

TERMS OF TRADE SHOCKS AND INVESTMENT IN COMMODITY-EXPORTING ECONOMIES

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Commodity prices have experienced significant swings over the past two decades. Real commodity prices have, on average, more than doubled in the last decade compared to the previous one, while the prices of some commodities, such as copper and other industrial metals, have more than tripled in real terms. Commodity-exporting economies such as Chile have therefore enjoyed very favorable terms of trade (ToT) by historical standards (figure 1); for Chile, the only main exception is the golden period of saltpeter mineral extraction from 1895 to 1930. Hence, it is not surprising that many policy discussions in commodity-exporting economies have focused on the effects of commodity price fluctuations on output, inflation, real exchange rates, the current account and other macroeconomic variables, as well as on appropriate policy frameworks to deal with commodity price volatility.¹ This issue is also highly relevant in the present context where monetary policy in advanced economies

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1. See, for instance, IMF (2011) chapter 3 and IMF (2012) chapter 4.

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is being normalized and growth in emerging market economies is slowing down with adverse effects on commodity prices and exporters that are vulnerable to a fall in prices.

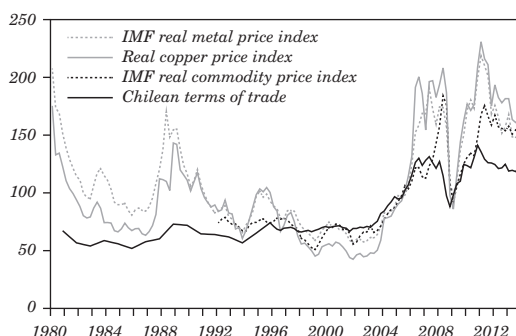
The macroeconomic effects of commodity price fluctuations have been widely studied in the literature, where two major strands can be distinguished.² The first one includes studies based on time-series methods such as structural vector autoregressions (SVARs) that attempt to estimate the effects of exogenous commodity price movements on macroeconomic aggregates through short-run or long-run identification and/or sign restrictions.³ Among those studies are, for instance, Bernanke and others (1997), Blanchard and Galí (2007), Kilian (2008; 2009), Kilian and Lewis (2011), Lombardi and others (2012), Baumeister and Peersman (2013), Gubler and Hertweck (2013), and Filardo and Lombardi (2014). However, most of these studies have focused on the impact of oil price shocks in developed countries such as the United States or Europe (all net commodity importers); whereas, relatively few studies have examined the effects of commodity price shocks in economies that rely heavily on commodity exports (and in particular mineral exports) like many developing and emerging market countries. Only a few recent studies have analyzed this topic, such as Camacho and Pérez-Quirós (2014) who investigate the dynamic interactions between commodity prices and output growth of major Latin American commodity exporters using Markov-switching impulse response functions, or Gruss (2014) who uses Global VAR analysis to examine the impact of commodity price cycles on output growth in Latin America and the Caribbean. In addition, Knop and Vespignani (2014) use SVAR analysis to estimate the effects of commodity price shocks on different industries such as mining, construction and manufacturing in Australia.

The second major strand of the literature is based on dynamic stochastic general equilibrium (DSGE) models that allow us to analyze, in a structural micro-founded framework, the different transmission channels and propagation mechanisms of commodity price shocks and to conduct policy experiments. Among these studies are, for instance,

2. Other related studies are Cashin and others (2004), Raddatz (2007), Izquierdo and others (2008), Adler and Sosa (2011), De Gregorio and Labbé (2011), and Céspedes and Velasco (2012), among others.

3. In the literature, sometimes commodity export price shocks are treated differently than ToT shocks. This distinction may or may not make sense depending on the size of the economy, importance of the commodity sector, co-movement of import and export prices, etc. For our selection of countries and sample periods, both definitions are fairly similar since the ToT for the countries considered are highly correlated with commodity prices.

Figure 1. Commodity Price Indices and Chilean ToT (2005 = 100), 1980.I-2013.IV



Source: See the appendix. Notes: The Chilean ToT series for the period from 1996 onwards is obtained from the Central Bank of Chile. For the period before 1996, we use interpolated annual ToT data from Clio Lab, Pontificia Universidad Católica de Chile. Further details on data sources and definitions are provided in appendix.

Kilian and others (2009), Tober and Zimmermann (2009), Bodenstein and others (2011), and Bodenstein and others (2012). However, most of these studies also focus on the effects of commodity price shocks (and mainly oil shocks) in developed countries, while the literature for developing and emerging commodity-exporting economies is less extensive. Some exceptions include Medina and others (2008) who explore what factors explain current account developments in Chile and New Zealand; Desormeaux and others (2010) who use a DSGE model to examine the transmission mechanism of commodity prices to inflation dynamics; Kumhof and Laxton (2010) who analyze Chile's structural surplus fiscal rule in the face of shocks to the world copper price; and Malakhovskaya and Minabutdinov (2014) who examine the effects of shocks to commodity export revenues in an estimated DSGE model for Russia. However, none of the above studies have analyzed the macro impact of commodity price shocks through their effects on investment in different sectors of the economy. A further examination to fill this gap is therefore interesting in view of recent sectoral investment dynamics in many commodity-exporting economies (also see Knop and Vespignani, 2014).

Hence, the objective of this paper is to analyze the effects of commodity price shocks in commodity exporters from a broad perspective, focusing on metals exporters such as Chile where we highlight the propagation of those shocks through investment in

mining and its macroeconomic spillover effects. This focus is motivated by the mining investment boom observed in most major commodity-exporting economies during the last decade, the impact of the latter on external savings balances, and their policy implications.

To conduct our analysis we employ two different methodologies: SVAR analysis and a DSGE model. First, the SVAR approach is aimed at exploring broad cross-country patterns and dynamics in the data. Here we analyze questions such as the following: How do commodity prices interact in the first place with other key variables of the world economy such as output, inflation and interest rates? How do commodity price shocks affect domestic variables? Are the effects similar across countries? Does the persistence of commodity price shocks matter for its impact on macroeconomic variables such as investment? To facilitate this econometric exercise, we analyze a group of small open economies as our identification approach relies on the exogeneity of commodity price fluctuations for commodity exporters.

Second, recognizing the usual difficulties that are involved in the identification of SVAR shocks, we use a DSGE model to add a different dimension to our analysis. This methodology not only allows to investigate the key propagation channels of commodity price shocks in a structural micro-founded way, but it is also useful to further explore several hypotheses that are raised by the SVAR results. For example, even though one may naturally expect a positive response of mining investment to a commodity price shock, it is not clear whether a rise in commodity prices triggers a boom in investment in both mining and non-mining sectors, or whether mining investment crowds out other aggregate demand components.⁴ In addition, we may ask whether the persistence of commodity price shocks matters. Finally, the DSGE model is useful to conduct counterfactual policy experiments to answer questions such as the following: How is the response of the economy to commodity price shocks affected by different types of fiscal rules? Should monetary policy try to limit exchange rate fluctuations due to such shocks? For this purpose, we use a New Keynesian small open economy model estimated for Chile. The DSGE model by Medina and Soto (2007a) is extended by including an endogenous commodity production structure. In

4. For instance, at the sectoral level, traditional exporters might suffer a loss of competitiveness if mining sectors compete with other sectors for resources. If this competition implies higher demand and inflation of non-tradable goods, there would be a real appreciation of the currency. The resulting reallocation is challenging for traditional export sectors, a widely studied phenomenon known as the Dutch disease.

addition, we parameterize the block of external variables with the SVAR estimates for Chile. With this model we are able to analyze the main propagation channels of a commodity price shock to decompose historical fluctuations of investment and GDP and to conduct two counterfactual experiments: alternative fiscal rules and response of monetary policy to exchange rate fluctuations.

Our contribution to the literature is thus twofold. First, we provide a study of the impact of commodity price shocks on sectoral investment in commodity-exporting economies based on a SVAR approach. Second, we augment an otherwise standard New Keynesian small open economy model with a commodity sector by an endogenous production structure in order to analyze the transmission channels and policy implications of commodity price shocks.

The main results from the SVAR analysis corroborate that commodity price shocks are an important source of business cycles in commodity-exporting economies. More in particular, we find that those shocks have significant effects on real GDP through their impact on investment where investment in mining shows relatively large, lagged and persistent responses in most analyzed countries. We also find that local currencies appreciate and current account balances deteriorate in some countries as investment rises; inflation shows mixed responses depending on the size and persistence of the exchange rate effect, and interest rates rise in most countries. Furthermore, a stronger persistence of commodity price shocks generates a much larger expansion of mining investment that tends to spill over to non-mining sectors.

Most of these empirical findings are in line with the dynamics predicted by the DSGE model for Chile. In fact, according to the model, mining investment is an important commodity price shock propagation channel where there is a direct link between the duration of the price increases and their macroeconomic impact. Moreover, the model shows that an investment boom in mining can generate a relatively persistent current account deficit. From a policy perspective, our results further suggest that while different monetary and fiscal policy reactions have, in general, important implications for the response of the economy to commodity price shocks, they do not majorly affect investment decisions in the commodity sector that are mainly driven by sectoral productivity developments and, particularly, commodity prices.

The remainder of the paper is structured as follows. Section 1 discusses a number of stylized facts regarding the recent evolution

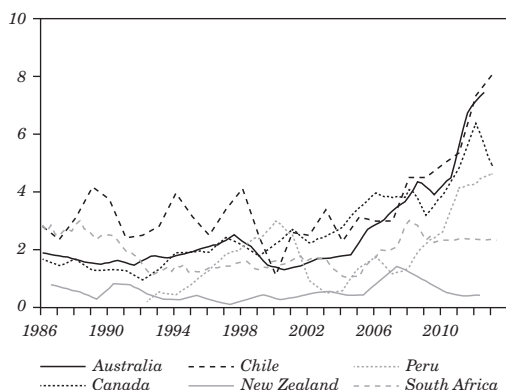
of investment, real GDP growth and current account balances in selected commodity exporters. Section 2 presents the SVAR analysis conducted for several commodity exporters. Section 3 describes the DSGE model for Chile while section 4 documents the results of the model-based analysis. Finally, section 5 concludes.

1. RECENT EVOLUTION OF INVESTMENT, GDP GROWTH AND CURRENT ACCOUNT BALANCES IN COMMODITY-EXPORTING ECONOMIES

In this section we discuss a number of common patterns regarding the recent evolution of investment, GDP growth and current account balances in commodity-exporting economies.

To begin with, mining investment has expanded at a higher rate than GDP (in terms of nominal ratios) in most major commodity-producing countries as figure 2 shows. This increase in investment evolved, to a certain extent, in parallel with the commodity price boom after 2004, but with some lag. For example, in Australia, Canada, Chile and Peru investment in mining as a share of GDP more than doubled in the late 2000s with respect to the average observed in the nineties and early 2000s. The case of South Africa is somehow

Figure 2. Investment in Mining Sectors 1986.IV-2013.IV
Percentage of nominal GDP



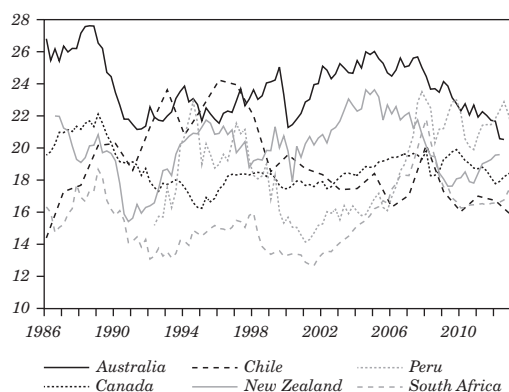
Source: See the appendix.

Note: Investment in mining for Canada includes oil well industries.

different because the increase in the ratio after the mid-2000s recovered figures observed in the eighties. Finally, New Zealand experienced a milder and shorter increase in mining investment.

Furthermore, figure 3 illustrates the evolution of non-mining investment shares for our selection of commodity exporters. In the mid-2000s, non-mining investment increased in several countries compared to its early 2000s volume, but much less than mining investment and relative to historical averages. Hence, most of the increase in total investment in those countries during the recent commodity cycle was due to higher investment in mining.

Figure 3. Investment in Non-Mining Sectors, 1986.IV-2013.IV
Percentage of nominal GDP



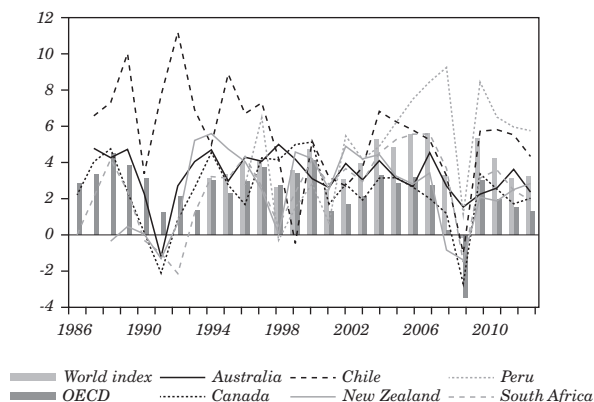
Source: See the appendix.

Higher investment in those countries has pushed aggregate demand and real GDP growth. Figure 4 compares the growth performance of our selection of countries with the world average and with the average of OECD countries between 1986 and 2013. Notably, the annual real GDP growth rates of most of the selected countries since the mid-2000s were above the OECD average. Economic growth was especially high in Chile and Peru, who grew at a faster pace than the world and OECD average. South Africa was located in the middle as it grew similarly as the world average. Finally, Australia, Canada and New Zealand performed slightly better than the OECD average, but worse than the world average. Differences in these countries' economic growth rates are driven by both structural and cyclical

factors. One possible structural explanation hinges on the capital-deepening hypothesis according to which economic growth rates tend to reflect different stages of development (Chile and Peru are less developed than Australia, Canada and New Zealand). In addition, as Gruss (2014) suggests, the commodity price boom may have pushed real GDP growth of Latin American countries above trend.

Figure 4. Real GDP Growth, 1986-2013

Percentage, annual average

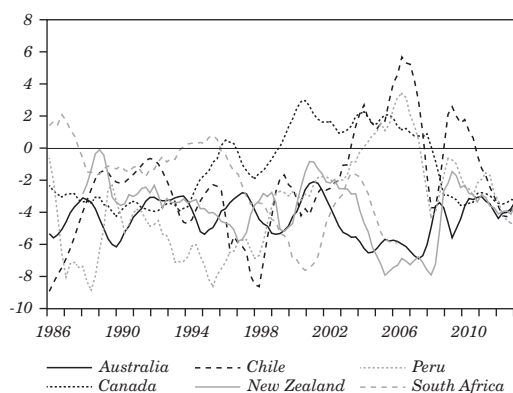


Source: See the appendix.

Finally, figure 5 shows that, despite the high commodity prices, the current account balances of most commodity exporters have been in deficit. Some countries such as Australia, New Zealand and South Africa have been net international borrowers since the late nineties, but it seems surprising that these countries did not save at least part of the unprecedented rise in commodity income since the mid-2000s. The remaining countries, and in particular Chile and Peru, did have positive external savings balances during the mid-2000s, but their current accounts also moved into deficit later on.⁵ Are those current

5. There are several hypotheses regarding underlying mechanisms that might explain such current account reversals. For instance, Fornero and Kirchner (2014) show that changes in agents' perceptions on the persistence of the commodity boom can explain the observed behavior of Chile's current account. Their argument is based on evidence of forecast revisions by professional forecasters and the panel of experts that determines the parameters of Chile's fiscal rule.

