Natural Gas Prices and Unnatural Propagation Effects: The Role of Inflation Expectations in the Euro Area*

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Abstract

This paper investigates the recent increases in natural gas prices and its propagation effects via inflation expectations. Using a structural vector autoregression, we identify a euro area natural gas price shock with a combination of sign- and zero-restrictions. We rely on market-based measures of inflation expectations. We find that natural gas price shocks have strong effects on both inflation and inflation expectations. To understand the relative importance of the pass-through from inflation expectations to inflation after a natural gas price shock, we conduct a counterfactual analysis in which we turn off the expectation channel. Our findings indicate the presence of strong second-round effects via expectations. Furthermore, these effects are stronger for short-term expectations than for long-term expectations. Our analysis provides a guidance for policymakers to better understand the potential trade-offs of different policy responses to natural gas price shocks.

Keywords: Natural Gas Price Shocks, Inflation Expectations, Euro Area, Counterfactual Analysis.

JEL Codes: C32, E31, Q43.

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1. Introduction

The sharp oil price increases in the 1970s and its detrimental effects on the macroeconomy are well anchored in the collective memory. However, since then the sensitivity of industrial economies with respect to oil price surges are associated with less pronounced movements in output and inflation (Blanchard and Gali, 2009; Blanchard and Riggi, 2013). Observing secular trends, non-renewable fossil energy sources, such as oil or coal, are also likely to experience a further decrease in the future share used in production and consumption. Particularly, the European Union (EU) is committed to its Green New Deal (European Commission, 2019) with the ambitious goal of zero net emissions of greenhouse gases by 2050. For achieving that, the EU financially supports investments into the expansion of using renewable energy sources. Despite being a fossil energy source, natural gas, however, takes a special role as a *transition* energy and has been therefore classified as one of the generators of green energy (European Commission, 2021).[1] Thus, natural gas is of great significance in the EU's future energy supply. Together with the high import dependency, the EU is thus more susceptible to unforeseeable supply disruptions. Recent geopolitical events, particularly the Russian invasion of Ukraine in 2022 but also ongoing supply-chain disruptions due to the Covid pandemic, have led to unprecedented increases in the price of natural gas in Europe. At the same time, as depicted in Figure 1, inflation expectations also started to rise at the end of 2021 and gained utter momentum in 2022. This leads to a major concern among researchers and policymakers, particularly important for the successful conduct of monetary policy: The "de-anchoring" of (long-run) inflation expectations (Blanchard, 2022; Reis, 2022a; Steinsson, 2022).

This paper thus investigates the recent natural gas price surge and its implications for inflation expectations and the pass-through effects on prices. The literature focuses mostly on the effects of oil prices and their pass-through on inflation (expectations) (see, inter alia, Clark and Terry, 2010; Wong, 2015; Aastveit, Bjørnland and Cross, forthcoming) and only attributes a limited role to oil price shocks in driving inflationary responses. Kilian and Zhou (2022b) investigate specifically the impact of rising oil prices on inflation in 2020-23 and find limited evidence on overall price developments. This paper, however, departs from these approaches and examines the *natural gas* price surge in Europe. Hence, we are interested in an array of questions: How do natural gas prices affect inflation and inflation expectations? What is the role of inflation expectations in propagating natural gas price shocks to inflation? What is the role of the inflation expectation horizon? And finally, do we find similar effects in the US?

We address these questions based on a structural vector autoregressive (SVAR) model of the relationship between real natural gas prices, inflation expectations, and inflation. The time frame for the analysis covers 2004 until the end of 2022. First, we identify this baseline model via timing restrictions along the lines of Wong (2015). In a next step, we extend the baseline model with industrial production and short-term interest rates to take the supply side and monetary policy properly into account. This allows us to pursue a sign-restriction identification strategy, which is based on but also extends the work by Kilian and Zhou (2022a).

[1] While using natural gas as energy source also creates greenhouse gas emissions like other fossil fuels, it produces lower emissions and less air pollution compared to other hydrocarbons, like oil or coal. A report of the International Energy Agency (2019), for instance, documents that switching to natural gas (mainly from coal) has prevented faster growth in emissions. Furthermore, Burney (2020) documents that the shift from coal to gas in the United States has led to significant reductions in mortality due to less negative external (environmental) effects.

Figure 1: Real Gas Prices and 1Y ahead Inflation Linked Swaps in the Euro Area (EA).

To this end, we are able to orthogonalize natural gas price shocks from supply- and demand-side induced fluctuations. Additionally, we employ external variable constraints to mitigate the effects of confounding oil shocks. To achieve that, we impose that the correlation with well-identified structural oil shocks from the literature (Baumeister and Hamilton, 2019; Känzig, 2021) is small. In order to investigate the role of inflation expectations in propagating real gas price shocks, we conduct a structural scenario analysis (SSA) following the recent contribution by Antolin-Diaz, Petrella and Rubio-Ramirez (2021).

The natural gas market comprises several features that make it an intriguing subject to study. First, natural gas has been seen as a crucial energy resource during the transitional period towards a green economy and is supposed to replace oil and coal (see, e.g., the European Commission's green agenda). Moreover, unlike oil, natural gas is traded much more locally due to necessary infrastructures resulting in different price dynamics across the world. Finally, the recent geopolitical events brought strong distortions in the natural gas market revealing the vulnerability of especially Europe to exogenous energy shocks. The impact of these shocks do not only have to be properly assessed but also need to be appropriately and timely addressed to ensure not to jeopardize future growth prospects.

Commodity prices in general, and natural gas in particular, may be the source of external shocks, which may feed into inflation. Conceptually, inflation arising from commodity price shocks can be separated into two components. The first is the *cost channel*, where higher energy costs directly affect inputs of production. This can also be deemed as a *first-round effect*. On the contrary, *second-round effects* pertain directly to increases in inflation through the price setting or wage bargaining channel originating from higher inflation expectations. We are particularly interested in the effects of the second channel, because it opens an additional mandate for policy actions. Werning (2022) shows for an array of pricing models that the expectational pass-through is close to unity and decreases with increasing expectation horizon. To measure inflation expectations, we resort to inflation linked swaps (ILS), which offer a market-based view on expectations.[2] Since ILS data is available on a high-frequency (i.e., monthly in our case), this allows us to confidently estimate the SVAR on a rather short sample period. This comes with the cost that ILS also contain an inflation risk premia. Nevertheless, ILS provide better information than other market-based measures (e.g., inflation-indexed treasury yields) as shown by Haubrich, Pennacchi and Ritchken (2012). Market-based measures are similar to expectations of professional forecasters but less to household inflation expectations. The latter exhibit substantially higher expectations, as documented by D'Acunto, Malmendier and Weber (2023). Furthermore, Coibion and Gorodnichenko (2015a) document that there is also evidence of information rigidities in inflation expectations measured via ILS.

Moreover, inflation expectations and especially their anchoring to a target are important aspects for central banks in their conduct of stabilization policies (Clarida, Gali and Gertler, 2000). Elevated expectations may directly and indirectly affect the wage and price setting behavior of an economy via the Phillips curve (Coibion, Gorodnichenko and Kamdar, 2018). Especially in the current situation, highly increased energy prices may pose a threat to inflation anchoring around the targeted level and therefore require appropriate actions by monetary policy makers (Reis, 2022b). Hence, it is of utmost importance to understand the role of inflation expectations as transmission channel of energy price shocks to realized inflation. Equipped with this information, centrals banks can tailor their measures adequately to combat inflation that is caused by rising energy prices and fulfil their stabilization goals (Ider et al., 2023).

Our results show that natural gas price shocks affect both inflation and inflation expectations. A one standard deviation shock (which is an about 10% price increase) to real gas prices moves the price level 0.5 percentage points up. By disentangling first- and second-round effects with a counterfactual exercise, the impulse response analysis points to a pronounced *expectation* channel and a rather muted *cost* channel. The pass-through of inflation expectations to realized inflation is clearly below unity. Furthermore, when examining the whole inflation expectation horizon up to thirty years ahead, short-term inflation expectations show the strongest second-round effects. Since long-run expectations are less strongly affected, we do not find strong evidence for de-anchored inflation expectations. Results are robust to a variety of choices, such as using the survey-based expectation indicators (based on the survey of professional forecasters) or using alternative commodity price indicators. Interestingly, and in line with the literature, we do not find evidence for these effects in the US. The question regarding the differences can be answered on the one hand with less strongly affected natural gas prices. On the other hand, short-run inflation expectations are not as firmly anchored in the euro area compared to the US. Nevertheless, other explanations arise, which we discuss further below.

The contribution of the paper is thus twofold. First, the paper provides an identification scheme for real natural gas price shocks by drawing on the literature on identifying oil price shocks. Second, we investigate the effects of commodity price shocks to inflation and inflation expectations in the euro area. Third, and most important, we specifically examine the pass-through of inflation expectations to inflation via a structural scenario analysis after commodity price shocks in the euro area. To the best of our knowledge, we are thus

[2] In principle, these swaps are derivative products that are linked to some sort of price index. Per design, the swap is a forward contract between two parties, where the buyer party pays a (fixed) nominal rate and receives a real rate from the seller party. Hence, the swap's price depends on realized and expected inflation, such that they can be used for hedging inflation.

the first to highlight the potential euro area's inflationary risks stemming from commodity price shocks, such as a natural gas price shock.

The paper is organized as follows. Section 2 embeds the paper in the context of the relevant literature and Section 3 discussed the particularities of the natural gas market. Section 4 presents the econometric framework, the identification strategy, and how we construct the counterfactual experiment. Section 5 shows the baseline results and in Section 6 we offer some extensions. Finally, Section 7 concludes.

2. Related Literature

We connect to three strands of literature intersecting the field of the macroeconomic importance of commodity markets, the implications of inflation expectations for realized inflation, and, finally, to the literature about counterfactuals in time series models.

While there is an abundant literature analyzing the impact of commodity prices on the macroeconomy, it focuses traditionally on crude oil and respective shocks in the 1970s (Barsky and Kilian, 2002; Hamilton, 2003; Kilian, 2008; Kilian, 2009; Bjørnland, Larsen and Maih, 2018). Studies explicitly tackling the role of natural gas in this setting are scarce and focused rather on small settings. For instance, Nick and Thoenes (2014) find that a natural gas supply shortfall has significant effects for the German economy and should be tackled by both demand- and supply-side measures. Interestingly, Blanchard and Gali (2009) and Baumeister and Peersman (2013) show that the sensitivity of real variables to oil price fluctuations are attenuated over time. Together with overall increases in the efficiency of production processes, the usage of alternative energy resources in line with the goals of the green transition may serve as an explanation. This diminishing relevance over time can also be found for reactions of both expected and realized inflation after oil price shocks (Harris et al., 2009; Wong, 2015; Coibion and Gorodnichenko, 2015a; Conflitti and Luciani, 2019; Aastveit, Bjørnland and Cross, forthcoming). However, given the recent large economic distortions due to the Covid pandemic, both inflation expectations and the role of energy markets gained revived attention (Kilian and Zhou, 2022b; Kilian and Zhou, 2022a). Especially, (short-term) inflation expectations seem to play an important role for the impact and the transmission of energy price shocks. To this end, the present study focuses particularly on how inflation expectations and their role for realized inflation are affected by natural gas price shocks. As we show, another dimension concerns the management of inflation expectations to mitigate second-round effects on the real price of natural gas.

Secondly, we relate to the recent literature studying inflation anchoring and inflation surges. A recent contribution by Blanco, Ottonello and Ranosova (2022) studies inflation surges, how short- and long-run expectations react to that, and the respective optimal policy responses. Similarly, Reis (2021) inspects historical episodes in which inflation expectations became de-anchored. A couple of papers are looking more closely at the recent inflation surge focusing on US data (Schmitt-Grohé and Uribe, 2022) or international evidence (di Giovanni et al., 2022). Gagliardone and Gertler (2023) investigates the recent inflation surge in the US and show that a combination of oil price shocks and loose monetary policy is responsible for the surge. Carvalho et al. (2023) show in a learning model that long-run inflation expectations are endogenous and driven by short-run inflation surprises. Episodes of de-anchored inflation expectations can thus arise due to large and persistent forecast errors, which lead firms to doubt a constant inflation target. We contribute

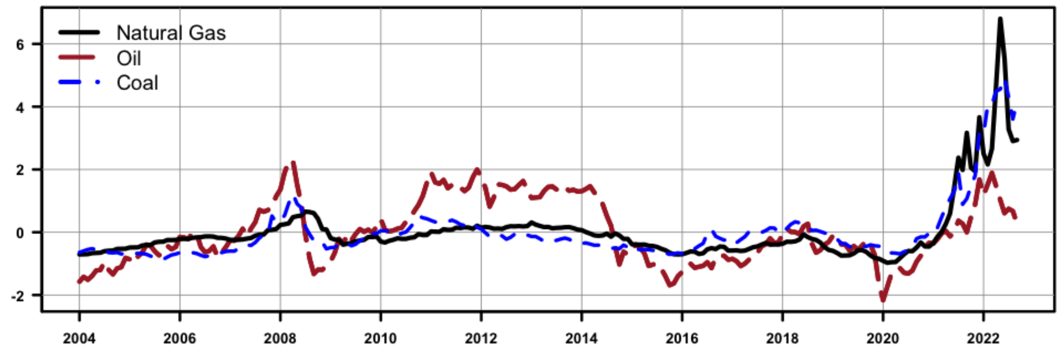


Figure 2: Standardized Natural Gas Prices (TTF), Oil Prices (Brent), and Coal Prices (Australian benchmark).

to this stream of literature by focusing on the recent natural gas price hikes and their effects on inflation expectations. Particularly, the model by Carvalho et al. (2023) suggest that a short price hike should not result into de-anchoring dynamics of long-run inflation expectations, which we empirically confirm.

Lastly, we also relate to the literature using counterfactuals in time series models. Counterfactual analysis is strongly tied to conditional forecasting, which goes back to Waggoner and Zha (1999). Recently, Antolin-Diaz, Petrella and Rubio-Ramirez (2021) provide a unified treatment of conditional forecasting and structural scenario analysis, relating them to entropic tilting (Robertson, Tallman and Whiteman, 2005). Specifically, scholars have used counterfactuals to decompose *direct*, or first-round, effects and *indirect*, or second-round, effects. To study indirect effects, several contributions isolate the hypothetical impulse response of the variable under consideration to a particular shock by shutting down the indirect effects via counterfactuals. For instance, Bernanke et al. (1997) or Kilian and Lewis (2011) investigate the systematic component of monetary policy, while Breitenlechner, Georgiadis and Schumann (2022) focus on the spillback effects of monetary policy. Bachmann and Sims (2012), however, are interested in how important confidence is for the transmission of government spending shocks. Most closely related to our paper is Wong (2015), who studies how inflation expectations propagate the inflationary impact of real oil price shocks in the US. In contrast to their study, we examine more closely real natural gas prices and focus on the euro area. We discuss (and corroborate) their findings more closely when we re-do our analysis for the US.

