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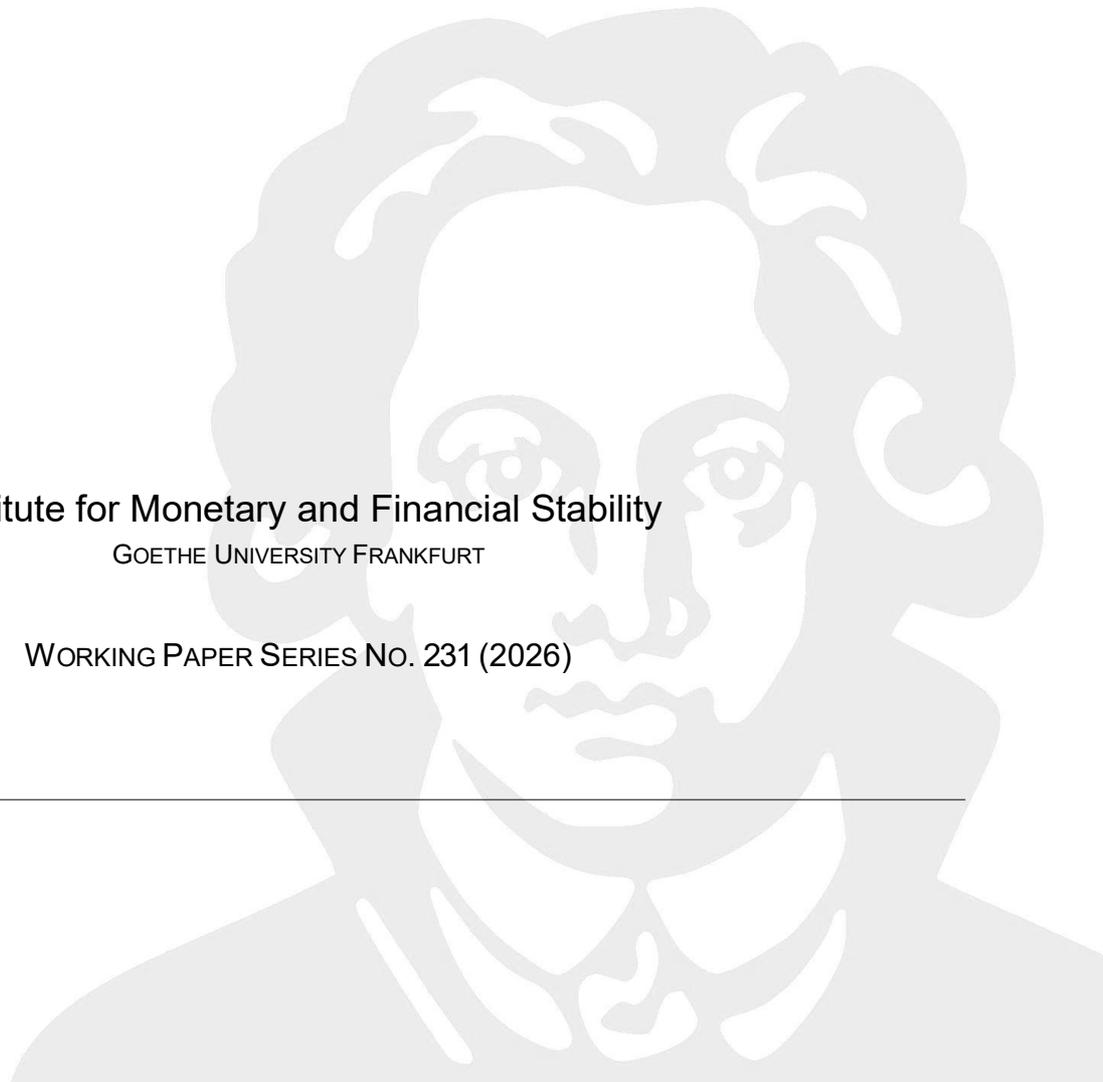
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Institute for Monetary and Financial Stability

GOETHE UNIVERSITY FRANKFURT

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Energy Price Shocks and Inflation in the Euro Area

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Abstract

The Euro Area experienced historically high inflation in 2022, with energy prices playing a central role. This paper examines the joint impact of various energy price shocks on inflation in the Euro Area, with a focus on the period encompassing the COVID-19 pandemic and the Russia–Ukraine war. Using a structural VAR model, the analysis identifies shocks to gasoline, diesel, jet fuel, natural gas, and electricity prices and evaluates their effects on headline and core inflation.

Historically, before the pandemic, gasoline price shocks had the most substantial impact on the Euro Area HICP, while the effects of other energy price shocks were relatively minor. Spillover effects to non-energy goods were very limited, implying negligible effects on core inflation. Extending the sample to May 2023 reveals a notable change in these relationships. In particular, natural gas price shocks become substantially more important and exhibit significantly more persistent effects on inflation.

In contrast to previous findings for the United States, the results suggest that energy prices, especially natural gas price shocks, played a major role in the surge in the HICP and core HICP during 2021 and 2022 within the Euro Area.

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1 Introduction

In 2022, the Euro Area experienced historically high inflation rates, with energy price developments playing an important role. The inflation rate for energy temporarily surged to over 44%, making a substantial contribution to the overall increase in consumer prices. Previous literature primarily concentrated on the impact of gasoline or crude oil prices on inflation. However, the Russian invasion of Ukraine in 2022 led to a sharp increase in natural gas prices, which substantially elevated electricity prices and led to a significant rise in the inflation rate in the Euro Area. Additionally, 2020 witnessed substantial fluctuations in jet fuel prices due to the COVID-19 pandemic. Kilian and Zhou (2023) underscores that traditional estimates of inflationary impacts may be biased when concentrating solely on gasoline prices and neglecting other forms of energy. Energy use in industry, transportation, and the commercial sector depends not only on petroleum but also on natural gas and electricity, such that several energy prices can significantly contribute to inflationary pressures. Despite this, the combined effects of a broad set of energy prices on inflation in the Euro Area have not yet been systematically analyzed.

This paper studies how shocks to different energy prices affect headline and core inflation in the Euro Area. In particular, it examines whether the transmission of energy price shocks to inflation changed during the period surrounding the COVID-19 pandemic and the European energy crisis following Russia's invasion of Ukraine, and to what extent energy price shocks contributed to the inflation surge observed in 2021 and 2022.

Building on the structural VAR model of Kilian and Zhou (2023), this study examines the influence of gasoline, diesel, jet fuel, natural gas, and electricity price shocks on the HICP and core HICP for the Euro Area. A separate analysis of the Euro Area compared to the U.S., as in Kilian and Zhou (2023), is warranted due to substantial structural differences in the energy markets in the two regions. While crude oil markets are globally integrated and oil prices therefore tend to move similarly across regions, natural gas markets are considerably more regional. Natural gas is predominantly transported via pipelines and the global liquefied natural gas infrastructure remains limited and costly. Crude oil can be transported relatively easily across regions, leading to more synchronized global price movements. Nevertheless, prices of refined petroleum products such as gasoline and diesel may still exhibit temporary regional differences due to refinery capacity constraints.

Following the shale gas revolution, the U.S. has become a net exporter of natural

gas, whereas the Euro Area remains highly dependent on imports. Consequently, natural gas prices in the two regions can diverge substantially. These differences became particularly pronounced during the European energy crisis. In August 2022, both Europe and the U.S. experienced record high natural gas prices, with the most substantial absolute price difference reaching \$70.0 per mmbtu in Europe compared to \$8.79 per mmbtu in the U.S.. This divergence was largely driven by the sharp reduction in Russian pipeline gas deliveries to Europe and the limited ability to quickly replace these volumes with LNG due to infrastructure constraints and higher transportation costs.

In addition, natural gas prices play a particularly important role in the formation of electricity prices in the Euro Area. Due to the marginal pricing mechanism in European electricity markets, gas-fired power plants frequently determine the wholesale electricity price, implying that natural gas price shocks can translate directly into electricity price fluctuations. As electricity represents a key input for both households and firms, these structural features amplify the transmission of energy price shocks to inflation in the Euro Area.

The results show that energy price shocks played a central role in the inflation surge in the Euro Area in 2021 and 2022. This is in contrast with the findings of Kilian and Zhou (2023) for the U.S., where energy price shocks account for only a limited share of the post-pandemic inflation increase. The estimates indicate that natural gas price shocks were particularly important for the rise in Euro Area inflation. Spillover effects to non-energy goods remain relatively small overall, although they become more pronounced in the post-pandemic period. The results indicate that the COVID-19 pandemic itself had only a limited impact on the underlying structural relationships between energy price shocks and inflation.

The literature on energy and inflation has primarily focused on the impact of oil prices and oil-related products. This attention has been particularly directed towards the U.S., with a significant emphasis on the oil price shocks in the 1970s and the era of the Great Moderation (Hamilton, 1983; Barsky and Kilian, 2002; Hamilton, 2003; Kilian, 2009). The large fluctuations in energy prices during the COVID-19 pandemic and after Russia's invasion of Ukraine have renewed interest in the role of energy prices in the recent inflation surge. For the U.S., Kilian and Zhou (2022a,b) argue that energy price shocks explain only a limited share of the inflation increase in 2021 and 2022. In contrast, Gagliardone and Gertler (2023), using their New Keynesian model, contend that the substantial rise in inflation results from the interplay of an oil

price shock and an overly accommodative monetary policy. Similarly, Blanchard and Bernanke (2023) explain through their dynamic model of wage-price determination that energy price shocks played an important role in the initial rise of US inflation in late 2021 and early 2022, although other factors such as labor market tightness contributed to the persistence of inflation thereafter.

For the Euro Area, the literature has also mostly focused on oil shocks. Baumeister (2023) discusses how the pandemic and the Russia–Ukraine war reshaped oil markets and renewed the relevance of oil shocks for inflation dynamics. Other works investigating the relationship between oil price shocks and inflation in Europe include studies by Jacquinet et al. (2009), Peersman and van Robays (2014), and Conflitti and Luciani (2019). An overview of the macroeconomic effects of oil prices is offered by Bjørnland (2022).

In contrast, energy sources other than oil have received much less attention in the context of their impact on inflation. Some studies examine aggregate energy price measures. Binici et al. (2022) analyze the impact of a price change of an energy price index encompassing coal, natural gas, oil, and propane on inflation. They find that, in Europe, while external factors like the Russia–Ukraine war had a significant impact on inflation, domestic factors such as increased aggregate demand played a central role. Corsello and Tagliabracchi (2023) base their analysis on the changes in the energy component of the HICP. They conclude that the influence of energy prices on the non-energy goods in the HICP has notably increased in the Euro Area from mid-2021. Nonetheless, it remains unclear which energy sources were responsible for these effects.

Beyond oil, individual energy sources have received considerably less attention. Böck and Zörner (2023) find a substantial effect of a natural gas price shock on inflation in both the Euro Area and the U.S.. One of the first comprehensive studies examining the inflationary effects of several disaggregated energy prices is Kilian and Zhou (2023). They analyze the price effects of gasoline, diesel, jet fuel, natural gas, and electricity on the CPI and core CPI in the U.S.. Their results indicate that considering only individual energy sources, such as gasoline, can underestimate the inflationary pressures of the energy sector. As previously mentioned, their findings suggest that the majority of the inflation increase in the U.S. in the years 2021 and 2022 cannot be attributed to energy price shocks.

The remainder of this paper is structured as follows. Section 2 provides a description of the dataset selection. Section 3 presents the structural VAR model used for

analyzing the impacts of five energy price shocks on inflation, alongside the exposition of the employed recursive identification and Bayesian estimation methods. Section 4 illustrates how the HICP and the core HICP for the Euro Area respond to the different energy price shocks. Particular emphasis is placed on distinguishing between the periods preceding the outbreak of the COVID-19 pandemic and the Russia–Ukraine war, and the subsequent periods. Concluding remarks can be found in Section 5.

2 Data

The dataset covers the period from January 2005 to May 2023 and consists of monthly observations for seven time series: gasoline prices, diesel prices, jet fuel prices, natural gas prices, electricity prices, as well as headline inflation (HICP) and core inflation (HICP excluding energy, food, alcohol, and tobacco) for the Euro Area. Figure A.1 in the appendix presents the transformed time series, while Table A.1 details the definitions and data sources for each variable.

With five distinct energy sources, a broad spectrum of energy forms utilized in the Euro Area is encompassed by the dataset. The selection of these energy sources follows Kilian and Zhou (2023). To comprehensively capture the inflationary pressures originating from the energy sector, focusing solely on individual energy sources would be insufficient. This is particularly relevant for the post-2020 period, during which several energy prices experienced historically large fluctuations (see Figure A.1).

Households are directly or indirectly affected by energy price shocks in diverse ways. For instance, they directly consume gasoline, diesel, natural gas and electricity, which are also utilized as intermediate goods in the production or transportation of other consumer goods. Therefore, it is essential to also consider energy sources such as jet fuel, which are not part of the HICP but indirectly affect inflation through air travel and air freight transportation.

As emphasized by Kilian (2008), when analyzing the effects of energy prices, it is crucial to not only consider broad energy price indices but also retail or intermediate energy goods prices, given the potentially significant price discrepancies between primary energy sources and the final consumer energy product. For example, during the autumn of 2012, there were notably high diesel prices in Europe, especially for heating oil, even though the price of crude oil was far from its peak. The root cause of this situation was maintenance work carried out in numerous refineries ahead of

the winter season, leading to a divergence in prices between diesel and crude oil.¹

Hence, all time series used in the VAR model in Section 3 were chosen to provide broad coverage of the energy market while staying as close as possible to final consumer energy goods prices. For gasoline and diesel, final consumer prices from the European Commission’s weekly oil bulletin are used. These prices closely reflect retail market conditions in the Euro Area. Comprehensive consumer price data for jet fuel are not available across the entire Euro Area. Therefore, an approximation was used, relying on the euro-denominated prices of ‘Jet Kerosene CIF NWE’ from Platts. Kilian and Zhou (2023) also approximates missing final consumer prices using exchange prices. Given that jet fuel is a refined oil product, exchange prices and final consumer prices are expected to closely align.

For natural gas and electricity, Eurostat provides consumer price data for households and non-households only at a semi-annual frequency. Since the VAR model is estimated at a monthly frequency, producer price indices for gas and electricity are used instead. These series are available monthly for the Euro Area starting in 2005. Figure A.2 shows that producer prices closely track the available semi-annual consumer price series.

In the model, the impacts of price changes in energy sources on the HICP and core HICP are examined. The HICP is the key target variable for the ECB’s monetary policy decisions, while core HICP allows for an analysis of the extent to which energy price shocks affect other less volatile goods and influence the more fundamental inflation dynamics. Figure A.1 illustrates that substantial fluctuations in the HICP coincide with those in energy prices (e.g., 2008 and 2015), suggesting that energy prices could explain part of the HICP’s behavior. This relationship becomes particularly evident after 2021 when nearly all energy prices experience a prolonged, sharp increase, accompanied by significant rises in HICP and core HICP.

For all time series, logarithmic differences were computed, and each series was demeaned. Additionally, the time series for natural gas, electricity, HICP, and core HICP were seasonally adjusted.² For ease of interpretation, the monthly inflation rates were annualized.

¹See for example “Diesel Price Spikes: A Persistent Phenomenon,” Reuters - Energy & Oil News, October 17, 2012,

<https://www.reuters.com/article/distillate-supply-crunch-idAFL5E8LCEXP20121017>.

²Seasonal adjustment is performed using the MATLAB X-13 Toolbox, which implements the X-13 ARIMA-SEATS seasonal adjustment procedure developed by the U.S. Census Bureau.

3 Structural VAR Model for Energy Prices

To analyze the effects of energy price shocks on inflation, a structural VAR model is employed. The reduced-form representation of the model is given by

$$y_t = A_1 y_{t-1} + \dots + A_p y_{t-p} + u_t \quad (1)$$

where $y_t = (y_{1t}, \dots, y_{Kt})'$ is a vector of K endogenous variables, A_1, \dots, A_p are $K \times K$ coefficient matrices and $u_t = (u_{1t}, \dots, u_{Kt})'$ is a $K \times 1$ vector of reduced-form error terms with a $K \times K$ invertible variance-covariance matrix Σ_u . The lag length of the VAR model is specified as $p = 6$, which aligns with the common lag length used in the literature for VAR models examining energy price shocks (see, for example, Gao et al. (2014), Conflitti and Luciani (2019), Kilian and Zhou (2023)). This choice of lag length exceeds what typical information criteria would recommend. However, it is essential, as emphasized in the literature, to allow for longer lags in estimating the transmission of energy price shocks effectively.

