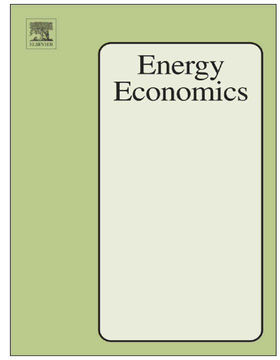
Journal Pre-proof



The impact of rising oil prices on U.S. inflation and inflation expectations in 2020–23

Lutz Kilian, Xiaoqing Zhou

PII: S0140-9883(22)00373-5

DOI: https://doi.org/10.1016/j.eneco.2022.106228

Reference: ENEECO 106228

To appear in: *Energy Economics*

Received date: 21 February 2022

Revised date: 17 July 2022

Accepted date: 25 July 2022

Please cite this article as: L. Kilian and X. Zhou, The impact of rising oil prices on U.S. inflation and inflation expectations in 2020–23, *Energy Economics* (2022), https://doi.org/10.1016/j.eneco.2022.106228

The Impact of Rising Oil Prices on U.S. Inflation and Inflation Expectations in 2020-23

Lutz Kilian
Federal Reserve Bank of Dallas
CEPR

Xiaoqing Zhou
Federal Reserve Bank of Dallas

July 7, 2022

Abstract
The sustained increase in oil and gasoline prices since mid-2020 has raised fears of persistently high U.S. inflation for years to come and rising inflation expectations, along with concerns about the emergence of a wage-price spiral. Using data through May 2022, we show that these concerns have been overstated. There is no evidence that gasoline price shocks have moved long-run household inflation expectations or that the inflationary effect of gasoline price shocks is persistent. The short-run effects on headline inflation are sizable, but have accounted for only a small fraction of overall inflation. For example, on a year-over-year basis, gasoline price shocks are expected to raise headline PCE inflation by 1.9 percentage points at the end of 2022 and by 0.8 percentage points at the end of 2023, under the assumption that the price of oil remains at $110/barrel after May 2022. In contrast, the impact on core PCE inflation in 2022 and 2023 is only 0.3 percentage points each. These estimates already account for increases in inflation expectations. The peak impact on 1-year household inflation expectations is 0.7 percentage points, while that on 5-year expectations is only 0.15 percentage points.

JEL code: E31, E52, Q43

Key words: Scenario, inflation, expectation, oil price, gasoline price, pandemic, recovery, invasion of Ukraine.

Acknowledgments: The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of Federal Reserve Bank of Dallas or the Federal Reserve System. We thank Jim Dolmas, Marc Giannoni and the referees for helpful comments. The authors have no conflict of interest to disclose.

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

The acceleration in U.S. inflation rates starting in 2021 reflected rising demand, as the economy adapted to the COVID-19 pandemic, tight labor markets, supply chain disruptions and the recovery of energy prices from their pandemic lows. With the price of West Texas Intermediate (WTI) oil rising above $80/barrel in October 2021 and temporarily reaching more than $120/barrel after the Russian invasion of Ukraine in early 2022, concerns have grown among policymakers and analysts that the surge in motor fuel prices could push U.S. inflation higher for extended periods and drive up consumers' inflation expectations, causing inflation expectations to become embedded in the wage and price setting process. For example, analysts at the Bank of America warned as early as October 1, 2021, that a surge in oil and gasoline prices above $100 would spark inflation (see Lee 2021). As U.S. inflation rates reached levels unprecedented in recent history in early 2022, a policy debate about how to curb rising motor fuel prices gathered momentum, yet there has been no quantitative analysis of the inflationary impact of the recent surge in gasoline prices.

These concerns prompt two key questions. First, to what extent have shocks to the gasoline price affected U.S. inflation and inflation expectations from the beginning of the pandemic in 2020 to today? We address this question using data through May 2022. This estimation period includes the rise in gasoline prices that followed the Russian invasion of Ukraine in late February 2022. Second, how much further are inflation and inflation expectations expected to rise in the remainder of 2022 and in 2023? The latter question is closely related to the former, since what matters to policymakers is the combined cumulative effect on inflation of gasoline price shocks that have already occurred and gasoline price shocks that are expected to occur in the future.

We address these questions based on a structural vector autoregressive (VAR) model of the relationship between nominal retail gasoline prices, headline inflation, core inflation, and the Michigan Survey of Consumers median 1-year and 5-year inflation expectations. This model recognizes that it is gasoline prices rather than the price of crude oil that enter the consumer basket and that the gasoline price is what matters for the determination of household inflation expectations because of its salience (see, e.g., Coibion and Gorodnichenko 2015; Binder 2018).

The identification of the model builds on insights in Kilian and Zhou (2022), who show that a structural VAR model is a more natural framework for estimating the effect of gasoline price shocks on inflation and inflation expectations than reduced-form correlations. In this paper, we take the analysis a step further. We not only extend the original VAR framework to include other policy-relevant variables, but we discuss how scenarios about the future evolution of the price of crude oil may be mapped into future gasoline price shocks whose inflationary impact may be quantified within our structural VAR model, along with the impact of past gasoline price shocks on inflation and inflation expectations. This allows us to consider any conceivable scenario for the future evolution of the price of crude oil, including a scenario in which the price of oil remains unchanged at $110/barrel starting in June 2022.

Kilian and Zhou's (2022) empirical analysis ends with the outbreak of the Covid-19 pandemic, before the events of interest in our paper took place. Our analysis provides important additional details about the inflationary impact of gasoline price shocks starting in 2020. We first show that gasoline price shocks account for much of the sharp temporary decline in headline inflation early in the COVID-19 pandemic. Gasoline price shocks started creating systematic inflationary pressures in early 2021, but, by late 2021, the cumulative impact of these gasoline price shocks had greatly diminished, indicating that much of the continued surge in core inflation and headline inflation at that point was driven by upward pressure on the prices of other goods and services rather than rising oil and gasoline prices.

The rise in gasoline prices following the invasion of Ukraine has not changed this conclusion fundamentally. This event was associated with a sharp, but temporary surge in headline inflation in March 2022. By May 2022, the component of headline CPI inflation driven by gasoline price shocks accounted for only one third of the observed monthly inflation rate for May and 15% of the year-over-year headline CPI inflation rate. This suggests that the broad-based price increases from, for example, durable goods (vehicles, furniture, consumer electronics), shelter (rent and owners' equivalent rent) and other services (such as medical care) will be the main drivers of inflation in the years to come. These pressures are likely to persist, in many cases, even if oil and gasoline prices were to stabilize at current levels.

We then examine how inflation and inflation expectations are expected to evolve after May 2022, if the oil price remains at $110/barrel from June 2022 to December 2023. Our analysis suggests that concerns about persistently high headline inflation rates in response to gasoline price shocks have been overstated. A $110 oil scenario would be consistent with a much lower impact on monthly headline inflation rates in the remainder of 2022 than in May 2022 and further declines to 0.3 and 0.6 percentage points at annualized rates by the end of 2023, for headline PCE and headline CPI inflation, respectively. The 12-month inflation rate would continue to rise until early 2023 before declining, reflecting the construction of this rate as a trailing 12-month average.

The precise magnitude of the impact on inflation differs depending on whether we focus on CPI or PCE headline inflation. On a year-over-year basis, under the $110 oil price scenario, gasoline price shocks would drive up headline CPI inflation by 2.3 percentage points by early 2023, and headline PCE inflation by 2.0 percentage points, for example. By the end of 2023, the impact would drop below 1 percentage point for both inflation measures. By comparison, the impact on core CPI inflation, core PCE inflation, and trimmed mean PCE inflation measures is much more modest. On a year-over-year basis, they would rise by between 0.33 and 0.66 percentage points at the end of 2023, depending on the measure.

All these estimates already incorporate the effect higher gasoline prices have on inflation expectations. We find that under our scenario the cumulative effect of gasoline price shocks on 1-year inflation expectations rises to 0.7 percentage points in May 2022, before gradually declining to 0.4 percentage points by the end of 2023. The impact on 5-year inflation expectations is much smaller with a peak increase of only 0.15 percentage points, suggesting that long-term household inflation expectations are hardly affected by gasoline price shocks.

Our work relates to a large literature on how household survey inflation expectations respond to oil and gasoline price shocks (see, e.g., Coibion and Gorodnichenko 2015; Wong 2015; Binder 2018; Conflitti and Cristadoro 2018; Binder and Makridis 2022; Kilian and Zhou 2022). In addition, our analysis is related to earlier empirical work on how oil and gasoline price shocks are transmitted to inflation (see, e.g., Kilian 2009; Clark and Terry 2010; Kilian and Lewis 2011; Wong 2015; Conflitti and Luciani 2019; Kilian and Zhou 2022). Our analysis differs from this earlier literature not only in that we are the first to examine the major fluctuations in inflation and inflation expectations during the COVID-19 pandemic and following the invasion of Ukraine. We also go beyond quantifying inflationary effects in the historical data and show how to evaluate hypothetical scenarios for the future evolution of oil and gasoline prices and their impact on inflation and inflation expectations. Moreover, we consider both short-term and long-term household inflation expectations and we report results for a range of alternative inflation measures of interest to policymakers rather than just monthly headline inflation.