3. Some Facts about the Natural Gas Market

Together with the increased demand after the Covid crisis, the recent geopolitical events brought mayhem to global energy markets, either due to sanctions to or unilateral supply stops from Russia. While the price of almost all conventional energy sources surged during this period, three facts stand out. First, not all energy sources exhibit the same pace and magnitude in price increases. Second, the economic importance of the different energy sources changed over time. Both of these facts can be seen in the price developments of the three widely used energy commodities, depicted in Figure 2. Third and finally, there are marked differences in price increases across geographic locations, especially for natural gas.

Fossil fuels (still) provide the main resource for generating energy and, to a certain extent, for industrial processes. However, given the negative environmental effects of their usage, considerable efforts have being made to either make production processes more input-efficient or finding other, more environmentally friendly, sources of energy. This is reflected in the change in the composition of the final energy consumption for developed countries, like the US and the European Union (EU27). Tracing the final energy consumption over time reveals a transition from coal, to crude oil and, finally, to natural gas. Most prominently, Europe put the stakes on natural gas as transition energy source, which is less carbon intensive compared to coal and oil to facilitate the Green transformation. Eventually, this strategy is also reflected in the European commission's recent reclassification of natural gas as a green energy source (European Commission, 2019).

Moreover, a significant share of natural gas across countries is not only used as a direct energy resource but also as an input for a broad range of production processes, with potentially very limited substitutability. According to the U.S. Energy Information Administration (2023), in 2021 both the electric power generation and the industrial sector account for over 70% of the natural gas demand in the US. In industrial processes, natural gas is consumed either as a source for heating or as a raw material for producing fertilizer or other chemical products. Considerably less demand stems from the residential and commercial sector, as well as from the transport sector. For the former two, natural gas serves as an input for space and water heating. The transportation sector (5% of total US demand) uses natural gas predominantly to operate the infrastructure and only a tiny share for fueling vehicles. In Europe, the residential sector accounts for the bulk of natural gas demand, followed by energy production and the industrial sector. Interestingly, European households predominantly use natural gas as their main source of energy. Between 2000 and 2020, consumption by the industrial sector, however, has declined by 20% with a shift to power generation by 15%. Over time the EU27 demand profile changed considerably, again reflecting the switch from coal to natural gas and the measures intended by the Green transformation (European Union Agency for the Cooperation of Energy Regulators, 2023).

With less domestic production and higher demand, Europe and especially Germany secured its supply from Russia, which is not only rich in natural gas resources but also features the necessary infrastructure. Before the onset of the Russian invasion in Ukraine this facilitated the flow of cheap energy reflected in a very low volatility of the European natural gas price, as seen in Figure 2. After the implementation of sanctions and the Russian retaliation in terms of squeezing the energy supply towards Europe, the *locality* of the natural gas market became obvious. On the one hand, this is reflected in benchmark prices that differ markedly.[3] For instance, at the peak of the uncertainty right after the start of the war, the U.S. benchmark, the Henry Hub, quotes well below the European reference price, i.e., the Dutch TTF (Title Transfer Facility). The maximum price on the TTF spot market was slightly below 350 EUR/MWh on August 26, 2022, while on the same day, the Henry Hub benchmark quoted 32.35 USD/MWh. A first and rather straightforward explanation is given by the fact that the EU27 has cut its domestic production since the last ten years in half and has to import about 80% of its demand in 2021, from what about 41% comes from Russia (European

[3] Note, that there exists also a variety of crude oil types, but three benchmarks, Brent, WTI, and Dubai Crude form the international reference price. While they differ in their refinery characteristics, they usually exhibit a very strong comovement. Only for the Russian sorts, we observe a pronounced spread since the implementation of the price cap of 60 USD as a sanction of the G7 against Russia applicable as of February 5, 2023.

Union Agency for the Cooperation of Energy Regulators, 2023; Eurostat, 2023). The US, however, satisfies their own demand either through fracking or standard gas field exploitation and even became a net exporter of natural gas in recent years. Another factor, the locality of the market, concerns the rather static and thus less flexible infrastructure (e.g., pipelines) necessary for the transport. This crucially impedes the finding of alternative suppliers.[4] Moreover, while oil resources are still available and can be more or less flexibly adjusted, the situation for natural gas is more complex. On the one hand, gas extraction can not simply be adjusted due to technological reasons and, on the other hand, operates with the existing gas fields at its capacity limit. Finally, gas is used not only as an energy resource but also as an input for a broad range of production processes, with very limited substitutability.

Together, these reasons gave rise to the extraordinary increase in European natural gas prices, exacerbated by the member country's individual policy decisions to fill the storage before the heating season in 2022. As a result, we observed in general an increasing inflation. In addition, most of the global economies already arrived from the Covid crisis with strong inflationary pressures caused by pent-up demand, supply chain frictions, and expansive fiscal policy measures. In this tense situation surrounding the future of the price developments and energy security in Europe, and partly in the US, distortions in energy markets may occur more frequently than in the decades before. Hence, a clear cut analysis about the channels at work behind energy price hikes is beneficial for fiscal and monetary policymakers alike to ultimately provide well-balanced policy actions.

4. Empirical Methodology

To model the effects that gas price shocks have on expected and actual inflation, we require a structural model that is capable of disentangling the sources of variation in the price of natural gas, inflation expectations, and inflation. Our focus lies on the identification of real gas price shocks. We will start with a small-scale baseline model identified with recursive ordering, as in Wong (2015). This model will feature no demand-side forces, which we include in the extended model. The extended version, additionally featuring a supply side as well as monetary policy, will then be identified with sign-restrictions to disentangle supply and demand forces more thoroughly.

Both models are estimated on monthly data starting in January 2004 and ending in December 2022. The baseline model has three variables $\boldsymbol{y}_t = [rgas_t, \pi_t^e, \pi_t]$, where $rgas_t$ denotes the log level of the real gas price (deflated with consumer prices), π_t consumer price inflation, and π_t^e inflation expectations measured through inflation swaps.[5] The extended model, $\boldsymbol{y}_t = [rgas_t, ip_t, i_t, \pi_t, \pi_t^e]$, additionally features an industrial production index, ip_t and a short-term interest rate, i_t. An overview on the exact variable definitions and transformations is available in Appendix A.

[4] The same holds true for the liquified version of natural gas, LNG. While being liquid and therefore simpler to transport by shipping, it again needs a special infrastructure for regasification. In the time being, LNG simply cannot fully satisfy Europe's gas demand.

[5] Here, a question about the liquidity of the ILS arises, potentially giving rise to a liquidity premium. Reis (2021) argues that the inflation swap market was only reasonably liquid starting in 2009. However, the later presented results are robust if start the analysis in 2010. This further alleviates possible concerns that the global financial crisis is driving the effects.

4.1 Structural VAR Model

The reduced-form VAR model representation is

$$\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \ldots + \boldsymbol{A}_p\boldsymbol{y}_{t-p} + \boldsymbol{u}_t, \qquad \boldsymbol{u}_t \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}), \tag{4.1}$$

where $\boldsymbol{y}_t$ is an $n \times 1$ vector of macroeconomic variables, which are modeled as a function of its own past values, and an $n \times 1$ vector $\boldsymbol{u}_t$ of forecast errors with an $n \times n$ covariance matrix $\boldsymbol{\Sigma}$. For the sake of brevity, we omit any deterministics. We allow that up to $p = 12$ lags enter the equation to account for the long and variable lags in the transmission of gas/oil price shocks (see Hamilton and Herrera, 2004). The reduced-form shocks are a linear combination of n orthogonal structural disturbances $\boldsymbol{\varepsilon}_t$, which we write as $\boldsymbol{\varepsilon}_t = \boldsymbol{S}\boldsymbol{u}_t$. The structural VAR equation thus reads

$$\boldsymbol{S}\boldsymbol{y}_t = \boldsymbol{B}_1\boldsymbol{y}_{t-1} + \ldots + \boldsymbol{B}_p\boldsymbol{y}_{t-p} + \boldsymbol{\varepsilon}_t, \qquad \boldsymbol{\varepsilon}_t \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{I}_n), \tag{4.2}$$

where $\boldsymbol{B}_j = \boldsymbol{S}\boldsymbol{A}_j$ $(j = 1, \ldots, p)$ holds. By definition, structural shocks are mutually uncorrelated, i.e., $\mathrm{Var}(\boldsymbol{\varepsilon}_t) = \boldsymbol{I}_n$ being diagonal, and are thus identified up to a sign and scale convention. From the linear mapping of the shocks, $\boldsymbol{\Sigma} = \boldsymbol{S}\boldsymbol{S}'$ holds. Identification amounts of finding a suitable matrix $\boldsymbol{S}$.

A first approach to identify the effects of real gas price shocks is to assume that movements in the gas price are exogenous to inflation and inflation expectations. This yields a recursive system in which we order real gas prices first and has been commonly used in applied work (see, inter alia, Kilian, 2009, Kilian and Park, 2009, or Wong, 2015). We interpret the structural shock as a gas supply shock: unpredictable surprises to the global gas production, which drives its price up. As seen in Figure 1, the political turmoil ensuing the Russian invasion of Ukraine in 2022 led to huge constraints in the supply of gas, driving up its price tremendously.

Technically, the approach is simple to implement. We define the structural impact matrix $\boldsymbol{S} = \boldsymbol{L}$, where $\boldsymbol{L} = \mathtt{chol}(\boldsymbol{\Sigma})$ is the lower-triangular Cholesky factor of the variance-covariance matrix. A potential drawback of this identification procedure is that we cannot disentangle shocks to the real gas price from supply and demand factors. Hence, we move to the extended specification, where we include industrial production and short-term interest rates in the model to disentangle supply and demand factors and model the monetary authority's policy reaction function. The identification of this structural model exploits a combination of sign- and zero-restrictions on the structural impact matrix $\boldsymbol{S}$, as shown in Equation 4.3. We use the algorithm outlined in Arias, Rubio-Ramírez and Waggoner (2018). Specifically, we search for an orthonormal matrix $\boldsymbol{Q}$, such that $\boldsymbol{Q}\boldsymbol{Q}' = \boldsymbol{I}$ holds. This yields the structural impact matrix $\boldsymbol{S} = \boldsymbol{L}\boldsymbol{Q}$.

Our main aim is to disentangle supply and demand forces from a real gas price shock. In order to distinguish between supply and demand forces, we add a demand-side to the model. Generally, supply and demand shocks can be disentangled by putting different signs on the reaction of industrial production. A supply-side shock is assumed to raise inflation, inflation expectations, and short-term interest rates and lowers industrial production on impact. A demand-side shock, however, is assumed to raise real gas prices, industrial production, inflation, short-term interest rates, and inflation expectations. Since we seek to identify a real gas price shock, our identification procedure so far does not distinguish between supply-side shocks and real gas price shocks. Hence, we assume that an increase in the real gas price leads on impact to a deterioration of industrial production and to a surge of inflation and inflation expectations, consistent with a supply-side shock. To purge the shock from other supply-side related factors, we assume that any other supply-side related shock depresses the real gas price. Finally, we have two additional shocks in the model. A monetary policy shock is assumed to decrease the real gas price, industrial production, inflation, and inflation expectations. A positive shock to idiosyncratic inflation expectations leaves the real price of gas, industrial production, and inflation unaffected on impact because expectations shocks that move actual consumer prices are already captured by the real gas price shock and the supply-side shock. These restrictions are consistent with sign-restrictions approaches on oil prices (see, inter alia, Kilian and Murphy, 2014 or Kilian and Zhou, 2022). Jointly, these restrictions imply that

$$\begin{pmatrix} u_t^{rgas} \\ u_t^{wip} \\ u_t^{mp} \\ u_t^{\pi} \\ u_t^{\pi^{exp}} \end{pmatrix} = \begin{bmatrix} + & + & - & - & 0 \\ - & + & - & - & 0 \\ + & + & + & + & 0 \\ + & + & - & + & 0 \\ + & + & - & + & + \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{real gas price shock}} \\ \varepsilon_t^{\text{demand-side shock}} \\ \varepsilon_t^{\text{monetary policy shock}} \\ \varepsilon_t^{\text{supply-side shock}} \\ \varepsilon_t^{\text{idiosyncratic inflation expectation shock}} \end{pmatrix}. \tag{4.3}$$

An additional obstacle to identification is the confounding effect of oil supply shocks. The identification so far hinges on the assumption that natural gas prices react negatively to oil supply shocks. Since these variables often move together, this assumption is hardly plausible and deserves more attention. Hence, we add an additional constraint to the identification of the structural model. Specifically, we add an external variable constraint, where we impose that the correlation between external variables and the natural gas price shock is small.[6] Let $\mathbf{Z}_t = (z_{1t}, z_{2t})'$ denote the structural oil supply shock series of Baumeister and Hamilton (2019) and Känzig (2021), and ε_{1t} the structural natural gas price shock. The external variable constraints require to satisfy the following restrictions

$$\begin{aligned} &(i) \quad |\texttt{corr}(\varepsilon_{1t}, z_{1t})| < 0.2, \\ &(ii) \quad |\texttt{corr}(\varepsilon_{1t}, z_{2t})| < 0.2. \end{aligned} \tag{4.4}$$

The constraints requires that the natural gas price shocks are only weakly correlated with oil supply shocks, which means that the correlation is below 0.2 in absolute terms. We impose these restrictions only in the model, in which we identify natural gas price shocks but not other commodity price shocks.

We estimate the VAR with Bayesian methods following the approach in Huber and Feldkircher (2019), Carriero, Clark and Marcellino (2019), and Carriero et al. (2022). For a detailed treatment of the MCMC algorithm we refer to these papers. We draw 35,000 posterior draws from the posterior distribution, from which we discard the first 10,000 as burn-ins.

4.2 Structural Scenario Analysis Counterfactuals

If a real gas price shock causes movements in inflation expectations that subsequently feed into inflation, we define this as second-round effects. The first-round effect is the direct effect of real gas price shocks to inflation, while the second-round effect is any increase in inflation arising due to elevated inflation expectations. Ultimately, we are interested in measuring second-round effects. Note that even if inflation

[6] This approach has been dubbed *external variable constraint* by Ludvigson, Ma and Ng (2021) in the context of uncertainty shocks.

expectations rise in response to a real gas price shock, this does not automatically imply these second-round effects. Therefore, we resort to a counterfactual analysis by shutting down the effects originating from inflation expectations. Hence, we construct a counterfactual where inflation expectations are insensitive to real gas price shocks, thereby isolating first-round effects. Constructing a counterfactual has a long tradition in macroeconomics and goes back to Kilian and Lewis (2011), Bachmann and Sims (2012), and Wong (2015). Here, one creates a sequence of inflation expectations shocks such that they mute out the inflation expectations response after a real gas price shock. A more recent contribution by Antolin-Diaz, Petrella and Rubio-Ramirez (2021) builds on these ideas and introduces a *structural scenario analysis*, where structural shocks are allowed to deviate from their unconditional distribution. In what follows, we describe this approach for the case of impulse response analysis (similar to the approach in Breitenlechner, Georgiadis and Schumann, 2022).

