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Lutz Kilian and Xiaoqing Zhou

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Center for Financial Studies | Goethe University | Theodor-W.-Adorno-Platz 3 | 60323 Frankfurt am Main | Germany
| Phone +49 69 798 30050 | info-cfs@hof.uni-frankfurt.de | www.gfk-cfs.de

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Lutz Kilian
Federal Reserve Bank of Dallas
CEPR

Xiaoqing Zhou
Federal Reserve Bank of Dallas

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Consumers purchase energy in many forms. Sometimes energy goods are consumed directly, for instance, in the form of gasoline used to operate a vehicle, electricity to light a home, or natural gas to heat a home. At other times, the cost of energy is embodied in the prices of goods and services that consumers buy, say when purchasing an airline ticket or when buying online garden furniture made from plastic to be delivered by mail. Previous research has focused on quantifying the pass-through of the price of crude oil or the price of motor gasoline to U.S. inflation. Neither approach accounts for the fact that percent changes in refined product prices need not be proportionate to the percent change in the price of oil, that not all energy is derived from oil, and that the correlation of price shocks across energy markets is far from one. This paper develops a vector autoregressive model that quantifies the joint impact of shocks to several energy prices on headline and core CPI inflation. Our analysis confirms that focusing on gasoline price shocks alone will underestimate the inflationary pressures emanating from the energy sector, but not enough to overturn the conclusion that much of the observed increase in headline inflation in 2021 and 2022 reflected non-energy price shocks.

JEL code: E31, E52, Q43

Key words: Headline, core, oil, gasoline, diesel, jet fuel, natural gas, coal, electricity

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Correspondence to: Lutz Kilian, Federal Reserve Bank of Dallas, Research Department, 2200 N. Pearl St., Dallas, TX 75201, USA. E-mail: lkilian2019@gmail.com.

Xiaoqing Zhou, Federal Reserve Bank of Dallas, Research Department, 2200 N. Pearl St., Dallas, TX 75201, USA. Email: xqzhou3@gmail.com.

1. Introduction

While many observers have attributed high U.S. inflation rates to rising gasoline prices, recent research has shown that gasoline price shocks have had only a modest impact on U.S. inflation since 2019 (e.g., Kilian and Zhou 2022a,b). Motor gasoline, however, is only one form of energy that households purchase. This fact raises the concern that studies focusing on gasoline price shocks alone may understate the inflationary impact of rising energy prices during periods such as 2021-22, when U.S. energy prices surged across the board. For example, steep increases in 2021 and 2022 in the price of natural gas used for home heating and in the price of residential electricity, along with rising prices for heating oil and propane gas in regions that do not have access to natural gas, are likely to have added to inflationary pressures, as the economy recovered from the Covid-19 pandemic. From a policymaker's point of view, it is therefore important to understand how biased conventional estimates of the inflationary impact are.[1]

Including residential electricity and natural gas prices in the analysis, however, does not come close to capturing all channels by which energy price fluctuations affect consumer prices. For example, households traveling by air are directly exposed to fluctuations in jet fuel prices, even if they never purchase jet fuel themselves. Likewise, few households in the United States drive diesel vehicles, but diesel fuel is used in transporting consumer goods on trains, trucks and barges. These transportation costs are ultimately borne by consumers. Diesel fuel is also used to operate machinery in construction and in agriculture. Given that diesel and gasoline prices need not move proportionately, as illustrated by recent data, diesel price increases may add to inflationary pressures.

[1] This is not only a concern for this episode. Going forward, one would expect electricity prices to play a larger role in the transmission of energy price shocks to inflation, as the energy transition unfolds and the consumption of electricity increases. For example, to the extent that electric vehicles replace vehicles powered by internal combustion engines, the current focus on gasoline price shocks will become less and less relevant. Thus, understanding the inflationary impact of electricity price shocks in particular is policy relevant.

In addition, we need to account for the fact that much of the electricity and natural gas consumed in the United States is used by the commercial and industrial sectors rather than directly by households. These uses range from heating and lighting a mall to the production of energy-intensive products such as aluminum and glass. As energy prices increase, these additional costs will be reflected in higher consumer prices. For example, Ganapati, Shapiro and Walker (2020) estimate that 70% of energy price-driven changes in input costs of the U.S. manufacturing sector are passed through to consumers in the short to medium run.

Finally, consumers as well as firms rely on countless products manufactured by the petrochemical industry that heavily rely on oil products and natural gas, including plastics, fertilizer, pharmaceuticals, insulation materials, packaging materials, synthetic rubbers, detergents, adhesives, solvents, and lubricants. These products are major components of vehicles, home and office buildings and furnishings, electronics and clothing, for example. To the extent that the cost of these products depends on the price of energy and is passed on to the consumer, one would expect these energy costs to add to inflationary pressures associated with energy price shocks.

These considerations suggest that previous research focusing on the inflationary impact of gasoline price shocks may have understated the overall inflationary impact of energy price shocks on inflation, especially in recent years. For example, the increase in diesel fuel prices in 2022 far outpaced that in gasoline prices, so there is no reason to expect these effects to be captured by models only including gasoline price shocks. Nor do these models take into account the surge in natural gas prices, as the demand for liquefied natural gas (LNG) accelerated in response to Russia's invasion of Ukraine, or the recovery in coal prices following the EU coal embargo, both of which contributed to U.S. electricity price increases.[2]

In this paper, we examine for the first time to what extent shocks to the prices of diesel fuel, jet fuel, natural gas and electricity create inflationary pressures beyond what is captured by traditional models based on gasoline price shocks only. We address this question by generalizing the block recursive partially identified structural vector autoregressive (VAR) model of Kilian and Zhou (2022a,b). Given the limited availability of some of the energy price data, we estimate the model on data from February 1995 to August 2022. We show that the relationship between the energy prices of interest can be plausibly viewed as recursive, conditional on past data. All energy prices are treated as predetermined with respect to headline inflation, extrapolating results for oil and gasoline prices in Kilian and Vega (2011) to other fuel prices, electricity prices and natural gas prices.

Our analysis confirms that focusing on gasoline price shocks alone will underestimate the inflationary pressures emanating from the energy sector, but not enough to overturn the conclusion that much of the observed increase in headline and core inflation in 2021 and 2022 reflected other shocks. Depending on the model specification, of the 6.9% average rate of headline CPI inflation in the year of 2021, gasoline price shocks explain 1.3 percentage points, whereas all energy price shocks combined explain between 1.3 and 1.9 percentage points. Of the 8.1% average inflation rate in 2022 (as of August 2022), between 0.2 and 1 percentage point is explained by gasoline price shocks and between 1.1 and 1.8 percentage points by all energy price shocks combined. Depending on the time period of interest, the discrepancy can be larger or smaller in monthly data, as other energy price shocks need not be highly correlated with gasoline price shocks.

[2] It should be noted that this concern cannot be addressed by focusing on the inflationary impact of oil price shocks, as had been common in earlier studies (e.g., Clark and Terry 2010; Kilian and Lewis 2011; Wong 2015; Conflitti and Luciani 2019). Not only do the prices of oil products such as gasoline or diesel not necessarily move proportionately with percent changes in the price of oil, as documented in Kilian and Zhou (2022a), but this approach would also ignore the inflationary impact of fluctuations in coal, natural gas and electricity prices.

