Carbon Emissions and the Transmission of Monetary Policy*

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Abstract

This paper studies the dynamic causal effects of monetary policy on carbon emissions in the United States. I identify a structural monetary policy shock using high-frequency changes in financial assets prices around Federal Open Market Committee (FOMC) announcements (i.e. monetary policy surprises). An analysis of the effects of these shocks reveals that, contrary to the consensus view, a contractionary monetary policy shock is associated with a one percent *increase* in total carbon emissions from energy consumption: while emissions from the industrial sector decline (as expected), emissions from non-industrial sectors rise significantly in the short run. A detailed exploration reveals that the channels of monetary policy transmission vary in strength and relevance across sectors and help explain these heterogeneous responses: while the conventional *aggregate demand* channel plays a central role in the response of industrial sector emissions, the evidence suggests a more significant role of the *commodity price* and *energy substitution* channels of monetary policy for the transmission of shocks to the non-industrial sectors.

Keywords: Monetary policy, carbon emissions, commodity prices, business cycle fluctuations, high-frequency identification.

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1 Introduction

The increase in carbon dioxide emissions and other greenhouse gases, alongside the resulting acceleration of climate change in recent decades, poses a significant challenge and is considered one of the most critical threats to global economic prosperity and well-being. Addressing these challenges has become a priority on the public policy agenda, with carbon pricing, through carbon taxes and emissions trading systems, widely recognized as a key policy tool. However, while there is substantial consensus and evidence on the effectiveness of these policies in reducing emissions, there is less agreement on the potential role of complementary tools, such as monetary policy, in mitigating the drivers and impacts of climate change.

An ongoing debate centers on whether central banks should integrate climate change considerations into their monetary policy frameworks and adopt a more active role in addressing it. Key points in this discussion include the manner in which monetary policy should address climate change while adhering to its primary objective of price stability, the potential trade-offs between climate-related goals and these core objectives, and how these trade-offs should be managed given the range of policy instruments available to central banks (Ferrari and Nispi Landi, 2024; Nakov and Thomas, 2024). While this issue has sparked growing controversy, several institutions have already taken proactive steps by incorporating climate change into their policy mandates.[1] However, despite these theoretical discussions and policy developments, a critical gap remains in empirical evidence regarding the actual capacity of monetary policy to influence environmental outcomes, its effectiveness in addressing climate-related challenges, and the practical implications of conventional monetary policy for the drivers and determinants of climate change.

This paper contributes to addressing this gap by providing novel empirical evidence on the response of carbon emissions and emission intensity metrics to monetary policy. I estimate the impact of exogenous variations in monetary policy on aggregate and sectoral carbon emissions by extending a standard structural monetary policy vector autoregression (VAR) model to include these flows. Following Gertler and Karadi (2015), Jarociński and Karadi (2020), Miranda-Agrippino and Ricco (2021), Bauer and Swanson (2023), and others, I identify the effects of monetary policy on the economy and carbon emissions using high-frequency changes in interest rate futures around Federal Open Market Committee (FOMC) announcements as an external instrument. Crucially, I also employ the recent methodology of Jarociński and Karadi (2020), which disentangles monetary policy shocks from contemporaneous information shocks by analyzing the high-frequency co-movement

[1] Notably, the Bank of England has explicitly integrated climate change considerations into its mandate. Similarly, the European Central Bank, following a recent review of its monetary policy strategy, has developed a comprehensive climate action plan. Additionally, the Network for Greening the Financial System, founded in 2017 with eight members, now includes 95 members and 15 observers, including all major central banks. The International Monetary Fund, which joined as an observer in 2019, further underscores the global recognition of the link between monetary policy and climate change mitigation.

of interest rates and stock prices in the narrow window around policy announcements. This approach seeks to isolate the 'pure' policy component of the announcements and allows for accurate, unbiased estimates of the responses of macroeconomic aggregates and carbon emission flows to monetary policy shocks.

The results indicate that monetary policy shocks have statistically and economically significant effects on both the macroeconomy and carbon emissions dynamics. Consistent with established findings in the monetary VAR literature, an unanticipated monetary tightening leads to a significant and persistent decline in consumer prices and economic activity. In addition, financial conditions tighten and commodity prices deteriorate sharply following the monetary contraction. However, contrary to the consensus view, carbon emissions from total energy consumption *increase* significantly on impact and return to pre-contraction levels only after approximately two quarters. The impact is sizeable, as a 25-basis-point tightening of the policy indicator leads to a rise in emissions of about one percent. A detailed exploration of the factors behind this counterintuitive behavior—given the typical positive association between economic activity and carbon emissions—reveals that the increase is primarily driven by the responses of *non-industrial* sector emissions (electric power, transport, residential, and commercial), all of which rise following the monetary tightening. Given the substantial contribution of these non-industrial sectors to aggregate emissions, this unusual aggregate response can largely be attributed to the behavior of these energy-consuming sectors.

To explain these empirical findings, I explore the transmission mechanisms of monetary policy and find evidence of increased heterogeneity across sectors. For the industrial sector, which broadly encompasses facilities and equipment used in manufacturing, agriculture, mining, and construction, the dominant channel appears to be the standard *aggregate demand* channel: higher interest rates reduce aggregate consumption and output. Since most consumer goods are produced in this sector, demand for labor and energy inputs declines sharply following the monetary tightening. The reduction in emissions for this sector, approximately 0.4 percent at its lowest point, almost mechanically follows from the decreased consumption of electricity and fossil fuels by these productive activities, mirroring the timing and pattern of the decline in economic activity discussed earlier.

In contrast, complementary evidence suggests that alternative transmission channels, namely the *energy substitution* and *commodity price* channels, play a more prominent role in non-industrial sectors. The *energy substitution* channel, particularly relevant to the residential and commercial sectors, emerges as employment and leisure move in opposite directions over the typical business cycle, and at the onset of a downturn, involuntary accumulation of stocks and inventories occurs when demand falls faster than production can adjust. In the residential sector, increased leisure time during economic downturns leads to higher energy and electricity consumption as individuals spend more time at home, driving up emissions in this sector. Meanwhile, a similar pattern of increased energy demand arises in commercial buildings, where firms store inventories of goods, manufactured products, merchandise, and raw materials, further contributing to higher emissions. This heightened activity in residential and commercial facilities drives up energy and electricity consumption following a monetary contraction, resulting in substantial increases in carbon emissions of approximately 2.5 percent in the residential sector and 1.8 percent in the commercial sector. This effect also extends to the electric power sector, which must accommodate the rising electricity demand.

The second channel, the *commodity price* channel, arises as monetary policy actions by major central banks affect global economic activity and financial conditions, which are key drivers of commodity price fluctuations (Miranda-Pinto et al., 2023; Degasperi et al., 2023; Castelnuovo et al., 2024). This channel is particularly relevant to the electric power sector, which primarily generates electricity and heat for sale to other energy-using sectors. Large and heterogeneous commodity price responses to monetary policy shocks directly influence the marginal costs of electricity generation, pushing the sector toward more polluting, cheaper fuels, such as coal, in the short term, displacing cleaner but more expensive alternatives like natural gas. Specifically, my findings indicate that, following an unexpected 25-basis-point monetary tightening, the average cost of coal declines by more than 4 percent relative to the cost of natural gas, prompting a shift in fuel use at the margin. This shift ultimately triggers a significant 1 percent increase in the electric power sector's emissions in the short run. Given the heavy dependence of both the commercial and residential sectors on electricity, the electric power sector's adjustment to tighter monetary policy has substantial implications for the indirect carbon dioxide emissions from these sectors.

To better understand the driving forces behind these divergent responses in energy commodity prices, which appear to trigger input substitution in the electric power sector, I examine the mechanisms through which monetary policy shocks may influence commodity prices, as suggested by Frankel (1986, 2008). Specifically, I focus on coal and natural gas, which together accounted for 65 percent of the energy consumed in this sector by 2023 (U.S. Energy Information Administration, 2024b) and represent the main sources of carbon emissions. My results suggest that the negative impact of a monetary policy tightening on the price of coal can be attributed to incentives for stock depletion and immediate extraction. In contrast, while there is some suggestive evidence of stock depletion for natural gas, the effect on extraction appears to be much less pronounced.

A comprehensive set of robustness and sensitivity checks confirms that the results hold across various dimensions, including the construction of the instrument, estimation techniques, model specifications, alternative data sources and transformations, as well as the sample period analyzed.

The mechanisms uncovered in this exhaustive empirical analysis are formalized through the lens of a New Keynesian model, extended with an energy block, similar to the frameworks of Olovsson and Vestin (2023), Ferrari and Nispi Landi (2024), and Nakov and

Thomas (2024). The model's energy block features two key sectors: an electric power sector, which purchases *energy inputs* to produce and supply *energy services* (i.e., electricity) to households and intermediate goods firms, and an energy sector, consisting of representative firms that produce *energy inputs* (coal and natural gas) using labor. Households consume both goods and energy services, while intermediate goods firms combine labor and energy services to produce consumption goods. Importantly, household electricity consumption is modeled as a complementary good to leisure, meaning that more leisure time increases household demand for electricity (e.g., for entertainment, heating, or cooling). I calibrate the model using macro and micro moments from the data and drawing upon values previously used in the literature.

The model qualitatively captures the observed empirical responses to monetary policy shocks, demonstrating that these findings can be explained within a standard framework under reasonable assumptions and calibration. Specifically, it highlights the role of leisure in household electricity demand and the impact of fluctuations in relative energy input prices on the energy mix in the electric power sector. Additionally, the model is also able to replicate the unconditional procyclicality of emissions observed in the data through the dynamics generated by a technology shock. This reinforces the conclusion that monetary policy shocks play a limited role in driving both business cycle and emissions fluctuations, aligning with the view that such shocks account for only a negligible share of short-term variations in industrial production and unemployment (Caldara and Herbst, 2019; Plagborg-Møller and Wolf, 2022).

Related literature and contribution — This paper contributes to several strands of literature. First, my empirical analysis relates closely to the extensive literature on monetary policy VARs and high-frequency identification (Stock and Watson, 2012; Gertler and Karadi, 2015; Ramey, 2016; Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023). I extend this literature by incorporating carbon emissions, energy consumption, energy prices, and emission intensity measures into the baseline monetary VAR. This allows for an exploration of the dynamic interaction between monetary policy and the environment, identification of the potential mechanisms driving this relationship, and an assessment of the role of different sectors in the response of aggregate carbon emissions to a surprise monetary tightening.

