

THE SHORT-RUN MACROECONOMICS OF THE ENERGY TRANSITION: A REVIEW AND DIRECTIONS FOR RESEARCH

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Implications of Climate Change and
Ecosystem Services Degradation for
Macroeconomic and Financial Stability

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THE SHORT-RUN MACROECONOMICS OF THE ENERGY TRANSITION: A REVIEW AND DIRECTIONS FOR RESEARCH

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The global transition to a decarbonized energy system will be as consequential as it is necessary to avoid substantial warming. The transition will reshape the global energy sector and fundamentally transform the role of fossil fuel production and use in the economy. These vast changes introduce significant risks for short-run macroeconomic performance, and those risks are increasing as climate change and the energy transition accelerate.

In his seminal speech in 2015, Mark Carney, then Governor of the Bank of England, called for central banks to better prepare for managing the macroeconomic risks of climate change. He categorized those risks as physical, transition, and liquidity risks.

In this paper, we take stock of what we have learned about transition risks nearly ten years on from Carney's (2015) speech. To keep this task manageable, we focus on policy risk and geopolitical transition risk. Given the significance of the 2021–2024 inflation episode, we pay particular attention to the inflationary risks of the energy transition. This paper entirely omits physical risks, which we discuss in complementary work.¹

We reach two main conclusions. First, recent empirical work on the macroeconomic impacts of climate policy suggests that large policies—

1. See Bilal and Stock (2025).

Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability, edited by Maximilian Auffhammer, Elías Albagli, Sofia Bauducco, and Gonzalo García-Trujillo, Santiago, Chile. © 2025 Central Bank of Chile.

ones that encompass a large segment of emissions and thus economic activity—can have negative consequences for short-run real economic activity; however, this conclusion depends on the nature of the policy. In particular, the policy is benign if it induces a carbon price that is predictable and smooth (a carbon tax) but less benign if the induced carbon price is highly volatile and unpredictable (cap-and-trade). Unlike many macroeconomic shocks, carbon-price shocks are directly observable. Moreover, their macroeconomic impacts are of a magnitude readily handled by monetary policy. More work is warranted to clarify how monetary authorities should respond to carbon-price shocks. Other large energy policies, such as the U.S. Inflation Reduction Act (IRA), which provided large subsidies for low-carbon investments, and green industrial policies, have not yet been the subject of careful empirical evaluation from a macroeconomic perspective. These findings lead to the practical conclusion that large climate policies strive to minimize implicit or explicit carbon-price volatility.

Second, global energy shocks—a leading cause of macroeconomic volatility over the past half-century—are likely to be present well into the future. Even under an aggressive net-zero path, demand for fuels in developed economies and globally is likely to persist for decades. Moreover, the economics of decarbonized fuels are similar to those of unabated fossil fuels (inelastic demand, sluggish supply response, and interconnected prices on global markets). As Bordoff and O’Sullivan (2022) emphasize, the geopolitical shifts brought on by the energy transition could be turbulent. Until the role of fossil fuels in production and consumption falls significantly, geopolitical turbulence could well imply an era of enhanced volatility in international energy prices. Although central banks now have considerable experience addressing fuel-supply shocks, now is the time to improve our understanding of how those supply shocks will evolve as the fuels decarbonize.

The history of macroeconomics is one of surprising events with major consequences: the Great Depression, the oil-price shocks and stagflation of the 1970s, the Global Financial Crisis, the Covid-19 pandemic, and more. With its vast scale and global reach, the energy transition is poised to provide fiscal and monetary policymakers with unexpected consequential developments. Macroeconomists can play a unique role in looking around the corner to identify the connections, through institutions, incentives, and political economy, between energy transition shocks and macroeconomic performance.

Adjacent surveys. There are a number of recent complementary surveys on the macroeconomics of climate change, largely focusing on

longer-run macroeconomics. Bilal and Stock (2025) provide a broad overview of loss and damage, mitigation and adaptation. Fernández-Villaverde and others (2024) review recent developments in stochastic integrated assessment models (IAMs). Desmet and Rossi-Hansberg (2024) focus on dynamic spatial integrated assessment models. Hassler and others (2024) review recent climate science for economists through the lens of IAMs. Three surveys of damage estimates are Rising and others (2022) and Bastien-Olvera and Moore (2022), who focus on reconciling the large gap between perceived damages among natural scientists and the comparatively small damages estimated by economists, and de Juan Fernández and others (2022), who focus on econometric estimates of damages including in the context of simultaneous causality between activity and temperature. Timilsina (2022) surveys the large literature on carbon taxes, and Blanchard and others (2023) provide a comprehensive organizing framework for the multiplicity of climate policies from an economics perspective. The field of climate finance is growing rapidly—Hong and others (2020) provide an early framing of this nascent field, and Acharya and others (2023) review climate stress tests of financial institutions.

The remainder of this paper is organized as follows. Section 1 reviews the literature on the macroeconomics of energy and climate policy, with a focus on empirical papers. Section 2 turns to the role of global energy-price shocks, both in the 2021–2024 inflationary episode and looking ahead.

