for parameter variations only. The results show that we cannot reject the existence of a breakpoint for the four marginal cost specifications. Furthermore, the PR1 and PR2 tests consistently estimate the date of the breakpoint around the first quarter of 2001, which is close to the date that the inflation target reached its stationary annual value of 3 percent. We also report the estimated values of the parameter κ and the duration of price stickiness before the breakpoint date, $\kappa 1$ and D1 respectively in the table. In most cases, the first subsample value of κ is larger than the estimated parameter using the whole sample, suggesting that after the breakpoint in 2001 firms have given a larger weight to inflation targets when updating their prices. Finally, we find that the estimated duration of price stickiness is smaller before the breakpoint, as expected.

These results are consistent with the findings of Hutchison and Walsh (1998), who provide evidence of a possible shift in the output-inflation tradeoff in New Zealand after the implementation of the 1989 Reserve Bank Act. In their case, both direct tests of parameter instability and inference from inflation forecast errors indicate that the 1989 Act may have altered some fundamental economic relationships by changing the degree of central bank independence and the Reserve Bank's commitment to price stability.

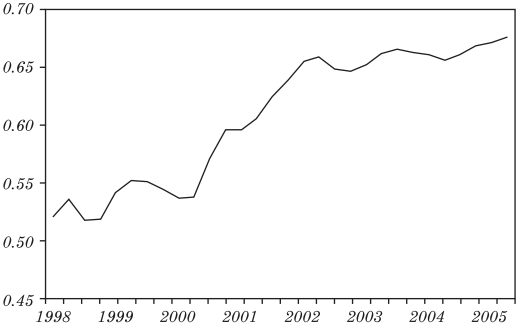
12. For our purposes, this approach has several advantages over alternative approaches like the Wald-type tests proposed by Andrews (1993) and Andrews and Ploberger (1994). First, we only use first subsample estimates of the parameters, which allows us to test for the presence of a break even when the second subsample contains few observations and parameter estimates are not feasible. A common drawback of Wald-type tests is that they cannot be applied to detect structural instability at the end of the sample. Second, we do not set a priori orthogonality conditions equal to zero in the second subsample, so we avoid rejecting stability when the parameters are, in fact, stable but there are certain types of misspecification (for example, omitted variables). A brief description of the test can be found in Céspedes, Ochoa, and Soto (2005).

Table 2. PR Test for Structural Breaks in the Hybrid Phillips Curve[a]

Model	*Sup PR1*	*Avg PR1*	*Exp PR1*	*Sup PR2*	*Avg PR2*	*Exp PR2*
Cobb-Douglas						
PR test statistic	152.63*	32.56*	73.12*	85.86*	17.29*	39.63*
Estimated breakpoint	2001:3					
κ1	0.921					
D1	2.41					
Overhead labor						
PR test statistic	117.84*	15.48**	55.62*	81.52*	9.97	37.46*
Estimated breakpoint	2001:4					
κ1	0.868					
D1	3.18					
CES						
PR test	79.40*	20.45**	37.10*	46.98*	10.01	20.21*
Estimated breakpoint	2001:4					
κ1	0.765					
D1	2.46					
CES for an open economy						
PR test	141.42*	34.50*	67.49*	89.77*	18.17**	41.67*
Estimated breakpoint	2001:4					
κ1	0.768					
D1	2.59					

Source: Authors' calculations.
* Statistically significant at the 1 percent level.
** Statistically significant at the 5 percent level.
a. The table reports predictive tests for the null hypothesis of structural stability, along with the estimated breakpoint date, the value of parameter κ, and the duration of price stickiness before the breakpoint date (κ1 and D1 respectively). The tests are estimated using Monte Carlo simulations with 10,000 replications.

Figure 5. Price Rigidity: Phillips Curve (θ)



Source: Authors' calculations.

