Carbon Emissions and the Transmission of Monetary Policy*

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José Nicolás Rosas†
Universitat Pompeu Fabra

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Abstract

This paper studies the dynamic causal effects of monetary policy on carbon emissions in the U.S. Using high-frequency changes in interest rates around Federal Open Market Committee (FOMC) announcements (i.e. monetary policy surprises), I identify a structural monetary policy shock. 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 *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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†Contact: José Nicolás Rosas, Universitat Pompeu Fabra, C/ Ramon Trias Fargas, 25-27, 08005, Barcelona, Spain. Email: josenicolas.rosas@upf.edu. Web: `sites.google.com/view/jnrosasg`

1 Introduction

The increase in anthropogenic 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 isolates 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—by about one percent—on impact and return to pre-contraction levels only after approximately two quarters. 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 *substitution* and *commodity price* channels, play a more prominent role in non-industrial sectors. The *substitution* channel, particularly relevant to the residential and commercial sectors, emerges as both employment and leisure move in opposite directions over the typical business cycle, and at the onset of a downturn, involuntary stockpiling 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 1.75 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 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 the 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 (**?**). My results indicate that [details to be filled in].

The results from this exhaustive empirical analysis suggest that the observed changes in total carbon emissions from energy consumption following a monetary contraction are largely driven by the previously discussed *aggregate demand*, *substitution*, and *commodity price* channels. These mechanisms 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). In the model, the 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 on 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).

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.

Related literature — 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 CO_2 emissions variation per unit of GDP over a 20-year horizon in a Bayesian VAR. Although their shock leads to a permanent 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

[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).

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 emis-

[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.

sions (U.S. Energy Information Administration, 2024b)[5].

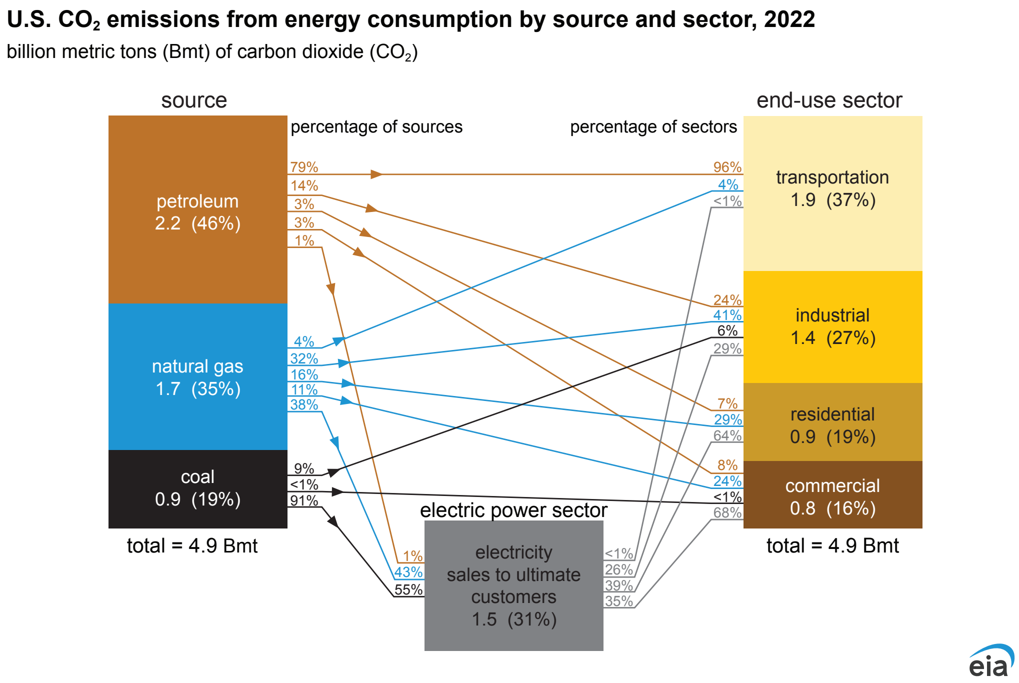

Figure 1: U.S. CO2 emissions from energy consumption by source and sector, 2022

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 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

[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.

[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.

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 the causal effect of policy, 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 total interest rate surprises by analyzing the high-frequency co-movement of interest rates 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, they 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 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 $\text{Var}(\mathbf{u}_t) = \Sigma$,

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

$\mathbf{B}_1, \ldots, \mathbf{B}_p$ 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 $\text{Var}(\boldsymbol{\varepsilon_t}) = \boldsymbol{\Omega}$, where $\boldsymbol{\Omega}$ 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 $\boldsymbol{\Sigma} = \mathbf{S}\boldsymbol{\Omega}\mathbf{S}'$. 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 $\mathbf{s}_1$, 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 $\mathbf{s}_1$, 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 $\mathbf{s}_1$ 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 XXX.