Figure 5. Current Account Balances, 1986.I-2013.IV
Percentage of nominal GDP



Source: See the appendix. Note: Current account ratios of Australia, Chile, Peru and South Africa are four quarters moving averages.

account deficits due to the investment boom in those countries, and how is the latter related to the surge in commodity prices? What does the macroeconomic adjustment to commodity price shocks look like in commodity exporters such as Canada, Chile, Peru and New Zealand? Are the adjustments different or are they similar? To answer these questions, we now conduct a SVAR analysis of the effects of commodity price shocks in those countries.

2. STRUCTURAL VAR ANALYSIS

In this section we estimate SVAR models for Australia, Canada, Chile, New Zealand, Peru and South Africa. These countries are commodity exporters that satisfy the small open economy assumption such that foreign variables may be regarded as exogenous. Table 1 reports the recent export shares of this selection of countries. It is noteworthy that Australia, Chile, Peru and South Africa are major exporters of industrial metals. Exports of Canada and New Zealand are also concentrated in commodities, but not as much metals. Hence, these two countries are useful benchmarks to compare our results.

Table 1. Top Five Products Exported in 2013 in Selected Commodity Exporters

Australia	Iron ore & concentrates (26.7%)	Canada	Petroleum (21.4%)
	Coal (15.2%)		Motor vehicles & equipment (12.6%)
	Natural gas (5.6%)		Gold (3.6%)
	Gold (5.3%)		Aircrafts & equipment (2.3%)
	Petroleum (4.5%)		Natural gas (2.2%)
Chile	Copper (29.7%)	N. Zealand	Milk, cream & milk products (20.4%)
	Copper ores & concentrates (22.4%)		Meat (11.4%)
	Fruits (8.0%)		Rough wood (4.9%)
	Fish (5.0%)		Butter (4.6%)
	Pulp & waste paper (3.6%)		Petroleum (3.6%)
Peru	Copper ores & concentrates (17.0%)	S. Africa ^a	Iron ore & concentrates (15.8%)
	Gold (14.2%)		Silver, platinum (7.4%)
	Petroleum (10.0%)		Ores & concentrate of base metals (6.5%)
	Ores & concentrate of base metals (8.7%)		Coal (6.1%)
	Copper (7.6%)		Gold (5.3%)

Source: UNCTAD Statistics, based on UN DESA and UN Comtrade.

a. Estimated values.

2.1 Data

Regarding the data, apart from an external block of variables, we use official quarterly data for each country on GDP, mining and non-mining investment, inflation, interest rates, real exchange rates and current account balances. The sample coverages include explicit or implicit inflation targeting monetary regimes. For Australia, the sample begins in 1993.II and ends in 2013.II due to restrictions of mining investment data. For Canada, the sample covers the period 1991.III-2013.IV. For Chile, the considered period is 1996.I-2014.IV.⁶ For New Zealand, the sample period is 1991.I-2013.IV. For Peru, the sample spans the period from 1998.I to 2013.IV. Finally, for South Africa the sample period is 1995.I-2014.I. The foreign block of variables includes a measure of world GDP, foreign inflation and interest rates and a real commodity price index. Details of variable definitions, transformations and sources are provided in appendix. We apply homogeneous transformations to facilitate the comparison of shock sizes and their effects across countries.

2.2 Empirical Model

The empirical model is a standard SVAR with block exogeneity to account for the main characteristics of small open economies. Thereby, it is assumed that foreign variables do not respond to changes in domestic variables. This methodology allows an efficient estimation (compared to an unrestricted VAR) of the joint evolution of domestic and foreign variables. Following Hamilton (1994), the reduced-form VAR can be written as follows:

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \mathbf{A}'_1 & \mathbf{A}'_2 \\ \mathbf{B}'_1 & \mathbf{B}'_2 \end{bmatrix} \times \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + \mathbf{D} \begin{bmatrix} z_{1,t} \\ z_{2,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$$

6. Chilean nominal mining investment in 2014 is estimated using the 2014 annual growth rate of mining investment of Cochilco and FECU (*Ficha Estadística Codificada Uniforme*) reports. Both sources report downward revisions: the former implies a larger fall of -39.7%, while the latter yields -18.2%. Notice that these growth rates result from taking investment denominated in U.S. dollars, so we adjust for annual changes of the nominal exchange rate. In particular, the 2014 annual growth rate estimated from FECU combines effective data for 2014Q1-2014Q3, and the investment for the fourth quarter is assumed to be equal to the average of the first three quarters.

where $y_{1,t}$ and $y_{2,t}$ are vectors of n_1 foreign variables and n_2 domestic variables, respectively. Accordingly, current outcomes are explained by previous developments measured by p lags in the variables $y_{1,t-1}, \dots, y_{1,t-p}$ and similarly for y_2 . This lagged information is gathered in $x_{1,t}$ and $x_{2,t}$, of dimensions $n_1 p \times 1$ and $n_2 p \times 1$, respectively. In addition, the vector z_t includes deterministic terms such as time trends and constants. The unknown coefficients to be estimated are the elements of the vectors c_1 and c_2 and the matrices $\mathbf{A}'_1$, $\mathbf{A}'_2$, $\mathbf{B}'_1$, $\mathbf{B}'_2$, and $\mathbf{D}$. The errors $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are of dimension $n_1 \times 1$ and $n_2 \times 1$, respectively. By definition, errors are expected to be zero on average and their variance-covariance matrix is positive definite.

The VAR is further restricted to reflect the small open economy assumption, namely, we impose that $\mathbf{A}'_2 = 0$ such that y_1 forms an exogenous block of variables (under the identification scheme that is described below). The resulting system of equations, subject to $\mathbf{A}'_2 = 0$, can be estimated by full information maximum likelihood. The implementation is standard and follows the algorithm described in Hamilton (1994).

The exogenous foreign block is composed of the following: (1) an index of real world GDP (in logs), (2) annual U.S. CPI inflation, (3) U.S. federal funds nominal rate and (4) a real commodity price index (in logs).⁷ Structural shocks are identified using a Cholesky decomposition of the variance-covariance matrix of the VAR residuals. Therefore, the ordering of the variables implies a recursive identification scheme with the first of the aforementioned variables being the most exogenous. In particular, we assume that U.S. inflation and interest rates respond contemporaneously to exogenous changes in world GDP while world GDP does not respond within a quarter to exogenous changes in inflation and interest rates. The interest rate is assumed to respond to exogenous changes in inflation in the same quarter, but not vice versa. This ordering of variables is fairly standard in monetary SVARs. In addition, we order commodity prices after the remaining external variables to reflect the usage of commodities as financial assets that adjust instantaneously to news on the remaining foreign variables, including foreign interest rates.⁸ Hence, under this particular recursive

7. Due to parsimony reasons, the oil price is not included in the external block of the VAR system. In the model of the following section, the oil price is thus assumed to follow an exogenous AR(1) process.

8. We have tried alternative orderings (e.g., ordering commodity prices before interest rates to reflect the fact that these form part of the Fed's information set when monetary policy decisions are taken), overall our main results remain robust to those alternative orderings.

identification scheme, commodity price shocks could also be interpreted to capture signals on future changes in world demand for commodities that are associated with a delayed response of world GDP, inflation and interest rates.⁹

The endogenous domestic block includes seven key variables for each country: (1) real GDP (in logs), (2) nominal non-mining investment as a percentage of nominal GDP, (3) nominal mining investment as a percentage of nominal GDP, (4) the annual CPI inflation rate, (5) the annual nominal monetary policy rate, (6) the real exchange rate (in logs), and (7) the current account balance as a percentage of nominal GDP.

Regarding the lag length of the SVARs, standard information criteria (Schwarz, Akaike and Hannan-Quinn) point towards one or two lags. However, for the sake of parsimony and to facilitate comparisons across countries we choose one lag for all reported estimations. Finally, we add a constant and a quadratic time trend as deterministic terms.

2.3 Cross-Country Comparison of SVAR Results

Table 2 reports the impulse responses of foreign variables to an unexpected commodity price shock of 50%, which roughly corresponds to the observed average increase of real commodity prices in the mid-2000s. In general, the SVAR estimates suggest that the increase in commodity prices is relatively persistent for all countries with a half-life of the commodity price responses ranging between two and three years for most countries (except Peru where the half-life of the shock is less than two years). The estimated shocks are coherent with a delayed expansion of world GDP that is statistically significant at conventional levels and persistent across countries. The peak effect on world GDP materializes after two to three years and ranges between 1.5% and 2.5%. Moreover, all estimations suggest a statistically significant rise in global inflation, which increases up to around one percent after a year. Higher output and inflation explain why interest rates increase consistently with flexible inflation targeting frameworks adopted by the Federal Reserve and other leading central banks around the world.

9. This interpretation is in line with Frankel (2006; 2008a; 2008b) and Calvo (2008).

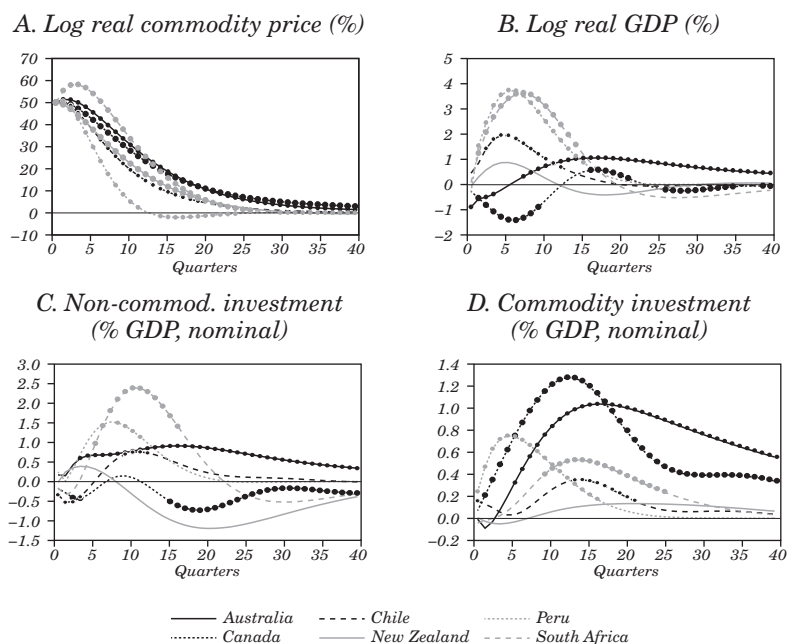
Table 2. Impulse Responses to Commodity Price Shocks (50%) from SVAR Models, External Variables

Qrt.	Log real foreign GDP					Annual foreign inflation						
	Aus.	Can.	Chile	NZ	Peru	SA	Aus.	Can.	Chile	NZ	Peru	SA
$t = 0$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$t = 1$	0.7	0.5	0.8	0.5	0.9	0.9	0.5	0.4	0.4	0.4	0.7	0.5
$t = 4$	1.9	1.5	1.6	1.5	1.9	2.3	1.2	0.9	0.7	1.0	1.4	1.2
$t = 8$	2.2	1.9	1.3	1.8	1.3	2.4	1.2	1.0	0.5	0.9	0.8	1.1
$t = 12$	1.9	1.7	0.7	1.6	0.4	1.6	0.9	0.8	0.2	0.7	0.2	0.8
$t = 16$	1.4	1.4	0.3	1.2	0.0	0.9	0.6	0.6	0.1	0.5	0.0	0.4
$t = 20$	1.0	1.0	0.1	0.8	-0.1	0.4	0.4	0.4	0.0	0.3	-0.1	0.2
Qrt.	Foreign interest rate					Log real commodity price						
	Aus.	Can.	Chile	NZ	Peru	SA	Aus.	Can.	Chile	NZ	Peru	SA
$t = 0$	0.0	0.0	0.0	0.0	0.0	0.0	50	50	50	50	50	50
$t = 1$	0.4	0.5	0.5	0.5	0.6	0.5	51	50	51	49	51	55
$t = 4$	1.1	1.3	0.9	1.4	1.2	1.1	48	45	41	41	36	57
$t = 8$	1.2	1.5	0.6	1.4	0.8	1.0	37	34	26	28	13	42
$t = 12$	1.0	1.1	0.2	1.0	0.3	0.6	25	23	15	17	1	26
$t = 16$	0.6	0.6	0.0	0.5	0.0	0.2	17	16	8	10	-2	13
$t = 20$	0.4	0.2	-0.1	0.1	0.0	0.0	11	11	5	6	-1	6

Source: Authors' elaboration.
Note: Bold values are statistically significant at the 90% confidence level.

Concerning the domestic effects of the commodity price shocks, figure 6 shows the responses of real GDP and investment in mining and non-mining sectors (as a ratio of nominal GDP). The results show that the estimated commodity price shocks generate an expansion of real GDP in most countries that is partly driven by investment. On one hand, investment in mining tends to react little on impact, but afterwards the responses are positive, relatively large and persistent for the majority of countries, pointing to an expansion of capacity that takes time to materialize. The effects of the commodity price are estimated to be stronger in countries with larger commodity sectors, i.e., Australia, Canada, Chile, Peru and South Africa, whereas, they are not significant for New Zealand. In the case of Chile, the effects are smaller due to the lower persistence of the shock. In Peru, where the shock is also less persistent than in other countries, the effects are stronger initially but less persistent than on average.

Figure 6. Impulse Responses from SVAR Models, Selected Countries

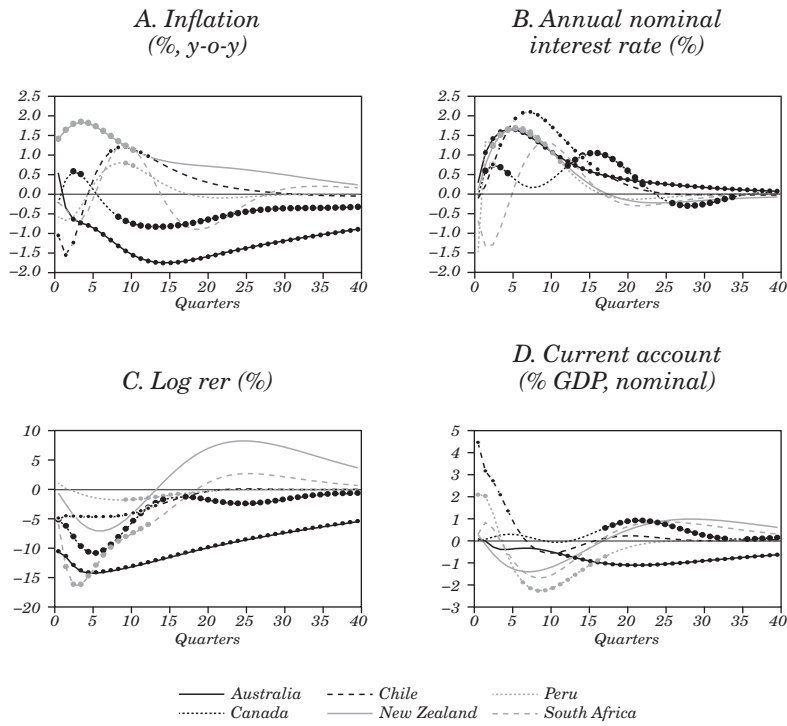


Source: Authors' elaboration.

Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% confidence level.

On the other hand, non-mining investment shows more heterogeneous responses across countries. In the mining-exporting countries (Australia, Chile, Peru and South Africa), the increase in non-mining investment is larger than real GDP. One interpretation of this result is that mining investment induces more investment in construction while it boosts imports of machines and equipment. In contrast, in countries with a more diversified trade structure such as New Zealand and Canada, the reaction of non-mining investment is not significant or negative such that mining investment may crowd out other investment in those countries.

Figure 7. Impulse Responses from SVAR Models, Selected Countries



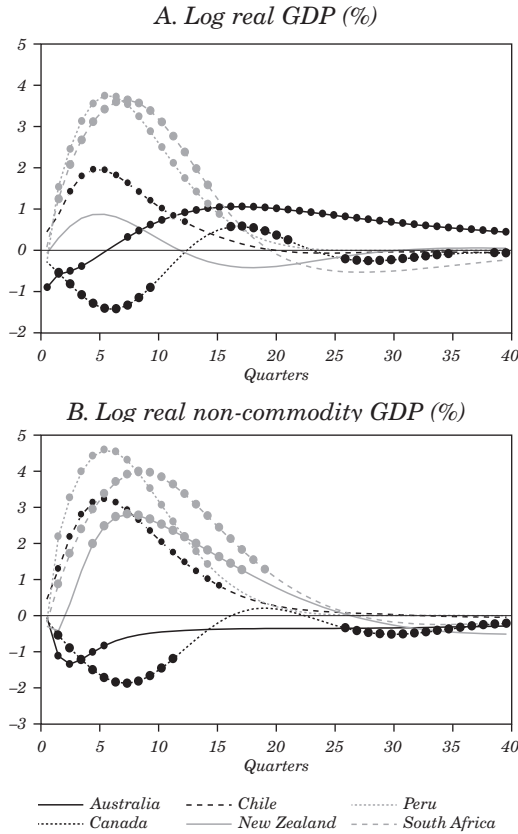
Source: Authors' elaboration.
Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% confidence level.

Figure 7 shows the responses of real exchange rates, inflation, interest rates and the current account balances in the different countries. With the exception of Peru and New Zealand, all countries present a significant real appreciation of local currencies in the short-run. These movements in real exchange rates are consistent with an upward adjustment in domestic absorption and demand due to the positive wealth effect associated with the shock. They also explain why inflation falls in some cases despite the increase in demand due to the pass-through effect of the real appreciation on consumer prices. In fact, the negative effects on inflation are stronger in countries with a more persistent real exchange rate appreciation (Australia and Canada). In addition, consistently with higher output and in some cases positive inflation, the estimated responses of monetary policy rates are significantly positive in all countries except South Africa.

Interestingly, current account balances move into deficit in several countries while in some countries (Chile and Peru) we observe a reversal effect after initial surpluses (although this effect is not significant for Chile). The negative and delayed current account responses are evidently related to the hump-shaped dynamics of investment and in particular higher mining FDI.

So far, we have discussed the positive effects of commodity price shocks on investment and total GDP. Here we ask whether these results are robust when considering non-commodity GDP instead of total GDP. Figure 8, panel (B) shows the impulse responses of SVAR models with non-commodity GDP instead of total GDP while panel (A) shows the impulse responses with total GDP (as in figure 6). The evidence reaffirms our previous findings: higher commodity prices generate expansionary effects on the non-commodity sector. For the majority of the countries, except for Australia, the expansion in non-commodity GDP is stronger than in the case with total GDP. This result is consistent with the hypothesis that it is costly to increase the added value of the commodity sector in the short-run. Furthermore, the responses from panel (B) are statistically more significant. The responses for Australia are smaller and less significant in the case with non-commodity GDP, which is consistent with greater flexibility in expanding supply in the commodity sector. However, this evidence also suggests that other sectors in Australia diminish activity because of a crowding out effect. The responses of other variables included in the SVAR models are not reported since they are both quantitatively and qualitatively very similar (the only exception again being Australia).

Figure 8. Responses of Total GDP and Non-Commodity GDP to a Commodity Price Shock from SVAR Models, Selected Countries



Source: Authors' elaboration. Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% confidence level.

In summary, our main findings from the SVAR analysis across countries are as follows:

- The commodity price shocks estimated from the data are relatively persistent. All SVARs associate these shocks with expansionary effects on world GDP, inflation and interest rates.
- We observe delayed responses of domestic investment concentrated in mining sectors and expansion in aggregate output. However, non-mining investment may fall in countries with a more diversified trade structure.

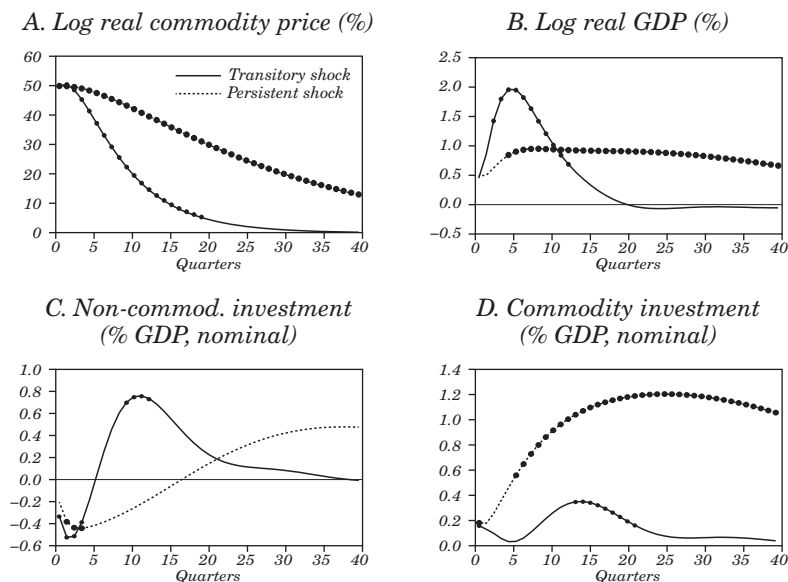
- Commodity price shocks also have important expansionary effects on non-commodity output (in most analyzed countries). In addition, most countries show relatively low short-run supply elasticities in the commodity sector.
- Across countries, as investment rises, local currencies appreciate in the short-run and current account balances deteriorate in the medium term.
- The responses of inflation are positive for some countries while they are negative in others where the exchange rate appreciation is relatively persistent. Interest rates rise in all countries consistently with a tightening response of monetary policy.

2.4 The Case of Chile with Persistent and Transitory Shocks

In the analysis of the previous section we added time trends as controls to the estimated VARs to match long-run dynamics. In this section, we implement an alternative exercise where we assume that the real price of copper is stationary in the long-run. In other words, we maintain the assumption that the nominal copper price and the U.S. CPI are cointegrated. This assumption is consistent with the finding that, based on longer spans of data, we reject the null hypothesis of a unit root in the real copper price.

Figure 9 shows that the estimated commodity price shock is significantly more persistent in this variant of the SVAR for Chile where the half-life of the shock is more than 6 years. The impulse responses of investment in mining and non-mining sectors are very different from the previous transitory shock case. Under the more persistent shock, mining investment increases by more than 1 percentage point of GDP while under the transitory shock it reaches less than 0.4 percentage points of GDP at maximum. However, while the response of non-mining investment under the transitory shock is positive and significant, under the persistent shock, the response of non-mining investment is not significant and positive after only 4 years.

In summary, the persistence of commodity price shocks seems to matter for the responses of output and commodity investment in commodity-exporting economies to such shocks. While transitory shocks do not seem to activate much investment in commodity sectors, persistent shocks tend to have larger effects. In the following section, we analyze the transmission mechanisms that can explain these dynamics based on a DSGE model in more detail where some of the

Figure 9. Impulse Responses from Alternative SVAR Models for Chile

Source: Authors' elaboration. Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% confidence level.

features of the model (such as time to build frictions) are motivated by the SVAR results.

3. THE DSGE MODEL FOR CHILE

In this section we describe an extended version of the DSGE model developed by Medina and Soto (2007a). The model of Medina and Soto (2007a) is a New Keynesian small open economy model with several standard elements¹⁰ and some specific features of the Chilean economy such as a commodity-exporting sector that is owned

10. The standard ingredients (see, for instance, Adolfson and others, 2008) include a production structure with domestic and foreign tradable goods, sticky prices and wages with partial indexation to past inflation, incomplete exchange rate pass-through into import prices in the short-run, adjustment costs in investment, and habit persistence in consumption. The model also includes a fraction of non-Ricardian households, oil in the consumption basket and as an input for domestic goods production and food consumption.

in part by the government and in part by foreign agents, as well as a structural balance rule to describe fiscal policy in Chile. However, commodity production is assumed to be exogenous in the Medina and Soto (2007a) framework. We drop this assumption and instead assume that commodity production is conducted in an endogenous way through capital with time to build in capital accumulation and investment adjustment costs following Kydland and Prescott (1982) and Uribe and Yue (2006).¹¹ This extension is described in detail below while the description of the basic framework is relatively brief and we refer to Medina and Soto (2007a) for a more detailed discussion.¹² Finally, we assume that the dynamics of the relevant foreign variables are described by the external block of the SVAR model for Chile from the previous section.

3.1 Households

There is a continuum of households indexed by $j \in [0, 1]$. A fraction λ of those households are non-Ricardian ones without access to the capital market. These households receive no profits and do not save and, thus, consume their disposable wage income entirely. The remaining households are Ricardian ones that do have access to the capital market and make intertemporal consumption and savings decisions in a forward-looking manner.

Households of the Ricardian type maximize the present value of expected utility at time t :

$$\max E_t \sum_{i=0}^{\infty} \beta^i \zeta_{C,t+i} \left[\log(C_{t+i}^R(j) - hC_{t+i-1}^R) - \psi \frac{l_{t+i}(j)^{1+\sigma_L}}{1+\sigma_L} \right], \quad j \in (1-\lambda, 1],$$

subject to the period-by-period budget constraint

$$P_{C,t} C_t^R(j) + E_t \{d_{t,t+1} D_{t+1}(j)\} + \frac{B_t(j)}{r_t} + \frac{\varepsilon_t B_{P,t}^*(j)}{r_t^* \Theta_t} =$$

$$W_t(j) l_t(j) + \Xi_t(j) - TAXN_t(j) + D_t(j) + B_{t-1}(j) + \varepsilon_t B_{P,t-1}^*(j),$$

11. We include time to build and investment adjustment costs, as in Uribe and Yue (2006), to obtain more plausible investment and output dynamics in the commodity sector.

12. A shock to the stock of capital is also added to the basic framework of Medina and Soto (2007a) to resemble the 2010 earthquake in Chile.

where $C_t^R(j)$ is consumption of household j and C_t^R is aggregate consumption of Ricardian households, respectively, while $l_t(j)$ is household j 's labor effort (in hours). The variable $\zeta_{C,t}$ is a preference shock to the households' subjective discount factor. Further, $P_{C,t}$ is the aggregate consumer price index (CPI), $W_t(j)$ is the nominal wage set by the household, $\Xi_t(j)$ collects payouts by firms, $TAXN_t(j)$ are lump-sum tax payments to the government, ε_t is the nominal exchange rate (units of domestic currency to buy one unit of foreign currency), and $d_{t,t+1}$ is the period t price of one-period domestic contingent bonds $D_t(j)$ normalized by the probability of the occurrence of the state. The variable r_t denotes the gross interest rate on a non-contingent domestic bond denominated in domestic currency $B_t(j)$, whereas, r_t^* is the (exogenous) interest rate on a non-contingent foreign bond denominated in foreign currency $B_{P,t}^*(j)$. The term $\Theta(\cdot)$ is a premium paid by domestic agents on top of the foreign interest rate.¹³

Following Erceg and others (2000), each household is a monopolistic supplier of a differentiated labor service. These labor services are bundled by a set of perfectly competitive labor packers that hire labor varieties and combine them into an aggregate labor service unit used as an input in production of domestic intermediate varieties. Cost minimization of labor packers yields the demand for each type of labor as a function of relative wages and aggregate labor demand by firms. There are wage rigidities in the spirit of Calvo (1983). In each period, a household faces a probability $(1 - \phi_L)$ of being able to re-optimize its nominal wage. The households that can re-optimize at time t will maximize the expected discounted future stream of labor income net of the disutility from work, subject to the labor demand constraint. All those that cannot re-optimize at time t set their wages according to a weighted average of past CPI inflation and the inflation target set by the central bank. Once a household has set its wage, it must supply any quantity of labor service demanded at that wage.

Households of the non-Ricardian type consume their disposable wage income each period:

$$P_{C,t}C_t^{NR}(j) = W_t l_t(j) - TAXN_t(j), \quad j \in [0, \lambda].$$

13. The premium is a function of the aggregate (private, $B_{P,t}^*$, plus government, $B_{G,t}^*$) net foreign bond position relative to nominal GDP ($BY_t = \varepsilon_t B_t^*/P_{Y,t} Y_t$), i.e. $\Theta_t = \bar{\Theta} \exp[-\varrho(BY_t - \bar{B}\bar{Y}) + \zeta_{\Theta,t}/\bar{\zeta}_{\Theta} - 1]$ where $\varrho > 0$ to ensure stationarity of net foreign bonds and where $\zeta_{\Theta,t}$ is a shock to the premium (throughout, bars indicate deterministic steady state values).

For simplicity, it is assumed that non-Ricardian households set a wage equal to the average wage set by Ricardian households. As a consequence, the supply of labor by non-Ricardian households coincides with the average labor supply of Ricardian households.

The households' consumption bundle is a constant elasticity of substitution (CES) composite of a core consumption bundle $C_{Z,t}(j)$, food consumption $C_{A,t}(j)$, and oil consumption $C_{O,t}(j)$. Core consumption is a CES composite of final domestic goods $C_{H,t}(j)$, and imported goods $C_{F,t}(j)$. Food consumption is a similar composite of domestic and imported goods but subject to an exogenous shock ($\zeta_{A,t}$) to capture deviations of food price inflation from core inflation. Households minimize the costs of the different bundles, which yields standard Dixit-Stiglitz type demand functions for the individual components as well as expressions for the headline CPI, food prices, and the core CPI excluding oil and food (given oil prices).

3.2 Domestic Goods

In the domestic goods sector, there is a continuum of firms that produce differentiated varieties of intermediate tradable goods using labor, capital and oil as inputs. They have monopoly power over the varieties they produce and adjust prices infrequently. These firms sell their varieties to competitive assemblers that produce final domestic goods that are sold in the domestic and foreign market. Another set of competitive firms produces the capital goods used in intermediate goods production. All firms in this sector are owned by Ricardian households.