1. SURVEY OF THE LITERATURE ON ENERGY AND CLIMATE POLICY RISKS FOR SHORT-TERM MACROECONOMICS

There is a vast literature on the economics of carbon pricing and energy policies. The empirical literature on their macroeconomic impact, however, is small and recent, and that is the focus of this survey. We begin with carbon pricing and then turn to other climate policies, including subsidies, standards, and green industrial policies.

1.1 Carbon Taxes

For more than one hundred years, fossil fuels have been the primary source of energy globally. While nuclear power and hydropower were alternatives for new nonemitting generation of electricity and biofuels provided a limited and partial alternative for surface transportation, each had constraints that prevented substituting those energy

sources for fossil fuels at scale. Therefore, until recently the main way to lower carbon dioxide emissions was to reduce the demand for energy services and to improve energy efficiency. In this context, it was natural that carbon pricing—which introduces a Pigouvian tax—became the standard device in economists’ toolkit to internalize the carbon externality.

Starting with Nordhaus’s (1992) Dynamic Integrated Climate-Economy (DICE) model, the conventional approach to modeling the macroeconomic effect of carbon pricing is to use a dynamic model with growth through capital accumulation, potentially with exogenous technical progress. Imposing a carbon tax increases the price of energy and shifts the mix of capital, labor, and energy from the privately optimal equilibrium to one that uses less energy and thus is less economically productive. The carbon tax therefore reduces long-run capital accumulation, output, and consumption. Using his DICE model, Nordhaus (1992) showed that the optimal per-ton tax on carbon dioxide emissions equals the monetized net present value of current and future damages inflicted by those emissions, that is, the social cost of carbon (SCC). This approach underpins the more complex computable general equilibrium (CGE) models in, for example, Goulder and Hafstead (2017) and Jorgenson and others (2013).

A typical CGE estimate of the effect of a USD 50 carbon tax is a smooth reduction in GDP by approximately 0.7 percent over six years and approximately 1 percent cumulatively over 15 years, for a 15-year average annual reduction in the GDP growth rate of 0.06 percentage points.² Introducing short-run labor market frictions can further reduce employment and activity in the short run as the labor market adjusts to the new growth path.³ These models typically do not include directed technical change or learning-by-doing.⁴

According to the World Bank Carbon Pricing Dashboard, in 2024, there were 53 national and 40 subnational jurisdictions that had implemented a carbon tax, an emissions trading system, or a crediting mechanism. Given this historical experience, the recent literature has embarked on estimating the macroeconomic effects of carbon taxation and comparing them to structural model estimates.

2. This estimate was computed using the Goulder-Hafstead G3 model as implemented on the Resources for the Future (RFF) website, with per capita lump-sum redistribution of the tax revenues to households, as accessed on 14 May 2024.

3. See Hafstead and Williams (2020).

4. See, for example, Fischer and Newell (2008), Acemoglu and others (2012), and Lemoine (2024).

Most of this recent literature consists of event studies of the emissions effects of carbon taxes.⁵ Metcalf and Stock (2023) study the 31 countries participating in the European Union Emissions Trading System (EU-ETS), 15 of which had a carbon tax at some point during 1990–2020. The EU-ETS started in 2005 and, during this data span, it covered stationary point sources (power sector and industrial emissions), while nearly all the carbon taxes instead covered transportation fuels and, in some cases, fuels for heating buildings. A key challenge is identifying the causal effect of the carbon tax either because of potential confounders (for example, the carbon tax might be paired with more comprehensive tax reform, making it difficult to disentangle the two effects) or because of endogenous adoption of a carbon tax by a legislature. Using panel local projections and vector autoregression methods, Metcalf and Stock (2023) identify the effect of a shock to the carbon tax by exploiting the institutional timing requirement that the tax be set in advance and thus cannot be affected by current-period shocks to real economic activity. They find that a carbon tax of USD 40 covering 30 percent of emissions reduces emissions by 4 to 6 percent, consistent with estimates in the literature of price elasticities of fuel demand (which in turn reflects the historical lack of alternatives to fossil fuels for transport). Their main macroeconomic finding is that the carbon tax has essentially no effect on the level of GDP or employment after six years (their longest horizon).

These results contrast with the predictions of conventional structural models discussed above, in which a carbon tax induces inefficient production (relative to the private optimum) and thus a loss in GDP and a slight decrease in employment. The empirical finding is consistent with Conte and others (2023), who find that in a multisector spatial integrated assessment model, a small European carbon tax can increase aggregate European economic activity by shifting activity to higher-productivity nonagricultural sectors, which demonstrates the sensitivity within conventional capital accumulation models to sectoral and trade considerations. More expansively, Finkelstein Shapiro and Metcalf (2023) show that the surprising noneffect could be the result of the carbon tax spurring firm creation and technology adoption.