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.

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 converg-

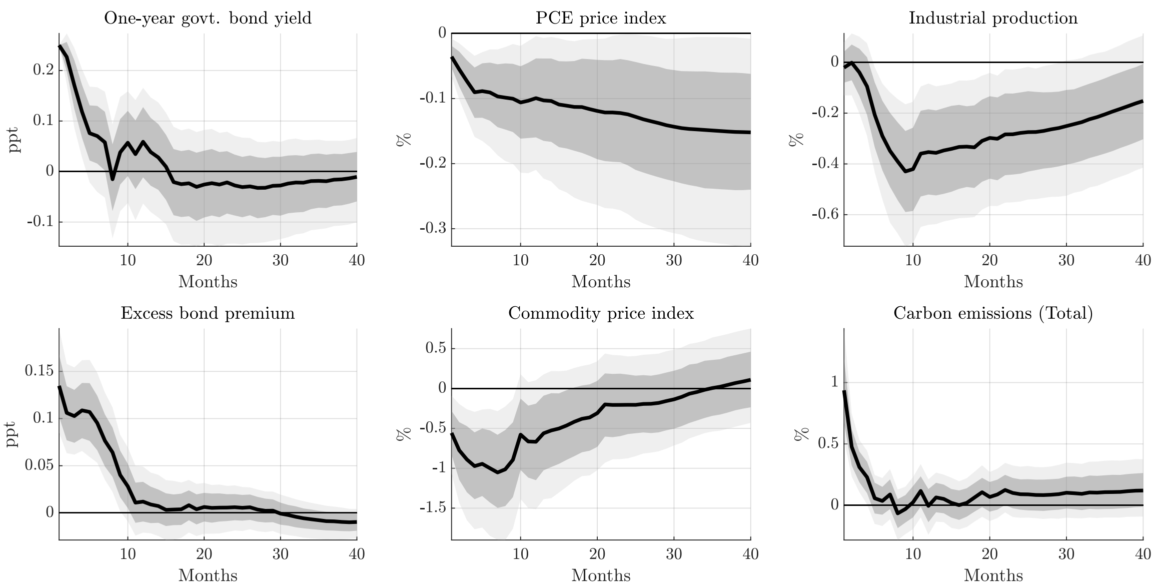

Figure 2: Impulse responses to a monetary policy tightening: Aggregate variables

ing 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 XXX, 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 above suggest that, despite the unconditional procycality of emissions, conditional on a monetary policy shock they exhibit countercyclical dynamics in response to a monetary tightening. To make reasonable estimates of potential future prices, supply, and energy demand, the Energy Information Administration (EIA) divides energy use into five economic sectors: residential, commercial, transportation, industrial, and the electric power sector. I extend my baseline six-variable monetary VAR to examine how emissions in each of these sectors respond to a monetary policy shock. Extending the VAR to include all five sectors at once would introduce too many parameters into the VAR, resulting in imprecise estimates and overfitting. Therefore, I follow the approach used by Gertler and Karadi (2015) and extend 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, consisting of the six original variables from the baseline VAR, along with the sectoral emissions variable listed at the top of each panel[8].