The shocks in the reduced-form VAR model do not allow for a structural interpretation. To recover economically interpretable shocks, the VAR is transformed into a structural representation:

$$B_0 y_t = B_1 y_{t-1} + \dots + B_p y_{t-p} + \epsilon_t \quad (2)$$

where $B_i = B_0 A_i$ for $i = 1, \dots, p$. ϵ_t is a $K \times 1$ vector of orthogonal shocks with a $K \times K$ variance-covariance matrix denoted as Σ_ϵ . The structural shocks ϵ_t can be expressed as a linear combination of the reduced-form shocks, represented as $\epsilon_t = B_0 u_t$. The matrix Σ_ϵ is diagonal since it captures the instantaneous causality of the variables through B_0 .

The identification of the structural form of the VAR model is achieved by introducing restrictions in the inverse of the instantaneous coefficient matrix B_0 . In terms of identification assumptions, I follow the approach presented by Kilian and Zhou

(2023). They utilize a recursive structure to identify the shocks.

$$\begin{pmatrix} u^{\Delta p^{\text{gasoline}}} \\ u^{\Delta p^{\text{diesel}}} \\ u^{\Delta p^{\text{jet fuel}}} \\ u^{\Delta p^{\text{natural gas}}} \\ u^{\Delta p^{\text{electricity}}} \\ u^{\pi^{\text{HICP}}} \\ u^{\pi^{\text{core HICP}}} \end{pmatrix} = \begin{bmatrix} * & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & 0 & 0 & 0 & 0 & 0 \\ * & * & * & 0 & 0 & 0 & 0 \\ * & * & * & * & 0 & 0 & 0 \\ * & * & * & * & * & 0 & 0 \\ * & * & * & * & * & * & 0 \\ * & * & * & * & * & * & * \end{bmatrix} \begin{pmatrix} \epsilon^{\text{gasoline}} \\ \epsilon^{\text{diesel}} \\ \epsilon^{\text{jet fuel}} \\ \epsilon^{\text{natural gas}} \\ \epsilon^{\text{electricity}} \\ \epsilon^6 \\ \epsilon^7 \end{pmatrix} \quad (3)$$

Entries marked with * denote unrestricted parameters in the matrix of contemporaneous effects B_0^{-1} . The model is partially identified, focusing solely on the identification of energy price shocks. The estimates regarding the effects of energy price shocks on inflation measures are not influenced by the non-identification of all structural shocks (Keating, 1996).

The recursive ordering follows the production chain and market linkages across different energy products. The following discussion explains why these identification assumptions of Kilian and Zhou (2023) are plausible for the Euro Area as well. The gasoline price shock can be interpreted as a common demand shock that drives up demand and consequently the prices for all energy sources. Diesel and jet fuel are additionally affected by fuel-specific shocks. Furthermore, the jet fuel price can be affected by the diesel-specific price shock. This can be explained by situations in which, under normal circumstances, the more expensive jet fuel is blended with diesel by European refiners when the jet fuel price falls significantly and is expected to remain below the diesel price for an extended period. A prominent example of this is the COVID-19 pandemic, during which the jet fuel price in Europe reached a 20-year low. European refiners continued to blend jet fuel with diesel well into 2021.³ In situations where jet fuel is relatively inexpensive compared to diesel, it is also used to improve the cold properties of diesel.⁴ This blending of jet fuel into diesel leads to a reduction in the supply of jet fuel, thereby raising prices. Conversely, the impact of a jet fuel-specific price shock on the diesel price can be neglected due to the differing

³See for example "Sluggish jet demand to cap European crude refinery runs, FGE says", Reuters - Energy, June 25, 2021, <https://www.reuters.com/business/energy/sluggish-jet-demand-cap-european-crude-refinery-runs-fge-says-2021-06-25/>.

⁴See for example "Jet fuel being bought for blending into diesel for winter spec: traders", S&P - Oil, October 14, 2016, <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/101416-jet-fuel-being-bought-for-blending-into-diesel-for-winter-spec-traders>.

market sizes. Diesel consumption in the Euro Area has been approximately six times higher than that of jet fuel over the last decade.

The natural gas price can also be influenced by the gasoline price, as economic expansion tends to impact not only gasoline prices but also, typically, natural gas prices. Furthermore, in Europe, approximately 23% of the natural gas sold in 2021 was still priced using oil price indexation, indicating some dependency of the natural gas price on oil prices.⁵ The natural gas price is also affected by a natural gas-specific price shock. Geopolitical tensions, as seen in the Russia–Ukraine war of 2022, the civil war in Libya in 2011 and the Russian-Ukrainian transit dispute of January 2009 resulting in significant supply shortfalls of natural gas in the Euro Area, can lead to gas price developments independent of oil-based energy sources (Nick and Thoenes, 2014).

Electricity prices are ordered after natural gas prices. In European wholesale electricity markets, prices are determined according to a marginal pricing mechanism. Since natural gas–fired power plants frequently act as the marginal generator, fluctuations in natural gas prices can translate directly into changes in electricity prices (Gruber et al., 2022). Therefore, in the VAR model, the electricity price can be influenced by both the natural gas-specific price shock and the gasoline price shock. Electricity prices may also respond to shocks affecting other generation inputs, such as coal⁶ or renewable energy sources, which are captured by the electricity-specific shock.

For the Euro Area, the substitutability between diesel and natural gas and, consequently, for electricity can be neglected (the same applies to jet fuel, as it is closely associated with diesel in production). Diesel and jet fuel are virtually unused for electricity production in the Euro Area, accounting for only 0.5% of gross electricity production in 2021. Conversely, electricity plays a minor role in the production of diesel and jet fuel. Following the approach of Kilian and Zhou (2023), exclusion restrictions for the effects of diesel-specific price shocks and jet fuel-specific price shocks on the natural gas price and the electricity price are not implemented. Instead, the recursive structure of the model is retained to avoid overidentification, which complicates inference (Sims and Zha, 1998). The results of the VAR model also show that the impact response of the natural gas price and the electricity price to a diesel-specific

⁵Cf. "2022 Global Wholesale Gas Price Survey Report", International Gas Union, London, October 5, 2022.

⁶81% of coal use in the Euro Area has been for electricity generation or combined electricity-heat generation since 2005.

and jet fuel-specific price shock is very close to zero and statistically insignificant. This provides strong evidence that substitution effects between these energy sources can be ignored.

Furthermore, the findings of Kilian and Vega (2011) that gasoline price shocks are predetermined with respect to inflation are applied analogously to the other energy-specific price shocks. This justifies the exclusion restrictions in the last two columns of the matrix B_0^{-1} and allows for the description of the structural VAR model as in Equation 3.

The VAR is estimated using Bayesian methods with a normal–inverse–Wishart prior, a standard choice in the literature on energy price shocks (e.g., Peersman and van Robays (2014); Kilian and Zhou (2022b,a, 2023)). The prior distributions are given by

$$p(\beta|\Sigma) \sim N(\beta_0, \Sigma \otimes H) \quad (4)$$

$$p(\Sigma) \sim IW(S_0, \nu_0) \quad (5)$$

where β_0 is the prior mean of the lag coefficients. H is a diagonal matrix with the following i^{th} diagonal elements:

$$\left(\frac{\lambda_0 \lambda_1}{p^{\lambda_2} \sigma_i} \right)^2 \quad (6)$$

where σ_i is approximated by the variance of the error terms in an AR(1) regression for the respective variable in the model, and p is the lag. S_0 is also a diagonal matrix with diagonal elements:

$$\left(\frac{\sigma_i}{\lambda_0} \right)^2 \quad (7)$$

The mean for all lag coefficients, β_0 , is set to zero. The parameters are chosen according to the literature: $\lambda_0 = 1$, $\lambda_1 = 0.2$, $\lambda_2 = 1$, and $\nu_0 = n + 2$.

Following the simulation of the posterior distribution of the impulse responses, I adopt the methodology proposed by Inoue and Kilian (2022) for estimating the impulse response functions and constructing the joint credible sets. In this context, an absolute loss function is employed as the chosen criterion. The same approach is applied in the historical decomposition discussed in Section 4.3.

4 Findings from the Empirical Analysis

4.1 Responsiveness of Inflation to Energy Price Shocks

The VAR model is estimated for two sample periods. The first period spans from January 2005 to December 2019 (EP 2019) and represents the pre-pandemic period. The second period extends the sample until May 2023 (EP 2023) and therefore includes both the COVID-19 pandemic and the European energy crisis following Russia’s invasion of Ukraine. This split allows the analysis of whether the transmission of energy price shocks to inflation changed during these episodes.

Figure 1 presents the impulse response functions of HICP to one-standard-deviation energy price shocks estimated for the EP 2019 period.

The largest response of HICP is observed in response to a gasoline shock, showing an on-impact effect of 1.2%. However, this effect diminishes rapidly in the first two months following the shock and approaches near-zero levels after six months. Moreover, after the second month following the shock, the effect ceases to maintain statistical significance.

In contrast, the on-impact effect of a diesel-specific price shock is notably smaller at 0.4%. This discrepancy in effect size can be attributed, in part, to the inherent distinctions in shock magnitudes. If a diesel-specific price shock equivalent to one standard deviation of a gasoline price shock were employed, the impact effect would reach 0.7%. It is noteworthy that although gasoline exhibits a higher weight in the HICP compared to diesel, of approximately 23% on average for the years 2017 to 2019⁷, this difference has negligible implications due to gasoline’s modest weight of approximately 2% and a shock size of less than 3%.

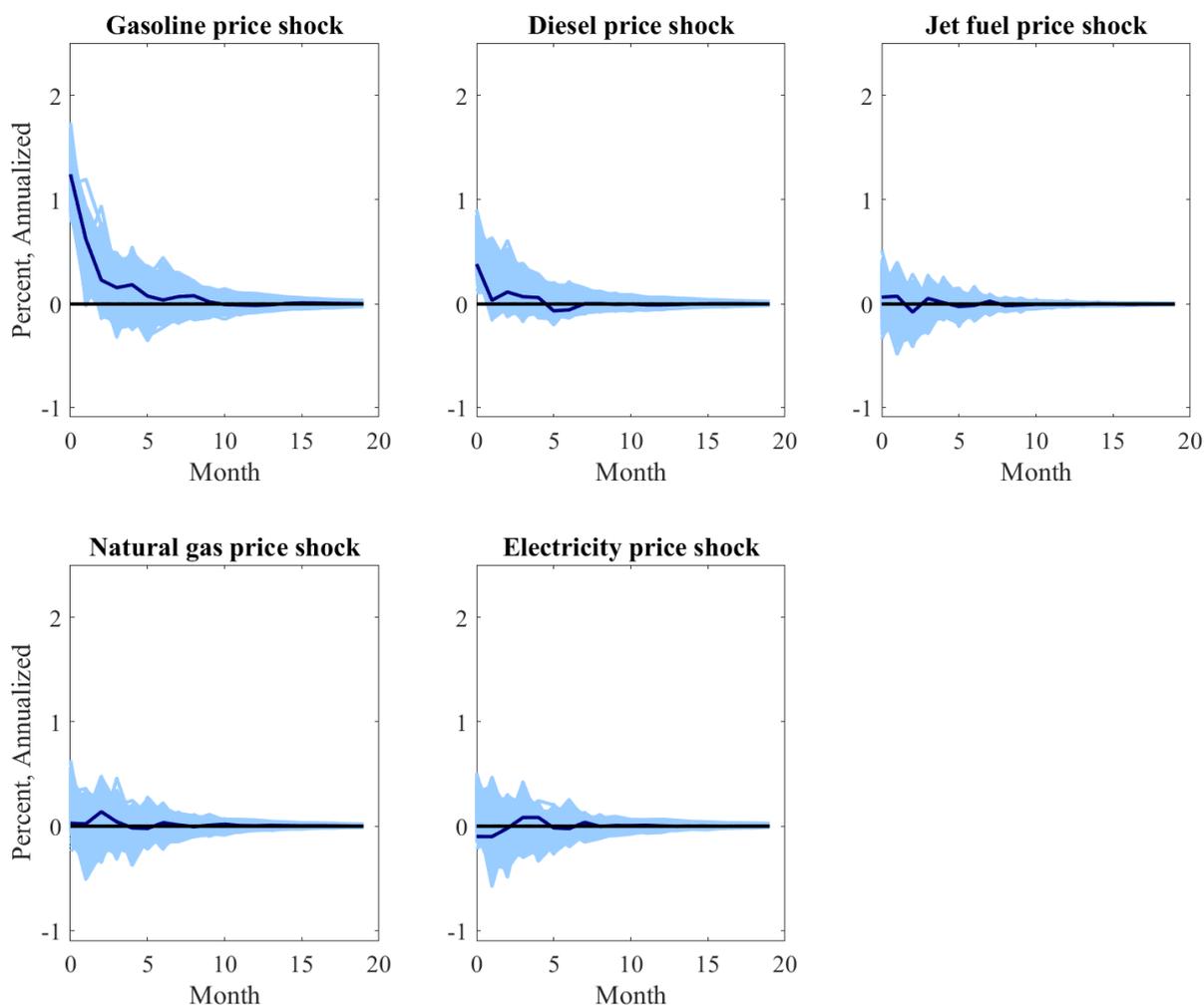
Jet fuel, which is not part of the HICP, has an indirect impact on the prices of goods included in the HICP when subjected to price shocks. While certain goods, like air travel or transporting goods by air, could theoretically affect the inflation rate, a shock in jet fuel prices has almost no noticeable effect on the HICP.

Natural gas and electricity price shocks also have only limited effects on HICP in the EP 2019 period. This partly reflects the relatively low volatility of these prices during most of the pre-2020 sample.

Overall, the effects of energy price shocks on monthly inflation appear to be short-lived during the EP 2019 period. In most cases the responses return close to zero

⁷Not until the year 2017 did Eurostat commence the separate reporting of the weighting for gasoline and diesel within the Euro Area. For the period spanning from 2017 to 2019, the average weighting for gasoline exceeded that of diesel by 23%.

Figure 1. IRFs of Energy Price Shocks on HICP (EP 2019)



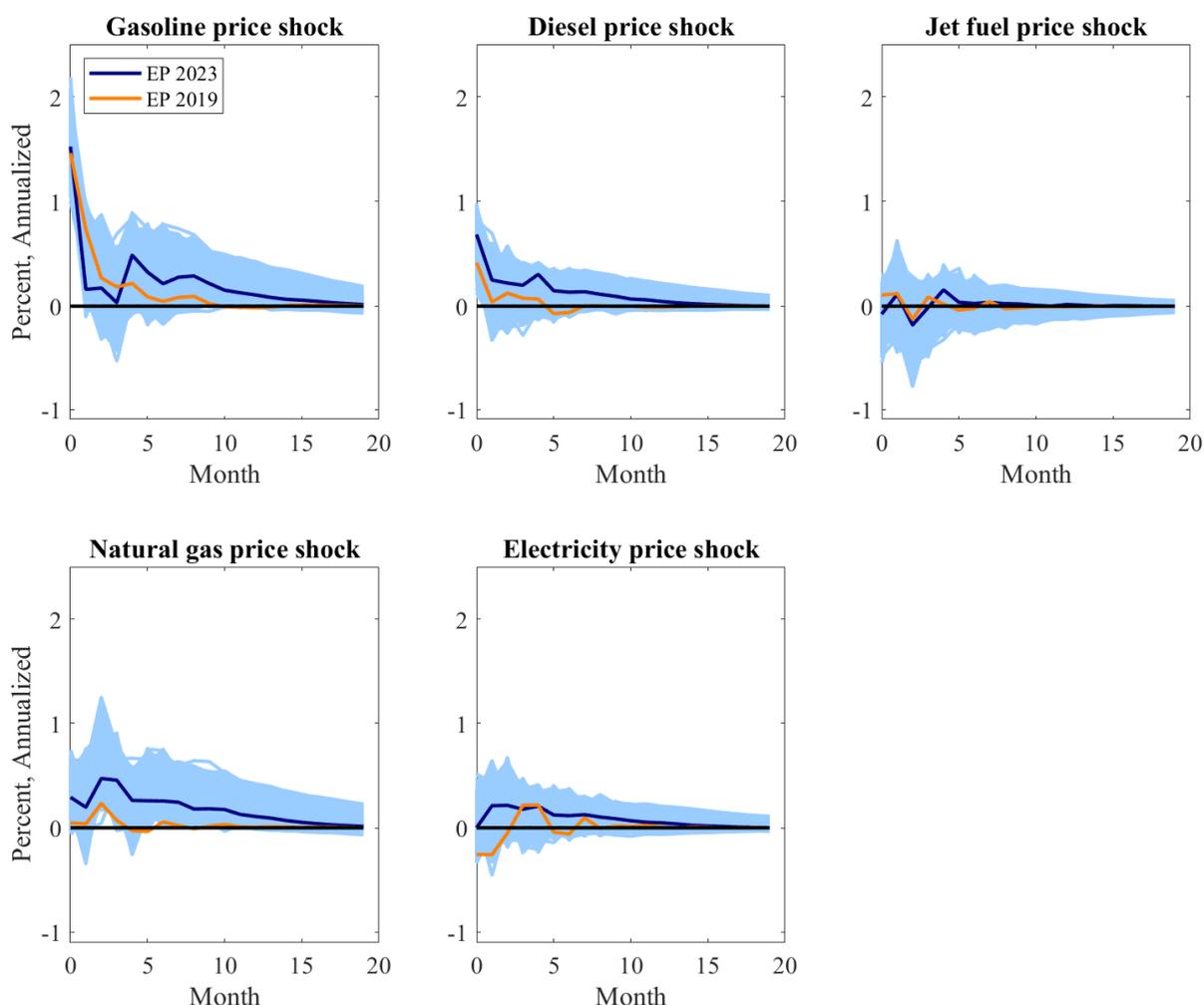
The impulse response functions illustrate the impact of respective energy price shocks at the magnitude of one standard deviation on the seasonally adjusted monthly HICP (annualized). The light blue impulse response functions delineates the 68% joint credible set. These estimations were derived using data spanning from January 2005 to December 2019 (EP 2019).

within a few months. It should be noted, however, that the joint credible sets remain relatively wide for several months following the shock. Using year-on-year inflation instead of annualized monthly inflation would mechanically generate more persistent responses due to base effects.