Our estimates suggest that energy price shocks affect overall inflation mainly through the energy component of the consumer basket and have only modest effects on core inflation. We find that no shock comes close to rivaling the importance of gasoline price shocks for headline inflation. Our substantive conclusions are robust to allowing for cointegration between petroleum prices, to changes in the lag order, and to the definition of core inflation.

The remainder of the paper is organized as follows. In section 2, we empirically motivate the importance of distinguishing between a range of energy price shocks. In section 3, we propose a structural VAR model that allows us to study the impact of five energy price shocks under minimal identifying assumptions and we discuss the econometric methods used in the empirical analysis. Section 4 assesses how responsive headline and core inflation measures are to various energy price shocks, quantifies the contribution of these shocks to the variability of inflation, and compares the cumulative impact of all energy price shocks combined to that of gasoline price shocks alone during 2019.6-2022.8. Section 5 contains sensitivity analysis including results based on an alternative model that allows for cointegration between selected energy prices. The concluding remarks are in Section 6.

2. How does the evolution of U.S. energy prices differ by market?

In modeling the transmission of energy price shocks to the economy, it is common to assume that fluctuations in energy prices by and large follow the evolution in the price of crude oil. In reality, however, every energy market is different. In the United States, the prices of natural gas and coal decoupled from the price of crude oil many years ago. Likewise, the evolution of electricity prices may differ greatly from that of fuel prices.

Figure 1 shows the growth rates of selected U.S. energy price indicators, including the retail price of motor gasoline (all grades, city average), the retail price of on-highway diesel, the price of kerosene-type jet fuel, the front-month Henry Hub price of natural gas and the average U.S. price of electricity.[3] There are striking difference in the timing and amplitude of the changes in these energy prices. For example, the amplitude of positive and negative spikes may differ substantially even across closely related petroleum products. Moreover, while there is hardly any volatility in electricity prices, the price of natural gas, which is a major cost determinant in electricity production, is even more volatile than the price of gasoline.

Table 1 quantifies the co-movement between these energy prices. It shows that percent changes in the price of gasoline are positively correlated with percent changes in other energy prices. This result makes sense because an economic expansion would be expected to raise all these prices at the same time. However, the strength of the correlations varies widely from 0.79 to 0.03. Even for diesel fuel (and to an even larger extent for jet fuel), the co-movement is far from perfect. For natural gas, the correlation drops to 0.15, and for electricity the correlation is only 0.03.

The correlation between diesel fuel and jet fuel prices with 0.82 exceeds their respective correlations with gasoline prices. Likewise, the correlation between natural gas and diesel prices with 0.26 is higher than the correlation between gasoline and natural gas prices. Henry Hub natural gas and electricity prices have a correlation of only 0.14.

Given this heterogeneity, one would not expect a model of the transmission of gasoline price shocks alone to capture the effects of other energy price shocks. This evidence motivates the development of a quantitative model in Section 3 that allows for energy price shocks to differ across markets and for these shocks to have different effects on inflation. The model focuses on the response of headline CPI inflation and CPI inflation excluding food and energy (commonly referred to as core CPI inflation). Core CPI inflation is a better measure of

[3] The fuel prices and electricity prices were obtained from the U.S. Energy Administration's *Monthly Energy Review*. The refiner price of jet fuel to end users was extrapolated for two months based on the growth rate of the U.S. Gulf Coast FOB price. The Henry Hub price from NYMEX was downloaded from the EIA website.

the underlying trend of inflation than headline inflation because it abstracts from the more volatile food and energy components, whereas headline CPI inflation is the measure most often focused on in the financial press.

Figure 2 compares the evolution of these three inflation measures since February 1995. While the core inflation measures are less volatile than headline inflation, as expected, there are spikes in both inflation series near episodes of large energy price shocks (notably in 2008, 2014, 2020) and sustained increases during periods of rising energy prices (for example in 2021-22) that suggest that energy price shocks might be useful in understanding these inflation dynamics.

3. The Structural VAR Model

Our empirical model generalizes the block recursive partially identified structural VAR model proposed in Kilian and Zhou (2022a,b). There are seven monthly model variables. Let $y_t = [\Delta p_t^{gasoline},\ \Delta p_t^{diesel}, \Delta p_t^{jet\ fuel}, \Delta p_t^{natural\ gas}, \Delta p_t^{electricity}, \pi_t^{headline}, \pi_t^{core}]'$, where $\Delta p_t^{gasoline}$ denotes the growth rate of the retail price of gasoline, Δp_t^{diesel} the growth rate of the price of highway diesel, $\Delta p_t^{jet\ fuel}$ the growth rate of the price of jet fuel, $\Delta p_t^{natural\ gas}$ the growth rate of the front-month futures price of Henry hub natural gas, $\Delta p_t^{electricity}$ the growth rate of the average price of electricity. We use the Henry hub front-month futures price, because it is similar to the spot price, but extends back further than the spot price. π_t is the headline CPI inflation rate and π_t^{core} is the corresponding core inflation rate. Given the limited availability of some of the energy price data, we estimate the model on data from February 1995 to August 2022.[4] All variables are measured in percent (see Figures 1 and 2).

3.1. Model structure

[4] The end of the estimation periods reflects the availability of the electricity price data at the time the analysis was conducted. Electricity prices typically become available only with a lag of three months.

The structural VAR model can be written as $B_0 y_t = B_1 y_{t-1} + ... + B_p y_{t-p} + w_t$, where y_t is the 7×1 vector of date t observations for $t = p+1,...,T$, w_t denotes the vector of mutually uncorrelated i.i.d. structural shocks and B_i, $i = 0,..., p$, represent 7×7 dimensional coefficient matrices. The intercept has been dropped for expository purposes. The reduced-form VAR model representation is $y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + u_t$, where $A_i = B_0^{-1} B_i, i = 1,..., p$, and $u_t = B_0^{-1} w_t$. The lag order, p, is set to 6. The model explains variation in the data in terms of the structural shocks w_t. The model is partially identified in that only the first five structural shocks are identified. The estimates of the inflation responses to these shocks are invariant to the identification of the remaining structural shocks (see Keating 1996).

3.2. Identification

The model is block recursive with three distinct blocks. The first block consists of gasoline, diesel, and jet fuel prices, the second block contains natural gas and electricity prices, and the third block alternative measures of U.S. CPI inflation. We impose a recursive ordering within each energy price block, but make no assumptions about the identification within the inflation block. The model allows all three refined product prices (gasoline, diesel, jet fuel) to be driven by the shock that is labelled as a gasoline price shock. This shock may, more generally, be interpreted as a common demand shock driving all three refined product prices. Diesel prices are allowed to be driven in addition by a shock specific to the diesel market that may drive a wedge between gasoline and diesel prices. Similarly, jet fuel prices respond to a shock specific to jet-fuel market, while also depending on the diesel-specific price shock, given the substitutability between diesel and jet fuel production. When diesel becomes more expensive, refiners blend as much jet fuel as possible into the diesel they produce, reducing the availability of jet fuel and raising jet fuel prices. The reverse link can effectively be ignored, given the relative size of these markets.

We also allow the price of natural gas in the second energy price block to respond to the gasoline price shock since an economic expansion would stimulate demand for both petroleum products and natural gas, thereby inducing positive co-movement. While this link is likely to be weak in practice, it is important to allow for this dependence. Because electricity prices may depend in part on natural gas prices, they must also be allowed to respond to gasoline price shocks. At the same time, the price of natural gas responds to a natural gas-specific shock that allows the price of natural gas to decline without a simultaneous decline in other fossil fuel prices, as happened during the shale gas boom of the 2000s, for example, or when LNG exports were disrupted in 2022.