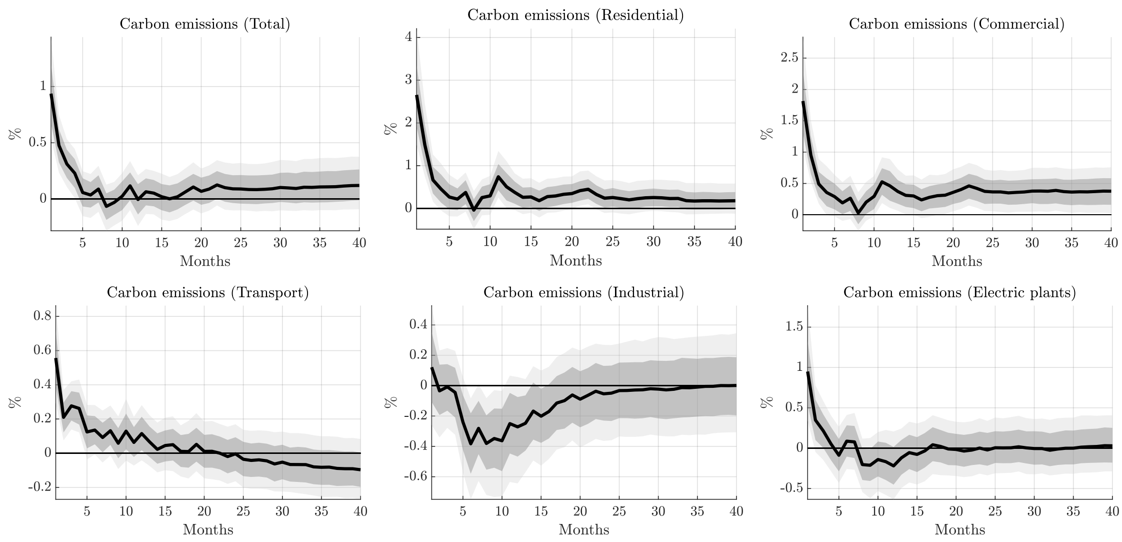

Figure 3: Impulse responses to a monetary policy tightening: Sectoral emissions

Regarding the interpretation of the results in Figure 3, in response to a 25bps monetary policy tightening, emissions from the residential, commercial, transportation, and electric power sectors (which I will jointly label the *non-industrial* sectors given the similar dynamics) *increase* on impact and gradually return to steady state, being the residential and commercial sectors the ones that experience the most persistent responses. Furthermore, the responses of these sectors are also the largest in terms of economic magnitude: following a surprise monetary tightening, carbon emissions from energy consumption in the residential sector increase by 3.3pp while the emissions from the commercial sector increase by 2.4pp. These four *non-industrial* sectors seem to be the ones jointly driving and dominating

[8]In the interest of space, the IRFs for the five baseline macroeconomic variables are not reported in Figure 3, as they closely resemble those from the baseline VAR in Figure 2.

the aggregate response of carbon emissions to a monetary contraction, as the response of the industrial sector exhibits the expected behavior: after a contraction in industrial output, as proxied by industrial production, emissions from this sector's energy consumption decrease in a similar fashion and timing. In fact, following a shock, the industrial sector emissions respond sluggishly with a trough response of about 0.4% after about one year.

4 The Heterogeneous Transmission Channels of Monetary Policy

The results in the previous section suggest that monetary policy plays a relevant role in the determination of the dynamics of carbon emissions, both at the aggregate and sectoral level, at business cycle frequencies. However, with the exception of the industrial sector, the response of emissions to a surprise monetary tightening appear to be puzzling and goes in the opposite direction of what the consensus view has agreed upon. To further uncover the drivers of this increase in emissions in response to a monetary contraction and get a better understanding of how monetary policy shocks transmit to the different sectors of the economy, I analyze the response of key variables for each of the sectors, namely metrics of energy consumption, energy prices and emission intensity, following a monetary policy shock. These five energy use sectors vary substantially in their principal usage and primary sources of energy, as summarized in Figure 4. For example, homes and commercial buildings use energy for heating, cooling, lighting, and operating appliances and electronic devices. On the other hand, industrial needs vary from employing energy products as direct production inputs (feedstock) to utilizing electricity to run machinery and equipment. Regarding energy sources, the residential and commercial sectors mainly rely on electricity and natural gas, while the transportation sector is a heavy user of motor gasoline. This marked heterogeneity regarding sources and uses could shed some light on the drivers behind the wide range of responses reported in Figure 3.

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) activities. In 2022, this sector accounted for almost 35% of total U.S. end-use energy consumption and 27% of total U.S. carbon dioxide emissions (Figure 1).

Regarding energy consumption, industrial needs vary from employing energy products as direct production inputs to make products such as plastics and chemicals, to utilizing electricity for operating industrial motors and machinery, lights, computers and office equipment, and equipment for facility heating, cooling, and ventilation. Figure 5 presents the relative importance and evolution of energy sources consumed in the industrial sector across time, including both primary energy sources (gas, oil, coal, renewables) and elec-