A representative capital goods producer rents capital goods to domestic intermediate goods producing firms. It decides how much capital to accumulate each period, assembling investment goods I_t with a CES technology that combines final domestic goods $I_{H,t}$ and imported goods $I_{F,t}$. The optimal composition of investment is determined through cost minimization. The firm may adjust investment to produce new capital goods K_t in each period, but there are convex costs of adjusting investment $\Phi(\cdot)$ following Christiano and others (2005). The firm chooses the level of investment and its stock of capital to maximize the present value of expected profits to households (rental returns on capital net of the cost of investment):

$$\max E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} [Z_{t+i} \exp(\zeta_{K,t+i}) K_{t+i-1} - P_{I,t+i} I_{t+i}],$$

subject to the law of motion of capital

$$K_t = (1 - \delta) \exp(\zeta_{K,t}) K_{t-1} + [1 - \Phi(I_t / I_{t-1})] \zeta_{I,t} I_t,$$

where $\Lambda_{t,t+i}$ is the stochastic discount factor for nominal payoffs from the Ricardian household's problem and Z_t is the rental price of capital.¹⁴ The variable $\zeta_{I,t}$ is an investment-specific shock that alters the rate at which investment is transformed into productive capital (see Greenwood and others, 2000), while $\zeta_{K,t}$ is an i.i.d. shock to the stock of capital that captures physical destruction of capital due to natural disasters such as an earthquake.

There is a large set of firms that use a CES technology to assemble final domestic goods from domestic intermediate varieties. A quantity $Y_{H,t}$ of those goods is sold domestically, and a quantity $Y_{H,t}^*$ is sold abroad. The assemblers demand intermediate goods of variety z_H for domestic sale $Y_{H,t}(z_H)$ and intermediate goods for foreign sale $Y_{H,t}^*(z_H)$. Input cost minimization yields the typical Dixit-Stiglitz demand functions for each variety.

Intermediate goods producers decide on the most efficient combination of labor, capital and oil (i.e., to minimize input costs given factor prices). The available technology is as follows:

$$\mathbf{Y}_{H,t}(z_H) = a_{H,t} \left[\alpha_H^{1/\omega_H} V_{H,t}(z_H)^{1-1/\omega_H} + (1 - \alpha_H)^{1/\omega_H} O_{H,t}(z_H)^{1-1/\omega_H} \right]^{\omega_H},$$

where $V_{H,t}$ denotes value added produced from labor and capital while $O_{H,t}(z_H)$ is the amount of oil used as intermediate input and $a_{H,t}$ represents a stationary productivity shock common to all firms.¹⁵ Value added is generated through a Cobb-Douglas function:

$$V_{H,t}(z_H) = [T_t l_t(z_H)]^{\eta_H} [\exp(\zeta_{K,t}) K_{t-1}(z_H)]^{1-\eta_H},$$

where $l_t(z_H)$ is the amount of labor utilized, T_t is a stochastic trend in labor productivity, and $K_{t-1}(z_H)$ is the amount of capital rented at the beginning of period t .¹⁶

14. The stochastic discount factor satisfies $\Lambda_{t,t+i} = \beta^i (\zeta_{C,t+i} / \zeta_{C,t}) (C_t^R - h C_{t-1}^R) / (C_{t+i}^R - h C_{t+i-1}^R) (P_{C,t} / P_{C,t+i})$. Further, the function $\Phi(\cdot)$ satisfies $\Phi(1 + g_Y) = \Phi'(1 + g_Y) = 0$ and $\Phi''(1 + g_Y) = \mu_S > 0$ where g_Y is the steady state (balanced) growth rate of the economy.

15. By market clearing, it holds that $Y_{H,t}(z_H) = Y_{H,t}(z_H) + Y_{H,t}^*(z_H)$.

16. The productivity trend evolves according to the process $T_t / T_{t-1} = \zeta_{T,t} = (1 + g_Y)^{1-\rho_T} \zeta_{T,t-1}^{\rho_T} \exp(\varepsilon_{T,t})$.

The intermediate producers have monopoly power and set their prices separately in the domestic market $P_{H,t}(z_H)$, and the foreign market $P_{H,t}^*(z_H)$, maximizing profits subject to the corresponding demand constraints. Prices are set in a staggered way following Calvo (1983). In every period, the probability that a firm receives a signal for optimally adjusting its price for the domestic market is $1 - \phi_{H_D}$ and the probability of optimally adjusting its price for the foreign market is $1 - \phi_{H_F}$. If a firm does not receive a signal, it updates its price according to a weighted average of past changes of aggregate producer prices ($P_{H,t}$ or $P_{H,t}^*$) and steady state domestic or foreign CPI inflation. Let $MC_{H,t}$ denote the marginal cost of producing variety z_H . When a firm can re-optimize its price for the domestic market or foreign market, it solves

$$\max E_t \sum_{i=0}^{\infty} \phi_{H_D}^i \Lambda_{t,t+i} [\Gamma_{H_D,t}^i P_{H,t}(z_H) - MC_{H,t+i}] Y_{H,t+i}(z_H),$$

subject to the final domestic goods producer's demand $Y_{H,t}(z_H) = [P_{H,t}(z_H)/P_{H,t}]^{-\varepsilon_H} Y_{H,t}$. Analogously, when a firm can re-optimize its price for the foreign market, it solves

$$\max E_t \sum_{i=0}^{\infty} \phi_{H_F}^i \Lambda_{t,t+i} [\Gamma_{H_F,t}^i P_{H,t}^*(z_H) - MC_{H,t+i}] Y_{H,t+i}^*(z_H),$$

subject to the demand constraint $Y_{H,t}^*(z_H) = [P_{H,t}^*(z_H)/P_{H,t}^*]^{-\varepsilon_H} Y_{H,t}^*$.¹⁷

3.3 Imported Goods

In the imported goods sector, there is a continuum of retail firms that repackage a homogeneous good bought from abroad into differentiated imported varieties through a brand naming technology. Those firms have monopoly power in the domestic retailing of their particular variety and set prices infrequently. They sell their varieties to competitive assemblers that produce final imported goods that are bought by households and firms. As in the case of the domestic

17. For $i > 1$, the passive price updating rules are $\Gamma_{H_D,t}^i = \Gamma_{H_D,t}^{i-1} \pi_{H,t+i-1}^{\chi_{H_D}} \bar{\pi}^{1-\chi_{H_D}}$ for domestically sold goods and $\Gamma_{H_F,t}^i = \Gamma_{H_F,t}^{i-1} \pi_{H,t+i-1}^{*\chi_{H_F}} \bar{\pi}^{*1-\chi_{H_F}}$ for goods sold abroad where $\pi_{H,t} = P_{H,t}/P_{H,t-1}$, $\pi_{H,t}^* = P_{H,t}^*/P_{H,t-1}^*$ and $\bar{\pi}^*$ denotes steady-state foreign CPI inflation. For $i = 0$, we have $\Gamma_{H_D,t}^0 = \Gamma_{H_F,t}^0 = 1$.

goods sector, all firms in the imported goods sector are owned by Ricardian households.

There is a large set of firms that uses a CES technology to assemble final imported goods $Y_{F,t}$ from imported varieties. Demand for a particular imported variety $Y_{F,t}(z_F)$ is determined through minimization of costs, which yields the Dixit-Stiglitz demand functions for each variety.

Imported goods retailers buy a homogeneous good from abroad at the price $P_{F,t}^*$, which is then differentiated into a particular variety and sold domestically to assemblers of final imported goods. It takes one unit of the homogenous foreign good to produce a unit of retail output. Each importing firm has monopoly power and adjusts the domestic price of its variety in a staggered way following Calvo (1983). Each period, a firm optimally adjusts its price with probability $1 - \phi_F$. If a firm does not receive a signal, it updates its price according to a weighted average of past changes of aggregate producer prices $P_{F,t}$ and steady state CPI inflation. When a firm can re-optimize its price, it solves

$$\max E_t \sum_{i=0}^{\infty} \varphi_F^i \Lambda_{t,t+i} [\Gamma_{F,t}^i P_{F,t}(z_F) - \varepsilon_{t+i} P_{F,t+i}^*] Y_{F,t+i}(z_F),$$

subject to the final imported goods producer's demand $Y_{F,t}(z_F) = [P_{F,t}(z_F)/P_{F,t}]^{-\varepsilon_F} Y_{F,t}$.¹⁸

3.4 Commodity Goods

We extend the model of Medina and Soto (2007a) by endogenizing commodity production. As in Medina and Soto (2007a), there is a representative firm in the commodity sector S that produces a homogeneous commodity good. The entire production is exported. A fraction χ of the assets of that firm is owned by the government and the remaining fraction is owned by foreign investors. The revenue generated in the commodity sector is shared accordingly, but the government levies taxes on the profits that accrue to foreign investors.

18. The passive price-updating rule is $\Gamma_{F,t}^i = \Gamma_{F,t}^{i-1} \pi_{F,t+i-1}^{\chi_F} \bar{\pi}^{1-\chi_F}$ for $i > 0$ and $\Gamma_{F,t}^0 = 1$ for $i = 0$.

3.4.1 Production technology

The firm in sector S uses capital specific to that sector $K_{S,t}$ to produce commodity goods $Y_{S,t}$. Production evolves along the balanced growth path of the economy, but we admit transitory deviations from that growth path due to sectoral technology shocks $a_{S,t}$. Specifically, commodity production satisfies

$$Y_{S,t} = a_{S,t} F^S(T_t, K_{S,t-1}). \quad (1)$$

The function $F^S(\cdot)$ is homogeneous of degree one in its arguments and has diminishing returns to capital additions. While we focus on capital-intensive commodity production and, for simplicity, abstract from other inputs such as labor, the shock $A_{S,t}$ can be interpreted to capture any variations in such additional inputs.¹⁹ We also allow for a fixed transfer to households to capture eventual labor remunerations or other fixed costs (see below).

3.4.2 Profits and cash flow

Let $P_{S,t}^*$ denote the international price of the commodity good, and let $P_{S,t} = \epsilon_P P_{S,t}^*$ be its domestic price, which the firm takes as given. Gross profits of the firm are given by

$$\Pi_{S,t} = P_{S,t} Y_{S,t} - P_{C,t} T_t \kappa_S$$

where $P_{C,t} T_t \kappa_S$ is a fixed cost of production that grows at the same rate as nominal output. We assume that this fixed cost is a lump-sum transfer to Ricardian households. The cash flow of the firm is $CF_{S,t} = \Pi_{S,t} - P_{I,S,t} I_{S,t}$ where $P_{I,S,t} I_{S,t}$ is the firm's investment. The objective of the firm is to maximize the present real value of its expected cash flow:

19. For instance, we could take the Cobb-Douglas production function $Y_{S,t} = \tilde{F}^S(T_t l_S, T_t F_{S,t}, K_{S,t-1}) = (T_t l_S)^{\eta_{LS}} (T_t F_{S,t})^{\eta_{FS}} K_{S,t-1}^{1-\eta_{LS}-\eta_{FS}}$ where l_S would be a fixed input of labor and $F_{S,t}$ would capture variations in other factors such as the mineral content of land. Defining $\eta_S = \eta_{LS} + \eta_{FS}$, we obtain $Y_{S,t} = a_{S,t} T_t^{\eta_S} K_{S,t-1}^{1-\eta_S}$, which is a representation of (1) with $a_{S,t} = l_S^{\eta_{LS}} F_{S,t}^{\eta_{FS}}$ and with $F^S(T_t, K_{S,t-1}) = T_t^{\eta_S} K_{S,t-1}^{1-\eta_S}$. Under those assumptions, total factor productivity $a_{S,t}$ is a function of labor and other factors subsumed in $F_{S,t}$.

$$\max E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i}(S) \frac{CF_{S,t+i}}{P_{C,t+i}},$$

where $\Lambda_{t,t+i}(S)$ denotes the stochastic discount factor relevant to the firm. This discount factor is taken to be identical to the one of the households, i.e., $\Lambda_{t,t+i}(S) = \Lambda_{t,t+i}$.²⁰

3.4.3 Law of motion of capital

Notice that the definition of profits does not have any importance for a firm's optimality, however, it is a key determinant of the tax base, which is needed to characterize the Chilean fiscal rule (see next section for details). The stock of capital in sector S is augmented through investment projects $X_{S,t}$. Following Uribe and Yue (2006), there are adjustment costs in investment and time to build in the installation of capital à la Kydland and Prescott (1982). In particular, the firm can start new investment projects in each period, but at a cost that is convex: the larger the change in investment, the larger the implied cost. In addition, new investment projects take $n \geq 1$ periods to mature. Collecting these assumptions results in the following law of motion of capital:

$$K_{S,t} = (1 - \delta_S) K_{S,t-1} + [1 - \Phi_S(X_{S,t-n+1} / X_{S,t-n})] X_{S,t-n+1}. \quad (2)$$

The function $\Phi_S(\cdot)$ is analogous to the Christiano and others (2005) style flow adjustment cost function from the law of motion of capital used in the domestic goods sector, and satisfies $\Phi_S(1 + g_Y) = \Phi'_S(1 + g_Y) = 0$ and $\Phi''_S(1 + g_Y) = \mu_{I_S} > 0$. A similar specification of the law of motion of capital is employed in Uribe and Yue (2006). The effective flow of investment in period t is given by

$$I_{S,t} = \sum_{j=0}^{n-1} \varphi_j X_{S,t-j}, \quad (3)$$

where φ_j denotes the fraction of projects initiated in period $t - j$ that is financed in period t , with $\sum_{j=0}^{n-1} \varphi_j = 1$. We will assume that

20. The relation $\Lambda_{t,t+i}(S) = \Lambda_{t,t+i}$ holds, as we assume, that the government has a stochastic discount factor equivalent to the one of the households and that foreign investors have access to domestic currency bonds.

$\varphi_0 = \varphi_1 = \dots = \varphi_{n-1}$ as in Kydland and Prescott (1982), i.e., the cost of a project is spread equally over the horizon of its installation. In the extreme, when $n = 1$, we obtain the familiar law of motion $K_{S,t} = (1 - \delta_S)K_{S,t-1} + [1 - \Phi_S(I_{S,t}/I_{S,t-1})]I_{S,t}$.

3.4.4 Capital-investment choice

The firm's first-order optimality conditions are as follows:

$$K_{S,t} : \frac{Q_{S,t}}{P_{C,t}} = E_t \left\{ \Lambda_{t,t+1} \left[\frac{Q_{S,t+1}}{P_{C,t+1}} (1 - \delta_S) + \frac{P_{S,t+1} A_{S,t+1} F_{K_S}^S(T_{t+1}, K_{S,t})}{P_{C,t+1}} \right] \right\},$$

$$X_{S,t} : \phi_0 \frac{P_{I_{S,t}}}{P_{C,t}} + \phi_1 E_t \left\{ \Lambda_{t,t+1} \frac{P_{I_{S,t+1}}}{P_{C,t+1}} \right\} + \dots + \phi_{n-1} E_t \left\{ \Lambda_{t,t+n-1} \frac{P_{I_{S,t+n-1}}}{P_{C,t+n-1}} \right\}$$

$$= E_t \left\{ \begin{aligned} & \Lambda_{t,t+n-1} \frac{Q_{S,t+n-1}}{P_{C,t+n-1}} [1 - \Phi_S(X_{S,t} / X_{S,t-1}) \\ & - \Phi_S'(X_{S,t} / X_{S,t-1}) X_{S,t} / X_{S,t-1}] \\ & + \Lambda_{t,t+n} \frac{Q_{S,t+n}}{P_{C,t+n}} \Phi_S'(X_{S,t+1} / X_{S,t}) (X_{S,t+1} / X_{S,t})^2 \end{aligned} \right\}$$

where $F_{K_S}^S(\cdot)$ is the derivative of the production function in (1) with respect to capital. These two conditions jointly determine the evolution of investment projects and the mark-to-market value of capital $Q_{S,t}$ in sector S . The law of motion (2) determines the evolution of the stock of capital and (3) determines the effective flow of investment in this sector.