My findings suggest that the heterogeneous effects of monetary policy shocks on commodity prices, particularly energy inputs in the electric power sector, play a critical role in shaping carbon emissions from energy consumption in both the sector and the broader economy. In this respect, I contribute to the literature on the various transmission channels through which monetary policy influences energy and, more broadly, commodity prices (Barsky and Kilian, 2004; Frankel, 2008; Anzuini et al., 2013; Rosa, 2014; Miranda-Pinto et al., 2023; Degasperi et al., 2023; Castelnuovo et al., 2024). Building on this work, I reassess the transmission of monetary policy through commodity prices, extending the analysis to examine its role in the demand and consumption of different energy sources and the corresponding emissions response.

In addition, my analysis relates to the growing literature on the dynamic relationship between output and emissions. A closely related study by Khan et al. (2019) examines the cyclicality of emissions in response to various demand and supply shocks identified in the literature. They distinguish between different types of technology shocks, demonstrating that emissions typically rise following these shocks. However, they also find that demand shocks (i.e., monetary and fiscal policy) generate procyclical comovements between emissions and GDP, though the responses are not statistically significant. In contrast to Khan et al. (2019), I find that monetary policy shocks generate a negative correlation between emissions and economic activity, using a state-of-the-art identification strategy (i.e., external instruments), longer-horizon policy indicators (potentially unconstrained during the ZLB period), higher-frequency data, and additional controls.[2]

Similarly, Jo and Karnizova (2021) contribute to this literature by identifying structural shocks that reveal distinct patterns of correlation between GDP and emissions. Their findings show that, surprisingly, emissions and output moved in opposite directions in approximately 45 percent of the quarters between 1973Q1 and 2019Q4. They interpret this negative correlation (NC) shock as representing energy-efficiency improvements in U.S. homes. Likewise, Känzig and Williamson (2023) identify energy-saving technology shocks that lead to negative comovement between output and emissions, with this decoupling driven by a reduction in energy intensity, defined as energy use per unit of output.

Building on these findings, my analysis also reveals that monetary policy shocks generate negative correlations between emissions and economic activity. However, unlike the energy-efficiency and energy-saving technology shocks studied by Jo and Karnizova (2021) and Känzig and Williamson (2023), I find that monetary policy operates through heterogeneous channels across sectors, including aggregate demand and commodity prices. These results suggest that monetary policy shocks should also be considered within the NC category, broadening the set of shocks that can explain negative comovements between emissions and economic activity beyond energy-efficiency changes. In contrast to Känzig and Williamson (2023), the negative correlation in my findings arises from the emission intensity of energy use (i.e., emissions per unit of energy), particularly in the electric power sector, where substitution between coal and natural gas is driven by changes in relative prices triggered by monetary shocks.

In this same branch of the literature, Moench and Soofi-Siavash (2023) identify an emission intensity shock that explains the largest share of CO2 emissions variation per unit of GDP over a 20-year horizon in a Bayesian VAR. Although their shock leads to a permanent

[2] Including the excess bond premium by Gilchrist and Zakrajšek (2012) aggregates high-quality forward-looking information about the economy, thereby improving the reliability and forecasting performance of small-scale VARs (Caldara and Herbst, 2019).

decline in emissions per unit of output, it does not result in a permanent reduction in per capita emissions, as emissions eventually overshoot their initial levels. My findings align with their work in that I also observe the role of emission intensity in explaining fluctuations in carbon emissions. However, while they focus on long-term emission intensity shocks, I show that monetary policy shocks can similarly affect emission intensity, but over shorter horizons, particularly through the energy mix in the electric power sector. This highlights that, although monetary policy may not generate permanent shifts in emissions, it plays a significant role in shaping short- to medium-term emission dynamics.

Finally, Känzig (2023) examines a carbon policy shock in the European carbon market, finding that tightening the carbon pricing regime reduces greenhouse gas emissions, though at the cost of higher energy prices. While my paper does not directly address carbon pricing, my findings suggest that monetary policy shocks can also influence energy prices, leading to adjustments in emissions through price-sensitive substitutions between energy inputs. This suggests a broader policy relevance, where both monetary and carbon policy interventions can drive emission reductions, though through different mechanisms and with distinct economic trade-offs. Unlike the carbon policy shock, which targets emissions directly, the effects of monetary policy on emissions occur indirectly, through its impact on economic activity, energy prices, and sectoral energy consumption.

Roadmap —The remainder of the paper is organized as follows. In Section 2, I introduce the carbon emissions data and describe the empirical VAR analysis, including the high-frequency identification of monetary policy shocks and the econometric approach. Section 3 presents the baseline results on how carbon emissions from aggregate energy consumption respond to a monetary policy shock, along with the disaggregated responses across different energy-consuming sectors. In Section 4, I explore how different channels play heterogeneous roles in the transmission of monetary policy across sectors, conditioning the aggregate emissions response. Section 5 presents the model, the calibration and the simulation and discusses the results and mechanisms through which the model is able to qualitatively replicate the empirical results. Finally, Section 6 presents some concluding remarks and suggests directions for future research.

2 Data and Econometric Approach

2.1 Data on carbon dioxide emissions and energy consumption

One of the key data series in my analysis is total CO2 emissions from energy consumption, estimated by the U.S. Energy Information Administration (EIA). Understanding how emissions are measured in practice is crucial for interpreting the results of this paper. The EIA employs a bottom-up approach, beginning with energy consumption data disaggregated by fuel type (coal, natural gas, and oil products) and energy-use sectors. Physical quantities for each fuel type are first converted to British thermal units (Btu) of heat[3], then multiplied by fuel-specific CO2 emissions coefficients provided by the U.S. Environmental Protection Agency[4], and finally summed across fuels and sectors to calculate total emissions (U.S. Energy Information Administration, 2024d)[5].

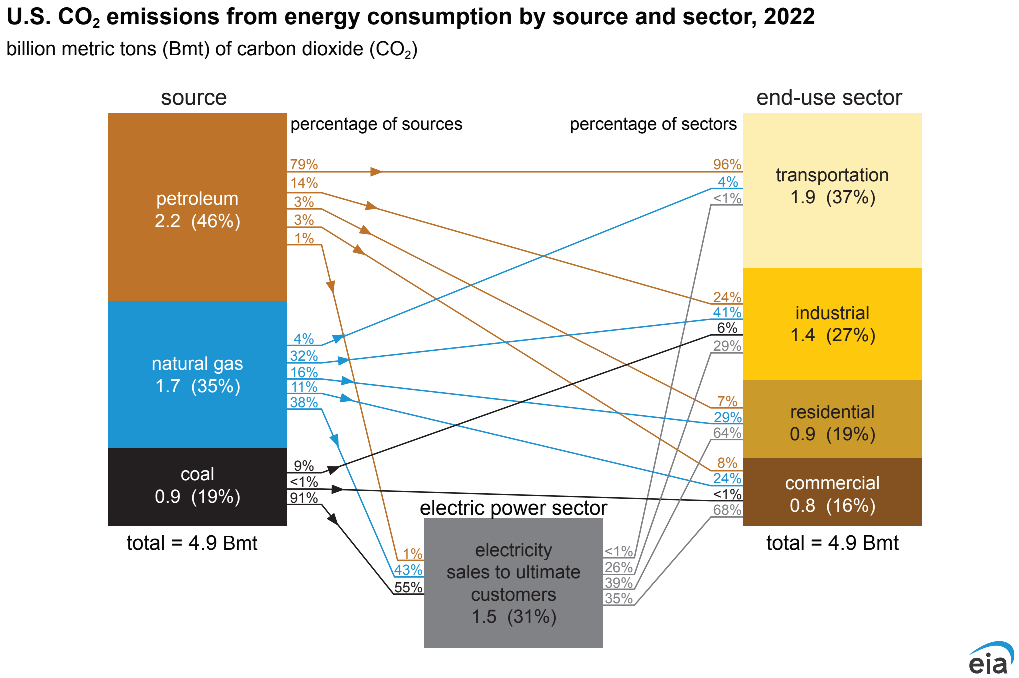

Figure 1: U.S. CO2 emissions from energy consumption by source and sector, 2022

Notes: The U.S. Energy Information Administration (EIA) chart on U.S. CO2 emissions from energy consumption by source and sector illustrates carbon dioxide (CO2) emissions from fossil fuel consumption in the United States, along with the relative contributions of sectors and sources. *Source*: U.S. Energy Information Administration (EIA), Monthly Energy Review (April 2023), Tables 11.1—11.6.

To provide additional context on the nature and magnitude of these variables, Figure 1 presents aggregate CO2 emissions from energy consumption by source and sector in the U.S. In 2022, total carbon emissions from energy consumption reached nearly five billion metric tons (Bmt) of CO2. Petroleum consumption accounted for 2.2 Bmt, or about 46% of the U.S. total, while natural gas and coal contributed 1.7 Bmt (35%) and 0.9 Bmt (19%), respectively. Importantly, different fuels emit varying amounts of CO2 depending on their carbon content and the energy produced when burned. The amount of CO2 emitted is determined by the fuel's carbon content, while the energy produced (or heat content) is influenced by both its carbon (C) and hydrogen (H) content. Natural gas, primarily composed of methane (CH4), has a higher energy content relative to other fuels and thus produces

[3]One Btu is the amount of heat required to raise the temperature of one pound of water from 39 to 40 degrees Fahrenheit.

[4]Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022, Tables A-20, A-25, A-32, and A-226.

[5]Fossil fuels primarily consist of carbon and hydrogen. When burned, carbon combines with oxygen to form CO2, and hydrogen combines with oxygen to form water (H2O). These reactions release heat, which is used for energy.

lower CO2 emissions per unit of energy. By contrast, coal is the most carbon-intensive of the major fossil fuels, emitting nearly twice as much CO2 per unit of energy as natural gas and approximately 33% more than oil.

Regarding energy-consuming sectors, although the industrial sector used the most energy in 2022 (including direct primary energy use[6] and electricity purchases from the electric power sector), the transportation sector emitted more CO2 due to its near-total reliance on petroleum fuels. Emissions from the electric power sector are allocated to each end-use sector based on their share of total annual retail electricity sales. Even with these adjustments, the transportation sector accounted for the largest share of U.S. energy-related CO2 emissions in 2022 (37%), followed by the electric power (31%) and industrial (27%) sectors.

2.2 High-frequency identification and econometric framework

Several recent studies have used high-frequency financial asset price changes around the Federal Reserve's Federal Open Market Committee (FOMC) announcements, or monetary policy "surprises", as an instrument to estimate the causal effects of monetary policy on macroeconomic variables in structural VARs (Cochrane and Piazzesi, 2002; Stock and Watson, 2012, 2018; Gertler and Karadi, 2015; Ramey, 2016; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023). To accurately measure this effect, it is crucial to control for the variation in economic fundamentals to which policy endogenously responds. Monetary policy surprises are particularly useful in these applications because focusing on price changes within a narrow window around FOMC announcements (usually a half-hour window starting 10 minutes before and ending 20 minutes after the announcement) plausibly rules out reverse causality and other endogeneity concerns.