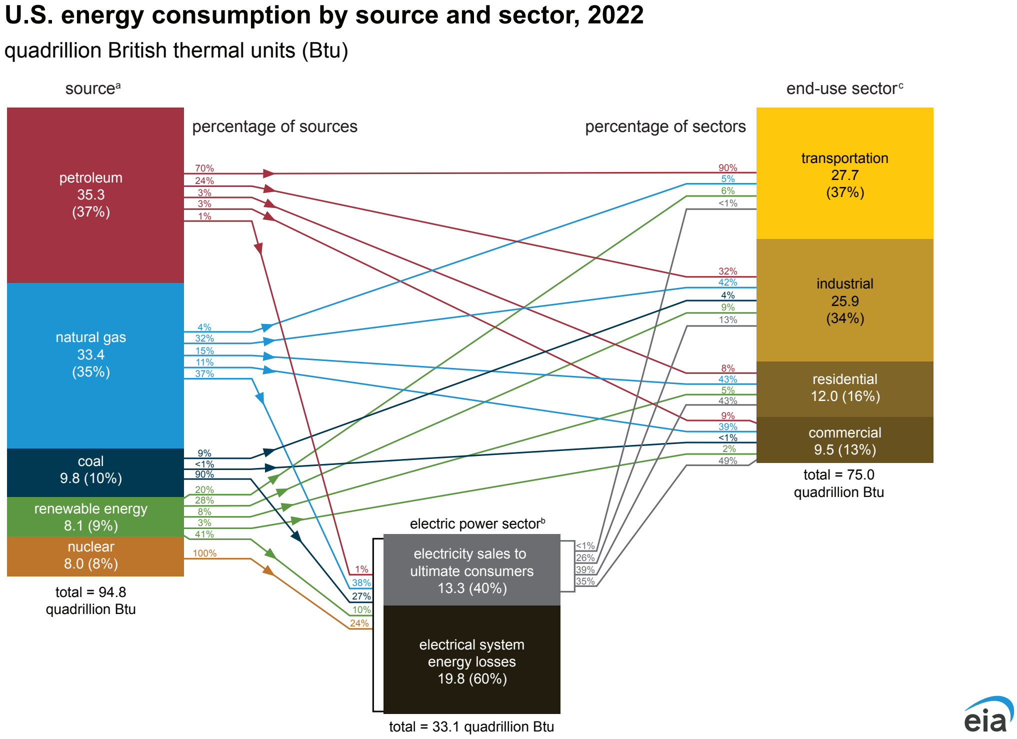

Figure 4: U.S. energy consumption by source and sector, 2022

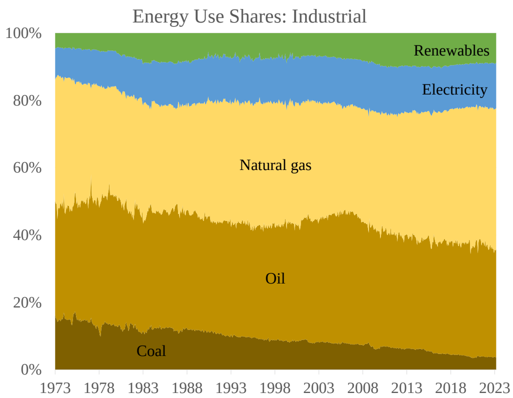

Figure 5: Energy consumption by source and year: Industrial sector

tricity. Natural gas and petroleum products, such as distillate and residual fuel oils and hydrocarbon gas liquids (HGLs), represent the largest fraction of energy consumption in the sector, while electricity's percentage share of energy use has been fairly consistent at about 15% across the years. Hence, to understand the behavior of emissions for this sector following a surprise monetary contraction, reported in the bottom middle panel of Figure 3, the response of sectoral activity and the consumption of these energy sources is of vital importance.

Figure 6 presents the impulse responses to the monetary policy shocks of variables related

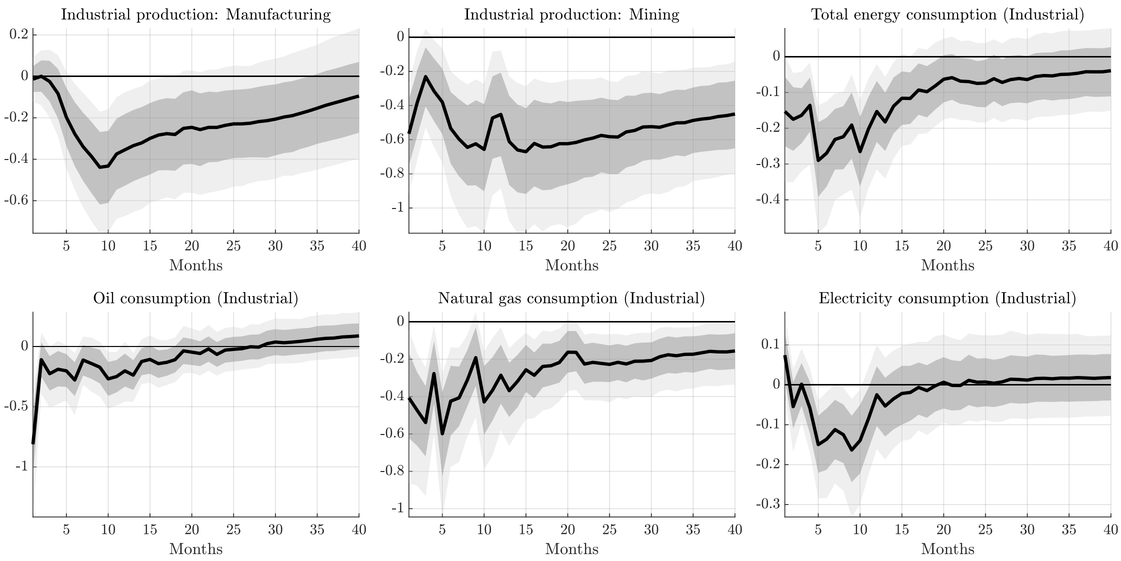

Figure 6: Impulse responses to a monetary policy tightening: Industrial energy and activity

