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CO2 Emissions and Macroeconomy

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Abstract

This thesis examines the impact of oil supply news shocks on sectoral CO2 emissions in the U.S., building on the work of Känzig (2021). Using a surprise series, the baseline oil market VAR model is augmented with additional CO2 emission data. The findings confirm that oil supply news shocks lead to significant economic and environmental effects, particularly a substantial reduction in CO2 emissions across all sectors. The response patterns vary across sectors, with the transportation sector displaying the most immediate and pronounced reduction in emissions. Furthermore, the study highlights that emissions from natural gas and petroleum experience significant declines, while emissions from coal usage initially rise before eventually decreasing. These results suggest that sectoral dependencies on oil and the substitution effect play crucial roles in shaping the environmental impact of oil supply expectations.

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1 Introduction

Over the past decades, the global oil market has experienced transformative changes with profound implications for oil supply expectations and the environment. Geopolitical tensions, particularly in the Middle East and the Russia-Ukraine conflict, have disrupted supply chains and significantly affected market dynamics (Baumeister & Kilian, 2016). In response, strategic production cuts by OPEC+ have been implemented to stabilize prices amid fluctuating demand (International Energy Agency, 2024; OPEC, 2024). In addition, the rise of renewable energy technologies and electric vehicles has shifted traditional oil demand patterns, necessitating a reevaluation of CO2 emissions trajectories and the broader energy transition (Bauer et al., 2013; van der Ploeg & Rezai, 2020). Understanding how shocks to the oil market affect CO2 emissions is essential for developing strategies to mitigate climate change while maintaining economic resilience.

To disentangle supply-driven and demand-driven shocks, structural vector autoregression (SVAR) models are widely used in the literature, employing various identification mechanisms (Kilian & Murphy, 2012; Baumeister & Peersman, 2013; Baumeister & Hamilton, 2019). While previous studies have extensively examined the macroeconomic effects of oil supply shocks (Hamilton, 2003; Kilian, 2009), there is a growing need to explore their environmental implications. Känzig (2021) utilizes high-frequency identification of oil supply news shocks from OPEC announcements to isolate their effects on the macroeconomy, demonstrating significant impacts on various macroeconomic variables. He finds that, following a negative shock to oil supply expectations, industrial production declines, consumer prices rise significantly, and the U.S. economy experiences decreased activity, increased prices and inflation expectations, and dollar depreciation. However, the sector-specific consequences for CO2 emissions and environmental effects remain unexplored.

Building on Känzig (2021), this study, to the best of our knowledge, is the first to examine sectoral CO2 emissions in the U.S. in response to oil supply news shocks. Utilizing a VAR model with external instruments for identification, we isolate the exogenous variation in shocks to oil supply expectations and trace their impact across different sectors, including industrial, transportation, residential, commercial, and electric power. This approach captures the heterogeneity in sectoral responses, which is crucial for understanding the broader environmental impacts. Furthermore, we investigate sector-specific transmission mechanisms by analyzing the influence on different energy sources.

Our findings reveal significant variation in sectoral responses to oil supply news shocks. The transportation sector exhibits an immediate decline in emissions, reflecting a rapid adjustment to changes in oil supply expectations. In contrast, other sectors, including industrial, residential, and commercial, show delayed responses. The industrial sector, in particular, experiences the most pronounced long-term reduction in emissions, with significant declines occurring within the first two years and persisting over an extended period. Conversely, the electric power sector exhibits a shift towards increased coal usage, resulting in stabilized or even elevated emissions over time. For the residential and commercial sectors, the effects of oil supply news shocks are weak and statistically insignificant for the initial three years; however, these sectors ultimately show a reduction in CO2 emissions in the long run. These results highlight the importance of considering sectoral dynamics when assessing the environmental impact of oil supply news shocks.

Our analysis further indicates significant shifts in energy usage patterns following oil supply news shocks. Specifically, we observe a notable reduction in CO2 emissions from natural gas and petroleum, while emissions from coal usage show a marginal increase. The substitution between different energy sources varies considerably across sectors, suggesting the complex dynamics at play. This finding emphasizes the critical role of energy source substitution in accounting for the environmental impact of oil supply news shocks and contributes to a more nuanced understanding of how markets respond to changes in supply expectations, which can inform more sustainable energy policy decisions.

Literature Review:

The interaction between the environment and the macroeconomy has been a central theme in the literature, with a particular focus on the relationship between economic growth and environmental degradation. The Environmental Kuznets Curve (EKC) hypothesis posits that environmental degradation initially increases with economic growth but eventually decreases as economies mature and adopt cleaner technologies (Grossman & Krueger, 1995). Recent empirical evidence offers mixed support for the EKC hypothesis, with some studies confirming its validity while others highlight its limitations (Dinda, 2004; Stern, 2004; Destek & Sinha, 2020). Balsalobre-Lorente et al. (2018) emphasize the critical role of renewable energy and technological innovation in achieving sustainable development, suggesting that policy measures should focus on promoting these areas to mitigate environmental impacts.

In recent years, the intricate relationship between the oil market and greenhouse gas emissions, particularly the impact of oil prices on CO2 emissions, has garnered significant attention. Barrales-Ruiz and Neudörfer (2024) highlight that increases in oil prices do not uniformly lead to reductions in CO2 emissions. Specifically, reductions are observed when price increases are supply-driven, prompting a shift from fossil fuels to renewable energy sources. Conversely, CO2 emissions tend to rise when oil prices increase due to positive shocks in global economic activity. Omar and Klose (2022) emphasize the importance of this dynamic in the post-COVID-19 era and during geopolitical events such as the Russian invasion of Ukraine, which have heightened oil price volatility. Mahmood et al. (2022)

observe that rising oil prices have a positive impact on emissions in Oman, Qatar, and Saudi Arabia, but a negative impact in Kuwait and the UAE due to technique and composition effects.

Okwanya et al. (2023) employ a panel non-linear autoregressive distributed lag (NARDL) methodology to reveal an asymmetric relationship between oil prices and CO2 emissions in African countries. They find that positive oil price changes reduce CO2 emissions, while negative changes increase them, with these effects being more pronounced in oil-importing countries. Similar asymmetrical effects were observed in GCC countries by Mahmood et al. (2022), with urbanization and economic growth further complicating the dynamics. Aydın and Acar (2011), through dynamic CGE analysis, demonstrate that oil price shocks significantly impact macroeconomic indicators and carbon emissions in Turkey. Their simulations underline the varying effects of high, low, and reference oil price scenarios on the Turkish economy. Mujtaba and Jena (2021) and Nenavath Sreenu (2022) similarly highlight the significant impact of positive and negative oil price shocks on CO2 emissions, emphasizing the broader energy consumption patterns influenced by these price changes.

On the other hand, studies such as Ssali et al. (2019) and Malik et al. (2020) suggest that rising oil prices can positively influence the environment, particularly in net oil-importing economies where lower oil prices lead to higher energy consumption and increased emissions. Malik et al. (2020) further note that in Pakistan, rising oil prices initially increase emissions but reduce them in the long run. Nwani (2017) finds similar positive and statistically significant causal effects of crude oil prices on energy consumption and CO2 emissions in the Ecuadorean economy. Vielle and Viguier (2007) explain that high oil prices may not drastically impact greenhouse gas emissions due to fuel substitution effects, such as shifting from oil and gas to coal.

