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Summary

We develop a Bayesian Structural VAR model to study the relationship between different energy shocks and inflation dynamics in Europe. Specifically, we model the endogenous transmission from shocks identified by the global market of crude oil and the European natural gas market to two target macroeconomic variables, i.e. inflation expectations and realized headline inflation rate. Our results demonstrate that, since the post-pandemic recovery, inflation in the Euro area is mostly driven by energy price shocks and aggregate supply factors. In particular, the high peaks of the Eurozone inflation are mostly associated with natural gas supply shocks.

Keywords: Bayesian Structural VARs, Inflation, New Keynesian Phillips Curve, Energy shocks, Oil and gas markets.

JEL Classification: C11, E31, Q41, Q43

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Energy shocks in the Euro area: disentangling the pass-through from oil and gas prices to inflation

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Abstract

We develop a Bayesian Structural VAR model to study the relationship between different energy shocks and inflation dynamics in Europe. Specifically, we model the endogenous transmission from shocks identified by the global market of crude oil and the European natural gas market to two target macroeconomic variables, i.e. inflation expectations and realized headline inflation rate. Our results demonstrate that, since the post-pandemic recovery, inflation in the Euro area is mostly driven by energy price shocks and aggregate supply factors. In particular, the high peaks of the Eurozone inflation are mostly associated with natural gas supply shocks.

Keywords: Bayesian Structural VARs, Inflation, New Keynesian Phillips Curve, Energy shocks, Oil and gas markets.

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1 Introduction

The socio-economic context in Europe is currently characterized by a large amount of uncertainty. The post-pandemic recovery has been weakened by the beginning of the

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Russian-Ukrainian conflict. The war scenario has been additionally exacerbated by two exceptional and related events: energy prices have recently hit their historical record and inflation has remarkably increased after some decades of moderate growth. The Eurozone annual inflation rate reached is all-time record of 10.6% in October 2022, far above the 2% target set by the European Central Bank (ECB) and the 2.6% rate registered one year before.[1]

Uncovering the factors behind high inflation rate and disentangling the nexus with the energy markets is essential in order to guide the ECB monetary policy. The European phenomenon is not isolated. The UK annual inflation rate reached 11.1% in October 2022, while in the US the average rate for 2022 was 8%.[2] However, by comparing the general macroeconomic conditions, important differences emerge, making it essential to conduct different and specific analyses for each economic system. By looking at the difference between headline and core inflation rates in the US and the Euro area, it emerges that the two inflation rates in US are closer than the corresponding Eurozone inflation rates. Whereas the high inflation in the US is pushed by increasing aggregate demand, in the Eurozone it is the result of pressures from the energy and the food sectors. Immediately after the high peak of inflation in October 2022, energy was the most important contributor to the annual growth of the Euro area Harmonized Index of Consumer Prices (HICP), accounting for 38% of headline inflation (Koester et al., 2023).

Given the relevance of this topic, an increasing amount of studies has focused on the energy-inflation pass-through. For instance, the relationship between inflation, inflation expectations and the oil market is studied by Aastveit et al. (2021), who explicitly consider the source of oil shocks to explain the inflation pass-through in a Bayesian SVAR model. Kilian and Zhou (2022a,b), studying the impact of gasoline prices on US inflation conclude that the rise in energy prices has no persistent impact on both US inflation and inflation expectations. However, gasoline price shocks account on average for 42% of the variation in inflation expectations and the US increase in expected inflation during the period 2009-2013 is mostly explained by rise in gasoline prices.

[1] Source: Eurostat.

[2] Sources: Bank of England, U.S. Bureau of Labor statistics.

It is important to point out that the majority of studies focuses on the US, while the number of contributions analysing the European economy is still limited. The European inflation rate is examined, for instance, by Peersman (2022), who considers food commodity price shocks and food retail prices nexus. Moreover, Peersman and Van Robays (2009) compare the US and Euro area inflationary effects of different energy shocks. Finally, the energy-inflation link is examined in two recent works by Conflitti and Luciani (2019), who study the oil price pass-through into core consumer prices within the Euro area and Clerides et al. (2022), who analyze the European case considering world crude oil and gasoline prices impacts on consumers sentiment.

The European energy sector is highly dependent on natural gas, whose market is characterized by an increasing level of integration among the European countries (see Bastianin et al., 2019; Broadstock et al., 2020; Papież et al., 2022, as examples). Given the increasing importance of natural gas as an energy source, the literature has dedicated specific attention to investigate its main characteristics. For example, using a SVAR setup, Rubaszek et al. (2021) model the natural gas market distinguishing among different shocks, whereas Jadidzadeh and Serletis (2017) provide a version of the oil market model augmented with a natural gas price equation. However, their structural specification explicitly considers the entire oil market, by including equations for supply, real economic activity and demand, while the gas market is represented only by means of a gas price equation, without structurally disentangling the different types of shocks.

In this article we depart from the existing literature since we develop a new model where both the global oil market and the European gas market are related to European expected and realized inflation rates. In particular, we build a novel Bayesian SVAR model that consists of an oil market block, a block modeling natural gas fundamentals and an inflation block. An additional novelty of our paper is the methodological challenging task of identifying the causal relationships among the oil market, the gas market and inflation. The endogeneity of inflation and its expectations requires to depart from recursive models based on Cholesky identification schemes.[3] In this respect, the peculiar-

[3]The issue of endogeneity of economic expectations is discussed in Coibion et al. (2020), among others.

ity of our Bayesian SVAR model is to examine the energy-inflation pass-through, taking into account the simultaneous relation between inflation and its expectations.

The rest of the article is structured as follows. Section 2 revises the main literature dealing with the effects of energy prices on realized inflation and expected inflation. Section 3 describes the dataset. Section 4 focuses on the model specification. The empirical results are presented and discussed in Section 5. Section 6 concludes.

2 Literature review

Whereas oil is the most important energy commodity worldwide in terms of market size, natural gas has become an increasingly important energy source. Within the Euro area, natural gas is the primary energy source in terms of consumption in the industrial sector. Most of the gas market growth can be attributed to the efforts aimed at removing the frictions characterizing its imports, exports and storage. Even if the oil and gas markets are not comparable in terms of value or size, still it may be crucial to consider both when analyzing the effects of energy shock on inflation. Moreover, there are no reasons to expect that the channels of transmissions from oil prices to inflation should not apply also for the natural gas price shocks.

There is consensus that increases in oil prices lead to higher inflation rates, but the intensity of the pass-trough varies across different empirical investigations. Choi et al. (2018) find that, for both developed and developing economies, the pass-through is asymmetric, with positive oil price shocks having larger effects. On average, they estimate that a 10% increase in the price of oil causes a rise of inflation by around 0.4 percentage points, and that it takes two years for the effect to vanish. According to Conflitti and Luciani (2019), the pass-through takes up to four years to vanish, both in the US and in the Euro area.

Energy price shocks can affect inflation through two different channels. The first relates to costs, as an increase in energy prices reflects directly a push in input costs, especially in the most energy-intensive sectors. The second is the indirect effect of wage bargaining and price setting, arising from an increase in inflation expectations (Wong, 2015), or the transmission from headline to core inflation (Peersman and Van Robays, 2009). Increasing energy prices rise inflation expectations, which eventually lead to the demand for higher wages. The inclusion of both expected and realized inflation is important to understand the channels through which energy price movements are transmitted to the macroeconomy. Uncertainty about the future, captured via expected inflation, influences (and is influenced by) the general economic conditions. Specifically, consumers tend to be pessimistic when energy prices are high and viceversa, although the effect may be asymmetric.