The unconditional forecast of the observed variables in the VAR, denoted with the $nh \times 1$ vector $\boldsymbol{y}_{T+1,T+h} = (\boldsymbol{y}'_{T+1}, \boldsymbol{y}'_{T+2}, \ldots, \boldsymbol{y}'_{T+h})'$, can be written as

$$\boldsymbol{y}_{T+1,T+h} = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\boldsymbol{\varepsilon}_{T+1,T+h}, \tag{4.5}$$

where the vector $\boldsymbol{b}_{T+1,T+h}$ is predetermined and depends on the full history of the observables and the reduced-form parameters. In absence of any future shocks, $\boldsymbol{b}_{T+1,T+h}$ denotes the dynamic forecast of the system. The $nh \times 1$ vector $\boldsymbol{\varepsilon}_{T+1,T+h} = (\boldsymbol{\varepsilon}'_{T+1}, \boldsymbol{\varepsilon}'_{T+2}, \ldots, \boldsymbol{\varepsilon}'_{T+h})'$ thus denotes all future values of the structural shocks. Lastly, the $nh \times nh$ matrix $\boldsymbol{M}$ constitutes the dynamic propagation of future structural shocks and is a function of the structural VAR parameters. Note that if the VAR is stationary, in steady state at T and $\boldsymbol{b}_{T+1,T+h} = \boldsymbol{0}$, and if there is only a single future shock $\boldsymbol{\varepsilon}_{T+1,T+h} = (\boldsymbol{e}'_1, \boldsymbol{0}_{n(h-1)\times 1})$, then $\boldsymbol{M}$ reflects the usual impulse response functions to a unit shock. $\boldsymbol{e}_i$ denotes the unit vector with unity on the i-th position. For instance, for the impulse responses to a real gas price shock we have $\varepsilon_{1,T+1} = 1$, $\varepsilon_{1,T+s} = 0$ for $s > 1$ and $\varepsilon_{j,T+s} = 0$ for $s > 0$ and $j \neq 1$. We denote this in the following as *unconditional* impulse response function.[7]

In the framework of Antolin-Diaz, Petrella and Rubio-Ramirez (2021), the structural VAR parameters captured in $\boldsymbol{M}$ remain *unchanged* in the counterfactual. In principle, the analysis does not risk falling int to the criticism put forward by Lucas (1976) as long as the structural shocks used to construct the counterfactuals are not *too unusual*. We use the modesty statistic proposed by Leeper and Zha (2003) and the q-divergence distribution proposed in Antolin-Diaz, Petrella and Rubio-Ramirez (2021) to safeguard us against these issues. In Appendix B, we provide the details how to implement these tests. In order to satisfy the imposed constraints on the impulse response $\tilde{\boldsymbol{y}}_{T+1,T+h}$, additional shocks are allowed in $\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h}$ to materialize over the impulse response horizon. We choose those values such that we offset the effects of inflation expectations to a real gas price shock.

We implement the constraints on the paths of one endogenous variable (i.e., inflation expectations) in $\tilde{\boldsymbol{y}}_{T+1,T+h}$ as follows

$$\overline{\boldsymbol{C}}\tilde{\boldsymbol{y}}_{T+1,T+h} = \overline{\boldsymbol{C}}\boldsymbol{M}'\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}\left(\overline{\boldsymbol{f}}_{T+1,T+h}, \overline{\boldsymbol{\Omega}}_f\right), \tag{4.6}$$

[7] Technically, the impulse response function is *conditional* on a shock in the first period. Nevertheless, we deem the term appropriate since both – the baseline impulse response and the counterfactual impulse response – are *conditional* on a shock in the first period. Hence, we distinguish between *conditional* counterfactual impulse responses and *unconditional* impulse responses to a shock in the first period.

where $\overline{\boldsymbol{C}}$ is a $k_o \times nh$ selection matrix, $\overline{\boldsymbol{f}}_{T+1,T+h}$ is a $k_o \times 1$ vector, and $\overline{\boldsymbol{\Omega}}_f$ a $k_o \times k_o$ matrix. $\overline{\boldsymbol{f}}_{T+1,T+h}$ and $\overline{\boldsymbol{\Omega}}$ are the mean and covariance matrix restrictions. This formulation also accommodates the special case $\boldsymbol{\Omega}_f = \boldsymbol{0}$, which we will adopt. This resembles then the classic "hard" conditional forecasting exercise as defined in Waggoner and Zha (1999). In the context of this study, we impose the restriction that the inflation expectations spillovers to real gas price shocks are zero. Furthermore, the constraints on the structural shocks are given by

$$\boldsymbol{\Xi}\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}\left(\boldsymbol{g}_{T+1,T+h}, \boldsymbol{\Omega}_g\right), \tag{4.7}$$

where $\boldsymbol{\Xi}$ is a $k_s \times nh$ selection matrix. $\boldsymbol{g}_{T+1,T+h}$ is a $k_s \times 1$ vector and $\boldsymbol{\Omega}_g$ is a $k_s \times k_s$ matrix and denote the mean and covariance matrix restrictions. Again, we implement exact restrictions, such that we fix $\boldsymbol{\Omega}_g = \boldsymbol{0}$. Here, we allow that the structural idiosyncratic inflation expectation shock is the offsetting force such that the impulse response to inflation expectation to real gas price shocks is zero. Therefore, we impose here that all structural shocks are zero over the whole impulse response horizon except the structural shock to natural gas prices in the first period and the structural shocks to inflation expectation along the impulse response horizon. Antolin-Diaz, Petrella and Rubio-Ramirez (2021) show how to obtain the solution in terms of $\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h}$, which satisfies the constraints in Equation (4.6) and Equation (4.7). The counterfactual impulse response is then given by $\tilde{\boldsymbol{y}}_{T+1,T+h} = \boldsymbol{M}'\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h}$. We refer to Appendix B for further technical details.

5. Baseline Results

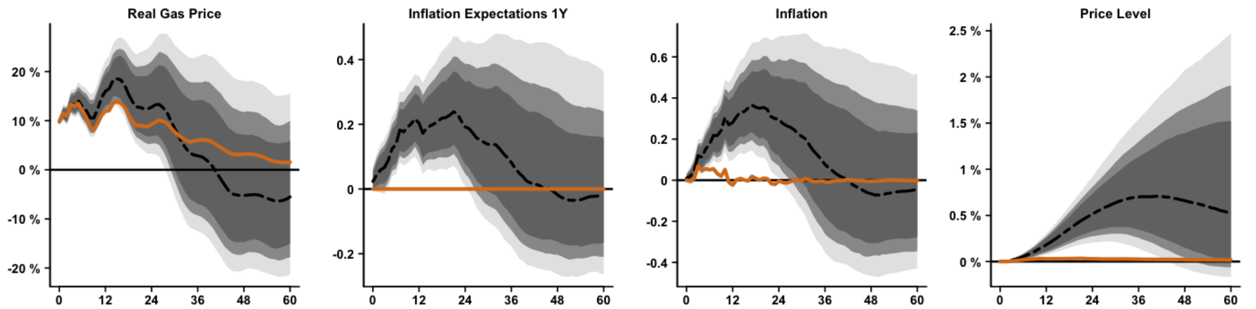
In this section, we report and discuss the results obtained with both of the above elaborated specifications. In a next step, we investigate the second-round effects of inflation expectations and the role of their respective horizon. For all models, we use $p = 12$ lags in order to account for long and variable lags in the transmission of real gas price shocks. Furthermore, we always standardize the shock to a one standard deviation increase in the real price of natural gas. Both model specifications feature annualized inflation, which we convert back to price level deviations. The main results are depicted in Figure 3 and Figure 4, where the impulse response functions along with their 68/80/90 percent confidence bands are shown.

5.1 The Effects of Natural Gas Price Shocks

In Figure 3, the baseline model comparable with Wong (2015), we observe that a one standard deviation shock triggers about a 10% increase in real gas prices on impact. While inflation does not exhibit a reaction on impact at all, short term expectations show a somewhat slight reaction. Afterwards, both variables, however, reach their maximum response after about one year before gradually starting to return to the zero line. Correspondingly, we observe an increase in the price level of 0.5% at maximum. For comparison, the recent gas price surge in summer 2022 can be considered as an event which is a two to three standard deviations shock in real terms. This would amount to a total increase in the price level of about 1.0-1.5%. Hence, a rather strong increase in real gas prices leads to a comparably smaller effect on prices in the euro area economy. Also, for core inflation these effects appear to be rather stable as seen in Figure C1.

Obviously, this needs further investigation as the baseline model may be misspecified. Particularly, for a full depiction of the Phillips curve relationship, a measure of marginal costs should be included. Therefore,

Figure 3: Impulse Response Functions to a Real Gas Price Shock (Baseline model).



Notes: The baseline model features three variables, where the shock is identified with recursive ordering and standardized to a one standard deviation increase in the real price of natural gas. The price level is computed afterwards as cumulative sum of the inflation response. Black dashed lines denote the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise, where the expectation channel is shut off. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled to annualized percentage points.

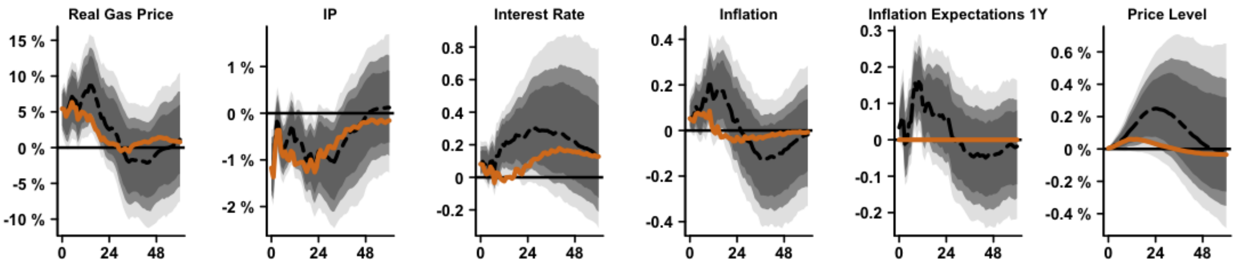
we now move to our extended model, which not only features two additional variables but also implements sign- and zero-restrictions for identification. This allows us to disentangle supply- and demand-side shocks as well as the consideration of the reaction function of a monetary authority. Thus, the model is still rather small-scale but sophisticated enough to generate more realistic estimates. Figure 4 presents the results. Overall, the extended model paints a similar picture to the three-variable model qualitatively and the additional reactions are as expected. A one standard deviation shock raises real gas prices by about 5% on impact. Industrial production drops substantially by about 1.1 percentage points, while the monetary policy stance turns restrictive. Again, inflation and inflation expectations react muted on impact but reach their maximum after about one to one and half years after the shock. The magnitudes are smaller than before taking into account the smaller and more uncertain shock to real gas prices. The implied effects of the recent gas price surge are higher in this model since the shock elicits an attenuated response of real gas prices. We observe a 0.2% increase in inflation at maximum to a 5% increase in the real gas price. Interestingly, this is quite consistent with evidence from microdata provided by Lafrogne Joussier, Martin and Mejean (2023), who examine the cost pass-through to inflation to energy price shocks in the French manufacturing. Again, these effects remain almost identical in shape and magnitude if we use core inflation as our target inflation measure as shown in Figure C2.[8]

Both models highlight that inflation expectations react to a natural gas price shock. This is consistent with the empirical evidence that inflation expectations are sensitive to commodity price (however, mostly oil price) shocks (Harris et al., 2009; Coibion and Gorodnichenko, 2015b; Aastveit, Bjørnland and Cross, forthcoming). In both models inflation expectations react less pronounced than the inflation series. This implies a persistent positive forecast error of inflation for about two years.[9] This is consistent with prior studies

[8] Furthermore, the results are robust to a number of robustness checks. First, we estimated both models with stochastic volatility (Carriero, Clark and Marcellino, 2019; Carriero et al., 2022). Second, we estimate a specification in which the sample starts after the Great Financial Crisis in January 2010. For both of these robustness checks, the outcomes remain basically unchanged. All results are available from the authors upon request.

[9] We back out the implied forecast error impulse response function of inflation (constructed as the difference between realized inflation and the previous year's 1-year expected inflation) to validate this claim, as shown in Figure C3.

Figure 4: Impulse Response Functions to a Real Gas Price Shock (Extended Model).



Notes: The extended model features five variables, where the shock is identified with sign- and zero restrictions and standardized to a one standard deviation increase in the real price of natural gas. The price level is computed afterwards as cumulative sum of the inflation response. Black dashed line denotes the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise, where the expectation channel is shut off. The responses of the real gas price, industrial production, and the price level are in percent, while the interest rate, inflation, and inflation expectations are scaled to (annualized) percentage points.

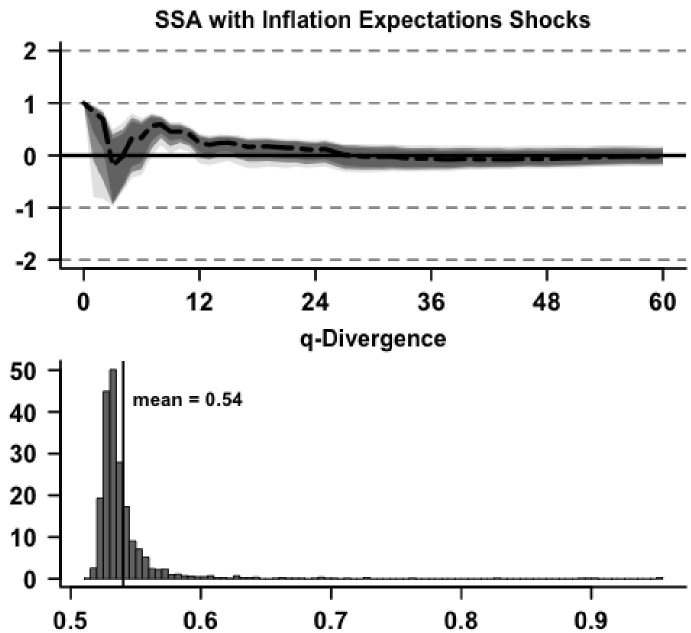
that document an underreaction of inflation expectations to economic shocks (Coibion and Gorodnichenko, 2012) and in general (Coibion and Gorodnichenko, 2015a). So far, we have not distinguished between first- and second-round effects. Hence, we cannot pin down the role of the inflation expectation channel in transmitting these kind of shocks to other (real) variables, which we address in the next section through a counterfactual exercise.