However, recent literature has highlighted the importance of considering the *information effects* of monetary policy announcements. These studies suggest that announcements reveal not only information regarding policy actions but also the central bank's assessment of the broader economic outlook (Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023). In light of these considerations, I rely on the updated "pure" monetary policy shock series by Jarociński and Karadi (2020)[7], which decomposes the surprises by analyzing the high-frequency co-movement of financial assets and stock prices around the policy announcement. The intuition behind this decomposition is that, according to a wide range of models, a pure monetary policy tightening should lead to a decline in stock market valuations. Based on this argument, the authors compute the first principal component of the surprises in interest rate derivatives with maturities from one month to one year (MP1, FF4, ED2, ED3, ED4) and identify a monetary policy shock when interest rates and stock prices move in opposite directions. Conversely, if interest rates and stock prices co-move positively, this is interpreted as reflecting an *information shock*, where

[6] Primary energy sources include fossil fuels (petroleum, natural gas, coal), nuclear energy, and renewables. Electricity is a secondary energy source generated from primary energy.

[7] Available at `https://marekjarocinski.github.io/jkshocks/jkshocks.html`

the central bank's announcement conveys new information about the economic outlook. This procedure isolates the structural monetary policy component of the announcements from the broader central bank information effect.

To study the causal impact of monetary policy on carbon emissions, I employ a structural vector autoregression (SVAR) model. Consider the following reduced-form VAR(p) model:

$$\mathbf{Y}_t = \mathbf{c} + \mathbf{B}_1 \mathbf{Y}_{t-1} + \cdots + \mathbf{B}_p \mathbf{Y}_{t-p} + \mathbf{u}_t \tag{1}$$

where $\mathbf{Y}_t$ is an $n \times 1$ vector of endogenous variables, $\mathbf{c}$ is a vector of constants, $\mathbf{u}_t$ is an $n \times 1$ vector of serially uncorrelated regression residuals with covariance matrix $\text{Var}(\mathbf{u}_t) = \Sigma$, $\mathbf{B}_1, \ldots, \mathbf{B}_p$ are $n \times n$ coefficient matrices, and p represents the lag order.

I follow standard practice in assuming that the economy is driven by a set of serially and mutually uncorrelated structural shocks, $\boldsymbol{\varepsilon_t}$, with $\text{Var}(\boldsymbol{\varepsilon_t}) = \mathbf{\Omega}$, where $\mathbf{\Omega}$ is diagonal. Assuming the VAR is invertible, the reduced-form innovations, $\boldsymbol{u_t}$, can be expressed as linear combinations of the structural shocks:

$$\mathbf{u}_t = \mathbf{S}\boldsymbol{\varepsilon_t} \tag{2}$$

where $\mathbf{S}$ is a non-singular, $n \times n$ structural impact matrix, and $\boldsymbol{\varepsilon_t}$ is an $n \times 1$ vector of structural shocks. From the linear mapping of the shocks, it follows that $\mathbf{\Sigma} = \mathbf{S\Omega S}'$. We are interested in characterizing the causal impact of a single shock. Without loss of generality, let us denote the monetary policy shock as the first shock in the VAR, ε_{1t}. Our goal is to identify the structural impact vector s_1, which corresponds to the first column of $\mathbf{S}$.

External instrument approach — Identification using external instruments (or "proxies") proceeds as follows. Suppose an external instrument, z_t, is available. In the application at hand, z_t represents the monetary policy surprise series. For z_t to be a valid instrument, the following conditions must hold:

$$\mathbb{E}[z_t \varepsilon_{1t}] = \alpha \neq 0 \tag{3}$$

$$\mathbb{E}[z_t \varepsilon_{2:nt}] = \mathbf{0} \tag{4}$$

where ε_{1t} is the structural monetary policy shock and ε_2 is an $(n-1) \times 1$ vector containing the other structural shocks. Assumption (3) refers to the relevance requirement, and assumption (4) ensures exogeneity. Together with the invertibility condition (2), these assumptions identify s_1, up to sign and scale:

$$\mathbf{s}_1 \propto \frac{\mathbb{E}[z_t \mathbf{u}_t]}{\mathbb{E}[z_t u_{1t}]} \tag{5}$$

provided that $\mathbb{E}[z_t u_{1t}] \neq 0$. To estimate the elements in the vector s_1 I proceed as follows: first, I obtain estimates of the vector of reduced form residuals from the ordinary least squares regression of the reduced form VAR in Equation 1, $\hat{\mathbf{u}}_t$. Then I implement the estimator with a 2SLS procedure and estimate the coefficients above by regressing $\hat{\mathbf{u}}_t$ on $\hat{u}_{1t}$ using z_t as the instrument. To conduct inference, I employ a wild bootstrap, as proposed by Mertens and Ravn (2013).

2.3 Empirical specification

Studying the impact of monetary policy on carbon emissions requires modeling them jointly with the U.S. economy. The baseline specification consists of six variables. For the core macroeconomic variables, I follow the literature on monetary VARs and include monthly measures of industrial production, the personal consumption expenditures (PCE) price index, the Bloomberg Commodity Spot Price Index, the Gilchrist and Zakrajšek (2012) excess bond premium, and the one-year Treasury yield as the relevant monetary policy indicator, given that the economy was at the effective lower bound for the latter part of the sample period. In the baseline specification, I further extend the VAR by including a measure of aggregate carbon emissions from energy consumption in the U.S. More information on the data and its sources can be found in Appendix A.

The data are monthly and span the period from 1973M1 to 2019M12. Following Gertler and Karadi (2015), I use a shorter sample for identification, specifically 1990M2 to 2019M12, as the futures data required to construct the instrument are only available for this period. The rationale for using the longer sample for estimation is to obtain more precise estimates of the reduced-form coefficients. However, restricting the sample to 1990-2019 produces very similar results. I end the sample in 2019 to avoid the dramatic swings in economic activity associated with the onset of the COVID-19 pandemic in the United States. Following Sims et al. (1990), I estimate the VAR in log levels. With the exception of the excess bond premium and the one-year rate, all variables are entered in log levels. The lag order is set to 12, and only a constant term is included as a deterministic component.

3 Empirical Results

3.1 Effects on carbon emissions and the macroeconomy

In this section, I examine the macroeconomic effects of monetary policy shocks through the lens of the baseline model. The main identifying assumption underlying the external instrument approach is that the instrument is correlated with the structural shock of interest but uncorrelated with all other structural shocks. Additionally, for standard inference to be valid, the instrument must be sufficiently strong. The F-statistic in the first stage is 13.31, which exceeds conventional critical values, allowing me to conclude that the instrument is strong enough to support standard inference.

Turning to the macroeconomic and environmental impacts of monetary policy shocks, Figure 2 presents the impulse responses to the monetary policy shock, normalized to increase the one-year rate by 25 basis points (bps) on impact. As most variables are in logs, the responses can be interpreted as elasticities. The solid black line in each panel shows the point estimates, while the dark and light-shaded regions represent 68 and 90 percent confidence bands, respectively, based on 2,000 bootstrap replications.

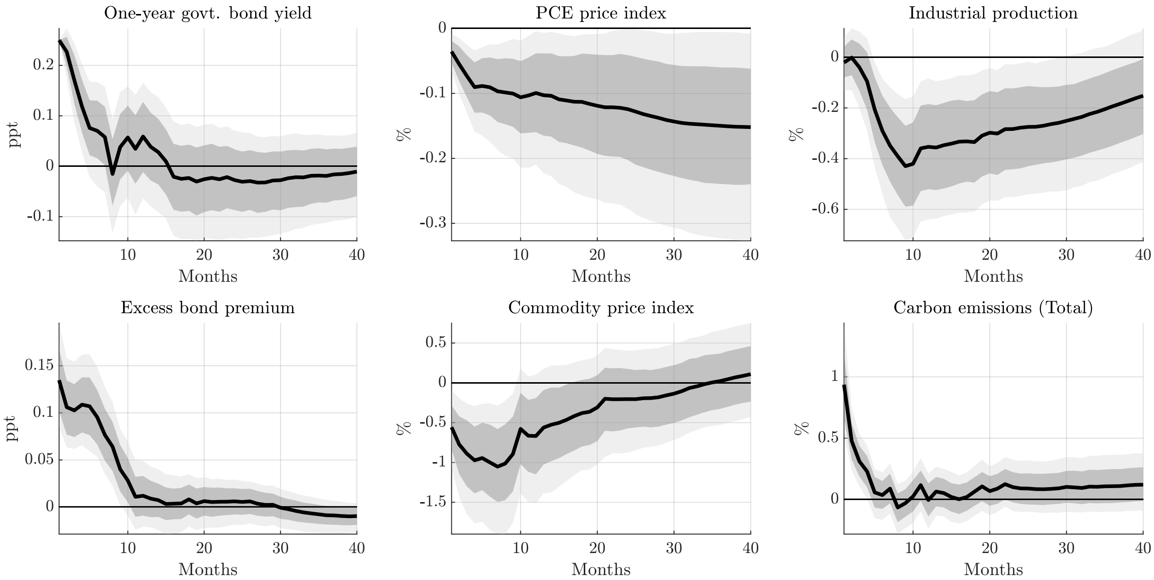

Figure 2: Impulse responses to a monetary policy shock: Aggregate variables

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

Turning to the effects on macroeconomic variables, a surprise monetary contraction results in a significant, immediate increase in the one-year government bond yield. This contraction slows down economic activity, as industrial production shows no immediate response but declines significantly in the following months. This has important implications for inflation and price dynamics, as the PCE price index shows little change on impact but begins to fall slowly and persistently afterward. Commodity prices, on the other hand, decrease sharply on impact and continue to decline for about three quarters before slowly converging back to normal. Financial conditions also tighten, as reflected by the excess bond premium, which increases significantly on impact, remains elevated for several months, and then gradually returns to steady state.

In terms of magnitudes, the shock leads to a decline in industrial production of about 0.42 percent after a little less than one year. Consumer prices fall slightly on impact by 0.07 percent and then decline gradually over the following years, while commodity prices fall by 1 percent at the peak of the response. The excess bond premium rises by 13 basis points on impact and returns to normal after about one year. These responses are very similar to those from monetary policy VARs estimated by other authors in the literature (Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023) and are consistent with the aggregate economy weakening moderately and inflation falling slightly after a monetary policy tightening.

Turning to the last panel in Figure 2, carbon emissions from aggregate energy consumption in the U.S. significantly *increase* on impact by approximately 0.99 percent in response to the monetary policy tightening, gradually returning to steady state after about six months.

These results are surprising, given the unconditional procyclicality of emissions documented in the economics literature (Heutel, 2012; Doda, 2014). However, recent studies such as Jo and Karnizova (2021) and Känzig and Williamson (2023) also document a negative correlation and decoupling between emissions and economic activity in recent years, exploring factors that influence emissions without necessarily leading to a trade-off between sustainability and economic performance.