to economic activity and energy consumption in the industrial sector. More precisely, I estimate the responses of the manufacturing and mining components of industrial production, and natural gas, oil, electricity and total energy consumption. As it was the case for the aggregate index of industrial production, both the manufacturing and mining components respond as expected: following a monetary contraction, economic activity moderately weakens and reacts with a small lag. Importantly, the response of the mining activity shows a high level of persistence, remaining below the steady state level even at the three year horizon. On the other hand, the response of the manufacturing activity closely resembles the behavior of the total index, plotted in the top right panel in Figure 2, returning to steady state roughly a year after the shock. This decline in activity in the sector entails a fall in total energy consumption, as corroborated in the top right panel, as lower production mechanically implies a decline in the demand for inputs, with energy entering into the production function as an additional component. Finally, in terms of specific energy sources, the three bottom panels in Figure 6 corroborate the behavior of aggregate energy consumption in the sector: oil, natural gas and electricity consumption fall in a similar fashion following the contractionary policy surprise, consistent with lower production in the sector and hence less demand for inputs. This responses are consistent with the behavior of carbon emissions from the industrial sector from Figure 3 and imply a close and positive relationhip between economic activity, energy demand and emissions for this 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's emissions through the real activity channel and provide empirical support to one of the main assumptions in the macro-environmental literature, namely that emissions are positively correlated and proportional to output (Heutel, 2012; Golosov et al., 2014, Annicchiarico and Di Dio, 2015; Nakov and Thomas, 2023). However, as previously noted, industrial emissions roughly represent about a third of U.S. CO2 emissions from energy consumption. Hence, to understand the dynamic response of overall emissions to the monetary policy shock, analyzing the responses of the remaining sectors is essential.

4.2 Residential and commercial sectors

According to the EIA, the residential sector is defined as the energy-consuming sector that consists of living quarters for private households[9]. On the other hand, the commercial sector consists of service-providing facilities and equipment of businesses; Federal, State, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. Both sectors, commonly labeled as the *buildings sector* given their similar common uses of energy, jointly represented 35% of carbon emissions from energy consumption in the U.S. (see Figure 1) and close to 30% of U.S. energy consumption (see Figure 4) in 2022.

Energy used in the residential and commercial sectors provides a wide range of services, including space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances. Figure 7 presents the evolution across time of the energy consumption profiles for these two sectors. This figure reveals another commonality between the two aforementioned sectors: their heavy reliance on electricity as major energy source, as sales from the electric power sector to the residential sector represented 43% of the latter's energy consumption needs, while the proportion for the commercial sector was 49% by 2022. This figure also shows that, if anything, the reliance on electricity by the two sectors has increased in recent years, displacing other fossil fuels like coal and oil. It follows that the energy mix of electricity generation ultimately matters for the indirect emissions of these two sectors, as almost half of their energy needs are covered by this source. On the other hand, natural gas also represents a substantial proportion in the energy profile of both sectors, accounting for 43% and 39% of U.S. residential and commercial sectors end-use energy consumption in that same year, respectively. In terms of its use, about 60% of U.S. homes use natural gas for space and water heating, cooking, and drying clothes, while consumers in the commercial sector also use natural gas as a fuel to generate electricity and in combined heat and power systems.

To understand the dynamics of emissions generating from these two sectors following a surprise monetary contraction and to identify the underlying drivers of the increases revealed in Figure 2, I study the response to the monetary policy shocks of different measures of energy demand in the residential and commercial 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, as jointly they represent close to 90% of both sectors end-use energy consumption. As it was the case in Figure 3, in response to a 25bp monetary policy tightening, total energy consumption from the residential and commercial

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

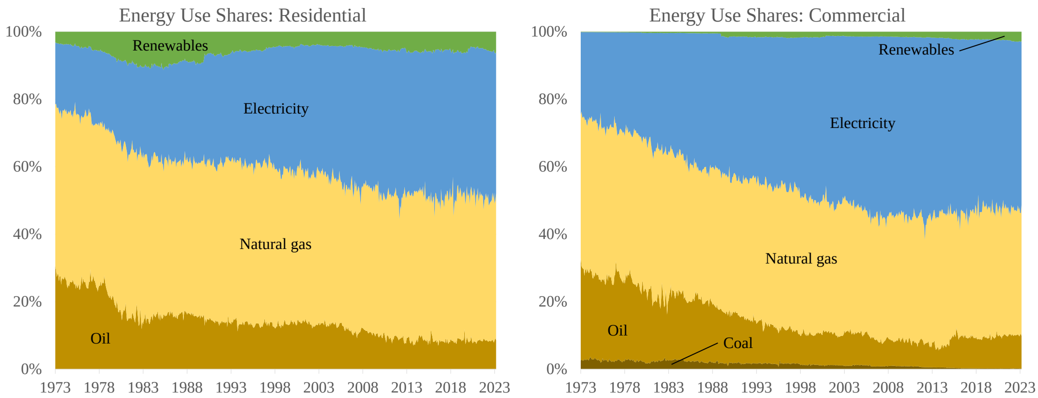

Figure 7: Energy consumption by source and year: Residential and commercial sectors