5.2 Second-Round Effects of Inflation Expectations

In this section, we investigate whether movements in inflation expectations caused by natural gas price shocks have amplifying or propagating inflationary effects. We identify this second-round effect with the help of a structural scenario analysis counterfactual. By constructing a structural scenario analysis in which inflation expectations do not react to natural gas price shocks, we are able to examine the differential response to inflation. The intuition of this exercise is to isolate first-round effects. If the expectation channel via inflation expectations is indeed an important propagation channel to inflation (the second-round effect), then the counterfactual impulse response of inflation will deviate substantially from the unconditional impulse response. This directly affects the implied Phillips curve as the natural gas price shock can be seen as a cost-push shock. In the counterfactual experiment, we shut off second-round effects via inflation expectations. Hence, the cost channel directly affects the price setting behavior or has implications for marginal costs, which can be linked to the wage bargaining channel. To visualize the results of this exercise, the solid orange line in Figure 3 and Figure 4 depicts these counterfactual impulse response. Furthermore, note that by construction only the structural shocks of inflation expectations are used to offset this effect. Put differently, only the idiosyncratic inflation expectation shock deviates from its unconditional impulse response, eventually changing the dynamics of the whole system.

In the baseline model, shown in Figure 3, the impulse response function of inflation expectations is zero over the full horizon, as assumed. The counterfactual response of the real gas price shock does not exhibit a strong deviation from its unconditional counterpart. On the contrary, turning to the response of inflation and the corresponding price level reveals a strong reduction in the inflation response. Inflation reacts only muted

Figure 5: Plausibility Statistics of Counterfactuals.



Notes: The upper panel shows the modesty statistic of Leeper and Zha (2003) and the lower panel shows the distribution of the q-divergence proposed by Antolin-Diaz, Petrella and Rubio-Ramirez (2021). The modesty statistic reports the implied shocks that impose the counterfactual constraint for inflation expectations. The black dashed line denotes the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals.

on impact, thus very similar to the unconditional response. However, mean reversion quickly sets in after one month, after reaching a very low maximum response. After about four months, inflation has returned to its steady state. The effect is even less pronounced for the corresponding price level. The baseline model thus implies strong second-round effects via inflation expectations after a real gas price shock.

When we move over to the extended model, depicted in Figure 4, the overall conclusion stays qualitatively the same as in the baseline model. When shutting off the responses of inflation expectations, both the real gas price and also industrial production do not deviate strongly from their unconditional responses. On the contrary, interest rates show the same pattern as inflation. The counterfactual responses show more muted on-impact reactions, pointing to less nominal adjustments. Thus, the monetary authority reacts stronger if the expectation channel is present. Taken at face value, this is a first suggestive evidence that the central bank is actively fighting the de-anchoring of inflation expectations. If anything, industrial production reacts more strongly in the model without a response from inflation expectations. This corresponds to the mechanism of the Phillips curve, which offers a trade-off between economic slack and inflation. By shutting down adjustments via inflation expectations (resulting in lower inflation) to a cost-push shock, the economic slack partly captures the effect. Further, this finding is also in line with the theoretical predictions of Werning (2022) who investigates the pass-through of inflation expectations on current inflation with arbitrarily (non-rational) formed expectations. The pass-through is close to but clearly below unity. Finally, the maximum price level response is only a quarter from the unconditional response, pointing again to a rather strong adjustment mechanism via the expectation channel.

The plausibility of the counterfactuals obtained by the structural scenario analysis depends on the offsetting structural shocks, i.e., the idiosyncratic inflation expectation shock. Specifically, we risk falling into the criticism by Lucas (1976) if the required shocks are unusual large or persistent. This is because under such a situation, agents may update their beliefs about the policy regime and the structure of the economy more substantially. Against this backdrop, we implement the modesty statistic of Leeper and Zha (2003) and the q-divergence proposed by Antolin-Diaz, Petrella and Rubio-Ramirez (2021). Both are presented in Figure 5. The top panel shows the modesty statistic, which are the implied offsetting shocks that impose the counterfactual constraint for inflation expectations. The offsetting shocks are *modest* if the statistic is smaller than two in absolute values. This is confirmed and thus the materialisation is unlikely to induce agents to adjust their expectation formation and beliefs about the structure of the economy showing no sign for the Lucas critique. In the lower panel, the q-divergence indicates how strongly the distribution of offsetting shocks in the counterfactual deviate from their unconditional distribution translated into a comparison of the binomial distribution of a fair and a biased coin. Again, the test does not indicate that the distribution of offsetting shocks in the counterfactual is notably different from the unconditional distribution.

Overall, our results stand in stark contrast to the findings of the literature for other commodity price shocks. Wong (2015) uses a model comparable to our baseline model but for the US and for oil price shocks. Nevertheless, he finds only limited evidence for second-round effects of inflation expectations and concludes that the US offers an environment where inflation expectations are well anchored. Further evidence for that is provided by Kilian and Zhou (2022b) who investigate the increase in oil and gasoline prices since mid-2020. They provide evidence that these kind of shocks have not moved long-run household inflation expectations. We will return to these points when comparing the results to the US in several extensions. Lastly, we assume that the inflation risk premium is not time-varying in this analysis. To alleviate possible concerns, we will return to this point later on when re-doing the analysis with inflation expectations originating from the survey of professional forecasters.

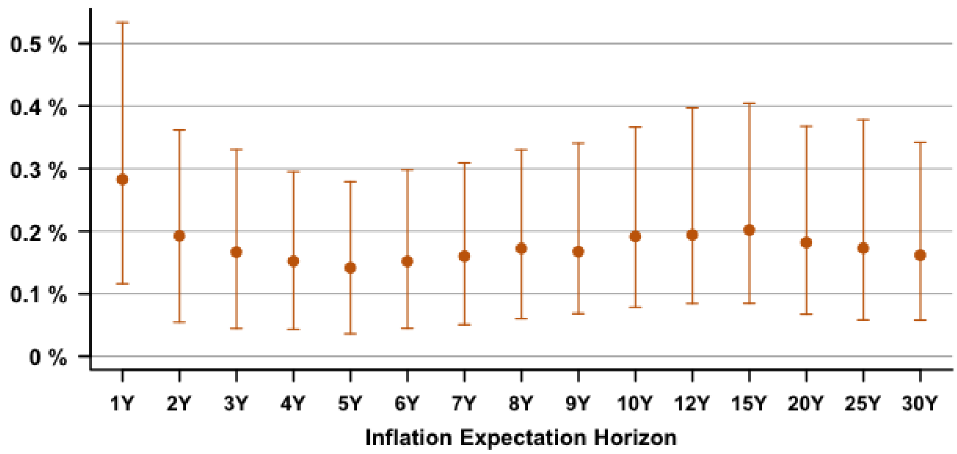
5.3 Does the Horizon of Inflation Expectations Matter?

In a next step of the analysis, we exploit one key advantage of using ILS inflation expectations, namely the availability of a variety of horizons up to thirty years. We re-estimate the extended model with different horizons of our inflation expectation measure.[10] Note that we exchange the measure of inflation expectations once at a time and do not pursue estimating a model including all the horizons.

We start with short-run expectations of one year ahead (see main results above) and move along until we reach long-run inflation expectations (30 years ahead). Then, for each estimated model we pick the maximum difference of the unconditional to the counterfactual impulse response of the price level. For example, we can directly compare the outcome of the maximum difference of 1Y inflation expectations to the difference in Figure 4. Here, the maximum difference between the impulse responses is shortly after two years and slightly below 0.3 percentage points. Put differently, without second-round effects via the expectation channel, the price level is 0.3 (annualized) percentage points lower on average. Additionally, we also report confidence sets

[10] In principle we can also do this with the baseline specification. However, the baseline model is most likely misspecified. In addition, the identification restrictions of the extended model are more restrictive and thus providing a more accurate picture.

Figure 6: Effect Sizes with Varying Horizon of Inflation Expectations.



Notes: Maximum difference of the unconditional and the counterfactual impulse response function of the price level in the extended model. Dots refer to the median of maximum response, while the whiskers denote the 68 percent confidence region.

for the differences such that the whiskers in Figure 6 are the full 68 % confidence interval of the differences' posterior distribution.

Figure 6 reveals several interesting results. First, all maximum differences between the unconditional and counterfactual impulse response are statistically significant different from zero. Second, the median difference response using short-term (i.e., one year) inflation expectations exhibits the highest difference. However, the effects almost gradually decrease from short- to long-term horizons. Arriving at 30-year expectations a maximum difference of almost 0.2 (annualized) percentage points are shown. Furthermore, (not visible in the plot) the maximum responses are usually reached after about two years. Finally, we do not really see statistically significant differences among short- to long-term horizons. From the median responses, we see that the effects at the short-run horizon are stronger. Most of the remaining horizons are rather stable with a maximum difference of about 0.2 percentage points.

5.4 Discussion of the Results

Summing up the results so far, we show that real gas price shocks have inflationary tendencies both via first- and second-round effects. Specifically, the counterfactual analysis reveals strong second-round effects through the inflation expectations channel. However, the time frame of the sample is crucial for the results, which is already indicated by our motivational figure Figure 1. If we exclude the period of the recent natural gas price surge, we do not obtain these reactions.[11] Furthermore, our findings indicate that second-round effects are stronger for shorter-term inflation expectations than for longer-term expectations. This is consistent with

[11] For this exercise, we split the sample before the onset of the pandemic (end of December 2019) and before the recent gas price surge (end of June 2021). In both cases, natural gas price shocks do not reveal strong effects on inflation and inflation expectations. This holds specifically for natural gas prices and, to a lesser extent, for coal and oil prices. Results are available from the authors upon request.

evidence that short-term expectations are more important than longer ones in determining inflation (Fuhrer, 2011; Fuhrer, Olivei and Tootell, 2012).

Still, a few questions about the interpretation of the results remain. For instance, the results point to the fact that inflation expectations in the euro area are rather sensitive to natural gas price shocks. Why are these reactions comparatively strong and why do they actually drive inflation? Three possible, – however, not mutually exclusive – interpretations offer an explanation. The first concerns issues around the anchoring of inflation expectations in the euro area. A second interpretation points towards the particularities of expectation formation processes. Finally, there could also be demand-side forces outside of our framework at work that affect inflation expectations.

With respect to the first question, we expect inflation expectations to not react strongly in an environment where they are well anchored (Reis, 2021; Carvalho et al., 2023). Monetary policy authorities put an emphasis on managing inflation expectations to ultimately stabilize inflation through various factors. These include, inter alia, the choice of the policy regime, the precise actions taken, and their communication. For instance, if a central bank pursues an inflation-targeting regime committing to keep inflation at a specific rate or range over a specified period provides a clear and measurable target. With their strategy review finished in summer 2021, the ECB changed from an asymmetric ("below but close to") to a symmetric target of 2% annual inflation. This target features a clear signal to the public and helps to anchor inflation expectations as economic agents know that the central bank will react to deviations from this target. Furthermore, credible central banks use a clear and effective communication of the economy's assessment and their decisions. For a further discussion on possible obstacles, see the discussion in Reis (2022b). As a result – and arguably in a perfect world – inflation should thus not respond beyond the cost channel, or, put differently, we should only observe first-round effects. However, our results point towards substantial second-round effects, particularly in the short-run while the effects are modest in the longer-run. Prima facie, our results allow the interpretation that short-run expectations may not be well anchored in the euro area. Regarding long-run inflation expectations, we interpret this as a slight deviation from target and not to de-anchoring per se.

Second, the expectation formation process of inflation expectations may be distorted in a way that it does not resemble rational expectation. A wide array of papers have shown that agents, may it be firms or households, are informationally constrained when forming inflation expectations, which holds true independently how inflation expectations are measured (Coibion and Gorodnichenko, 2012; Coibion and Gorodnichenko, 2015a). We confirm this in our analysis with market-based expectations. Specifically, D'Acunto, Malmendier and Weber (2023) and Weber, Gorodnichenko and Coibion (2023) point out that information provided by policymakers is often ignored or wrongly interpreted by economic agents and that personal experience, human cognition or gender play a larger role for households in forming inflation expectations. In terms of monetary policy, the pervasiveness of information rigidities in the economy has led to the conclusion that an optimal policy should respond aggressively to fluctuations in inflation (Reis, 2009). All of the above mentioned studies point to the fact that information frictions do not differ strongly between the US and the euro area. This empirical fact motivates our consecutive analysis, where we will re-do our analysis for the United States.

Third and lastly, inflation expectations may be affected by additional demand-side forces outside of our model. While natural gas prices have strongly gained momentum after the Russian invasion in Ukraine in February 2022, their elevation began already in mid 2021. In this time period, economies around the world were recovering economically from the Covid-19 pandemic. Part of this recovery process were generous fiscal transfers and support to households and firms, which we do not take explicitly into account with our model stance. Thus, these fiscally induced demand forces are not considered by our identification. According to Coibion, Gorodnichenko and Weber (2021) inflation expectations are sensitive to fiscal considerations, such as taxes and government spending. Specifically, news about the future debt leads anticipatory inflation expectation reactions, both in the short- and long-run. Using a new consumer survey in the euro area, Georgarakos and Kenny (2022) show in a randomized control trial that a more positive assessment of fiscal interventions improve household expectations about income prospects or future access to credit and financial sentiment. Needless to say, this serves only as an indirect evidence for an effect of inflation expectations. Still, we have to acknowledge that our approach can only partially filter out the effects of the various fiscal interventions during the Covid 19 pandemic, which we will thus leave for further research.

6. Extensions

We provide extensions along three lines. First, we re-do the analysis with the survey of professional forecasters (SPF) of the European Central Bank (ECB) on a quarterly frequency. While the case of natural gas is particularly interesting due to its recent classification as a *transition* energy source and, more importantly, will thus still be a crucial input in the future, commodity energy prices in general show a strong comovement (see the discussion in section 3). Hence, the second extension is dedicated to the choice of the commodity price. The third extension tackles the aforementioned question, if there is a different reaction to these shocks in the US. The main focus of the paper lies on the euro area as natural gas plays an important role. Given the heterogeneous situation around structural and economic factors about natural gas in the euro area and the US, this is a particularly intriguing comparison. Moreover, it allows us to investigate whether the inflation expectation formation process plays a central role in driving the results.

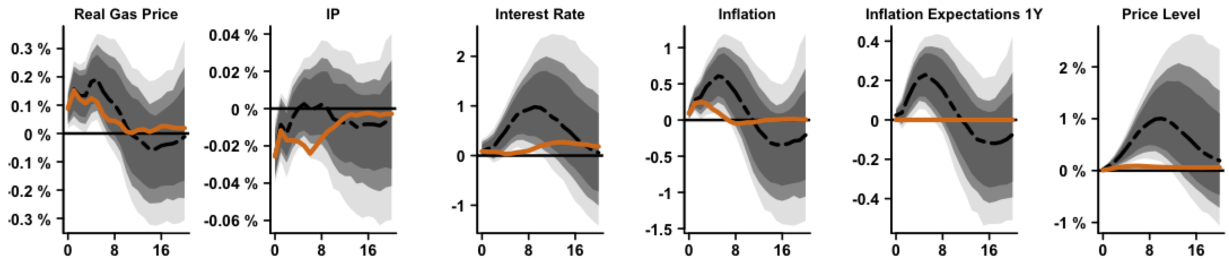
6.1 Inflation Expectations based on the Survey of Professional Forecasters

We mainly re-do the analysis with the inflation expectations from the SPF of the ECB to provide robustness with a survey-based measure of inflation expectations. Furthermore, we examine whether the assumption of a constant inflation risk premium holds.[12] However, the SPF data is only available on a quarterly frequency, which leaves us with 72 observations from 2004Q1 to 2022Q4. We use the 12-month ahead and longer-term forecast (5 years) of HICP for the analysis.