To the extent that diesel and natural gas (and hence electricity) are substitutes, one would expect possibly simultaneous feedback between diesel, natural gas and electricity prices. The same is potentially true for jet fuel prices, since jet fuel production is closely related to diesel production. However, in practice, this instantaneous substitutability is expected to be negligible. For example, while diesel generators may substitute for electricity, they are only used in emergencies. Nor do power plants regularly switch between natural gas and diesel fuel. Petroleum products only account for 0.5% of U.S. electricity generation, and electricity does not play an important role in the production of petroleum products. We therefore postulate that the first and second block of the structural impact multiplier matrix are uncorrelated except for the transmission of common demand shocks captured by the price of gasoline. Imposing the implied exclusion restrictions $b_0^{42} = b_0^{52} = b_0^{43} = b_0^{53} = 0,$ where b_0^{ij} denotes the impact response of variable i to shock $j,$ would render the model overidentified and would complicate inference (e.g., Sims and Zha 1998). Here we take the simpler approach of working with a recursive ordering that does not impose these restrictions. If our premise is correct, the impact effect of diesel-specific and jet-fuel specific shocks on natural gas and electricity prices should be negligible. In the data, all but one of these impact effects are indistinguishable from zero.

Finally, within the second block, we postulate that the natural gas price like the price of fuels is predetermined with respect to electricity prices. The observant reader may wonder why we did not include coal prices in this model. The reason is that currently 92% of U.S. coal consumption is used in electricity generation, so our electricity price shock for all practical purposes will capture the effect of coal price shocks on electricity prices. This fact is particularly helpful, given that there are no data on the average U.S. price of coal.

It is further assumed that all energy price shocks are predetermined with respect to the inflation variables in the third block. This assumption is supported by empirical evidence in Kilian and Vega (2011) for oil and gasoline prices. We assume that these results extend to other energy prices, yielding the zero restrictions in the last three columns of B_0^{-1}.

Combining these assumptions, we can write the structural VAR model as

$$\begin{pmatrix} u_t^{\Delta p^{\text{gasoline}}} \\ u_t^{\Delta p^{\text{diesel}}} \\ u_t^{\Delta p^{\text{jet fuel}}} \\ u_t^{\Delta p^{\text{natural gas}}} \\ u_t^{\Delta p^{\text{electricity}}} \\ u_t^{\pi^{headline}} \\ u_t^{\pi^{core}} \end{pmatrix} = \begin{bmatrix} * & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & 0 & 0 & 0 & 0 & 0 \\ * & * & * & 0 & 0 & 0 & 0 \\ * & * & * & * & 0 & 0 & 0 \\ * & * & * & * & * & 0 & 0 \\ * & * & * & * & * & * & 0 \\ * & * & * & * & * & * & * \end{bmatrix} \begin{pmatrix} w_t^{\text{gasoline}} \\ w_t^{\text{diesel-specific}} \\ w_t^{\text{jet fuel-specific}} \\ w_t^{\text{natural gas-specific}} \\ w_t^{\text{electricity-specific}} \\ w_t^{6} \\ w_t^{7} \end{pmatrix}, \qquad (1)$$

where $*$ denotes coefficients of the structural impact multiplier matrix that are unrestricted in estimation. Model (1) nests the conventional specification based on gasoline price shocks only. One way of interpreting our analysis is as answering the question of what would be gained by including additional energy prices in the model based on gasoline prices only, when modeling inflation dynamics.

3.3. Econometric evaluation of the structural VAR model

The model is estimated using Bayesian methods. We postulate a diffuse Gaussian-inverse

Wishart prior for the reduced-form parameters. The prior of the VAR slope parameter vector is $\beta \sim N(\beta_0, \Sigma \otimes \Omega_0)$, where the prior mean β_0 is set to zero, Ω_0 is a diagonal matrix with j^{th} diagonal element $\left(1/\sigma_j^2\right)\left(0.2/l\right)^2$, σ_j^2 is approximated as the residual variance of an AR(1) regression for variable j, l indicates the lag, and $\Sigma \sim IW(S_0, \alpha_0)$ with $\alpha_0 = 9$ and

$$S_0 = (\alpha_0 - 7 - 1)\begin{pmatrix} \sigma_1^2 & 0 & 0 & 0 \\ 0 & \sigma_2^2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \sigma_7^2 \end{pmatrix}.$$

Having simulated the posterior distribution of the structural impulse responses, we evaluate the joint distribution of all identified impulse responses under additively separable absolute loss, as discussed in Inoue and Kilian (2022). We construct the Bayes estimator of the impulse response vector by minimizing in expectation the loss function, and we approximate the corresponding lowest posterior risk joint credible set. Likewise, we evaluate the path of the historical decompositions jointly under the same loss function.

4. Empirical Analysis

We first present estimates of the responses of inflation to energy price shocks and quantify the average fraction of the variability in inflation driven by energy price shocks, before assessing the cumulative impact of these shocks on inflation between June 2019 and August 2022.

4.1. How responsive is inflation to energy price shocks?

Figure 3 shows the response of headline CPI inflation to a one-time one-standard deviation shock in each of the five energy prices. All response estimates tend to be positive, but the magnitude and pattern of the responses differs substantially. A positive gasoline price shock causes a sharp and precisely estimated increase in headline CPI inflation on impact that becomes indistinguishable from zero after two months, similar to the evidence provided in

Kilian and Zhou (2022a,b). This effect captures the direct response of consumer prices to rising gasoline prices. It may also capture the propagation of this shock through the economy, to the extent that businesses relying on gasoline-powered vehicles pass on higher gasoline costs.

The response of headline CPI inflation to a diesel-specific price shock is more muted, but still sizeable. Only the impact response is different from zero. This response reflects in part the use of heating oil and diesel fuel by consumers. It may also reflect the use of diesel fuel by trucks, trains, and barges as well as equipment used in construction and agriculture. To the extent that diesel price changes are being passed on to consumers, one would expect to see a larger response in CPI headline inflation than suggested by the share of diesel spending.

The impact of shocks specific to jet fuel on consumer prices is indistinguishable from zero, but positive and, like the response to diesel-specific price shocks, only dies out after about eight months. While air travel accounts for less than 1% of consumer spending, suggesting that the direct effect on headline inflation is small, the observed response of consumer price inflation also reflects the increases in the cost of the jet fuel used for air freight and for business travel. Likewise, the inflation response to the electricity price shock is positive for the first three months, but indistinguishable from zero.

Finally, the response of headline inflation to a natural gas-specific price shock is larger than that for diesel fuel, but less persistent and is precisely estimated only one month after the shock. The fact that this response is not larger may seem surprising given the extensive use of natural gas for commercial heating, power generation and as a feedstock for the production of petrochemicals. Of all the natural gas consumed in the United States, 37% is used by power plants, 33% by industry, 11% by the commercial sector, 4% by transportation and only 15% by the residential sector. A likely explanation is that the pass-through from natural gas cost shocks to electricity prices is moderated by the cost share of natural gas in power generation being less than one, dampening the indirect effect of natural gas price shocks. Likewise, the cost share of natural gas in industry and commerce is modest on average.