Figure B1 shows the responses of core HICP to the same energy price shocks. Across all shocks there is no statistically significant effect on core inflation. This suggests that energy price shocks during the EP 2019 period had only very limited spillover effects on non-energy goods prices.

For the extended estimation period EP 2023, which includes both the COVID-19 pandemic and the European energy crisis, Figure 2 compares the impulse responses estimated over the full sample with those obtained for the pre-pandemic period. To facilitate comparability, the shocks in the EP 2019 estimation are rescaled to match the standard deviation of shocks observed in the EP 2023 sample.

Figure 2. IRFs of Energy Price Shocks on HICP (EP 2023 and EP 2019)



The impulse response functions illustrate the effects of respective energy price shocks on the seasonally adjusted monthly HICP (annualized). Estimations were conducted using data spanning from January 2005 to May 2023 (EP 2023, depicted in dark blue) and January 2005 to December 2019 (EP 2019, depicted in orange). The light blue impulse response functions delineates the 68% joint credible set for the period EP 2023. The shock size for the period EP 2023 corresponds to one standard deviation of the respective energy price shocks. To ensure comparability, the initial energy price shock size for the period EP 2019 was scaled to the same value as in the estimation for the period EP 2023.

For gasoline, diesel, natural gas, and partially for electricity-specific price shocks, it is noteworthy that the effects of these shocks on the HICP are more pronounced and partly exhibit more persistence. While the impact of price shocks in the period EP 2019 typically returned to near-zero levels within six months, these effects only dissipated after two to two and a half years in the period EP 2023.

In particular, natural gas price shocks exhibit statistically significant effects several months after the initial shock, especially between months six and nine. These results highlight the important role of natural gas price developments during the European energy crisis. The effect of an electricity specific price shock is in this second estimation period constantly positive, although not statistically significant.⁸

The impulse response function for jet fuel price shocks changes only slightly between the two estimation periods, despite the large fluctuations in jet fuel prices during the COVID-19 pandemic. An explanation for this phenomenon could be that, while jet fuel prices significantly dropped at the onset of the pandemic, services directly dependent on jet fuel such as air travel were rendered impossible due to government-imposed restrictions during the COVID-19 pandemic. As a result, the costs of these services may not have declined and may even have increased.

Figure B2 presents the corresponding impulse responses for core HICP. Even in the EP 2023 period, energy price shocks have only very limited effects on non-energy goods prices. Overall, these results indicate that spillover effects of energy price shocks to core inflation remain limited.

4.2 Influence of Energy Price Shocks on Variability of Inflation

Table 1 reports the variance decomposition of HICP and core HICP for the EP 2019 and EP 2023 estimation periods. For the EP 2019 period, gasoline price shocks explain the largest share of HICP fluctuations, accounting for about 44% of its variance. Diesel-specific price shocks explain an additional 9%, while the combined contribution of jet fuel, natural gas, and electricity price shocks remains below 3%.

In contrast, energy price shocks explain only a very small fraction of the variance of core HICP during this period. Gasoline price shocks account for roughly 2% of the variance, while the contributions of the remaining energy shocks are negligible. This reaffirms the notion that energy price shocks have exerted negligible influence

⁸It should be noted that interpreting the impulse response function for the electricity specific price shock during the EP 2019 period is constrained due to the adjustment of the shock size to match the initial size observed in EP 2023, which are higher than the highest shock levels during EP 2019.

Table 1. Variance Decomposition of HICP and Core HICP (baseline model)

Explained Variable	Estimation Period	Share of variance explained by energy price shock				
		Gasoline Price Shock	Diesel Price Shock	Jet Fuel Price Shock	Natural Gas Price Shock	Electricity Price Shock
HICP	EP 2019	44.4	9.0	0.4	1.5	0.8
Core HICP	EP 2019	1.6	0.7	0.3	0.8	1.2
HICP	EP 2023	36.8	5.2	0.8	18.2	2.2
Core HICP	EP 2023	5.3	1.4	2.2	6.8	0.8

In the table, the percentage share of the variance in both HICP and core HICP explained by the various energy-specific price shocks is provided. The estimation period considered for this analysis spans from January 2005 to December 2019 (EP 2019) and from January 2005 to May 2023 (EP 2023).

on non-energy commodities within the EP 2019 period.

A somewhat similar pattern emerges when considering the extended estimation EP 2023 period but with some notable changes. Gasoline price shocks continue to explain the largest share of HICP variance, accounting for about 37%. Diesel-specific shocks contribute a small share of around 5%. However, the importance of natural gas price shocks increases substantially, rising from 2% in the EP 2019 period to 18% in the EP 2023 estimation. This highlights the growing importance of natural gas price developments during the European energy crisis. Jet fuel and electricity-specific shocks continue to explain only a small fraction of HICP fluctuations (combined contribution remaining around 3%).

The explanatory power of energy price shocks for core HICP also increases in the EP 2023 period. Energy price shocks together account for about 17% of the variance in core inflation, whereas their contribution in the EP 2019 sample was below 5%. Gasoline and natural gas shocks explain the largest shares, contributing roughly 5% and 7%, respectively. Although the overall contribution remains limited, the results indicate that energy price shocks have had a somewhat stronger influence on non-energy goods prices since 2020.

4.3 Influence of Energy Price Shocks on Inflation Amidst the COVID-19 Pandemic and the Russia–Ukraine war

To assess the contribution of energy price shocks to inflation during the COVID-19 pandemic and the onset of the Russia–Ukraine war, I perform a historical decomposition of monthly HICP and core HICP (both annualized). The decomposition isolates the cumulative contribution of the identified energy price shocks to observed inflation. Figure 3 displays three panels: the monthly HICP along with the cumulative impact of gasoline price shocks (top panel), natural gas-specific price shocks (middle panel), and the cumulative price shock of all five energy sources combined (bottom panel) from January 2019 to May 2023. Each panel also reports the counterfactual path of inflation in the absence of the respective shocks.

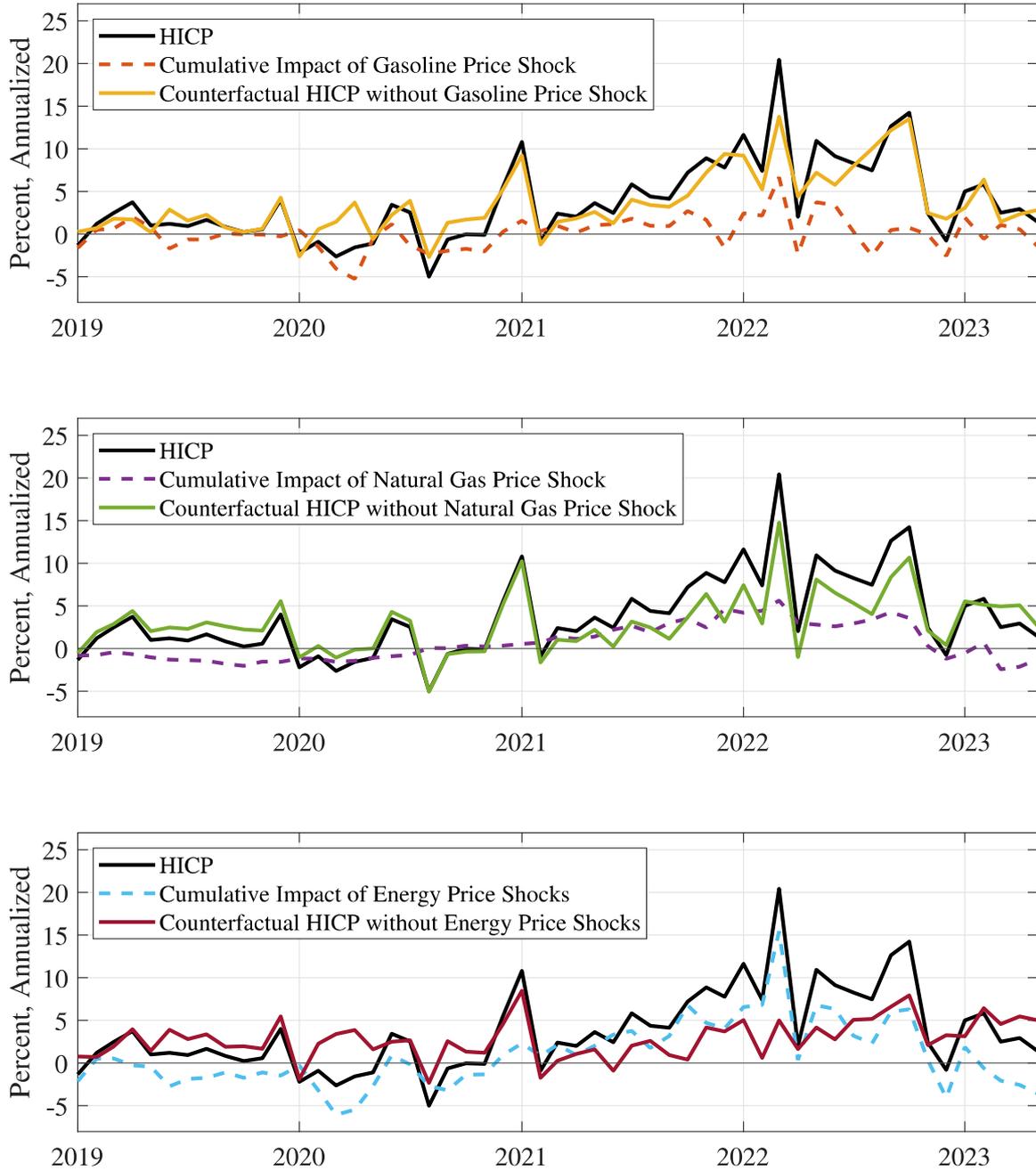
At the onset of the COVID-19 pandemic, gasoline price shocks exerted strong deflationary pressure on inflation. In April 2020, gasoline price shocks reduced the HICP by approximately 5.2 percentage points (annualized). During the remainder of 2020, the deflationary effect gradually diminished, averaging around -1.1 percentage points in the second half of the year. Other energy price shocks played only a minor role during this period. Accordingly, the cumulative contribution of gasoline price shocks closely tracks the combined contribution of all energy price shocks in 2020.

In 2021, the inflationary effect of natural gas-specific price shocks on the HICP (middle panel) proved to be highly persistent. Throughout the entire year of 2021, this effect steadily increased and reached its peak at 5.7 percentage points with the outbreak of the Russia–Ukraine war in March 2022. The effect gradually declined during the course of 2022 and returned close to zero toward the end of the year.

The surge in natural gas prices in 2021 can be attributed to various factors. The economic recovery following the COVID-19 pandemic led to an increasing demand for natural gas, coupled with tight supply conditions and intense competition for LNG between Europe and Asia. Additionally, gas reserves were at historically low levels after a relatively cold winter. By April 2021, gas reserves were only at 29%, whereas in the years 2018-2020, they averaged at 42% in the Euro Area.⁹ Throughout the year, the Russian state-owned energy company Gazprom did not replenish its European gas reserves for the winter of 2021/2022. While in the years 2018-2020, Gazprom's gas storage facilities were typically 91% full by September, they were only 26% full

⁹Calculations are based on data from the AGSI+ Platform of Gas Infrastructure Europe (<https://agsi.gie.eu/>). The countries considered for the Euro Area are Austria, Belgium, Croatia, France, Germany, Italy, Latvia, Netherlands, Portugal, Slovakia, and Spain. Monthly averages were derived from daily data.

Figure 3. Historical Decomposition of HICP



In the three graphs, the seasonally adjusted monthly HICP (annualized) is compared with the cumulative impact of gasoline, natural gas-specific price shocks, and the cumulative price shock of all five energy sources combined for the period from January 2019 to May 2023. The counterfactual HICP is derived as the difference between the HICP and the respective cumulative impact of energy price shocks.

in September 2021.¹⁰

The escalating tensions in the conflict between Russia and Ukraine contributed to growing unease in gas markets and a significant rise in gas prices (see the upper panel of Figure A.2). These factors have had a substantial and enduring impact on the price of natural gas and, consequently, on the inflation rate in the Euro Area. Concerning other energy sources, gasoline also had a significant effect on the HICP, with an increase of 6.7 percentage points in March 2022 coinciding with the outbreak of the war.

In summary, when considering the bottom panel of Figure 3, it becomes evident that energy prices, especially those of natural gas and gasoline, collectively played a significant role in driving historically high inflation rates in 2021 and 2022. In the absence of these shocks, inflation would have remained substantially lower during this period.

Figure B3 presents the corresponding historical decomposition for core HICP. From the summer of 2021 through the end of 2022, energy price shocks have indeed had a noticeable impact on the core inflation rate. The effect is relatively persistent, spanning nearly 1.5 years from mid-2021 to end of 2022. The natural gas-specific price shock had by far the most substantial effect. While the gasoline price shock also consistently contributed to inflation from mid-2021 through the end of 2022, its impact was comparatively small. Overall, the results suggest that energy price shocks during the European energy crisis generated measurable, but still limited, spillovers to non-energy goods prices.

4.4 Robustness Checks and Sensitivity Analysis

This section reports several robustness checks of the baseline specification presented in Sections 4.1 to 4.3. In particular, the structural VAR model is re-estimated (i) under a cointegrated specification, (ii) with an extended lag length of 12 months instead of 6, and (iii) over an alternative estimation period. Overall, the results of the baseline model prove to be robust across these alternative specifications.

Cointegration. If some energy prices are cointegrated and share a long-run equilibrium relationship, estimating the VAR in log-differences could lead to a misspecified model (Kilian and Zhou, 2023). Several energy prices exhibit clear comovement

¹⁰Refer to Footnote 9. The gas storage facilities attributed to Gazprom include UGS Jemgum H (astora), UGS Bergermeer, UGS Dambořice, UGS Etzel EKB, and UGS Haidach (astora).

over time. In particular, gasoline, diesel, and jet fuel prices are closely linked as refined petroleum products. Cointegration between oil-based fuels and natural gas also appears plausible, especially during earlier parts of the sample when natural gas contracts in Europe were frequently indexed to oil prices. As demonstrated by Yorucu and Bahramian (2015), there was a strong influence of oil prices on natural gas prices in Europe during the 2000s. At the beginning of the sample period in 2005, approximately 78% of natural gas contracts were priced using Oil Price Escalation (OPE), while only 15% were priced under Gas-on-Gas Competition.¹¹ The share of OPE declined gradually to about 23% by 2021.

Given that natural gas is used for electricity production and considering the merit order pricing of electricity, a long-term divergence between electricity and natural gas prices appears unrealistic. The 2022 energy crisis demonstrated the strong dependence of European electricity prices on gas prices. Assuming cointegration between natural gas and gasoline prices in the cointegration model, cointegration between electricity and gasoline is directly implied.

Specifically, for the cointegration model, the log-differences of the corresponding energy prices ($\Delta p_t^j = \ln(P_t^j) - \ln(P_{t-1}^j)$) are replaced by the following relative-price transformations:

$$\Delta p_t^{\text{diesel}} \quad \text{by} \quad \ln(P_t^{\text{diesel}}) - \ln(P_t^{\text{gasoline}}) \quad (8)$$

$$\Delta p_t^{\text{jet fuel}} \quad \text{by} \quad \ln(P_t^{\text{jet fuel}}) - \ln(P_t^{\text{gasoline}}) \quad (9)$$

$$\Delta p_t^{\text{natural gas}} \quad \text{by} \quad \ln(P_t^{\text{natural gas}}) - \ln(P_t^{\text{gasoline}}) \quad (10)$$

$$\Delta p_t^{\text{electricity}} \quad \text{by} \quad \ln(P_t^{\text{electricity}}) - \ln(P_t^{\text{gasoline}}) \quad (11)$$

For the EP 2019 period, the results of the cointegration model are very similar to those of the baseline specification. The impulse response functions indicate that the response of HICP to diesel-specific price shocks is initially somewhat stronger but becomes slightly negative after approximately six months (see Figure C1). In addition, the joint credible sets widen somewhat at longer horizons.