Another crucial aspect to take into account is the nature of the energy shocks, which may originate from different sources. This explains why historical periods characterized by high (or low) inflation rates are coupled with very different oil price levels (Barsky and Kilian, 2001, 2004). Blanchard and Gali (2007) provide evidence that the propagation from oil prices to macroeconomic fluctuations in the 1970s is difficult to compare with the 2000s', given the different nature of the shocks affecting the two periods. They further stress that the oil-inflation pass-through can be amplified or minimized, depending on the transmission of oil prices into wages, output and employment. It is not surprising, therefore, that a consistent strand of the empirical literature focuses on the estimation of the *indirect* channel, analyzing the relationship between oil prices and inflation expectations.[4]

Hammoudeh and Reboredo (2018) find that the effects of oil price movements on inflation expectations are larger when oil price levels are high, specifically above the threshold of USD 67 per barrel. When disentangling among different oil shocks, results are mixed. Güntner and Linsbauer (2018), for instance, provide evidence that only aggregate demand shocks affect inflation expectations, with a positive impact estimated for the first few months and a negative effect thereafter. On the contrary, there is a limited role for shocks coming from the oil supply side. Instead, Geiger and Scharler (2019) find that consumer expectations on inflation positively react to higher oil prices, regardless of the

[4] It is relevant to stress that, whereas expected inflation can be alternatively proxied by professional forecasters projections or consumer survey-based variables, in this framework consumer surveys provide a better alternative, as suggested in Coibion and Gorodnichenko (2015); Kilian and Zhou (2022b). This reflects the fact that households are generally more exposed to fluctuations in energy prices.

type of shock. Clerides et al. (2022) show that European consumer sentiment deteriorates in response to shocks to real gasoline prices, whereas oil demand shocks do not cause such a strong effect. Also Kilian and Zhou (2022b) focus on gasoline prices, rather than oil, and demonstrate that increases in fuel prices do cause inflation expectations to rise, in line with Coibion and Gorodnichenko (2015), although the effect is temporary and disappears after 5 months.

Finally, the pass-through from energy price shocks to inflation expectations may differ from the transmission mechanism to headline inflation. According to Arora et al. (2013), when energy prices explode, consumers tend to rely more on past inflation to form their expectations. This suggests that high energy prices increase the correlation between the expected and actual inflation rates, whereas in some phases core inflation may be dominant in explaining the headline inflation.[5] Aastveit et al. (2021) estimate that the effect of inflation expectations on actual inflation is larger than the effect of realized inflation on consumers' expectations, in line with the findings of Coibion et al. (2018, 2020). Kilian and Zhou (2022b) find that a positive shock to the core Consumer Price Index (CPI) has negligible effects on expected inflation, whereas, in contrast, a positive shock to inflation expectations raises both expected and headline inflation rates.

3 Data

Our dataset combines data on a monthly basis from different sources. For the oil market we mainly rely on EIA data, whereas data for the gas market come from the JODI database. We download macroeconomic data from multiple sources, namely the OECD, Eurostat and Fred databases. It is worth stressing that, whereas it is relatively easy to proxy inflation expectations in the US at a monthly frequency, using the Michigan Surveys of Consumers, this is not straightforward for Europe. We rely on the OECD index of consumer opinion survey on the future tendency of consumer prices. The construction of this index is significantly different from the US Michigan Survey of Consumers, since

[5] Giri (2022), for instance, shows that energy inflation is correlated with the headline inflation rate on a short-term horizon, nevertheless the correlation between the two variables is weakening since the mid-90s.

it weights answers from a qualitative survey run by the European Commission.[6] Table 1 describes the dataset, listing the sources of raw data and how we compute the final endogenous variables entering the model. Data span from January 2010 to July 2022.

Table 1: Dataset description and sources

	name	definition	source, raw data
Global oil production	q^o	log difference of global oil production (million barrels/day), 100-basis	world oil production
Global oil real price	p^o	log difference of real RAC (RAC price divided by US CPI index, 100-basis	RAC price and US CPI
Global oil inventories	Δi^o	change in oil inventories as a fraction of last period's oil production, 100-basis	US crude oil inventories, OECD petroleum inventories and US petroleum inventories
Global economic activity	y^o	log difference of the WIP index, 100-basis	monthly world industrial production index
European natural gas supply	q^g	log difference of the Euro area aggregated sum of country supply, 100-basis	natural gas monthly database
European gas price	p^g	log difference of real TTF 1 day ahead future price converted to Euros (TTF price divided from EA HICP index, 100-basis	TTF price, USD to EUR spot exchange rate and EA HICP
European gas inventories	Δi^g	change in gas inventories as a fraction of last period's gas supply, 100-basis and deseasonalized	natural gas monthly database: stock changes
European economic activity	y^g	log difference of the EA industrial production excluding construction, 100-basis	European industrial production
Expected inflation rate	π^e	monthly index of consumer opinion survey on consumer prices (inflation): future tendency (1 year after)	expected inflation
Inflation rate	π	monthly annual rate of change (log difference) in the EA HICP consumer price index, deseasonalized	Euro area HICP

Notes: the natural gas supply at country level is defined as the sum of domestic production, receipts from other sources and net imports (imports - exports). When needed, data have been deseasonalized by computing the residuals of a regression against monthly dummies. All data have been collected in December 2022.

We end up with $n = 10$ endogenous variables for a total of $T = 151$ time observations. We also add an exogenous variable to control for the Covid-19 pandemic effect. Specifically, following Ng (2021), we include the number of hospitalizations for Covid-19 in Europe as additional regressor, accounting also for its first lag.[7]

[6]The relevant question asked to household is: *by comparison with the past 12 months, how do you expect that consumer prices will develop in the next 12 months?* Possible answers are: *i*) *will increase more rapidly*, *ii*) *increase at the same rate*, *iii*) *increase at a slower rate* or *iiii*) *stay about the same*. For a detailed discussion on households' surveys and the alternatives to measure inflation expectations, see Bachmann et al. (2022).

[7]The variable is constructed as the log-difference of daily Covid-19 hospitalizations. Data are available at `https://www.ecdc.europa.eu/en/publications-data/data-daily-new-cases-covid-19-eueea-country`, accessed in February 2023.

4 Econometric approach

We model oil and gas markets as two inderdependent energy blocks interacting with expected and realized inflation in a Bayesian structural setup. The oil market specification is based on Baumeister and Hamilton (2019), and consists of five equations modeling oil production, real economic activity, consumption demand, global inventories and a measurement error equation for the oil inventories.[8] The same specification has been proposed for the natural gas market by Rubaszek et al. (2021), and extended to the inclusion of inflation and its expectations by Aastveit et al. (2021). Our model further extends Aastveit et al. (2021), since it allows for the contemporaneous interaction between inflation and European real economic activity in both directions. In this way, we can separately identify aggregate demand and supply shocks. Furthermore, we consider the oil and natural gas markets as independent on impact, apart for the global and European economic activity, which have a contemporaneous feedback in both directions. Our model consists of four endogenous equations referring to the global oil market, four endogenous equations relative to the European natural gas market and two endogenous equations describing inflation and its expectations.

The structural form of the VAR model is given by:

$$\boldsymbol{A}\boldsymbol{y_t} = \boldsymbol{b_0} + \sum_{l=1}^{12} \boldsymbol{B_l}\boldsymbol{y_{t-l}} + \boldsymbol{c}\boldsymbol{x_t^*} + \boldsymbol{v_t}, \tag{1}$$

in which: $\boldsymbol{y_t}$ denotes the $(n \times 1)$ vector of the $n = 10$ endogenous variables; $t = 1 \ldots T$, $T = 151$ monthly observations; $\boldsymbol{A}$ and $\boldsymbol{B_l}$ are the $(n \times n)$ matrices of structural contemporaneous and lagged coefficients; $\boldsymbol{x_t^*}$ and $\boldsymbol{c}$ are the $(m \times 1)$ vector and the associated $(n \times m)$ coefficient matrix for the $m = 2$ exogenous variables, namely the number of hospitalization for Covid-19 in Europe and its one-period lag; the $\boldsymbol{v_t} \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{D})$ is the $(n \times 1)$ vector collecting the structural shocks, with $\boldsymbol{D}$ a $(n \times n)$ diagonal variance matrix such that $\boldsymbol{D} \equiv E[\boldsymbol{v_t}\boldsymbol{v_t'}]$. The number of lags l is set to 12, as in Baumeister and Hamilton (2019), to capture the business cycle length and residual autocorrelation.

[8] The inclusion of a measurement error equation comes from the fact that inventories are not properly proxied in a global setup, while data on stocks are available only for the US and the OECD countries.