We conclude that energy price shocks other than gasoline price shocks do matter for inflation dynamics, but not all energy price shocks are equally important and none of the additional energy price shocks we included rivals the impact of gasoline price shocks on headline inflation. It is also of interest to note that no energy price shock causes persistently large increases in inflation, as assumed in standard models of wage-price spirals (e.g., Blanchard 1986). Figure 4 repeats this exercise focusing on core CPI inflation rather than headline CPI inflation. A striking result is how muted the response of core CPI inflation is to shocks that raise the prices of petroleum products and natural gas compared to the response of headline CPI inflation. Only for gasoline, jet fuel and electricity is there any evidence of a positive response, but the magnitudes are small and none of these responses are precisely estimated with the exception of the impact response to a jet fuel-specific price shock.

An interesting question is how to reconcile the modestly large effects of some energy price shocks on headline inflation with the comparatively low energy cost pass-through to core consumer prices implied by the same model. The responses to the jet fuel price shock are of particular interest because jet fuel is not included in the basket of consumer purchases, implying that it can only affect inflation indirectly, for example, by raising the price of airfares. Thus, we know a priori that the responses of core inflation and of headline inflation to the jet fuel-specific price shock must be identical in population unless an increase in jet-fuel prices causes other fuel prices to rise over time. This possibility cannot be ruled out a priori. For example, a rise in jet fuel prices may make air travel so expensive that consumers prefer to travel by car, raising the demand for gasoline and hence the price of gasoline.

Indeed, the baseline model provides evidence (not shown) that gasoline prices over time respond positively to a jet fuel-specific price shock.

4.2. How much of the variability of inflation is driven by energy price shocks

Table 2 quantifies how important energy price shocks are for the variability of U.S. CPI inflation. It shows that more than half of the variability of headline CPI inflation is explained by gasoline price shocks. By comparison, diesel-specific price shocks explain 5% and jet fuel-specific price shocks 6%. Natural gas-specific price shocks and electricity-specific price shocks only account for 4% and 2%, respectively. With the exception of shocks to electricity prices and jet fuel prices, the explanatory power of energy price shocks is lower when focusing on measures of core CPI inflation. For example, gasoline price shocks explain only 6% of the variability in core inflation, compared with 54% for headline inflation. For jet fuel, which is not part of the consumer basket, the share explained is much more similar across headline and core inflation.

4.3. How much have energy price shocks added to inflationary pressures since the pandemic?

While impulse response analysis helps us understand the transmission of energy price shocks and variance decompositions their average impact, in practice, policymakers are mainly concerned with the cumulative impact of all energy price shocks up to a given point in time. This question can be addressed by constructing a historical decomposition of the inflation rate (see. e.g., Kilian and Lütkepohl 2017).

Figure 5 shows the cumulative impact on headline CPI inflation between June 2019 and August 2022. Whereas the upper panel traces the cumulative effect of the gasoline price shock, abstracting from all other shocks, the lower panel shows the cumulative effect of all five energy price shocks combined. Each panel shows the actual inflation rate, the inflation rate that would have prevailed in the absence of the energy price shocks of interest, and the cumulative contribution of these shocks to the inflation rate. The upper panel confirms the substantive conclusion in Kilian and Zhou (2022b) that much of the recent evolution of headline CPI inflation was driven by shocks other than the gasoline price shock. The lower panel helps quantify the extent to which estimates based on gasoline price shocks alone understate the inflationary pressure exerted by energy price shocks.

There is evidence that at times considering all energy price shocks jointly matters. In general, focusing on gasoline price shocks alone causes the inflationary impact to be underestimated. For example, in April 2020, at the height of the lockdown, gasoline price shocks alone only attribute a cumulative decline in inflation by 5 percentage points (at annualized rates) to gasoline price shocks, whereas the overall effect of all energy price shocks jointly is a decline by 11 percentage points. Larger discrepancies also arise in March 2021 (3.8 pps), August 2021 (1.3 pps) and October 2021 (1.4 pps) as well as March 2022 (2.4 pps), for example. During other months, the underestimation is less pronounced. Overall, the difference is more a matter of degree than substance. The bulk of the inflation in 2021 and 2022 appears to be driven by factors other than energy price shocks. For example, of the 6.9% average rate of headline CPI inflation in the year of 2021 gasoline price shocks explain 1.3 percentage points and all energy price shocks combined also explain 1.3 percentage points. Of the 8.1% average inflation rate in 2022 (as of August 2022), 0.2 percentage points are explained by gasoline price shocks alone and 1.1 percentage points by all energy price shocks combined. Thus, accounting for other energy prices in addition to gasoline prices makes a difference only for the 2022 data and that difference is modest.

In contrast, in Figure 6 there is no evidence that gasoline price shocks alone have played more than a negligible role in driving core CPI inflation recently. Focusing on all energy price shocks combined does little to change this qualitative conclusion. As the lower panel shows, with the exception of the decline in core inflation during the lockdown, energy price shocks played only a small role in driving core CPI inflation. The bulk of this inflation appears driven by supply chain bottlenecks, strong consumer demand, and tight labor markets.

5. Sensitivity Analysis

In the remainder of the paper, we discuss a number of robustness checks that support the conclusions based on the baseline model.

5.1. Model specification

Our baseline model expresses all energy prices in log differences, which ignores potential long-run co-movement among these energy prices. To the extent that the prices of gasoline and diesel, for example, are cointegrated, the baseline model would be misspecified. Likewise, there might be cointegration between the prices of jet fuel and gasoline. We therefore also estimated an alternative model specification replacing Δp_t^{diesel} by $p_t^{diesel} - p_t^{gasoline}$ and $\Delta p_t^{jet\ fuel}$ by $p_t^{jet\ fuel} - p_t^{gasoline}$.[5]

As Figure 7 shows, this makes the peak response of headline inflation to diesel-specific price shocks slightly higher than in Figure 3, but the responses are less precisely estimated. Overall, the responses look very similar. Likewise, the response of core inflation to the diesel-specific price shock in Figure 8 is stronger than in Figure 4, but no more precisely estimated. The variance decomposition in Table 3 mirrors that in Table 2 except for the larger role of diesel-specific price shocks for core inflation (up from 1.8% in Table 2 to 6.6%).

Whereas the cumulative impact on headline inflation in Figure 9 is largely unchanged compared to the baseline model, the cumulative impact of all energy price shocks combined is somewhat stronger. For example, all energy price shocks combined explain 8 percentage

[5] We do not consider cointegration between the price of electricity and the price of natural gas because of the apparent lack of long-run co-movement between these variables.

points of the annualized actual inflation rate of 15% in March 2022, and they explain 6 percentage points of the actual rate of 16% in June 2022. This compares to 8 percentage points and 4 percentage points explained by gasoline price shocks alone in these months. Nevertheless, the substantive conclusion that energy price shocks are only one contributor to headline CPI inflation remains true, considering the much lower cumulative impact from April 2021 to February 2022. Similarly, Figure 10 illustrates that in the cointegrated model core inflation is more responsive to energy price shocks than suggested by the baseline model. During some months of high core inflation, the cumulative impact of energy price shocks explains as much as a quarter of the observed rate, but typically it explains much less. Thus, three quarters or more of the core inflation rate must be explained by other shocks.

Notwithstanding this additional slightly stronger evidence from the cointegrated model, it remains true that energy price shocks have not been the main determinant of elevated inflation rates in 2021 and 2022, consistent with the conclusions from the baseline model. Of the 6.9% average rate of headline CPI inflation in the year of 2021 gasoline price shocks explain 1.3 percentage points and all energy price shocks combined explain 1.9 percentage points. Of the 8.1% average inflation rate in 2022 (as of August 2022) 1.0 percentage points are explained by gasoline price shocks and 1.8 percentage points by all energy price shocks combined.