5. See the survey in Köppl and Schratzenstaller (2022).

1.2 Cap-and-Trade

Cap-and-trade systems are the dual of carbon taxes, in which the quantity of emissions is regulated through a system of emissions allowances; trading the allowances determines the carbon price. In a static model without uncertainty, cap-and-trade and a carbon tax are equivalent, but in reality, they differ in many ways. Perhaps most notably from a macroeconomic perspective, cap-and-trade systems have volatile and at least partially unpredictable carbon prices arising from shocks to energy supply and demand under a prespecified emissions quantity cap, which induces changes in the market-clearing allowance price. For example, in 2020, the EU-ETS allowance price was approximately €20/metric ton CO₂, rising to €80-€100 during 2022 and 2023 before falling to less than €60 in January 2024. In principle, this difference in price stability could impact macroeconomic performance in various ways, including the additional difficulty that price variability causes for investment planning by firms and for the conduct of monetary policy by central banks.

Känzig (2023) examines the effect of EU-ETS prices on economic activity in participating countries. As in estimating the effect of a carbon tax, identification of the effect is critical and must address the simultaneity problem that a high allowance price could retard demand, but an unexpected dip in economic performance will weaken the demand for allowances, so the price will fall. Känzig (2023) addresses this issue by using an instrument for ETS price changes, specifically the change in the ETS price around regulatory announcement windows, which he then uses to estimate the dynamic causal effect by using a structural vector autoregression instrumental variable (SVAR-IV) method. He estimates a substantial negative effect of the ETS price on economic activity, with higher energy prices leading to a decline in income, consumption, and investment. The magnitude of the effect is large, with an ETS shock that increases the harmonized index of consumer prices (HICP) by one percentage point, leading to an increase in the unemployment rate by 0.2 percentage points, and a decline in industrial production of nearly one percent, after two years. These large macroeconomic effects contrast with prior estimates of the ETS price on firm-level performance, which find little evidence of widespread negative effects on regulated firms,⁶ although those studies typically treated the ETS price as exogenous and firm-level

6. See Verde (2020) and Colmer and others (2025).

effects might have been offset by the free allocation of allowances at the outset of the program.⁷

1.3 Carbon Pricing and Inflation

Work on the inflationary impact of carbon pricing is sparse, perhaps because the workhorse calibrated models in the carbon-tax literature (CGEs and IAMs) are strictly real. While an increase in a carbon price, if passed through, will increase the relative price of energy, the effect of that relative price increase on inflation depends on the related questions of whether the central bank accommodates the price increase and whether the relative price increase translates into changes in inflationary expectations.

Konradt and di Mauro (2023) examine the inflationary effects of carbon taxes in the EU and Canada. Their methods and data largely parallel Metcalf and Stock (2023) (extended to include Canada). They find that carbon taxes did indeed increase the relative price of energy but did not change the overall rate of HICP inflation. In contrast, Känzig (2023) finds that a shock to the EU-ETS price acts like a supply shock increasing energy prices and that this increase in energy prices is passed through to overall inflation. This pair of findings is consistent with the results in Moessner (2022), which suggests that ETS prices, but not carbon taxes in EU countries, have an effect on inflation. For EU carbon-tax countries, one explanation for the muted inflation response to a carbon-tax change is that the European Central Bank did not accommodate the country-specific tax change. However, Konradt and di Mauro (2023) also find a muted inflation response for countries, including Canada, with autonomous central banks.

Del Negro and others (2023) introduce a carbon tax into a sectoral New Keynesian model of the United States, in which a carbon tax acts like a negative supply shock and increases the relative price of energy. If the Fed accommodates the tax and prices are sticky, then there is temporary inflation; if it does not, then there is a temporary (small) recession. Coenen and others (2024) echo these findings using the ECB's New Area-Wide Model with an expanded energy sector to model a carbon tax in the EU. Like Del Negro and others (2023), they find that the effects on inflation and output depend on the monetary policy reaction function. Using a New Keynesian model, Ferrari and

7. See Joltreau and Sommerfeld (2019).

Landi (2024) point out that expected future carbon-tax increases can depress current demand, countervailing the direct inflationary effect of a carbon tax.

Hensel and others (2024) use a survey of French manufacturing firms to estimate the effect of changes in carbon prices (the EU-ETS price, identified using the Känzig (2023) shock and estimated using panel local projections) on inflationary expectations. Like Känzig (2023), they find that an ETS price shock increases energy prices and that this shock is passed through to overall inflation; however, unlike Känzig (2023), the effect is short-lived, lasting only six months. Firms' expected inflation correctly increases, then remains elevated for a year—inaccurately, relative to Hensel and others' (2024) estimate of the HICP response, but accurately, relative to Känzig's (2023) longer-lived estimated response.⁸

1.4 Carbon Pricing and Short-Term Macroeconomics: an Assessment

Metcalf and Stock's (2023) benign empirical estimates of a carbon tax on real activity and Konradt and di Mauro's (2023) complementary benign estimates for inflation contrast with Känzig's (2023) strongly contractionary and inflationary effects of the ETS price. These studies arguably have well-identified estimates of the causal effects, the countries and time periods examined in the studies largely overlap, and the magnitudes of the carbon prices are similar for both the tax and ETS price data (generally in the range €15–€100/metric ton). Känzig and Konradt (2023) provide a careful, unified replication of these results, including finding robustness to variations in identification methods, and confirm the discrepancy between benign carbon-tax effects and contractionary and inflationary ETS price effects. Thus, one is left to conclude that these two different carbon pricing mechanisms may indeed have very different effects.