sectors *increases* on impact and gradually returns to steady state. Once again, the responses of these sectors are also large in terms of economic magnitude: following a surprise monetary tightening, total energy consumption in the residential sector increases by 2.8pp while total energy consumption in the commercial sector increases by 2.1pp. Regarding the individual energy surces, both consumption of natural gas and electricity increase folloiwng the monetary contraction, eplaining the overall increase in demand for energy across this two sectors. In all cases, the dynamics closely resemble those of sectoral emissions in Figure 3, increasing on impact and gradually returning to steady state in the following months.

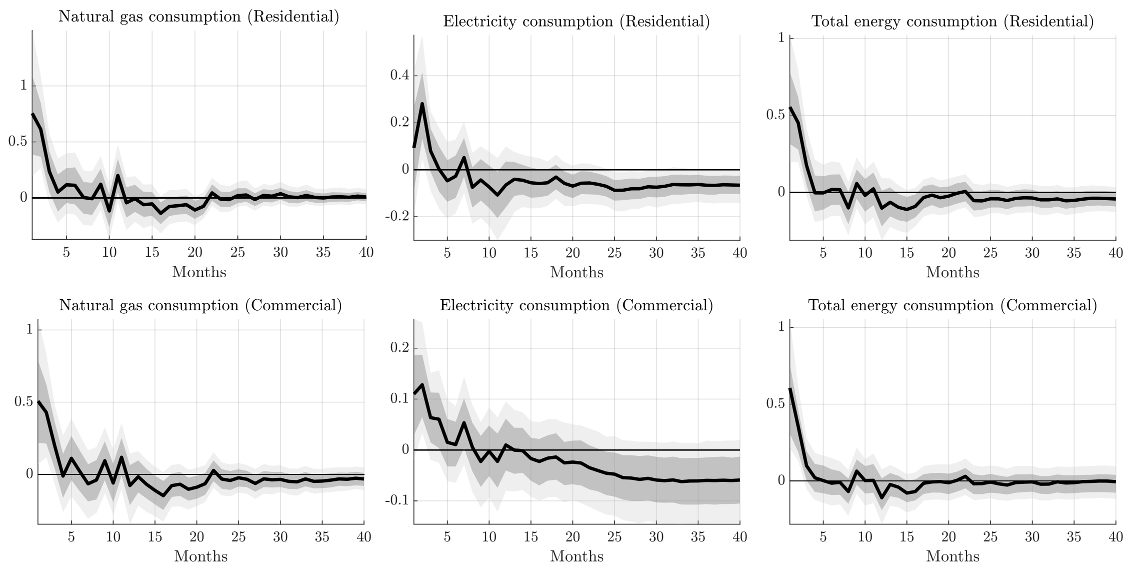

Figure 8: Impulse responses to a monetary policy tightening: Residential and commercial energy

What are the drivers for this increased demand for energy in these sectors, following a monetary contraction? The literature on monetary policy has generally focused on the effects of monetary policy on the productive sector of the economy, and, when analyzing the household side of the economy, have generally focused on the financial position of households and how it shapes the transmission of monetary policy. Nonetheless, some work in other strands of the literature has focused on the effect of business cycles on energy demand by households. For instance, Cicala (2015) documents an increase in residential electricity consumption during the COVID-19 pandemic in the United States, associated with the increase in the share of the labor force that may work from home. Intuitively, also during an economic downturn, agents may substitute some activities that they usually perform outside by more home-based activities, given a fall in their income. Furthermore, an increase in unemployment and a decrease in working hours given the contractionary shock might leave people at home for longer hours during the day, increasing the consumption of energy in these kinds of building, as over the typical business cycle, employment and leisure move in opposite directions. Regarding the commercial sector, although commonly associated by the name with activity in the retail and wholesale sector, were mostly warehouse and storage buildings, both in terms of quantity and floor-space square footage (EIA, 2021). The types of buildings are defined as those used to store goods, manufactured products, merchandise, raw materials, or personal belongings (such as public self-storage). Intuitively, following an economic downturn, inventories of merchandise would increase as sales fall, and the energy demand from these types of buildings would mechanically increase.