5.2. Choice of lag order

Another potentially important parameter choice is the autoregressive lag order. Our baseline models includes 6 lags. Choosing an even more conservative lag order of 12, following Kilian and Lütkepohl (2017), does not change the substance of our conclusions.

5.3. Choice of core inflation measure

Our baseline model treats the CPI inflation rate excluding food and energy as the measure of core inflation. Alternatively, one could have used the CPI inflation rate excluding energy (but including food) in the model. The estimates are very similar.

5.4. Model stability over time

Another potential concern is the stability of the response estimates over time. In related work, Clark and Terry (2010) made the case for quantifying the inflationary effects of oil price shocks based on a time-varying coefficient VAR model. Much of the time variation they estimated occurred before the beginning of our estimation period, however, and presumably does not affect our analysis. Moreover, Kilian and Zhou (2022a), using subsamples extending back further than our estimation period, documented that the inflationary effect of gasoline price shocks has remained remarkably stable over time. While these results cannot be verified using our model, given that many of the energy prices we use are not available before the mid-1990s, there is no obvious reason why the same result should not hold for diesel, natural gas or electricity prices. A final concern is that the Covid-19 epidemic may have changed the responses of inflation to energy price shocks, as consumers reduced their driving and flying, while increasingly relying on online orders and deliveries. Restricting the estimation period to end in early 2020, however, does not materially change our response estimates.

6. Concluding Remarks

In this paper, we addressed the question of how much shocks to the price of energy matter for inflation dynamics beyond the price of gasoline. This question is not only timely given recent increases in energy prices across the board, but also requires detailed energy price data that were not available even in the early 1990s, but are available now. Our analysis is intended as a first pass at this important question. Undoubtedly, some of our identifying assumptions will be refined over time, but they suffice for a preliminary answer.

We provided evidence that focusing on gasoline price shocks alone will tend to underestimate the overall inflationary effects of energy price shocks, given that energy price changes are imperfectly correlated across markets. We found shocks to the price of gasoline to be more important for headline inflation than shocks to the Henry Hub price of natural gas, diesel fuel, jet fuel or electricity, but all these shocks add to some extent to inflationary pressures. Energy price shocks affect overall inflation mainly through the energy component of the consumer basket and have only modest effects on core inflation.

We examined in detail the cumulative impact of these shocks on inflation since June 2019 and confirmed that focusing on gasoline price shocks alone will underestimate the inflationary pressures emanating from the energy sector, but not enough to overturn the conclusion that much of the observed increase in headline inflation in 2021 and 2022 reflected shocks outside the energy sector. Even more importantly from a policy point of view, energy price shocks collectively do not have large impacts on core CPI inflation.

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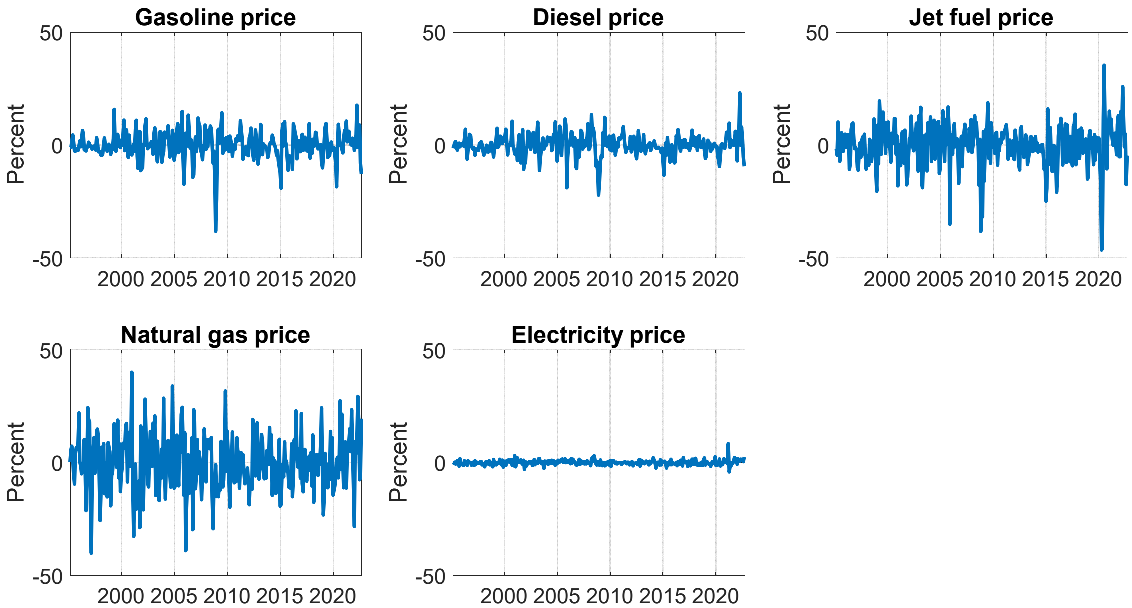
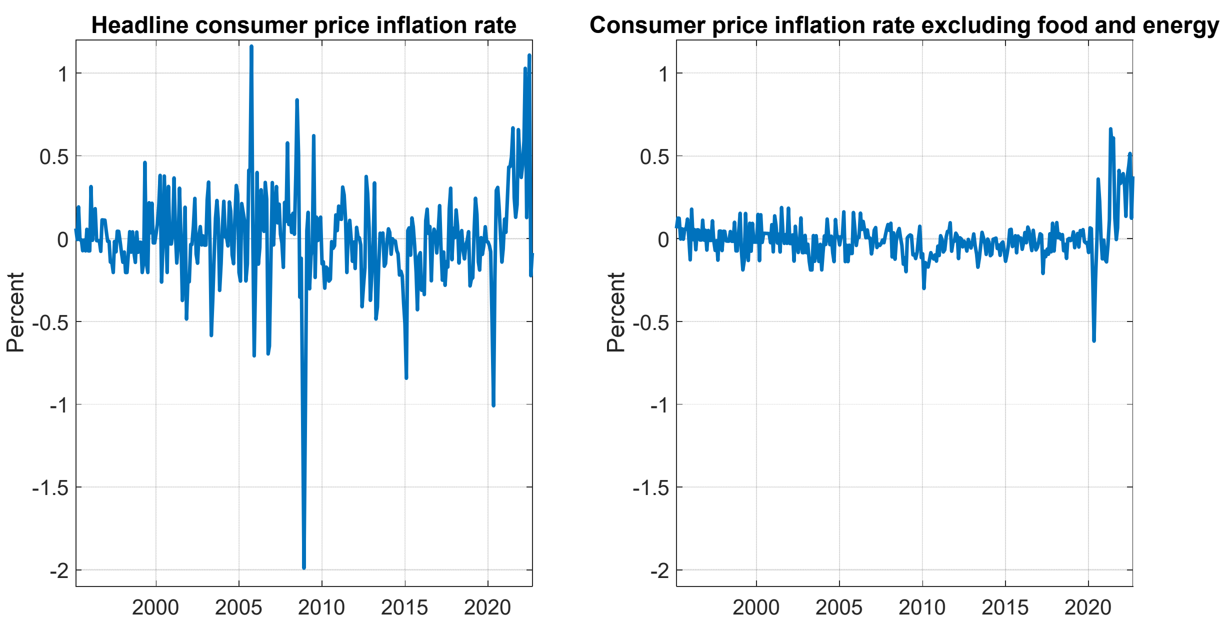
Figure 1: Key U.S. energy price indicators, 1995.2-2022.8