The remainder of the paper is organized as follows. In section 2, we introduce a structural VAR model that allows us to answer the questions of interest under minimal assumptions and we discuss the econometric tools required for the analysis of scenarios. Section 3 reports results for the CPI inflation measures most commonly discussed in the press and for household inflation expectations. Section 4 reports the corresponding results for the PCE inflation measures favored by central bankers. Section 5 examines the implications of our estimates for year-over-year inflation rates. The concluding remarks are in Section 6.

2. The Structural VAR Model

Let $y_t = [\Delta pgas_t, \pi_t, \pi_t^{core}, \pi_t^{1-yr\,\exp}, \pi_t^{5-yr\,\exp}]'$, where $\Delta pgas_t$ denotes the growth rate of the city average of nominal U.S. retail price for unleaded regular gasoline, π_t is the headline inflation rate, π_t^{core} is a measure of core inflation, and $\pi_t^{1-yr\,\exp}$ and $\pi_t^{5-yr\,\exp}$ are the Michigan Survey of Consumers' measure of the median household expectation of inflation over the next year and the next five years, respectively.[1] We focus on gasoline prices because, unlike in Europe, few consumers in the United States buy diesel fuel. Similar results are obtained based on alternative measures of gasoline and motor fuel prices. Including both headline and core inflation measures helps separate the broader inflationary impact of gasoline price shocks from their impact on headline inflation. The model also includes both short-run and long-run expectations data given the importance of household inflation expectations for the debate about the possible emergence of a wage-price spiral (see Blanchard 1986).[2]

We postulate that these data are jointly explained by a structural VAR model. We consider two variants of the model. One is based on headline CPI inflation and inflation in

[1] The CPI and PCE data are available in FRED. The gasoline price data were obtained from the U.S. Energy Administration's *Monthly Energy Review*. The inflation expectations data were downloaded directly from the website of the Survey Research Center at the University of Michigan.

[2] The use of survey data makes sense in this context not only because household expectations are widely viewed as a more appropriate indicator of the inflation expectations of businesses than alternative measures of inflation expectations such as professional inflation forecasts, making them the best overall measure of inflation expectations in the economy (e.g., Coibion and Gorodnichenko 2015). The Michigan survey data also provide a consistent measure of expectations for the short and the long run, with the 5-year expectation measuring inflation expectations at a longer horizon than alternative household data sources. Finally, they are available at monthly rather than just quarterly frequency and for a sufficiently long period.

the CPI excluding food and energy, as a measure of core inflation, reflecting the importance of CPI data for the public debate about inflation. The other is based on headline PCE inflation and core PCE inflation. We also selectively report additional results for trimmed mean PCE inflation. PCE inflation measures are what central bankers tend to focus on because they provide a better measure of changes in the overall price level in the economy, which matters for economic modeling. All variables are measured in percent (see Figure 1).

2.1. Model structure

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 5×1 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 5×5 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 $u_t = B_0^{-1} w_t$. We set the lag order, p, to a conservative upper bound of 12 lags (see Kilian and Lütkepohl 2017). 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 structural shock is identified. The estimates of the responses to this shock are invariant to the identification of the remaining structural shocks (see Christiano, Eichenbaum and Evans 1999).

The gasoline price shock is identified based on the assumption that the nominal price of gasoline is predetermined with respect to the other model variables. This assumption is supported by empirical evidence in Kilian and Vega (2011). Under our identifying assumption

$$\begin{pmatrix} u_t^{\Delta pgas} \\ u_t^{\pi^{CPI}} \\ u_t^{\pi^{CPI,core}} \\ u_t^{\pi^{1-yr\ \exp}} \\ u_t^{\pi^{5-yr\ \exp}} \end{pmatrix} = \begin{bmatrix} * & 0 & 0 & 0 & 0 \\ * & * & * & * & * \\ * & * & * & * & * \\ * & * & * & * & * \\ * & * & * & * & * \end{bmatrix} \begin{pmatrix} w_t^{\text{nominal gasoline price}} \\ w_t^2 \\ w_t^3 \\ w_t^4 \\ w_t^5 \end{pmatrix} \quad (1)$$

and

$$\begin{pmatrix} u_t^{\Delta pgas} \\ u_t^{\pi^{PCE}} \\ u_t^{\pi^{PCE,core}} \\ u_t^{\pi^{1-yr\ \exp}} \\ u_t^{\pi^{5-yr\ \exp}} \end{pmatrix} = \begin{bmatrix} * & 0 & 0 & 0 & 0 \\ * & * & * & * & * \\ * & * & * & * & * \\ * & * & * & * & * \\ * & * & * & * & * \end{bmatrix} \begin{pmatrix} w_t^{\text{nominal gasoline price}} \\ w_t^2 \\ w_t^3 \\ w_t^4 \\ w_t^5 \end{pmatrix}. \quad (2)$$

The use of a partially identified model not only dispenses with the need for potentially controversial additional identifying assumptions, but also facilitates the construction of scenarios for the identified shock. Models (1) and (2) are an extension of a lower-dimensional model examined and validated in Kilian and Zhou (2022) who show that in their setting very similar results are obtained under a range of alternative identifying assumptions.

Since the 5-year inflation expectations data are available only starting in 1990.4, the model is estimated on monthly data starting in 1990.4 and ending in 2021.9. We follow the Bayesian approach described in Arias, Rubio-Ramirez and Waggoner (2018) and postulate a diffuse Gaussian-inverse Wishart prior for the reduced-form parameters, as in Karlsson (2013). 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 $\alpha_0 = 7$ and

$$S_0 = (\alpha_0 - 5 - 1)\begin{pmatrix} \sigma_1^2 & 0 & 0 & 0 \\ 0 & \sigma_2^2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \sigma_5^2 \end{pmatrix}.$$

2.2. Econometric evaluation of the structural model

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. We start by computing, for each posterior draw, the expected path of the variables of interest in the absence of future shocks based on the structural moving average decomposition in the estimated model. Let

$$y_t \approx \sum_{i=0}^{t-1} \Theta_i w_{t-i},$$

where y_t denotes the vector of the data at date $t = 1,...,T$, T denotes May 2022 in our application, Θ_i is the 5×5 matrix of impulse response coefficients at horizon i whose elements are denoted by $\theta_{kl,i}$, and w_t denotes the vector of structural shocks. Then the fitted value

$$y_{kt}^{(1)} = \sum_{i=0}^{t-1} \theta_{k1,i} w_{1,t-i},$$

measures the cumulative causal effect of gasoline price shocks on variable $k = 1,...,5$.

This structural moving average representation also provides the starting point for evaluating scenarios about the future price of crude oil. This requires mapping the hypothesized change in the price of crude oil into the corresponding change in the retail price of gasoline from June 2022 until December 2023. Under the maintained assumption that among all costs components of the retail price of gasoline only the cost of crude oil is changing, this implies that the percent change in the price of gasoline is the hypothesized percent change in the price of crude oil weighted by the cost share of crude oil in the retail price of gasoline. Recent EIA data suggest a cost share of near 60% (see Golding and Kilian 2022). We refer to the resulting path for the growth rate of the price of gasoline as the target growth rate. We estimate the expected path of each model variable in the absence of future shocks by iterating this expression forward for 19 months beyond the end of the sample, given $w_{T+1} = ... = w_{T+27} = 0.$ We then compare the expected path for the growth rate of the price of gasoline in the structural VAR model with the targeted growth rate of gasoline prices (adjusted for the mean change in this growth rate) under the scenario, denoted $x_{T+1},....,x_{T+27}.$

This allows us to recursively infer, for each posterior draw, the magnitude of the gasoline price shock required for the predicted growth rate, $x_{T+1},...,x_{T+27},$ to match its targeted value. Let w_{1j}^c denote the counterfactual exogenous gasoline price shock at date j, where $w_{1j}^c = w_{1j}$ for $j \leq T.$ Then

$$w_{1j}^c = \frac{\left(x_j - x_{1j}\right)}{\theta_{11,j}}, \quad j = T+1,....,T+27,$$

where $x_{1t} = \sum_{j=1}^{4} x_{1t}^{(j)}$ and $x_{1t}^{(j)} = \sum_{i=0}^{t-1} \theta_{1j,i} w_{j,t-i}^c$ are updated recursively, while $x_{1t}^{(j)} = y_{1t}^{(j)}$ for $j \neq 1.$ The resulting counterfactual shock sequence is then imposed in generating future realizations of all variables of interest from the structural moving average representation for $T+1,...,T+19.$ This allows us to extrapolate the cumulative impact of gasoline price shocks on the model variables from the past into the future.[3] We evaluate the posterior draws of the

[3] A similar approach has been used in in Kilian and Zhou (2020) for assessing the impact of a hypothetical reduction in the U.S. Strategic Petroleum Reserve on fiscal revenues.

paths of each variable of interest under additively separable loss, as discussed in Inoue and Kilian (2022), and construct the Bayes estimate as well as approximations to the corresponding lowest posterior risk joint credible sets.