By writing the reduced form representation of the model as

$$\boldsymbol{y_t} = \boldsymbol{\beta_0} + \sum_{l=1}^{12} \boldsymbol{\mathcal{B}_l y_{t-l}} + \boldsymbol{\gamma x_t^*} + \boldsymbol{u_t}, \tag{2}$$

with $\beta_0 = \boldsymbol{A}^{-1}\boldsymbol{b_0}$, $\boldsymbol{\mathcal{B}_l} = \boldsymbol{A}^{-1}\boldsymbol{B}_l$, $\boldsymbol{\gamma = A^{-1}c}$, $\boldsymbol{u_t} = \boldsymbol{A}^{-1}\boldsymbol{v_t}$ and assuming that the reduced form errors $\boldsymbol{u_t}$ are normally distributed with 0 mean and variance-covariance matrix $\boldsymbol{\Sigma_u} \equiv E[\boldsymbol{u_t u_t'}]$, estimation of the parameters in model (2) can be performed via OLS. The identification of the structural shocks, however, requires to impose some restrictions. Specifically, we follow the estimation and identification procedure of Baumeister and Hamilton (2015), which allows to specify some prior beliefs about the structural parameters contained in $\boldsymbol{A}$, $\boldsymbol{B_l}$ and $\boldsymbol{D}$ and then applies a random walk Metropolis-Hastings algorithm in order to generate draws for the posterior distributions of the same structural coefficients. Further details are reported in the Appendix.

4.1 Identification

Our identification scheme consists on a matrix of contemporaneous structural parameters specified as:

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & -\alpha_{q^o p^o} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -\alpha_{y^o p^o} & 0 & 0 & -\alpha_{y^o y^g} & 0 & 0 & 0 & 0 \\ 1 & -\beta_{q^o y^o} & -\beta_{q^o p^o} - \chi^{-1}\rho & -\chi^{-1} & 0 & 0 & 0 & 0 & 0 & 0 \\ -\psi_1^o & 0 & -\psi_3^o + \rho & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -\alpha_{q^g p^g} & 0 & 0 & 0 \\ 0 & -\alpha_{y^g y^o} & 0 & 0 & 0 & 1 & -\alpha_{y^g p^g} & 0 & 0 & -\alpha_{y^g \pi} \\ 0 & 0 & 0 & 0 & 1 & -\beta_{q^g y^g} & -\beta_{q^g p^g} & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\psi_1^g & 0 & -\psi_3^g & 1 & 0 & 0 \\ -\lambda_{\pi^e q^o} & -\lambda_{\pi^e y^o} & -\lambda_{\pi^e p^o} & 0 & -\lambda_{\pi^e q^g} & -\lambda_{\pi^e y^g} & -\lambda_{\pi^e p^g} & 0 & 1 & -\lambda_{\pi^e \pi} \\ -\lambda_{\pi q^o} & -\lambda_{\pi y^o} & -\lambda_{\pi p^o} & 0 & -\lambda_{\pi q^g} & -\lambda_{\pi y^g} & -\lambda_{\pi p^g} & 0 & -\lambda_{\pi \pi^e} & 1 \end{bmatrix},$$

which implies a system of 10 equations and 10 corresponding structural shocks. The structural form of model (1) can be written as a system of equations consisting in the following three blocks.

4.1.1 Structural equations for the oil market

The first block describes the global oil market:

$$q_t^o = \alpha_{q^o p^o} p_t^o + \boldsymbol{b_1'} \boldsymbol{x}_{t-1} + v_{1t}^* \tag{3a}$$

$$y_t^o = \alpha_{y^o p^o} p_t^o + \alpha_{y^o y^g} y_t^g + \boldsymbol{b_2'} \boldsymbol{x}_{t-1} + v_{2t}^* \tag{3b}$$

$$q_t^o = \beta_{q^o y^o} y_t^o + \beta_{q^o p^o} p_t^o + \Delta i_t^{*o} + \boldsymbol{b_3'} \boldsymbol{x}_{t-1} + v_{3t}^* \tag{3c}$$

$$\Delta i_t^{*o} = \psi_1^{*o} q_t^o + \psi_3^{*o} p_t^o + \boldsymbol{b_4'} \boldsymbol{x}_{t-1} + v_{4t}^* \tag{3d}$$

$$\Delta i_t^o = \chi \Delta i_t^{*o} + e_t. \tag{3e}$$

The term $\boldsymbol{x}_{t-1} \equiv [\boldsymbol{y}_{t-1}', \ldots, \boldsymbol{y}_{t-12}', 1, \boldsymbol{x}_t^{*'}]'$ denotes a vector containing all the lags of $\boldsymbol{y}_t'$, the constant term and the exogenous variables, while $\boldsymbol{b_j'}$ contains all the corresponding structural parameters, with $j = 1, \ldots, n$.

Equation (3a) represents the global oil supply curve, where oil production is contemporaneously affected by the real price of oil via $\alpha_{q^o p^o}$, the short-run price elasticity of oil supply. By imposing exclusion restrictions on all the other contemporaneous structural parameters, the corresponding structural shock, v_{1t}^*, can be interpreted as an "oil supply shock". This is designed to capture unexpected changes in global crude oil production. In equation (3b), the world industrial production is instantaneously affected by the real price of oil and the European industrial production via the structural coefficients $\alpha_{y^o p^o}$ and $\alpha_{y^o y^g}$. Thus, the structural innovation v_{2t}^* can be interpreted as a "global economic activity shock". Equation (3c) illustrates the determinants of the oil consumption demand, that is assumed to respond on impact to changes in the real price of oil and the world industrial production, through the parameters $\beta_{q^o p^o}$ and $\beta_{q^o y^o}$, the short-run price and income elasticities of oil demand. The resulting structural shock, v_{3t}^*, denotes an "oil consumption demand shock". Equation (3d) represents the oil inventory demand curve, which is instantaneously affected by global crude oil production and real price of oil through the structural parameters ψ_1^{*o} and ψ_3^{*o}. The fourth structural shock, v_{4t}^*, corresponds to a "speculative (or inventory) demand shock", and accounts for a measurement error (e_t). In this respect, we use Equation 3e to rewrite the equations for oil-consumption demand and oil-inventory demand in terms of observed variables, that is:

$$q_t^o = \beta_{q^o y^o} y_t^o + \beta_{q^o p^o} p_t^o + -\chi^{-1} \Delta i_t^o + \boldsymbol{b_3'} \boldsymbol{x}_{t-1} + v_{3t}^* - \chi^{-1} e_t \tag{4a}$$

$$\Delta i_t^o = \psi_1 q_t^o + \psi_3 p_t^o + \boldsymbol{b_4'} \boldsymbol{x}_{t-1} + \chi v_{4t}^* + e_t \tag{4b}$$

where $\psi_1^o = \chi \psi_1^{*o}$ and $\psi_3^o = \chi \psi_3^{*o}$. Baumeister and Hamilton (2019) point out that the structural system of the global market for crude oil needs to be modified because v_{3t}^* and v_{4t}^* are simultaneously correlated due to the presence of e_t. Therefore, the uncorrelated structural shocks can be obtained by pre-multiplying the system formed by equations (3a), (3b), (4a) and (4b) by the matrix:

$$\boldsymbol{\Gamma} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \rho & 1 \end{bmatrix},$$

in which $\rho = \frac{\chi^{-1}\sigma_e^2}{d_{33}^* + \chi^{-2}\sigma_e^2}$, where d_{33}^* and σ_e^2 represent the structural variances of the oil consumption-demand equation and of the measurement error.