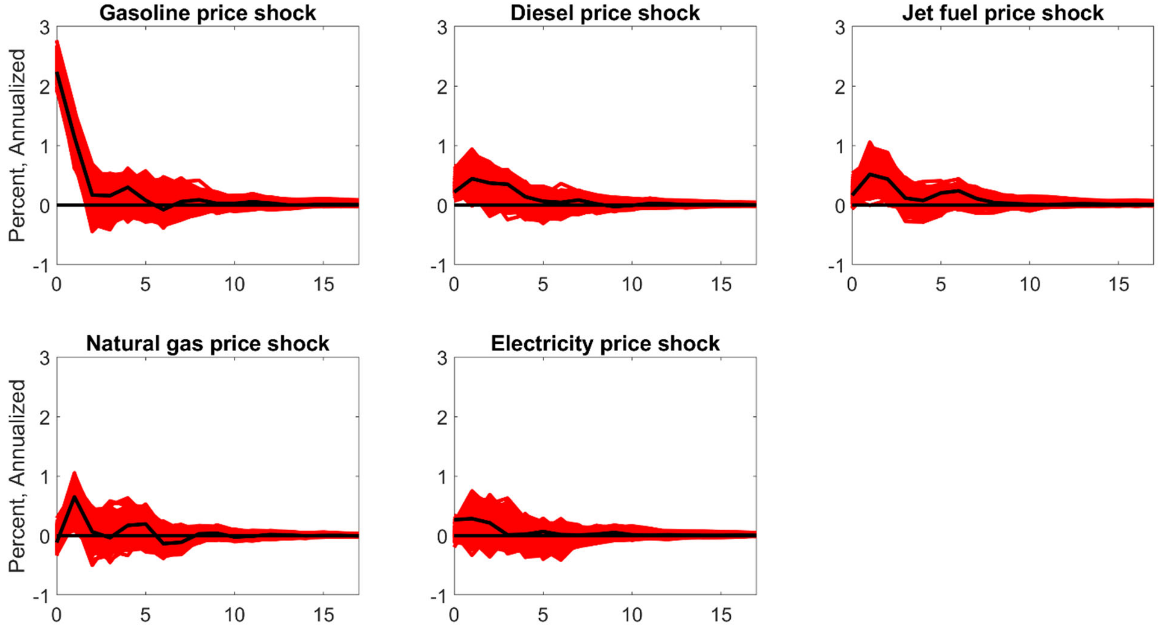
NOTES: Demeaned growth rates expressed in percentage points. The electricity price data have been seasonally adjusted.

Figure 2: U.S. inflation indicators, 1995.2-2022.8



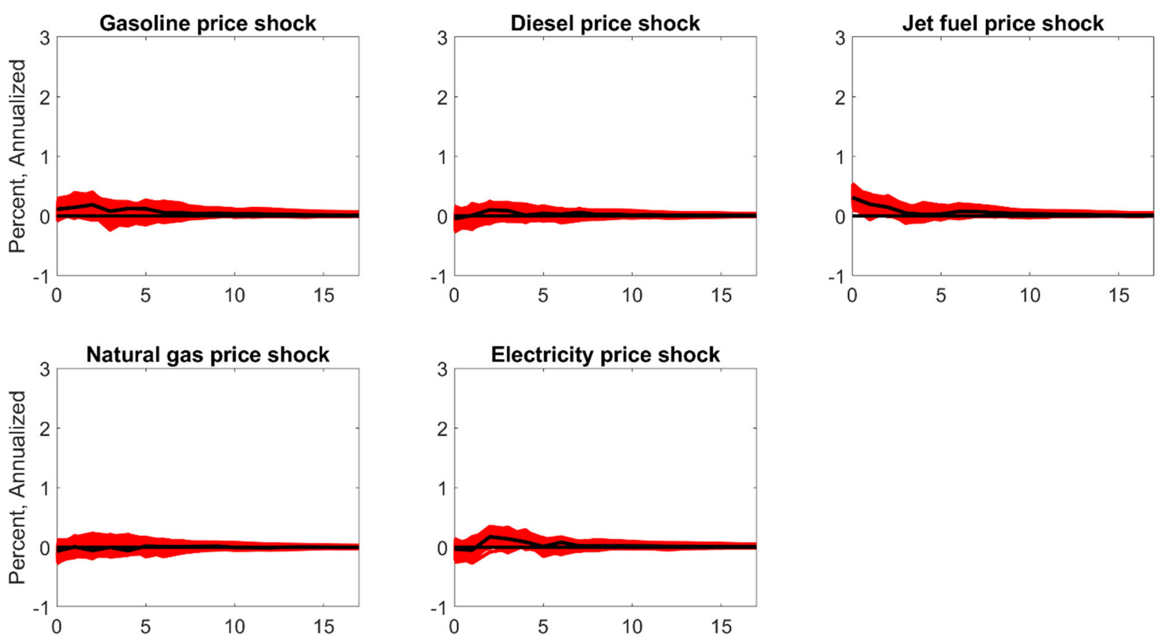
NOTES: Demeaned seasonally adjusted inflation rates expressed in percentage points.

Figure 3: Impact of energy price shocks on headline CPI inflation, baseline model



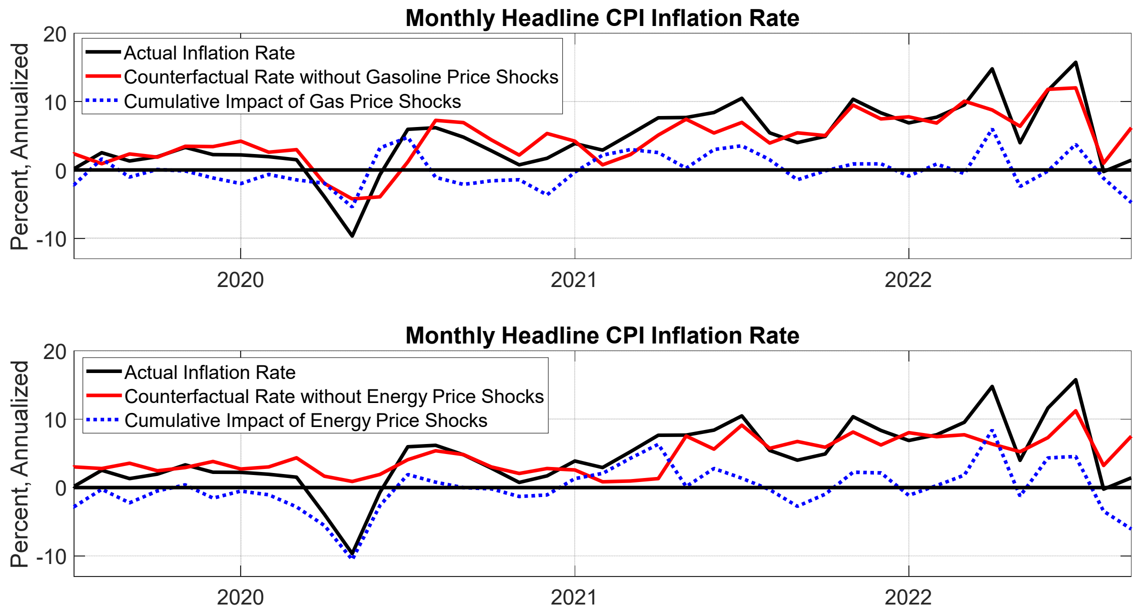
NOTES: The inflation rates have been annualized. The set of impulse responses shown in black is obtained by minimizing the absolute loss function in expectation over the set of admissible structural models, as discussed in Inoue and Kilian (2022). The responses in the corresponding 68% joint credible set are shown in a lighter shade.