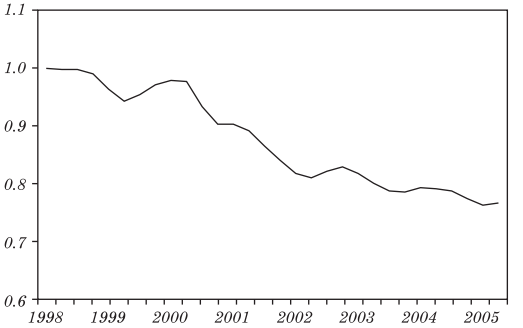
To further assess the potential direction of the structural change in the inflationary process in the Chilean economy, we run a set of regressions for the NKPC starting with the period 1991:1–1997:4 and then adding one more observation at a time. For these calculations, we use real marginal costs computed using a production function with overhead labor and firm-specific capital. The results indicate that price rigidity, captured by the parameter θ, has increased in recent years (see figure 5). Specifically, the estimated duration of price rigidity went from two quarters in the period previous to 2000 to around three quarters for the whole period. We also find that the parameter that measures the degree by which firms adjust their current prices based on previous inflation (κ) has decreased over time (see figure 6).

The evidence presented here is consistent with the view that some parameters are policy dependent (Rudd and Whelan, 2005). The increase in the price rigidity parameter and the decrease in the degree of indexation to past inflation support the hypothesis that monetary policy in Chile has become more credible. These results are also in line with the empirical and theoretical view that a more credible monetary policy is negatively correlated with inflation persistence (see Taylor, 2000; Sargent, 1999).

3.2 Changes in the Exchange Rate Pass-Through

Broad empirical literature shows that the pass-through from the exchange rate to prices is not full in the short run. Import prices in various countries deviate from the law of one price (Campa and

Figure 6. Weight of Past Inflation in the Passive Price Adjustment Rule (κ)



Source: Authors' calculations.

Goldberg, 2002), and the response of CPI inflation to changes in the exchange rate is often less than one to one in the short run (Borensztein and De Gregorio, 1999; Goldfajn and Werlang, 2000). In this subsection, we provide new evidence on the evolution of the pass-through in Chile in the last fifteen years using the new Keynesian Phillips curve as our analytical framework (see Monacelli, 2003).

The pass-through from the exchange rate to prices may be imperfect in the short run because of structural features of the market, as in Dornbusch (1977), or because of nominal rigidities. Given pricing-to-market behavior (Betts and Devereux, 1996), if a fraction of import prices are sticky in the domestic currency, then changes in the exchange rate will not be completely passed on to prices. In other words, the pass-through from the exchange rate to import prices will be incomplete. Therefore, changes in price rigidity will also imply changes in the exchange rate pass-through.

Since we are interested in the pass-through as a macroeconomic phenomena, we estimate the effect of changes in the nominal exchange on imported goods inflation based on a sticky-price model similar to the one used to derive the Phillips curve in the previous section. Following Monacelli (2003), we assume that domestic retail firms buy different varieties of imported goods in the international market and later sell them domestically. We assume that each retail firm has monopoly power over a particular imported variety, and it adjusts its prices infrequently with probability of $1 - \theta_M$ each period. Coefficient θ_M is a measure of nominal price rigidity in the import sector; it determines

the degree of imperfect pass-though. The larger this coefficient, the less frequently prices are changed and the lower is the pass-through from nominal exchange rate movements into imported price inflation (see the appendix).

A particular retail firm selling variety z_M that is able to adjust its price in period t chooses a new price, $P_{M,t}^{new}(z_M)$, to maximize its expected profits:

$$E_t \sum_{i=0}^{\infty} \theta_M^i \Lambda_{t,i} \left[\frac{P_{M,t}^{new}(z_M) - S_{t+i} P_{M,t+i}^{*}(z_M)}{P_{t+i}} C_{M,t+i}(z_M) \right],$$

subject to the domestic demand for that variety, given by $C_{M,t+i}(z_M)$. Variable S_t is the nominal exchange rate, and $P_{M,t}^{*}(z_M)$ is the international price of variety z_M expressed in foreign currency. From the first-order condition for this problem, we can establish the following relation for imported goods inflation, $\pi_{M,t}$:

$$\pi_{M,t} = \frac{(1-\theta_M)(1-\theta_M \beta)}{\theta_M} (s_t + p_{M,t}^{*} - p_{M,t}) + \beta E_t \pi_{M,t+1}. \tag{4}$$

where $s_t + p_{M,t}^{*}$ is the logarithm of the price of imported goods abroad expressed in domestic currency, and $p_{M,t}$ is the domestic price of imported goods in the domestic market.