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 9 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

The electric power sector is characterized by the EIA as an energy-consuming sector that consists of Electricity-only and Combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public, as classified under Code 22 in the North American Industry Classification System (NAICS).

Emissions from electricity generation vary by type of energy source and by type and efficiency of electric power plants. The amount of CO2 produced per kWh during any period of time will vary according to the sources of electricity supplied to the electric power grid during that time. Therefore, electricity-related CO2 emissions and CO2 emission factors will vary hourly, daily, monthly, and annually U.S. Energy Information Administration (2024a).

Figure 10 also presents the relative weights and sources of primary energy used by the

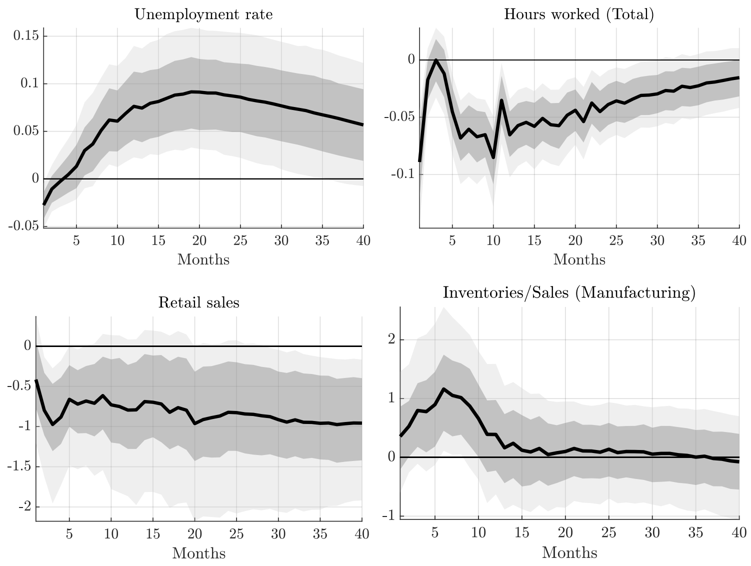

Figure 9: Impulse responses to a monetary policy tightening: Residential and commercial activity

electric power sector across time. The three major categories of energy for electricity generation are fossil fuels (coal, natural gas, and petroleum), nuclear energy, and renewable energy sources. In 2022, natural gas was the largest source (about 40%) of U.S. electricity generation, followed by coal (27%) and nuclear power (24%).

Further exploration of the responses of economic activity proxies for these sectors reveals that sectoral activity in the electric power sector *increases* after a monetary contraction, as captured by the response of net electricity generation and the Electric and Gas Utilities (NAICS = 2211,2) component of industrial production, as reported in Figure **??**.

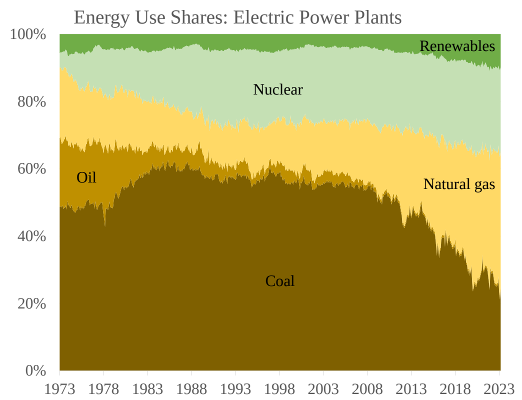

Figure 10: Energy consumption by source and year: Electric power sector

On the other hand, another potential explanation is related to substitution across energy sources: following a monetary contraction, it might be the case the electric power sector as a whole substitutes the inputs of production and leans towards more polluting sources. If the substitution were large enough, even paired with a decrease in energy consumption, carbon emissions could increase, explaining the results in Figure 3.