Figure 4: Impact of energy price shocks on core CPI inflation, baseline model



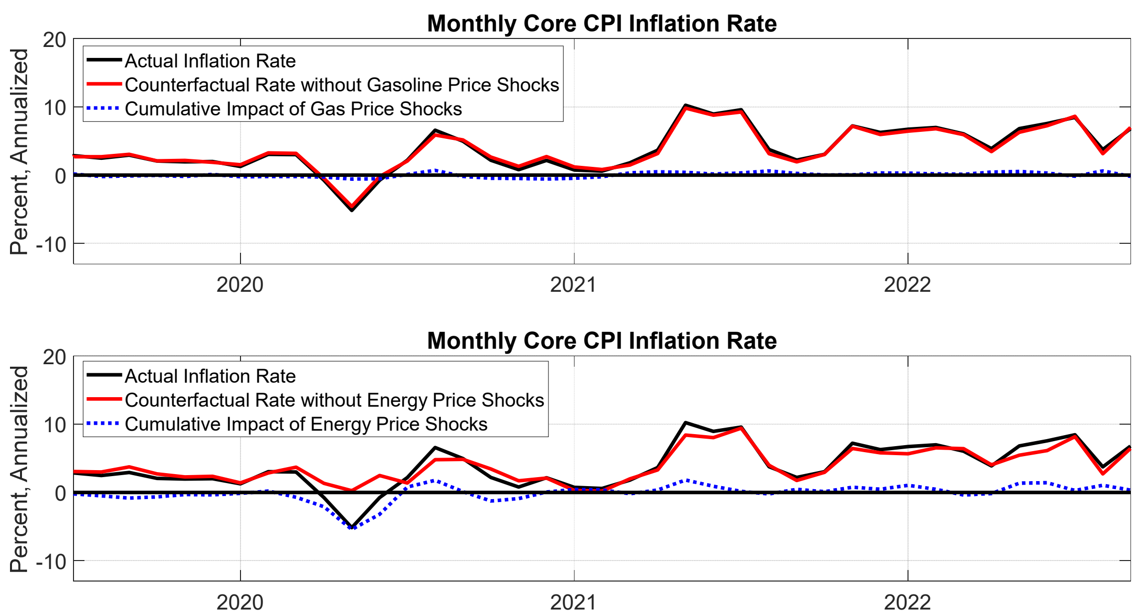
NOTES: See Figure 3.

Figure 5: Monthly headline CPI inflation caused by energy price shocks, baseline model



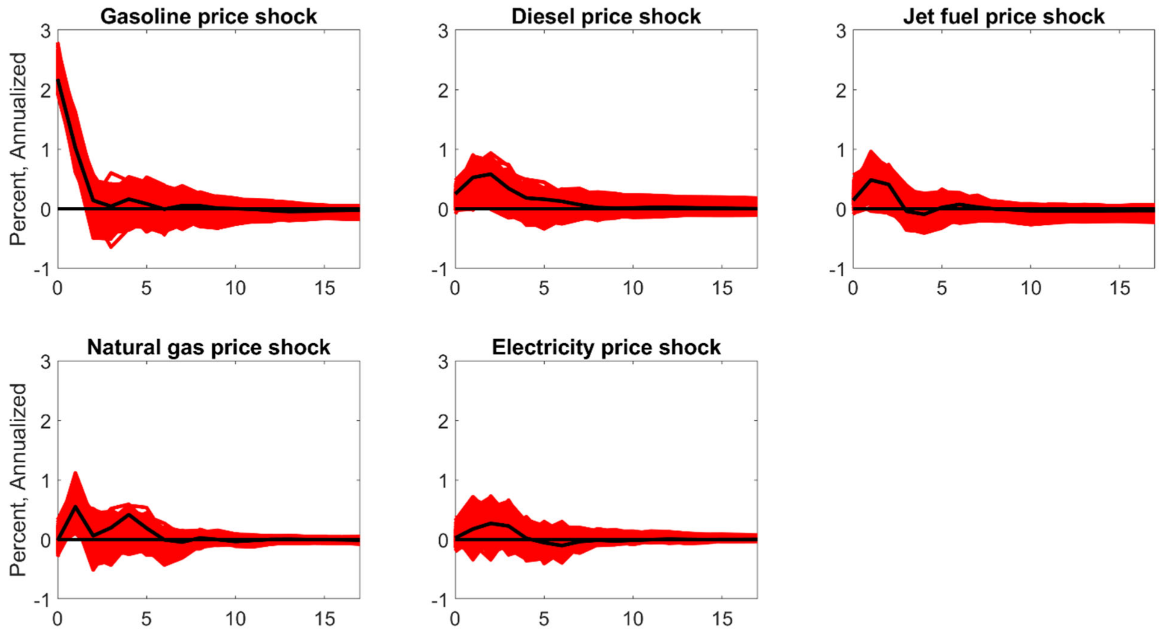
NOTES: Authors' computations based on estimated model.

Figure 6: Monthly core CPI inflation caused by energy price shocks, baseline model



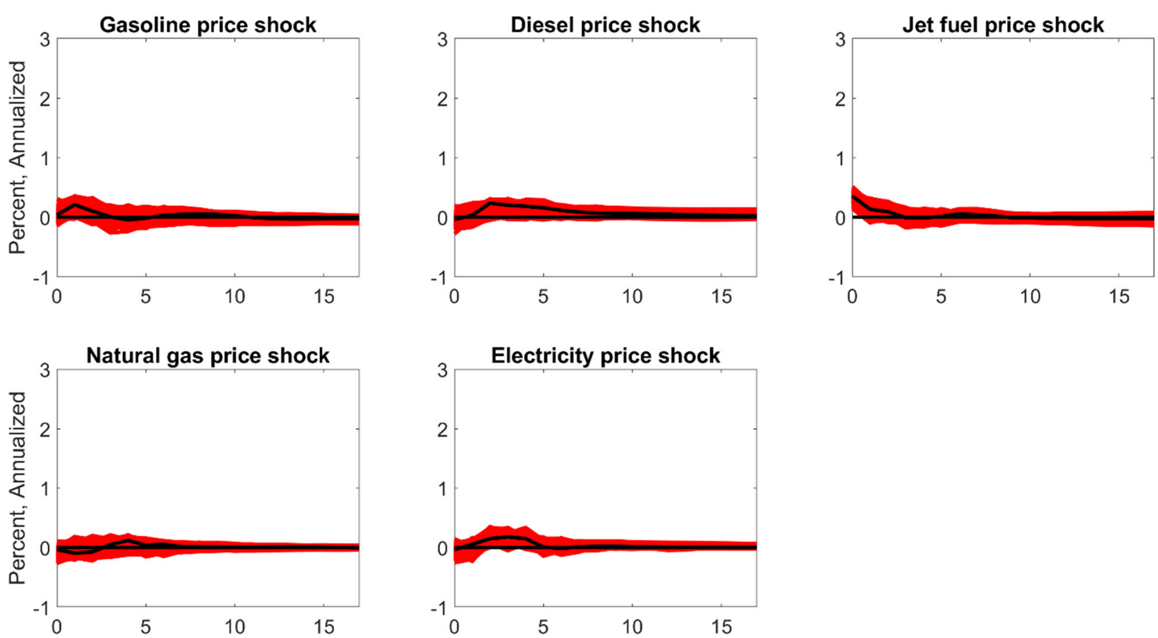
NOTES: See Figure 5.