Känzig and Konradt (2023) suggest that four key differences between the EU carbon tax and the EU-ETS are (a) the sectors covered, (b) the different forms of revenue recycling, (c) the spillovers and

8. Konradt and others (2024) find smaller effects of the ETS price on inflation (again using local projections). They do not instrument for the ETS price so it could be that the negative effect found by Känzig (2023) is offset by the positive correlation from a positive demand shock increasing the ETS price, making Konradt and others' (2024) results difficult to interpret.

leakage, and (d) the reaction of monetary policy. We provide some brief observations on these explanations before adding another to the list.

Concerning (a), for most of country-year observations, the EU-ETS covered the power sector and large manufacturing facilities, while the carbon tax covered transportation and (in some countries) home heating. To a first approximation, this means that the consumer experiences the EU-ETS price directly through the price of electricity and experiences the carbon tax through the price of diesel, gasoline, and home heating (mainly natural gas). Both electricity and transportation fuels have numerically similar and small short-run demand elasticities in the range of 0.1–0.4,⁹ so, in response to a price increase, the consumption share of the affected product increases, and other consumption shares fall. This suggests that the macroeconomic response to a short-run shock will be similar for electricity and fuels. Also, both have larger long-run elasticities because of adjustment options that take time (buying a more fuel-efficient car, home weatherization, and the like). Thus, from first principles, one would expect to see similar short-run macroeconomic responses to a carbon-price shock emanating from the ETS or a carbon-tax change.

Concerning (b) revenue recycling, Metcalf and Stock (2023) and Känzig and Konradt (2023) find a more negative, albeit noisy, real effect of a carbon tax in nonrevenue recycling countries. As both point out, the identification of the revenue recycling effect is not crisp. For example, the large carbon tax in Sweden was introduced in 1991 as part of a restructuring of the tax code that substantially reduced the marginal income tax rate, which remained at the 1991 level for decades; however, the reform also reduced government's role in society and initiated a long decline in the GDP share of government expenditures.¹⁰ Thus, the initial impact of the carbon tax is, at least for Sweden, confounded by the many other aspects of the reform that go well beyond recycling carbon-tax revenues. On the other hand, subsequent hikes in the carbon tax once it is in place—which comprise most of the variation in the carbon-tax data—are, for Sweden, not linked to subsequent changes in marginal rates¹¹ and flows into the overall government budget.¹² Notably, Känzig and Konradt (2023) find little difference in HICP response to a carbon-tax hike between revenue recycling and

9. See Table A.5 in EIA (2022). Also see Burke and Abayasekara (2018) and Coglianesi and others (2017).

10. See Henrekson and Stenkula (2015).

11. Ibid.

12. See Jonsson and others (2020).

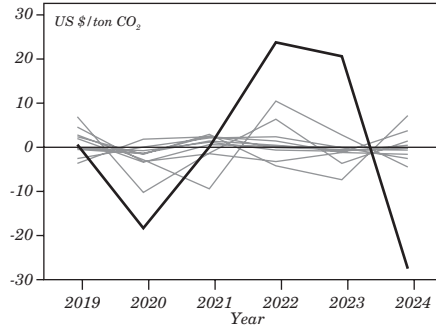
nonrecycling countries, so the differences in the inflationary effects of a carbon price between the two schemes are not explained by how the revenues are used. Thus, while there are differences in real responses between countries based on their revenue recycling schemes, it is difficult to attribute those differences to revenue recycling per se as opposed to treatment effect heterogeneity that happens to be correlated with intended revenue recycling—bearing in mind that the Nordics are four of the six revenue recycling countries.

Concerning (c), leakage is mainly a concern about emissions, not macroeconomic performance. One relevant channel is that European manufacturing, which is covered by the ETS, is disadvantaged in trade by ETS-induced higher energy prices, so an ETS price shock will adversely affect manufacturing employment, all else equal. The other sectors hit by the carbon prices are largely nontraded, for example, transportation services provided within a country. However, as noted above, firm-level studies find little or no negative effects of the ETS on covered manufacturing.

Concerning (d), Känzig and Konradt (2023) present evidence of different short-run interest-rate responses, with the short-run response to a hike in the carbon tax being a drop in the short rate with a slow return to no-change, whereas in response to an ETS price shock, interest rates do not change initially, and then increase for two years before returning to no-change. Thus, the central bank, mainly the ECB, seems to be accommodating carbon-tax increases but leaning against ETS price increases. This begs the question as to why the central bank would respond differently to these two shocks, which both show up in the price of end-use energy. How the central bank should handle carbon-price shocks is a worthy topic of future research.