For the extended estimation period EP 2023, the results remain broadly consistent with the baseline model (see Figures C3 and C4). The responses of HICP to gasoline and diesel price shocks become slightly less persistent, while electricity-specific shocks exhibit somewhat more persistent effects. For core HICP, natural gas and electricity

¹¹Cf. International Gas Union (IGU), “The 2022 Wholesale Gas Price Survey Report,” London, October 5, 2022.

price shocks become statistically significant at longer horizons (months 6–12 and 7–16, respectively), although the magnitude of these effects remains small.

Lag length. As discussed in Section 3, the literature emphasizes the importance of allowing for a sufficiently long lag structure when estimating the transmission of energy price shocks. Therefore, the model was re-estimated with a lag length of 12 periods instead of 6 periods. However, no significant differences can be observed in the results concerning the impulse response functions (see Figures C7, C8, C9, and C10), the variance decomposition (see Table C2), or the historical decomposition (see Figures C11 and C12). This indicates that the results are robust with respect to the choice of lag length.

Alternative estimation period. So far, I have examined two estimation periods: one until December 2019 (EP 2019) and the other until May 2023 (EP 2023). These two periods differ in their consideration of the COVID-19 pandemic and the Russia–Ukraine war. Both events have triggered substantial price fluctuations across various energy markets. The Russia–Ukraine war had an immediate impact on the energy markets in the Euro Area, owing to sanctions and the disruption of Russian energy deliveries to Europe. Furthermore, there is the prospect that energy trade relations between Russia and the Euro Area member states will not return to their pre-conflict status in the foreseeable future. Thus, the outbreak of the conflict can be seen as a structural break concerning the effects of energy prices on the inflation rate.

In contrast, the COVID-19 pandemic, which induced supply and demand shocks, some of which were induced by government measures, had only temporary and primarily indirect impacts on the energy markets. Therefore, it can be questioned whether the COVID-19 pandemic has led to structural changes in the energy markets. Consequently, examining a period that encompasses the COVID-19 pandemic but not the Russia–Ukraine war serves as an interesting comparative estimation. Therefore, the structural VAR model was also estimated for the period from January 2005 to August 2021 (EP 2021). The end of the estimation period was chosen because tensions between Russia and Ukraine escalated significantly starting in September 2021.

The impulse response functions for the EP 2021 estimation (Figures C13 and C14) are very similar to those obtained for the EP 2019 period. The main difference is that jet fuel price shocks generate somewhat larger responses of HICP and core HICP,

reflecting the pronounced volatility of jet fuel prices during the COVID-19 pandemic. For the other energy prices, the responses remain largely unchanged.

5 Conclusion

Using a structural VAR model, this study has demonstrated that, up until the end of 2019, gasoline price shocks exerted the most pronounced impact on the HICP within the Euro Area, with the effects of diesel, jet fuel, natural gas, and electricity price shocks being comparatively smaller. Furthermore, these shocks exhibited only marginal spillover effects on non-energy goods, resulting in negligible effects on the core HICP.

Extending the estimation period to May 2023, which encompasses the energy crisis in Europe, reveals an increase in the magnitude of energy shock effects. In particular, natural gas price shocks become significantly more important and exhibit substantially more persistent effects on headline inflation. While spillover effects to core inflation remain relatively small, they become measurable during the period of the energy crisis.

Incorporating a third estimation period, it was demonstrated that the COVID-19 pandemic exerted only minimal influence on the structural relationships of energy price shocks to inflation.

Furthermore, the findings suggest that energy prices, notably natural gas price shocks, played a major role in the surge in Euro Area inflation during 2021 and 2022. This stands in clear contrast to the findings of Kilian and Zhou (2023) for the U.S., who explicitly demonstrated that energy price shocks cannot account for the significant inflationary surge during this period.

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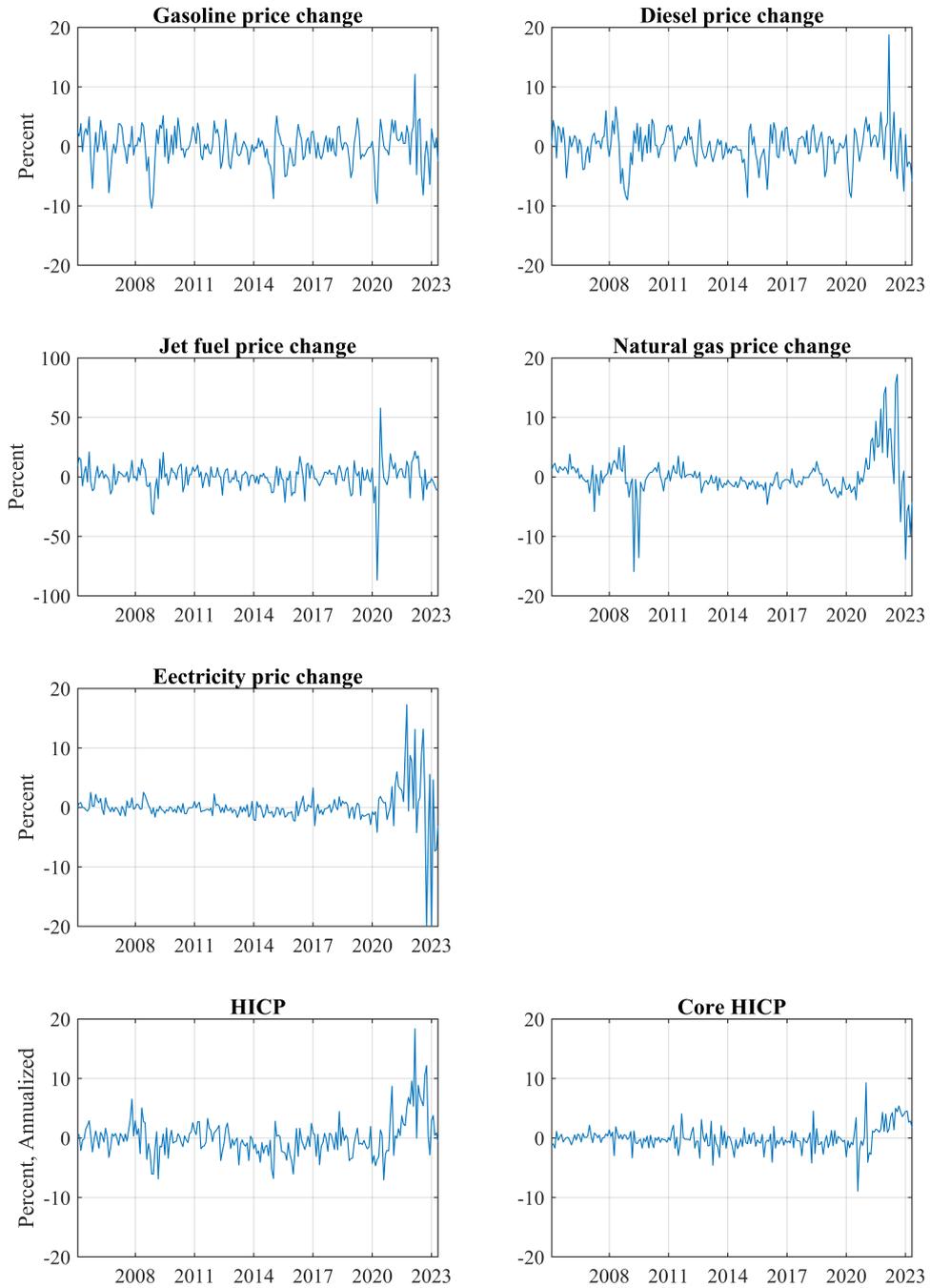
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A Appendix Data

Table A.1. Description Time Series Data

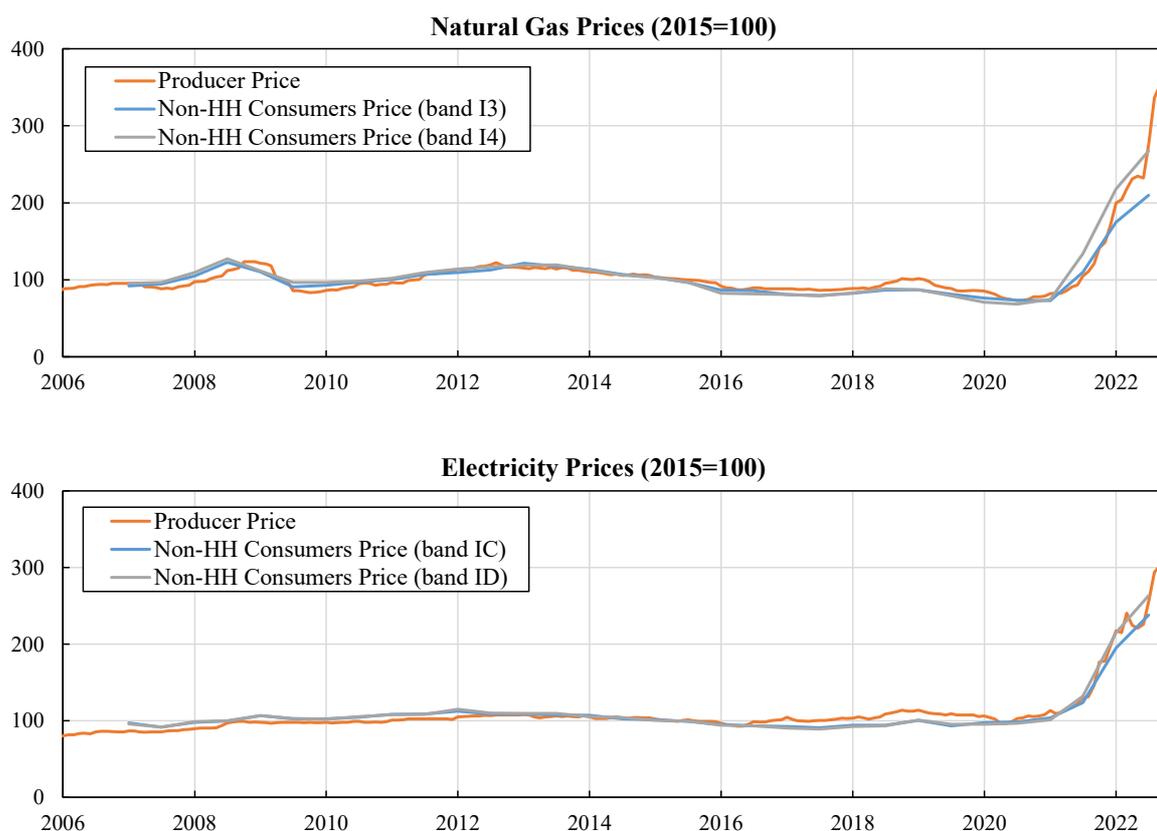
Variable	Description	Source
Gasoline Price	Consumer prices of Euro-super 95 per 1000L inclusive of duties and taxes. From the weekly data, the average for each respective month was computed.	European Commission Weekly Oil Bulletin
Diesel Price	Consumer prices of Automotive gas oil (diesel oil) per 1000L inclusive of duties and taxes. From the weekly data, the average for each respective month was computed.	European Commission Weekly Oil Bulletin
Jet Fuel Price	Jet Kerosene Cost, Insurance and Freight North West Europe, U.S. Dollar per Metric Tonne (Code: JETCNWE). The prices were converted from US dollar to euro.	Refinitiv Eikon
Natural Gas Price	Euro Area producer prices for manufacture of gas and distribution of gaseous fuels through mains (total output price index; Index: 2015=100)	Eurostat
Electricity Price	Euro Area producer prices for electric power generation, transmission and distribution (total output price index; Index: 2015=100)	Eurostat
HICP	Harmonised Index of Consumer Prices monthly data (Index, 2015=100).	Eurostat
Core HICP	Harmonised Index of Consumer Prices monthly data excluding energy, food, alcohol and tobacco (Index, 2015=100).	Eurostat
U.S. Dollars / Euro Exchange Rate	U.S. Dollars to Euro Spot Exchange Rate monthly frequency (daily average) (DEXUSEU)	FRED

Figure A.1. Time Series used for the VAR model of the Euro Area



The graphs depict the time series utilized in the VAR model for the Euro Area. All time series are presented in terms of monthly log-differences and have undergone demeaning. The time series for natural gas prices, electricity prices, HICP, and core HICP have undergone seasonal adjustments. The monthly rates of change for HICP and core HICP were annualized.

Figure A.2. Producer and Consumer Prices for Natural Gas and Electricity

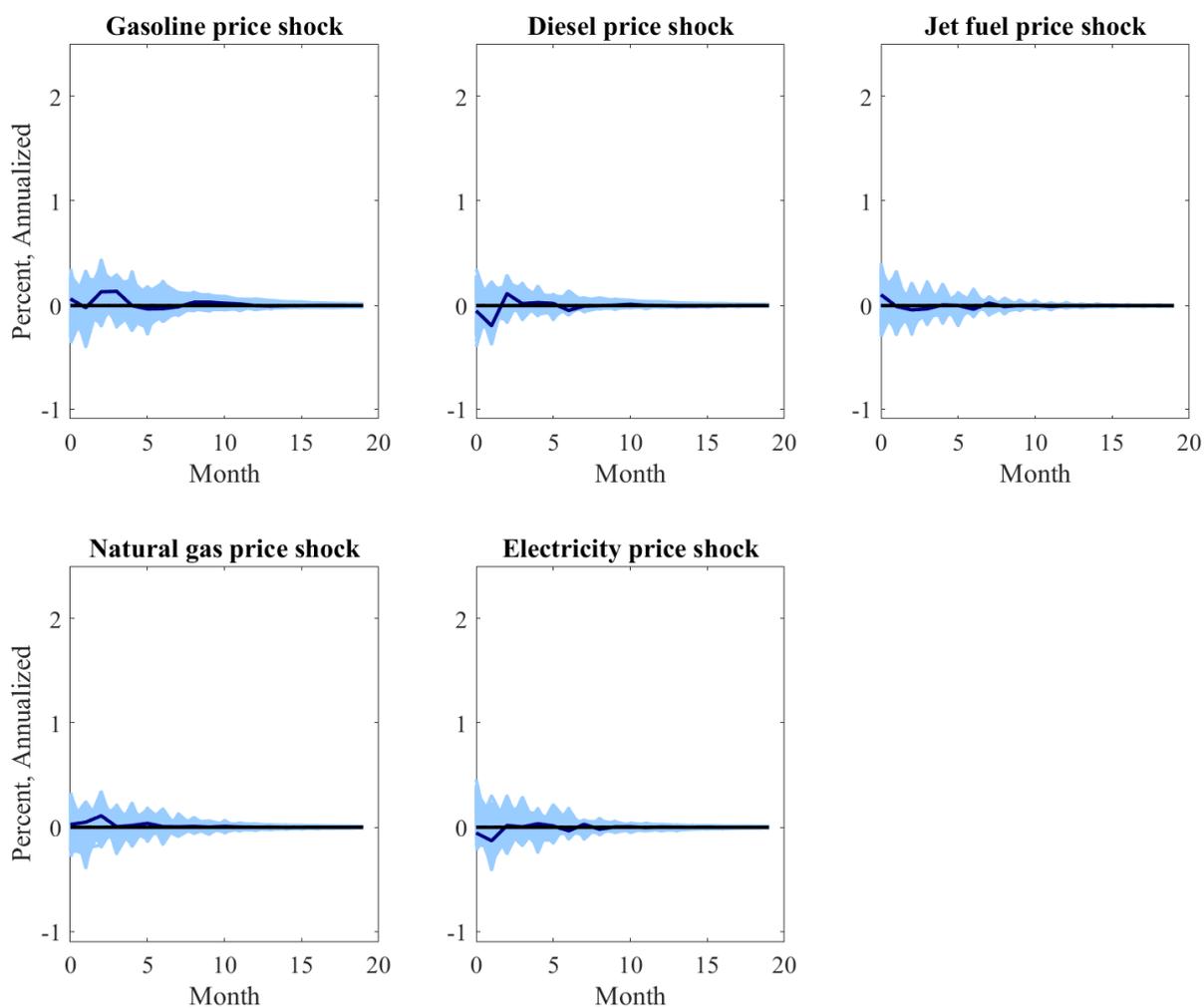


For both natural gas and electricity, producer prices and prices for non-household final consumers move uniformly. For natural gas, producer prices correspond to the monthly time series for "Manufacture of gas; distribution of gaseous fuels through mains" in Eurostat. Non-household final consumer prices are the bi-annual data for consumption from 10,000 to 99,999 gigajoules (band I3) and consumption from 100,000 to 999,999 gigajoules (band I4) excluding taxes and duties. For electricity, producer prices correspond to the monthly time series for "Electric Power Generation, Transmission, and Distribution" in Eurostat. Non-household end-use prices are the bi-annual data for consumption from 500 MWh to 1,999 MWh (band IC) and consumption from 2,000 MWh to 19,999 MWh (band ID) excluding taxes and levies.