3. Empirical Analysis of CPI Inflation

Model (1) focuses on CPI inflation which is the measure of inflation most closely observed by the public and most widely discussed in the press. In contrast, monetary policy decisions are based on PCE inflation measures, as included in model (2). There are important differences in how these inflation measures are constructed and what expenditure weights they use. For example, the CPI does not cover all health-related expenses of consumers, but attaches a larger weight to housing expenses. Moreover, the PCE price index is constructed taking into account additional data from business surveys and administrative data. An interesting question therefore is whether this distinction makes a difference for the impact of gasoline price shocks. When discussing the estimates of model (2) in section 4, we will show that there are indeed important differences across CPI and PCE inflation data.

3.1. How do CPI inflation and inflation expectations respond to nominal gasoline price shocks?

Estimates of model (1) show that a positive nominal gasoline price shock causes a persistent appreciation of the price of gasoline. Figure 2 shows the responses of the other variables to an unexpected increase in the nominal retail price of gasoline. It shows a sharp and precisely estimated increase in headline CPI inflation on impact that dies out after two months.

While the general public tends to focus on headline CPI inflation, economists tend to exclude volatile components of the CPI such as food or energy in an effort to measure broader inflationary pressures. One such inflation measure is based on the CPI excluding food and energy (often referred to as core CPI inflation). There are two reasons to expect gasoline price shocks to be associated with broader inflationary pressures. One is that gasoline price shocks have been shown to be a bellwether for broader demand shifts in the domestic economy. Since demand shifts may be persistent, one would expect gasoline price increases to be followed by other consumer price increases. The other reason is that higher gasoline price shocks also may directly and indirectly affect the cost of producing other goods. To the extent that these cost increases are being passed on to the consumer, it would not be surprising to see a delayed positive response in non-energy consumer prices.

Figure 2 addresses this question. It shows a much smaller initial response of core CPI inflation than for headline CPI inflation, which is precisely estimated only one and two months after the impact period. At longer horizons, the responses remain positive, but diminish. There is no evidence of large spillovers into core CPI inflation or of large secondary inflation increases, as implied by models of wage-price spirals (see Blanchard 1986).[4] Of course, our results only speak to the effect of gasoline price shocks. They do not preclude the possible emergence of a wage-price spiral as a result of other inflationary pressures and the rising bargaining power of workers since 2021.

Finally, Figure 2 shows a response of 1-year inflation expectations that is much smaller than that of headline CPI inflation, but more persistent and remains precisely estimated even after a year and a half. In assessing these responses, it has to be kept in mind that even the peak response is small relative to the typical level of inflation expectations. The response of 5-year inflation expectations is also persistent, but much smaller and precisely estimated only at horizon 1.[5] Thus, there is clear evidence that gasoline price shocks matter for all model variables, albeit to different degrees.

---

[4] The wage-price spiral, as discussed in Blanchard (1986), refers to a process of repeated adjustments of nominal prices and nominal wages that results from attempts by workers to maintain their real wage and by firms to maintain their markup of prices over wages. Such a spiral could start from attempts by workers to maintain the same real wage in the face of an adverse oil price shock, causing persistent inflationary pressures, especially as higher inflation becomes embedded in inflation expectations.

[5] It should be kept in mind that our analysis speaks to the component of inflation and inflation expectations driven by gasoline price shocks. Obviously, rising gasoline prices are only one source of inflationary pressures. The estimates in this paper by construction do not incorporate broader cost pressures from tight labor markets

The estimate of model (1) also indicates that over our estimation period gasoline price shocks accounted for 65% of the variability in the headline CPI inflation rate, but only 10% of the variability in the core CPI inflation rate. At the same time, gasoline price shocks explain 38% of the variability in 1-year inflation expectations, but only 19% of the variability in 5-year inflation expectations (see Table 1). Of course, there may be substantial differences in the explanatory power of gasoline price shocks over time. Next, we therefore quantify the extent to which gasoline price shocks caused inflation and inflation expectations to move from June 2019 until May 2022 specifically. Over this period first the Covid-19 pandemic and then the Russian invasion of Ukraine triggered major gasoline price fluctuations.

3.2. How much of the evolution of CPI inflation and inflation expectations up to May 2022 must be attributed to nominal gasoline price shocks?

Figure 3 plots the cumulative contribution of gasoline price shocks to headline CPI inflation rates based on the estimate of model (1). A positive value indicates by how many percentage points all gasoline price shocks to date have raised inflation in that month (expressed as annualized rates); a negative value indicates by how much they have lowered inflation in that month.

The unexpected drop in gasoline prices in early 2020, as the pandemic paralyzed the U.S. economy, lowered headline inflation by 9 percentage points on an annualized basis. This drop explains nearly all of the temporary decline in inflation during that period. Starting in May, the economy and hence gasoline prices began to recover. Inflation briefly spiked in June 2020 as a result. It was only in December 2020, however, that gasoline price shocks started to persistently raise headline inflation. In early 2021, the recovery in gasoline prices added as much as 4.4 percentage points to headline inflation. This effect starting waning later

and sustained disruptions of supply chains, which have also been putting upward pressure on U.S. consumer prices and price expectations.

in the summer of 2021, at times even turning negative. This period of relative calm was followed by a sharp spike in March 2022 in the wake of the Russian invasion of Ukraine. The cumulative effect of gasoline price shocks on headline CPI inflation temporarily reached 8.3 percentage points in March, accounting for more than half of the 14.9 percent inflation at annualized rates that month, before dropping to 0.3 percentage points in April 2022. As of May 2022, the cumulative impact of gasoline price shocks was 3.9 percentage points, accounting only for one third of observed headline CPI inflation. This point is of some interest because it suggests that the continued surge in headline CPI inflation at that point was not driven by gasoline price shocks so much, but mostly by price pressures resulting from higher demand, supply bottlenecks and tight labor markets that may be less transitory.

Not surprisingly, the cumulative effect on monthly core CPI inflation was much more muted (see Figure 4). There is evidence of a decline in core CPI inflation from 2020 through early 2021 by as much as 1.2 percentage point on an annualized basis. This decline is reversed only in 2021. Starting in 2022, the cumulative impact of gasoline price shocks turns positive, reaching 0.8 percentage points in May 2022.

The fall and rise in gasoline prices during the pandemic is also reflected in household inflation expectations. Figure 5 shows the response of households' 1-year inflation expectations to all gasoline price shocks to date. There is clear evidence that unexpected gasoline price fluctuations temporarily lowered inflation expectations by as much as 1 percentage point at the height of the lockdown. As the price of gasoline recovered, inflation expectations were pushed up by 0.7 percentage points in May 2022. In contrast, the cumulative impact of gas price shocks on 5-year inflation expectations has been muted at best (see Figure 6). Following a modest decline by 0.2 percentage points in early 2020, it recovered to near zero around mid-2021 and reached 0.1 percentage points by May 2022. This evidence shows that gasoline price shocks have played an important role in driving both headline CPI inflation rates and one-year inflation expectations during the pandemic, but have not had a large impact on five-year inflation expectations.

3.3. How much additional CPI inflation can we expect, if the price of oil were to remain at $110 per barrel?

The surge in inflation rates and one-year inflation expectations by May 2022 raises the question of how persistent these inflationary pressures are likely to be and how much further they may increase. We address this question by modeling within model (1) a scenario in which the price of oil remains at $110/barrel between June 2022 and December 2023.

3.3.1. A $110 Oil Scenario

The thought experiment that the price of WTI crude oil remains at the level of $110 per barrel from June 2022 until December 2023 amounts to assuming that the oil price remains unchanged at current levels. This scenario is not unreasonable, given that the EU oil embargo is not expected to take effect until early 2023 and is unlikely to be fully effective. If a sufficient amount of Russian petroleum exports is diverted from Europe to China and India, in particular, the remaining shortfall of global oil supplies in 2023 may be compensated for by increased oil production elsewhere in the world, especially given a slowdown in the rest of the world. Of course, this is only one possible scenario, but it provides a useful baseline against which other, less benign scenarios may be judged using the same tools.