4.1.2 Structural equations for the gas market

The second block of equations models the natural gas market in the Euro area:

$$q_t^g = \alpha_{q^g p^g} p_t^g + \boldsymbol{b_5'} \boldsymbol{x}_{t-1} + v_{5t} \tag{5a}$$

$$y_t^g = \alpha_{y^g y^o} y_t^o + \alpha_{y^g p^g} p_t^g + \alpha_{y^g \pi} \pi_t + \boldsymbol{b_6'} \boldsymbol{x}_{t-1} + v_{6t} \tag{5b}$$

$$q_t^g = \beta_{q^g y^g} y_t^g + \beta_{q^g p^g} p_t^g + \Delta i_t^g + \boldsymbol{b_7'} \boldsymbol{x}_{t-1} + v_{7t} \tag{5c}$$

$$\Delta i_t^g = \psi_1 q_t^g + \psi_3 p_t^g + \boldsymbol{b_8'} \boldsymbol{x}_{t-1} + v_{8t}. \tag{5d}$$

Equation (5a) states that gas supply is contemporaneously affected only by the real price of gas via $\alpha_{q^g p^g}$, the short-run price elasticity of gas supply. Therefore, v_{5t} is denoted as a "gas supply shock", triggered by any event that causes unanticipated changes of the Euro area gas supply. Equation (5b) illustrates the determinants of the European industrial production, which is contemporaneously explained by world industrial production via $\alpha_{y^g y^o}$, the real price of natural gas through $\alpha_{y^g p^g}$ and the inflation rate via $\alpha_{y^g \pi}$. Crucially, $\alpha_{y^g \pi}$ links the Euro area economic activity to inflation, coherently with the aggregate demand specification in New Keynesian models, thus we expect this parameter to be negative. The structural shock v_{6t} corresponds to a "European economic activity shock", reflecting shifts on the Eurozone business cycle. Equation (5c) represents the European gas consumption demand approximated by the difference between gas supply, q_t^g, and gas inventories, Δi_t^g. Coefficients $\beta_{q^g y^g}$ and $\beta_{q^g p^g}$ are the income and price elasticities of consumption demand for natural gas. Therefore, a positive shock to consumption demand, v_{7t}, represents an unexpected increase of gas consumption, which rises the gas demand curve to the right, along the gas supply curve. Finally, the dynamics of natural gas inventories in the Eurozone are described by Equation (5d). Gas stock changes immediately respond to gas supply and price, through ψ_1^g and ψ_3^g.[9] The corresponding structural innovation, v_{8t} denotes a "natural gas speculative (or inventory) demand shock".

Notice that the global oil and Eurozone natural gas markets are not considered completely independent on impact, as we allow for interaction between European and world industrial production. However, all the other variables are not interdependent between the two markets, but only within. This is consistent with the idea that interdependence between oil and natural gas markets takes some time to emerge. Energy producers and suppliers face physical constraints that do not allow to rapidly switch to the most convenient energy source, neither consumers can decide to adapt households heating plants after sudden price shocks. As for the price interconnections, which could be simultaneous in principle, Kaminski (2016) evidences that the two markets have become more independent since the increment of natural gas use.[10]

[9]Following Rubaszek et al. (2021), the equation for gas inventories is modeled without including a measurement error.

[10]Nevertheless, the dynamic interdependence may still be substantial. As stressed in Kaminski (2013), the dynamics of a single energy market can be understood only by taking into account the relationship with the whole energy system.

4.1.3 Structural equations for expected and headline inflation

Finally, the last block of equations governs the evolution of inflation expectations and the headline realized inflation rate of the Eurozone:

$$\begin{aligned}\pi_t^e = &\lambda_{\pi^e q^o} q_t^o + \lambda_{\pi^e y^o} y_t^o + \lambda_{\pi^e p^o} p_t^o + \\ &\lambda_{\pi^e q^g} q_t^g + \lambda_{\pi^e y^g} y_t^g + \lambda_{\pi^e p^g} p_t^g + \lambda_{\pi^e \pi} \pi_t + \boldsymbol{b}_{\mathbf{9}}' \boldsymbol{x}_{t-1} + v_{9t}\end{aligned} \tag{6a}$$

$$\begin{aligned}\pi_t = &\lambda_{\pi q^o} q_t^o + \lambda_{\pi y^o} y_t^o + \lambda_{\pi p^o} p_t^o + \\ &\lambda_{\pi q^g} q_t^g + \lambda_{\pi y^g} y_t^g + \lambda_{\pi p^g} p_t^g + \lambda_{\pi \pi^e} \pi_t^e + \boldsymbol{b}_{\mathbf{10}}' \boldsymbol{x}_{t-1} + v_{10t}.\end{aligned} \tag{6b}$$

Equation (6a) models the determinants of the expected inflation, that is, global crude oil production (q_t^o), world industrial production (y_t^o), real price of oil (p_t^o), gas supply (q_t^g), European industrial production (y_t^g), real price of gas (p_t^g) and the actual inflation rate (π_t). The corresponding effects are captured by the parameters $\lambda_{\pi^e q^o}$, $\lambda_{\pi^e y^o}$, $\lambda_{\pi^e p^o}$, $\lambda_{\pi^e q^g}$, $\lambda_{\pi^e y^g}$, $\lambda_{\pi^e p^g}$ and $\lambda_{\pi^e \pi}$. Equation (6a) is consistent with the view that economic agents use different sources to form their expectations about future inflation. Inflation expectations are driven by general indicators of the state of the economy, that is the global and European real economic activity and the current rate of inflation. The developments of the oil and gas markets play a crucial role in explaining the evolution of agents expectations about the future price movements. It is worth noting that the parameters associated with the oil- and gas-specific variables capture the indirect effect of wage bargaining and price setting, which may be further transmitted to inflation.

Finally, Equation (6b) represents a New Keynesian Phillips Curve (NKPC) augmented with energy variables, which models the inflation evolution accounting for world and European economic activity (via $\lambda_{\pi y^o}$ and $\lambda_{\pi y^g}$) and inflation expectations (via $\lambda_{\pi \pi^e}$). Moreover, we assume that current inflation is contemporaneously affected by production of crude oil and natural gas (through $\lambda_{\pi q^o}$ and $\lambda_{\pi q^g}$) and their corresponding real prices (via $\lambda_{\pi p^o}$ and $\lambda_{\pi p^g}$). It is worth recalling that the structural parameters of Equation (6b) are designed to capture the direct effects of energy markets conditions on current inflation. The structural innovations v_{9t} and v_{10t} denote idiosyncratic shocks to expected and realized inflation, where v_{9t} is designed to capture expectation-specific shocks to economic sentiment, and v_{10t} can be interpreted as any unobserved cost-push shock to either firms mark-up or production inputs (Mavroeidis et al., 2014).

4.2 Priors for the contemporaneous structural parameters

We specify a set of prior beliefs on the contemporaneous structural parameters of model (1) that are grounded on economic theory and empirical evidence from previous studies on energy markets and inflation. Specifically, we rely on a mixture of dogmatic (e.g. exclusion restrictions) and non-dogmatic priors beliefs (in terms of Student t distributions) on the elements of $\boldsymbol{A}$, with mode, scale parameters and degrees of freedom as reported in Table 2. The rest of this section discusses the priors for the parameters of the two inflation variables, whereas priors for all the other coefficients are described in the Appendix.

Priors for parameters of the expected inflation equation. The structural coefficients $\lambda_{\pi^e p^o}$ and $\lambda_{\pi^e p^g}$ represent the effect of oil and gas prices on expected inflation. In this respect, we use the estimates in Coibion and Gorodnichenko (2015); Coibion et al. (2018), to center the Student t distribution priors for both $\lambda_{\pi^e p^o}$ and $\lambda_{\pi^e p^g}$ at 0.02, whose support is constrained to be positive, as higher prices lead to increasing inflationary pressure. In this way, we put equal weight on the prior knowledge about the effect of oil and gas price shocks to expected inflation. According to Bordalo et al. (2020); Coibion et al. (2020), a 1% increase in the actual inflation raises the inflation expectations by less than 1%, that is, expectations tend to under-react. Consistently with Coibion et al. (2020), we set for $\lambda_{\pi^e \pi}$ a Student t prior distribution with mode $c_{\lambda_{\pi^e \pi}} = 0.55$ and support restricted on the positive domain, since upward shifts in aggregate demand boost inflation expectations. Finally, given our limited knowledge about parameters $\lambda_{\pi^e q^o}$, $\lambda_{\pi^e q^g}$, $\lambda_{\pi^e y^o}$ and $\lambda_{\pi^e y^g}$, we use relatively uninformative Student t prior distributions. Specifically, for $\lambda_{\pi^e q^o}$ and $\lambda_{\pi^e q^g}$ we decide to center both the priors at -0.1. Since rises in crude oil production and natural gas supply are associated with less pressure on prices, we restrict the support of these priors to be negative. Regarding the effects of global and European real economic activity on expected inflation, $\lambda_{\pi^e y^o}$ and $\lambda_{\pi^e y^g}$, we set the location parameter to 0.1 and we truncate the density to a positive support, as positive shifts in aggregate demand rise