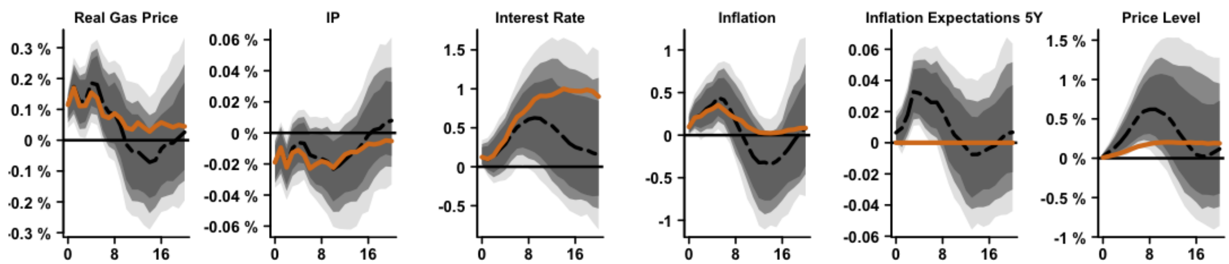
The results are presented in Figure 7. Overall, they confirm the picture presented so far. Real natural gas price shocks elicit a jump in the real gas price of about 10%. Industrial production drops while the monetary authority raises interest rates. Inflation and its expectations increase. Notably, longer-term expectations

[12] The Federal Reserve of Cleveland provides an estimate of the inflation risk premium for the US. This series fluctuates mildly around a long-run mean and shows no obvious correlations to business cycle fluctuations and/or historical episodes (e.g., the high-inflation period of the 1970s).

Figure 7: Impulse Response Functions to a Real Gas Price Shock (SPF).



(a) SPF: 1Y ahead Inflation Expectations.



(b) SPF: 5Y ahead Inflation Expectations.

Notes: The extended model with inflation expectations from the survey of professional forecasters (SPF). The shock is identified with sign- and zero restrictions and standardized to a one standard deviation increase in the real price of natural gas. The price level is computed afterwards as cumulative sum of the inflation response. Black dashed lines denote the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise, where the expectation channel is shut off. The responses of the real gas price, industrial production, and the price level are in percent, while the interest rate, inflation, and inflation expectations are scaled to (annualized) percentage points.

increase much less pronounced. The counterfactual exercise reveals that the second-round effects are quite sizable in the model with short-term expectations but almost vanish for longer-term expectations. The decrease in the pass-through is again corroborating the theoretical predictions of Werning (2022). The pass-through in short-term expectations is now only about 0.6-0.7 and the decrease of longer-term expectations is also expected, while long-term expectations should be completely irrelevant. Again, in both models expectations clearly underreact to new information. We corroborate our earlier findings that the duration of an underreaction to information is about two years (as seen in Figure C3) which is consistent with earlier findings (Coibion and Gorodnichenko, 2012; Coibion and Gorodnichenko, 2015a). Furthermore, the uncertainty bounds are generally more sizable, which is due to the limited time span of the sample.

The SPF data confirms our initial findings, although a stronger drop in longer-term expectations can be seen. Interestingly, in this model inflation shows much more sensitivity towards natural gas price shocks, which yields also a stronger effect on the price level. Hence, the apparent smaller decrease in the model with 5Y expectations is still a sizable decrease of about 0.4 percentage points at maximum in the price level. The assumption of a non time-varying inflation risk premium in the market-based expectation data can be defended. Therefore, these findings confirm that short-term inflation expectations matter most for the pass-through of commodity price shocks. They also show that longer-term expectations are more stable in the survey-based than in the market-based measure. We conclude that inflation expectations did not show a de-anchoring dynamic, or were at least only picking up slightly after the recent shocks the euro area experienced.

6.2 Alternative Commodity Prices as External Shocks

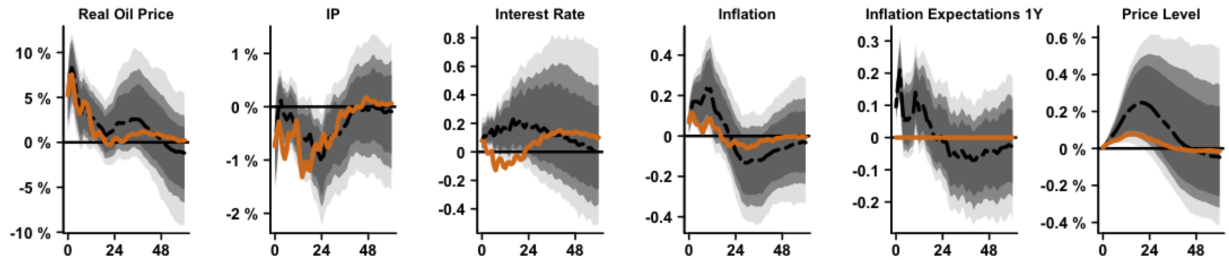
We look into two alternative fossil fuels used as energy and partly direct inputs thus possibly serving as external shocks to energy prices in the euro area: crude oil and coal. Oil prices are historically an interesting case and still – while with a vanishing effect – important for economic activity. The usage of coal, however, has increased after the energy crunch triggered by the supply disruptions from Russia as a substitute energy in the euro area, most notably in Germany. These energy commodities exhibit a strong comovement, as can be seen in Figure 2, and can be measured with the correlation coefficient. Natural gas and oil show a correlation coefficient of 0.45 in the total sample, while the correlation coefficient of natural gas and coal is as high as 0.89. Interestingly, the picture reverses if we end the sample before mid 2021. Now, natural gas and oil have a correlation coefficient of 0.76 while the correlation of natural gas and coal is around 0.53. This serves as preliminary evidence that natural gas and oil show a stronger comovement before the recent gas price surge with decoupling tendencies before. Similarly, the rise in the correlation coefficient of natural gas and coal from 0.53 to 0.89 is probably explained by strong substitution effects of natural gas and coal.

The findings of this exercise are presented in Figure 8. Panel (a) shows the model featuring the real crude oil price, while panel (b) shows the model featuring coal with identified a real oil and coal price shocks, respectively. The identification strategy resembles the same sign- and zero-restrictions as in the extended model. Both commodity price shocks show similar dynamics as in the model featuring the real gas price. Industrial production contracts on impact and inflation as well as inflation expectations increase. Short-term interest rates show a tightening monetary policy stance. The responses' magnitudes vary but are in the ballpark of the estimates before. Interestingly, the uncertainty around our responses is higher in models with crude oil and coal compared to the ones with natural gas. This can potentially be explained by the higher volatility of these commodities in our sample compared to natural gas.

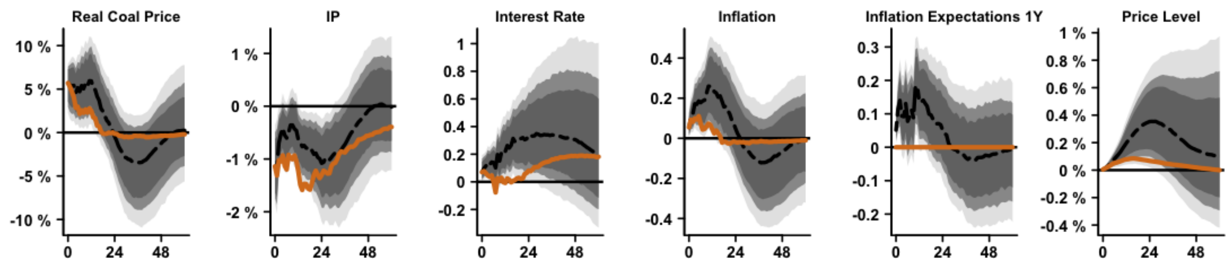
Turning to the counterfactual exercise, i.e., the orange lines in Figure 8, the outcomes are again qualitatively similar to the model with real gas price shocks. Again, the impulse response of inflation expectations are nil to real oil/coal price shocks by construction. Thus, the structural shocks of inflation expectations itself are responsible to create the offsetting force. While the counterfactual impulse responses of the commodity prices and industrial production do not strongly deviate from their unconditional response, we see again a strong adjustment for interest rates and inflation. The implied price level is about 50-60% lower than in the unconditional response (moving from a 0.35% increase to a 0.1% increase). This is a somewhat smaller impact but still comparable to the decrease observed when analyzing a natural gas price shock.

We also re-estimated these models with the respective 5-year inflation expectations. The impulse response functions can be found in Figure C5. Both the impulse responses and the counterfactual responses are similar to the exercise before. Inflation expectations with a medium-term horizon (such as five years) only react shortly and less pronounced on impact. This is again in line with the evidence that longer-term inflation expectations are less important for determining inflation. Therefore, the counterfactuals point to a less strong deviation from the unconditional response.

Figure 8: Impulse Response Functions to an Alternative Commodity Price Shock (Extended).



(a) Alternative Commodity Price: Oil.



(b) Alternative Commodity Price: Coal.

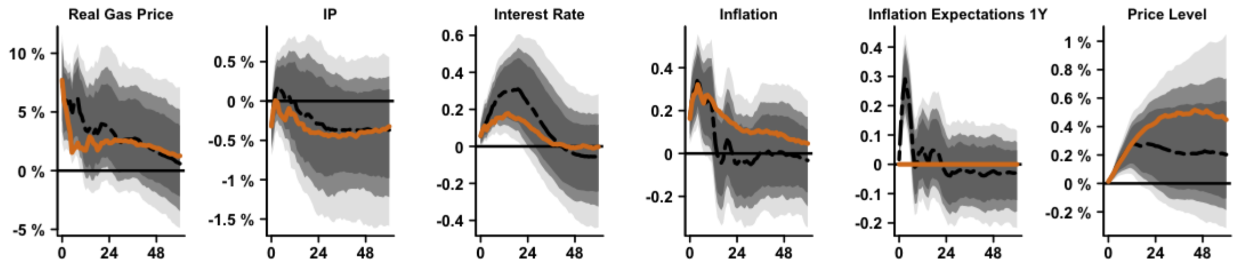
Notes: The extended model for alternative commodity prices features five variables, where the shock is identified with sign- and zero restrictions and standardized to a one standard deviation increase in the real price of crude oil or coal, respectively. The price level is computed afterwards as cumulative sum of the inflation response. Black dashed lines denote the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise, where the expectation channel is shut off. The responses of the real oil/coal price, industrial production, and the price level are in percent, while the interest rate, inflation, and inflation expectations are scaled to (annualized) percentage points.

6.3 Do We Find Similar Effects in the US?

To answer this question, we re-estimate the extended model again for the US. Hence, we use US variables and the US real gas price benchmark (Henry Hub). For the short-term interest rates we use the federal funds rate, and inflation is characterized by the consumer price index. Inflation expectations are again inflation linked swaps with the same characteristics and maturity structure as the European swaps. We refer to Appendix A for exact data details. Furthermore, we keep the sample starting in 2004M1 to 2022M11.

Results are presented in Figure 9, where the the effects are relatively obvious. The real gas price increases loose power relatively quickly and industrial production drops only on impact before almost immediately returning to zero. Inflation is elevated for about one year, while inflation expectations shoot up only temporarily with a quick mean reversion. The counterfactual exercise, however, is remarkably different to the euro area results. Shutting down second-round effects via inflation expectations does not alter the unconditional responses substantially. Most importantly, inflation does not show a strong difference from its unconditional response and thus we do not see a strong impact on the price level. Furthermore, these results are robust to using core inflation (see Figure C6) or 5Y inflation expectations (see Figure C7). Similar results are obtained when using real oil prices instead of real gas prices (see Figure C8). This corroborates the findings of Wong (2015), who investigates this in a simpler specification. Nevertheless, he also finds

Figure 9: Impulse Response Functions to a Real Gas Price Shock (Extended Model for the US).



Notes: The extended model for the US features five variables, where the shock is identified with sign- and zero restrictions and standardized to a one standard deviation increase in the real price of natural gas. The price level is computed afterwards as cumulative sum of the inflation response. Black dashed lines denote the posterior median responses while gray shaded areas depict the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise, where the expectation channel is shut off. The responses of the real gas price, industrial production, and the price level are in percent, while the interest rate, inflation, and inflation expectations are scaled to (annualized) percentage points.

only mild evidence (in a sample dating back to the early 80s) that inflation expectations feed into inflation reactions to a real oil price shock.

So why do we see strong second-round effects in the euro area but not in the US? An intuitive explanation is again given by the anchoring of inflation expectations, by information rigidities in the formation of inflation expectations, and demand-side forces due to the recovering from the Covid-19 pandemic. Coming back to our earlier discussion, Coibion and Gorodnichenko (2015a) show that information rigidities are relatively similar in a set of countries, including the US and the euro area. Hence, we discard the presence of information rigidities as a potential explanation for the differences between the US and the euro area. With regards to the remaining two explanations, our econometric model and identification distinguishes between supply- and demand-side forces, but the Covid 19 pandemic and the respective fiscal responses hit both economies in a rather similar way. Hence, we are in line with Wong (2015) who points to the expectation anchoring issue. He argues that inflation expectations in the US are tightly anchored, which immediately translates to less pronounced second-round effects. On the contrary, short-run inflation expectations are more sensitive towards movements in the commodity prices than in the US.

7. Concluding Remarks

This paper investigates the recent natural gas price surge and its implications for inflation and inflation expectations in the euro area. In particular, we are interested in the second-round effects characterized as the pass-through of inflation expectations to inflation after a shock in natural gas prices. To investigate this issue, we develop a structural vector autoregressive model and use a combination of sign- and zero restrictions to identify a natural gas price shock. Finally, we construct a counterfactual exercise in which the responses of inflation expectations to gas price shocks are nil. Furthermore, the paper is interested in the role of the horizon of inflation expectations. We also provide several extensions, in which we re-do the analysis with survey-based expectations, provide additional results with additional commodity prices, and discuss the comparison of our findings to the case of the United States.

We find that both inflation and inflation expectations react positively to real natural gas price shocks. In the baseline model, we identify the effects only via recursive ordering. To further disentangle supply- and demand-side shocks, we use an extended model and utilize sign-restrictions. The counterfactual exercise reveals that inflation reacts much more muted when we zero out second-round effects via inflation expectations. This points to only a limited role of the cost channel and a more pronounced expectation channel. Furthermore, the expectation channel is stronger for short-term expectations compared to long-term expectations. This points towards a relatively stable inflation expectations anchor. These findings are robust to a number of design choices. We find the same outcomes if we use the survey of professional forecasters. Furthermore, we show in additional exercises that also other commodity prices, such as oil and coal, raise inflation and inflation expectations but the second-round effects are somewhat attenuated. The findings are sensitive to the inclusion of the period starting in mid 2021 and cannot be replicated for the US.