3.3.2. Implications of the scenario for CPI inflation and inflation expectations

Under our thought experiment, the growth rate in the nominal U.S. retail price of gasoline is 60% of the growth rate of the price of crude oil, given that the share of crude oil in the cost of producing gasoline recently has been near 60%.[6] We use the estimates of our structural model

[6] This approach does not contradict the point in Kilian and Zhou (2021) that oil prices in general do not move proportionately with gasoline prices because other gasoline cost components such as taxes, markups, labor and capital costs and the costs of marketing and distribution tend to vary independently of the cost of crude oil. Because under the counterfactual only the oil cost component of the price of gasoline is changing, postulating a proportionate pass-through of this component to the price of oil is a reasonable assumption.

to simulate the evolution of headline inflation and inflation expectations under the maintained assumption that the change in gasoline prices follows this hypothesized path, while setting all other shocks in the model to zero in expectation, as discussed in section 2. Since the estimates of structural models similar to ours have been shown to be stable over time in related research, there is no reason to discount the implications of the estimated structural model for the 2021-23 period.[7] It should be noted that this scenario may alternatively be interpreted as a prediction of inflation and inflation expectations conditional on a no-change forecast of the price of crude oil.

Figure 3 shows that this scenario is associated with a fall in the cumulative impact of gasoline price shocks on monthly headline CPI inflation from 4.2 percentage points to 1.1 percentage point in June at annualized rates. For the remainder of 2022, the gasoline price driven component of inflation remains above 1 percentage point, but falls to 0.7 percentage points by the end of 2023. In other words, the inflationary effects of positive gasoline price shocks largely vanish almost as soon as gasoline prices stop rising. Figure 3 suggests that, under the $110 oil price scenario, the worst impact of rising gasoline prices on inflation is already behind us. At the same time, the inflationary impact on core CPI inflation, shown in Figure 4, reaches as much as 1 percentage point at annualized rates in 2022, before stabilizing near current levels in 2023. The cumulative impact of gas price shocks on one-year inflation expectations, following its peak near 0.7 percentage points in mid-2022, gradually declines, reaching 0.4 percentage points at the end of 2023 (see Figure 5). In contrast, the cumulative impact on 5-year inflation expectations stabilizes near current levels at about 0.15 percentage

[7] The analysis of scenarios based on structural VAR models is valid only to the extent that the hypothesized shock sequence does not cause economic agents to change their behavior, rendering the structural model unstable (see Kilian and Lütkepohl 2017). For example, the stability of the structural model is in doubt when implementing a scenario requires structural shocks that are larger in magnitude than historical structural shocks. Likewise, long sequences of shocks of the same sign under the scenario may cause agents to change their behavior, causing the structural model coefficients to drift. Plots of the historical and hypothetical gasoline price shocks suggest that this critique is not a concern for our analysis.

points (see Figure 6).

Table 2 summarizes the main results by year. Consistent with the evidence in Figures 3 and 4, Table 2 suggests that fears that gasoline price shocks would trigger an era of prolonged inflation under the scenario of interest are not supported by the data. Although headline CPI inflation rises from 1% in 2021 to 2.2% in 2022 in response to these shocks, the inflationary impact drops to 0.9% in 2023. In other words, whereas the price level remains elevated, its rate of growth declines fairly quickly. For core CPI inflation the initial impact in 2021 was negligible. In 2022, the effect on core CPI inflation rises to half a percentage point reaching 0.7 percentage points in 2023, indicating a persistent, but modest inflationary effect. This pattern roughly mirrors that for one-year inflation expectations. The corresponding increases in 5-year inflation expectations in 2022 and 2023 are negligible.

4. Empirical Analysis of PCE Inflation

Model (2) replaces CPI headline inflation in model (1) by PCE headline inflation and uses PCE inflation excluding food and energy as the measure of core PCE inflation.[8] Figure 7 highlights that headline PCE inflation tends to be less responsive to gasoline price shocks than headline CPI inflation. The impact response is only 1.6 percentage points on an annualized basis, compared with more than 2 percentage points in Figure 2. This difference mainly reflects the lower share of gasoline in the PCE index. The general pattern is the same, however. The responses of inflation expectations are similar to those in Figure 2.

Table 3 shows that gasoline price shocks, on average, explain only 51% of the variability in headline PCE inflation, compared with 65% for headline CPI inflation,

[8] An alternative would be the trimmed mean PCE inflation rate developed at the Federal Reserve Bank of Dallas (see Dolmas and Koenig 2019). The trimmed mean measure is more robust than the PCE inflation measure excluding food and energy in that it controls for outliers in all inflation components rather than just food and energy, which is particularly important during the pandemic recession. It can be shown that replacing the core inflation measure in model (1) by the trimmed mean generates broadly similar results, so we concentrate on the results for headline PCE inflation and for core PCE inflation in this section. Additional results for the trimmed mean PCE inflation measure will be reported later.

indicating again that the PCE inflation rate appears less sensitive to gasoline price shocks. There is no such difference when focusing on the core inflation measures. 12% of the variability in the core PCE inflation rate is explained by gasoline price shocks compared with 10% for core CPI inflation in Table 1. Similar shares are also obtained for the 1-year inflation expectations measure in the two model specifications. The variability of 5-year expectations is more sensitive to gasoline price shocks in model (1) than in model (2), but these differences are likely explained by estimation error.

Figure 8 shows a more muted cumulative response of headline PCE inflation to gasoline price shocks in early 2020, with a trough of -6 percentage points compared to -9 percentage points in Figure 3, and peaks of 3.5 and 5.5 percentage points, respectively, in early 2021 and early 2022, compared with 4.4 and 8.3 percentage points, respectively, in Figure 3. This impression is confirmed in Table 2, which shows an impact of only 0.7 percentage points in 2021, 1.9 percentage points in 2022, and 0.8 percentage points in 2023, lower than for headline CPI inflation. Thus, the choice of the inflation measure matters.

The results for the core PCE inflation rate in Figure 9 differ only slightly from those for core CPI inflation in Figure 4. While the pattern of the cumulative response is similar, as Table 2 illustrates, the overall impact of gasoline price shocks on core PCE inflation in 2022 and 2023 is somewhat lower. Additional analysis based on replacing the core PCE inflation rate in model (2) by the trimmed mean PCE inflation rate indicates an impact on annual inflation of 0 percentage points in 2021, 0.4 percentage points in 2022, and 0.5 percentage points in 2023, somewhere between the core CPI and core PCE results.

5. Implications for Year-Over-Year Inflation Rates

Whereas our analysis has been based on monthly observations, much of the policy debate is concerned with the evolution of year-over-year changes in the price level. This distinction is important because measuring inflation as a trailing 12-month moving average of annualized rates may affect the duration of the deflationary and inflationary effects of gasoline price shocks, their magnitude and their timing.

As Figure 10 shows, by this metric, gasoline price shocks caused a sustained decline in headline CPI inflation in 2020, which was overcome only in the second quarter of 2021. Inflationary effects reached their highest value to date in May 2022 at 1.3 percentage points, which is only 15% of the 12-month headline CPI inflation rate of 8.5% recorded for this month, underscoring that gasoline price shocks are an important determinant, but not the main determinant of recent headline inflation as sometimes suggested in the public debate. Under the $110 oil price scenario, the cumulative impact of gasoline price shocks on 12-month headline CPI inflation continues to rise throughout the remainder of 2022, peaking at 2.3 percentage points in early 2023. Likewise, the impact on headline PCE inflation peaks in early 2023 at a slightly lower rate of 2 percentage points. As Figures 3 and 8 illustrate, this result does not indicate rising inflationary pressures going forward, but is an artifact of the construction of year-over-year inflation rates as 12-month trailing averages of monthly annualized rates. By comparison, the effect on year-over-year core CPI inflation, trimmed mean PCE inflation, and core PCE inflation steadily increase in 2022, before stabilizing in early 2023 and reaching 0.66, 0.46 and 0.33 percentage points, respectively, at the end of 2023.

6. Concluding Remarks

In this paper, we presented simple tools that allow researchers to understand the impact of oil price fluctuations on inflation and inflation expectations, both based on historical data and under hypothetical scenarios about the future evolution of the price of crude oil. The methods discussed in this paper are of general interest to central bankers and macroeconomists. We focused on the scenario of the WTI price of oil remaining at $110/barrel after May 2022. Recently, more aggressive oil price scenarios have been advanced. For example, analysts working for J.P. Morgan Chase & Co in July 2022 warned that oil prices could reach $380 per barrel if Russia responds to sanctions by cutting its crude oil production. At the same time, analysts at Citigroup cautioned that oil prices may drop as low as $45/barrel by the end of 2023, if the world enters a steep recession. It would be straightforward to examine the implications of such more extreme scenarios using the tools we employed in this paper. While we have analyzed the impact of oil price scenarios from the point of view of the United States, which simplifies the analysis because oil is traded in U.S. dollars, our analysis could be easily extended to other countries with the important difference that the oil price under a given scenario would have to be expressed in the domestic currency of those countries first, before computing the implied path of gasoline price inflation.

References

Arias, J.E., Rubio-Ramirez, J.J., and D.F. Waggoner (2018), "Inference based on structural vector autoregressions identified by sign and zero restrictions: Theory and applications," *Econometrica*, 86, 685-720.