For all time series, indexing was applied using the average value of 2015 as the base year, with an index value of 100.

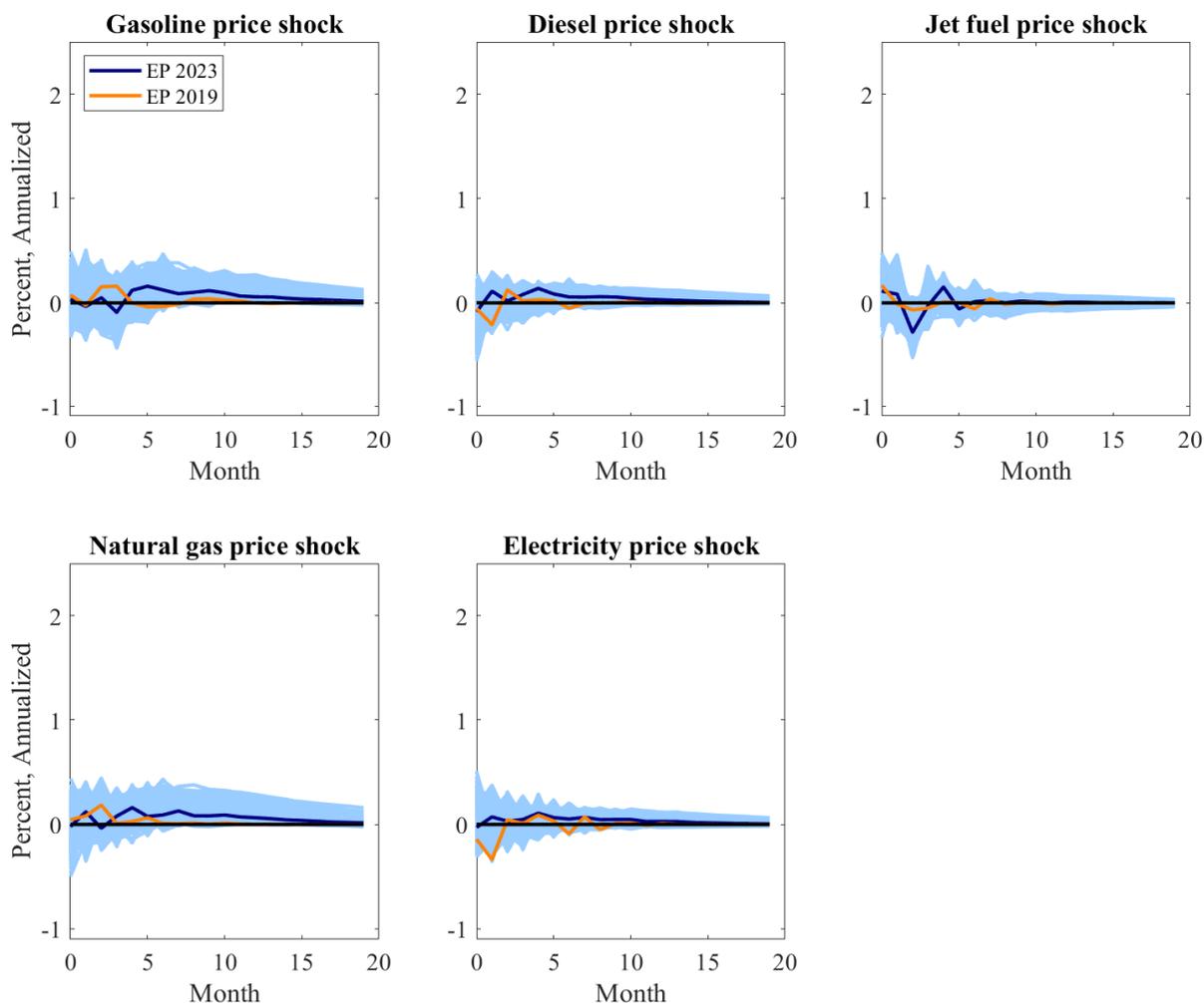
B Appendix Baseline Model

Figure B1. IRFs of Energy Price Shocks on Core HICP (EP 2019, baseline model)



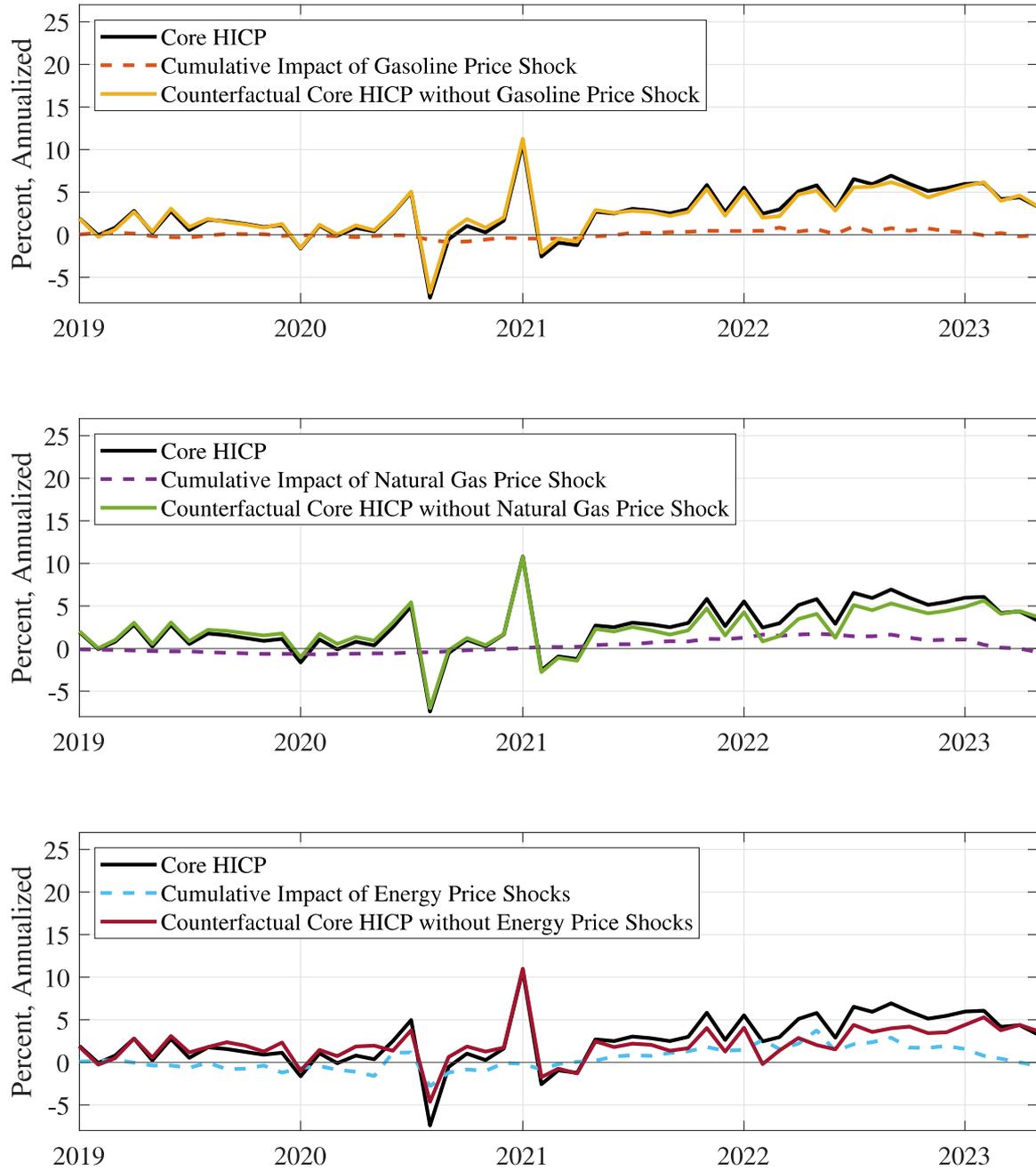
The impulse response functions depict the effect of each respective energy price shock at a level of one standard deviation on the seasonally adjusted monthly core HICP (annualized). Estimations are conducted using data spanning from January 2005 to December 2019 (EP 2019).

Figure B2. IRFs of Energy Price Shocks on Core HICP (EP 2023 and EP 2019, baseline model)



The impulse response functions illustrate the effect of the respective energy price shocks on the seasonally adjusted monthly core HICP (annualized). The estimations were carried out using data for the periods from January 2005 to May 2023 (EP 2023, dark blue) and January 2005 to December 2019 (EP 2019, orange). The light blue region represents the 65% joint credible set for the period EP 2023. The shock size for the period EP 2023 corresponds to one standard deviation of the respective energy price shocks. For the period EP 2019, the initial shock size was scaled to the same value as in the estimation for the period EP 2023 to facilitate comparability.

Figure B3. Historical Decomposition of Core HICP (baseline model)

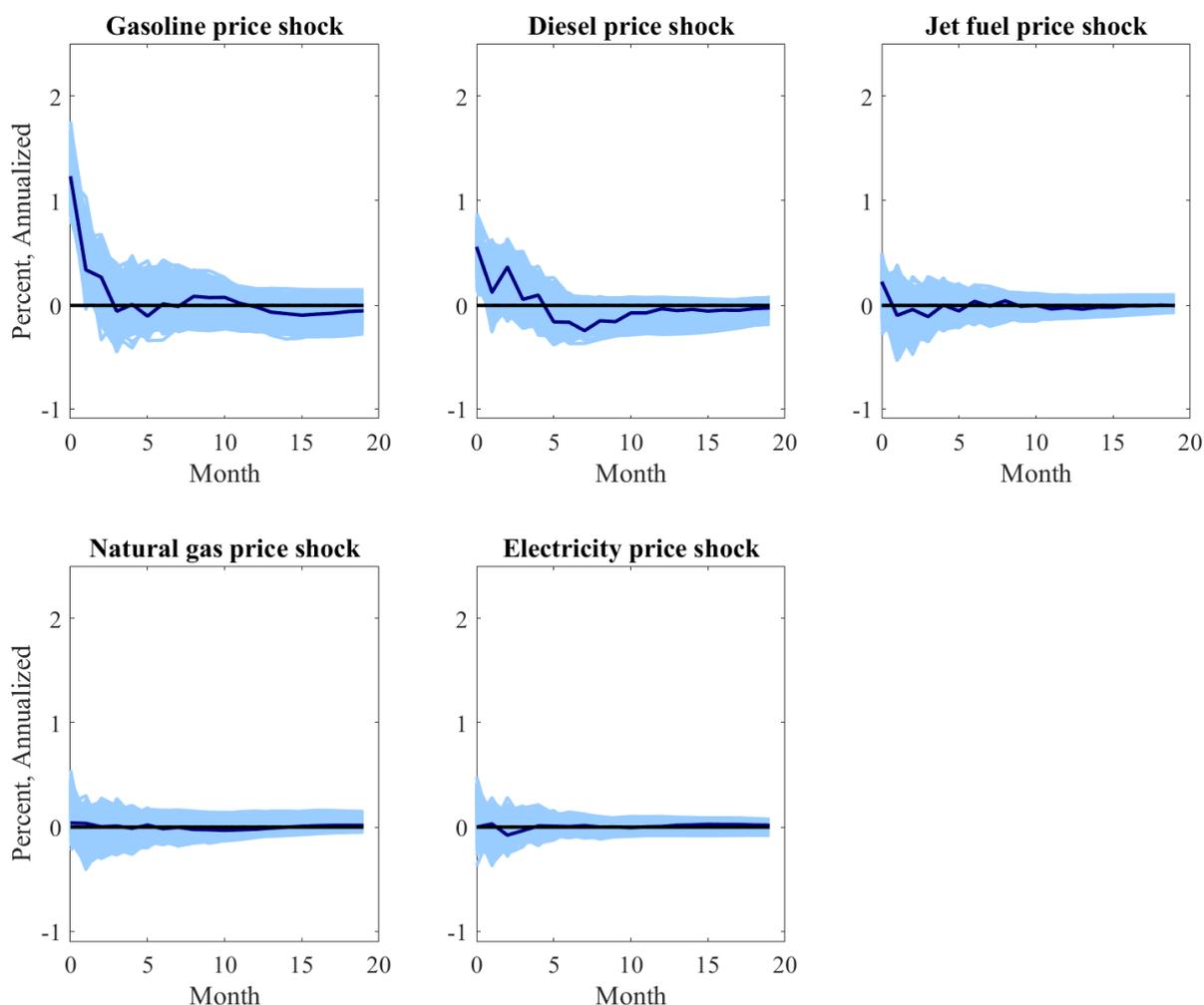


See caption of Figure 3. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP.

C Appendix Robustness Checks and Sensitivity Analysis

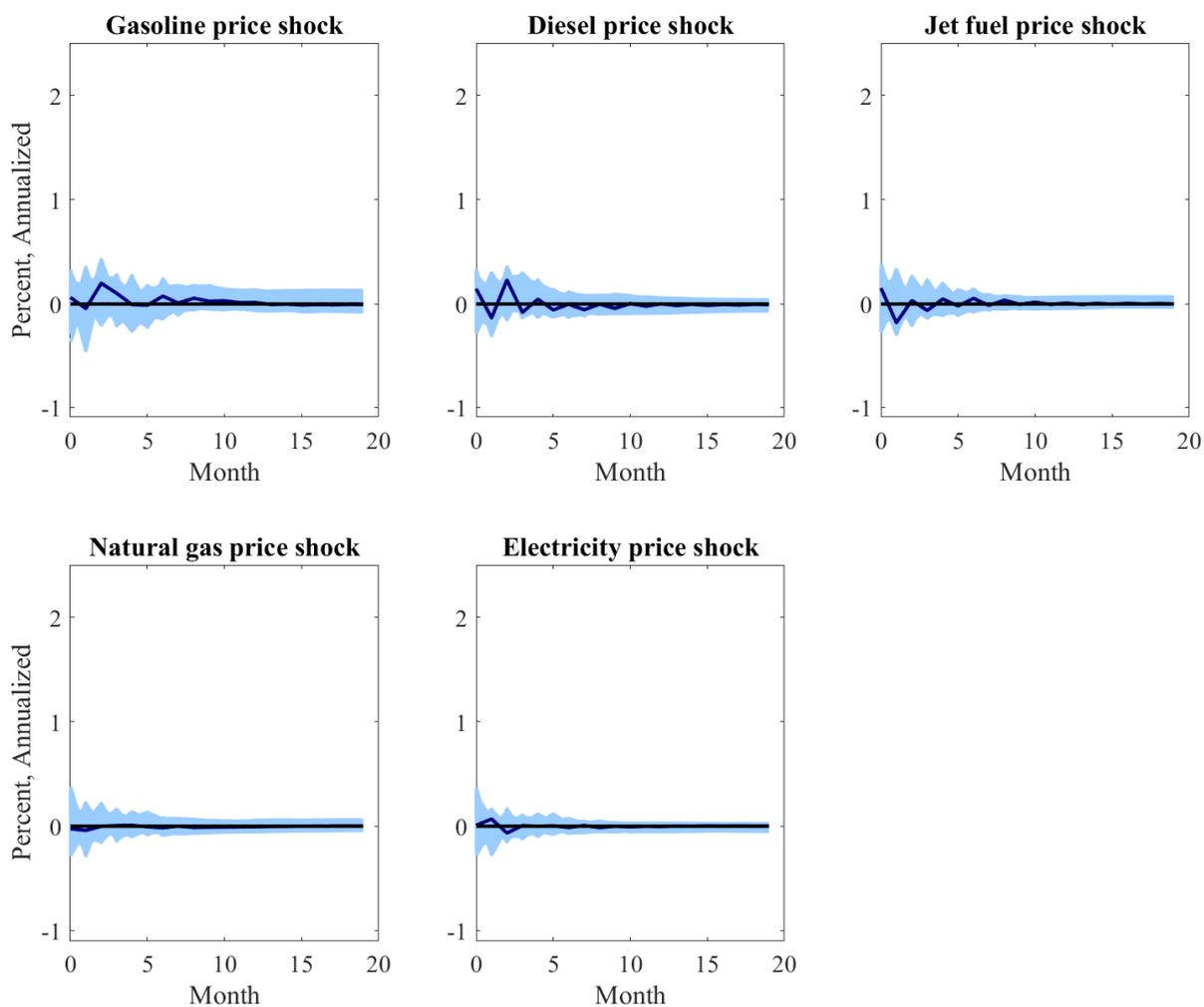
C.1 Cointegrated Models

Figure C1. IRFs of Energy Price Shocks on HICP (EP 2019, cointegrated model)