To better understand the significance of these results, it is useful to compare my findings on the estimated impact of monetary policy shocks on carbon emissions with those from related studies. For instance, Känzig (2023) reports that greenhouse gas (GHG) emissions decline by around 0.6 percent following a restrictive carbon policy shock that raises the HICP energy component by one percent on impact, within the context of the European emissions trading system. In response to this shock, monetary policy appears to lean against inflationary pressures, with the two-year rate increasing by about 25 basis points. Additionally, Martin et al. (2014) estimate the effects of the Climate Change Levy (CCL) on manufacturing plants using panel data from the UK production census. Their findings show that the implementation of the CCL package led to a significant reduction in total CO2 emissions by 7.3 percent. In the case of Sweden, Andersson (2019) finds that after the introduction of a carbon tax and a value-added tax on transport fuel, carbon dioxide emissions from the transport sector declined by nearly 11 percent, with the majority of the reduction attributed to the carbon tax alone, relative to a synthetic control group constructed from a comparable set of OECD countries.

Hence, based on these findings in the literature, a 0.99 percent increase in emissions following a surprise monetary contraction, while smaller in magnitude compared to the effects of carbon taxes, still represents an economically significant impact. This suggests that the effect of monetary policy shocks on carbon emissions, though not directly comparable to targeted environmental policies, should be considered by policymakers when assessing the broader implications of carbon reduction strategies, especially if such policies are implemented during periods of monetary tightening. A better understanding of how monetary policy might influence emissions could help ensure that climate objectives are not inadvertently undermined by macroeconomic stabilization efforts.

In Appendix B, I perform a comprehensive series of robustness checks on the identification strategy and empirical approach used to isolate the monetary policy shocks. These checks indicate that the results are robust along a number of dimensions including the construction of the instrument, the estimation technique, the model specification, alternative data sources and transformations, and the sample period.

While the aggregate increase in emissions following a monetary contraction offers an important macroeconomic perspective, understanding the full extent of this response requires a closer examination of sectoral dynamics. Different energy-consuming sectors may react differently to changes in monetary policy, contributing in various ways to the observed overall increase in emissions. To further explore these potential drivers, I rely on sectoral data on carbon emissions for each of the energy-consuming sectors depicted in Figure 1. By disaggregating emissions, my aim is to shed light on how different sectors contribute to the aggregate outcome and explain the seemingly counterintuitive response of carbon emissions to a monetary tightening.

3.2 Effects on sectoral carbon emissions

The results in the previous section suggest that, despite the unconditional procyclicality of emissions, they exhibit countercyclical dynamics in response to a monetary tightening when conditioned on a monetary policy shock. However, to fully understand this response, a closer examination of sectoral dynamics is necessary. The Energy Information Administration (EIA) divides energy use into five economic sectors—residential, commercial, transportation, industrial, and the electric power sector—in order to make reasonable estimates of potential future prices, supply, and energy demand, as well as accurate calculations of carbon emissions from energy consumption, as mentioned in Section 2.

To analyze how emissions from each of these sectors respond to a monetary policy shock, I extend my baseline six-variable monetary VAR. Including all five sectors at once would introduce too many parameters, leading to overfitting and imprecise estimates. Therefore, I follow the approach of Gertler and Karadi (2015) and Graves et al. (2024), extending the baseline VAR by adding one sectoral emissions variable at a time. The results for each sector are presented in Figure 3. Each panel in Figure 3 corresponds to a separate seven-variable VAR, comprising the six original variables from the baseline VAR along with the sectoral emissions variable listed at the top of each panel[8].

Regarding the interpretation of the results in Figure 3, consistent with the aggregate evidence, a 25-basis-point monetary policy tightening leads to an *increase* in emissions from the residential, commercial, transportation, and electric power sectors—collectively referred to as the *non-industrial* sectors due to their similar dynamics. These emissions rise on impact and gradually return to their steady states, with the residential and commercial sectors exhibiting the most persistent responses. In terms of economic magnitude, carbon emissions from energy consumption in the residential sector increase by approximately 3 percent, while emissions from the commercial sector rise by nearly 2 percent. Importantly, emissions from the electric power sector also increase by around 1 percent, but with a lower degree of persistence, returning to normal within a few months. In contrast, emissions from the transportation sector rise by about 0.5 percent but show greater persistence, only returning to steady state after nearly one year. Finally, emissions from the industrial sector are the only ones that exhibit the "expected" behavior, declining significantly by about 0.4 percent at the trough of the response. The emissions response from this sector closely

[8]For space considerations, the IRFs for the five baseline macroeconomic variables are not shown in Figure 3, as they closely resemble the responses reported in Figure 2.

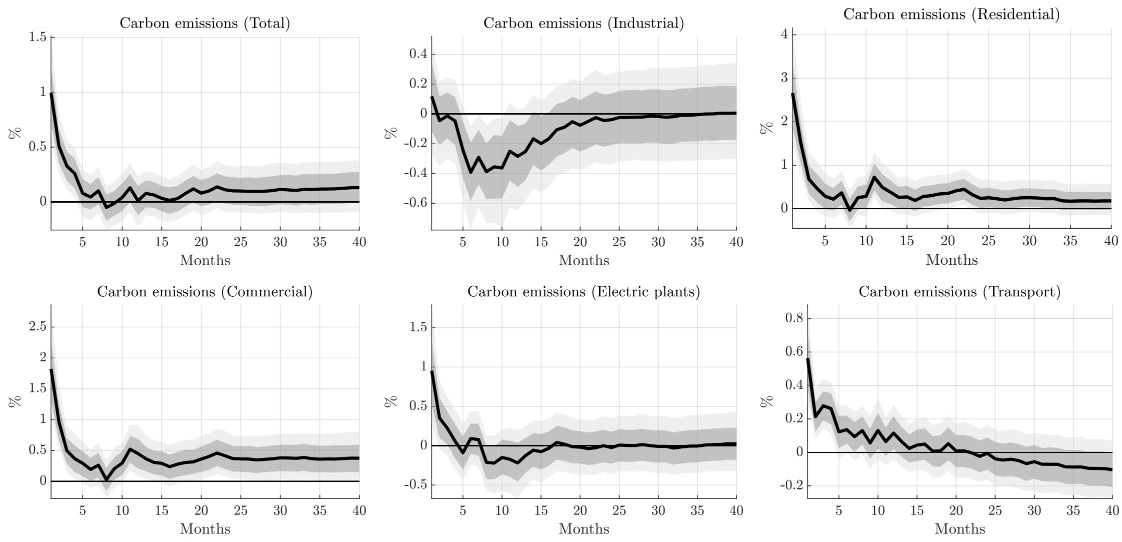

Figure 3: Impulse responses to a monetary policy tightening: Sectoral emissions

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. These IRFs are computed by appending the given sectoral emissions variable to the baseline VAR from Figure 2. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

mirrors the fluctuations in economic activity documented in the previous section, aligning with the contraction in industrial output typically associated with a monetary tightening.

Based on the findings from this section, the empirical evidence suggests that the four *non-industrial* sectors (residential, commercial, transportation, and electric power) are the primary drivers of the aggregate carbon emissions response to a monetary contraction. The sharp and persistent increases in emissions from the residential and commercial sectors, along with the notable but more short-lived responses from the electric power and transportation sectors, indicate that non-industrial patterns play a crucial role in shaping the overall emissions response. In contrast, emissions from the *industrial* sector decline in line with reduced output, aligning predictably with the contraction in economic activity following the monetary policy shock. This divergence between *industrial* and *non-industrial* sectors highlights the sector-specific nature of monetary policy's transmission.

These results suggest the need for a deeper investigation into the mechanisms driving these sectoral responses. In the next section, I explore key variables related to energy consumption, energy prices, and emission intensity across sectors. This analysis aims to uncover the channels through which monetary policy affects energy use and emissions dynamics, shedding light on the differential impacts observed between *non-industrial* and *industrial* sectors.

4 The Heterogeneous Transmission Channels of Monetary Policy

The results in the previous section suggest that monetary policy plays a relevant role in shaping the dynamics of carbon emissions, both at the aggregate and sectoral levels, at business cycle frequencies. However, with the exception of the industrial sector, the response of emissions to a surprise monetary tightening appears puzzling, going in the opposite direction of what the consensus view would predict. To better understand the drivers behind this increase in emissions following a monetary contraction, and to gain further insight into how monetary policy shocks transmit through different sectors of the economy, I examine the responses of key sector-specific variables. These include metrics such as energy consumption, energy prices, and emission intensity (that is, emissions per unit of energy consumed) following a monetary policy shock. The five energy-use sectors vary considerably in both their primary energy uses and their dominant energy sources, as summarized in Figure 4. For instance, residential and commercial buildings use energy mainly for heating, cooling, lighting, and operating appliances, whereas the industrial sector uses energy both as a direct production input (feedstock) and to power machinery. In terms of energy sources, the residential and commercial sectors predominantly rely on electricity and natural gas, while the transportation sector is heavily dependent on motor gasoline. This marked heterogeneity in energy usage and sources could help explain the wide range of responses reported in Figure 3.

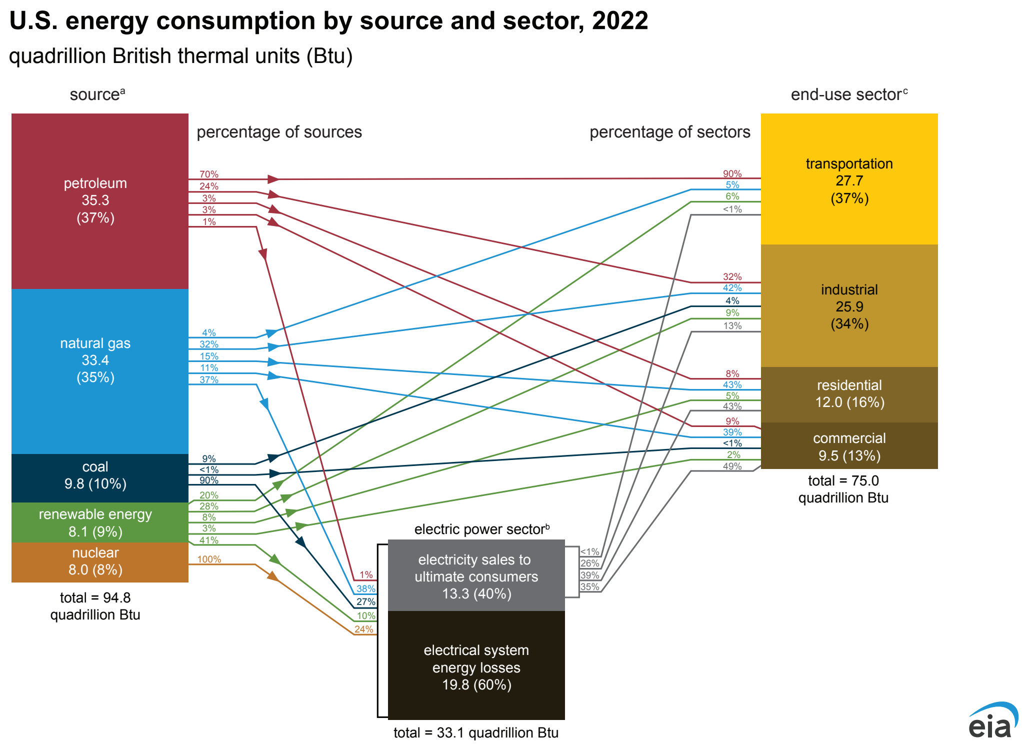

Figure 4: U.S. energy consumption by source and sector, 2022

Notes: The U.S. Energy Information Administration's (EIA) chart shows the types and amounts of primary energy consumed in the U.S., energy use by the electric power and end-use sectors, and electricity sales to end-use sectors. *Source*: U.S. Energy Information Administration (EIA), Monthly Energy Review (April 2023), Tables 1.3, 1.4c, and 2.1a-2.6.