Binder, C. (2018), "Inflation expectations and the price at the pump," *Journal of Macroeconomics*, 58, 1-18.

Binder, C., and C. Makridis (2022), "Stuck in the seventies: Gas prices and macroeconomic expectations," *Review of Economics and Statistics*, 104, 293-305.

Blanchard, O.J. (1986), "The Wage Price Spiral," *Quarterly Journal of Economics*, 101, 543-565.

Christiano, L., Eichenbaum, M., and C. Evans (1999), "Monetary policy shocks: What have we learned and to what end?", *Handbook of Macroeconomics*, eds. M. Woodford and J. Taylor, North Holland.

Clark, T.E., and S.J. Terry (2010), "Time variation in the inflation passthrough of energy prices," *Journal of Money, Credit and Banking*, 42, 1419-1433.

Coibion, O., and Y. Gorodnichenko (2015), "Is the Phillips curve alive and well after all? Inflation expectations and the missing disinflation," *American Economic Journal: Macroeconomics*, 7, 197-232.

Conflitti, C., and R. Cristadoro (2018), "Oil prices and inflation expectations", Banca d'Italia Occasional Papers No. 423.

Conflitti, C. and M. Luciani (2019). "Oil price pass-through into core inflation," *Energy Journal*, 40, 221-247.

Dolmas, J., and E.F. Koenig (2019), "Two Measures of Core Inflation: A Comparison," F*ederal Reserve Bank of St Louis Review*, 101, 245-258.

Golding, G., and L Kilian (2022), "Don't Look to Oil Companies to Lower High Retail Gasoline Prices," May 22, https://www.dallasfed.org/research/economics/2022/0510.

Inoue, A., and L. Kilian (2022), "Joint Bayesian inference about impulse responses in VAR models," *Journal of* Econometrics, forthcoming.

Karlsson, S. (2013), "Forecasting Bayesian vector autoregressions," in: G. Elliott and A. Timmermann (eds.), *Handbook of Economic Forecasting*, 2, Amsterdam: North-Holland, 2013, 791-897.

Kilian, L. (2009), "Comment on 'Causes and Consequences of the Oil Shock of 2007-08' by James D. Hamilton," *Brookings Papers on Economic Activity*, 1, Spring, 267-278.

Kilian, L., and H. Lütkepohl (2017), *Structural Vector Autoregressive Analysis*, Cambridge University Press: Cambridge.

Kilian, L., and L.T. Lewis (2011), "Does the Fed Respond to Oil Price Shocks?," *Economic Journal*, 121, 1047-1072.

Kilian, L., and C. Vega (2011), "Do energy prices respond to U.S. macroeconomic news? A test of the hypothesis of predetermined energy prices," *Review of Economics and Statistics*, 93, 660- 671.

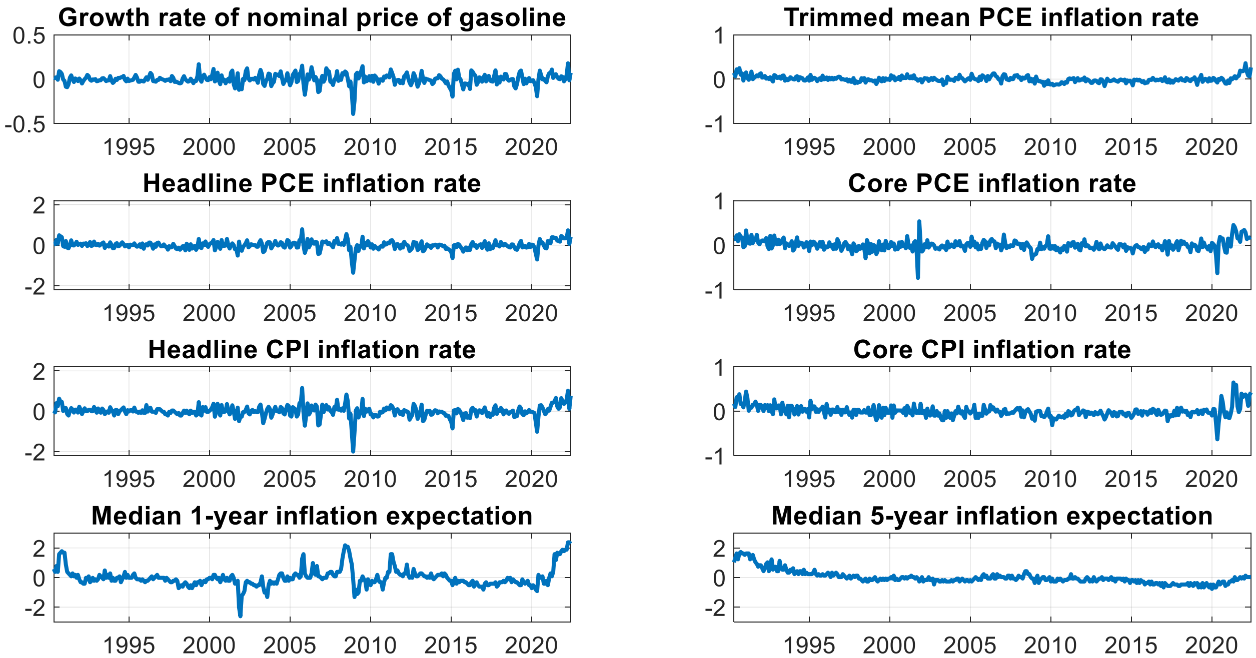
Kilian, L. and X. Zhou (2020), “Does Drawing Down the U.S. Strategic Petroleum Reserve Help Stabilize Oil Prices?” *Journal of Applied Econometrics*, 35, 673-691.

Kilian, L. and X. Zhou (2022), “Oil prices, gasoline prices and inflation expectations,” *Journal of Applied Econometrics*, forthcoming.

Lee, I. (2021), “Oil could surge above $100 in the event of a cold winter - and spark inflation that drives the next macro crisis, BofA says,” *Markets Insider*, Oct 1, 2021.

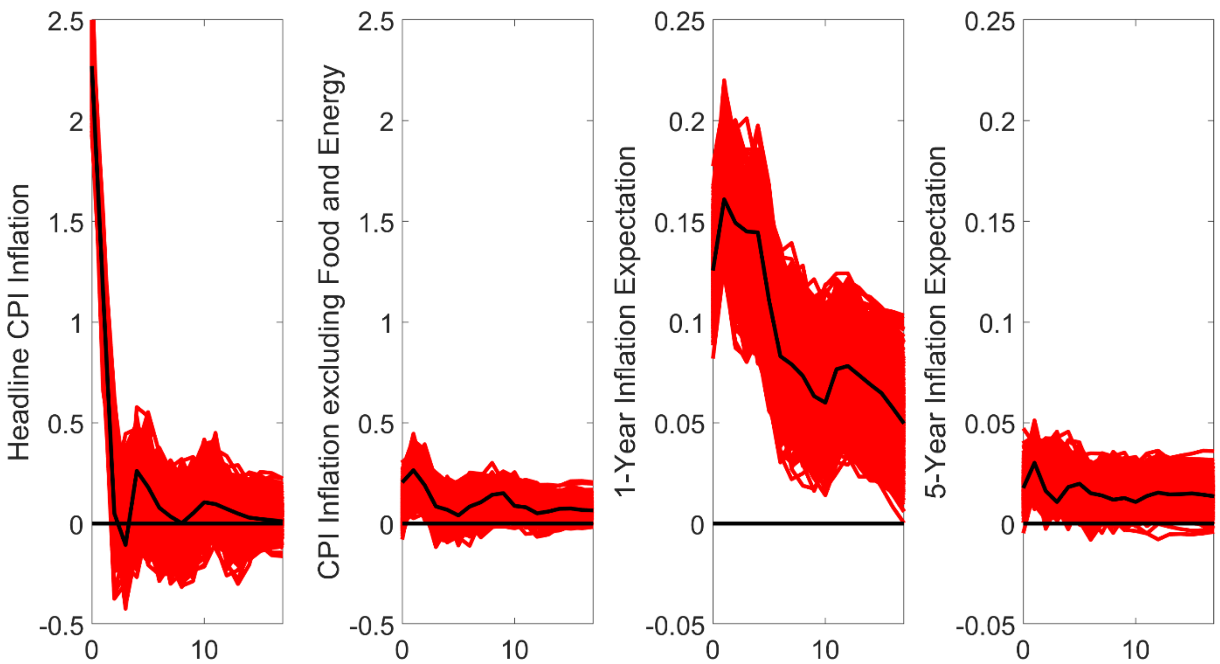
Wong, B. (2015), “Do inflation expectations propagate the inflationary impact of real oil price shocks? Evidence from the Michigan Survey,” *Journal of Money, Credit and Banking*, 47, 1673-1689.