Table 2: Prior Student t distributions: contemporaneous structural parameters in $\boldsymbol{A}$

Parameter	Prior			
	mode (c)	scale (σ)	d.o.f. (ν)	sign restriction
$\alpha_{q^o p^o}$	0.1	0.2	3	+
$\alpha_{y^o p^o}$	-0.05	0.1	3	−
$\alpha_{y^o y^g}$	0	0.5	3	+
$\beta_{q^o y^o}$	0.7	0.2	3	+
$\beta_{q^o p^o}$	-0.1	0.2	3	−
ψ_1^o	0	0.5	3	()
ψ_3^o	0	0.5	3	()
$\alpha_{q^g p^g}$	0.1	0.2	3	+
$\alpha_{y^g y^o}$	0	0.5	3	+
$\alpha_{y^g p^g}$	-0.05	0.05	3	−
$\alpha_{y^g \pi}$	0	0.5	3	−
$\beta_{q^g y^g}$	0.5	0.3	3	+
$\beta_{q^g p^g}$	-0.3	0.3	3	−
ψ_1^g	0	0.5	3	()
ψ_3^g	0	0.5	3	()
$\lambda_{\pi^e q^o}$	-0.1	10	3	−
$\lambda_{\pi^e y^o}$	0.1	10	3	+
$\lambda_{\pi^e p^o}$	0.02	1	3	+
$\lambda_{\pi^e q^g}$	-0.1	10	3	−
$\lambda_{\pi^e y^g}$	0.1	10	3	+
$\lambda_{\pi^e p^g}$	0.02	1	3	+
$\lambda_{\pi^e \pi}$	0.55	1	3	+
$\lambda_{\pi q^o}$	-0.1	10	3	−
$\lambda_{\pi y^o}$	0.25	1	3	+
$\lambda_{\pi p^o}$	0.04	1	3	+
$\lambda_{\pi q^g}$	-0.1	10	3	−
$\lambda_{\pi y^g}$	0.25	1	3	+
$\lambda_{\pi p^g}$	0.04	1	3	+
$\lambda_{\pi \pi^e}$	1	1	3	+

Notes: the scale parameter is the standard deviation; d.o.f. denotes the degrees of freedom of the distribution; absence of sign restrictions is associated with ().

inflation. We set the scale parameters at 10, reflecting uncertainty around our priors, on $\lambda_{\pi^e q^o}$, $\lambda_{\pi^e q^g}$, $\lambda_{\pi^e y^o}$ and $\lambda_{\pi^e y^g}$.

Priors for parameters of the NKPC. For the effects of crude oil and natural gas prices on actual inflation, our prior beliefs rely on Aastveit et al. (2021); Coibion and Gorodnichenko (2015); Coibion et al. (2018). In particular, for $\lambda_{\pi p^o}$ and $\lambda_{\pi p^g}$, we adopt Student t prior distributions with positive prior mode equal 0.04. Again, we equally weight the prior beliefs about the effects of oil and natural gas price shocks. For the structural parameters describing the effect of world and European industrial production on actual inflation, $\lambda_{\pi y^o}$ and $\lambda_{\pi y^g}$, we use Student t distributions with support restricted on the positive domain and location parameters equal 0.25, which are consistent with the recent studies of Aastveit et al. (2021); Coibion et al. (2018). The sign restriction is grounded on economic theory, as NKPC models the supply-side dynamics of inflation and output. As a result, higher economic growth raises input costs and thus inflation rates. The structural coefficient $\lambda_{\pi\pi^e}$ represents the effect of inflation expectations on actual inflation. We specify a Student t prior distribution, with mode $c_{\lambda_{\pi p^g}} = 1$ and truncated to be positive. This is grounded on the rational expectations hypothesis and coherent with the empirical estimates of the pass-through from expected to actual inflation (see Lagoa, 2017; Werning, 2022, as examples). In other words, $\lambda_{\pi\pi^e}$ captures how much of households' sentiment about future price tendency is actually transmitted to the observed headline inflation. Finally, given limited knowledge about $\lambda_{\pi q^o}$ and $\lambda_{\pi q^g}$, we use Student t negative truncated prior distributions with location parameters of -0.1 and assume a large standard deviation, as reported in Table 2.

5 Results

5.1 Priors and posteriors for the structural parameters: inflation variables

In this section we compare the prior and the posterior distributions of the contemporaneous structural parameters, focusing on the coefficients of Equations (6a) and (6b). Panels 1 and 4 of Figure 1 show that the posterior distributions of parameters capturing the effects of oil and natural gas supply on expected inflation have most of their mass concentrated around zero. The posterior median of $\lambda_{\pi^e q^o}$ is slightly smaller than the median of $\lambda_{\pi^e q^g}$. The posterior distributions of $\lambda_{\pi^e p^o}$ and $\lambda_{\pi^e p^g}$ are narrower than the priors, suggesting that data are informative about the positive relationship between energy prices and expected inflation (see panels 3 and 6 of Figure 1). The oil price effect on inflation expectation is mildly larger than the effect of real natural gas price, consistent with the view that economic agents are more sensitive to oil market fundamentals. Panels 2 and 5 of Figure 1 plot the posterior distributions of the contemporaneous effects of world and

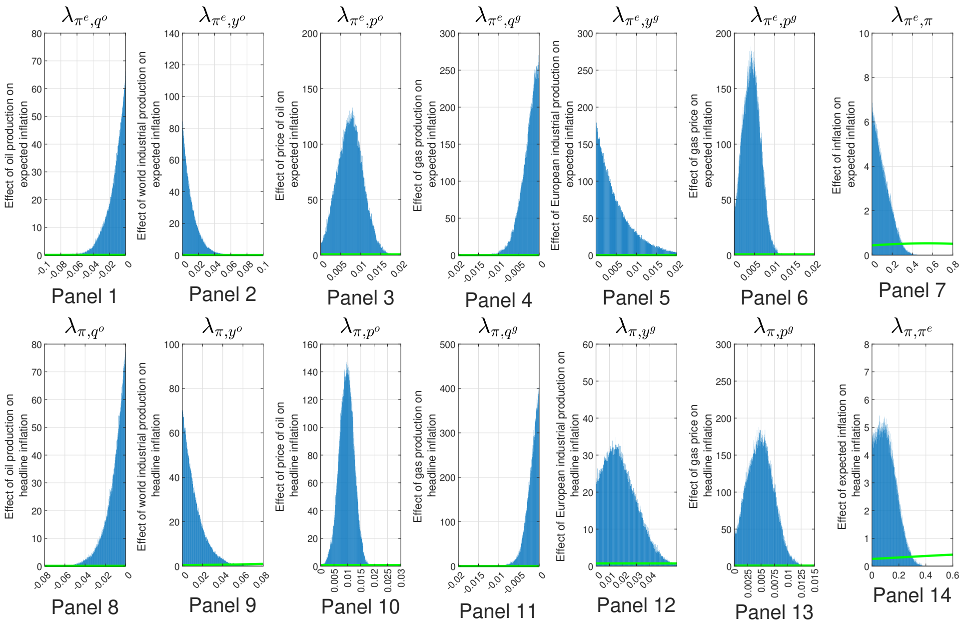

Figure 1: Prior and posterior distribution for the structural coefficients of Equations (6a) and (6b).
Note: green lines correspond to the prior distributions; blue histograms denote the posterior distribution.

European industrial production on inflation expectations. We provide empirical evidence that most of the mass of the posterior distribution for $\lambda_{\pi^e y^o}$ and $\lambda_{\pi^e y^g}$ is centered at 0.01 and 0.002, respectively. Finally, the median of posterior distribution for parameter $\lambda_{\pi^e \pi}$ is 0.08, considerably lower than its prior.