We estimate equation (4) by GMM, using an imports price index (the *índice de valor unitario de importaciones*, or *IVUM*) as a proxy for the price of imported goods in foreign currency. The domestic price of imported goods is proxied by the price index corresponding to tradable goods included in the CPI basket. Our measure of inflation thus corresponds to the quarterly change in the tradable goods price index. The specification in equation (4) assumes that the distribution service provided by retail firms does not require the use of any inputs.[13] Our results indicate that the relative price of imports abroad is a strong driver of the tradables inflation rate, and the forward-looking component is also very relevant. Moreover, the coefficient associated with price rigidity, θ_M, is positive and significant (see table 3). This value yields an estimated duration of price stickiness of around five quarters.

13. Results under alternative specifications, in which labor is required to distribute the imported goods, are similar to the ones reported here.

Table 3. Tradable Inflation Phillips Curve

Parameter	*(1)*	*(2)*	*(3)*
β	0.972	0.907	0.919
	(0.01)*	(0.00)*	(0.01)*
θ_M	0.816	0.648	0.846
	(0.05)**	(0.00)*	(0.04)**
λ	0.047	0.223	0.040
	(0.03)**	(0.01)*	(0.02)**
Sample	1991:1–2005:4	1991:1–2000:4	1995:1–2005:4
J statistic	4.870	3.229	3.533
P value	(0.99)	(1.00)	(1.00)
SupPR test	1287.22	276.01	2396.41
Estimated breakpoint	2000:1	1999:4	2003:1

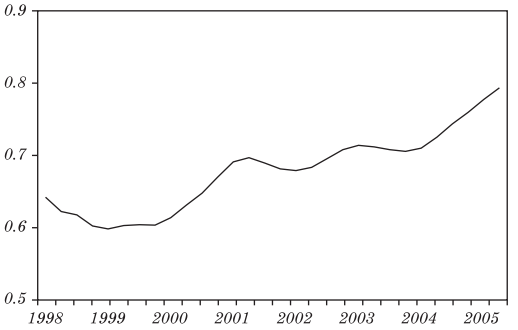
Source: Authors' calculations.
* Statistically significant at the 1 percent level.
** Statistically significant at the 5 percent level.
Standard errors in parentheses.

To test for potential structural breaks, we consider the predictive test for structural change discussed in the previous section. The supPR test points to a structural break around the first quarter of 2001. Again, to assess the scope of this change, we estimate a set of regressions starting with the period 1991:1–1997:4 and then adding one observation at a time. The results from this exercise indicate that the average price rigidity in the 1990s was close to 2.5 quarters, half the value for the whole sample (see figure 7). Also in table 3 we report results obtained when splitting the sample. Again, we find evidence that the frequency of imports price adjustments has decreased over time.[14]

These results indicate that the short-run pass-through was lower after 1999, during the Chilean economy's low-inflation period, than in the previous period. Taylor (2000) argues that the pass-through coefficient should be lower in low-inflation environments, as low inflation may be associated with less persistent changes in costs. From the perspective of our theoretical framework, we argue the higher credibility of monetary policy, interpreted as a credible commitment

14. Although the resulting number of observations is low, we divided the sample into two parts: from 1991:1 to 1997:4 and from 1998:1 to 2005:4. We find results consistent with the hypothesis of a change in price rigidity. In particular, the average duration of price stickiness in the second period is almost twice as large as in the first period.