3.4.5 Composition of investment

The investment good that is required to build the stock of capital in sector S is a CES bundle of final domestic goods $I_{H,t}(S)$ and imported goods $I_{F,t}(S)$:

$$I_{S,t} = \left[\gamma_{I_S}^{1/\eta_{I_S}} I_{H,t}(S)^{1-1/\eta_{I_S}} + (1 - \gamma_{I_S})^{1/\eta_{I_S}} I_{F,t}(S)^{1-1/\eta_{I_S}} \right]^{\eta_{I_S}} \frac{I_{S,t}}{I_{S,t}^{-1}}. \quad (4)$$

The optimal composition of investment is determined through cost minimization. In each period, given the effective flow of investment, the firm minimizes $P_{I_{S,t}} I_{S,t} = P_{H,t} I_{H,t}(S) + P_{F,t} I_{F,t}(S)$ subject to (4), which yields the following demands for investment inputs originating in sector S :

$$I_{H,t}(S) = \gamma_{I_S} (P_{H,t} / P_{I_{S,t}})^{-\eta_{I_S}} I_{S,t},$$

$$I_{F,t}(S) = (1 - \gamma_{I_S}) (P_{F,t} / P_{I_{S,t}})^{-\eta_{I_S}} I_{S,t}.$$

3.5 Fiscal Policy

A share χ of the cash flow that is generated in sector S goes directly to the government, and the government also levies taxes at a fixed rate τ_S on the profits—net of depreciation—that accrue to foreign investors. The budget constraint of the government is therefore as follows:

$$P_{G,t} G_t + \frac{\varepsilon_t B_{G,t}^*}{r_t^* \Theta_t} = \varepsilon_t B_{G,t-1}^* + \tau_t P_{Y,t} Y_t + \chi CF_{S,t} \\ + \tau_S (1 - \chi) (\Pi_{S,t} - \delta_S Q_{S,t} K_{S,t-1}),$$

where $P_{G,t} G_t$ denotes nominal government consumption expenditure, $B_{G,t}^*$ is the government net foreign asset position, and τ_t are lump-sum taxes from households net of transfers (as a share of nominal GDP, $P_{Y,t} Y_t$). Note that the government net asset position is assumed to be completely denominated in foreign currency, as in Medina and Soto (2007a). In addition, government consumption is characterized by complete home bias, i.e., $G_t = G_{H,t}$ and $P_{G,t} = P_{H,t}$.

Government expenditure follows a structural balance fiscal rule analogous to the one described in Medina and Soto (2007a):

$$\frac{P_{G,t} G_t}{P_{Y,t} Y_t} = \left[\left(1 - \frac{1}{r_{t-1}^* \Theta_{t-1}} \right) \frac{\varepsilon_t B_{G,t-1}^*}{P_{Y,t} Y_t} + \tau_t \frac{P_{Y,t} \bar{Y}}{P_{Y,t} Y_t} + \chi \frac{CF_{S,t}}{P_{Y,t} Y_t} \right. \\ \left. + \tau_S (1 - \chi) \frac{\Pi_{S,t} - \delta_S Q_{S,t} K_{S,t-1}}{P_{Y,t} Y_t} - \frac{VC_t}{P_{Y,t} Y_t} - \bar{s}_B \right] \frac{P_{G,t} \zeta_{G,t} T_t}{P_{Y,t} Y_t}$$

where $VC_t = [\chi + \tau_S(1 - \chi)]\varepsilon_t(P_t^* - \tilde{P}_t^*)Y_{S,t}$ is the cyclical adjustment of the rule that depends crucially on the difference between the effective commodity price P_t^* and the long-run reference price $\tilde{P}_t^*$, which is calculated as the forecast of the effective commodity price averaged over a 10-year horizon. In addition, $\bar{Y}$ stands for potential real GDP, which, for simplicity, is taken to be equal to steady state output, and the parameter $\bar{s}_B$ is the structural balance target. The variable $\zeta_{G,t}$ is a shock capturing deviations of government expenditure from the fiscal rule.

3.6 Monetary Policy

Monetary policy is conducted through a simple Taylor-type feedback rule for the nominal interest rate, which is a slightly modified version of the one presented in Medina and Soto (2007a). In particular, while the latter assumes that the central bank responds entirely to deviations of core CPI inflation from target, and output growth from potential growth, we allow for a partial response to headline CPI inflation to capture possible concerns by the central bank on oil and food price inflation. Hence, the monetary policy rule is specified as follows:

$$\frac{r_t}{\bar{r}} = \left(\frac{r_{t-1}}{\bar{r}} \right)^{\psi_r} \left[\left(\frac{\pi_{Z,t}}{\bar{\pi}} \right)^{\psi_\pi \psi_{\pi Z}} \left(\frac{\pi_t}{\bar{\pi}} \right)^{\psi_\pi (1 - \psi_{\pi Z})} \left(\frac{Y_t / Y_{t-1}}{T_t / T_{t-1}} \right)^{\psi_Y} \right]^{1 - \psi_r} \exp(\zeta_{m,t})$$

where $\pi_{Z,t}$ and π_t are core and headline CPI inflation, respectively, Y_t is real GDP, and $\zeta_{m,t}$ is an i.i.d. shock that captures deviations of the interest rate from the monetary policy rule.

3.7 Rest of the World

Foreign agents demand the commodity good and the final domestic good. They supply oil and the homogeneous good that is bought by importing firms. Foreign demand for the commodity good is assumed to be completely elastic at its international price $P_{S,t}^*$. Likewise, foreign supply of oil is assumed to be completely elastic at any given price $P_{O,t}^*$. The real exchange rate is defined as the domestic currency price of a foreign price index $\varepsilon_t P_t^*$ relative to the domestic CPI. The domestic economy is assumed to be small relative to the rest of the world. As a consequence, the price of the homogeneous foreign

good $P_{F,t}^*$ coincides with the foreign price index. Foreign demand for the final domestic good depends on its relative price abroad $P_{H,t}^*/P_t^*$ and foreign aggregate demand Y_t^* according to the demand function $Y_{H,t}^* = \zeta^*(P_{H,t}^*/P_t^*)^{-\eta^*} Y_t^*$.

3.8 Aggregate Equilibrium

The market clearing condition for each variety of domestic goods is

$$Y_{H,t}(z_H) = [P_{H,t}(z_H) / P_{H,t}]^{-\varepsilon_H} Y_{H,t} + [P_{H,t}^*(z_H) / P_{H,t}^*]^{-\varepsilon_H} Y_{H,t}^*,$$

where $Y_{H,t} = C_{H,t} + I_{H,t} + I_{H,t}(S) + G_{H,t}$. In the labor market, labor demand by intermediate goods producers equals labor supply: $\int_0^1 l_t(z_H) dz_H = l_t$ where the aggregate labor service unit is given by

$$l_t = \left[\int_0^1 l_t(j)^{1-1/\varepsilon_L} dj \right]^{\varepsilon_L^{-1}}.$$

Nominal GDP satisfies $P_{Y,t} Y_t = P_{C,t} C_t + P_{I,t} I_t + P_{IS,t} I_{S,t} + P_{G,t} G_t + P_{X,t} X_t - P_{M,t} M_t$ where $P_{X,t} X_t = \varepsilon_t (P_{H,t}^* \dot{Y}_{H,t}^* + P_{S,t}^* \dot{Y}_{S,t}^*)$ and $P_{M,t} M_t = \varepsilon_t [P_{F,t}^* \dot{Y}_{F,t}^* + P_{O,t}^* (C_{O,t} + O_{H,t})]$ are nominal exports and imports, respectively, with $\dot{Y}_{F,t} = \dot{C}_{F,t} + \dot{I}_{F,t} + \dot{I}_{F,t}(S)$. Real GDP is defined as $Y_t = C_t + I_t + I_{S,t} + G_t + X_t - M_t$. Substituting out aggregate profits in the budget constraint of the households, and combining the latter with the budget constraint of the government, yields the following expression for the evolution of aggregate net foreign bonds:

$$\begin{aligned} \frac{\varepsilon_t B_t^*}{r_t^* \Theta_t} &= P_{X,t} X_t - P_{M,t} M_t + \varepsilon_t B_{t-1}^* - (1 - \chi) CF_{S,t} \\ &\quad + \tau_S (1 - \chi) (\Pi_{S,t} - \delta_S Q_{S,t} K_{S,t-1}). \end{aligned}$$

The terms on the right-hand side are net exports, net interest receipts minus the cash flow from the commodity sector that accrues to foreign investors, and transfers from foreigners due to taxes on profits net of the mark-to-market value of capital depreciation in the commodity sector. Finally, the current account balance is equivalent

to the quarter-on-quarter change in the international investment position of the country (relative to nominal GDP):

$$CAY_t = \frac{1}{P_{Y,t}Y_t} \left[\frac{\varepsilon_t B_t^*}{r_t^* \Theta_t} - \frac{\varepsilon_t B_{t-1}^*}{r_{t-1}^* \Theta_{t-1}} \right] - (1 - \chi) \frac{Q_{S,t}(K_{S,t} - K_{S,t-1})}{P_{Y,t}Y_t}.$$

3.9 Exogenous Processes and Foreign SVAR

There are fifteen exogenous variables in the model: preferences $\zeta_{C,t}$, neutral technology $a_{H,t}$, productivity growth $\zeta_{T,t}$, investment-specific technology $\zeta_{I,t}$, capital destruction $\zeta_{K,t}$, commodity-specific technology $a_{S,t}$, fiscal policy $\zeta_{G,t}$, monetary policy $\zeta_{m,t}$, stationary foreign demand $y_t^* = Y_t^*/T_t$, foreign inflation $\pi_t^* = P_t^*/P_{t-1}^*$, food prices $\zeta_{A,t}$, real commodity price $p_{S,t}^* = P_{S,t}^*/P_t^*$, real oil price $p_{O,t}^* = P_{O,t}^*/P_t^*$, foreign interest rate r_t^* , and the country premium $\zeta_{\Theta,t}$. The domestic exogenous variables are assumed to follow autoregressive processes of order one in logs AR(1) except the monetary policy shock and the capital destruction shock, which are i.i.d. processes in levels. The foreign variables are assumed to be determined by the external block of the SVAR model from section 2.²¹

4. ANALYSIS WITH THE DSGE MODEL

We now use the model from the previous section to analyze the impact of commodity price shocks in Chile. In particular, we highlight how the effects of those shocks on the main macroeconomic variables are amplified through the endogenous response of investment in the commodity sector, and discuss the role of the persistence of those shocks. We also compute historical decompositions of investment and real GDP growth in terms of the different structural shocks of the model to examine the importance of commodity price shocks relative to other types of shocks for observed macroeconomic dynamics. Finally, we conduct some counterfactual policy exercises to analyze the effectiveness of alternative macroeconomic policy frameworks in mitigating the impact of commodity price shocks in a commodity-exporting economy such as Chile.

21. As the real oil price does not enter the foreign VAR, it is assumed to follow an AR(1) process.

4.1 Parameterization

The model is parameterized following Fornero and Kirchner (2014), who combine calibration and Bayesian estimation of the structural parameters of the model. In addition, the parameters of the foreign SVAR are assigned using the results from the previous section where we take the persistent case as a benchmark (see section 2.4). Tables 3 and 4 summarize our choice of parameters where we use the posterior mode estimates from Fornero and Kirchner (2014). For reasons of limited space, we only discuss the key parameters related to the commodity sector and refer to Fornero and Kirchner (2014) for a more detailed discussion.

Table 3. Calibrated Parameters

<i>Parameter</i>	<i>Value</i>	<i>Description</i>
<i>Steady state (SS) values</i>		
g_Y	2.5%	Balanced growth path (net rate, annual basis)
π	3%	SS inflation target (net rate, annual basis)
π^*	3%	SS foreign inflation rate (net rate, annual basis)
$\bar{r}^*$	4.5%	SS foreign interest rate (net rate, annual basis)
$\bar{\Theta}$	1.3%	SS country premium (net rate, annual basis)
$\bar{s}_B$	0%	SS structural fiscal balance target
$\bar{g}$	0.055	SS government consumption (stationary level)
$\bar{a}_S$	0.081	SS productivity in commodity sector
$\bar{y}^*$	1	SS foreign demand (stationary level)
$\bar{p}_O$	1	SS real international price of oil (dom. currency)
$\bar{p}_S$	1	SS real int. commodity price (dom. currency)
<i>Non-Ricardian households</i>		
λ	0.500	Share of non-Ricardian households
<i>Ricardian households</i>		
β	0.999	Subjective discount factor (quarterly basis)
σ_L	1	Inverse Frisch elasticity of labor supply
ψ	15.622	Disutility of labor parameter
α_a	0.19	Share of food consumption in total consumption
α_o	0.03	Share of oil consumption in total consumption

Table 3. (continued)

<i>Parameter</i>	<i>Value</i>	<i>Description</i>
α_c	0.780	Share of core consumption in total consumption
γ_c	0.740	Share of domestic goods in core and food consumption
<i>Non-commodity sectors</i>		
δ	0.010	Depreciation rate (quarterly basis), sector <i>H</i>
α_H	0.990	Share of non-oil inputs in production, sector <i>H</i>
η_H	0.660	Share of labor in Cobb-Douglas value added, sector <i>H</i>
ε_L	11.000	Elast. of substitution among labor varieties, sector <i>H</i>
ε_H	11.000	Elast. of substitution among domestic varieties, sector <i>H</i>
ε_F	11.000	Elast. of substitution among imported varieties, sector <i>F</i>
γ_I	0.640	Share of domestic goods in investment, sector <i>H</i>
<i>Commodity sector</i>		
χ	0.310	Government ownership of assets, sector <i>S</i>
τ_S	0.350	Tax rate on foreign profits, sector <i>S</i>
κ_S	0.009	Fixed cost of production, sector <i>S</i>
$1-\eta_S$	0.314	Capital elasticity of production, sector <i>S</i>
δ_S	0.032	Depreciation rate (quarterly basis), sector <i>S</i>
γ_{IS}	0.590	Share of domestic goods in investment, sector <i>S</i>
n	6.000	Periods of time to build (quarters), sector <i>S</i>
ϕ_j	0.167	Financing profile of investment projects, sector <i>S</i>
<i>Foreign economy</i>		
ζ^*	0.101	Import share of foreign economy
<i>Exogenous processes</i>		
$\rho_{p_o^*}$	0.893	AR(1) coef., international oil price shock (ML)
$\sigma_{p_o^*}$	0.139	Innov. s.d., international oil price shock (ML)
σ_{z_k}	0.004	Innov. s.d., capital destruction shock

Source: Fornero and Kirchner (2014).