The literature on the impact of oil price shocks on sectoral responses provides a comprehensive understanding of how these shocks influence different industries and economic activities. Lee and Ni (2002) demonstrate that industries with a high oil cost share primarily experience supply reductions due to oil price shocks, whereas other industries, especially the automobile sector, face reduced demand. This suggests that oil price shocks extend their influence beyond direct input cost effects, potentially delaying purchases of durable goods. Jo et al. (2017) corroborate these findings, showing that in the U.S., most industries experience oil price shocks through demand reductions, with supply-driven reductions limited to a few high-oil-intensity sectors. Conversely, Taghizadeh Hesary et al. (2015) highlight varying sensitivities to oil price shocks across economic sectors, noting that while the residential sector remains relatively unaffected, the commercial, industrial, and transport sectors are highly sensitive to sharp oil price changes. The sectoral differentiation is further explored by Raifu and Oloyede (2020), who find that oil price shocks negatively impact Nigeria's agricultural sector in both the short and long run, but have positive effects on the industrial and services sectors. Interestingly, their nonlinear ARDL analysis reveals that negative oil price shocks benefit all sectors, whereas positive shocks are detrimental. Ibrahim (2018) adds to this discussion by indicating that while oil price fluctuations positively influence aggregate output, they negatively impact the agricultural, manufacturing, and service sectors, suggesting that such fluctuations introduce uncertainty and challenge effective fiscal management. This study also contributes to the literature by investigating the effects of oil supply news shocks—leading to changes in oil prices—on sectoral CO2 emissions responses in the U.S., providing new insights into the environmental impacts of such shocks.

This thesis is structured as follows: Section 2 provides a concise overview of the identification strategy used in Känzig (2021). Section 3 introduces the econometric framework employed in this study and outlines the specific model specifications. Section 4 presents the empirical results, beginning with an assessment of the instrument strength, followed by an analysis of the baseline model, sectoral CO2 emissions, and the contribution of industrial CO2 emissions to key historical events in the oil market. Additionally, this section explores the responses of various energy sources and renewable energy consumption to oil supply news shocks. The thesis concludes with final remarks.

2 Overview of the Identification

Our work adopts the identification strategy outlined in Känzig (2021). This strategy is based on several key observations. The oil market is heavily influenced by a major player, OPEC, which frequently announces its production plans. These announcements are closely monitored by market participants and often trigger substantial market reactions. This context supports the application of high-frequency identification techniques. Specifically, the approach involves creating a series of high-frequency surprises coinciding with OPEC announcements to identify a structural oil supply news shock. In this section, we provide a very concise overview of the identification strategy in Känzig (2021). For details on the construction of the surprise series and essential information on OPEC and global oil markets, please refer to the second section of his paper.

To isolate the effect of OPEC's decisions, Känzig (2021) measures price changes within a very narrow window around the OPEC announcements. It should be noted that the reverse causality from global economic conditions is unlikely since such conditions are already known and factored into market prices before the announcements and are unlikely to change within such a short window. To construct the benchmark surprise series, Känzig gathered OPEC press releases spanning from 1983 to 2017, which include 119 announcements. Using this information, he constructed a series of oil supply surprises as:

$$Surprise_{t,d}^{h} = F_{t,d}^{h} - F_{t,d-1}^{h} \tag{1}$$

Here, d represents the day of the announcement, t the month, and $F_{t,d}^{h}$ the (log) settlement price of the h-month ahead oil futures contract on day d of month t.

$$Surprise_{t,d}^{h} = (\mathbf{E}_{t,d}[P_{t+h}] - RP_{t,d}^{h}) - (\mathbf{E}_{t,d-1}[P_{t+h}] - RP_{t,d-1}^{h}) \tag{2}$$

Assuming the risk premium $RP_{t,d}^{h}$ does not vary within the narrow daily window around the announcement, that is $RP_{t,d}^{h} = RP_{t,d-1}^{h}$, the surprise can be seen as a change in oil price expectations triggered by the specific OPEC announcement.

In high-frequency identification, selecting the appropriate event window size is critical to balancing the capture of the announcement's response against minimizing background noise. While typical event windows range from 30 minutes to several days, Känzig employs a daily window. This choice is motivated by the slower market processing of OPEC announcements, the practical limitations posed by unavailable official announcement times, and the lack of intraday data for earlier periods. Regarding the maturity of the futures contract, a composite measure of oil supply surprises spanning the first year of the oil futures term structure is used. In addition, daily surprises are aggregated into a monthly series by summing daily surprises when multiple announcements occur within a month. Value 0 is assigned when there are no announcements for a given month.

To validate the series, several diagnostic checks are performed, including a narrative assessment, a placebo exercise to evaluate noise levels, and tests for autocorrelation, forecastability, and correlation with other shocks. These checks confirm that the surprise series possesses desirable properties. Detailed information on these diagnostics can be found in Appendix A.1 of his paper.

3 Methodology

3.1 Econometric Framework

As shown in Känzig (2021), the oil supply surprise series exhibits several favorable properties. However, it remains an imperfect measure of shocks since it does not encompass all relevant oil supply news and may include measurement errors. Thus, it is appropriate to consider these exogenous variables as external instruments, similar to microeconometric instrumental variables derived from quasi-experiments. Stock (2008) highlights this perspective and demonstrates how these external instruments can be utilized to identify structural shocks in structural VARs and determine their impulse response functions. Here, we utilize the oil supply series as an external instrument in an augmented oil market VAR model to identify a structural oil supply news shock, following the methodology established by Stock and Watson (2012) and Mertens and Ravn (2013).

Let us consider the standard stationary finite-order SVAR. Using the following notation:

$$x_t = l + \phi_1 x_{t-1} + \phi_2 x_{t-2} + ... + \phi_p x_{t-p} + u_t \tag{3}$$

where x_t is $n \times 1$ vector of endogenous variables, p is the lag order, u_t is a $n \times 1$ vector of reduced-form VAR innovations, l is a $n \times 1$ vector of constants, and $\phi_i, i = 1, 2, ..., p$ are $n \times n$ coefficient matrices.

In a structural vector autoregression (SVAR) model, the reduced form innovations (u_t) are related to the vector of structural shocks (ϵ_t) through the equation:

$$u_t = B\epsilon_t \tag{4}$$

where B is a non-singular $n \times n$ matrix. This implies that the structural model is invertible, meaning that the VAR forecast errors at time t are a non-singular transformation of the structural errors at time t. It is assumed that the structural shocks are serially uncorrelated and mutually orthogonal.

$$\mathbf{E}(\epsilon_t) = 0 \qquad \mathbf{E}(\epsilon_t \epsilon_t) = Var(\epsilon_t) = \Omega \tag{5}$$

such that Ω is diagonal.

The covariance matrix for the reduced form innovations is then:

$$\mathbf{E}(u_t u_t') = \Sigma = B\Omega B' \tag{6}$$

We aim to identify the impulse responses to a specific structural shock (e.g., an oil supply news shock). Without loss of generality, this shock is ordered first, so the shock of interest is $\epsilon_{1,t}$ The structural impulse response coefficient, which represents the response of $x_{i,t+k}$ to a one-unit change in $\epsilon_{1,t}$, oil supply news shock, is given by:

$$\partial x_{i,t+k} / \partial \epsilon_{1,t} = e_i' C_k(\phi) B_1 \tag{7}$$

where B_1 stands for the first column of B and $C_k(\phi)$ indicates the dependence of moving average coefficients as in $\phi = (\phi_1, \phi_2, ..., \phi_p)$.

Due to linear mapping $u_t = B\epsilon_t$, we can not identify $\epsilon_{1,t}$ and B_1 separately. We normalize the scale of the target shock $\epsilon_{1,t}$ to make it interpretable in terms of the observed data x_t. Following the convention in Känzig (2021), we normalize the target shock so that it oil supply news shock has a 10 percent contemporaneous effect on a pre-specified variable, which is the oil price. Thus, this implies $\partial x_{1,t+k}/\partial \epsilon_{1,t} = B_{1,1} = 10$.