Figure 7. Price Rigidity: Tradables Phillips Curve (θ_M)



Source: Authors' calculations.

to low and stable inflation rate around 3 percent, has reduced the frequency of price changes.[15]

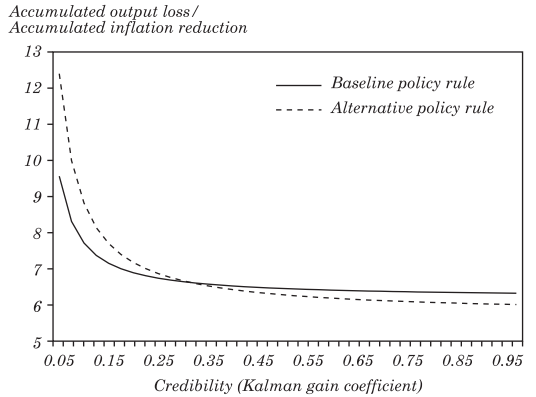
One special feature of the change in the pass-through coefficient in Chile is that it seems to have occurred not at the moment in which inflation rates reached low values (around 1998), but sometime later. We interpret this result as indicating that only when monetary policy was credible did the pass-through coefficient change. This evidence is related to the findings of Bailliu and Fujii (2004), who report that the exchange rate pass-through coefficients for a group of industrialized economies declined following the inflation stabilization in the early 1990s, but they did not decline following a similar episode in the early 1980s. One interpretation for this result is that the disinflationary process of the 1990s was perceived as more credible than the previous one.

4. Credibility and Monetary Policy

The previous section showed that the frequency of price adjustments, the degree of indexation to past inflation, and the exchange rate pass-through have decreased over time, especially after 2000. We interpreted this evidence as support for the view that monetary policy has become more credible over the last several years.

15. Céspedes and Valdés (2006) provide evidence that countries with more independent central banks, which are associated with a more credible monetary policy, have lower pass-through coefficients.

Figure 8. Sacrifice Ratio and Credibility



Source: Céspedes and Soto (2005).

A broad literature shows that when the monetary authority is not fully credible, its tradeoff between output and inflation stabilization is worse than when credibility is larger. In fact, in the simplest version of the new Keynesian Phillips curve, a fully credible stabilization process can be carried out without any output losses (Ball, 1995).

In Céspedes and Soto (2005), we present a model for comparing the sacrifice ratio implied by different monetary policy rules under alternative assumptions regarding the credibility of a disinflationary shock. We show that if the central bank is strict in fulfilling its inflation target, then inflation stabilization may generate significant output losses and large sacrifice ratios for low credibility levels. Figure 8 depicts the sacrifice ratio—that is, accumulated output losses relative to the accumulated reduction in inflation—for a disinflationary shock as a function of credibility, measured by a Kalman gain coefficient, under two alternative policy rules: a baseline Taylor rule and an alternative policy rule with a strong feedback response of the interest rate to deviation of inflation from the target.[16] The figure clearly illustrates

16. The model in Céspedes and Soto (2005) follows Erceg and Levin's (2003) approach to model imperfect credibility, assuming that private agents must solve a signal extraction problem in order to sort out whether a shock to the inflation target is permanent or transitory. They use the Kalman filter to solve for the signal extraction problem. The larger the Kalman gain coefficient, the faster they understand the nature of the shock to the target (that is, the more credible is a permanent shock to the inflation target).

how the sacrifice ratio falls as the credibility of the inflation target rises (that is, with a higher Kalman gain coefficient). The tougher rule has a higher sacrifice ratio than the baseline Taylor rule when credibility is low. As credibility increases, however, the sacrifice ratio of the alternative rule drops below the sacrifice ratio of the baseline policy rule. In other words, as credibility increases, a central bank can reduce inflation faster without having to sacrifice too much output.