Table 4. Estimated Parameters

Parameter	Description	Prior			Posterior				
		dist.	mean	s.d.	mean	mode	s.d.	5%	95%
Households									
h	Habit formation	B	0.70	0.1	0.893	0.862	0.028	0.847	0.939
ω_C	EoS oil and core cons.	IG	1	Inf	0.389	0.385	0.109	0.224	0.551
η_C	EoS H and F core cons.	IG	1	Inf	1.477	1.575	0.706	0.341	2.480
Wages									
ϕ_L	Calvo prob. wages	B	0.75	0.1	0.966	0.975	0.013	0.947	0.987
ξ_L	Indexation wages	B	0.50	0.2	0.785	0.710	0.119	0.610	0.967
Prices									
ϕ_{H_D}	Calvo prob. dom. prices	B	0.75	0.1	0.630	0.626	0.060	0.536	0.727
ϕ_{H_F}	Calvo prob. exp. prices	B	0.75	0.1	0.901	0.890	0.045	0.838	0.969
φ_F	Calvo prob. imp. prices	B	0.75	0.1	0.507	0.504	0.050	0.424	0.588
ξ_{H_D}	Indexation dom. prices	B	0.50	0.2	0.260	0.268	0.141	0.040	0.465
ξ_{H_F}	Indexation exp. prices	B	0.50	0.2	0.430	0.346	0.192	0.112	0.738
ξ_F	Indexation imp. prices	B	0.50	0.2	0.414	0.399	0.148	0.170	0.657

Table 4. (continued)

Parameter	Description	Prior			Posterior				
		dist.	mean	s.d.	mean	mode	s.d.	5%	95%
Production									
ω_H	EoS oil, other inputs	IG	1.000	Inf	0.393	0.460	0.126	0.212	0.565
Investment									
η_I	EoS H and F inv., non-S	IG	1.000	Inf	1.345	0.497	0.942	0.251	2.822
η_{I_S}	EoS H and F inv., S	IG	1.000	Inf	0.868	0.695	0.637	0.234	1.608
μ_S	Inv. adjustm. cost, non-S	G	2.000	0.5	1.844	1.533	0.422	1.154	2.506
μ_{I_S}	Inv. adjustm. cost, S	G	3.000	0.5	2.864	3.078	0.517	2.025	3.708
Foreconomy									
η_F	Price elast. for. demand	IG	1.000	Inf	0.273	0.239	0.055	0.189	0.356
ρ	Country prem. debt elast.	IG	0.010	Inf	0.008	0.009	0.002	0.005	0.010
Mon.policy									
ψ_r	Interest rate smoothing	B	0.750	0.1	0.818	0.828	0.023	0.780	0.856
$\bar{\psi}_Y$	Int. feedb. GDP growth	N	0.125	0.05	0.101	0.116	0.044	0.030	0.174
ψ_π	Int. feedb. inflation	N	1.500	0.1	1.700	1.733	0.079	1.570	1.831
ψ_{π_Z}	Feedb. weight core infl.	B	0.500	0.2	0.740	0.656	0.128	0.546	0.944

Table 4. (continued)

Parameter	Description	Prior			Posterior				
		dist.	mean	s.d.	mean	mode	s.d.	5%	95%
AR(1)coef.									
ρ_{a_H}	Neutral technology shock	B	0.75	0.1	0.783	0.785	0.087	0.645	0.924
ρ_{ζ_T}	Productivity growth shock	B	0.75	0.1	0.768	0.718	0.060	0.676	0.868
ρ_{ζ_C}	Preference shock	B	0.75	0.1	0.757	0.715	0.073	0.642	0.876
ρ_{ζ_I}	Inv.-specif. techn. shock	B	0.75	0.1	0.619	0.627	0.072	0.503	0.740
ρ_{ζ_G}	Fiscal policy shock	B	0.75	0.1	0.870	0.878	0.039	0.808	0.934
ρ_{ζ_Θ}	Country premium shock	B	0.75	0.1	0.955	0.958	0.020	0.927	0.985
ρ_{ζ_A}	Food price shock	B	0.75	0.1	0.781	0.0825	0.806	0.657	0.918
ρ_{a_S}	Comm.-specif. techn. sh.	B	0.75	0.1	0.959	0.960	0.017	0.932	0.986
Innov.s.d.									
u_{a_H}	Neutral technology shock	IG	0.005	Inf	0.008	0.008	0.002	0.005	0.010
u_{ζ_T}	Productivity growth shock	IG	0.005	Inf	0.011	0.012	0.002	0.007	0.015
u_{ζ_C}	Preference shock	IG	0.005	Inf	0.047	0.036	0.013	0.027	0.067
u_{ζ_I}	Inv.-specif. techn. shock	IG	0.005	Inf	0.047	0.040	0.012	0.029	0.065
u_{ζ_G}	Fiscal policy shock	IG	0.005	Inf	0.038	0.036	0.005	0.030	0.045
u_{ζ_m}	Monetary policy shock	IG	0.005	Inf	0.002	0.002	0.0002	0.001	0.002
u_{ζ_Θ}	Country premium shock	IG	0.005	Inf	0.001	0.001	0.0001	0.0008	0.001
u_{ζ_A}	Food price shock	IG	0.005	Inf	0.014	0.013	0.003	0.008	0.019
u_{a_S}	Comm.-specif. techn. sh.	IG	0.005	Inf	0.034	0.034	0.004	0.029	0.040

Source: Forno and Kirchner (2014).

Among the calibrated parameters, the share of government ownership in the commodity sector χ is set to 0.31, consistent with the average share of production of the state-owned copper mining company (Codelco) relative to total copper production since 2001. The tax rate on foreign profits τ_S is set to 0.35, which is the flat rate tax on foreign companies in Chile. The fixed costs in production parameter κ_S is chosen to match a labor share in total value added of about 14%, according to recent data. The elasticity of production with respect to capital $1 - \eta_S$ is set to 0.31 in order to obtain a share of physical capital to quarterly output in the commodity sector of 12. This number is in line with available data on the value of financial assets over total sales of Codelco. The quarterly depreciation rate of capital in the commodity sector δ is approximately 3%, chosen to match an average investment-to-output ratio in Chile's mining sector of about 4% from 2001-2012. The home bias in investment in the commodity sector is set to 0.59, consistent with available data on the share of construction in total investment in the mining sector. The horizon of time to build is set to $n = 6$ quarters, consistent with the average duration of investment projects by private mining companies according to data from a regular survey of the Chilean Corporation of Capital Goods (CBC). Following Kydland and Prescott (1982), the financing profile of projects ϕ_j is set to $1/n$.

In addition, the estimated parameters in table 4 reflect a relatively high degree of investment adjustment costs in the commodity sector relative to other sectors in addition to the time to build structure in this sector. Hence, investment in the commodity sector tends to respond relatively sluggishly to commodity price shocks and other types of shocks. The estimates also indicate some degree of complementarity between domestic and foreign inputs for investment in that sector, which tends to enhance the spillover effects from the commodity sector to the rest of the economy. We now proceed to analyze the effects of different types of commodity price shocks on the main macroeconomic variables.

4.2 Effects of Persistent and Transitory Commodity Price Shocks

Figure 10 shows the impulse responses of selected variables to a commodity price shock of 50% in size as in the SVARs from section 3. We distinguish two types of persistence of the shock: a more persistent case where the foreign block is taken from the estimated

VAR model for Chile from section 3.4 (where the real copper price is not de-trended) and a less persistent case where the persistence of the copper price in the foreign VAR is adjusted so that the half-life of the shock matches the half-life of the real copper price in the VAR where all variables including the copper price are de-trended using quadratic trends.

The results show the following in both cases: the shock generates an expansion of real GDP and investment in all sectors, a real exchange rate appreciation, lower inflation in the short-run and higher inflation after some periods, with the associated interest rate response. However, the expansion of investment and GDP is significantly stronger when the shock is persistent. In this case, there is a strong incentive to invest in the commodity sector, as indicated by the persistent rise in the sectoral Tobin's q , such that commodity investment increases by more than 2% above its steady state level with positive spillover effects on investment in other sectors and on real GDP. However, when the shock is transitory, the relatively short-lived increase in the expected Tobin's q is not sufficient to generate a significant response of investment in the commodity sector since it would take too long relative to the duration of the shock (and it would be too costly) to install the additional productive capacity due to the time to build frictions. Another difference between the two cases is that the transitory shock is associated with a current account surplus while the persistent shock is already followed by a relatively sizable current account deficit after just a few quarters. As shown in Fornero and Kirchner (2014), these differences in the response of the current account balance are mainly due to the endogenous response of investment in the commodity sector and its effects on the economy's net international investment position.

Overall, the predictions of the model are therefore in line with the empirical results from section 3. However, an advantage of using a DSGE model is that we can decompose the dynamics of macroeconomic variables such as investment and GDP growth according to the different structural shocks that drive economic dynamics, as we do next.

Figure 10. Impulse Responses to Commodity Price Shocks (50%) with Different Persistences

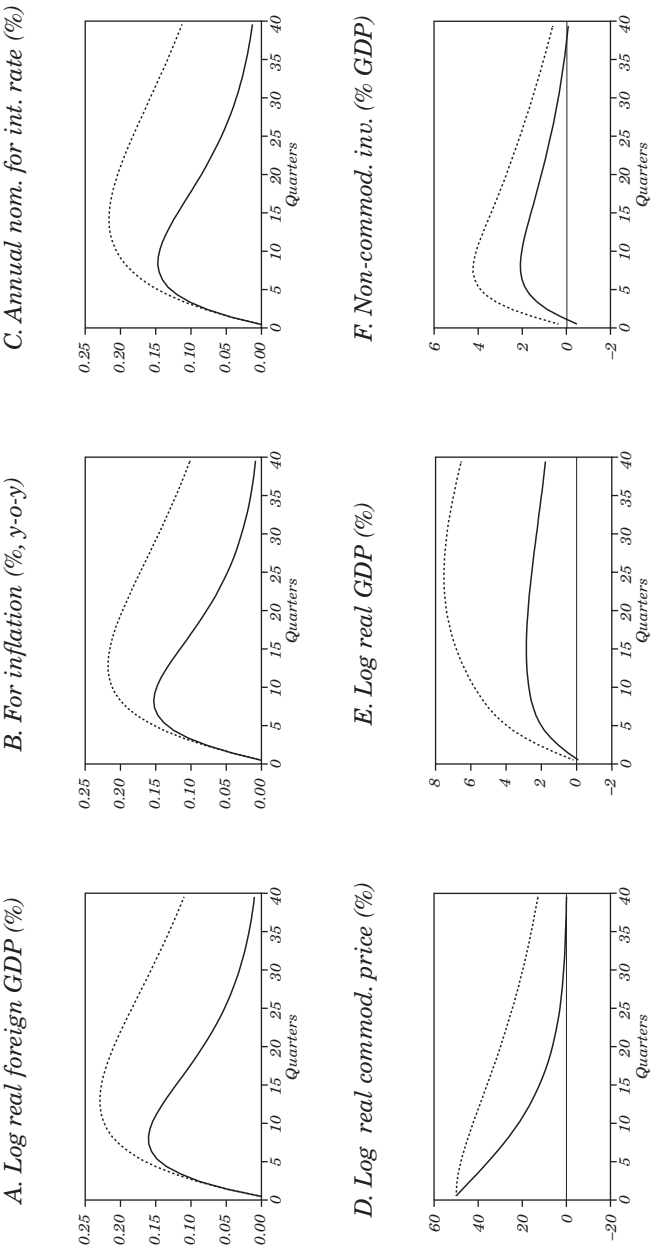
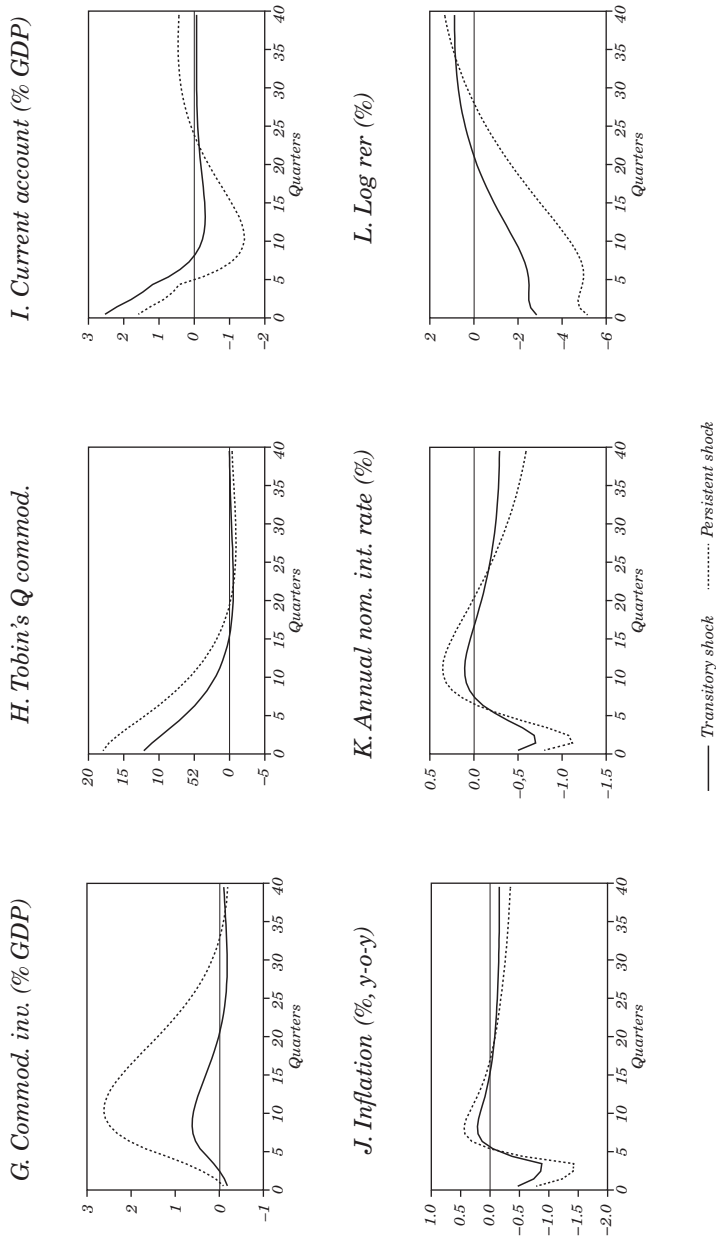


Figure 10. (continued)



Source: Authors' elaboration.
Note: $\Delta\%$ from Steady State in y-axes.

4.3 Share of Domestic Investment in the Commodity Sector and Trade Balance Adjustments

Do the macroeconomic effects of commodity price shocks depend on the structure of investment in the commodity sector? Changes on commodity investment may be absorbed by trade balance adjustments if the share of foreign inputs in the commodity sector is sufficiently high. To analyze this issue, figure 11 compares the responses to a persistent commodity price shock for the benchmark case having a relatively high share of domestic investment in the commodity sector (59%)²² to the case with a low share of domestic investment (5%). The results show that expansionary effects on real GDP and investment in the non-commodity sector are significantly smaller in the case with a low share of domestic investment. In this case, the negative trade balance adjustments absorb the positive effects of investment on real GDP, which is more than 2% smaller after 10 quarters in the case with a low share of domestic investment.