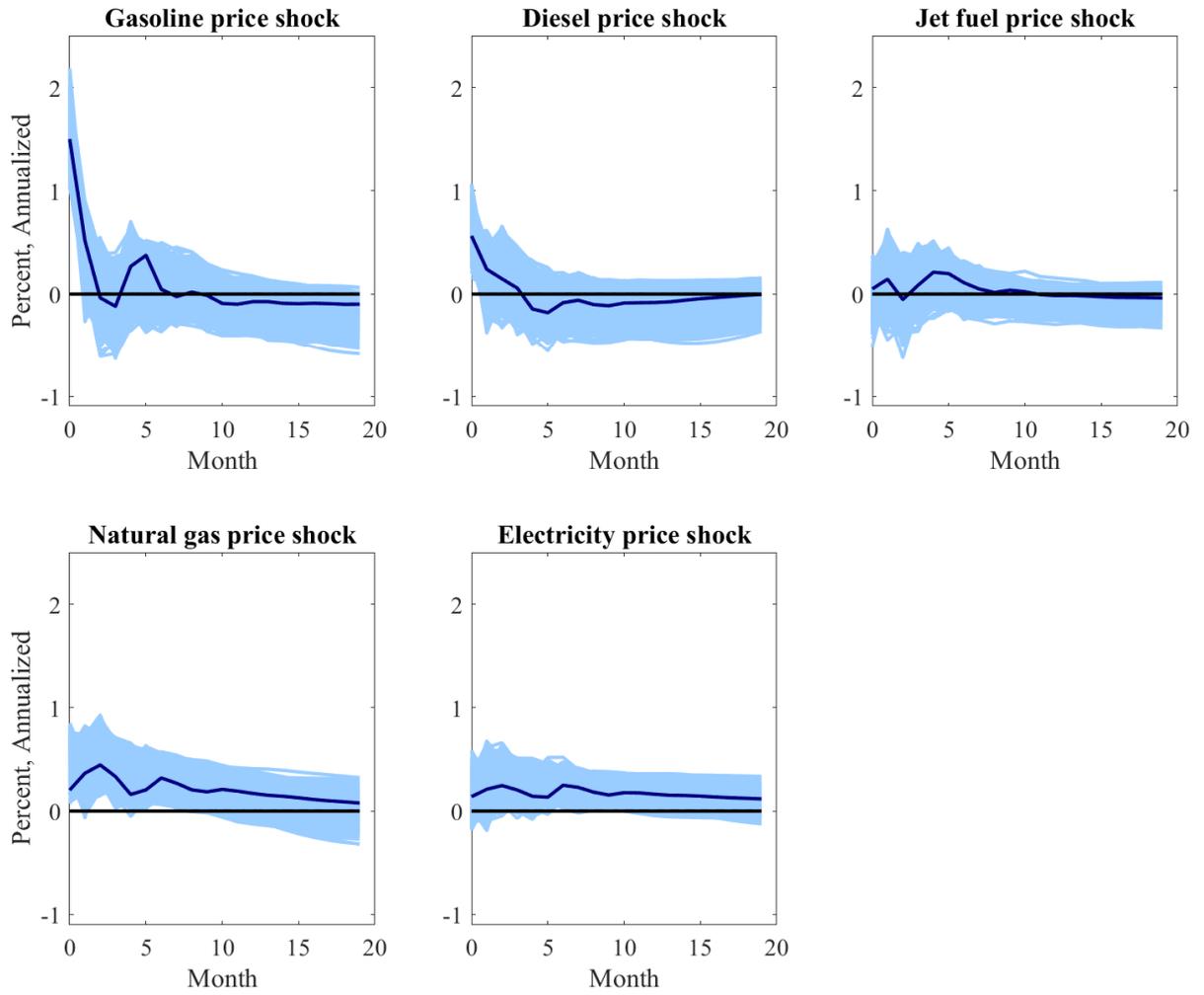
The impulse response functions illustrate the effect of the respective energy price shocks at a level of one standard deviation on the seasonally adjusted monthly HICP (annualized). The light blue region represents the 65% joint credible set. Estimations were conducted using data spanning from January 2005 to December 2019 (EP 2019). It was assumed that gasoline and diesel, gasoline and jet fuel, gasoline and natural gas, as well as gasoline and electricity are cointegrated.

Figure C2. IRFs of Energy Price Shocks on Core HICP (EP 2019, cointegrated model)



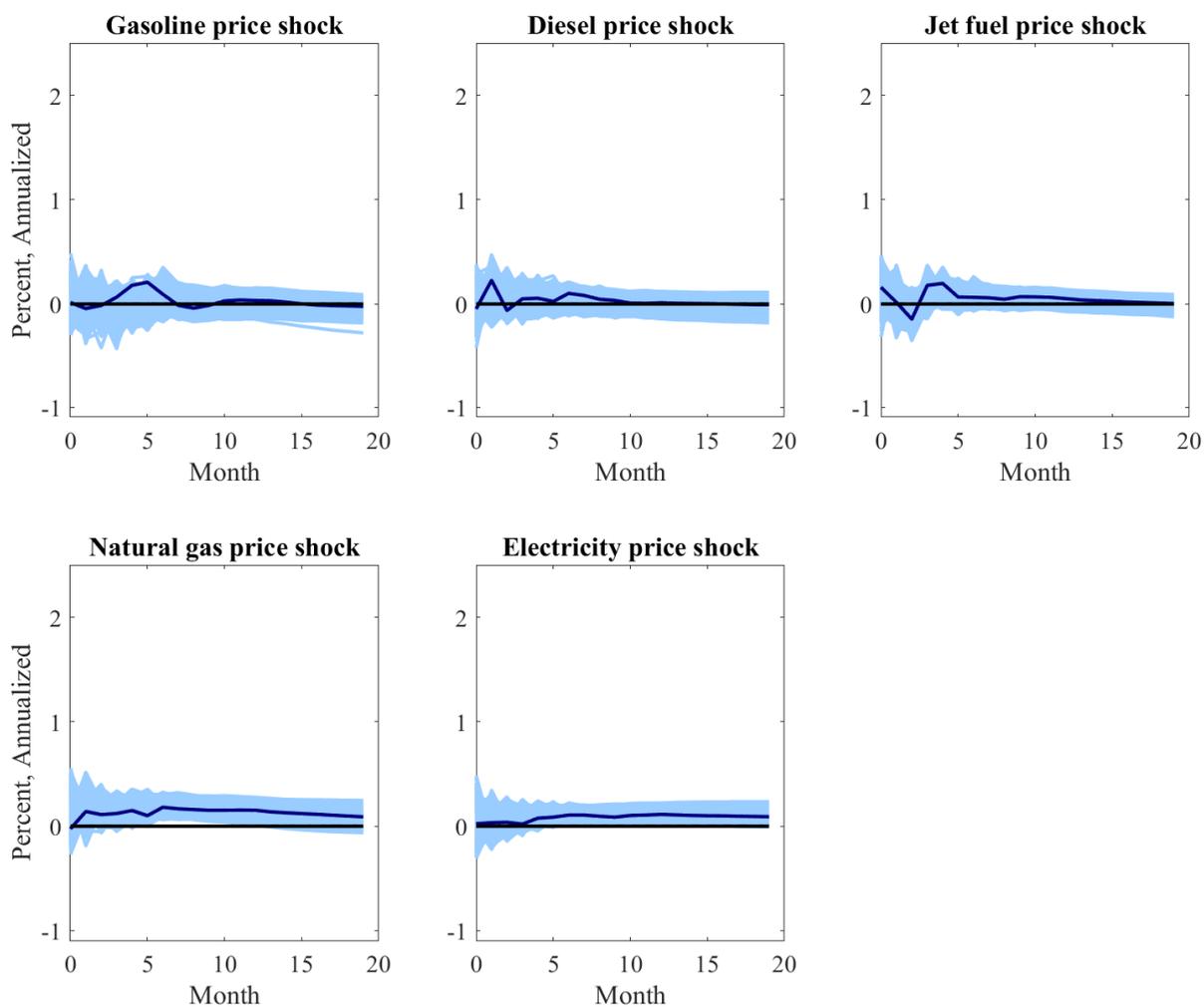
See caption of Figure C1. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP.

Figure C3. IRFs of Energy Price Shocks on HICP (EP 2023, cointegrated model)



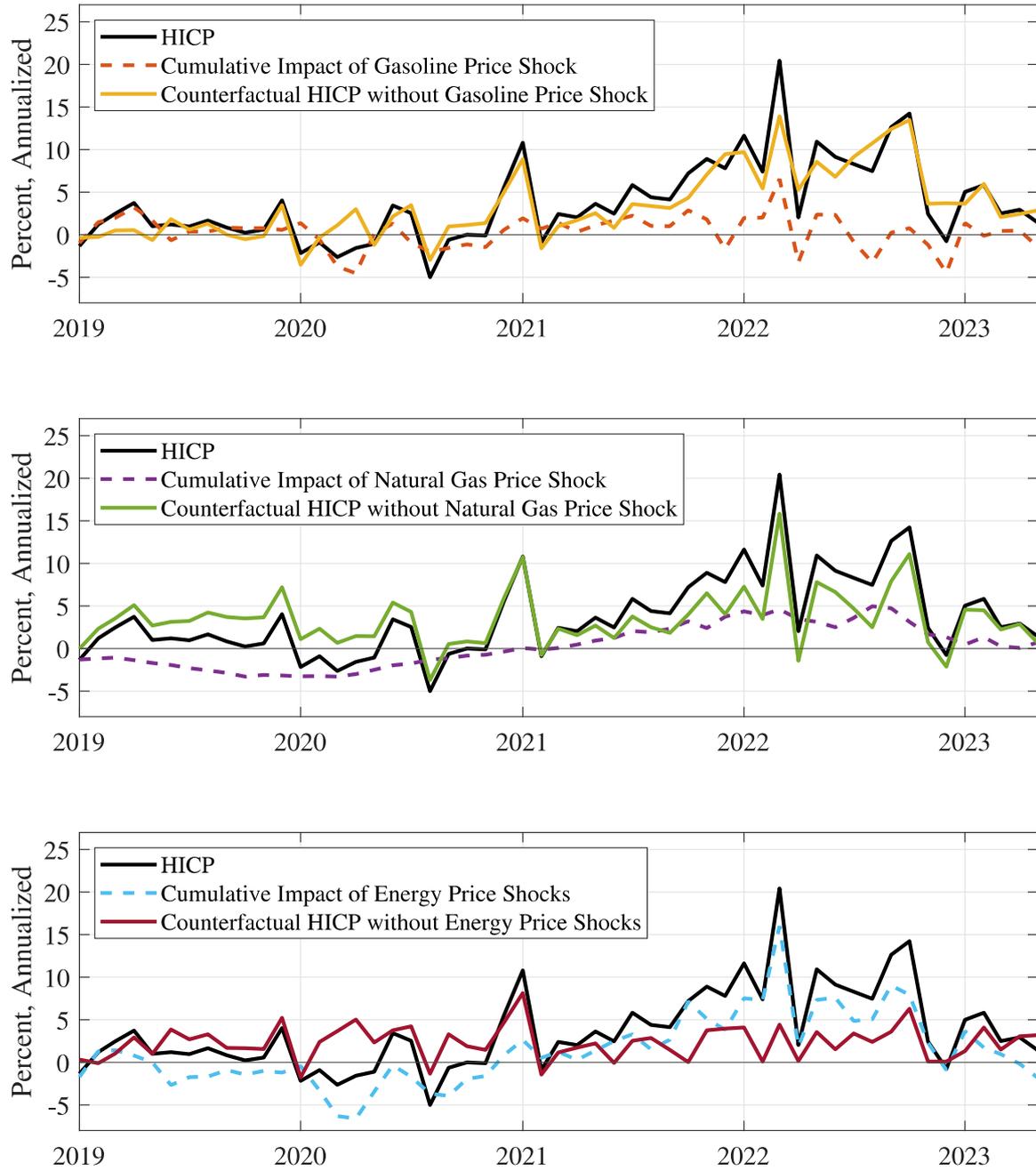
See caption of Figure C1. The estimations are being conducted using data from January 2005 to May 2023 (EP 2023).

Figure C4. IRFs of Energy Price Shocks on Core HICP (EP 2023, cointegrated model)



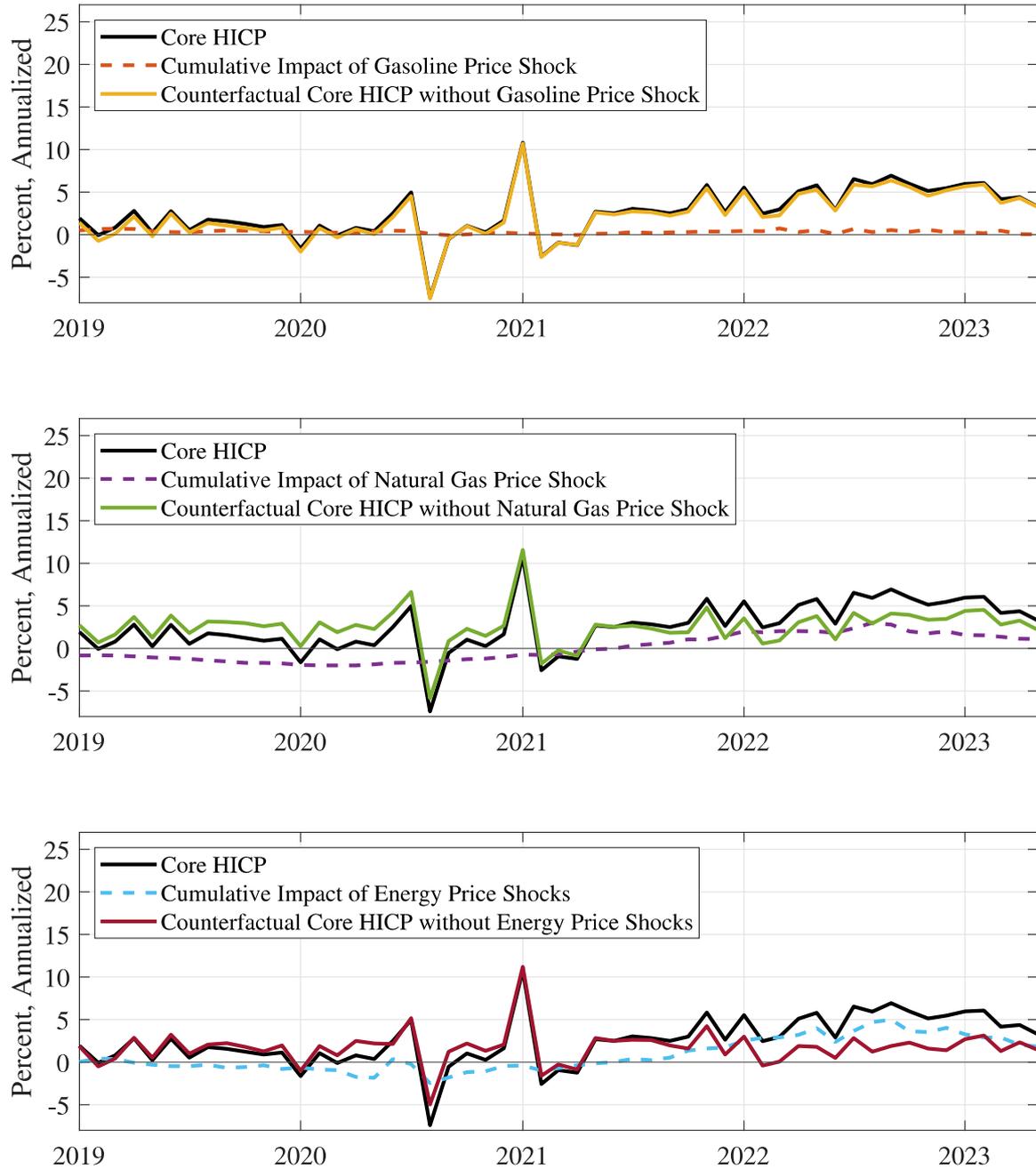
See caption of Figure C1. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. The estimations are being conducted using data from January 2005 to May 2023 (EP 2023).

Figure C5. Historical Decomposition of HICP (cointegrated model)



See caption of Figure 3. It is assumed that gasoline and diesel, gasoline and jet fuel, gasoline and natural gas, as well as gasoline and electricity are cointegrated.

Figure C6. Historical Decomposition of Core HICP (cointegrated model)



See caption of Figure 3. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. It is assumed that gasoline and diesel, gasoline and jet fuel, gasoline and natural gas, as well as gasoline and electricity are cointegrated.