Figure 1: Indicators used in the VAR analysis, 1990.4-2022.5



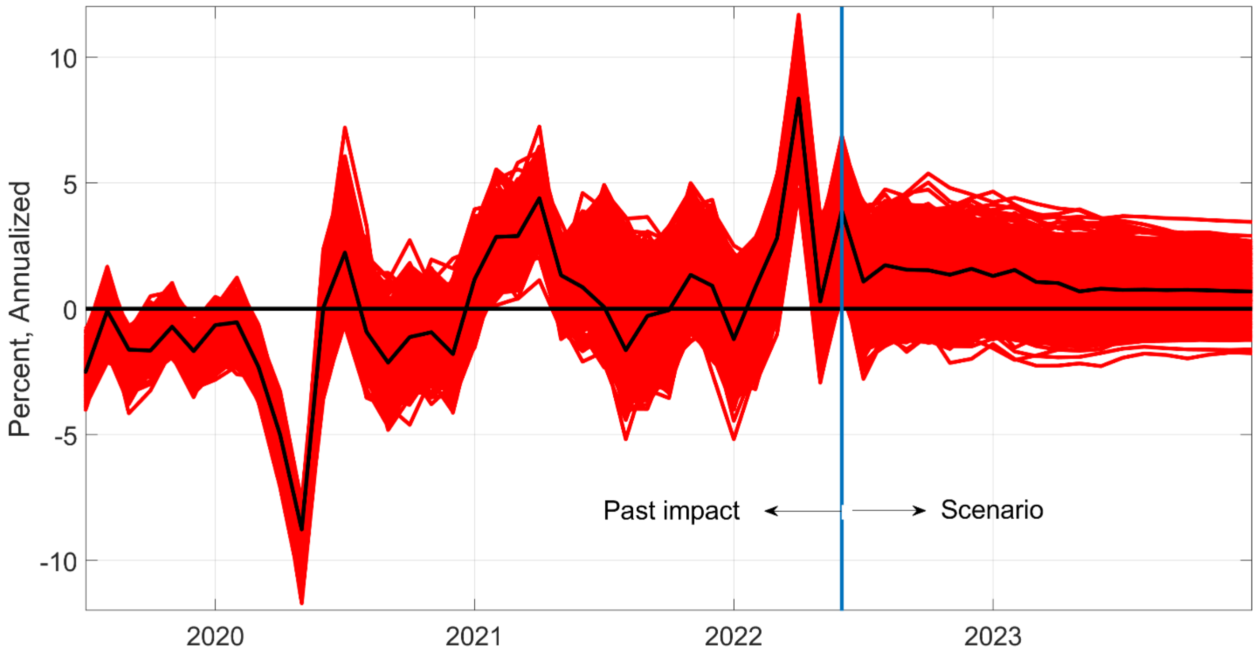
NOTES: All data have been demeaned and expressed in percentage points.

Figure 2: Estimated responses to gasoline price shock in model (1), 1990.4-2022.5



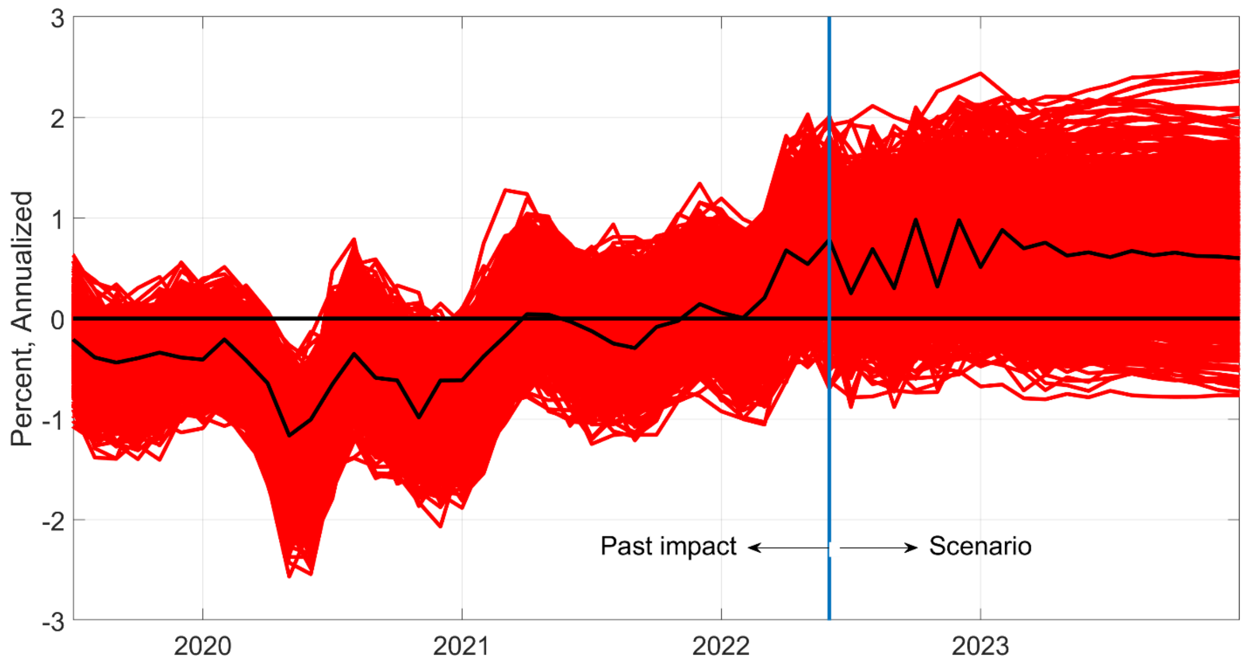
NOTES: The core and headline CPI inflation rates have been annualized. The set of impulse responses shown in black is obtained by minimizing the absolute loss function in expectation over the set of admissible structural models, as discussed in Inoue and Kilian (2021). The responses in the corresponding 68% joint credible set are shown in a lighter shade.

Figure 3: Monthly headline CPI inflation caused by gasoline price shocks, 2019.6-2023.12



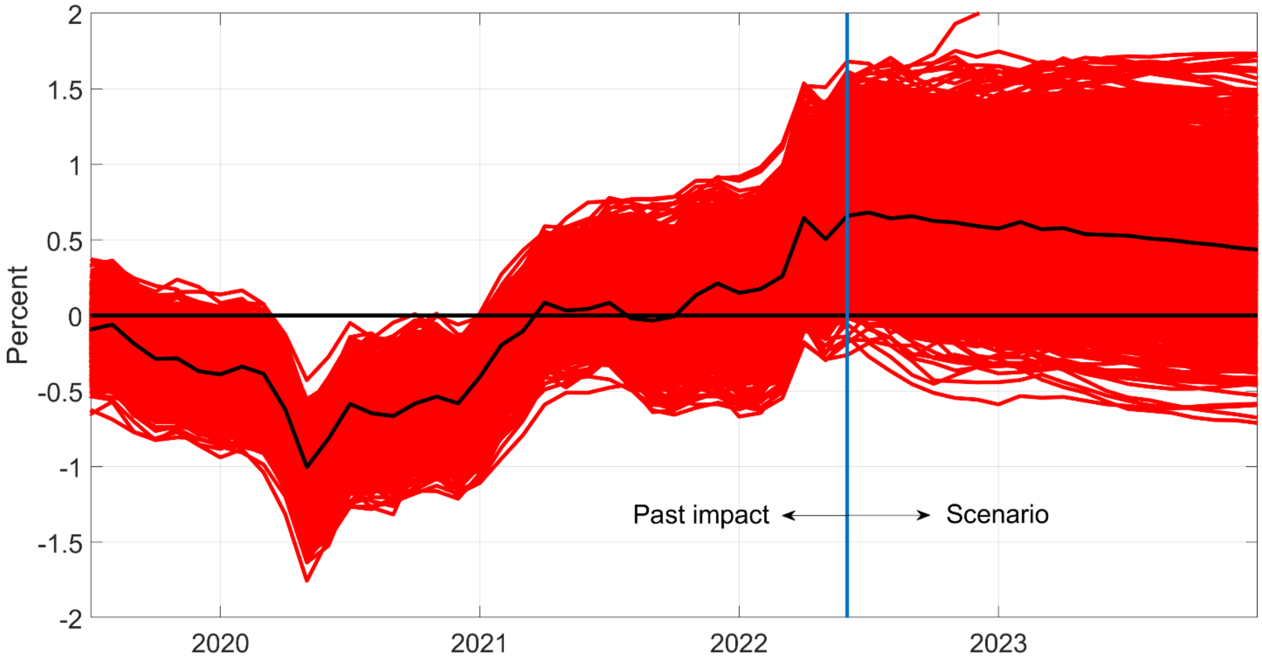
NOTES: Authors' computations based on estimated model (1). The expected path is shown as the black line. The other lines capture the uncertainty about this path based on an approximation to the 68% joint credible set.