External Instruments Identification:

Let z_t denote a scalar random variable serving as an instrument for the target shock. In our case, z_t represents the oil supply surprise series. It is assumed that the stochastic process for $\{\epsilon_t, z_t\}_{t=1}^{\infty}$ satisfies the following:

$$A.1 : \mathbf{E}[z_t \epsilon_{1,t}] = \alpha \neq 0$$
$$A.2 : \mathbf{E}[z_t \epsilon_{j,t}] = 0 \; for \; j \neq 1$$

This assumption reflects the definition of an instrumental variable: z_t is correlated with the target shock (relevance) and uncorrelated with other shocks (exogeneity).

Now, we can identify the impulse response coefficients of interest. Let $\mathbf{IR}_{k,i} = \partial x_{i,t+k}/\partial \epsilon_{1,t}$. Using the assumption A.1, B_1 is identified up to scale by the covariance between z_t and the reduced form innovations u_t.

$$\Theta = \mathbf{E}[z_t u_t] = \mathbf{E}[z_t B \epsilon_t] = \alpha B_1 \tag{8}$$

Scaling $B_{1,1} = 10$ implies $\Theta_{11} = \mathbf{E}[z_t u_{1,t}] = 10\alpha$. Then, $B_1 = \Theta/\Theta_{1,1} = \Theta/e_1'\Theta$. Hence, we obtain the impulse response coefficients of interests as:

$$\mathbf{IR}_{k,i} = e_i' C_k(\phi)\Theta/e_1'\Theta \tag{9}$$

After obtaining the impact vector and impulse response coefficients, calculating key outputs such as Forecast Error Variance Decompositions (FEVDs), the structural shock series, and historical decompositions becomes straightforward.

3.2 Data - Model Specification

The dataset, including the surprise series and baseline oil market variables, is taken from Känzig (2021). For our study, we utilize the extensive data provided by the U.S. Energy Information Administration (EIA). As the monthly EIA data is not deseasonalized, we apply a 12-month moving average to remove seasonal effects from all emissions and energy data. Figure 1 displays the CO2 emissions across sectors.

The baseline specification in Känzig (2021) includes six key variables. These are the real price of oil, world oil production, world oil inventories, world industrial production, U.S. industrial production and the U.S. consumer price index (CPI). We augment the baseline model with additional two variables: the U.S. one-year Treasury bill rate, and U.S. CO2 emissions across all sectors. The former accounts for the impact of monetary policy, while the latter allows us to delve into the relationship between macroeconomic variables and CO2 emissions. The dataset is monthly, covering the period from January 1974 to December 2017. For detailed information on the data and sources, refer to Appendix B.2. in Känzig's paper. The VAR model is estimated in log levels with a lag order of 12, including only a constant term as a deterministic component. Robustness checks are performed to ensure the reliability of the results; see the Appendix for further details.

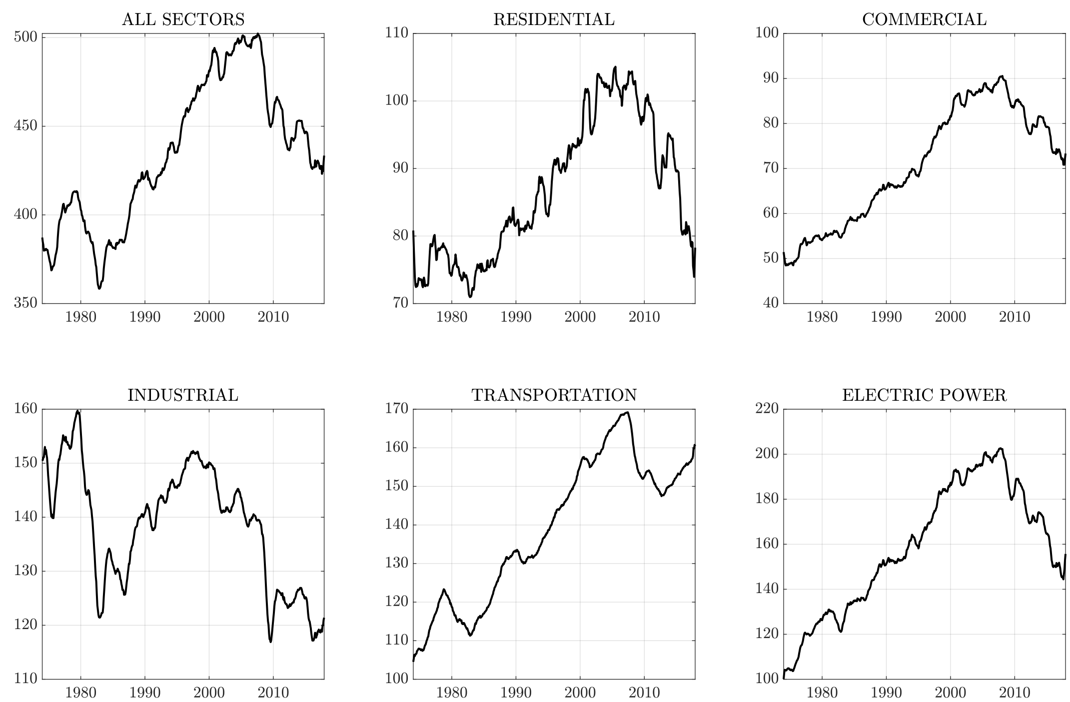


Figure 1: Sectoral CO2 emissions

Notes: Sectoral CO2 emissions data. Seasonal effects have been adjusted using a 12-month moving average. CO2 emissions are reported in million metric tons of carbon dioxide.

To ensure the robustness of our results, we estimate the augmented baseline and sectoral models using various lag orders, as well as both linear and no-constant estimation techniques. Detailed results can be found in Appendix 6.2. Additionally, we examine how the responses vary within a restricted sample by applying different structural break points; these findings are displayed in Appendix 6.2.3.

4 Results & Discussion

4.1 Instrument Strength

In the context of VAR models with external instrument identification, a crucial identifying assumption is that the external instrument is contemporaneously correlated with the structural shock of interest but uncorrelated with other structural shocks. This identification allows us to isolate the exogenous variation necessary to identify the effect of the targeted shock on the endogenous variables within the VAR framework. However, it is essential to assess the strength of the instrument, as weak instruments can lead to biased and inconsistent estimates.