4.1 Industrial sector

The industrial sector encompasses all facilities and equipment used for producing, processing, or assembling goods. Formally, it includes manufacturing (NAICS codes 31-33); agriculture, forestry, fishing, and hunting (NAICS code 11); mining, including oil and gas extraction (NAICS code 21); and construction (NAICS code 23). In 2022, this sector accounted for nearly 35 percent of total U.S. end-use energy consumption and 27 percent of total U.S. carbon dioxide emissions (Figure 1).

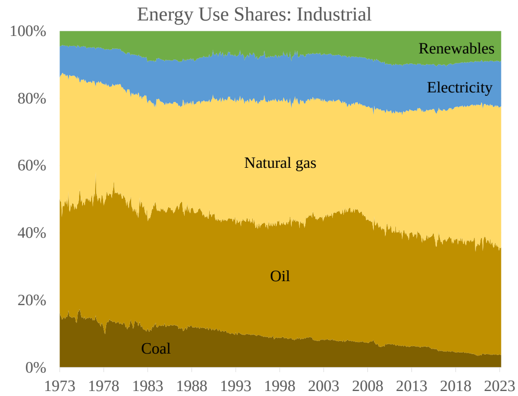

Figure 5: Energy consumption by source and year: Industrial sector

Regarding energy consumption patterns, the industrial sector's needs vary from using energy products as direct inputs to produce goods such as plastics and chemicals, to employing electricity for operating industrial motors, machinery, lighting, computers, and office equipment, as well as for facility heating, cooling, and ventilation (U.S. Energy Information Administration, 2024e). Figure 5 illustrates the relative importance and evolution of energy sources consumed in the industrial sector over time, including primary energy sources (natural gas, oil, coal, renewables) and electricity. Natural gas and petroleum products, such as distillate and residual fuel oils and hydrocarbon gas liquids (HGLs), represent the largest share of energy consumption in the sector, while the electricity share has remained fairly consistent at around 15 percent over the years. To understand the behavior of emissions in this sector following a surprise monetary contraction, as reported in the top middle panel of Figure 3, it is essential to consider the response of sectoral activity and the consumption of these key energy sources.

Figure 6 presents the impulse responses of several variables related to economic activity and energy consumption in the industrial sector to the identified monetary policy shock. Specifically, I estimate the responses of the manufacturing (NAICS 31–33) and mining (NAICS 21) components of industrial production, as well as natural gas, oil, electricity, which by 2022 represented about 87 percent of the sector's energy needs, as well as total energy consumption. As with the aggregate index of industrial production, both the manufacturing and mining components behave as expected: following a monetary contraction, economic activity weakens moderately, and responds to the tightening with a slight lag. Notably, the

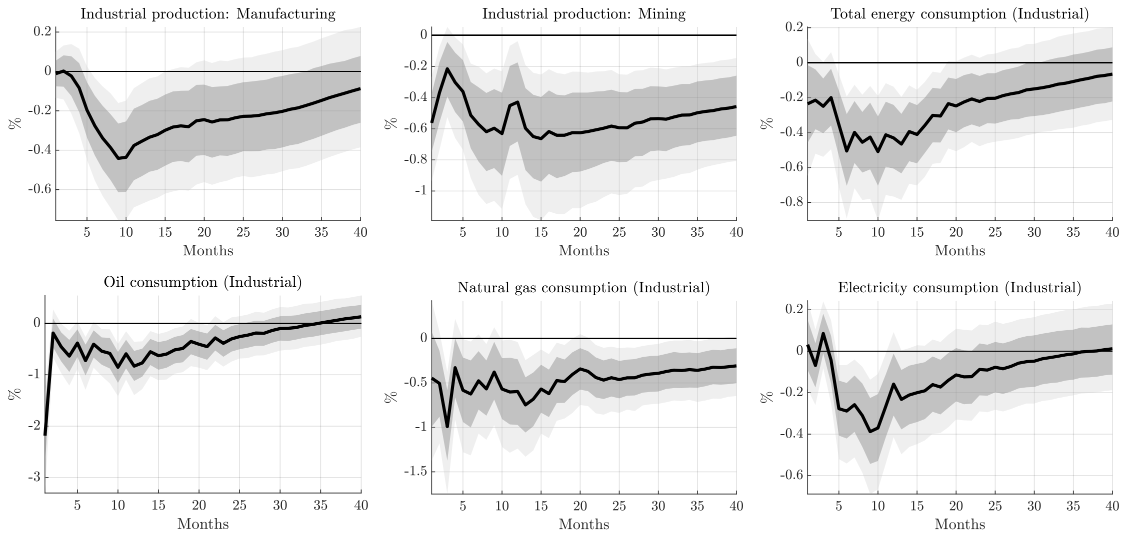

Figure 6: Impulse responses to a monetary policy tightening: Industrial energy and activity

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. These IRFs are computed by appending the given sectoral variables to the baseline VAR from Figure 2. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

response of mining activity is highly persistent, remaining well below the steady-state level even three years after the shock. In contrast, the response of manufacturing activity mirrors the behavior of the overall industrial production index, plotted in the top right panel of Figure 2, peaking at around -0.4 percent approximately one year after the shock.

This decline in industrial activity results in a corresponding drop in total energy consumption in the sector, as shown in the top right panel of Figure 6. Lower production mechanically leads to reduced demand for inputs, with energy being a key component in the production process. Furthermore, the three bottom panels in Figure 6 corroborate this trend: consumption of oil, natural gas, and electricity all decrease in line with reduced production, reflecting a decline in the sector's energy needs. These responses align with the behavior of carbon emissions illustrated in Figure 3, indicating a strong, positive relationship between economic activity, energy demand, and emissions within the industrial sector.

Overall, the responses of the industrial sector's activity and energy consumption measures in Figure 6 suggest that monetary policy operates on this sector through its effect on real economic activity, which I label the *aggregate demand* channel. This result is consistent both with the unconditional procycality of emissions as well as with key assumptions in the macro-environmental literature, namely that emissions are positively correlated and proportional to output (Heutel, 2012; Golosov et al., 2014; Doda, 2014; Annicchiarico and Di Dio, 2015; Nakov and Thomas, 2024). However, as noted earlier, industrial emissions account for only about a third of U.S. CO2 emissions from energy consumption. To fully understand the overall emissions response to a monetary policy shock, it is crucial to analyze the dynamics in the remaining sectors.

4.2 Residential and commercial sectors [Incomplete]

According to the EIA, the residential sector is defined as the energy-consuming sector that consists of living quarters for private households[9]. In contrast, the commercial sector comprises service-providing facilities and equipment used by businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. Both sectors, commonly referred to as the *buildings sector* due to their similar energy uses, together accounted for 35 percent of U.S. carbon emissions from energy consumption (Figure 1) and nearly 30 percent of U.S. energy consumption (Figure 4) in 2022.

Energy used in the residential and commercial sectors provides a variety of services, including space and water heating, air conditioning, lighting, refrigeration, cooking, and the operation of various appliances. Figure 7 shows the evolution of energy consumption profiles for these two sectors over time. The figure highlights a key similarity between the residential and commercial sectors: their heavy reliance on electricity as a major energy source. By 2022, electricity sales from the electric power sector accounted for 43 percent of the residential sector's energy consumption and 49 percent for the commercial sector. This reliance on electricity has increased in recent years, gradually displacing fossil fuels such as coal and oil. Consequently, the energy mix used in electricity generation plays a critical role in determining the indirect emissions of these two sectors, as nearly half of their energy needs are met by electricity.

Natural gas is also a significant energy source for both sectors, representing 43 percent of residential and 39 percent of commercial end-use energy consumption in 2022. In the residential sector, about 60 percent of U.S. homes use natural gas for space and water heating, cooking, and drying clothes. In the commercial sector, natural gas is used not only for heating and cooling but also as a fuel for generating electricity and in combined heat and power systems.

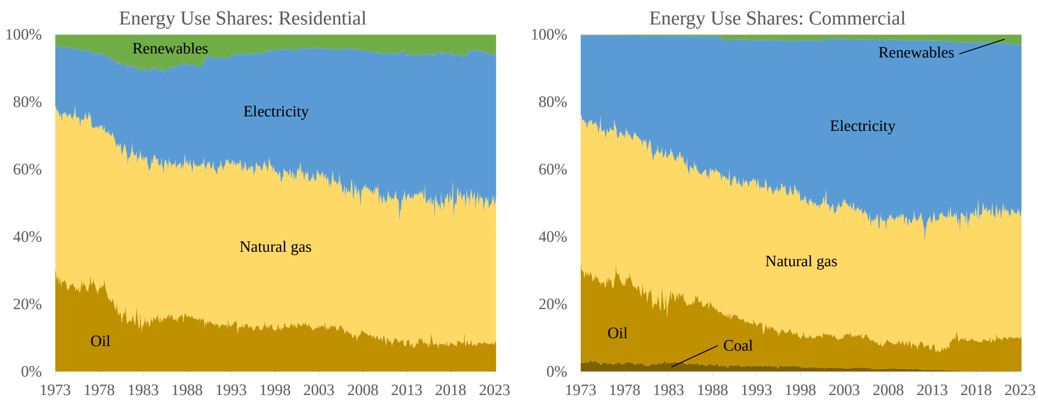

Figure 7: Energy consumption by source and year: Residential and commercial sectors

[9]It excludes institutional living quarters, which are included in the commercial sector.