Figure 4: Monthly core CPI inflation caused by gasoline price shocks, 2019.6-2023.12



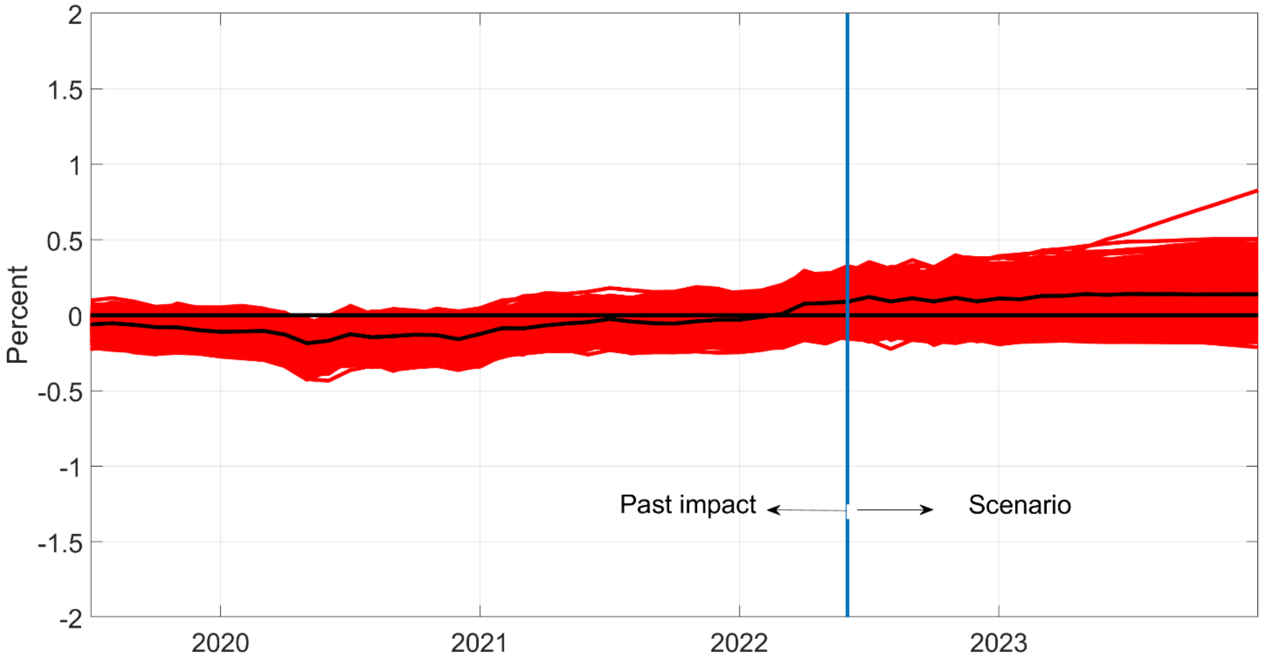
NOTES: See Figure 3.

Figure 5: 1-Year household inflation expectation caused by gasoline price shocks, 2019.6-2023.12



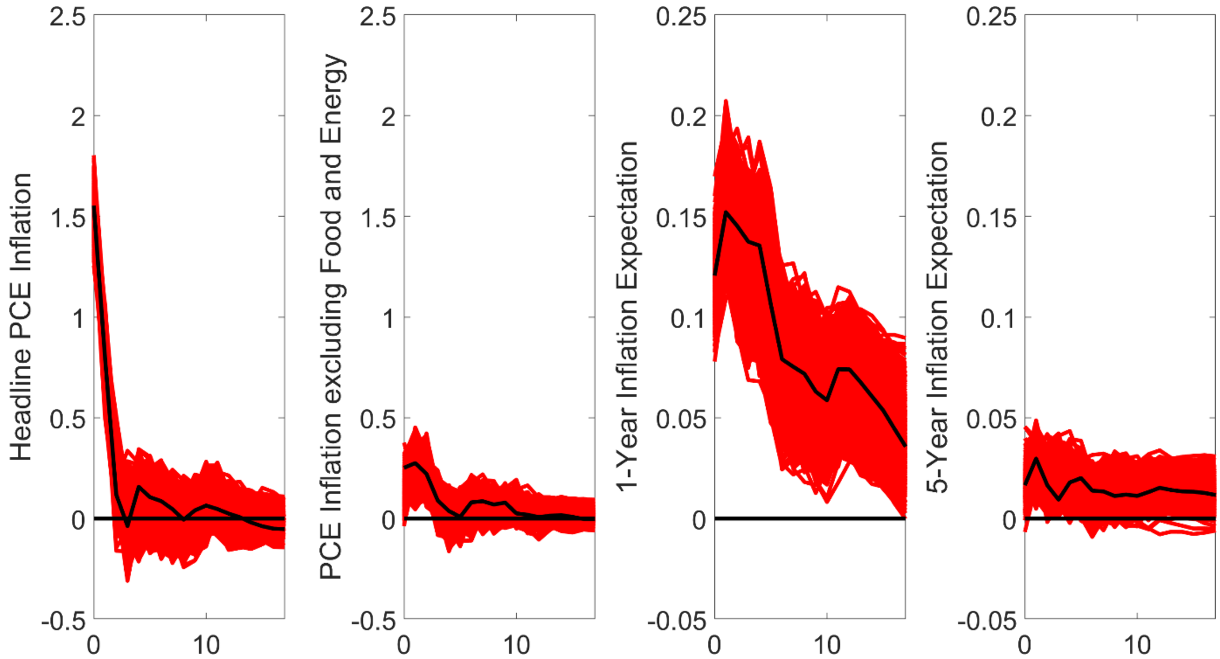
NOTES: See Figure 3.

Figure 6: 5-Year household inflation expectation caused by gasoline price shocks, 2019.6-2023.12



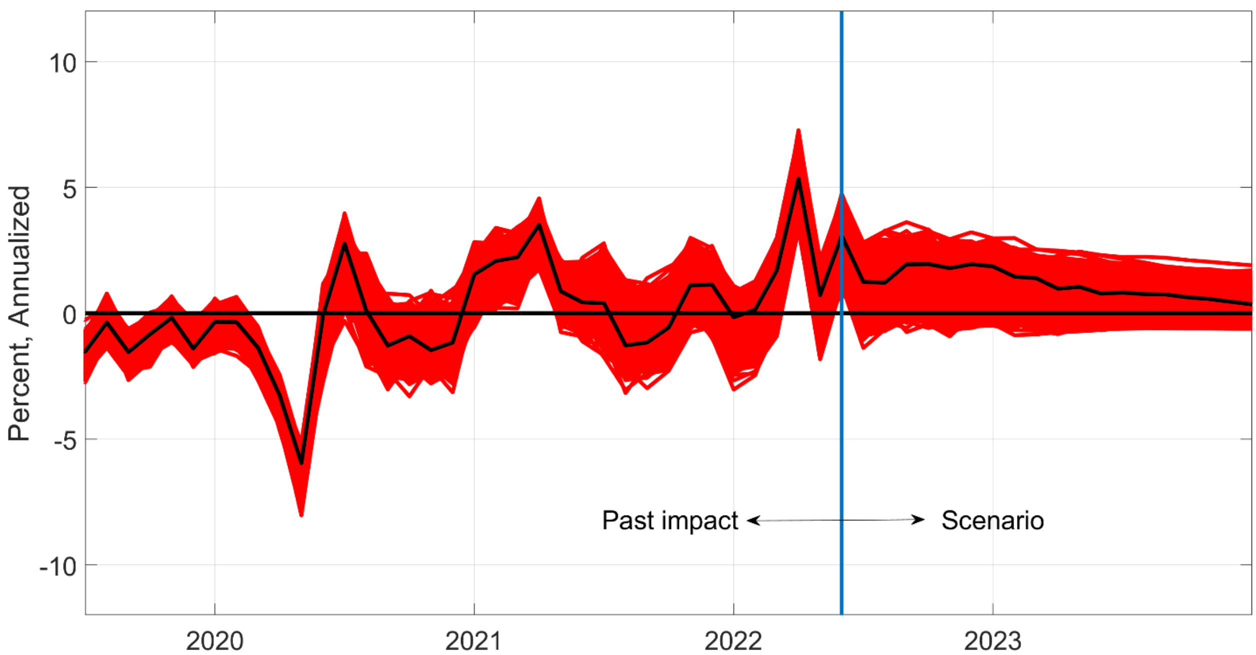
NOTES: See Figure 3.