4.4 “Pure” Effects of Commodity Price Shocks

According to the results from figure 10, a positive commodity price shock is associated with expansionary external conditions for the domestic economy (increase in foreign demand, decrease in real foreign interest rate), which do not allow to identification of the “true” or “pure” effects of higher commodity prices. To isolate these effects, in figure 12 we compare the responses to a persistent commodity price shock under the benchmark case (i.e., with a foreign SVAR block) with the case where the commodity price follows a first order autoregressive process (the half-life of the shock matches the half-life of the real copper price in the SVAR case). The results show that the expansionary effects on investment are slightly smaller in all sectors when the commodity price is independent from the other foreign variables. In this case, there is a smaller incentive to invest in the domestic economy and this is mainly due to a lower world demand for domestic goods, a neutral foreign monetary policy and a lower Tobin's q . However, the differences in the responses are small and the pure spillover effects in the domestic economy are crucial. In fact, in the AR(1) case, investment in the non-commodity sector still increases by more than 3% of GDP and investment in the commodity sector by more than 2% of GDP.

22. This corresponds to the share of construction investment in total investment during the period 2003-2010.

Figure 11. Impulse Responses to Commodity Price Shocks (50%) with Different Shares of Domestic Investment in the Commodity Sector

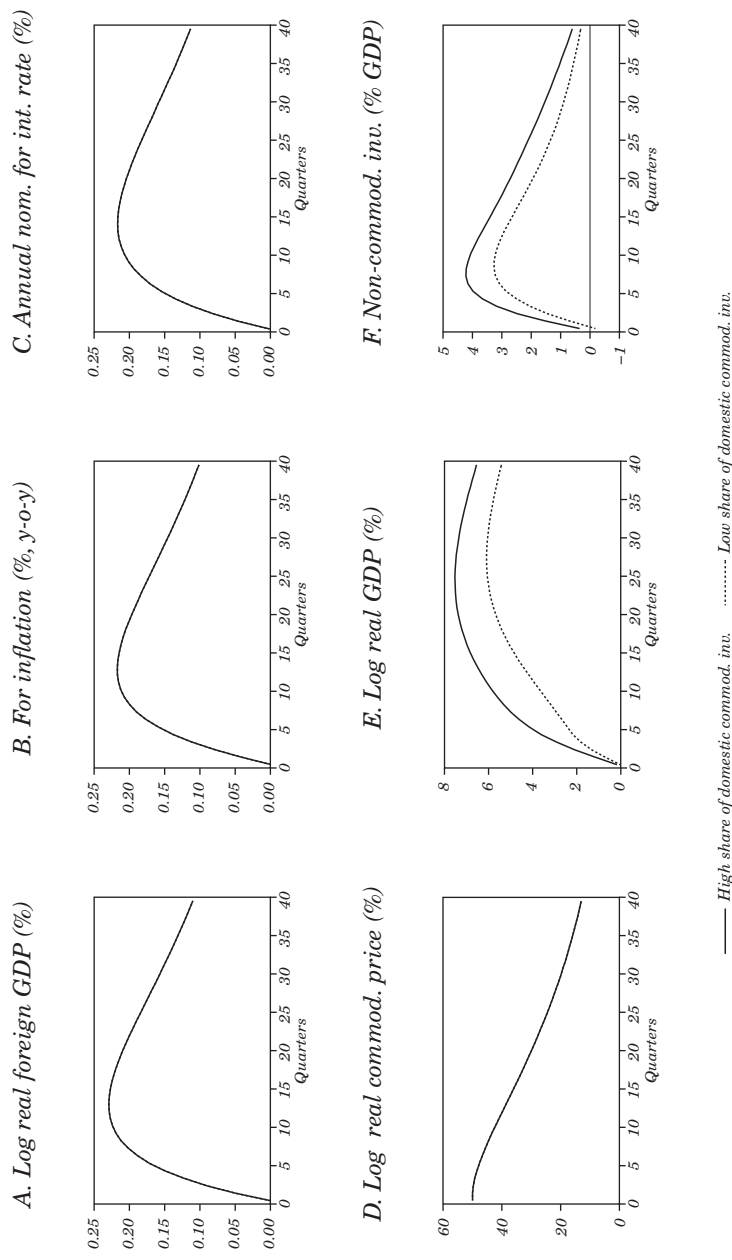
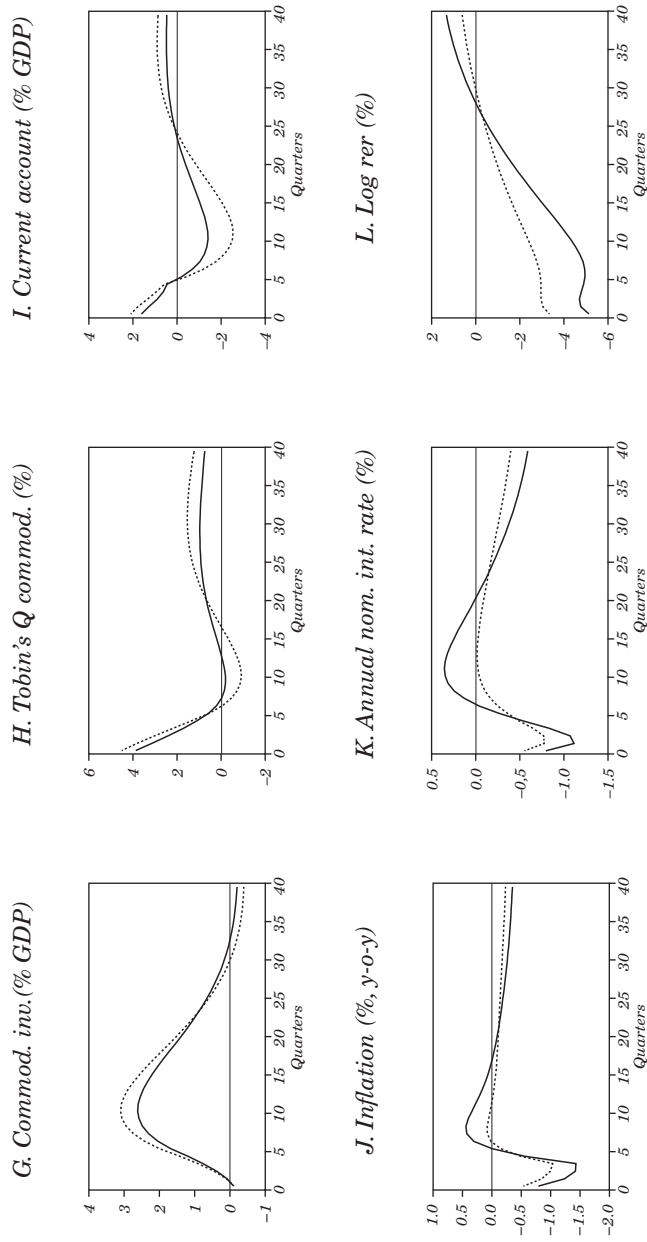


Figure 11. (continued)



Source: Authors' elaboration.
Note: $\Delta\%$ from Steady State in y-axes.

Figure 12. Impulse Responses to Commodity Price Shocks (50%) with Different Shock Processes

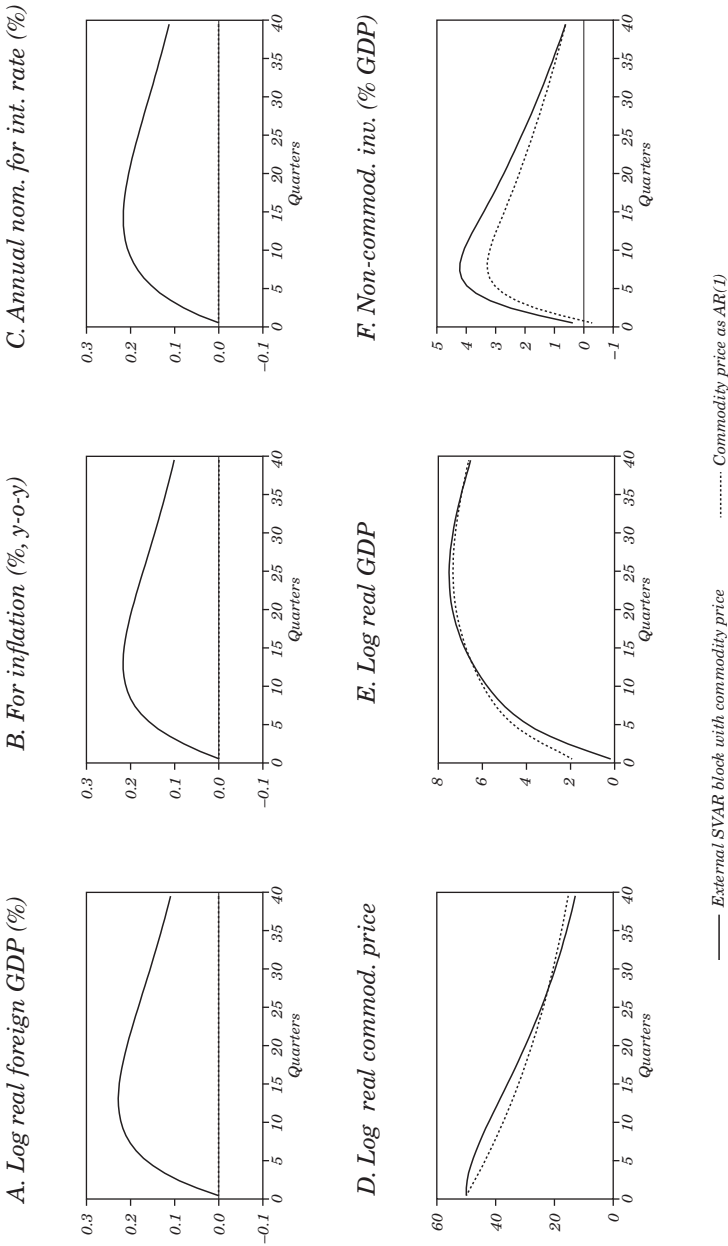
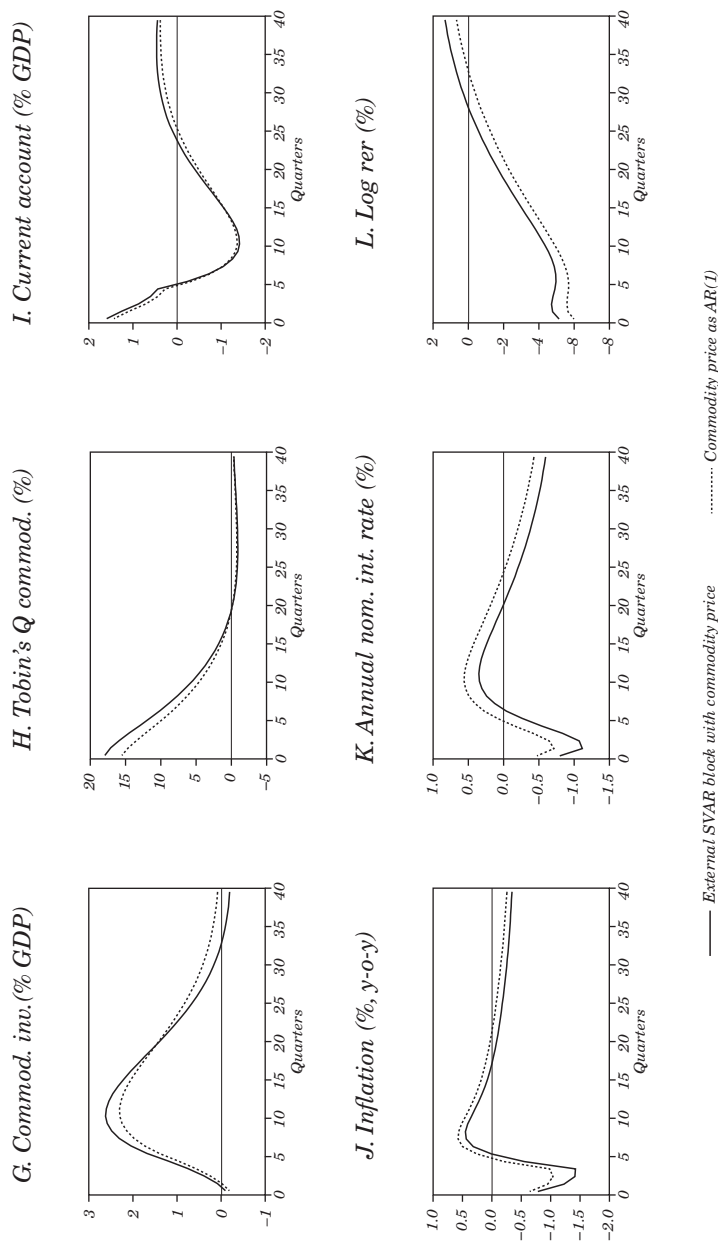


Figure 12. (continued)



Source: Authors' elaboration.
Note: $\Delta\%$ from Steady State in y-axes.

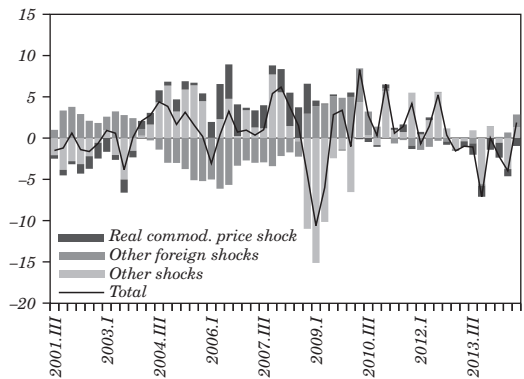
4.5 Historical Decomposition of Investment and GDP Growth

Figure 13 shows the historical decomposition of real investment growth in Chile over the period 2001.III-2014.IV when the contributions of commodity price shocks and other foreign shocks are separated from the contributions of other shocks.²³ According to the results, most of the above-average growth of investment in Chile between 2004 and 2009 is explained by commodity price shocks while other foreign shocks (e.g., relatively high foreign interest rates until 2008) had a negative influence on investment growth until the global financial crisis and a positive influence afterwards (e.g., due to better external financing conditions for emerging economies). However, the investment boom seems to have come to an end after 2012 mainly due to lower commodity prices. Hence, these results suggest that commodity price fluctuations have been a significant driving force of the investment cycle in Chile over the last decade, in line with the empirical findings presented in the previous section and the impulse responses of figure 10.

In terms of real GDP growth, figure 14 shows that commodity price shocks have been an equally important determinant. In fact, the effects of the commodity price surge before the financial crisis and the quick rebound of commodity prices after the crisis have counteracted the impact of the recession and accelerated the recovery of the Chilean economy. However, the effects of the commodity price boom on GDP growth have by now diminished due to the end of the investment cycle. Overall, our model therefore points towards an important role of commodity price fluctuations for business cycles in Chile and similar commodity-exporting economies. Given these findings, we now analyze some policy implications of our model.