To understand the dynamics of emissions generated by the residential and commercial sectors following a surprise monetary contraction, and to identify the underlying drivers of the increases observed in Figure 2, I examine the responses of various measures of energy demand in these sectors. Figure 8 presents the impulse responses of overall sectoral energy use to the monetary policy shock. I focus on the responses of electricity and natural gas consumption, as these two sources together account for nearly 90 percent of end-use energy consumption in both sectors. Consistent with the findings in Figure 3, a 25-basis-point monetary policy tightening leads to an *increase* in total energy consumption in both the residential and commercial sectors, with the effect gradually dissipating over time. In terms of economic magnitude, total energy consumption in both sectors increases by about 0.6 percent. Both natural gas and electricity consumption increase following the monetary contraction, explaining the overall rise in energy demand across these two sectors. In all cases, the dynamics closely mirror those of sectoral emissions in Figure 3, with energy consumption and emissions increasing on impact and gradually returning to steady state in the subsequent months.

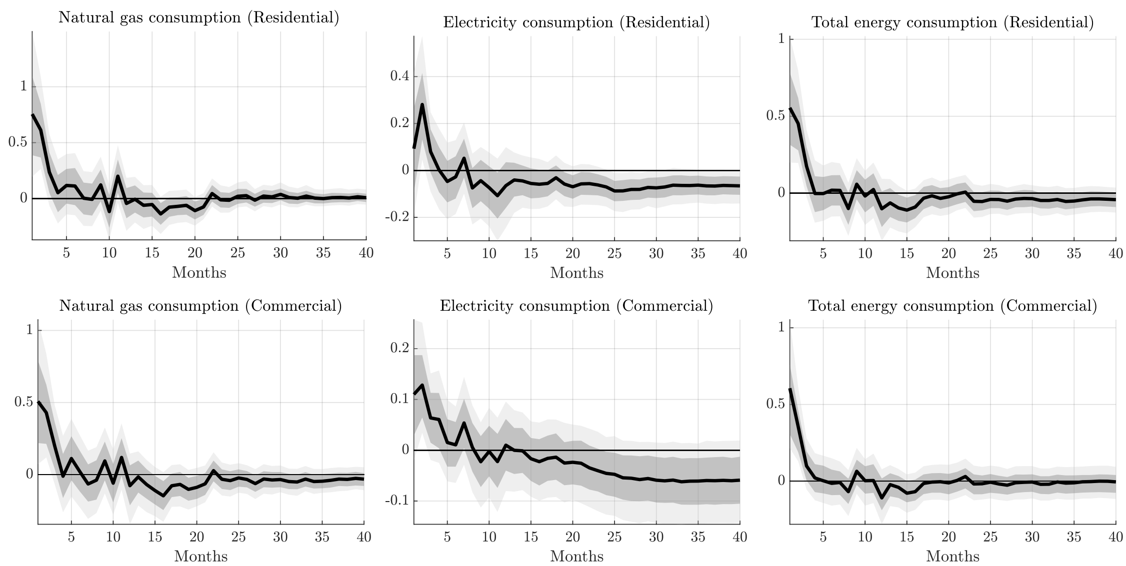

Figure 8: Impulse responses to a monetary policy tightening: Residential and commercial energy

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. These IRFs are computed by appending the given sectoral variables to the baseline VAR from Figure 2. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

What drives the increased energy demand in the residential and commercial sectors following a monetary contraction? When examining the household side, the literature on monetary policy transmission has primarily focused on households' financial positions and how these shape the transmission of monetary policy (Kaplan et al., 2018; Debortoli and Galí, 2024). However, some strands of literature have explored how business cycles affect household energy demand. For instance, Cicala (2023) documents an increase in residential electricity consumption in the U.S. during the COVID-19 pandemic, linked to the rise in remote work. Similarly, during an economic downturn, households may substitute activities typically performed outside the home for more home-based activities due to falling incomes. Additionally, rising unemployment or reduced working hours following a contractionary shock might leave people at home for longer periods during the day, thereby increasing energy consumption in residential buildings. This is consistent with the typical business cycle dynamic in which employment and leisure move in opposite directions.

In the commercial sector, while commonly associated with retail and wholesale activity, the largest share of energy consumption comes from warehouses and storage buildings, both in terms of quantity and total square footage (**?**). These buildings are primarily used to store goods, manufactured products, raw materials, and personal belongings (e.g., self-storage). Following an economic downturn, as sales decline, inventories are likely to increase, driving up energy demand in these facilities as storage and stockpiling grow.

To empirically analyze the validity of these intuitive mechanisms underlying the increase in energy demand from the residential and commercial sectors following a monetary contraction, Figure **??** presents the impulse responses of certain activity metric for the residential and commercial sector. Following a surprise monetary tightening, unemployment rises with a lag and hours worked fall unequivocally, both in the short and the medium run. This response supports the hypothesis of substitution between in-home and out-of home activities, under which energy demand in the residential sector would increase following an economic downturn, pushing electricity and natural gas demand. The same is evidenced in the commercial sector, as a measure of inventories over sales increases in the short run, supporting the hypothesis of an increase in energy demand from warehouses and storage buildings following the monetary contraction.

4.3 Electric power sector [Incomplete]

The electric power sector is defined by the EIA as an energy-consuming sector consisting of electricity-only and combined-heat-and-power (CHP) plants, whose primary business is to sell electricity or electricity and heat to the public. These plants are classified under Code 22 in the North American Industry Classification System (NAICS). In 2022, this sector accounted for 31 percent of U.S. carbon emissions from energy consumption (Figure 1) and nearly 35 percent of U.S. energy consumption (Figure 4).

The energy profile for U.S. electricity generation has shifted dramatically over time, particularly in recent years. Natural gas and renewable energy sources have gained an increasing share of electricity generation, while coal-fired generation has steadily declined. In 1990, coal-fired power plants accounted for approximately 52 percent of total electricity generation, but by the end of 2023, coal's contribution had dropped to about 16 percent. In contrast, the share of natural gas-fired electricity generation more than tripled, rising from 12 percent in 1990 to 43 percent in 2023 (U.S. Energy Information Administration, 2024a). This growth has been primarily driven by technological advances in horizontal drilling and multistage hydraulic fracturing (fracking), which have unlocked vast natural gas deposits in shale formations, significantly boosting production and reducing market prices (Holladay and LaRiviere, 2017; Knittel et al., 2019; Acemoglu et al., 2023). Figure 9 illustrates the evolution of primary energy sources used by the electric power sector over time.

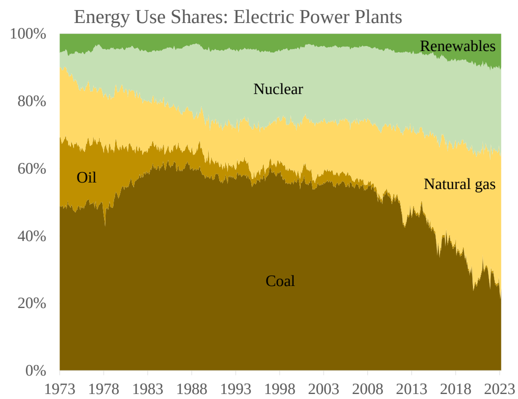

Figure 9: Energy consumption by source and year: Electric power sector

To understand the dynamics of emissions from the electric power sector, it is crucial to understand how the sector operates. The U.S. electric power grid is a complex network of generators, transformers, transmission lines, and distribution systems that spans the entirety of the lower 48 states, with connections to Canada and Mexico. This system ensures that electrical energy is reliably available for residential, commercial, and industrial use. The electric power industry has three major components: generation, transmission, and distribution. *Generation* refers to the actual production of electrical energy at power stations, *transmission* involves transporting electricity over long distances at high voltages, and *distribution* describes the circulation of electricity to customers on local networks at usable voltages. As electricity cannot be stored in significant quantities, the grid faces the constant challenge of instantaneously balancing generation with load. To ensure a steady supply of electricity to consumers, operators of the electric power grid call on power plants to produce and supply the right amount of electricity to the grid at every moment, thereby balancing electricity demand and supply (United States Environmental Protection Agency, 2024). Figure 10 provides a simplified representation of this system.

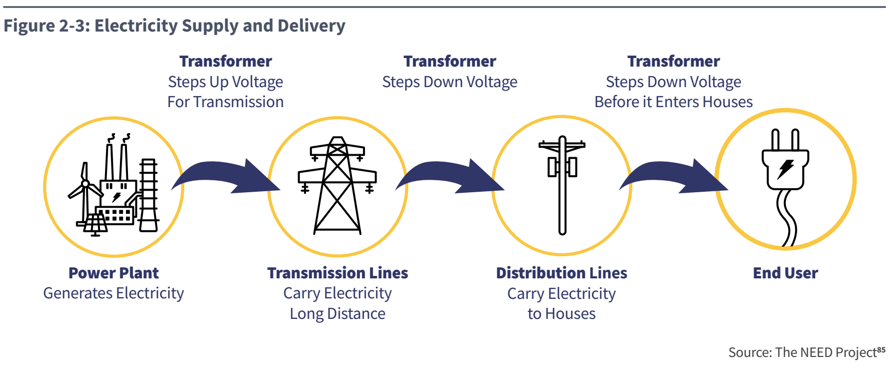

Figure 10: The electric power grid

Carbon emissions from the sector are mainly produced during electricity generation when fossil fuels are burned and vary by energy source, as well as by the type and efficiency of electric power plants. The amount of CO2 produced per kWh during any period will vary according to the sources of electricity supplied to the grid during that time. Therefore, electricity-related carbon emissions and emission factors will fluctuate hourly, daily, monthly, and annually (U.S. Energy Information Administration, 2024c). To understand the behavior of emissions in this sector following a surprise monetary contraction, as reported in the bottom middle panel of Figure 3, it is essential to consider the response of sectoral activity and the consumption of key energy sources to the shock.