Table 1: First Stage Regression Results

	1M	2M	3M	4M	5M	6M	7M
Coefficient	0.947	0.983	1.016	1.037	1.051	1.067	1.094
F-stat	25.59	25.51	25.50	24.91	24.22	23.85	23.97
F-stat (robust)	12.15	11.95	11.87	11.58	11.26	11.12	11.21
R^2	4.74	4.73	4.73	4.62	4.50	4.43	4.46
R^2 (adjusted)	4.56	4.54	4.54	4.44	4.31	4.25	4.27
Observations	516	516	516	516	516	516	516

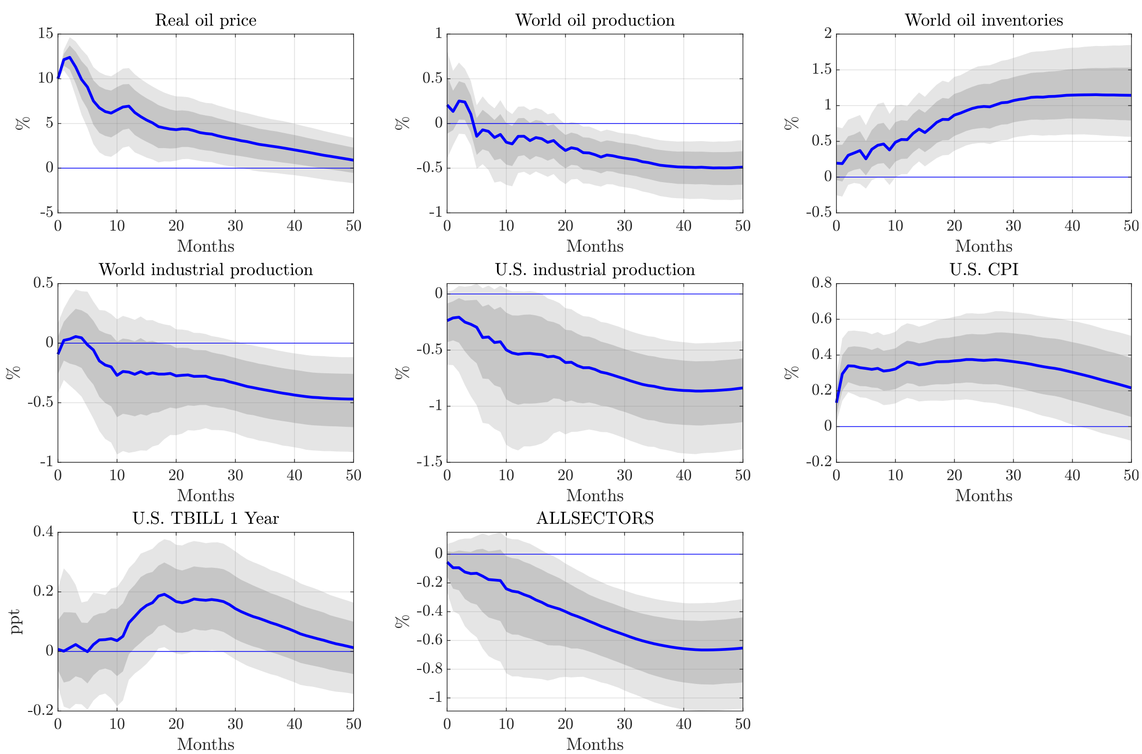
	8M	9M	10M	11M	12M	COMP
Coefficient	1.108	1.118	1.121	0.945	1.035	1.074
F-stat	23.69	23.19	22.31	11.06	12.60	23.25
F-stat (robust)	11.09	10.83	10.32	6.85	7.64	10.42
R^2	4.41	4.32	4.16	2.11	2.39	4.33
R^2 (adjusted)	4.22	4.13	3.97	1.92	2.20	4.14
Observations	516	516	516	516	516	516

Researchers typically rely on the first-stage F-statistic in the regression of the endogenous variable on the instrument to evaluate instrument strength. According to Montiel Olea et al. (2020), an F-statistic below 10 suggests that the instrument may be weak. Ensuring that the instrument is strong and valid is critical to making credible causal claims in VAR models with external instrument identification.

Table 1 presents the results for various instruments derived from futures contracts with different maturities within Känzig's dataset. The table includes a robust F-statistic to account for heteroskedasticity. The final column, labeled "COMP," represents the composite measure spanning the first year of the term structure. Most instruments with different maturities show a robust F-statistic above the critical value of 10. However, instrument strength tends to decrease as the futures contract maturity increases. For the composite measure, the F-statistic is 23.25, and the instrument explains approximately 4.33 percent of the variation in oil price residuals. These findings collectively indicate that weak instruments are not a concern in this analysis.

4.2 Effects on the Baseline Model

To identify the propagation channels through which sectoral CO2 emissions are affected, we augment the baseline model in Känzig's paper with two additional variables: U.S. Treasury bills with a maturity of one year and total CO2 emissions across all U.S. economic sectors. The impulse responses for the augmented model are shown in Figure 2.



First stage regression: F: 23.25, robust F: 10.42, R^2: 4.33%, Adjusted R^2: 4.14%

Figure 2: Impulse responses to a negative oil supply news shock

Notes: Impulse responses to an oil supply news shock, scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

First of all, the results of Känzig's original paper remain unchanged. Following a negative oil supply news shock, a significant and immediate increase in oil prices is observed.

While global oil production remains largely unaffected initially, it declines gradually and persistently over time. Additionally, global oil inventories experience a significant and sustained increase. Examining the impact on the U.S. economy, the shock results in a more pronounced and rapid decline in industrial production compared to global industrial production. Furthermore, a significant and immediate increase in U.S. consumer prices is identified, with prices continuing to rise for two years before eventually stabilizing, though not fully returning to pre-shock levels.

Turning to the newly introduced variables, we observe that there is initially no change in the monetary policy stance. However, approximately one and a half years later, monetary policy begins to tighten, eventually converging back to normal levels. This response, while modest, highlights the well-known trade-off between managing inflationary pressures and addressing an economic slowdown. The gradual and measured tightening is consistent with the Federal Reserve's prioritization of inflation control over output stabilization. In contrast, CO2 emissions across all U.S. sectors exhibit an immediate and significant reduction, an effect that intensifies over time. At its peak, a 10 percent increase in oil prices due to an oil supply news shock results in a 0.7 percent decrease in CO2 emissions across all sectors in the U.S. Thus, oil supply news shocks have substantial economic and environmental impacts. To further explore the underlying mechanisms, we decompose CO2 emissions across sectors and energy sources in the subsequent section.

Several key factors may explain the observed reduction in CO2 emissions across all U.S. sectors following a negative oil supply news shock. First, the substitution effect likely plays a significant role; as oil prices rise, industries often shift to less carbon-intensive energy sources, such as natural gas and renewables, leading to decreased emissions (Pata & Balcilar, 2024). Additionally, higher oil prices incentivize improvements in energy efficiency, prompting both businesses and consumers to adopt more efficient technologies, which in turn lowers emissions (Acemoglu et al., 2010). Moreover, price shocks associated with negative oil supply news may lead to an economic slowdown, resulting in reduced industrial activity and energy consumption. Finally, government policy responses often shift significantly in response to oil price volatility, with increased support for renewable energy and stricter emissions regulations further driving the decline in emissions (Klepacz, 2017).

4.3 Effects on the Sectoral CO2 Emissions

We then investigate how the oil supply news shock transmits to CO2 emissions in each U.S. sector.

With the exception of the transportation sector, a negative oil supply news shock does not have an immediate impact on economic sectors in the U.S. For the residential, commercial, and electric power sectors, the response patterns are quite similar, with effects becoming apparent after approximately two and a half years. In these sectors, CO2 emissions continue to decrease significantly over the long run. In the industrial sector, although an immediate impact is not initially observed, emissions begin to decline rapidly within the first year and stabilize at a significant level after 20 months. The transportation sector, however, exhibits a distinct response compared to other sectors. From the onset of the shock, there is a notable and immediate decline in emissions, with the effect intensifying over time.