In what follows, we investigate whether the way monetary policy is conducted in Chile has changed in line with the previous analysis. We estimate monetary policy interest rate rules for two periods that roughly coincide with the two phases described earlier: the first quarter of 1991 to the fourth quarter of 1997; and the first quarter of 1998 to the fourth quarter of 2005. As mentioned, the first phase was characterized by short-run horizons for the inflation targets, a managed exchange rate, and a target for the current account. We capture these features by assuming that the real interest rate (r_t) set by the Central Bank during the first period of inflation targeting was a function of current inflation, the output gap, and the current difference between the real exchange rate and its equilibrium level. We estimate the following relation:

$$r_t = (1-\rho_0)r + \rho_0 r_{t-1} + (1-\rho_0)\omega_{\pi,0}(\pi_t - \pi_t^{tar}) + (1-\rho_0)\omega_{y,0}g_{t-1} + (1-\rho_0)\omega_{e,0}q_t^{mis} + u_t, \quad (5)$$

where g_{t-1} corresponds to the output gap in $t-1$, q_t^{mis} is the real exchange rate misalignment, and u_t is a linear combination of prediction errors and policy innovations.[17] Since the term u_t could be correlated with actual values of inflation and the output gap, we estimate this relation using GMM, as suggested by Clarida, Galí, and Gertler (2000).

The results indicate that the specification of the monetary policy rule in equation (5) is a good description of monetary policy actions for the period 1991–97 (see table 4). The estimated coefficients have the

17. The output gap measure corresponds to the difference between effective output and a trend measure for output. This trend measure is obtained using the Hodrick-Prescott (HP) filter. The real exchange rate misalignment corresponds to the difference between the effective real exchange rate and the equilibrium real exchange rate. The equilibrium real exchange rate is computed by applying the HP filter to the effective real exchange rate. A positive value for q_t^{mis} implies that the real exchange rate is undervalued relative to its equilibrium level.

expected sign and are significant in all cases. In addition to responding to deviations of inflation from the target, the Central Bank of Chile responded to deviations of output from its trend value and to the exchange rate. As discussed previously, the Central Bank also targeted the current account during this period.[18]

Table 4. Monetary Policy Rules: Chile 1991–2005[a]

Parameter	*(1)*	*(2)*
ρ_0, ρ_1	0.63 (0.06)*	0.63 (0.04)*
$\omega_{\pi,0}$, $\omega_{\pi,1}$	0.35 (0.17)***	1.84 (0.28)*
$\omega_{y,0}$, $\omega_{y,1}$	0.35 (0.04)*	0.65 (0.24)**
$\omega_{q,0}$	0.15 (0.05)**	
Period	1991:1–1997:4	1998:1–2005:4
R^2	0.81	0.94
J statistic	1.92	3.52
P value	(0.98)	(0.99)

Source: Authors' calculations.
* Statistically significant at the 1 percent level.
** Statistically significant at the 5 percent level.
*** Statistically significant at the 10 percent level.
a. The dependent variable is the monetary policy real interest rate. The regressions are estimated using GMM. Regression 1 estimates parameters with subscript 1; regression 2 estimates parameters with subscript 2. The J statistic is the Hansen test of overidentifying restrictions (we report the p values in parentheses).Standard errors in parentheses.

When we include 1998–2005 in the sample, our estimations of the policy reaction function in equation (5) yield poor results. Most coefficients become insignificant or have the wrong sign (or both). This may reflect the change in the inflation-targeting framework starting in 1999. To explore the possibility of a structural change, we use the

18. To test how this could have been reflected in the policy rule (other than through the exchange rate), we included the current account in some of our estimations. The coefficient associated with the current account balance turned out to be negative and significant, indicating that the Central Bank responded actively to changes in the current account. Increases in the current account deficit beyond the target level triggered increases in the interest rate to cool down domestic expenditure.

predictive test proposed by Ghysels, Guay, and Hall (1997) and Guay (2003) and discussed in the context of the Phillips curve estimation above. The results of the test indicate that there is a structural break and that this break occurs around the first quarter of 2000.[19]

To account for this structural change, we estimate the following policy reaction function:

$$r_t = (1-\rho_1)r + \rho_1 r_{t-1} + (1-\rho_1)\omega_{\pi,1}\left[E_t(\pi_{t+4}) - \pi^{tar}_{t+4}\right] + (1-\rho_1)\omega_{y,1}g_{t-1} + u_t, \quad (6)$$

using quarterly data from 1998:1 to 2005:4. We do not split the sample exactly at the breakpoint detected with the PR test in order to have enough data to estimate the monetary policy rule for the second phase.