We discuss potential drivers of these findings. A promising explanation points to the anchoring of inflation expectations. If the central bank does not stabilize inflation expectations at the onset of external commodity price shocks, this can trigger strong second-round effects. These effects describe inflationary pressures due to heightened inflation expectations, either via the price setting or the wage bargaining channel. We also acknowledge that we cannot rule out entirely yet another explanation of de-anchored inflation expectations. In response to the Covid 19 pandemic, governments have provided generous stimulus packages which may also have affected inflation expectations. The proposed identification scheme is in principle designed to distinguish between demand- and supply-side forces but the pandemic has led to unprecedented policy responses, affecting both the supply and demand side. Nevertheless, the policy recommendation of the presented findings are straightforward because they hold even in the case of additional demand interventions. If there are signs that inflation expectations are starting to de-anchor, aggressive monetary policy reactions can tame heightened inflation expectations, especially in the presence of information rigidities (Reis, 2009). These findings are particularly important in the transition period to renewable energy sources. The EU has to import most of its natural gas demand, which it has recently classified as *green energy*. Hence, the EU is also susceptible to supply side disruptions in these markets, particularly via the expectations channel. This logic broadly transfers to other supply side disruptions as well. Therefore, clear and credible policy of the central bank can manage the process and guide expectations.

Declaration of Interest

The authors declare to have no conflict of interest.

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A. Data Appendix

All series were gathered from the sources listed below, including the FRED database (McCracken and Ng, 2016), the World Bank Commodity Price Data (*Pink Sheet*) (The World Bank, 2023), the statistical data warehouse of the European Central Bank, or Macrobond.

If necessary, series are seasonally adjusted with the X-13ARIMA-SEATS model. All series are approximately stationary.

Table A1: Variable Definitions.

Variable	Transformation	Details	Source
Euro Area			
$\mathbf{rgas}_t$	$\ln\left(\frac{\mathtt{PGAS}_{it}}{\mathtt{E}_t^{US/EUR}\times\mathtt{HICP}_t}\right)$	real gas price	constructed
$\mathbf{roil}_t$	$\ln\left(\frac{\mathtt{POIL}_{it}}{\mathtt{E}_t^{US/EUR}\times\mathtt{HICP}_t}\right)$	real oil price	constructed
$\mathbf{rcoal}_t$	$\ln\left(\frac{\mathtt{PCOAL}_{it}}{\mathtt{E}_t^{US/EUR}\times\mathtt{HICP}_t}\right)$	real coal price	constructed
$\mathbf{ip}_t$	$100\times\ln\mathtt{IP}_t$	logarithm of industrial production	constructed
$\mathbf{sr}_t$	$\mathtt{SR}$	Shadow rate for euro area by Wu and Xia (2016)	website of Jing Cynthia Wu
π_t	$100\times\ln\left(\frac{\mathtt{HICP}_t}{\mathtt{HICP}_{t-12}}\right)$	year-on-year growth rate of harmonized index of consumer prices	constructed
π_t^e	$\mathtt{ILS}^{xY}$	inflation linked swaps with x year ahead	Macrobond
π_t^e	$\mathtt{SPF}^{xY}$	survey of professional forecasters with $x=\{1,5\}$ years ahead	SPF ECB
$\mathbf{PGAS}_t$	$\mathtt{PGAS}_t$	price of natural gas (TTF) in $/mmBTU from Pink Sheet	World Bank
$\mathbf{POIL}_t$	$\mathtt{POIL}_t$	crude oil prices: Brent - Europe	FRED
$\mathbf{PCOAL}_t$	$\mathtt{PCOAL}_t$	Coal prices: Australian from Pink Sheet	World Bank
$\mathbf{E}_t^{US/EUR}$	$\mathtt{E}_t^{US/EUR}$	U.S. Dollars to Euro spot exchange rate	FRED
$\mathbf{HICP}_t$	$\mathtt{HICP}_t$	harmonized index of consumer prices	FRED
$\mathbf{HICP}_t^{core}$	$\mathtt{HICP}_t^{core}$	harmonized index of consumer prices excluding food, energy, alcohol, and tobacco	FRED
$\mathbf{IP}_t$	$\mathtt{IP}_t$	industrial production index	SDW ECB
United States			
$\mathbf{rgas}_t$	$\ln\left(\frac{\mathtt{PGAS}_{it}}{\mathtt{CPI}_t}\right)$	real gas price	constructed
$\mathbf{roil}_t$	$\ln\left(\frac{\mathtt{POIL}_{it}}{\mathtt{CPI}_t}\right)$	real oil price	constructed
$\mathbf{rcoal}_t$	$\ln\left(\frac{\mathtt{PCOAL}_{it}}{\mathtt{CPI}_t}\right)$	real coal price	
$\mathbf{ip}_t$	$100\times\ln\mathtt{IP}_t$	logarithm of industrial production	constructed
$\mathbf{sr}_t$	$\mathtt{SR}$	Shadow rate for euro area by Wu and Xia (2016)	website of Jing Cynthia Wu
π_t	$100\times\ln\left(\frac{\mathtt{CPI}_t}{\mathtt{CPI}_{t-12}}\right)$	year-on-year growth rate of harmonized index of consumer prices	constructed
π_t^e	$\mathtt{ILS}^{xY}$	inflation linked swaps with x year ahead	Macrobond
$\mathbf{PGAS}_t$	$\mathtt{PGAS}_t$	price of natural gas (Henry Hub) in $/mmBTU from Pink Sheet	World Bank
$\mathbf{POIL}_t$	$\mathtt{POIL}_t$	crude oil prices: West Texas Intermediate (WTI), Dollars per Barrel	FRED
$\mathbf{PCOAL}_t$	$\mathtt{PCOAL}_t$	Coal prices: Australian from Pink Sheet	World Bank
$\mathbf{CPI}_t$	$\mathtt{CPI}_t$	consumer prices index for all urban consumers	FRED
$\mathbf{CPI}_t^{core}$	$\mathtt{CPI}_t^{core}$	consumer price index for all urban consumers excluding food and energy	FRED
$\mathbf{IP}_t$	$\mathtt{IP}_t$	industrial production index	FRED

B. Details on Structural Scenario Analysis Counterfactuals

Building on the work of Waggoner and Zha (1999), the structural scenario analysis framework of Antolin-Diaz, Petrella and Rubio-Ramirez (2021) provides a general framework on how to impose specific paths on observed variables in a VAR model as conditional forecasts with and without constraints on the set of offsetting – or *driving* – shocks. Breitenlechner, Georgiadis and Schumann (2022) adapt this to the case of impulse response analysis with structural scenario analysis (SSA). Again, iterate the VAR model in Equation (4.1) forward and re-write it as

$$\boldsymbol{y}_{T+1,T+h} = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}'\boldsymbol{\varepsilon}_{T+1,T+h}, \tag{B.1}$$

where the $nh\times 1$ vector $\boldsymbol{y}_{T+1,T+h} = (\boldsymbol{y}'_{T+1}, \boldsymbol{y}'_{T+2}, \ldots, \boldsymbol{y}'_{T+h})'$ denotes future values of the endogenous variables, $\boldsymbol{b}_{T+1,T+h}$ an autoregressive component that is due to initial conditions as of period T, and the $nh \times 1$ vector $\boldsymbol{\varepsilon}_{T+1,T+h} = (\boldsymbol{\varepsilon}'_{T+1}, \boldsymbol{\varepsilon}'_{T+2}, \ldots, \boldsymbol{\varepsilon}'_{T+h})'$ future values of the structural shocks. The $nh \times nh$ matrix $\boldsymbol{M}$ reflects the impulse responses and is a function of the structural VAR parameters. The definition of $\boldsymbol{M}$ is as follows

$$\boldsymbol{M} = \begin{bmatrix} \boldsymbol{M}_0 & \boldsymbol{M}_1 & \ldots & \boldsymbol{M}_{h-1} \\ \boldsymbol{0} & \boldsymbol{M}_0 & \ldots & \boldsymbol{M}_{h-2} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \ldots & \boldsymbol{M}_0 \end{bmatrix}, \tag{B.2}$$

where $\boldsymbol{M}_0 = \boldsymbol{S}$ and $\boldsymbol{M}_i = \sum_{j=1}^{i} \boldsymbol{M}_{i-j}\boldsymbol{B}_j$ with $\boldsymbol{B}_j = \boldsymbol{0}$ if $j > p$. From this representation it is clear that the matrix $\boldsymbol{M}$ only depends on the structural parameters. Furthermore, note that $\boldsymbol{M}'\boldsymbol{M}$ only depends on the reduced-form parameters. Thus, one only needs the history of observables and the reduced-form parameters to characterize the distribution of the unconditional forecast.

Then, the unconditional forecast is distributed

$$\boldsymbol{y}_{T+1,T+h} = \mathcal{N}\left(\boldsymbol{b}_{T+1,T+h}, \boldsymbol{M}'\boldsymbol{M}\right). \tag{B.3}$$

In the framework of Antolin-Diaz, Petrella and Rubio-Ramirez (2021), structural scenarios involve

i) *Conditional-on-observables* forecasting, i.e., specifying paths for a subset of observables in $\boldsymbol{y}_{T+1,T+h}$ that depart from their unconditional forecast, and/or

ii) *Conditional-on-shocks* forecasting, i.e., specifying the subset of structural shocks $\boldsymbol{\varepsilon}_{T+1,T+h}$ that are allowed to deviate from their unconditional distribution to produce the specified path of the observables in (i).

In the following, we will discuss how to implement both options. Therefore, one should note that

$$\tilde{\boldsymbol{y}}_{T+1,T+h} \sim \mathcal{N}\left(\boldsymbol{\mu}_y, \boldsymbol{\Sigma}_y\right), \tag{B.4}$$

denotes the distribution of the future values of the *constrained* observables. The goal is to determine $\boldsymbol{\mu}_y$ and $\boldsymbol{\Sigma}_y$ such that the constraints in (i) and (ii) are satisfied simultaneously.

Under (i), *conditional-on-observables* forecasting can be implemented as follows. Let $\overline{\boldsymbol{C}}$ be a $k_o \times nh$ selection matrix, with k_o denoting the number of restrictions. Then, *conditional-on-observables* restrictions can be written as

$$\overline{\boldsymbol{C}}\tilde{\boldsymbol{y}}_{T+1,T+h} \sim \mathcal{N}\left(\overline{\boldsymbol{f}}_{T+1,T+h}, \overline{\boldsymbol{\Omega}}_f\right), \tag{B.5}$$

where the $k_o \times 1$ vector $\overline{\boldsymbol{f}}_{T+1,T+h}$ is the mean of the distribution of the observables constrained under the conditional forecast, and the $k_o \times k_o$ matrix $\overline{\boldsymbol{\Omega}}_f$ is the associated variance-covariance matrix.

Under (ii), *conditional-on-shocks* forecasting can be implemented as follows. Let $\boldsymbol{\Xi}$ be a $k_s \times nh$ selection matrix, with k_s denoting the number of restrictions. Then, *conditional-on-shocks* restrictions can be written as

$$\Xi \tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}\left(\boldsymbol{g}_{T+1,T+h}, \boldsymbol{\Omega}_g\right), \tag{B.6}$$

where the $k_s \times 1$ vector $\boldsymbol{g}_{T+1,T+h}$ is the mean of the distribution of the shocks constrained under the conditional forecast and the $k_s \times k_s$ matrix $\boldsymbol{\Omega}_g$ is the associated variance-covariance matrix. Under invertability, the shocks can always be expressed as a function of observed variables and allows us to re-write the restrictions:

$$\begin{aligned} \Xi \boldsymbol{M}'^{-1} \tilde{\boldsymbol{y}}_{T+1,T+h} &= \Xi \boldsymbol{M}'^{-1} \boldsymbol{b}_{T+1,T+h} + \Xi \tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \\ \underline{\boldsymbol{C}} \tilde{\boldsymbol{y}}_{T+1,T+h} &= \underline{\boldsymbol{C}} \boldsymbol{b}_{T+1,T+h} + \Xi \tilde{\boldsymbol{\varepsilon}}_{T+1,T+h}, \end{aligned} \tag{B.7}$$

and thus

$$\underline{\boldsymbol{C}} \tilde{\boldsymbol{y}}_{T+1,T+h} = \underline{\boldsymbol{C}} \boldsymbol{b}_{T+1,T+h} + \Xi \tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}\left(\underline{\boldsymbol{f}}_{T+1,T+h}, \underline{\boldsymbol{\Omega}}_f\right), \tag{B.8}$$

where $\underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g$.

Now we can combine the k_o restrictions on the observables under *conditional-on-observables* forecasting and the k_s restrictions on the structural shocks under *conditional-on-shocks* forecasting. This amounts to $k = k_o + k_s$ total restrictions. We define the $k \times nh$ matrices $\boldsymbol{C} = [\overline{\boldsymbol{C}}', \underline{\boldsymbol{C}}']'$ and $\boldsymbol{D} = [\boldsymbol{M}\overline{\boldsymbol{C}}', \Xi']'$, which allows us to write

$$\boldsymbol{C} \tilde{\boldsymbol{y}}_{T+1,T+h} = \boldsymbol{C} \boldsymbol{b}_{T+1,T+h} + \boldsymbol{D} \tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}\left(\boldsymbol{f}_{T+1,T+h}, \boldsymbol{\Omega}_f\right), \tag{B.9}$$

where the $k \times 1$ vector $\boldsymbol{f}_{T+1,T+h} = [\overline{\boldsymbol{f}}'_{T+1,T+h}, \underline{\boldsymbol{f}}'_{T+1,T+h}]'$ stacks the means of the distribution and the $k \times k$ matrix $\boldsymbol{\Omega}_f = \mathtt{diag}(\overline{\boldsymbol{\Omega}}_f, \underline{\boldsymbol{\Omega}}_f)$ denotes the associated variance-covariance matrix.