Panels 8 and 11 of Figure 1 illustrate the posterior distributions of $\lambda_{\pi q^o}$ and $\lambda_{\pi q^g}$. We provide empirical evidence that, if crude oil production increases by 1%, inflation reduces by 0.01%. In addition, a 1% increase in the gas supply causes a decline in inflation of 0.001%. In Panels 10 and 13 of Figure 1 we report the posterior distributions of $\lambda_{\pi p^o}$, with median equal to 0.01, and $\lambda_{\pi p^g}$, with median equal to 0.005. These results point out that the direct channel from energy prices to inflation, which acts through input costs, is predominantly driven by crude oil prices. Next, the posterior medians of world and European industrial production effects on inflation are both 0.01, that is, both European and global economic conditions influence the Eurozone inflation rate similarly. Finally, the posterior median of the effect of the expected inflation on actual inflation is 0.12, as reported in Panel 14 of Figure 1. It is important to stress that all the priors assigned to the structural coefficients are substantially revised when sample information is considered.

5.2 Impulse response functions: expected and headline inflation

Figure 2 illustrates the dynamic responses of the two target inflation variables to one-unit standard deviation changes in each energy price shock. The structural impulse responses for expected inflation are shown in the top panel of Figure 2, while the bottom panel plots the responses of headline inflation to oil and gas market shocks.

An oil supply disruption causes a positive and highly persistent increase in both expected and headline inflation rates. An unexpected positive global economic activity shock mildly affects both inflation expectations and headline inflation, in line with economic theory. Actually, an increase in industrial production at world level pushes input prices and consequently results in higher inflation. A positive oil consumption demand shock causes a large increase in expected and headline inflation, and the effect is also long-lasting. An oil speculative demand shock has a negligible effect on both inflation variables at all horizons, with the exception of the first month.

Moving to the European gas market, a negative supply shock produces a strong and persistent increase in headline inflation and its expectations. A European economic activity shock has an uncertain effect on inflation expectations, and a slightly positive effect on inflation. However, this effect seems to be less persistent, and the posterior median response estimates show a gradual reversion to the equilibrium level over the subsequent months. An unexpected gas consumption demand shock is responsible for a large increase in headline inflation and expected inflation. Finally, a natural gas speculative demand shock has an unclear effect for inflation expectations, but has a positive and short-lived effect for headline inflation. Overall the responses of headline inflation are smoother than the dynamic effects of expected inflation, while they exhibit similar level of uncertainty.

From these results some interesting considerations emerge. First, energy supply and consumption demand shocks are remarkable and persistent drivers of both expected and headline inflation. In particular, the response of inflation to a negative oil supply shock gradually increases up to 0.20% after one year, whereas a natural gas supply disruption causes headline inflation to increase by 0.24%. Conversely, a natural gas consumption demand shock raises inflation by 0.20% after one year, while the response of inflation to

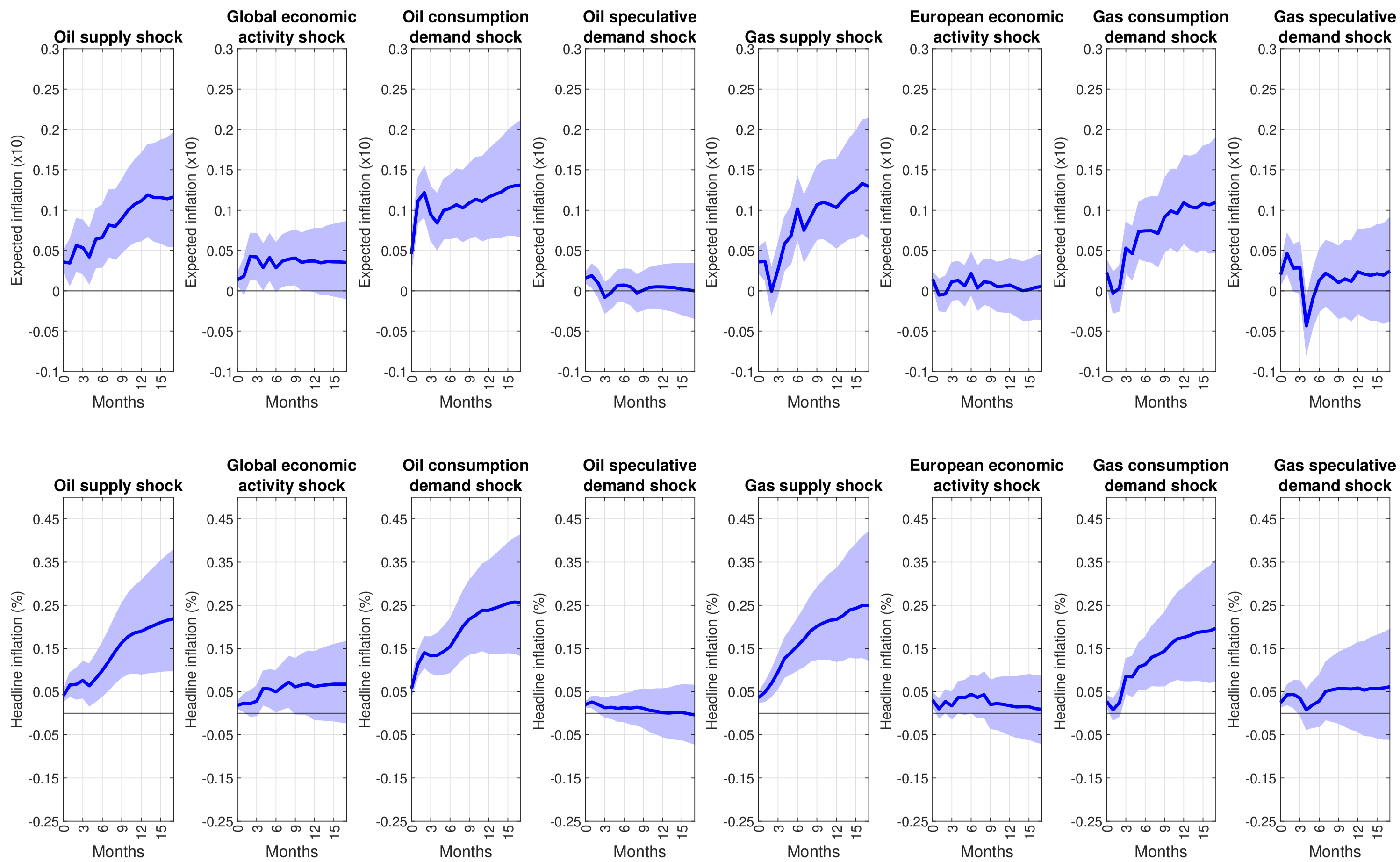

Figure 2: Impulse response functions of expected (top panel) and headline (bottom panel) inflation to oil and gas market specific shocks
Note: blue lines denote the median responses and shaded areas correspond to the relative density at 68% credibility level.

an oil consumption demand shock is higher, specifically 0.25%. Second, global economic activity shocks are, on average, more important in explaining the Eurozone inflation dynamics than European economic activity shocks. Third, the response of headline inflation to gas speculative demand shocks is larger than the response to oil speculative demand shocks. However, both speculative demand shocks have negligible effects in driving inflation for almost all the time horizons.

5.3 Priors and posteriors for the structural parameters: energy markets

We report in Figure 3 the prior and posterior distributions of the structural parameters in $\boldsymbol{A}$, focusing on the oil and natural gas markets equations. The posterior median distribution of the short-run price elasticity of oil supply, $\alpha_{q^o p^o}$, is equal to 0.01, as reported in Panel 1 of Figure 3. This result suggests that the responsiveness of oil producers is less sensitive to oil price changes, that is consistent with the empirical literature (see Kilian and Murphy, 2014; Zhou, 2020, as examples). Our estimate of the posterior median of the short-run price elasticity of oil demand, $\beta_{q^o p^o}$, is -0.29, which is in line with the empirical estimates of Coglianese et al. (2017); Baumeister and Hamilton (2019), and is larger, in absolute values, than the prior (see Panel 5). Panel 8 reports the posterior distribution of the short-run price elasticity of gas supply, with a median of 0.34. This result suggests that the slope of the gas supply curve is more elastic than the corresponding prior and the estimated posterior supply elasticity for the US market (Rubaszek et al., 2021). Finally, the posterior distribution of $\beta_{q^g p^g}$, reported in Panel 13, has median of -0.47 and mass concentrated on the negative support. This implies that the European gas demand for current consumption is more elastic than the corresponding supply.