The estimations of this last policy rule indicate that in the full-fledged inflation-targeting phase, the monetary authority has become more forward looking in terms of inflation. In contrast to the previous phase, the evidence indicates that the Central Bank is willing to allow deviation of current inflation from the target as long as it does not have an impact on future inflation. Additionally, the coefficient associated with inflation, $\omega_{\pi,1}$, increased relative to the corresponding coefficient in the interest rate rule for the previous inflation-targeting phase. This stronger response of the interest rate to inflation deviations is consistent with a central bank that takes advantage of an improved trade-off between inflation and output, possibly as a consequence of higher credibility or commitment to controlling inflation.

5. Conclusions

In this paper, we have provided new evidence of changes in the dynamics of the Chilean inflationary process in recent years. Based on a new Keynesian Phillips curve, we showed that price rigidity has increased in recent years, while the degree of indexation in the economy—based on past inflation—has decreased. We also showed that the exchange rate pass-through into tradable goods inflation has decreased. Our findings are consistent with the idea that the

19. The PR test results were as follows: supPR: 174.48; avgPR: 71.27; and exp PR: 83.94. The tests were calculated using a Newey-West covariance matrix robust to serial correlation up to twelve lags.

credibility of monetary policy has increased over time. As monetary policy has become more credible, costly price adjustments have been carried out less frequently, and the prevalence of indexation based on past inflation has decreased.

These changes in the inflationary process, triggered by an enhanced credibility of monetary policy, may have had significant repercussions on the way monetary policy is implemented in Chile. In particular, as the Central Bank improves its credibility, it may fight inflation deviation from target strongly without having to sacrifice much output. In this context, the paper also presented evidence on a structural change in the policy rule that characterizes the conduction of the monetary policy. Our results are consistent with the idea that over the last several years, Chilean monetary policy has been operating in an improved credibility environment. The monetary policy rule has become more forward-looking in terms of inflation and more aggressive in fighting deviations of inflation from the target.

Appendix
Frequency of Price Adjustment and Pass-Though

From the main text, we have that imported goods inflation is given by,

$$\pi_{M,t} = \frac{(1-\theta_M)(1-\theta_M\beta)}{\theta_M}(s_t + p^*_{M,t} - p_{M,t}) + \beta E_t \pi_{M,t+1}.$$

When we normlaize $p^*_{M,t} = 1$, the law of motion for the domestic price is given by

$$p_{M,t} = \frac{\lambda_M}{1+\lambda_M+\beta} s_t + \frac{1}{1+\lambda_M+\beta} p_{M,t-1} + \frac{\beta}{1+\lambda_M+\beta} p_{M,t+1},$$

where $\lambda_M = [(1-\theta_M)(1-\theta_M\beta)]/\theta_M$. For simplicity, let us assume that the exchange rate follows a random walk process. Let δ_1 and $\delta_2 = (\beta/\delta_1)$ be the unstable and stable roots of the solution for $p_{M,t}$.[20] We can write the solution for the domestic currency price of imported goods as

$$p_{M,t} = \frac{1}{\delta_1} p_{M,t-1} + \frac{\lambda_M}{\delta_1}\frac{1}{1-\delta_2} s_t.$$

The short-run exchange rate pass-through coefficient is defined as

$$\frac{\partial p_{M,t}}{\partial s_t} = \lambda_M \frac{1}{\delta_1 - \beta}.$$

Under flexible prices, $\lambda_M \to \infty$, $\delta_1 \to \infty$, and $(\delta_1/\lambda_M) \to 1$. Then, the pass-through elasticity is unitary. If prices are completely sticky, however, then $\lambda_M = 0$ and $\delta_1 = 1$. In this case, the pass-through coefficient is zero. By a continuity argument, the pass-through coefficient is increasing in λ_M and, therefore, decreasing in θ_M.

20. Coefficient δ_1 is the solution to ${\delta_1}^2 - \delta_1(1 + \lambda_M + \beta) + \beta = 0$.

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