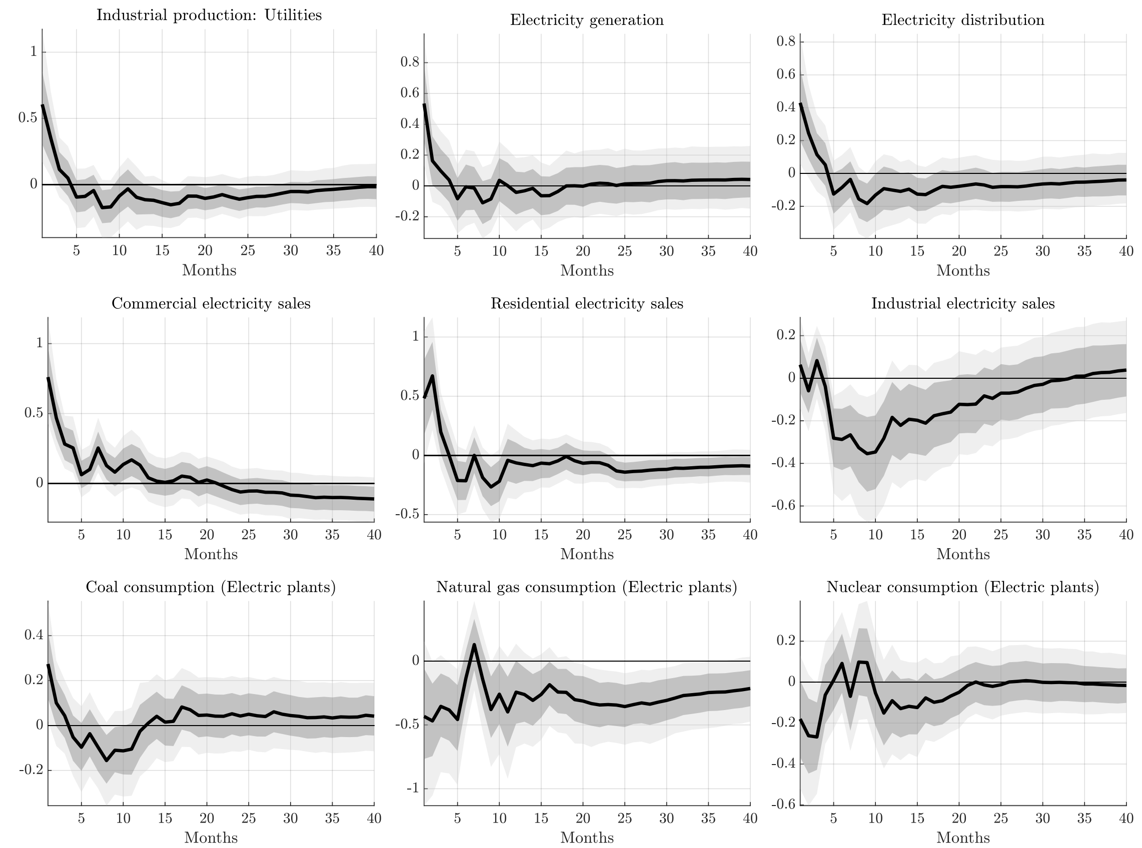

Figure 11: Impulse responses to a monetary policy tightening:: Electricity generation and sales

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. These IRFs are computed by appending the given sectoral variables to the baseline VAR from Figure 2. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

Figure 11 presents the impulse responses of several variables related to sectoral activity and energy consumption in response to the identified monetary policy shock. Specifically, I estimate the responses of the utilities subcomponent of industrial production (NAICS 2211,2), the series associated with electric power generation (NAICS 22111) and electric power transmission, control, and distribution (NAICS 22112), as well as the series for commercial and other electricity sales, industrial electricity sales, and residential electricity sales (NAICS 22112pt.). I also estimate the responses for natural gas, coal, and nuclear energy consumption in the sector, which in 2022 represented close to 90 percent of the sector's energy needs.

Following a surprise monetary tightening, activity in the sector *expands*, as captured by the increases in the indices of industrial production associated with the sector. Sales of electricity to the commercial and residential sectors also rise following the surprise monetary tightening, by around 0.8 and 0.5 percent, respectively, consistent with the increased activity and electricity demand in these sectors, as discussed in the previous section. On the other hand, industrial electricity sales decline by about 0.4 percent and respond with a lag to the shock, reinforcing the findings related to real economic activity and the response of industrial sector emissions.

Finally, regarding energy sources, interestingly, the increased economic activity in the sector is not supported by a uniform rise in demand for different energy sources, as was the case for other sectors. While coal consumption in the sector increases by about 0.3 percent, the consumption of natural gas and nuclear energy declines by approximately 0.5 and 0.2 percent, respectively. This suggests some substitution between energy sources within the sector in response to monetary contraction, which may have additional implications for emissions. Hence, the rising emissions from the electric power sector, shown in Figure 2, appear to be driven not only by increased sectoral activity in electricity supply for the commercial and residential sectors, but also by a short-term shift towards more polluting energy sources.

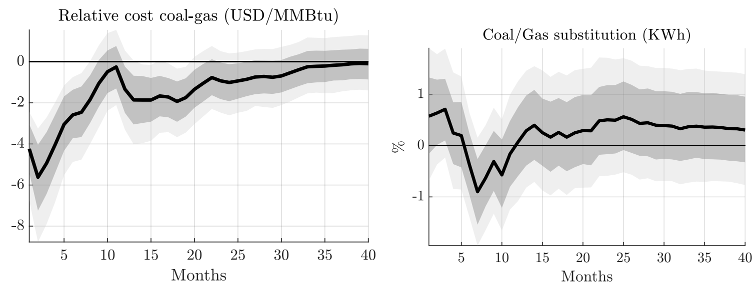

Figure 12: Impulse responses to a monetary policy tightening: Electricity generation and input relative costs

Notes: Impulse responses to a monetary policy shock, normalized to increase the one-year govt. bond yield by 25 basis points on impact. These IRFs are computed by appending the given sectoral variables to the baseline VAR from Figure 2. The solid line is the point estimate and the dark and light shaded areas are 68 and 90 percent confidence bands, respectively.

To explore the implications of this additional potential channel in greater detail, I estimate the response of the average input costs faced by electric power plants following a monetary policy shock. Figure 12 presents these results. In response to a monetary tightening, the cost of coal falls significantly by approximately 4 percent on impact relative to the cost of natural gas, decreases by an additional 1 percent in the first quarter after the shock, and then slowly recovers over the following years. This sharp decline in relative coal prices drives the sector toward more polluting energy sources, as coal-fired electricity generation increases by about 0.7 percent relative to natural gas-fired generation, remaining persistently higher in the long run, despite a notable but short-lived change in trajectory around a year after the shock.

These findings are consistent with those of Miranda-Pinto et al. (2023), who, using U.S. data from 1990M2 to 2019M5 and employing a local projections approach, find that a large fraction of commodity prices decline after a U.S. monetary tightening. In particular, more storable and industrial commodities show the strongest responses. Specifically, they report that coal (API2 and API4) exhibits the largest negative responses to a 10-basis-point monetary contraction, with peak declines of approximately -6.5 and -4.5 percent, respectively, after just 24 days. Conversely, their baseline results indicate no response from benchmark U.S. natural gas prices (Henry Hub) to monetary policy shocks, although they note that for the period 2016-2019, Henry Hub prices were among the most responsive commodities to monetary policy changes.

Furthermore, these results can be understood within the context of the dynamic and immediate nature of the electric power sector's operations. As mentioned earlier, grid operators dispatch power plants based on the least costly generation available to meet demand. According to Federal Energy Regulatory Commission (2023), this process typically begins with day-ahead market unit commitments, followed by real-time updates as needed. Dispatch decisions are driven by the cost of generation from available resources, with the lowest-cost resources being dispatched first and higher-cost resources dispatched last. For any given level of demand, the lowest marginal cost generators are dispatched until the market clears, and the wholesale price of electricity is set by the marginal cost of the last generator needed to meet demand (Fell and Kaffine, 2018). Crucially, fuel prices play a major role in determining the overall marginal cost of different generators. Given this structure, the observed decline in coal prices relative to natural gas in response to monetary policy shocks makes coal power plants more competitive in the short run, leading to an increase in coal-fired electricity generation and, consequently, higher emissions.

5 Model [Incomplete]

To study the role of redistributing carbon revenues more formally, I build a climate-economy model. The aim is to obtain a framework that can account for the empirical findings and can be used as a laboratory for policy experimentsThis section presents a standard New Keynesian framework extended with an energy block and climate change externalities

5.1 Households

The economy is assumed to be inhabited by a large number of identical households. The representative household seeks to maximize the objective function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma} - 1}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right) \tag{6}$$

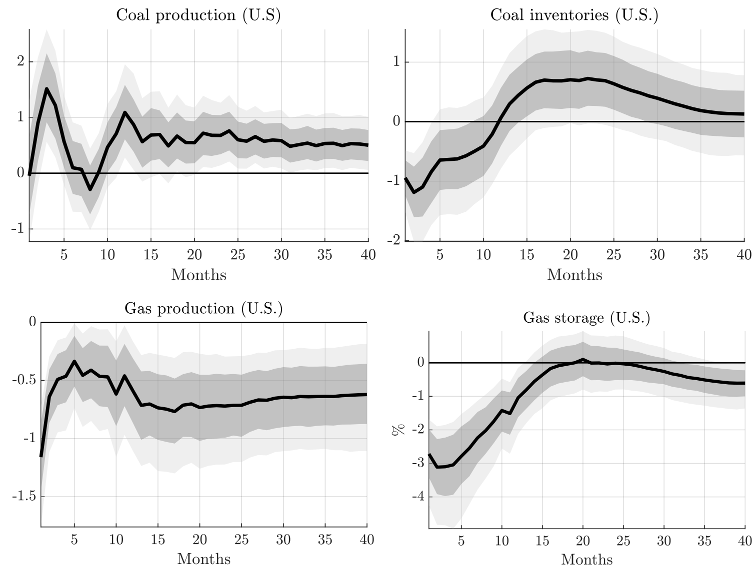

Figure 13: Impulse responses to a monetary policy tightening: Production and inventories of coal and natural gas

where C_t is the quantity consumed of the single good available in the economy, N_t denotes hours of work or employment, $\beta \in (0, 1)$ is the discount factor, σ is the inverse of the intertemporal elasticity of substitution, and φ represents the inverse of the Frisch elasticity of labor supply. $\mathbb{E}_t\{\cdot\}$ is the expectational operator, conditional on information at time t.

Maximization of (6) is subject to a sequence of flow budget constraints given by:

$$P_t C_t + P_t^E E_t^H + Q_t B_t = B_{t-1} + W_t N_t + D_t \tag{7}$$

for $t = 0, 1, 2, \ldots$, where P_t is the price of the consumption good, W_t denotes the nominal wage per hour, D_t represents dividends from ownership of intermediate goods-producing firms, and B_t denotes the quantity of one-period nominal riskless bonds purchased in period t. Each bond pays one unit of money at maturity, and its price is Q_t. As a departure from the standard model, households allocate their income not only between consumption and savings but also towards electricity usage, which directly influences their utility from leisure. P_t^E is the price of electricity and E_t^H is the demand for electricity from households.

Each household has a fixed amount of time available, which can be allocated between labor (N_t) and leisure (L_t). The time constraint for the household is then: $1 = N_t + L_t$. Importantly, in this framework, electricity consumption is assumed to be a *complementary* good to leisure: more leisure time *increases* the household's demand for electricity (e.g., for entertainment, heating/cooling, cooking, etc.):

$$E_t^H = \Xi(1 - N_t) \tag{8}$$

where Ξ is a parameter that indicates how strongly electricity consumption depends on leisure time. Based on this framework, the optimality conditions of the intertemporal problem of the household are standard and can be expressed as:

$$\frac{W_t}{P_t} = N_t^{\varphi} C_t^{\sigma} \tag{9}$$

$$1 = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{I_t}{\Pi_{t+1}} \right] \tag{10}$$

with $I_t = Q_t^{-1}$ the gross-yield on the one period bond and $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ the gross inflation rate in period $t+1$.