5.4 Impulse response functions: energy markets

In this section we illustrate the dynamic responses of the real price of oil, the real price of gas and inventory changes to each structural shock. Figure 4 reports the corresponding median impulse response estimates, together with posterior credible regions at 68% level.

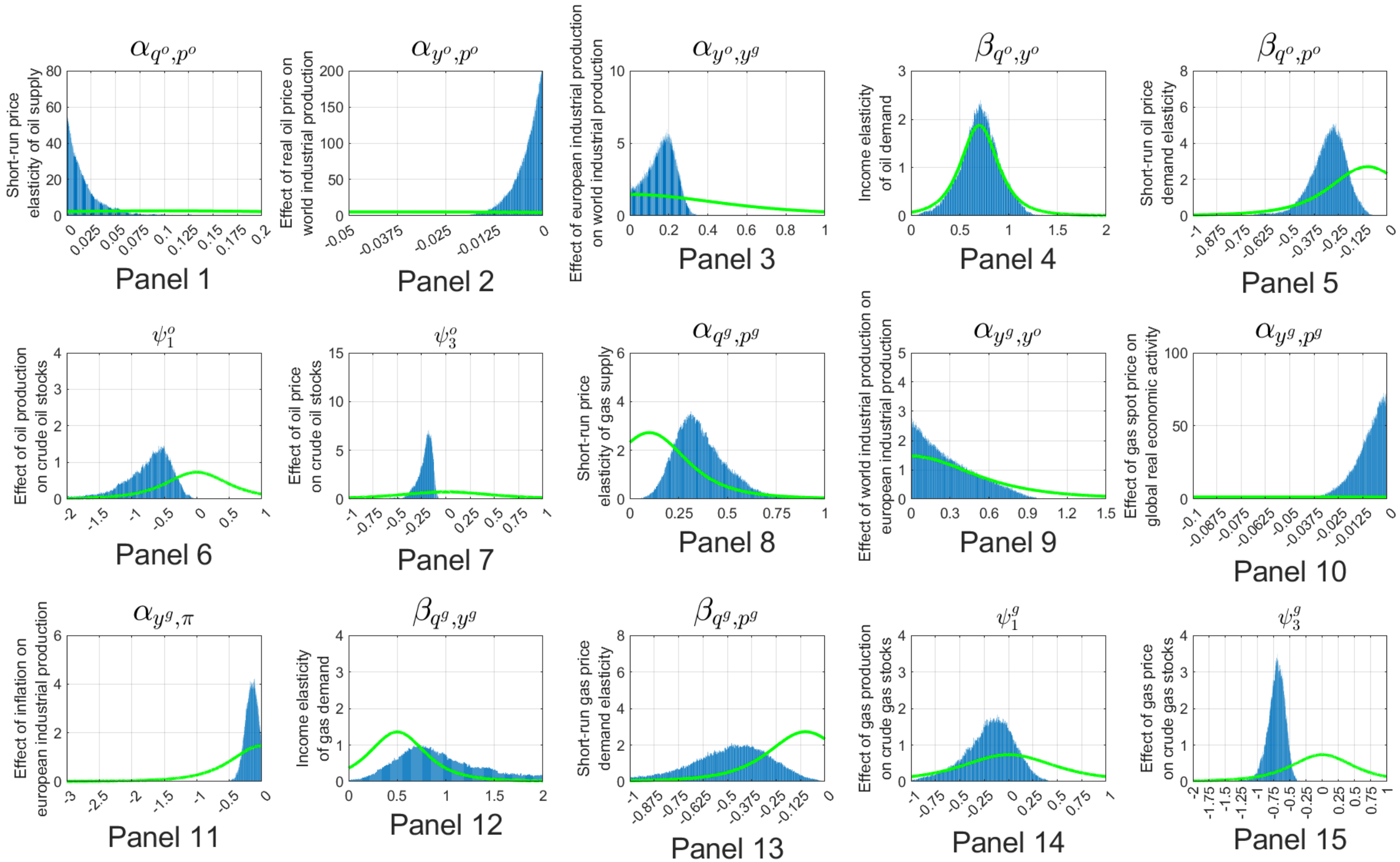

Figure 3: Prior and posterior distribution for the structural coefficients of Equations (3a) to (5d)

Note: green lines correspond to the prior distributions; blue histograms denote the posterior distributions.

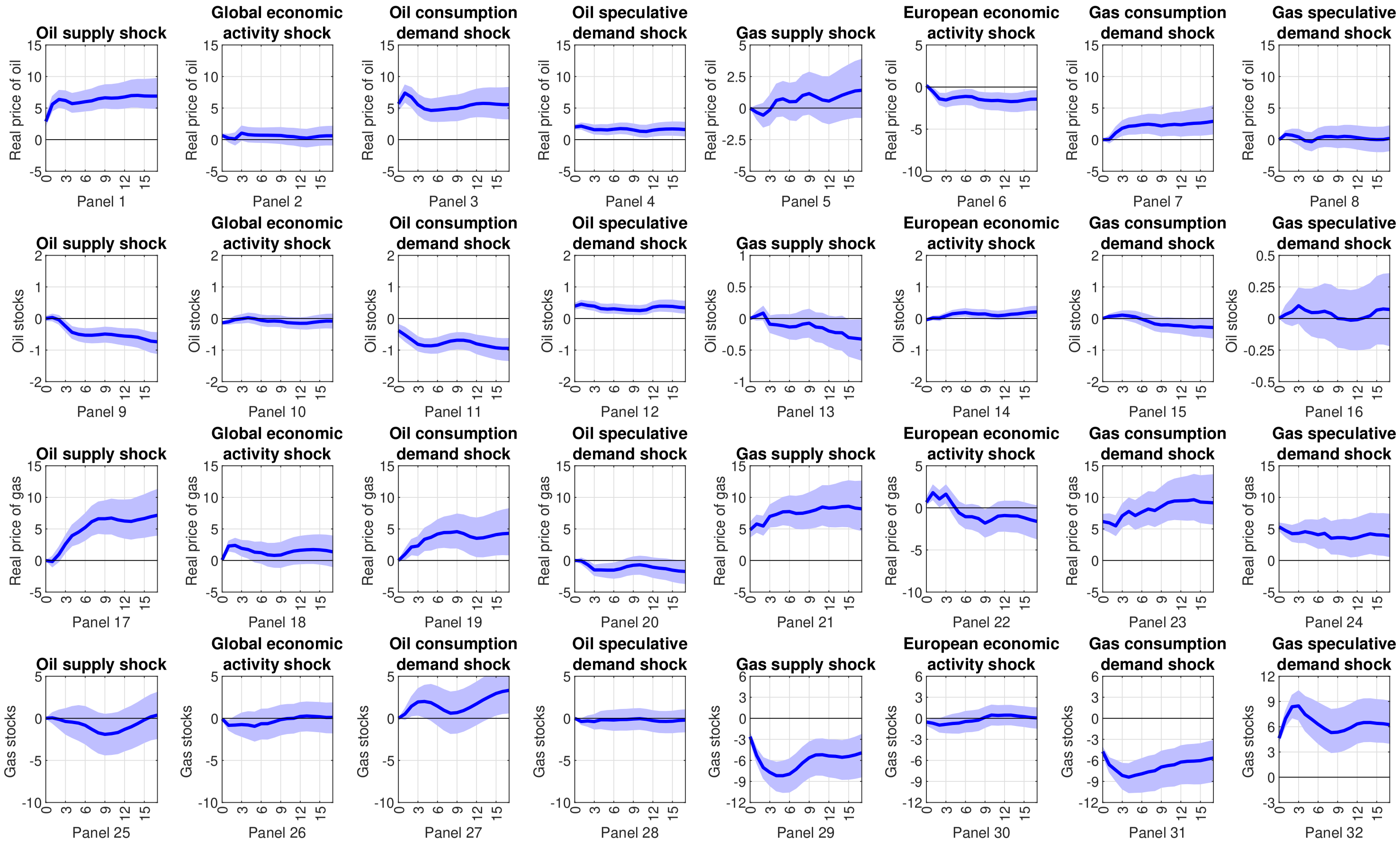

Figure 4: Impulse response functions of real energy prices and stocks to oil and gas markets specific shocks

Note: blue lines denote the median responses and shaded areas correspond to the 68% of credible regions.