Following the framework in Antolin-Diaz, Petrella and Rubio-Ramirez (2021) and given the restrictions specified above, we can derive solutions for $\boldsymbol{\mu}_y$ and $\boldsymbol{\Sigma}_y$. Define the restricted future shocks

$$\tilde{\boldsymbol{\varepsilon}}_{T+1,T+h} \sim \mathcal{N}(\boldsymbol{\mu}_\varepsilon, \boldsymbol{\Sigma}_\varepsilon), \tag{B.10}$$

where $\boldsymbol{\Sigma}_\varepsilon = \boldsymbol{I}_n h + \boldsymbol{\Psi}_\varepsilon$, such that $\boldsymbol{\mu}_\varepsilon$ and $\boldsymbol{\Psi}_\varepsilon$ denote the deviation of the mean and covariance matrix from their unconditional counterparts. Using Equation B.9, we match the first and second moment to get

$$\boldsymbol{f}_{T+1,T+h} = \boldsymbol{C} \boldsymbol{b}_{T+1,T+h} + \boldsymbol{D} \boldsymbol{\mu}_\varepsilon, \tag{B.11}$$

$$\boldsymbol{\Omega}_f = \boldsymbol{D}(\boldsymbol{I}_n h + \boldsymbol{\Psi}_\varepsilon)\boldsymbol{D}'. \tag{B.12}$$

Depending on k, the number of restrictions, and nh, the length of $\tilde{\boldsymbol{y}}_{T+1,T+h}$, the systems of Equation B.11 and Equation B.12 may have multiple solutions ($k < nh$), one solution ($k = nh$), or no solution ($k > nh$). Since $k < nh$ is the most interesting case, the solution are given by

$$\boldsymbol{\mu}_\varepsilon = \boldsymbol{D}^* \left(\boldsymbol{f}_{T+1,T+h} - \boldsymbol{C} \boldsymbol{b}_{T+1,T+h}\right), \tag{B.13}$$

$$\boldsymbol{\Psi}_\varepsilon = \boldsymbol{D}^* \boldsymbol{\Omega}_f \boldsymbol{D}^{*'} - \boldsymbol{D}^* \boldsymbol{D} \boldsymbol{D}' \boldsymbol{D}^{*'}, \tag{B.14}$$

where $\boldsymbol{D}^*$ is the Moore-Penrose inverse of $\boldsymbol{D}$. Equation B.13 shows that the path of the implied structural shocks under the conditional forecast depend on its deviation from the unconditional forecast. Furthermore, Equation B.14 shows that the variance of the implied future structural shocks depends on the uncertainty the researcher attaches to the conditional forecast. If the uncertainty is zero ($\boldsymbol{\Omega}_f = \boldsymbol{0}$), then $\boldsymbol{\Sigma}_\varepsilon = \boldsymbol{0}$. This means that a unique path for $\boldsymbol{\mu}_\varepsilon$ can be found.

Combining Equation B.3, Equation B.13, and Equation B.14, we get

$$\boldsymbol{\mu}_y = \boldsymbol{b}_{T+1,T+h} + \boldsymbol{M}' \boldsymbol{D}^* \left(\boldsymbol{f}_{T+1,T+h} - \boldsymbol{C} \boldsymbol{b}_{T+1,T+h}\right), \tag{B.15}$$

$$\boldsymbol{\Sigma}_y = \boldsymbol{M}' \boldsymbol{M} - \boldsymbol{M}' \boldsymbol{D}^* \left(\boldsymbol{\Omega}_f - \boldsymbol{D} \boldsymbol{D}'\right) \boldsymbol{D}^{*'} \boldsymbol{M}. \tag{B.16}$$

As before, if $\boldsymbol{\Omega}_f = \boldsymbol{0}$, then $\boldsymbol{\Sigma}_y = \boldsymbol{0}$ and thus there is no uncertainty about the path of the observables under the imposed restrictions.

B1. Restrictions in the Three-Variable VAR

In the three-variable VAR, we have $\boldsymbol{y}_t = [rgas_t, \pi_t^e, \pi_t]$. We want to constrain the effect of a real gas price shock on inflation expectations π_t^e to be zero. Denote with $\boldsymbol{e}_i$ a $n \times 1$ vector of zeros with unity at the i-th position.

Under (i), *conditional-on-observable* forecasting, we impose

$$\overline{\boldsymbol{C}} = \boldsymbol{I}_h \otimes \boldsymbol{e}_2', \tag{B.17}$$

$$\overline{\boldsymbol{f}}_{T+1,T+h} = \boldsymbol{0}_{h\times 1}, \tag{B.18}$$

$$\overline{\boldsymbol{\Omega}}_f = \boldsymbol{0}_{h\times h}. \tag{B.19}$$

These equations impose that the conditional forecast that underlies the impulse response of inflation expectations (which is ordered second in the VAR) is constrained to be zero over all horizons $T+1, \ldots, T+h$. Furthermore, we do not allow for any uncertainty.

Under (ii), *conditional-on-shocks* forecasting, we impose

$$\boldsymbol{\Xi} = \begin{bmatrix} \boldsymbol{e}_1' & \boldsymbol{0}_{1\times n(h-1)} \\ \boldsymbol{e}_3' & \boldsymbol{0}_{1\times n(h-1)} \\ \boldsymbol{0}_{(h-1)(n-1)\times n} & \boldsymbol{I}_{h-1} \otimes (\boldsymbol{e}_1, \boldsymbol{e}_3)' \end{bmatrix}_{h(n-1)\times nh} \tag{B.20}$$

$$\underline{\boldsymbol{f}}_{T+1,T+h} = \boldsymbol{g}_{T+1,T+h} = [1, 0, \boldsymbol{0}_{1\times(n-1)(h-1)}]' \tag{B.21}$$

$$\underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g = \boldsymbol{0}_{h(n-1)\times h(n-1)} \tag{B.22}$$

The first row in Equation B.20 selects the real gas price shock ordered first in $\boldsymbol{\varepsilon}_t$ and the first row in Equation B.21 constrains it to be unity in the impact period $T+1$. In the second row in Equation B.20 we select the structural shock to inflation (ordered last in the VAR) and the second entry of Equation B.21 constrains this shock to be zero in period $T+1$. Hence, in $T+1$ the only structural shock which is allowed to vary is the one of inflation expectations. Similarly, the third row selects the first and third structural shocks for remaining impulse response horizon $T+2, T+3, \ldots, T+h$ and constrains them to zero in Equation B.21. Hence, in $T+2, T+3, \ldots, T+h$ the only structural shock which is allowed to vary is again the one of inflation expectations. Lastly, Equation B.22 specifies that we do not allow for uncertainty. It is also interesting to consider the stacked matrices $\boldsymbol{C}$ and $\boldsymbol{D}$ which look as follows

$$\boldsymbol{C} = \begin{pmatrix} \overline{\boldsymbol{C}}_{h\times nh} \\ \underline{\boldsymbol{C}}_{h(n-1)\times nh} \end{pmatrix}_{hn\times nh}, \qquad \boldsymbol{D} = \begin{pmatrix} \overline{\boldsymbol{C}}_{h\times nh} \boldsymbol{M}'_{nh\times nh} \\ \boldsymbol{\Xi}_{h(n-1)\times nh} \end{pmatrix}_{hn\times nh}, \tag{B.23}$$

where $\underline{\boldsymbol{C}} = \boldsymbol{\Xi}\boldsymbol{M}^{'-1}$.

B2. Restrictions in the Five-Variable VAR

In the five-variable VAR, we have $\boldsymbol{y}_t = [rgas_t, ip_t, i_t, \pi_t, \pi_t^e]$. We want to constrain the effect of a real gas price shock on inflation expectations π_t^e to be zero. Denote with $\boldsymbol{e}_i$ a $n \times 1$ vector of zeros with unity at the i-th position.

Under (i), *conditional-on-observable* forecasting, we impose

$$\overline{\boldsymbol{C}} = \boldsymbol{I}_h \otimes \boldsymbol{e}_5', \tag{B.24}$$

$$\overline{\boldsymbol{f}}_{T+1,T+h} = \boldsymbol{0}_{h\times 1}, \tag{B.25}$$

$$\overline{\boldsymbol{\Omega}}_f = \boldsymbol{0}_{h\times h}. \tag{B.26}$$

These equations impose that the conditional forecast that underlies the impulse response of inflation expectations (which is ordered fifth in the VAR) is constrained to be zero over all horizons $T+1, \ldots, T+h$. Furthermore, we do not allow for any uncertainty.

Under (ii), *conditional-on-shocks* forecasting, we impose

$$\boldsymbol{\Xi} = \begin{bmatrix} \boldsymbol{e}_1' & \boldsymbol{0}_{1\times n(h-1)} \\ (\boldsymbol{0}_{n-2\times 1}, \boldsymbol{I}_{n-2}) & \boldsymbol{0}_{n-2\times n(h-1)} \\ \boldsymbol{0}_{(h-1)(n-1)\times n} & \boldsymbol{I}_{h-1} \otimes (\boldsymbol{I}_{n-2}, \boldsymbol{0}_{n-2\times 1}) \end{bmatrix}_{h(n-1)\times nh} \tag{B.27}$$

$$\underline{\boldsymbol{f}}_{T+1,T+h} = \boldsymbol{g}_{T+1,T+h} = [1, \boldsymbol{0}_{1\times n-2}, \boldsymbol{0}_{1\times(n-1)(h-1)}]' \tag{B.28}$$

$$\underline{\boldsymbol{\Omega}}_f = \boldsymbol{\Omega}_g = \boldsymbol{0}_{h(n-1)\times h(n-1)} \tag{B.29}$$

The first row in Equation B.27 selects the real gas price shock ordered first in $\boldsymbol{\varepsilon}_t$ and the first row in Equation B.28 constrains it to be unity in the impact period $T+1$. In the second row in Equation B.27 we select the structural shock to industrial production, short-term interest rate and inflation (ordered from the second to second-last position in the VAR) and the second entry of Equation B.28 constrains these structural shocks to be zero in period $T+1$. Hence, in $T+1$ the only structural shock which is allowed to vary is the one of inflation expectations. Similarly, the third row selects the first $n-1$ structural shocks over the remaining impulse response horizon $T+2, T+3, \ldots, T+h$ and constrains them to zero in Equation B.28. Hence, in $T+2, T+3, \ldots, T+h$ the only structural shock which is allowed to vary is again the one of inflation expectations. Lastly, Equation B.29 specifies that we allow for no uncertainty. It is also interesting to consider the stacked matrices $\boldsymbol{C}$ and $\boldsymbol{D}$ which look as follows

$$\boldsymbol{C} = \begin{pmatrix} \overline{\boldsymbol{C}}_{h\times nh} \\ \underline{\boldsymbol{C}}_{h(n-1)\times nh} \end{pmatrix}_{hn\times nh}, \qquad \boldsymbol{D} = \begin{pmatrix} \overline{\boldsymbol{C}}_{h\times nh} \boldsymbol{M}'_{nh\times nh} \\ \boldsymbol{\Xi}_{h(n-1)\times nh} \end{pmatrix}_{hn\times nh}, \tag{B.30}$$

where $\underline{\boldsymbol{C}} = \boldsymbol{\Xi}\boldsymbol{M}'^{-1}$.

B3. How plausible is the counterfactual?

Generally, structural scenario analysis counterfactuals based on SVARs are not prone to the Lucas critique (Lucas, 1976). However, if the implied shocks are so *unusual* the analysis might becomes subject to the Lucas critique anyway. Hence, measures of plausibility of the created counterfactual scenario are a remedy. We use two measures: the q-divergence proposed in Antolin-Diaz, Petrella and Rubio-Ramirez (2021) and adapted to the case of impulse response functions by Breitenlechner, Georgiadis and Schumann (2022) and the modesty statistic proposed by Leeper and Zha (2003). These measures intend to measure by how much the structural scenario deviates from its unconditional counterpart. When this deviation becomes too large, the scenario might be implausible.

Antolin-Diaz, Petrella and Rubio-Ramirez (2021) propose to use the Kullback-Leibler (KL) divergence as a measure how plausible a scenario is. Denote with $\mathcal{D}(\mathcal{N}_{SS}||\mathcal{N}_{UF})$ the KL divergence between the distributions of the structural scenario analysis $\mathcal{N}_{SS}$ and the unconditional distribution $\mathcal{N}_{UF}$. While it is straightforward to compute $\mathcal{D}(\mathcal{N}_{SS}||\mathcal{N}_{UF})$, it is difficult to grasp whether any value for the KL divergence is large or small. In other words, the KL divergence can be easily used to rank scenarios, but it is hard to understand how far away they are from the unconditional forecast. Therefore, Antolin-Diaz, Petrella and Rubio-Ramirez (2021) propose to compare the KL divergence with the divergence between two binomial distributions, one with probability q and the other with probability $p = 0.5$. The idea is to compare the implied counterfactual distribution with their unconditional distribution, which translates into a comparison of the binomial distributions of a fair and a biased coin. If the probability q is near to to p, then this suggests that the distribution of the offsetting shocks is not at all far from the unconditional distribution. Antolin-Diaz, Petrella and Rubio-Ramirez (2021) suggest calibrating the KL divergence from $\mathcal{N}_{UF}$ to $\mathcal{N}_{SS}$ to a parameter q that would solve the following equation $\mathcal{D}\left(\mathcal{B}(nh, 0.5)||\mathcal{B}(nh, q)\right) = \mathcal{D}\left(\mathcal{N}_{SS}||\mathcal{N}_{UF}\right)$. The solution to the equation is

$$q = 0.5 * \left(1 + \sqrt{1 - \exp\left(-\frac{2z}{nh}\right)}\right) \quad \text{with} \quad z = \mathcal{D}\left(\mathcal{N}_{SS}||\mathcal{N}_{UF}\right). \tag{B.31}$$

As Breitenlechner, Georgiadis and Schumann (2022) point out, in the context of impulse responses the KL divergence has to be slightly adjusted, because Antolin-Diaz, Petrella and Rubio-Ramirez (2021) propose their measure in the context of conditional forecasts relative to an unconditional forecast. As before, the unconditional scenario is the case with only a single shock of unity size, which occurs in $T+1$ with certainty. More formally, $\boldsymbol{\varepsilon}_{T+1,T+h} = (\boldsymbol{e}_1', \boldsymbol{0}_{n(h-1)\times 1})'$ denotes the *unconditional* impulse response of a natural gas price shock. $\boldsymbol{e}_i$ denotes the unit vector with unity on the i-th position. For the structural scenario analysis counterfactual, we impose the restrictions specified above (i.e., inflation expectations do not react to a natural gas price shock). Hence, we set

$$\texttt{UF:} \qquad \boldsymbol{\mu}_{UF} = \boldsymbol{M}'(\boldsymbol{e}_1', \boldsymbol{0}_{n(h-1)\times 1})' \tag{B.32}$$

$$\texttt{SS:} \qquad \boldsymbol{\mu}_{SS} = \boldsymbol{\mu}_y, \tag{B.33}$$

where $\boldsymbol{\mu}_y$ is given by Equation (B.15). Since we impose this with certainty, $\boldsymbol{\Psi} = \boldsymbol{0}$ such that the shocks have their unconditional variance. Hence, $\boldsymbol{\Sigma}_{UF} = \boldsymbol{\Sigma}_{SS} = \boldsymbol{\Sigma}_{\varepsilon} = \boldsymbol{I}$. The KL divergence between the distribution of the shocks under the unconditional and conditional scenario is then given by

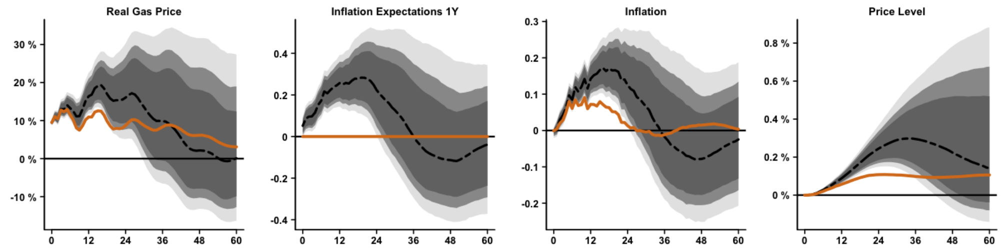
$$\mathcal{D}(\mathcal{N}_{SS}||\mathcal{N}_{UF}) = \frac{1}{2}\left(\operatorname{tr}\left(\boldsymbol{\Sigma}_{SS}^{-1}\boldsymbol{\Sigma}_{UF}\right) + (\boldsymbol{\mu}_{SS} - \boldsymbol{\mu}_{UF})'\boldsymbol{\Sigma}_{SS}^{-1}(\boldsymbol{\mu}_{SS} - \boldsymbol{\mu}_{UF}) - nh + \ln\left(\frac{\det \boldsymbol{\Sigma}_{SS}}{\det \boldsymbol{\Sigma}_{UF}}\right)\right), \tag{B.34}$$

where $\boldsymbol{\mu}_{\varepsilon}$ and $\boldsymbol{\Sigma}_{\varepsilon}$ are given by Equation (B.13) and Equation (B.14). Furthermore, we discard any SSA counterfactuals when the offsetting shocks are particularly unlikely. We set this to be above $q > 0.9$.