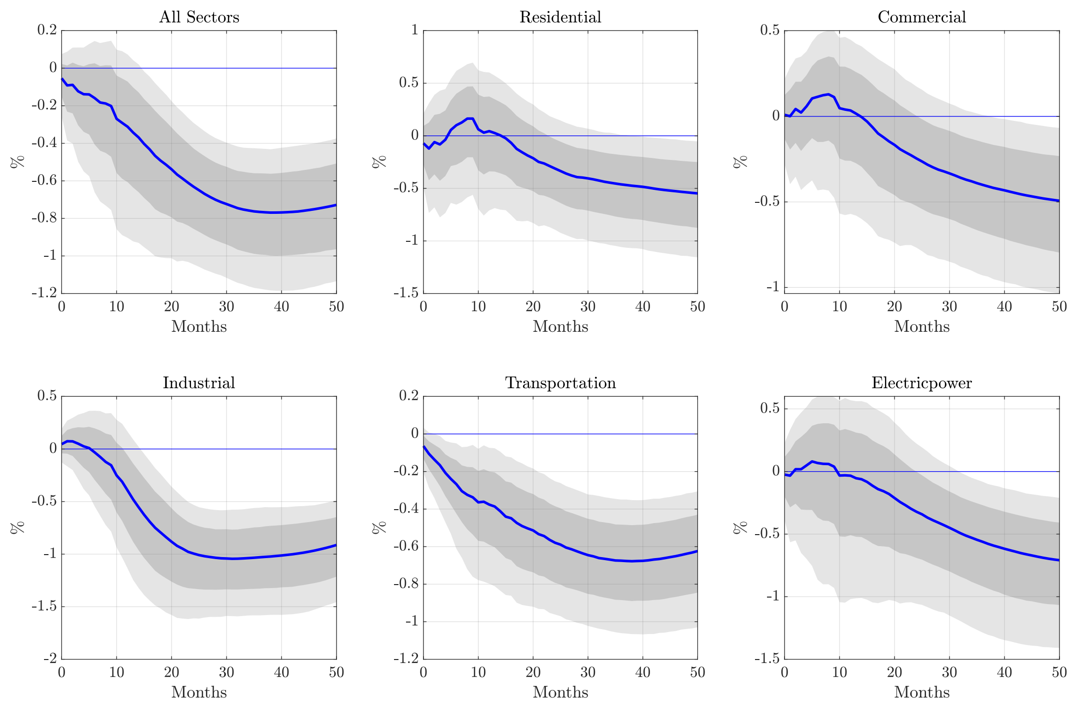


Figure 3: Impulse responses - Sectors

Notes: Impulse responses to an oil supply news shock, scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

Examining the reduction in sectoral CO2 emissions at peak response, we observe that an oil supply news shock leading to a 10 percent increase in oil prices results in a 0.8 percent decrease in industrial and 0.8 percent decrease in transportation sector CO2 emissions. For the other sectors, a decrease of approximately 0.5 percent is observed. Thus, oil supply news shocks have economically significant effects across sectors in the U.S.

These results align with key findings in the literature. The cost share of oil is a critical factor in determining a sector's response to an oil price shock. In industries with a high oil cost share, oil price shocks predominantly reduce supply. Conversely, in many other industries, these shocks primarily diminish demand (Lee & Ni, 2002). The conclusions of this seminal work have been confirmed by more recent studies, which support the original findings (Jo et al., 2017). For instance, examining the effect of oil price shocks on sectors in Japan, Taghizadeh Hesary et al. (2015) find that the commercial, industrial, and transportation sectors display strong sensitivity to drastic oil price changes, while the residential sector is less affected by sharp oil price fluctuations.

In the electric power sector, no immediate decline in emissions is observed within the first year following an oil supply shock. A detailed examination of the effects on different energy sources reveals a significant shift towards coal usage, which stabilizes CO2 emissions over an extended period. When restricting the sample, there is even a considerable increase in emissions within the electric power sector, attributed to increased coal usage in response to the oil supply shock.

Discussion: The observed decrease in emissions across various sectors can be attributed to several factors, including the substitution effect, investments in energy efficiency, changes in consumer behavior, and sectoral dependency on oil. Recent studies, such as Atalla and Bean (2023), highlight the transportation sector's distinct sensitivity to oil price fluctuations due to its high oil dependency, leading to shifts in consumer behavior and logistics. In contrast, sectors such as residential, commercial, and electric power require longer adjustment periods for fuel substitution and efficiency improvements (Sorrell et al., 2009). Sorrell et al. further elaborate that energy-intensive sectors benefit significantly from overcoming barriers to efficiency due to substantial cost savings, whereas less energy-intensive sectors may find the potential savings insufficient to justify investments. Factors such as risk, principal-agent problems, hidden costs, strategic priorities, and capital constraints also influence investment decisions in these sectors (Sorrell et al., 2009).

Analyzing the general trend in total CO2 emissions across sectors reveals a significant decrease post-2008. To further explore this, we examine the responses of U.S. sectors to a negative oil supply news shock before 2008. The impulse responses for the sectoral model are shown in Figure 4.

Discussion: The post-2008 decrease in CO2 emissions across sectors can be attributed to advancements in technical energy efficiency, increased electrification, a transition away from coal, and greater investment in clean energy (Singh, 2024). These developments emphasize structural shifts toward renewable energy sources and enhanced energy efficiency, marking a structural break in energy consumption patterns. Before 2008, sectors seemed to be more sensitive to oil price changes, leading to more pronounced and rapid emission responses to oil supply shocks. However, these effects dissipated quickly due to the temporary nature of adjustments before the transition to sustainable practices. In the restricted sample, the impact of oil supply news shocks is significantly higher across all sectors, materializing quickly at shorter horizons and diminishing faster over time, rendering the long-run impact less significant.

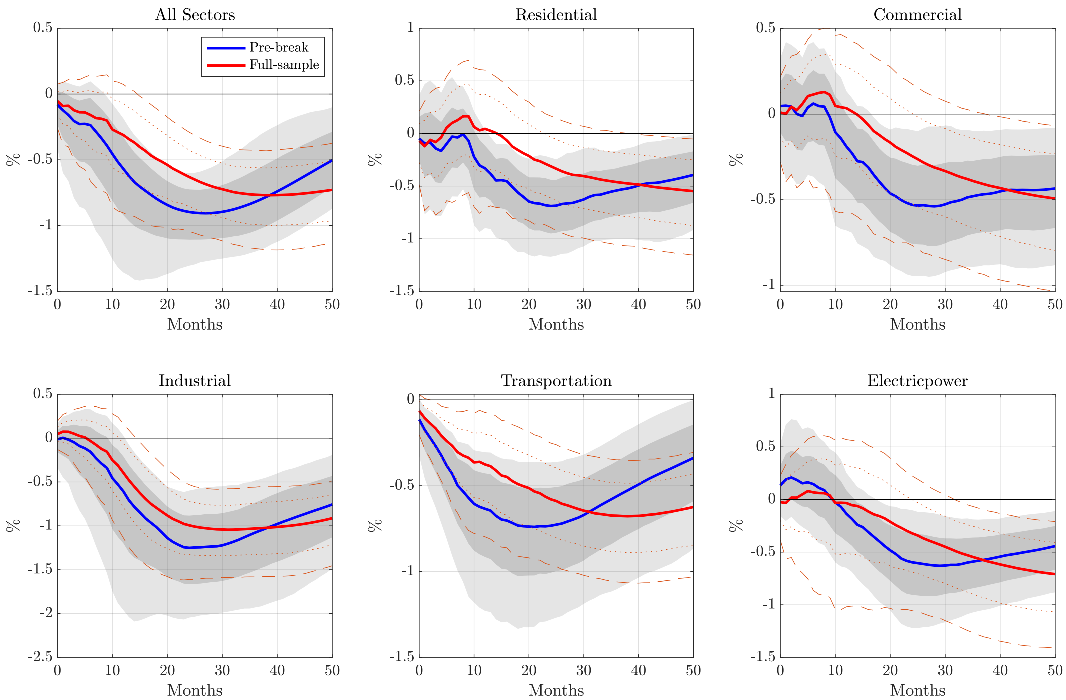


Figure 4: Impulse responses - Sectors with structural break

Notes: For the restricted sample, the solid blue line is the point estimate, and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively. The solid red line is the point estimate for the full sample.