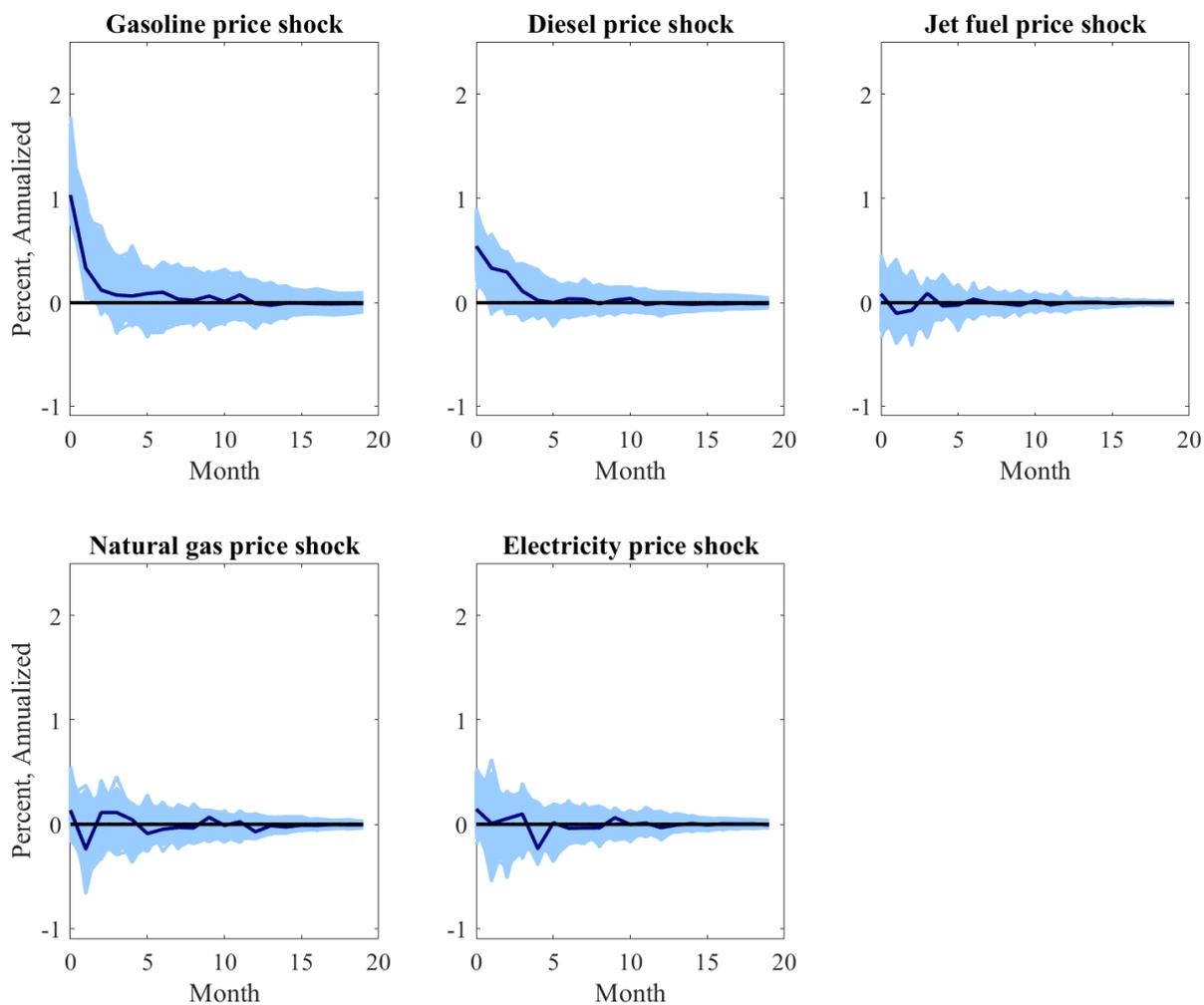
Table C1. Variance Decomposition of HICP and Core HICP (cointegrated model)

Explained Variable	Estimation Period	Share of variance explained by energy price shock				
		Gasoline Price Shock	Diesel Price Shock	Jet Fuel Price Shock	Natural Gas Price Shock	Electricity Price Shock
HICP	EP 2019	44.0	9.7	0.6	1.0	0.3
Core HICP	EP 2019	2.0	1.4	0.4	0.2	0.3
HICP	EP 2023	33.8	7.1	2.1	15.7	8.4
Core HICP	EP 2023	3.2	1.2	3.0	13.1	7.0

See caption of Table 1. It is assumed that gasoline and diesel, gasoline and jet fuel, gasoline and natural gas, as well as gasoline and electricity are cointegrated.

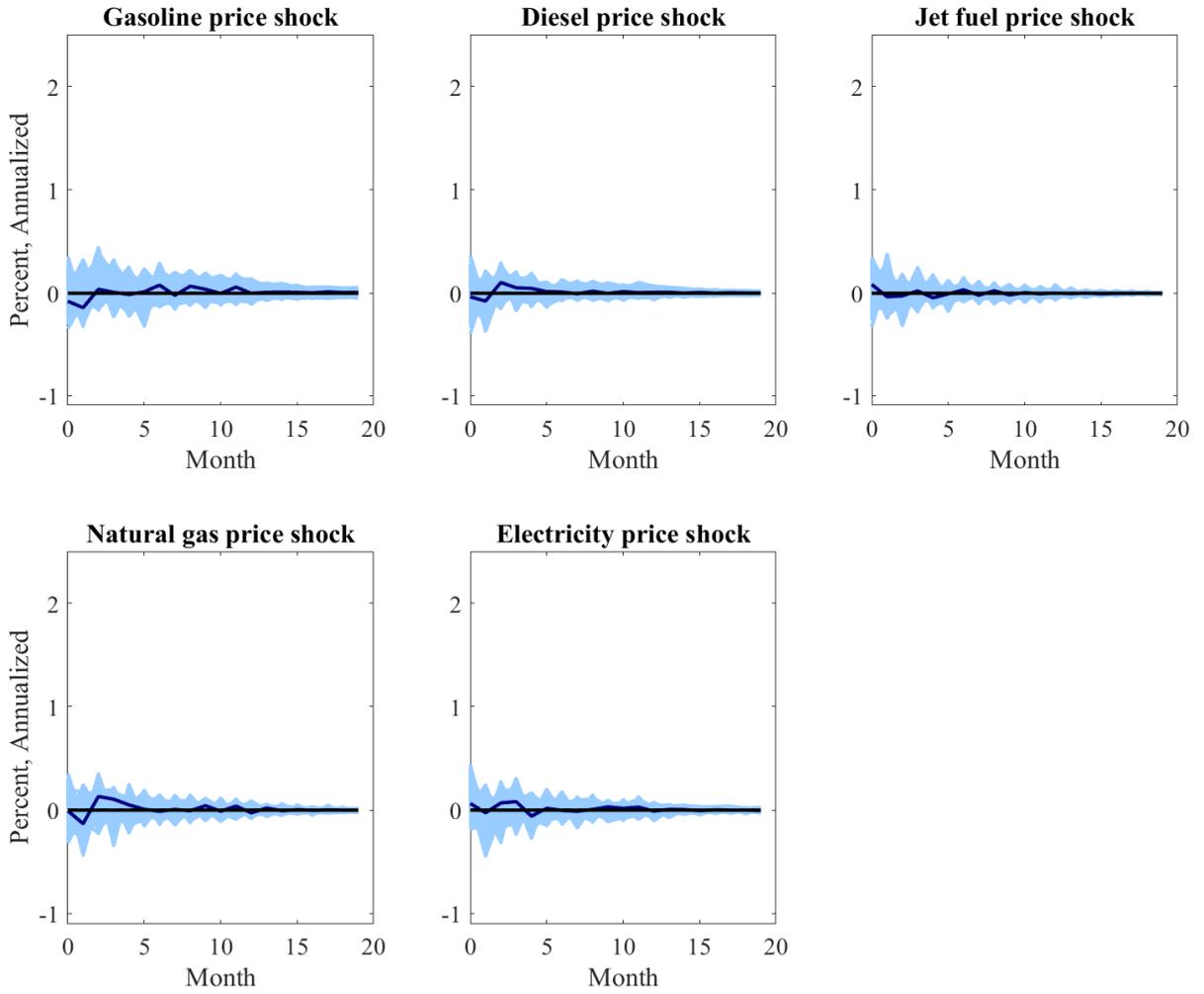
C.2 Models with Lag Length of 12 Periods

Figure C7. IRFs of Energy Price Shocks on HICP (EP 2019, lag length of 12 periods)



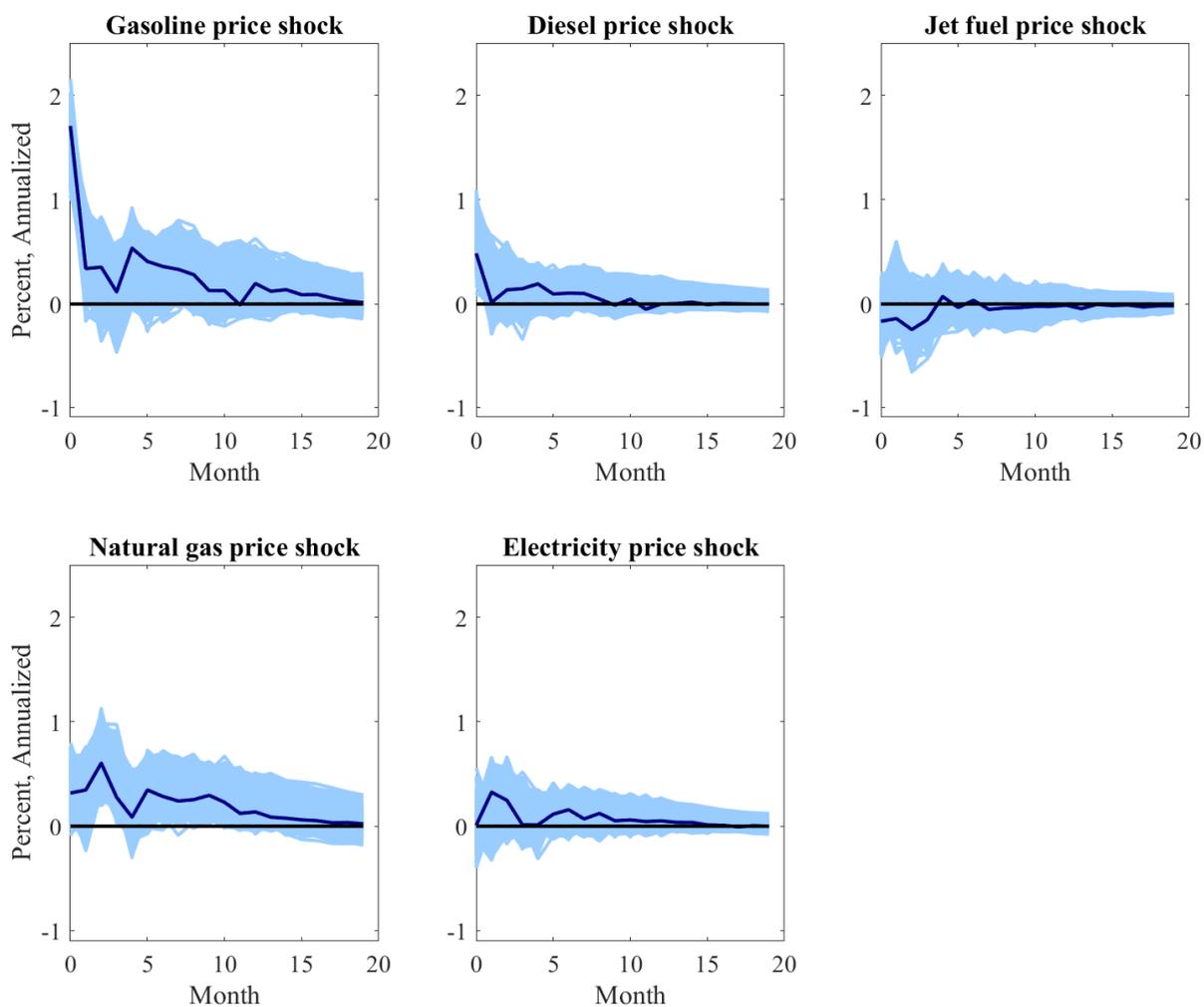
See caption of Figure 1. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

Figure C8. IRFs of Energy Price Shocks on Core HICP (EP 2019, lag length of 12 periods)



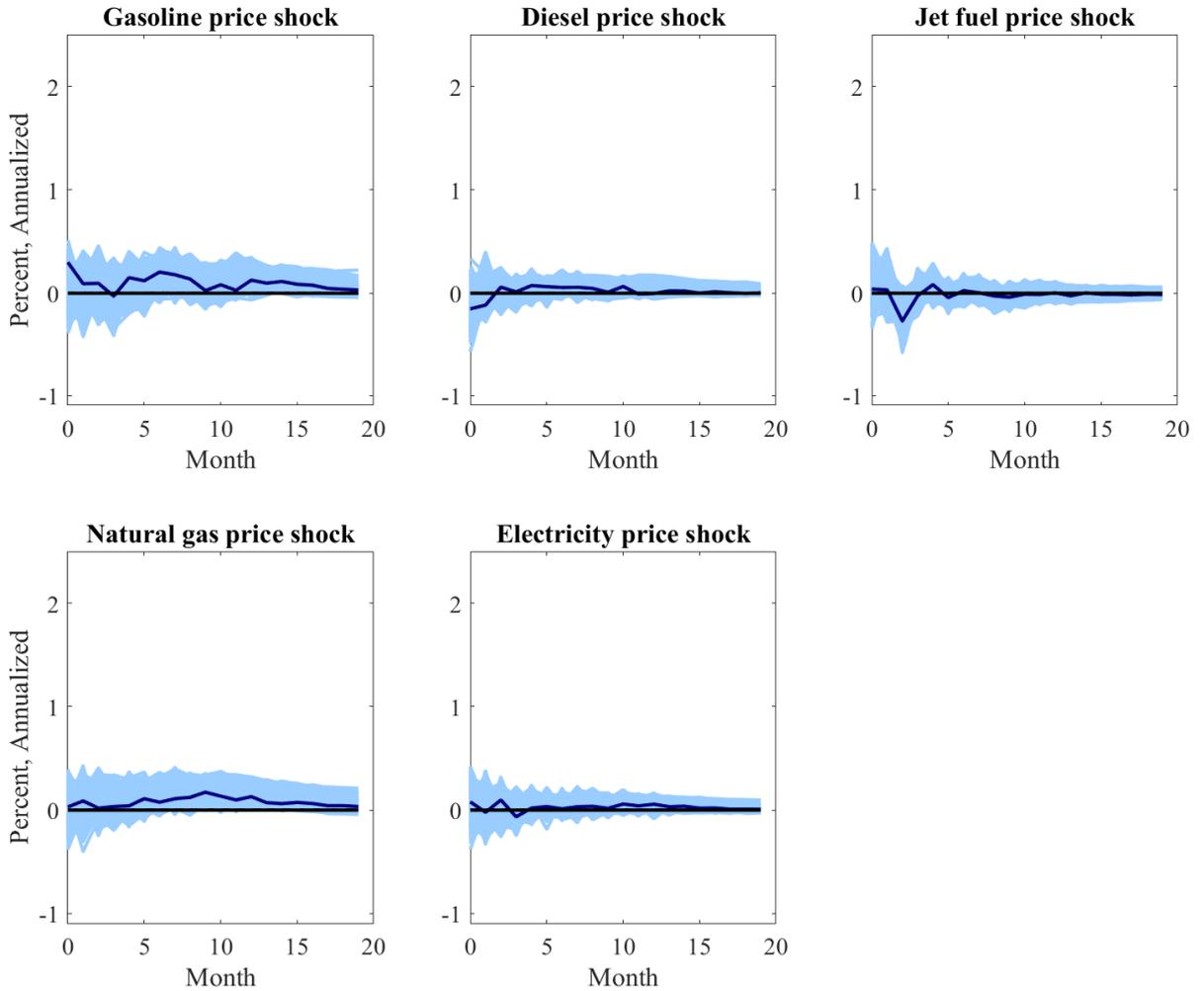
See caption of Figure 1. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

Figure C9. IRFs of Energy Price Shocks on HICP (EP 2023, lag length of 12 periods)