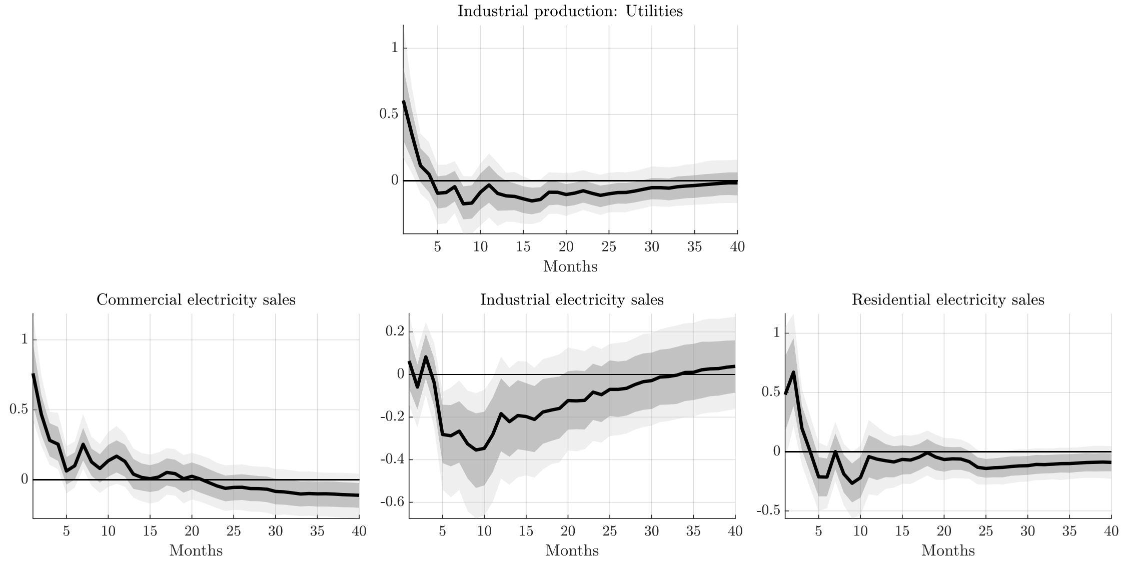

Figure 11: Impulse responses to a monetary policy tightening:: Electricity generation and sales

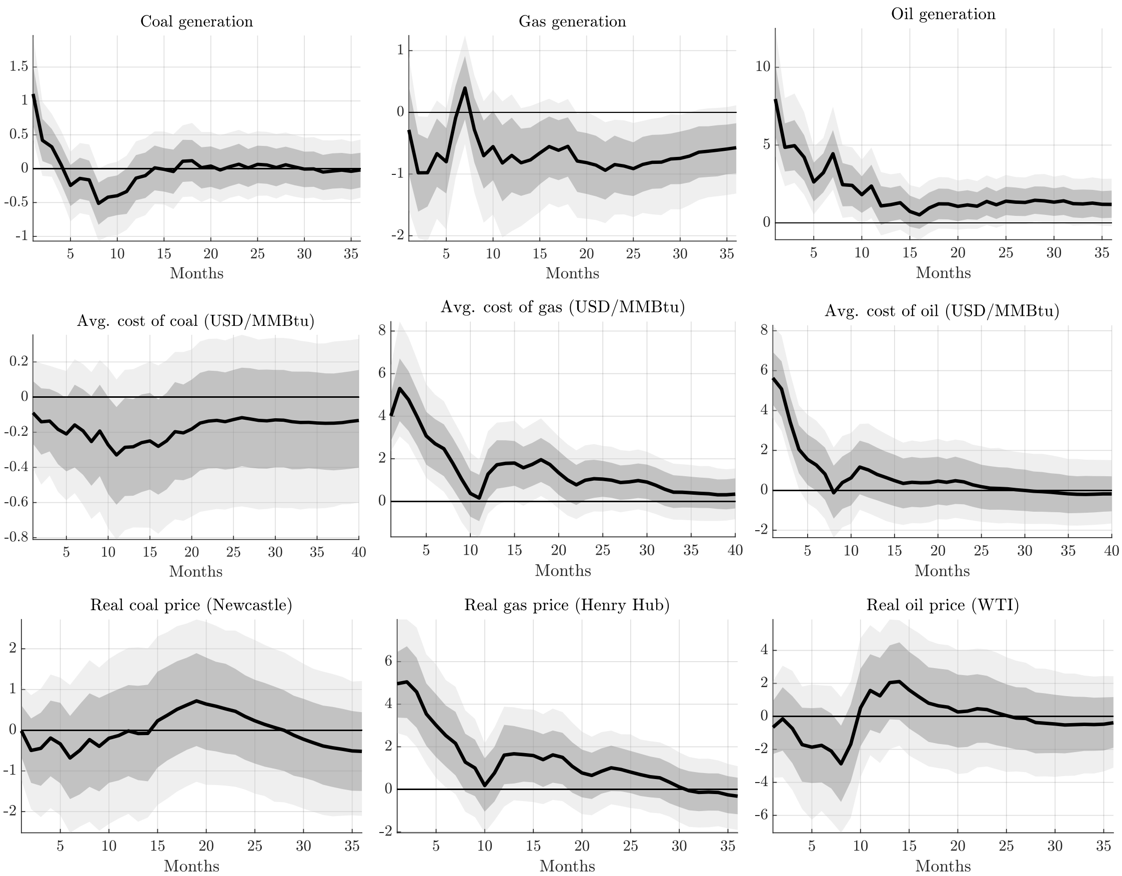

Figure 12: Impulse responses to a monetary policy tightening:: Electricity generation and input prices

5 Model

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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