4.4 Historical Decomposition for the Industrial Sector

We now explore whether oil supply news can explain historical variations in CO2 emissions, focusing on the industrial sector, which is particularly sensitive to oil supply shocks. This analysis is vital because CO2 emissions across all sectors are influenced by various factors. The historical decomposition allows us to isolate the impact of oil supply news on industrial CO2 emissions.

It is important to note that this decomposition captures only oil supply news related to OPEC announcements. Therefore, the actual contribution of oil supply news to CO2 emissions within the industrial sector may be even more significant. Nevertheless, the decomposition provides valuable insights into how oil supply news shocks have historically influenced variations in industrial CO2 emissions during certain periods.

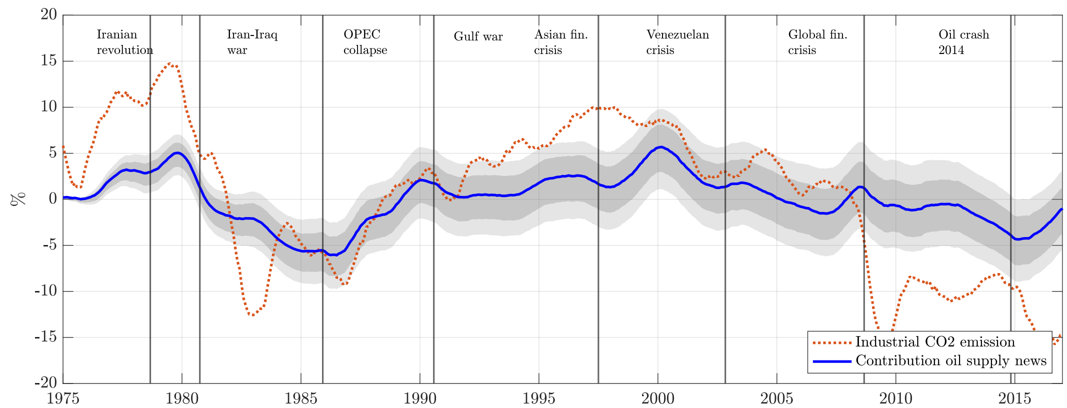


Figure 5: Historical decomposition of the industrial CO2 emission

Notes: Historical contribution of oil supply news shocks to the industrial CO2 emissions. The dark and light gray bands represent the 68 and 90 percent confidence levels, respectively. Important events in oil markets are shown by the vertical bars.

In the early years, a considerable share of industrial CO2 emissions is driven by oil supply expectations. Following the 1980s, CO2 emissions decline rapidly and consistently until the OPEC collapse, attributed to lower supply expectations, which reduce oil usage within the sector. After OPEC agreed on production quotas in 1986, CO2 emissions increase rapidly and persistently until the Asian financial crisis. During this period, the contribution of oil supply news closely mirror the trend in industrial CO2 emissions.

However, in recent decades, oil supply news has driven industrial emissions to a lesser extent. Notably, after the 2008 financial crisis, a significant and sustained reduction in CO2 emissions is observed, not significantly driven by oil supply news. This suggests a structural shift towards more energy-efficient practices and a reduced reliance on oil in the industrial sector.

4.5 Effects on the Energy Sources

Next, we focus on the transmission of oil supply news shocks to CO2 emissions across various energy sources, encompassing all sectors in the US.

Interestingly, oil supply news shocks result in the most substantial reduction in CO2 emissions from natural gas. The initial impact is significant and intensifies over time. For petroleum products used across various sectors, the initial impact is less pronounced but remains both economically and statistically significant. At the peak response, a 10 percent increase in oil prices due to an oil supply news shock reduces CO2 emissions from natural gas and petroleum in the U.S. by 1 percent and 0.8 percent, respectively. Conversely, CO2 emissions from coal usage show a slight but barely significant increase during the first two

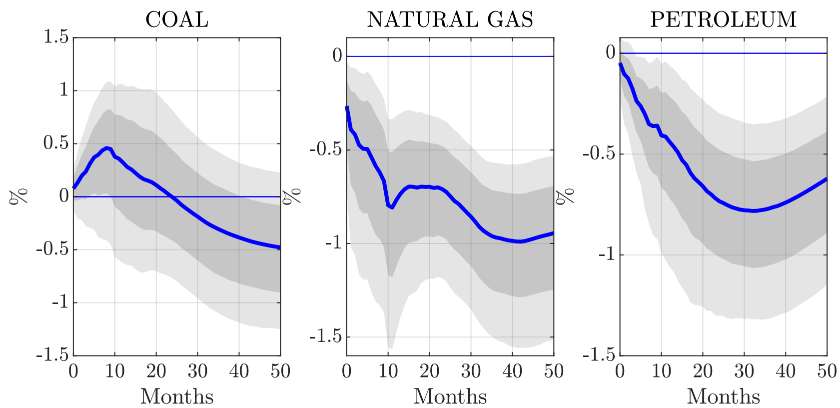


Figure 6: Impulse responses - Main energy sources

Notes: Impulse responses to an oil supply news shock, scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

years, after which emissions begin to decline.

Discussion: The initial increase in CO2 emissions from coal usage can be attributed to the short-term substitution effect. When oil prices rise, some industries may temporarily switch to coal, which is often cheaper but more carbon-intensive, to meet their energy needs. Zamani (2016) highlights a high degree of substitutability and asserts that oil supply and demand shocks significantly impact coal prices. However, in the long run, the decline in CO2 emissions from coal usage occurs as industries and power plants adopt cleaner technologies and gradually shift to less carbon-intensive energy sources.

The surprising extent of reduction in CO2 emissions from natural gas in response to oil supply news shocks can be attributed to several key factors. Sectors heavily reliant on natural gas, particularly electricity generation and residential sectors, demonstrate a greater capacity to transition to renewables when oil prices rise. This flexibility is evident in our findings, especially in Section 4.6, where renewable energy consumption in residential sector shows the most significant positive response to negative oil supply news shocks. Therefore, in sectors where natural gas is a primary energy source, a negative oil supply news shock triggers a substantial shift towards renewable energy. Conversely, in sectors like transportation, where natural gas plays a minimal role and petroleum products dominate, the substitution towards renewable energy is less pronounced. This difference in substitution patterns may explain why CO2 emissions from natural gas are more significantly affected than those from petroleum.