Figure 7: Estimated responses to gasoline price shock in model (2), 1990.4-2022.5



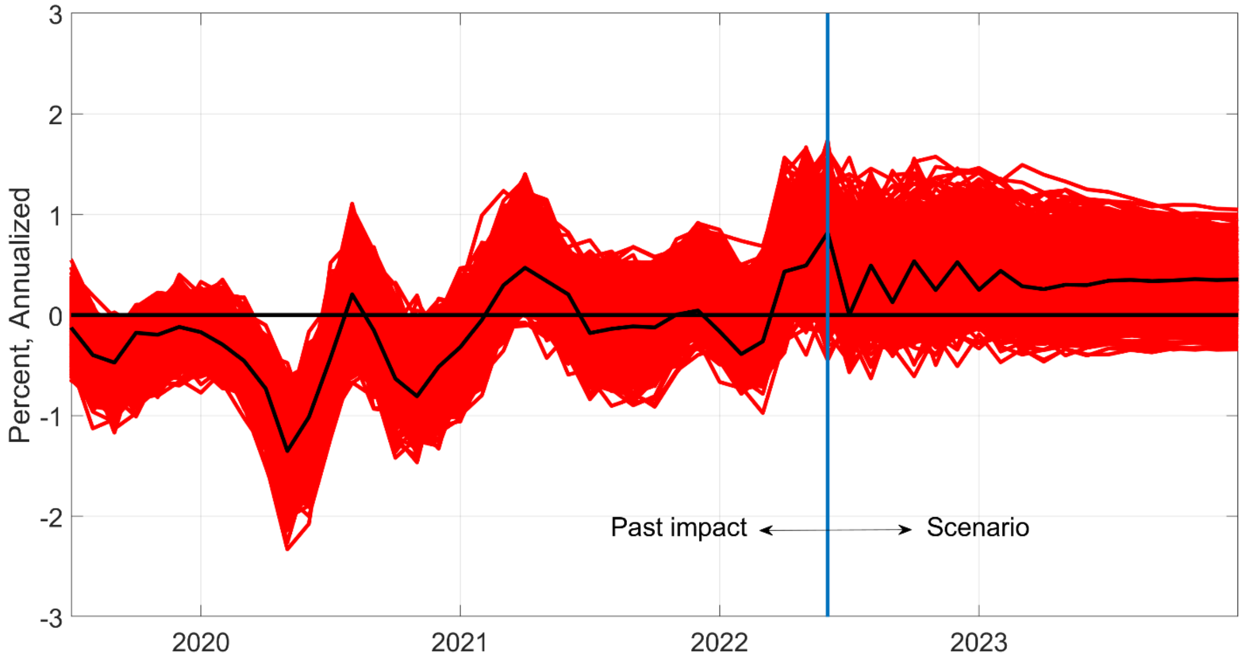
NOTES: The core and headline PCE inflation rates have been annualized. The set of impulse responses shown in black is obtained by minimizing the absolute loss function in expectation over the set of admissible structural models, as discussed in Inoue and Kilian (2021). The responses in the corresponding 68% joint credible set are shown in a lighter shade.

Figure 8: Monthly headline PCE inflation caused by gasoline price shocks, 2019.6-2023.12



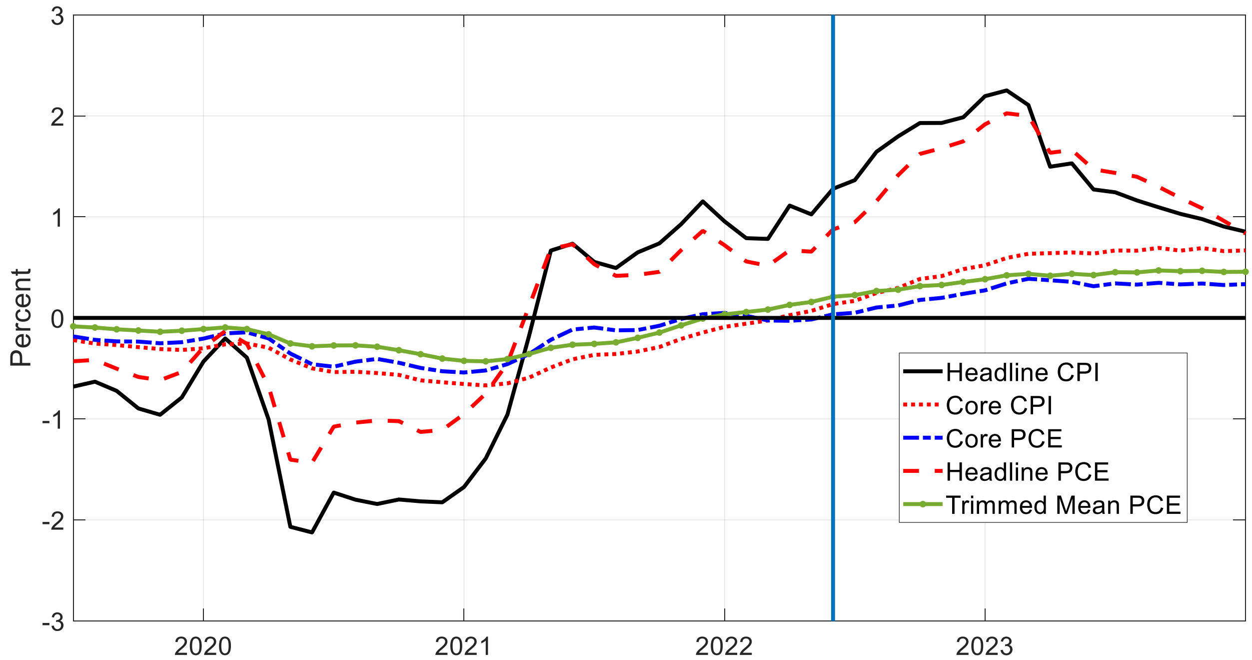
NOTES: Authors' computations based on estimated model (2). The expected path is shown as the black line. The other lines capture the uncertainty about this path based on an approximation to the 68% joint credible set.

Figure 9: Monthly core PCE inflation caused by gasoline price shocks, 2019.6-2023.12



NOTES: See Figure 8.

Figure 10: Year-over-year inflationary effects of gasoline price shocks, 2019.6-2023.12



NOTES: Estimates based on models (1) and (2). All results shown are based on 12-month trailing averages of the monthly Bayes estimates in Figures 3, 4, 8 and 9 and analogous results for the trimmed mean PCE inflation rate.

Table 1: The contribution of gasoline price shocks to the variability in inflation and inflation expectations

Variables in model (1)	Percent share of variance explained
Headline CPI Inflation	64.5
	[55.9, 64.8]
CPI Inflation excluding Food and Energy	10.5
	[8.0, 20.7]
1-Year Inflation Expectation	37.6
	[30.0, 46.0]
5-Year Inflation Expectation	19.0
	[10.1, 28.8]

NOTES: Authors' computations based on model (1). 68% error bands in parentheses.

Table 2: Inflationary effects by year under the $110 oil scenario (Percentage points)

	2021	2022	2023
Annual Headline CPI Inflation[a]	0.96	2.20	0.85
	[0.32, 1.91]	[0.60, 2.97]	[-0.33, 1.74]
Annual CPI Inflation excluding	-0.09	0.52	0.67
Food and Energy[a]	[-0.49, 0.26]	[-0.03, 0.96]	[-0.02, 1.12]
1-Year Inflation Expectation[a]	0.03	0.55	0.52
	[-0.25, 0.27]	[0.10, 0.92]	[0.00, 0.96]
5-Year Inflation Expectation[a]	-0.05	0.08	0.13
	[-0.15, 0.02]	[-0.06, 0.14]	[-0.03, 0.20]
Annual Headline PCE Inflation[b]	0.72	1.92	0.84
	[0.18, 1.13]	[0.56, 1.97]	[0.02, 1.09]
Annual PCE excluding Food	0.05	0.27	0.33
and Energy[b]	[-0.09, 0.33]	[0.08, 0.67]	[0.03, 0.50]
Annual Trimmed Mean PCE	0.04	0.38	0.46
Inflation[c]	[-0.16, 0.22]	[0.23, 0.74]	[0.16, 0.79]

[a] Based on estimates of model (1). [b] Based on estimates of model (2). [c] Based on estimates obtained when replacing the core PCE inflation in model (2) by trimmed mean PCE inflation. NOTES: Authors' computations based on estimates of models (1) and (2). The table shows the average value of the estimated path of each variable over the 12 months of a given year. The corresponding 68% error bands are shown in parentheses.

Table 3: The contribution of gasoline price shocks to the variability in inflation and inflation expectations

Variables in model (2)	Percent share of variance explained
Headline PCE Inflation	51.0
	[50.0, 58.1]
PCE Inflation excluding Food and Energy	11.8
	[7.6, 14.8]
1-Year Inflation Expectation	35.9
	[28.2, 42.7]
5-Year Inflation Expectation	11.2
	[8.1, 24.0]

NOTES: Authors' computations based on model (2). 68% error bands in parentheses.

We do not wish to provide a “credit author statement” or for such a statement to be included in the paper.

Lutz Kilian

Xiaoqing Zhou

- Gasoline price shocks have not moved long-run household inflation expectations
- Effects on headline inflation account only for modest fraction of overall inflation
- Inflationary effect of gasoline price shocks are not persistent
- No evidence of important secondary effects