To this list, we would add (e), the much greater price volatility and unpredictability of the ETS than the carbon tax. As an illustration, Figure 1 shows the deviation from a linear trend of the EU-ETS price and ten major carbon taxes from 2019 to 2024. The standard deviation of the EU-ETS residual is three times the mean standard deviation of the carbon-tax residuals. All else equal, this large variability of the ETS price deters investment in carbon-mitigating technologies. From the perspective of monetary policy, price shocks from the ETS are potentially more difficult for monetary policymakers to address than the predictable price changes from carbon taxes. From the perspective of consumers, volatile energy prices (through a carbon price or otherwise) are also difficult to adjust to because they do not support longer-term planning or investing in energy efficiency. Sorting out the seemingly quite different macroeconomic effects of carbon taxes vs. cap-and-trade is an important issue for macroeconomists.

Figure 1. Deviation of EU-ETS price (black) and Carbon Tax Rates (grey) from Linear Trend, 2019–2024



Source: World Bank Carbon Pricing Dashboard.

Notes: Carbon tax rates (grey) are for British Columbia, Denmark, Finland, France, Iceland, Latvia, Norway, South Africa, Switzerland, and the United Kingdom.

1.5 Climate-Industrial Policy

The Inflation Reduction Act in the United States uses targeted subsidies and tax credits to spur consumer electrification (electric vehicles, heat pumps, etc.), renewable power plants, and investments in manufacturing capacity for energy transition products. This approach is sometimes referred to as green industrial policy because it targets specific technologies and industries. For example, uncurtailed IRA tax credits subsidizing consumer purchases of electric vehicles (EVs) are estimated to cost roughly USD 400 billion through 2032,¹³ and the IRA made available a comparable amount of tax credits for new low-carbon electric power generating capacity on the grid. The IRA also included subsidies for manufacturing facilities, and the EV tax credits include requirements for domestic battery production. Although many of the tax credits existed before the IRA, this Act substantially extended their lifetimes, and uptake is projected to be much greater than in the 2010s because the underlying cost of renewables, batteries, and EVs have dropped also substantially. These policies have been augmented separately by tariffs on Chinese EVs and solar panels.

There have been few studies of the macroeconomic consequences of the IRA, its substantial repeal under President Trump, and its green industrial policy features. If there is limited ability to

13. See Cole and others (2023).

substitute clean technology for dirty and absent learning-by-doing, then green subsidies can potentially increase emissions by reducing the overall price of power.¹⁴ With low renewable prices, however, overall emissions reductions can be large and are estimated to be so under the IRA¹⁵. Bistline, Mehrotra, and Wolfram (2023) develop a structural model with learning-by-doing to evaluate the IRA and suggest that the macroeconomic impact of the IRA is likely to be small. Their analysis includes potential learning-by-doing spillovers created by manufacturing subsidies and domestic content provisions, a core economic argument for industrial policy. They argue that, if the learning-by-doing effect is sufficiently large, the subsidy-plus-domestic-content approach of the IRA can be welfare-enhancing relative to a carbon tax, consistent with Fischer and Newell (2008).

Another aspect of green industrial policy is large tariffs to encourage and protect domestic production. There is a vast literature on the historical effects of tariffs in general, which finds that they reduce welfare and that the price burden falls on the consumer. Additionally, tariffs that focus on green technologies (solar panels, EVs, etc.) drive up costs for low-carbon goods and thus slow the transition to a low-carbon energy system in the importing country. The arrival of the EU Carbon Border Adjustment Mechanism (CBAM) is prompting consideration of carbon border fees in other countries. From a macroeconomic perspective, if those fees are applied mainly to carbon-intensive manufactured imports, as is done in the EU, then the scope of the border fees is sufficiently small so the macroeconomic impact would be modest.

There is a growing empirical literature on industrial policy.¹⁶ The IRA, with its targeted subsidies and tax credits, will provide the opportunity to empirically assess the macroeconomics of green industrial policy.

1.6 Policy Uncertainty

There is now a large literature on the macroeconomic effects of climate policy uncertainty, and the general finding is that, all else equal, uncertainty retards GDP growth and employment.¹⁷ Gavriilidis

14. See Casey and others (2023).

15. See Bistline and others (2023).

16. See, for example, Juhász and others (2023).

17. See Baker and others (2016).

(2021) constructed a climate policy uncertainty akin to Baker and others' (2016) methods, and it has substantial independent variation controlling for overall policy uncertainty.

At the level of an individual firm, climate policy uncertainty tends to reduce investment by providing an incentive to wait until the uncertainty is resolved. Using data on Chinese firms in the mining, manufacturing, and energy sectors, Ren and others (2022) find that an increase in climate policy uncertainty reduces firm-level total factor productivity. Chen (2025) finds that policy uncertainty, through potential expiration of tax credits, adversely affects the timing and amount of investment in the U.S. wind industry.

At a macroeconomic level, because climate policy affects energy prices directly and because exogenous energy-price movements have direct impacts on economic activity, climate policy uncertainty could have a different macroeconomic impact than general economic policy uncertainty.¹⁸ Empirically, Gavriilidis and others (2024) find that controlling for general economic policy uncertainty, climate policy uncertainty retards real activity, with one channel operating through energy prices. A potential channel for climate policy uncertainty to affect economic activity is through asset prices and financial stress.¹⁹ Bauer and others (2023) examine this channel via an event study of the IRA, which during the legislative process had large changes in probabilities of passage. They find, however, that the magnitude of climate policies—and the fact that much of the energy transition has already been capitalized into the valuation of fossil fuel companies—is too small for this channel to be important macroeconomically. While return swings for focused portfolios exceeded 5 percent over three days for some IRA news events, they find a negligible aggregate effect, in part because the negative abnormal returns for fossil fuel companies were offset by positive abnormal returns by renewable or green companies.