In addition, petroleum can be decomposed into distinct products to determine which

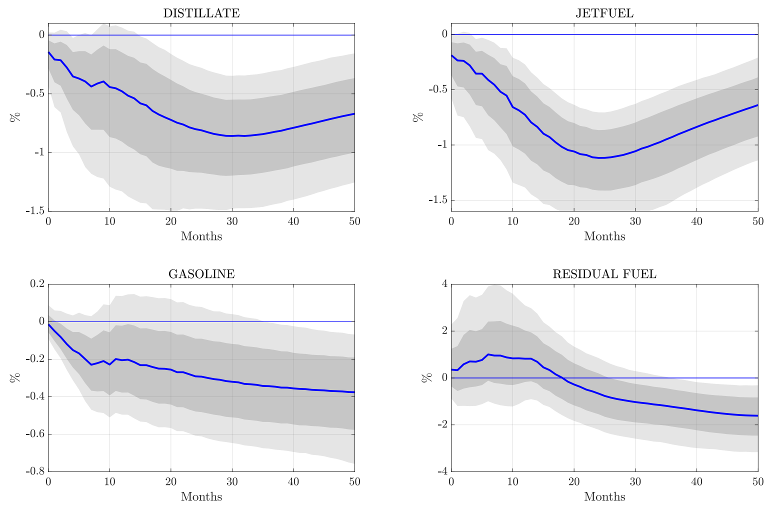


Figure 7: Impulse responses - Decomposition of petroleum

Notes: Impulse responses to an oil supply news shock, scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

industries are most affected by oil supply news shocks. Initially, these shocks have a significant impact on distillate fuel, with the response peaking towards the end of the third year. Distillate fuel is utilized by both on- and off-highway diesel engines and is also used for space heating and electricity generation. Its widespread use across various sectors complicates the identification of transmission channels. However, the primary consumers in the U.S. are the transportation and industrial sectors, with shares of 75% and 14%, respectively. Since a large portion of distillate fuel is consumed by on-highway diesel engines, such as trucks and automobiles, the industries most affected include trucking, railroads, shipping, and logistics firms. At its peak, the effect corresponds to a reduction of approximately 0.9% in CO2 emissions.

For jet fuel, we observe a significant initial impact that intensifies over time. The response forms an inverted U-shape and peaks at the end of the second year. At its peak, the effect on jet fuel is stronger than that on all other petroleum products. An oil supply news shock resulting in a 10% increase in oil prices decreases jet fuel CO2 emissions by 1.2%. Consequently, following an oil supply news shock, commercial aviation—the principal consumer of jet fuel—is more affected than trucking, shipping, and logistics firms.

Motor gasoline exhibits a weaker response compared to distillate and jet fuel. No immediate impact is observed following an oil supply news shock. Although the effect materializes over time, the response remains barely significant, even in the long run. A large portion of motor gasoline is consumed by light-duty vehicles (LDVs) in the transportation sector, indicating that LDVs are not highly sensitive to oil supply news shocks. At its barely significant peak, an oil supply news shock resulting in a 10% increase in oil prices decreases motor gasoline CO2 emissions by only 0.4%.

A surprising trend is observed with residual fuel. Unlike other petroleum products, residual fuel initially exhibits an increase in CO2 emissions until nearly the end of the second year. This can be attributed to its primary usage in steam-powered vessels used in government service and inshore power plants, where short-term sensitivity to oil supply shocks is likely to be weak. Substitution with alternative energy sources is not anticipated in the short term. However, after two years, there is a significant decrease in emissions. Over the long term, an oil supply news shock reduces residual fuel CO2 emissions by nearly 2%, making it the most affected petroleum product over time.

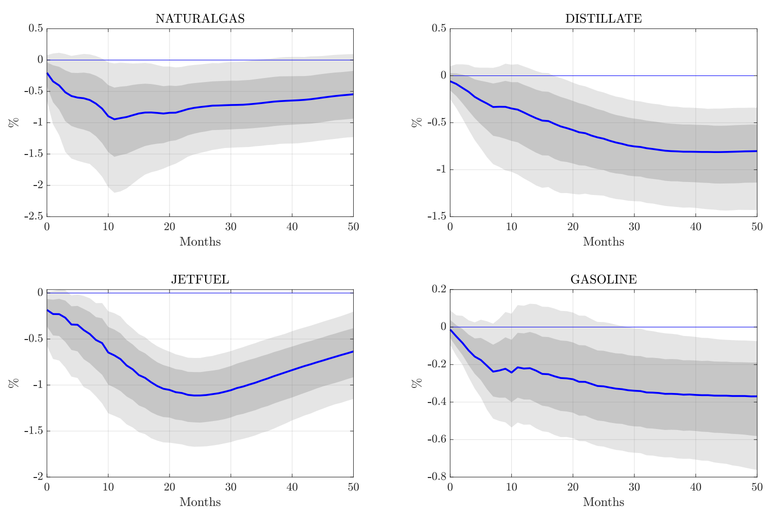


Figure 8: Impulse responses - Transportation sector

Notes: Scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

A closer examination of the transportation sector reveals a distinct response of natural gas compared to other sectors. While CO2 emissions from natural gas are generally most sensitive to oil supply news shocks across sectors, the response within the transportation sector is weak and barely significant. This result is anticipated, given that natural gas constitutes only a small portion of total energy usage in transportation. Making substitution from petroleum products to natural gas within transportation sector is unlikely. The results align with these expectations.

The findings from the cross-sector analysis indicate consistent impulse responses for distillate fuel, jet fuel, and gasoline within the transportation sector. In particular, both distillate fuel and jet fuel exhibit a more pronounced decline in CO2 emissions. This suggests that CO2 emissions in the transportation sector are highly sensitive to oil supply news shocks, given that coal usage is minimal and natural gas does not elicit a strong response.

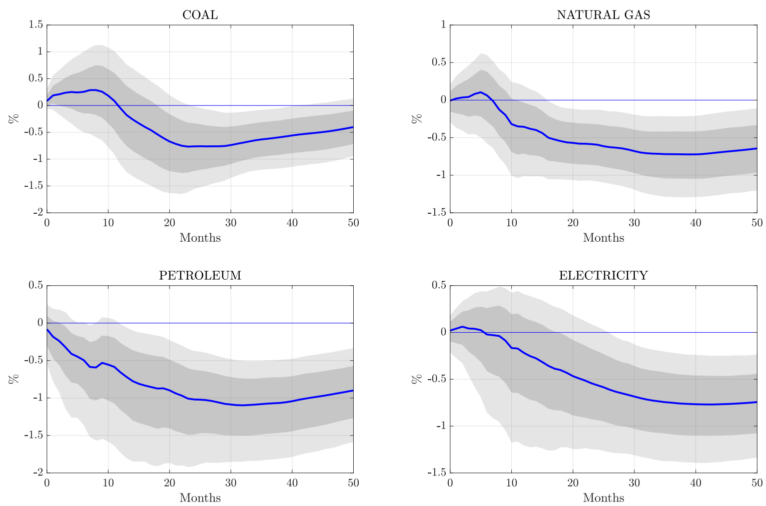


Figure 9: Impulse responses - Industrial sector

Notes: Scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

An analysis of coal reveals an initial increase in CO2 emissions during the first year, likely due to a short-term substitution from petroleum products to coal. However, a decline in emissions becomes evident after this period. In contrast, the industrial sector does not show an immediate significant impact on natural gas emissions, unlike other sectors.

In the short run, up to the first year, there is a substitution from petroleum products primarily to coal and, to a lesser extent, to natural gas. "Given that natural gas prices are also affected by an increase in oil prices, this may have led the sector to favor coal over natural gas as a substitute." Consequently, CO2 emissions within the industrial sector feature less sensitivity to oil supply news shocks compared to the transportation sector in the short term.

4.6 Effects on the Renewable Energy Usage

To better understand the propagation channels, we now examine renewable energy consumption across various sectors in the U.S. An analysis of each sector reveals an intriguing trend: oil supply news shocks, which result in increased oil prices, gradually lead to an increase in total renewable energy consumption over time. It is important to note that there is no immediate impact on total renewable energy consumption. However, in the long run, a statistically and economically significant increase is observed, with total renewable energy consumption rising by more than 1% in response to a 10% increase in oil prices.