5.2 Final-good firm

The representative and perfectly competitive final-good firm uses the following CES aggregator to produce the final good, Y_t:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} \, di \right)^{\frac{\epsilon}{\epsilon-1}} \tag{11}$$

where $Y_t(i)$ is an intermediate input produced by intermediate-goods firm i, whose price is $P_t(i)$, and $\epsilon > 1$ is the constant elasticity of substitution across intermediate goods. The final-good firm chooses $Y_t(i)$ and Y_t in order to maximize profits, taking $P_t(i)$ and P_t as given. The solution to this problem yields the final-good firm's demand schedule for the intermediate good i:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} Y_t \tag{12}$$

where

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} \, di \right)^{\frac{1}{1-\epsilon}} \tag{13}$$

is an aggregate price index.

5.3 Intermediate-goods firms

There is a a continuum of monopolistic firms indexed by $i \in [0,1]$. Each firm produces a differentiated good, but they all use an identical technology, represented by the production function:

$$Y_t(i) = A_t \left(E_t^Y(i) \right)^{\alpha} \left(N_t^Y(i) \right)^{1-\alpha} \tag{14}$$

where $N_t^Y(i)$ is the firm's labor demand, $E_t^Y(i)$ is its electricity consumption, and A_t represents the level of technology (TFP), assumed to be common to all firms and to evolve exogenously over time according to the process.

$$\log(A_t) = \rho_a \log(A_{t-1}) + \nu_t^a \tag{15}$$

Parameter	Description	Value	Notes
σ	Invese intertemporal elasticity of substitution	1	Galí (2015)
φ	Inverse Frisch elasticity of labor supply	5	Galí (2015)
β	Discount factor	0.99	Galí (2015)
Ξ	Intensity of household electricity consumption	1	For now
α	Electricity share in production	0.04	Golosov et al. (2014)
ϵ	Elasticity of substitution btw diff. goods	9	Galí (2015)
θ	Calvo parameter	0.75	Galí (2015)
δ	Elasticity of subst. btw brown-green	1	Ferarri and Nispi Landi (2020)
γ	Share of green energy in electricity production	0.59	EIA data
A^G	TFP in green energy sector	1	Olovsson and Vestin (2023)
A^B	TFP in brown energy sector	1	Olovsson and Vestin (2023)
$1-\eta$	Share of labor in green energy production	0.15	BEA and BLS data
$1-\zeta$	Share of labor in brown energy production	0.33	BEA and BLS data
ϕ^π	Monetary policy response to inflation	1.5	Galí (2015)
ϕ^y	Monetary policy response to output	0.125	Galí (2015)
ρ_a	Persistence technology shock	0.9	Galí (2015)
ρ_m	Persistence monetary policy shock	0.5	Galí (2015)

Table 1: Calibrated parameters

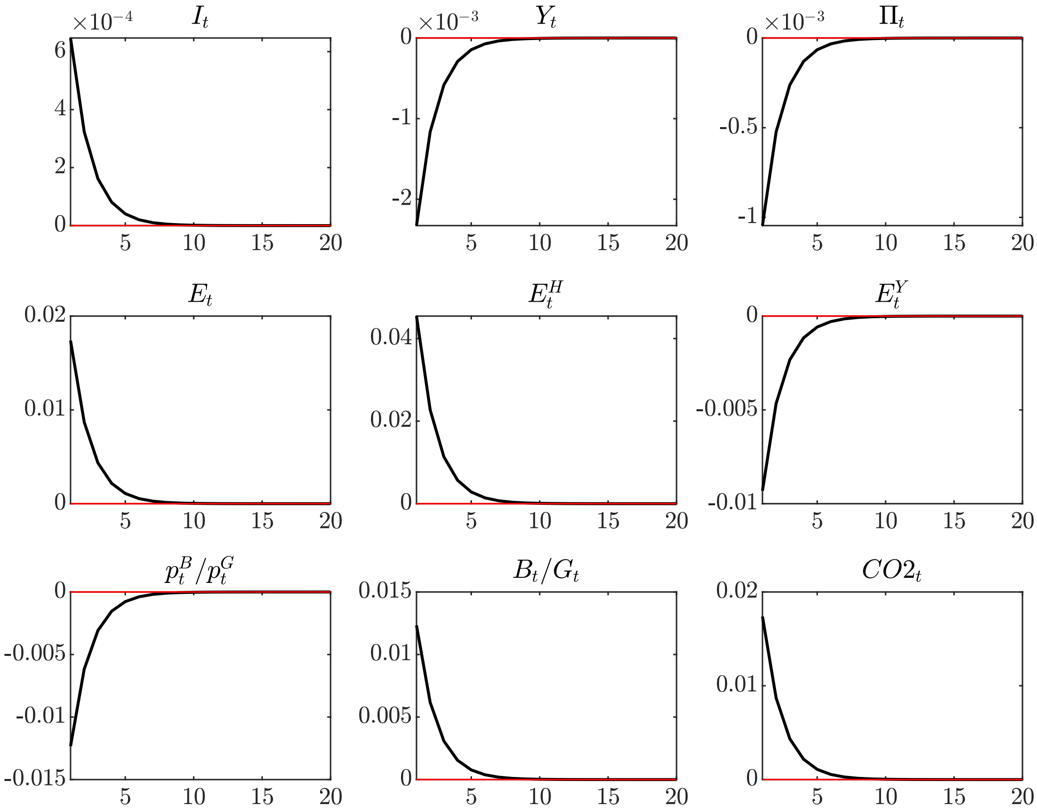

Figure 14: Dynamic responses to a monetary policy shock: Interest rate rule

6 Concluding Remarks

This paper offers new empirical evidence of a sizeable carbon emissions response to monetary policy. Using high-frequency identified monetary policy shocks from FOMC announcements, I show that a contractionary monetary policy shock generates quantitatively important increases in carbon emissions from total energy consumption, which are mainly driven by the responses of non-industrial sectors.

An important contribution of this analysis reveals that the Federal Reserve's conventional monetary policy has nuanced and, at times, unintended repercussions on carbon emissions and emission intensity within the economy. The unanticipated tightening of monetary policy, while initially associated with a rise in total emissions from energy consumption, exhibits a transitory effect lasting up to two quarters. This outcome can be attributed to the heterogeneous responses observed across different energy-consuming sectors.

Specifically, the industrial sector displays emissions patterns closely aligned with real output fluctuations, thereby highlighting the relevance of the *aggregate demand* channel in transmitting monetary policy effects. Moreover, the electric power sector experiences an increase in both energy consumption and activity following contractionary shocks, suggesting alternative channels of monetary policy transmission at play. Additionally, the residential, commercial, and electric power sectors demonstrate a noteworthy propensity for substitution across energy sources in response to relative price variations in energy commodities.

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Appendices

A Data

A.1 Data sources

In this Appendix, I provide details on the macroeconomic data used in the paper, including information on the data source and coverage.

B Sensitivity Analysis

B.1 Alternative instruments

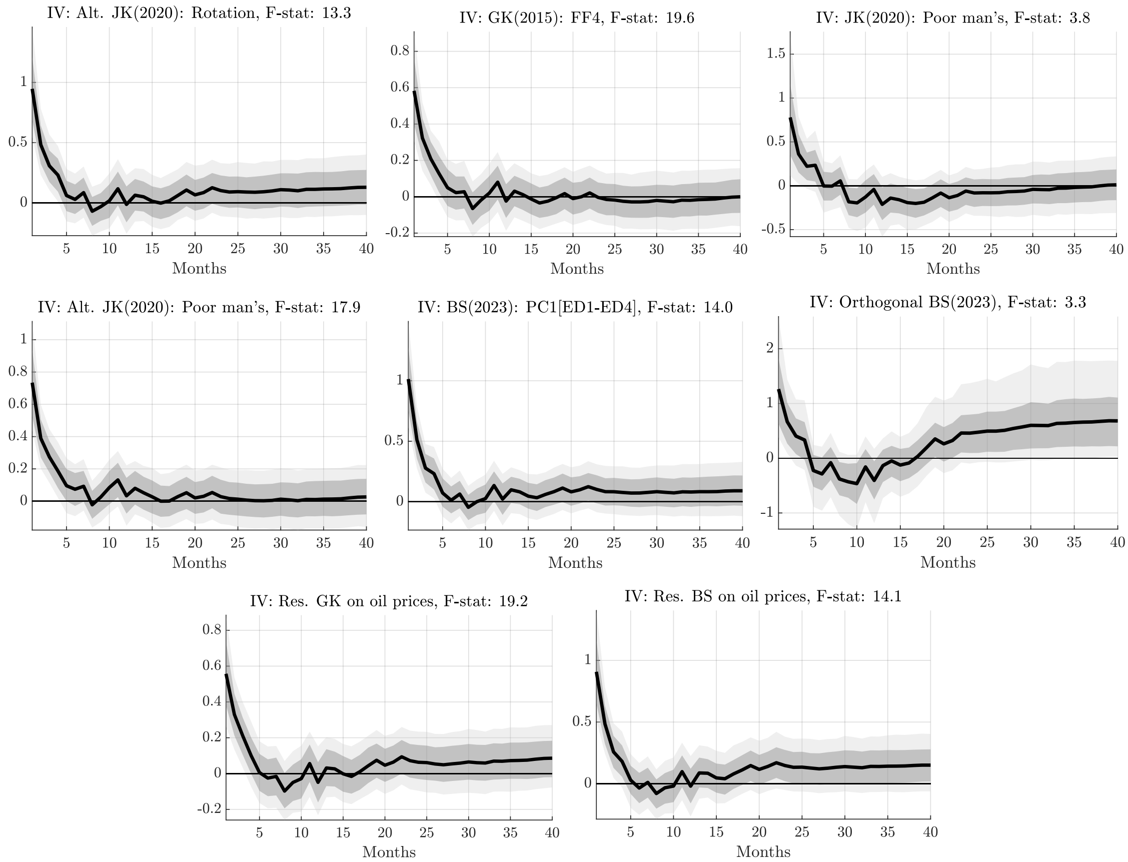

Figure 15: Response of total carbon emissions to a surprise monetary tightening: Alternative instruments

B.2 Alternative estimation techniques

A key advantage of the external instruments approach lies in its efficiency. However, this comes at the cost of assuming (partial) invertibility. If the invertibility assumption is not satisfied, the results may be biased

B.2.1 Internal instrument approach

Figure 16: Response of total carbon emissions to a surprise monetary tightening: Alternative instruments

B.3 Alternative data sources

B.4 Alternative data transformations

B.5 Alternative samples

C Model Derivations