2. ENERGY SHOCKS AND THE MACROECONOMY

Shocks to global energy prices have been a major cause of macroeconomic fluctuations since the oil crisis of the 1970s. One might reasonably state that the transition to a net-zero future based on

18. See Fried and others (2021).

19. See, for example, Engle and others (2020), Semieniuk and others (2022), Bolton and Kacperczyk (2023).

reliable domestic renewable energy offers the opportunity for developed economies to lower their exposure to energy-price fluctuations. This section examines this hypothesis. The section begins by recapitulating the role of energy prices in the 2021–2024 inflationary episode, both as evidenced in the now-vast literature on this episode and through some out-of-sample prediction exercises based on empirical Phillips curves. We then turn to the fundamentals of international fuel markets, how they might evolve under net-zero paths and geopolitical considerations of the energy transition.

2.1 Inflation and the COVID-Ukraine Energy Shocks

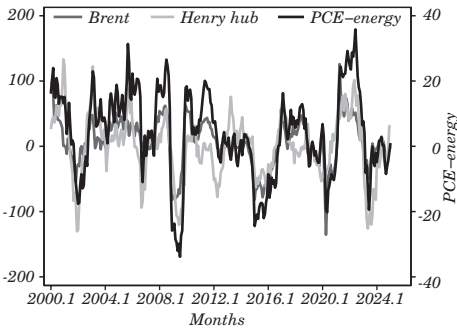
There are now a great many papers on the recent inflation; see Bernanke and Blanchard (2024) and Beaudry, Hou, and Portier (2024) for recent contributions and surveys. Although the quantitative contribution of various factors is still under debate, a common theme is that exogenous energy shocks driven by the war in Ukraine played a key role.

The Russia-Ukraine conflict provides a modern window into the macroeconomic role of energy supply disruptions. Those disruptions began in the late summer of 2021 when Russia did not undertake its normal seasonal refilling of its European gas storage capacity. Starting in June 2022, four months after the invasion, Russia sharply reduced gas supplies to Europe, mainly through the Nord Stream 1 pipeline, and ended Nord Stream 1 flows completely in August 2022. In September 2022, the Nord Stream 1 pipeline was disabled by underwater explosions. Germany's economy was the most directly affected by these curtailments, with German gas supply falling by approximately 20 percent. Moll and others (2024) provide convincing evidence that this large disruption caused surprisingly minor disruptions to aggregate real activity in Germany because of adjustments in demand (reductions by consumers and substitution by industry) and supply (from imports of U.S. liquid natural gas, LNG). The adjustments in demand were driven by extraordinary changes in the price of natural gas. According to the IMF, monthly average European gas prices rose from USD 12.50/mmBtu in July 2021 to USD 41.70 in March 2022, spiking further to USD 70 in August 2022 when Russia suspended Nord Stream 1 shipments. As Europe adjusted both demand and supply—and benefited from two warm winters in a row—prices fell to less than USD 10 in May 2023. These monthly averages mask considerable intramonth volatility, in fact at times

TTF natural gas prompt month futures traded in excess of USD 100. Because oil and gas are substitutes in some industrial applications and in power generation in Asia, and because of heightened uncertainty generally, oil prices also rose, resulting in a large global energy-price shock. This global energy-supply shock also appeared in U.S. gas prices because those prices are tied to international gas prices through LNG exports,²⁰ with a price decrement for the significant cost of liquefaction, transport, and regasification.

As seen in Figure 2, energy-price inflation in the United States closely tracks inflation in global oil prices (Brent) and in domestic natural gas prices (Henry Hub), and Henry Hub inflation closely tracks Brent inflation since the U.S. began exporting LNG in 2016. This observation and the previous discussion suggest that, for the 2021–2024 episode, it is plausible to treat inflation in PCE-energy as exogenous to the United States over this episode.

Figure 2. Twelve-Month Energy Price Inflation (percent per year) in the United States: Brent Crude Oil and Henry Hub Natural Gas Inflation (left) and PCE-Energy (right)



Sources: U.S. Energy Information Administration and FRED.