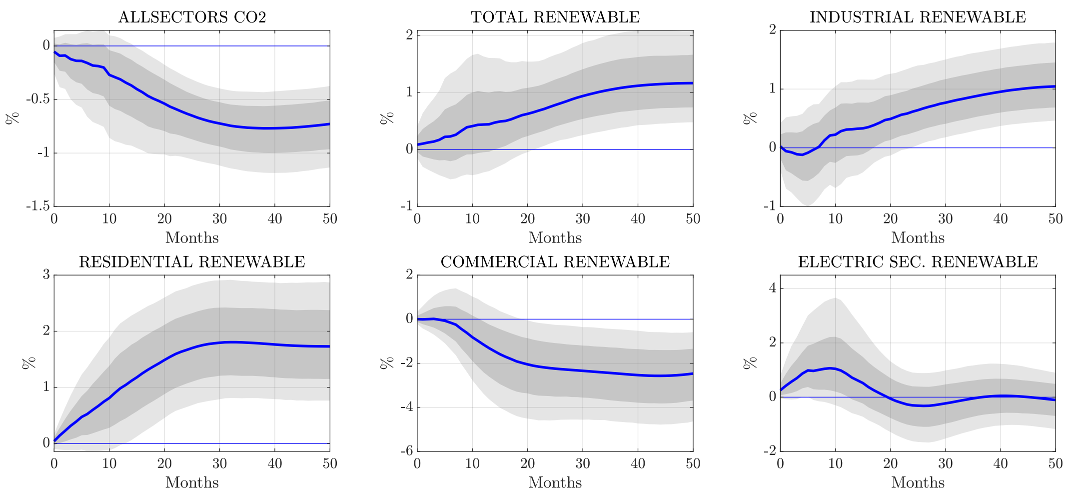


Figure 10: Impulse responses - Renewable energy consumption

Notes: Scaled for an immediate increase of 10 percent in the real price of oil. The solid blue line is the point estimate and the dark and light gray areas indicate the 68 and 90 percent confidence levels, respectively.

A closer look into the industrial sector reveals that, similar to the broader sectoral response, there is no immediate impact from oil supply news shocks. However, at longer time horizons, a significant increase in renewable energy consumption is observed, exceeding 1%. Interestingly, residential sector is the most positively affected by rising oil prices. While there is no immediate impact, the long-term response is notably strong, with renewable consumption increasing by nearly 2% following a 10% increase in oil prices.

In contrast, the commercial sector exhibits an opposite response. At longer horizons, oil supply news shocks result in a decline in renewable energy consumption within this sector. The long-term effect is substantial, with a reduction of nearly 3%. Within the electricity sector, although there is an initial increase in renewable consumption within the first two years, the effect is weak and barely significant.

Discussion: The initial lack of immediate impact on overall renewable energy consumption following oil supply news shocks can be attributed to the time required for market adjustments and infrastructure development. Research by Sorrell et al. (2009) and Borenstein (2014) indicates that the transition to renewable energy sources often necessitates substantial planning and capital investment, which delays observable changes in consumption patterns. The residential sector's significant response—a nearly 2% increase in renewable energy consumption following a 10% rise in oil prices—can be explained by consumer behavior and the influence of incentives. According to Matisoff and Johnson (2017) and Qiu, Colson, and Grebitus (2017), residential consumers are particularly responsive to price signals and benefit from subsidies and incentives for renewable technologies. In contrast, the weak and barely significant impact observed within the electricity sector can be attributed to challenges such as the extended lifespan of power sector capital equipment, lengthy development periods required for research and development, and the complexities of utility-scale energy production (Jenkins et al., 2018).

4.7 Historical Variation

Next, we examine the extent to which oil supply news shocks contribute to the historical variation in sectoral CO2 emissions within the U.S. Our analysis incorporates emissions data across all sectors (ALL), the residential sector (RES), the commercial sector (COM), the industrial sector (IND), and the transportation sector (TRA) into an augmented baseline model.

Table 2: FEVD Results

Känzig (2021) baseline model variables						
	POIL	OILPROD	OILSTOCKS	WORLDIP	IP	CPI
0	0.56	0.02	0.01	0.00	0.01	0.10
	[0.14, 0.81]	[0.00, 0.14]	[0.00, 0.07]	[0.00, 0.01]	[0.00, 0.05]	[0.00, 0.39]
12	0.46	0.03	0.05	0.02	0.00	0.36
	[0.13, 0.72]	[0.01, 0.08]	[0.01, 0.21]	[0.00, 0.08]	[0.00, 0.02]	[0.10, 0.61]
24	0.38	0.06	0.14	0.07	0.02	0.32
	[0.12, 0.62]	[0.02, 0.14]	[0.02, 0.40]	[0.01, 0.22]	[0.00, 0.09]	[0.08, 0.58]
48	0.35	0.17	0.30	0.12	0.05	0.28
	[0.12, 0.58]	[0.05, 0.36]	[0.05, 0.61]	[0.03, 0.27]	[0.01, 0.16]	[0.08, 0.55]
Augmented model variables						
	TBILL	ALL	RES	COM	IND	TRA
0	0.01	0.03	0.02	0.00	0.01	0.15
	[0.00, 0.10]	[0.00, 0.22]	[0.00, 0.19]	[0.00, 0.02]	[0.00, 0.11]	[0.01, 0.42]
12	0.04	0.02	0.00	0.00	0.01	0.22
	[0.01, 0.16]	[0.00, 0.13]	[0.00, 0.03]	[0.00, 0.02]	[0.00, 0.05]	[0.03, 0.51]
24	0.11	0.06	0.01	0.00	0.06	0.19
	[0.02, 0.30]	[0.01, 0.24]	[0.00, 0.02]	[0.00, 0.02]	[0.01, 0.22]	[0.02, 0.47]
48	0.17	0.15	0.04	0.02	0.16	0.20
	[0.05, 0.39]	[0.03, 0.38]	[0.01, 0.13]	[0.00, 0.08]	[0.03, 0.37]	[0.03, 0.47]

Känzig (2021) offers a comprehensive discussion on the historical variation of variables within the baseline model. When examining CO2 emissions across different sectors, our findings indicate that oil supply news shocks account for a relatively small proportion of emissions in the short run. However, in the long run, these shocks explain a substantial share of emissions, amounting to 15 percent. The transportation sector stands out as an exception. Even in the short run, a significant portion of transportation-related CO2 emissions is attributable to oil supply news shocks, with this influence peaking after one year. Over the long run, oil supply news explains a notable share—approximately 20 percent—of emissions in the transportation sector. In the industrial sector, while oil supply news shocks do not significantly explain emissions in the short run, they account for a considerable portion over longer horizons. On the other hand, the residential and commercial sectors exhibit only a minor response to oil supply news, with the impact being negligible in the commercial sector in the short run.

5 Conclusion

This study provides a comprehensive analysis of the effects of oil supply news shocks on sectoral CO2 emissions in the U.S., offering new insights into the intricate relationship between oil supply expectations and environmental outcomes. We identify significant variations in how different sectors respond to oil supply news shocks. The results demonstrate that oil supply news shocks have economically and statistically significant impacts, leading to a substantial reduction in CO2 emissions across most sectors, particularly in the transportation and industrial sectors. The findings also reveal a slight shift towards increased coal usage, which initially lowers emission reductions but ultimately contributes to long-term decreases. Moreover, post-2008 structural changes in energy consumption patterns are evident, showing a trend towards cleaner energy sources and improved energy efficiency. This thesis contributes to the literature by emphasizing the role of sectoral dependencies and energy transitions in moderating the environmental effects of oil supply news shocks. Future research should delve into the long-term implications of these shifts, particularly in the context of ongoing efforts to decarbonize the energy sector. Additionally, further investigation is essential to account for potential changes in market dynamics. Extending the study to include climate-related variables to observe long-term effects would also be valuable.

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