Figure 7: Impact of energy price shocks on headline CPI inflation, cointegrated model



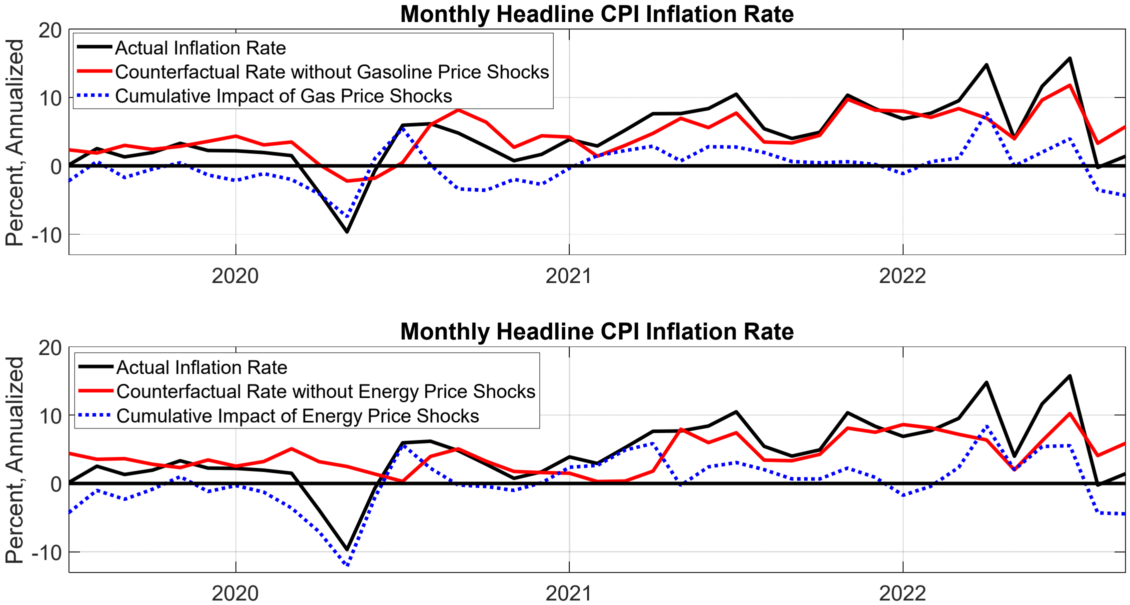
NOTES: See Figure 3.

Figure 8: Impact of energy price shocks on core CPI inflation, cointegrated model



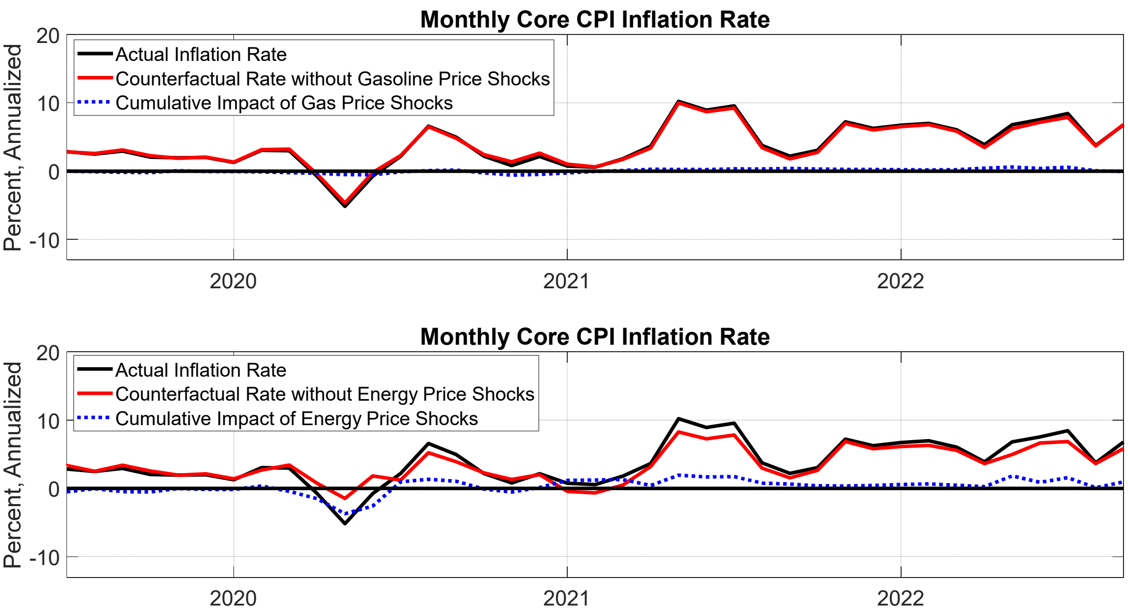
NOTES: See Figure 3.

Figure 9: Monthly headline CPI inflation caused by energy price shocks, cointegrated model



NOTES: See Figure 5.

Figure 10: Monthly core CPI inflation caused by energy price shocks, cointegrated model



NOTES: See Figure 5.

Table 1: Correlations among U.S. energy fuel prices expressed in percent changes

	Gasoline	Diesel	Jet fuel	Natural gas	Electricity
Gasoline	1.00				
Diesel	0.79	1.00			
Jet fuel	0.71	0.82	1.00		
Natural gas	0.15	0.26	0.24	1.00	
Electricity	0.03	0.06	0.02	0.14	1.00

NOTES: Authors' computations based on EIA data described in text.

Table 2: Average contribution of energy price shocks to the variability of inflation, baseline model

Variables	Percent share of variance explained by each price shock				
	Gasoline	Diesel	Jet fuel	Natural gas	Electricity
Headline CPI inflation	54.5 [50.0, 58.9]	4.6 [2.6, 6.6]	5.6 [3.3, 7.9]	4.1 [2.3, 5.8]	2.2 [1.0, 3.4]
CPI inflation excl. food and energy	6.1 [3.0, 9.3]	1.8 [0.8, 2.9]	8.6 [5.4, 11.8]	1.6 [0.7, 2.4]	4.2 [2.2, 6.1]

NOTES: Authors' computations based on estimate of baseline model. 68% error bands in parentheses.

Table 3: Average contribution of energy shocks to the variability of inflation, cointegrated model

Variables	Percent share of variance explained by each price shock				
	Gasoline	Diesel	Jet fuel	Natural gas	Electricity
Headline CPI inflation	52.6 [48.3, 57.6]	5.9 [3.1, 8.3]	5.8 [3.1, 7.5]	4.2 [2.5, 6.0]	2.3 [1.1, 3.5]
CPI inflation excl. food and energy	5.1 [2.6, 7.5]	6.6 [2.7, 10.5]	8.5 [4.7, 11.3]	1.6 [0.7, 2.4]	4.3 [2.4, 6.3]

NOTES: Authors' computations based on estimate of alternative cointegrated model. 68% error bands in parentheses.

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