The second plausibility measure is the one of *modest intervention* or *modesty statistic* used in Leeper and Zha (2003). The measure reports how unusual the path for policy shocks is relative to the typical size of these shocks, which are needed to impose the counterfactual restriction. For instance, if the counterfactual implies a sequence of shocks close to their unconditional mean, the policy intervention is considered *modest*, in the sense that the shocks are unlikely to induce agents to revise their beliefs about policy rules and the structure of the economy. Instead, if the counterfactual involves an unlikely sequence of shocks the analysis is likely to be prone to the critique by Lucas (1976). The offsetting shocks are considered to be modest if the statistic is smaller than two in absolute value.

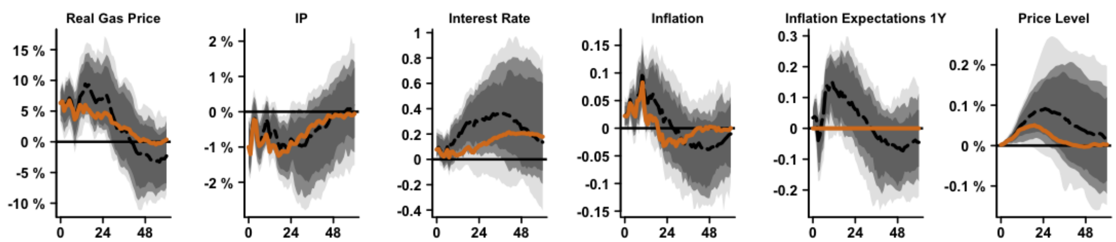
C. Additional Results

Figure C1: Impulse Response Functions to a Real Gas Price Shock (Baseline with Core Inflation).



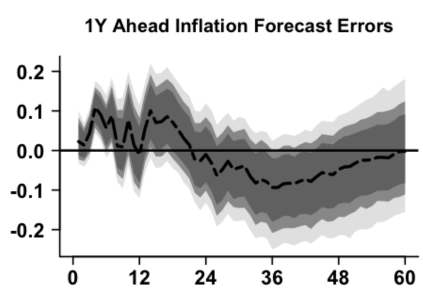
Notes: Baseline model featuring three variables with core inflation and identified with recursive ordering. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.

Figure C2: Impulse Response Functions to a Real Gas Price Shock (Extended with Core Inflation).

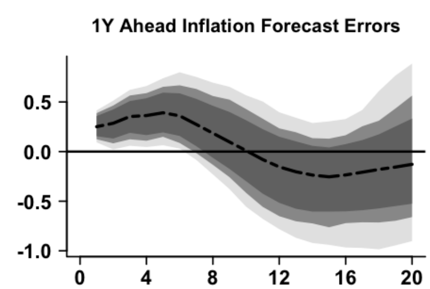


Notes: Extended model featuring five variables with core inflation and identified with sign-restrictions. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.

Figure C3: Implied Impulse Response Functions to a Real Gas Price Shock (Extended).



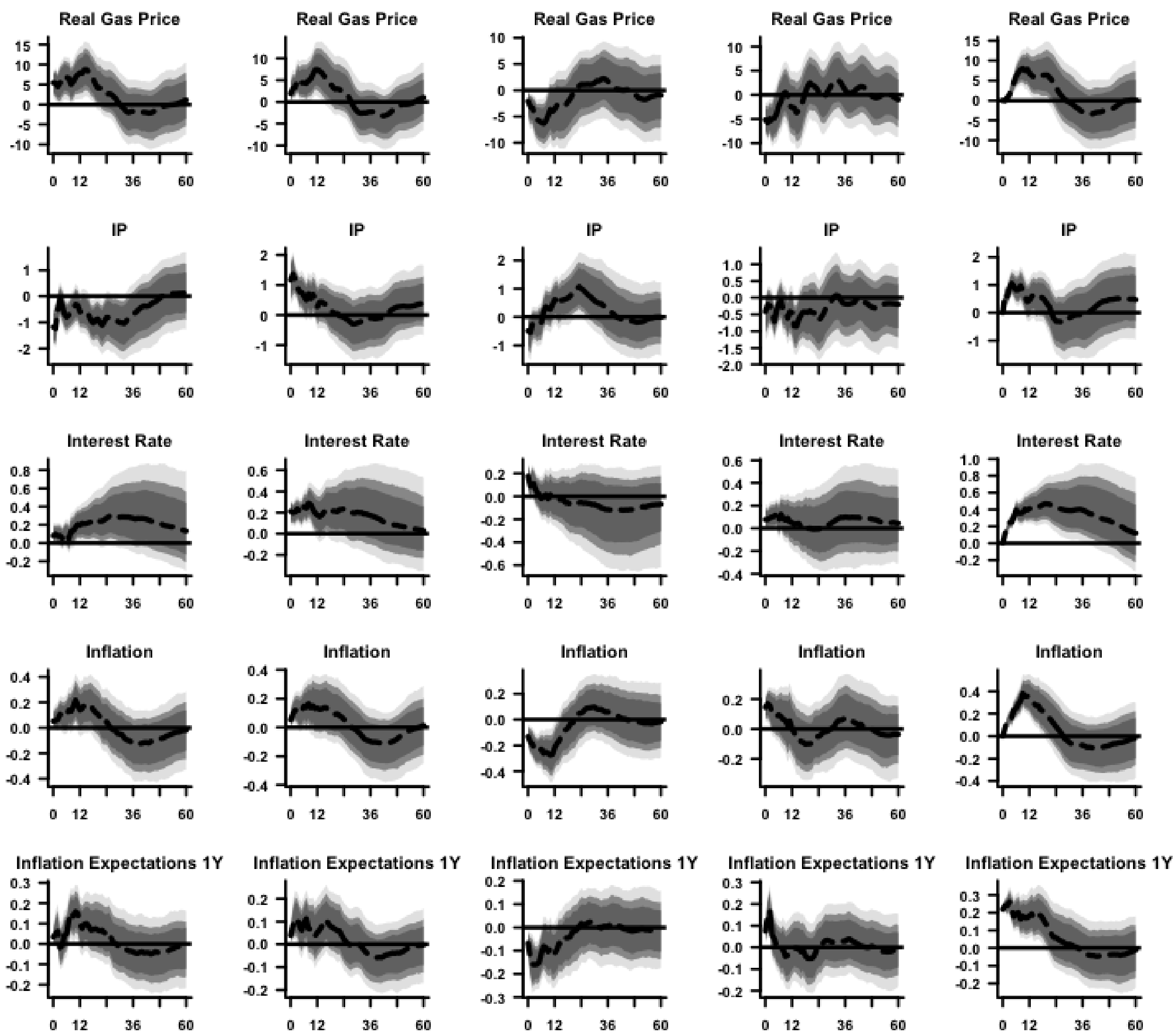
(a) ILS: Implied Forecast Error.



(b) SPF: Implied Forecast Error.

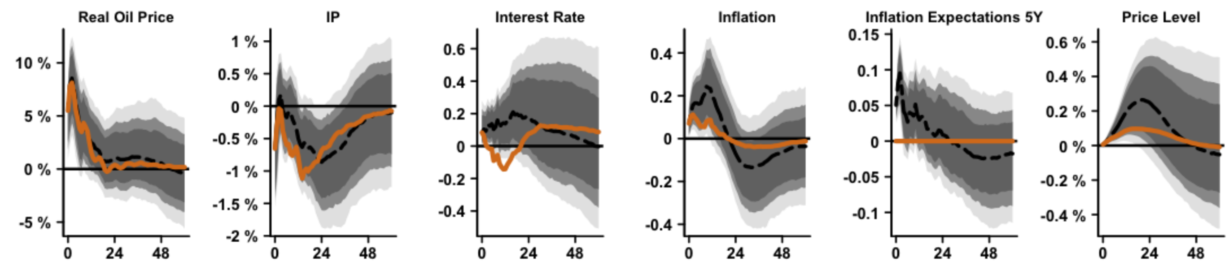
Notes: Implied impulse response function of forecast errors (constructed as the difference between realized inflation and the previous year's 1-year average expected inflation). Underlying model features five variables and is identified with sign-restrictions. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals.

Figure C4: Sign-restrictions all responses with 1Y ahead Inflation Expectations.

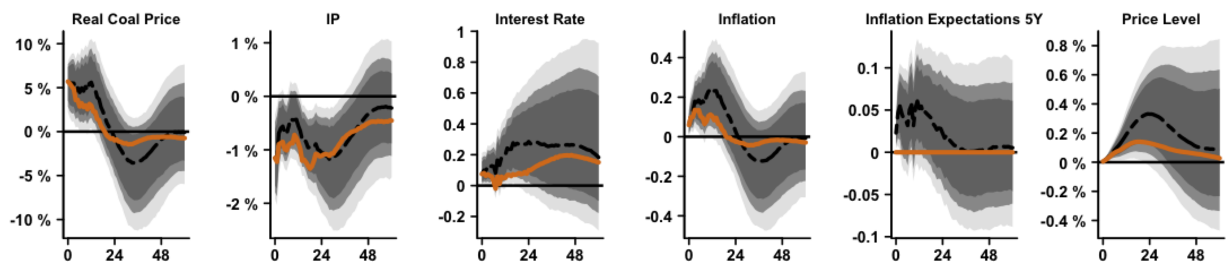


Notes: All impulse responses of extended model identified with sign-restrictions. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.

Figure C5: Impulse Response Functions to an Alternative Commodity Price Shock (5Y Inflation Expectations).



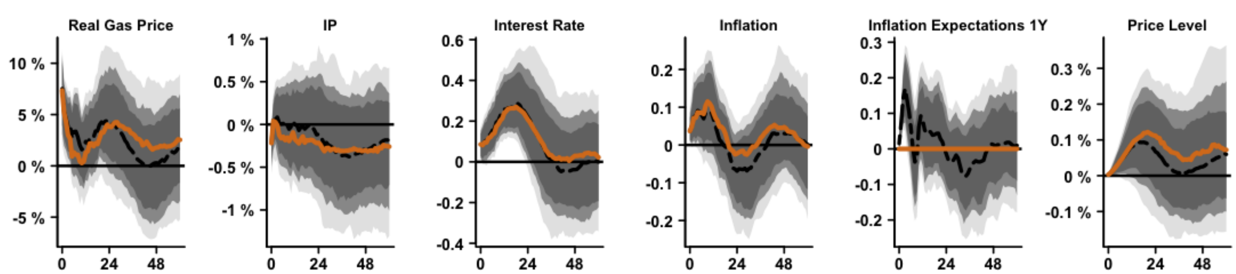
(a) Alternative Commodity Price: Oil.



(b) Alternative Commodity Price: Coal.

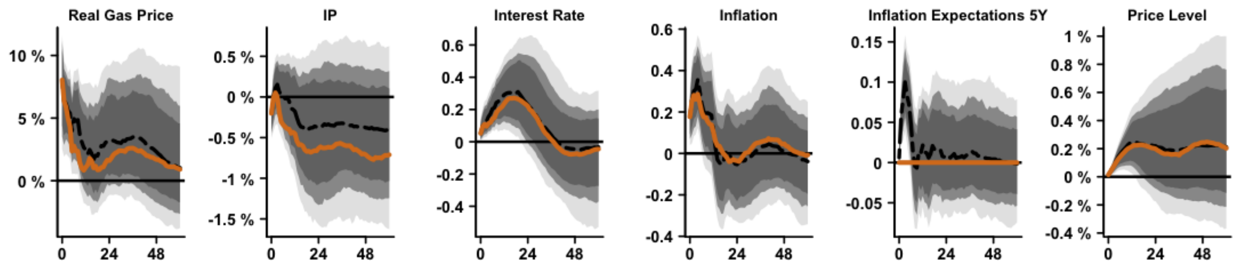
Notes: Extended model with alternative commodity prices featuring five variables and identified with sign-restrictions. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price, industrial production, and the price level are in percent, while the interest rate, inflation, and inflation expectations are scaled in (annualized) percentage points.

Figure C6: Impulse Response Functions to a US Real Gas Price Shock (Core Inflation).



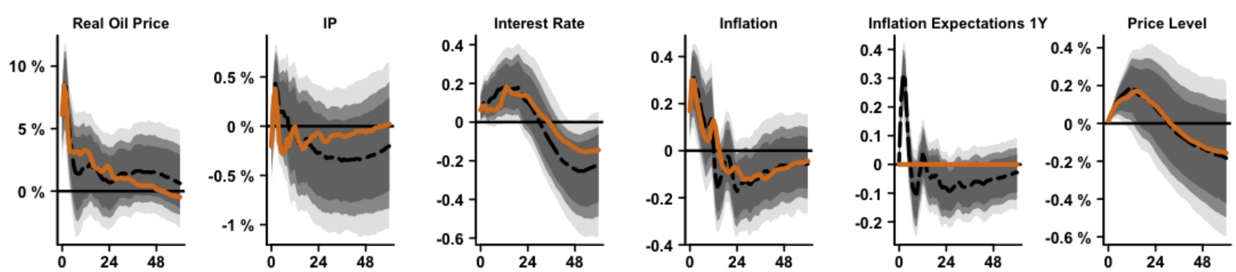
Notes: Extended US model featuring five variables with core inflation and identified with sign-restrictions. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.

Figure C7: Impulse Response Functions to a US Real Gas Price Shock (5Y Inflation Expectations).



Notes: Extended US model features five variables with 5Y inflation expectations and identified with sign-restrictions. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.

Figure C8: Impulse Response Functions to a US Real Oil Price Shock.



Notes: Extended US model features five variables with real oil prices and identified with sign-restrictions. Price level is computed afterwards as cumulative sum of inflation response. Black dashed line denotes median response while gray shaded areas denote the 68/80/90 percent confidence intervals. The orange solid line denotes the counterfactual exercise. The responses of the real gas price and the price level are in percent, while inflation and inflation expectations are scaled in annualized percentage points.