20. See Stock and Zaragoza-Watkins (2024).

With this motivation, we conduct an out-of-sample exercise to examine the role of energy prices in U.S. inflation. Specifically, we estimate regressions of the form,

$$\pi_t = \beta_e \pi_t^e + \beta_\chi x_t + \beta \pi_t^{energy} + u_t, \quad (1)$$

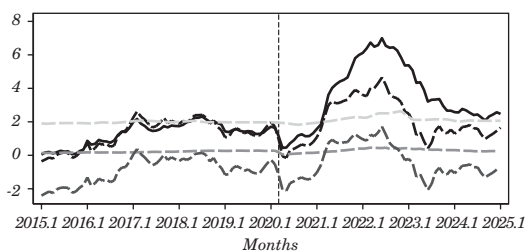
where π_t is the 12-month PCE overall rate of inflation, π_t^e , is expected inflation as measured by the Survey of Professional Forecasters (SPF) forecast of 10-year headline CPI inflation, x_t is the ratio of the vacancy rate to the unemployment rate, and π_t^{energy} is the 12-month rate of inflation of PCE-energy. A constant is included to allow for definitional differences between the dependent variable (PCE) and the SPF forecast (CPI). The main estimation period is January 1984 to December 2019, although we also consider estimation from January 1968 to December 2019. We assess the fit of these specifications over the 2021–2024 inflationary episode by comparing the predicted value of PCE inflation to the actual, where the predicted value is computed by using realized expected inflation, slack, and energy prices. Note that this is an entirely conventional pre-2020 Philips curve specification and does not rely on the many extensions used to fit the recent episode (nonlinearities such as cubics or logs, use of median inflation, use of additional shock variables like measures of supply chain restrictions, etcetera).

Our analysis consists of documenting out-of-sample stability using, separately, only two modifications: the estimation sample and the measure of inflation expectations. The results are summarized in Figure 3, which shows the in- and out-of-sample predicted and actual values from (1) and the decomposition of the predicted value into the three components in — expectations, slack, and energy inflation.

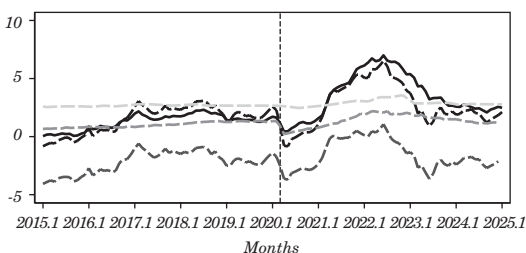
Panel (a) demonstrates the well-known breakdown of the benchmark Philips curve over this episode. Energy inflation explains nearly all the variation in predicted headline inflation, and the model correctly predicted the initial uptick in inflation in 2021. Thereafter, however, the model under-predicted inflation by 2–3 percentage points from mid-2021 through mid-2023. In this specification, the Phillips curve is very flat, with the vacancy-unemployment ratio making a negligible contribution to the predicted value. Because the SPF 10-year expectations are stable (remaining under 3 percent for this full episode), expected inflation also makes only a small contribution to predicted inflation.

Figure 3. Out-of-Sample Philips Curve Decomposition: Predicted and Actual 12-Month Headline PCE Inflation and Contributions of Expected Inflation, Slack (Vacancy-Unemployment Ratio, and PCE-Energy)

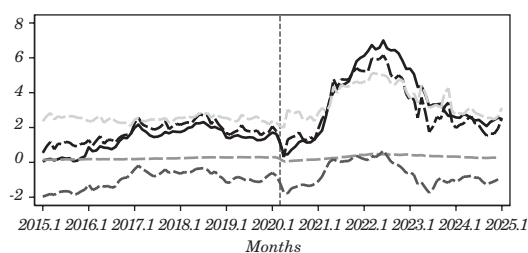
(a) *Benchmark: SPF 10-year expectation, estimation 1984-2019*



(b) *SPF 10-year expectation, estimation 1968-2019*



(c) *Michigan survey 1-year expectation, estimation 1984-2019*



— Actual - - - Predicted . . . Expectations - . - Slack - - - Energy

Source: Authors' calculations.

Historically, the episode with the greatest energy-price volatility was the 1970s, a period in which monetary policy initially accommodated the energy-price shocks that led to high headline inflation. Panel (b) therefore re-estimates (1) by extending the start of the estimation sample to January 1968. Using the extended sample has the effect of placing more weight on energy prices and yields a steeper Phillips curve. As a result, the predictions closely track the upswing in inflation and the magnitude of the decline, although the prediction leads the actual decline in inflation by several months.

Panel (c) modifies the benchmark specification by replacing the SPF expected inflation series with the 1-year-ahead CPI inflation expectation from the University of Michigan Survey of Consumers. As stressed by Beaudry, Hou, and Portier (2024), this change substantially improves the performance of the Phillips curve over this episode.

The improvements in panels (b) and (c) are more closely related than they might seem, because Michigan 1-year-ahead expectations are closely related to energy prices, in particular the highly salient gasoline price.²¹ In both panels, the change therefore provides more weight to energy prices, either directly (by including the 1970s in the estimation sample) or indirectly (through the Michigan index). Inspection of the contributions of the Michigan index and energy prices in panel (c) indicates that these two contributions are highly correlated, which suggests that it will be difficult to separate a pure expectations effect from a change in expectations induced by energy prices.