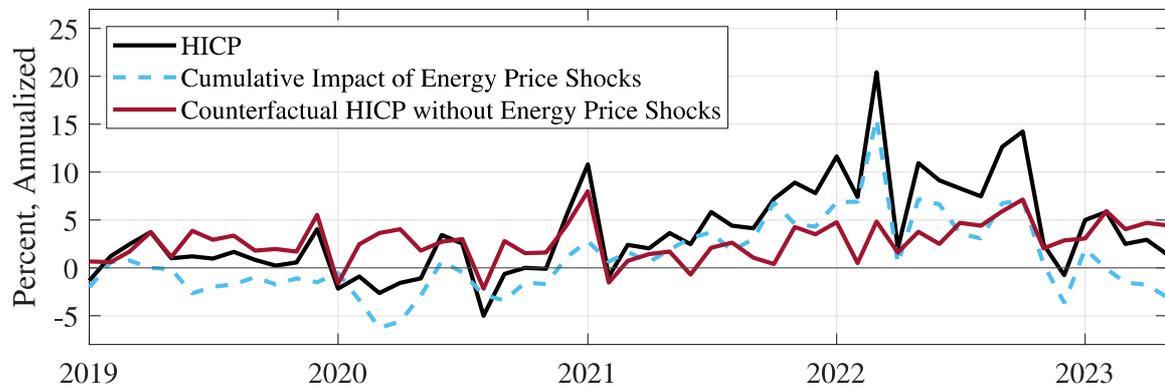
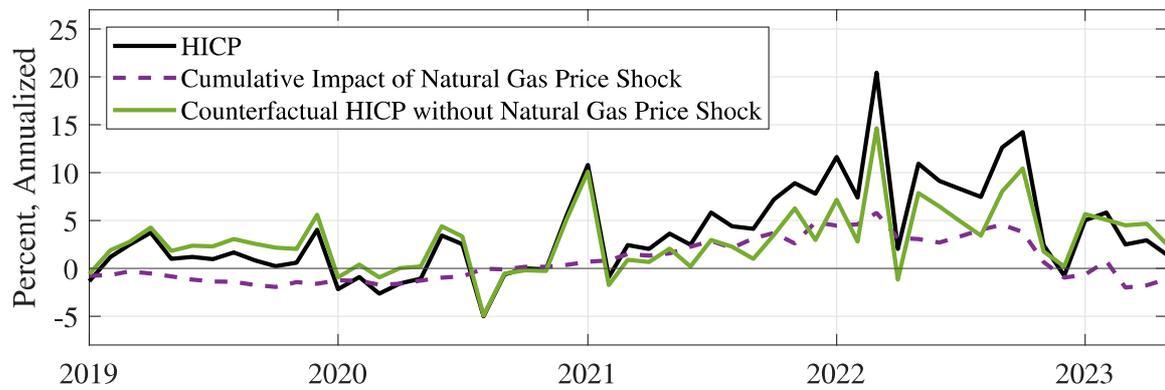
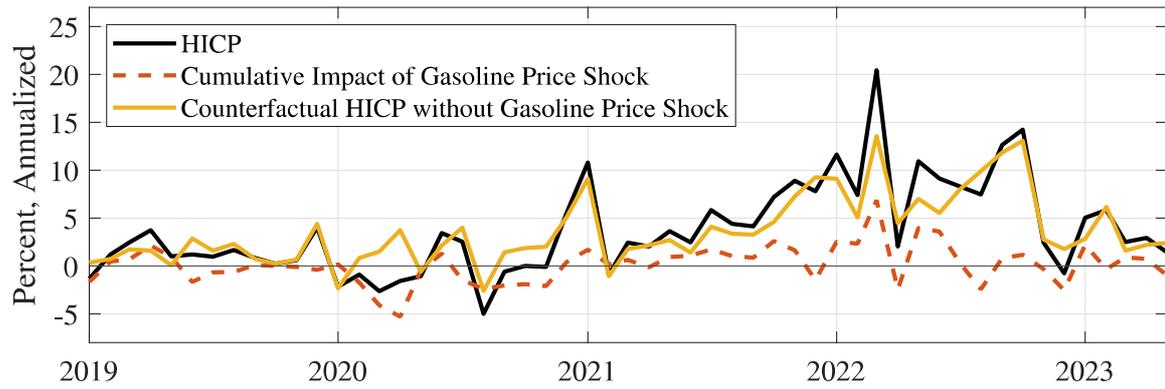
See caption of Figure 2. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

Figure C10. IRFs of Energy Price Shocks on Core HICP (2023, lag length of 12 periods)



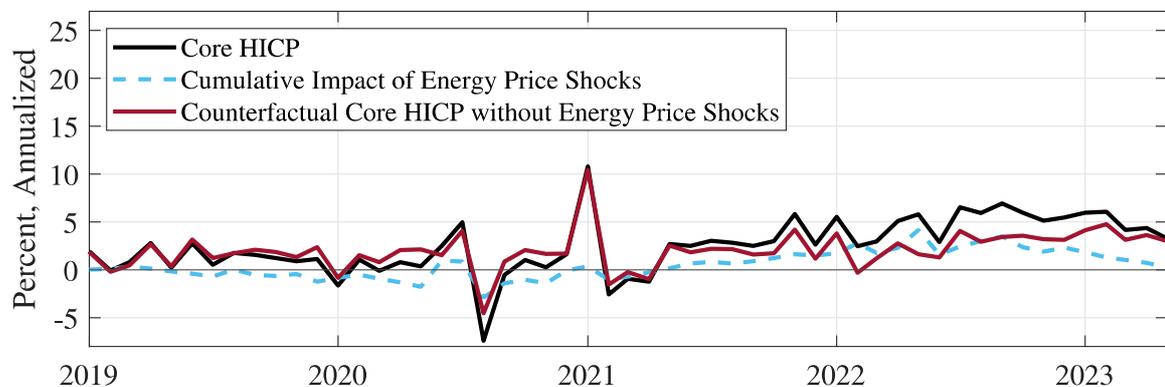
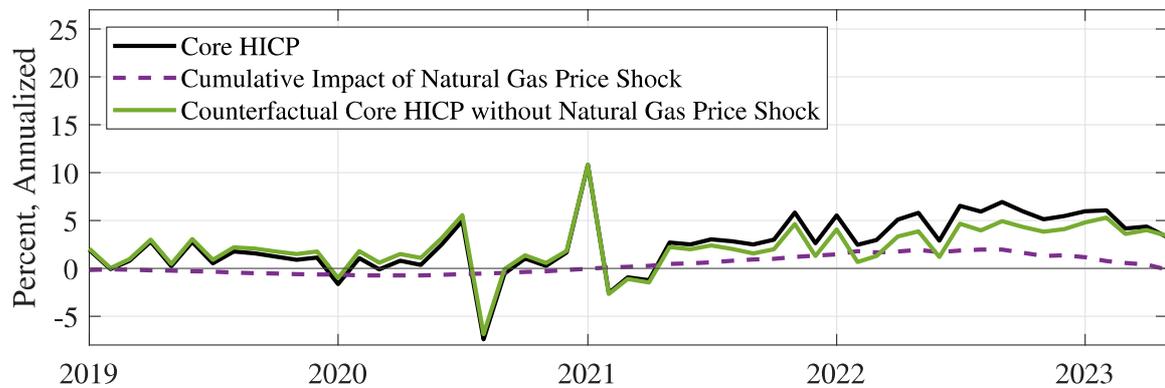
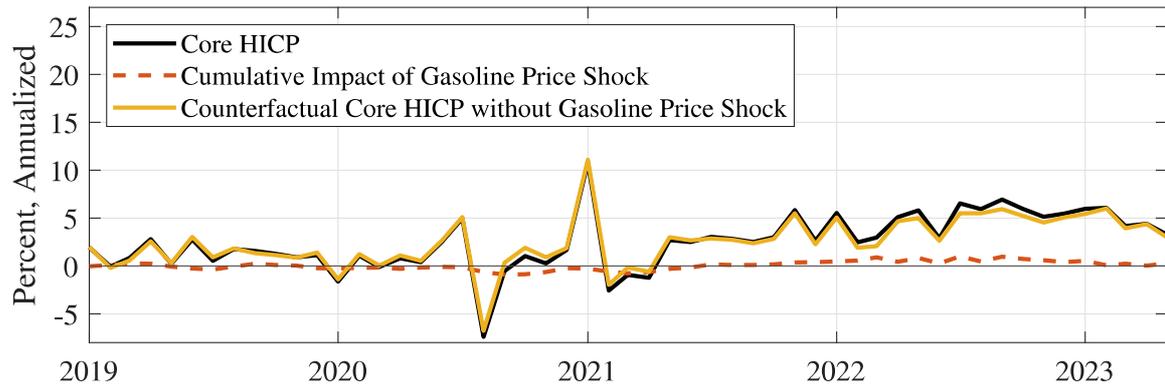
See caption of Figure 2. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

Figure C11. Historical Decomposition of HICP (lag length of 12 periods)



See caption of Figure 3. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

Figure C12. Historical Decomposition of Core HICP (lag length of 12 periods)



See caption of Figure 3. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

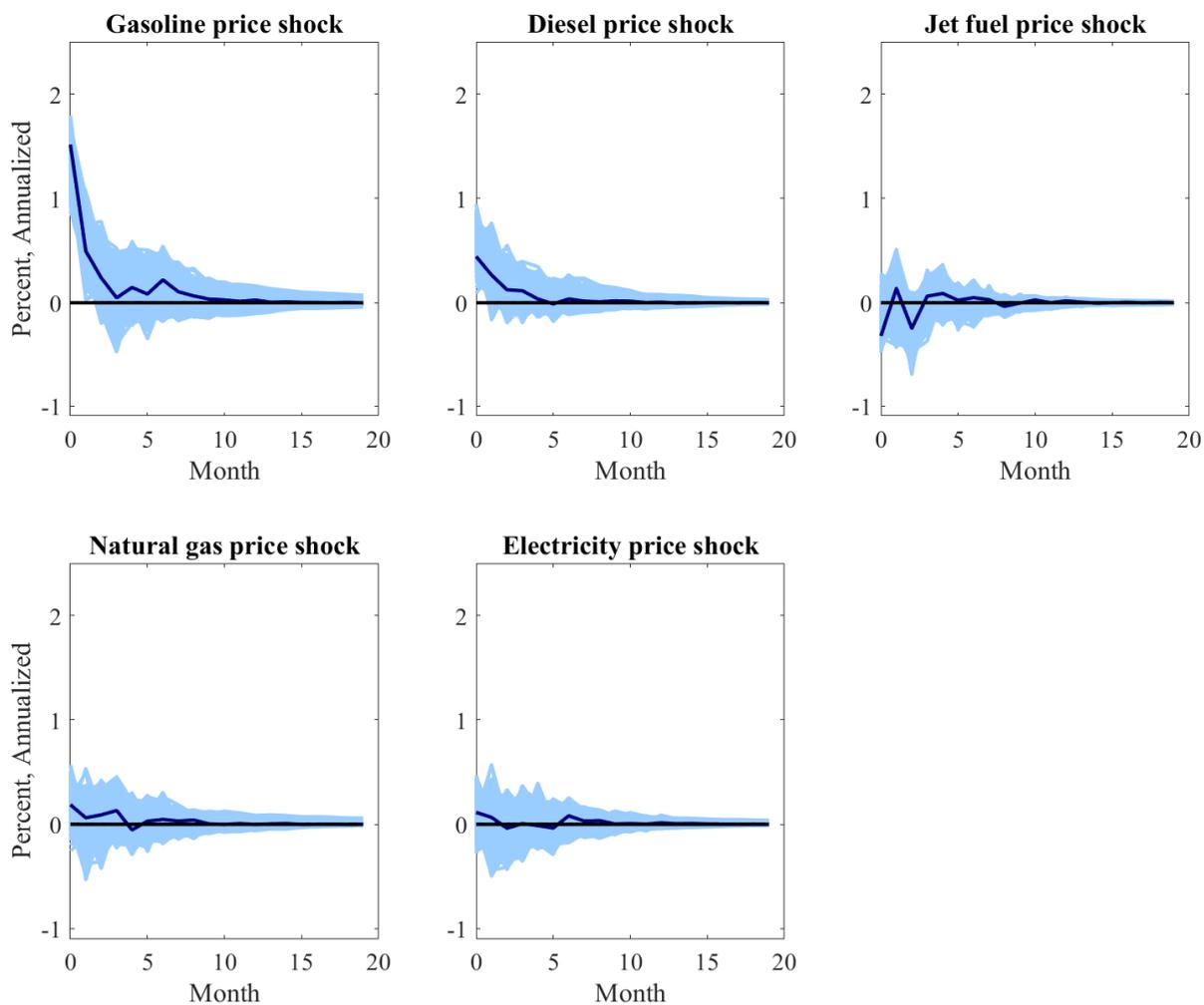
Table C2. Variance Decomposition of HICP and Core HICP (lag length of 12 periods)

Explained Variable	Estimation Period	Share of variance explained by energy price shock				
		Gasoline Price Shock	Diesel Price Shock	Jet Fuel Price Shock	Natural Gas Price Shock	Electricity Price Shock
HICP	EP 2019	43.5	9.8	0.4	1.6	0.9
Core HICP	EP 2019	1.7	0.8	0.4	0.7	1.6
HICP	EP 2023	37.3	5.6	0.8	19.3	2.3
Core HICP	EP 2023	6.6	1.4	2.2	8.8	1.1

See caption of Table 1. Compared to the baseline model, a lag length of 12 periods is being assumed instead of 6.

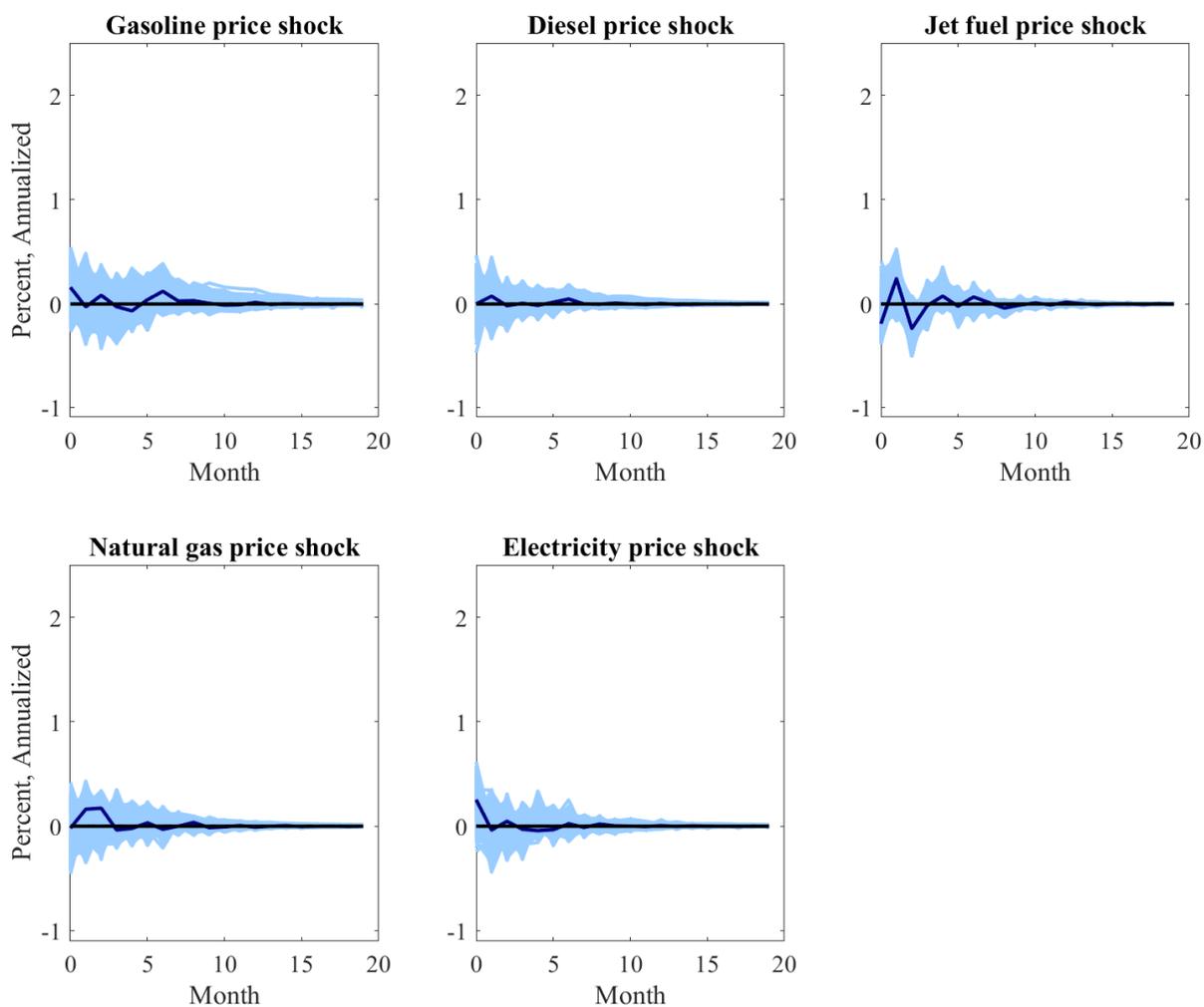
C.3 Models with Estimation Period until August 2021

Figure C13. IRFs of Energy Price Shocks on HICP (EP 2021)



See caption of Figure 1. The estimations are being conducted using data from January 2005 to August 2021 (EP 2021).

Figure C14. IRFs of Energy Price Shocks on Core HICP (EP 2021)



See caption of Figure 1. The seasonally adjusted monthly core HICP (annualized) is considered instead of the overall HICP. The estimations are being conducted using data from January 2005 to August 2021 (EP 2021).

Table C3. Variance Decomposition of HICP and Core HICP (EP 2021)

Explained Variable	Estimation Period	Share of variance explained by energy price shock				
		Gasoline Price Shock	Diesel Price Shock	Jet Fuel Price Shock	Natural Gas Price Shock	Electricity Price Shock
HICP	EP 2021	43.2	7.9	1.8	1.0	0.3
Core HICP	EP 2021	1.6	0.3	3.5	0.3	1.5

See caption of Table 1. The estimations are being conducted using data from January 2005 to August 2021 (EP 2021).

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