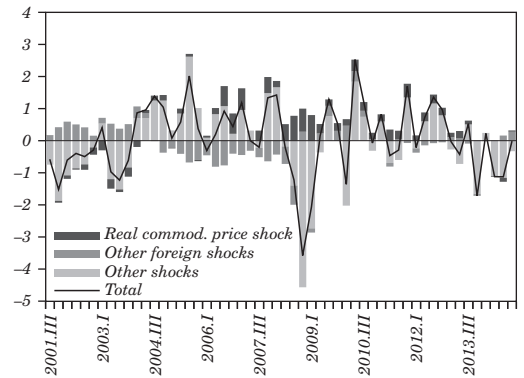
23. To compute the historical decompositions, we used, as observed variables, real GDP Y_t , real copper output as a proxy for commodity production $Y_{S,t}$, private non-durable consumption C_t , total investment $I_t + I_{S,t}$, government consumption G_t , CPI inflation $\pi_{C,t}$, the inflation rate of a price index excluding food and energy prices as a proxy for core inflation $\pi_{Z,t}$, the short-term central bank target rate r_t , the real exchange rate rer_t , the current account balance-to-GDP ratio CAY_t , the foreign variables from the VAR for Chile $Y_{F,t}$, π_t^* , r_t^* and $P_{S,t}^*/P_t^*$, the J.P. Morgan Emerging Market Bond Index (EMBI) spread for Chile as a proxy for the country premium Θ_t , and the real price of West Texas Intermediate crude oil $P_{O,t}^*/P_t^*$. Real GDP, private consumption, investment, and government consumption are measured as quarterly growth rates. The inflation and interest rates are in quarterly terms. Finally, copper output, the real exchange rate, and the real oil price are transformed into natural logarithms. Copper output and foreign output are de-trended using linear trends while the remaining variables are demeaned using their average sample values.

Figure 13. Historical Decomposition of Real Investment Growth in Chile, 2001.III-2014.IV
 Percentage, Q-o-Q



Source: Authors' elaboration. Note: The zero line means that the investment growth rate equals the sample average.

Figure 14. Historical Decomposition of Real GDP Growth in Chile, 2001.III-2014.IV
 Percentage, Q-o-Q



Source: Authors' elaboration. Note: The zero line means that the GDP growth rate equals the sample average.

4.6 Counterfactual Policy Analysis

What are the implications of alternative types of monetary and fiscal policies for the effects of commodity price shocks? For instance, on the monetary side, it is sometimes argued that a (strong) exchange rate appreciation may be responsible for current account imbalances by reducing the demand for exports and stimulating the demand for imports, which may be a motivation for monetary authorities in commodity-exporting countries to try to limit exchange rate fluctuations. On the fiscal side, a rules-based fiscal framework seems important in order to reduce spending pressures due to higher commodity income for the government, and it is therefore interesting to analyze the consequences of alternative fiscal rules.

Thus, in figure 15, we compare the responses to a persistent commodity price shock under the benchmark set of macroeconomic policies (i.e., a flexible inflation targeting regime with a floating exchange rate, and a structural balance fiscal rule) with the case where the monetary authority adjusts the interest rate in order to stabilize the real exchange rate (i.e., $rer_t = \overline{rer}$ for all t) and the case where the government adheres to a balanced budget rule.²⁴ The results show that under the real exchange rate target, the central bank needs to generate a reduction in the real interest rate in order to keep the real exchange rate unchanged, but this generates higher inflation that would imply an additional real appreciation and the central bank therefore raises the nominal interest rate initially before cutting it. However, the negative real interest rate response generates a larger expansion of the economy and a larger peak current account deficit than under an inflation targeting policy with a flexible exchange rate.

On the fiscal side, in comparison to a structural balance rule, a balanced budget policy implies a larger expansion of real GDP, higher inflation, a stronger interest rate response, a larger real appreciation and, initially, a somewhat larger expansion of private consumption due to the response of consumption by non-Ricardian households to higher labor income. However, consumption by Ricardian households and investment is crowded out, which explains why the current account response hardly changes even though government savings do not change. Interestingly, while non-commodity GDP and investment

24. We assume that government consumption is the fiscal instrument that adjusts to keep the government balance unchanged.

Figure 15. Impulse Responses to a Persistent Commodity Price Shock under Different Policies

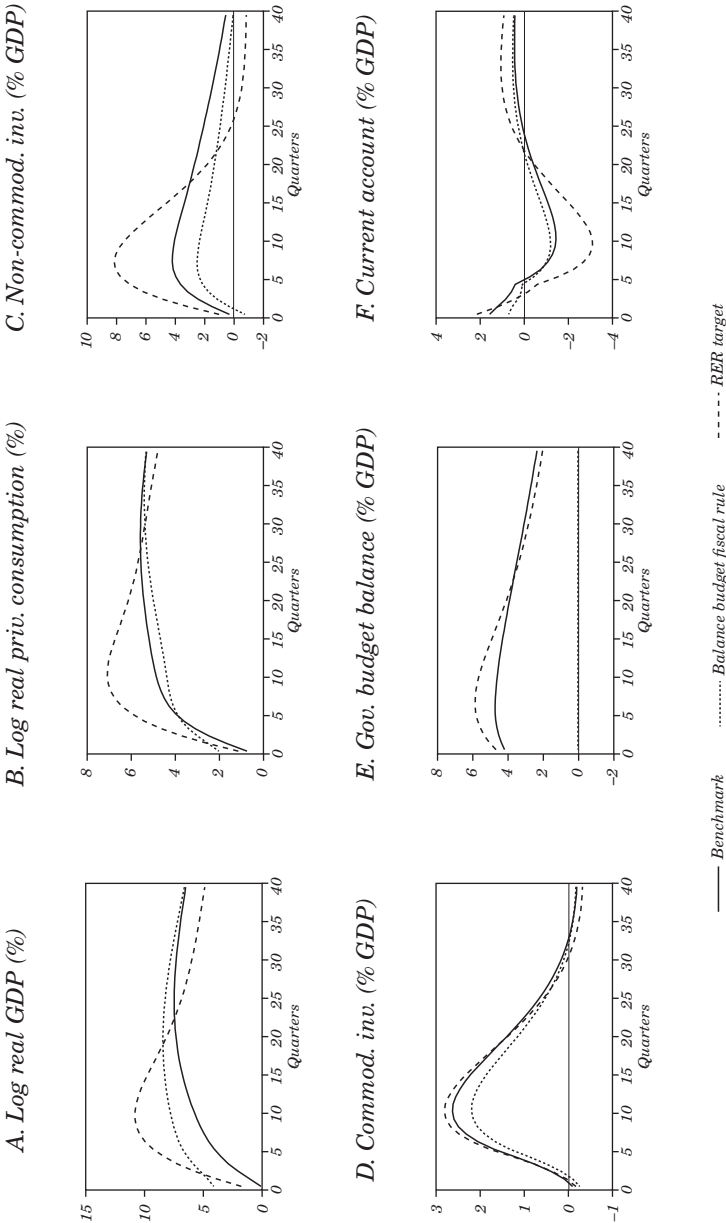
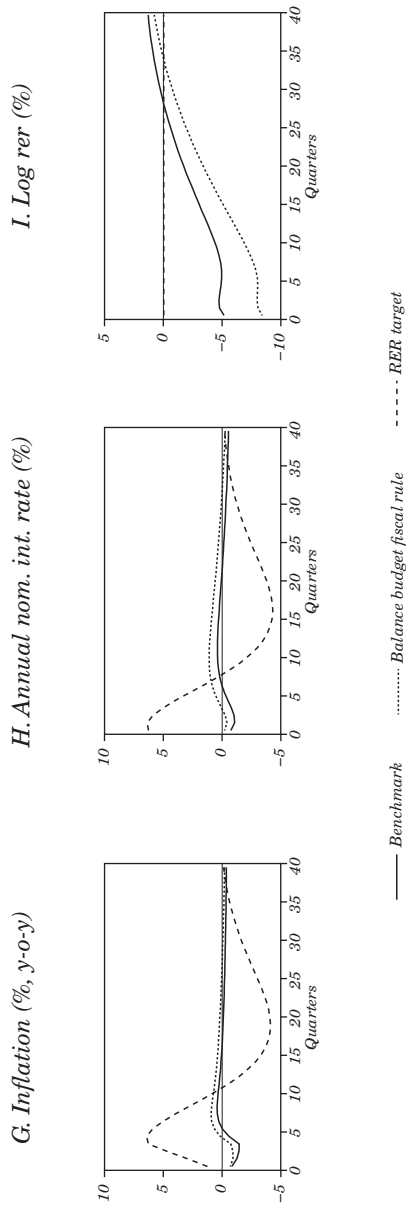


Figure 15. (continued)



Source: Authors' elaboration.
 Note: $\Delta\%$ from Steady State in y-axes.

are quite sensitive to the monetary and fiscal policy responses to the shock, the responses of real GDP and investment in the commodity sector are much less sensitive to the different policy responses. The reason is that commodity investment and production are primarily driven by the international commodity price, while the alternative policies—through different real interest rate and real exchange rate responses—mainly affect the economy-wide stochastic discount factor and the conversion of the international commodity price into domestic currency terms, but those indirect effects are less relevant for investment decisions in this sector. Therefore, these exercises show that while different monetary and fiscal policy reactions have in general important implications for the response of the economy to commodity price shocks, they do not majorly affect investment decisions in the commodity sector according to our model.

5. CONCLUSIONS

In this paper we have analyzed the impact of terms of trade shocks (i.e., commodity price shocks) in commodity-exporting economies. In particular, we have examined common patterns of macroeconomic responses in major commodity exporters based on SVAR analysis, and we have complemented this analysis using a DSGE model with a commodity sector for Chile.

The main results follow: first, depending on the share of commodity exports, a commodity price increase generates expansionary effects in the economy in line with previous studies. Part of this expansion is due to positive and delayed effects on investment in commodity sectors that may cause spillovers to non-commodity investment. Second, the persistence of commodity price shocks is crucial to understand those dynamics: when the shock is persistent, the response of investment, real GDP and other quantities are magnified and might lead to a current account deficit. If the share of foreign investment inputs in the commodity sector is sufficiently high, a portion of the expansionary effects on real GDP might be absorbed by balance trade adjustments. Third, according to historical decompositions of fundamental shocks for Chile, the copper price boom after the mid-2000s was a key driver of real investment and real GDP growth. Finally, our structural DSGE model provides additional policy insights. One main finding is that the implications of commodity price fluctuations for monetary policy are not trivial

since they depend on the persistence of shocks, their impact on private consumption and investment, the fiscal policy response, real exchange rate pass-through to prices, and so on. Moreover, the policy exercises that we have conducted show that changes in monetary and fiscal policy rules have small impacts on investment decisions in the commodity sector, which are mainly driven by sectoral productivity developments and commodity prices.

Our results thus complement previous studies that have analyzed the macroeconomic impacts of commodity price fluctuations for business cycles and inflation dynamics in commodity exporters (see Medina and others, 2008; Desormeaux and others, 2010), the role of sectoral investment (see Knop and Vespignani, 2014) and the role of macroeconomic policy (see Medina and Soto, 2007b, 2014; Kumhof and Laxton, 2010; Frankel, 2011). From a general perspective, our findings reaffirm the conclusions from previous studies that flexible inflation targeting frameworks, flexible exchange rates and fiscal rules are essential to limit the macroeconomic impact of commodity price volatility in commodity-exporting countries.

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APPENDIX

The Data

Since we study the particular case of mining investment, for Chile we use the real copper price as a proxy for a commodity price shock. For the remaining countries (Australia, Canada, New Zealand, Peru and South Africa) we use the real IMF metal price index. Alternative estimations were made for every country using different commodity price indices (see table 5) and the results were relatively robust. Commodity investment is measured as nominal gross fixed capital formation in mining as a percentage of nominal GDP. Tables 5 and 6 contain a detailed summary of the different variables and data sources for each country.

Following conventional data adjustments, a number of additional transformations were made. For missing observations of commodity/mining investment, due to a change in the periodicity of the data, we used standard linear interpolations to transform annual data into quarterly data. Real GDP, real exchange rates and commodity price indices were transformed into natural logarithms. We used the U.S. CPI to deflate commodity price indices that were available in nominal U.S. dollar terms from their sources. Real GDP, investment and current account balances were seasonally adjusted using the Census X-12 procedure when they were not available in seasonally adjusted form from the original source.

Table A1. Data Sources and Transformations for Each Country, Foreign Blocks

<i>Series</i>	<i>Country</i>	<i>Proxy</i>	<i>Source</i>
Log real foreign GDP (SA)	All	World real GDP index (SA)	Central Bank of Chile
Foreign inflation (annual % change)	All	Annual % change of US CPI	FRED
Foreign interest rate	All	US federal funds rate	FRED
Log real commodity price index (deflated with U.S. CPI, 2005 = 100) ^a	Australia	IMF metal price index RBA commodity price index RBA bulk price index	IMF RBA RBA
	Canada	IMF metal price index Local metal price index Local commodity price index	IMF Bank of Canada Bank of Canada
	Chile	Real copper price IMF metal price index	Cochilco IMF
	New Zealand	IMF metal price index Local commodity price index	IMF ANZ Bank NZ
	Peru	IMF metal price index Local commodity price index Real copper price	IMF CRB of Peru Cochilco
	South Africa	IMF metal price index Real gold price	IMF IFS

a. Bold letters indicate the indices used in the estimations.

Table A2. Data Sources and Transformations for Each Country, Domestic Blocks

<i>Series</i>	<i>Country</i>	<i>Source</i>
Log real GDP (SA)[1]	Australia	Australian Bureau of Statistics
	Canada	Statistics Canada
	Chile	Central Bank of Chile
	New Zealand	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
Nom. commodity investment (% of nom. GDP) [2]	South Africa	South African Reserve Bank
	Australia [3]	Australian Bureau of Statistics
	Canada [3]	UN STATS and Statistics Canada
	Chile [3]	Central Bank of Chile
	New Zealand [3]	Reserve Bank of New Zealand
	Peru [3]	Central Reserve Bank of Peru
	South Africa	South African Reserve Bank
Inflation (annual % change of CPI)	Australia	Reserve Bank of Australia
	Canada	OECD
	Chile	Central Bank of Chile
	New Zealand	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	South Africa	OECD

Table A2. (continued)

<i>Series</i>	<i>Country</i>	<i>Source</i>
Monetary policy rate	Australia	Reserve Bank of Australia
	Canada	IFS
	Chile	Central Bank of Chile
	New Zealand [4]	Reserve Bank of New Zealand
	Peru [5]	Central Reserve Bank of Peru
	South Africa	OECD
Log real exch. rate (increase means depreciation)	Australia [6]	Reserve Bank of Australia
	Canada	IFS
	Chile	Central Bank of Chile
	New Zealand [7]	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	South Africa	South African Reserve Bank
Current account (% of nominal GDP)	Australia	Reserve Bank of Australia
	Canada	Statistics Canada
	Chile	Central Bank of Chile
	New Zealand	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	South Africa	South African Reserve Bank

Notes: [1] Real non-commodity GDP was computed by subtracting real commodity GDP from real total GDP; [2] Measured as nominal gross fixed capital formation in mining where nominal non-mining investment was computed by subtracting nominal mining investment from nominal total investment; [3] Linear interpolation of annual data; [4] Interbank rate from 1991.I-1999.I; [5] Interbank rate from 1996.I to 2000.IV and overnight rate from 2001.I to 2003.IV; [6] Inverse of trade-weighted index, May 1970 = 100 [7] Inverse of trade-weighted index, long-run average = 100.