Figure 3 thus adds additional evidence that energy prices played a central role in both the inflation and disinflation of the 2021–2024 period. This role was arguably increased by the Fed initially accommodating the energy-price rise for nearly nine months before raising the Fed Funds rate sharply in the spring of 2022. Although the increase in the Fed Funds rate was insufficient to change the unemployment rate substantially, it did convey intention to sophisticated observers, and the SPF forecast remained under 3 percent. That nuance appears to have been lost, however, on consumers, whose expectations of inflation continued high, 5 percent or more, through November 2022. Whether through their effects on consumers' expectations or through direct passthrough along the supply chain (or both), energy price volatility—which largely stemmed from the geopolitical disruptions due to the conflict in Ukraine—played a numerically dominant role in this inflationary episode.

21. See Coibion and Gorodnichenko (2015).

2.2 Properties of Net-Zero Fuel Markets

One possible consequence of the energy transition is that replacing power generation by fossil fuels with renewable sources, and gasoline and diesel consumption by electrification or low-carbon fuels, will reduce the vulnerability of the economy to fossil fuel price shocks. Here, we provide some largely qualitative comments on the fundamentals of fuel markets that would need to be true for this optimistic view to transpire.

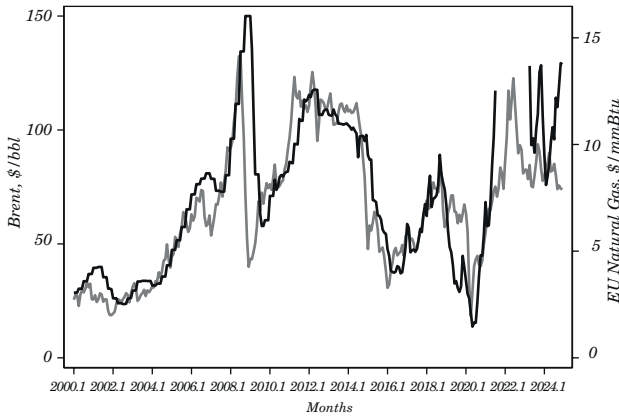
We begin with three observations.

First, prices in fuel markets are internationally determined. This has long been true for oil. Increasingly, with the expansion in trade in LNG, it is increasingly true for natural gas. Moreover, as can be seen in Figure 4, the prices of oil and natural gas are closely linked because they can be (and are) used as substitutes for the production of electricity and for process heat in some parts of the world. In fact, many long-term international LNG contracts are indexed to oil, although the spot prices displayed in Figure 4 are not.²² Coal prices also fluctuate with oil and gas prices (coal and gas are substitutes in generating electricity), although most coal is sold under long-term contracts.

Second, as discussed in Subsection 1.4, the short-run demand for energy is inelastic. The supply of energy is also inelastic in the short run. The net result is that relatively small disturbances in the supply of or demand for fuels lead to significant price fluctuations.

22. The EU price is a composite price index over the main EU trading hubs (IMF Primary Commodity Prices). Figure 4 omits the EU gas price from August 2021 to March 2023 because the index spiked during that period due to the severe supply disruptions associated with the Russia–Ukraine conflict. The index peaked at USD70/mmBtu in August 2022.

Figure 4. Spot Prices of Natural Gas in the EU (grey) and the Spot Price of Brent Oil (black)



Source: World Bank, FRED.

Notes: The EU gas price is omitted from August 2021 – March 2023 to facilitate plotting.

Third, although the ultimate technology for decarbonizing transportation is uncertain, it is likely that at least some modes of transportation will continue to use liquid fuels. This includes aviation, for which electrification is not expected to be a viable pathway except for low-capacity short-haul flights, marine transportation, and possibly heavy-duty trucking. The current technological options for aviation stress sustainable aviation fuels (SAFs), either low-carbon biofuels or so-called e-fuels, which combine green hydrogen with a low-emissions source of carbon such as direct air capture. Another option is to continue to use petroleum aviation fuel paired with ton-for-ton firm offsets from atmospheric carbon dioxide removal (CDR). For marine applications, currently likely options include green methanol or green ammonia made from green hydrogen, or petroleum marine fuel paired with CDR. For heavy-duty vehicles, the options are electrification, low-carbon biofuels, green hydrogen fuel cells, and diesel with CDR. In all these cases, these fuels are transportable and will compete with each other on price. In the case of aviation, all SAFs are chemically effectively equivalent to petroleum jet fuel (“drop-in” fuels). Because these fuels are substitutes, are transportable, and will be used internationally, we would expect their markets to be linked to oil markets just as natural gas and oil are linked today. Thus, it is reasonable to expect that fuel-price shocks will ripple through the entire fuel market, just as they do today.

These observations suggest that the time scale for the diminishing importance of fuel-price shocks thus depends not on whether those fuels are fossil or green but on the time scale for phasing out fuels altogether. That time scale is highly uncertain. Even for light- and medium-duty vehicles, however, it is measured in decades, not years, because of the slow turnover of the stock of vehicles—the average lifespan of a light-duty vehicle in the United States is more than a decade. For heavy-duty vehicles, the timeframe is longer. As a result, the use of motor gasoline and diesel for light- and medium-duty vehicles is likely to remain high for at least two decades. Taken together, these observations, combined with the inflation of 2021–2024, point towards global energy price fluctuations being a significant driver of overall inflation for decades to come.

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