The dynamic responses of the the real price of oil and oil stocks to oil market shocks are qualitatively similar to those presented by Baumeister and Hamilton (2019), as shown in Panels 1-4 and 9-12. Panels 21-24 and 29-32 display the posterior responses of the real price of gas and gas inventories to shocks within the gas market. Specifically, a gas supply disruption causes an increase in the real price of gas and a reduction in gas stocks, on impact. The real price of gas rises up to 8% after one year, and this effect is highly persistent on the subsequent months. In contrast, gas stock changes are negatively affected and decrease up to 6% after the first year. This result is consistent with the idea that gas suppliers release inventories in an effort to smooth consumption. A positive European economic activity shock produces a hump-shaped response in the real price of gas. The effect of the shock is however short-lived and ends in few months. The response of gas stock changes to an unexpected European economic growth is negative, but it becomes close to zero after two months. A gas consumption demand shock causes a gradual increase in the real price of gas, and a persistent reduction in gas stocks. Finally, a positive speculative gas demand shock rises inventory stocks by 8% and it is accompanied by a persistent increase in the real price of gas of 5%.

We move now to the analysis of how shocks to the global crude oil market transmit to the real price of gas, and viceversa. A negative oil supply shock causes a persistent increase in the real price of gas up to 6%. Conversely, a gas supply disruption has a negligible and uncertain effect on the global real price of oil. This finding can be rationalized as follows. First, crude oil is employed in the production and transport of natural gas (i.e., the two commodities are complementary). Second, some of natural gas wells might contain crude oil, but oil extraction is not economically convenient if the quantity of crude oil is limited. This motivates the presence of a spillover effect from crude oil supply shock to the real price of gas, as opposite to a negligible feedback from gas supply to the price of crude oil. Third, energy suppliers adjust their supply mix according to the most profitable strategy. If oil price increases, the production of crude oil becomes more economically attractive and crowds out the production of gas, causing its real price to increase.

A shock to oil consumption demand induces a persistent increase in the real price of gas. At the same time, a shock to gas consumption demand has a positive effect on the real price of crude oil, although of a lower size. These results support the idea that oil and gas are substitute commodities.

5.5 Historical decomposition

5.5.1 Expected inflation

The top panel of Figure 5 shows the evolution of expected inflation distinguishing different time spans. During the pre Covid-19 period (January-December 2019), inflation expectations are below the mean. This period is characterized by persistently low inflation, that, following Eickmeier and Hofmann (2022), can be explained by a combination of weak demand and strong supply. Expected inflation is mainly driven by inflation shocks.[11] Among the energy shocks, a relevant role is played by gas supply shocks, whose relevance increases over time. After the Covid-19 outbreak (January 2020-July 2021), there is a contemporaneous drop of both aggregated supply and demand and, as a result, European industrial production falls dramatically. As a consequence, the consumer sentiment on future prices drops, and shocks to expected inflation reduce the expected inflation index. Finally, during the post Covid-19 period (August 2021 - July 2022) we observe both economic recovery and the surge of geopolitical tensions due to the Russian invasion of Ukraine. Before the beginning of the Russia-Ukraine war, demand is increasing again, whereas supply reacts more slowly. As a result, inflation starts to increase, therefore leading to higher expectations. Interestingly, the combined effect of inflation expectations and inflation shocks is predominant. The peak of expected annual inflation, registered immediately after the beginning of the war in 24 February 2022, is mainly explained by a self-feed shock, due to the large uncertainty characterizing the households sector. Within the same month, gas speculative shocks explain a relevant portion of inflation expectations, if compared with the previous periods.

[11] We remind that, according to our identification scheme, inflation shocks capture the aggregate supply side effects.

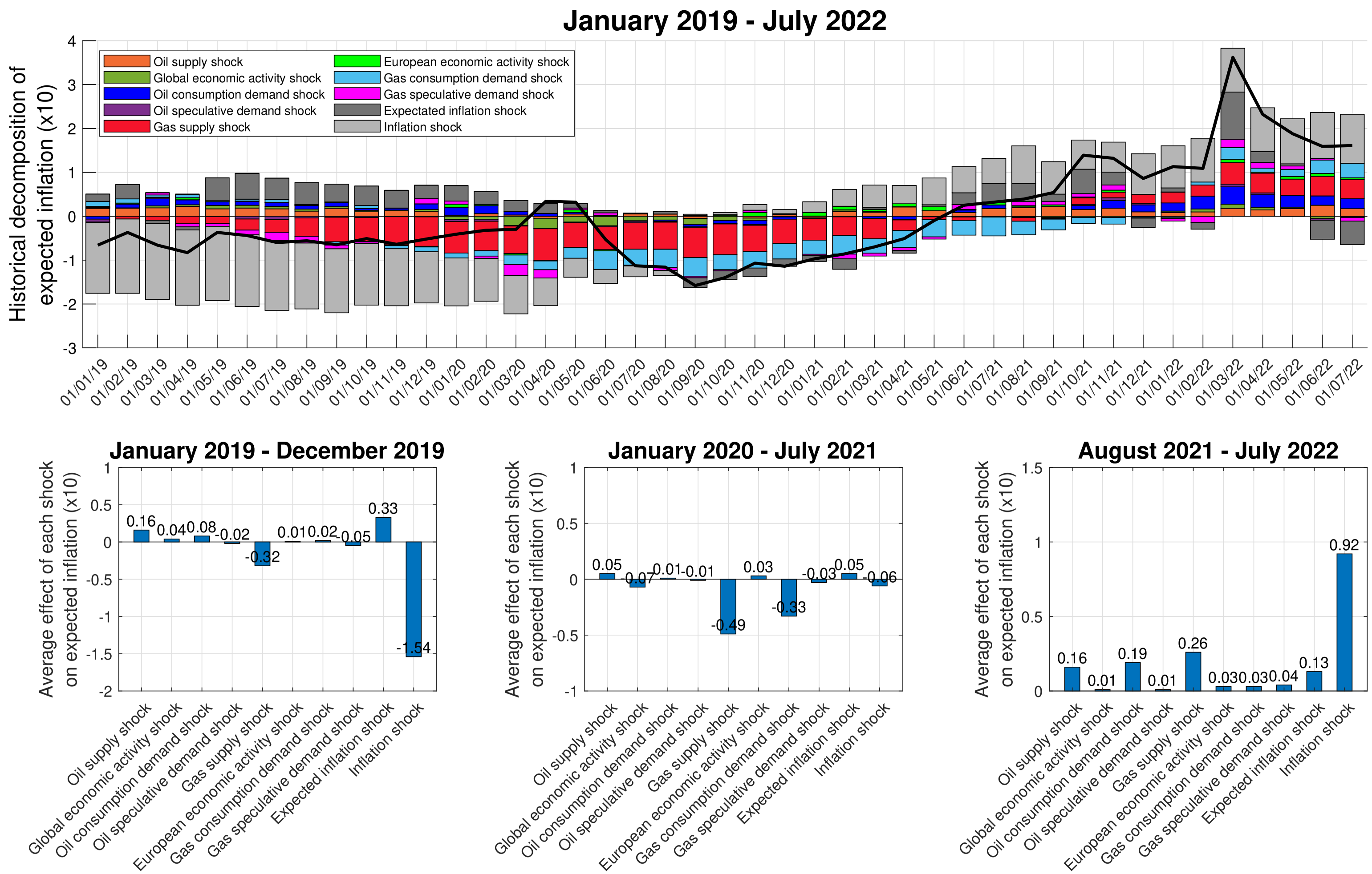

Figure 5: Historical decomposition of the expected inflation: pre, during and after Covid-19 periods

Note: top panel shows the de-meaned expected inflation (black line) and the corresponding historical decomposition (colored bars). Bottom panel reports the average contributions of each shock in three different periods.

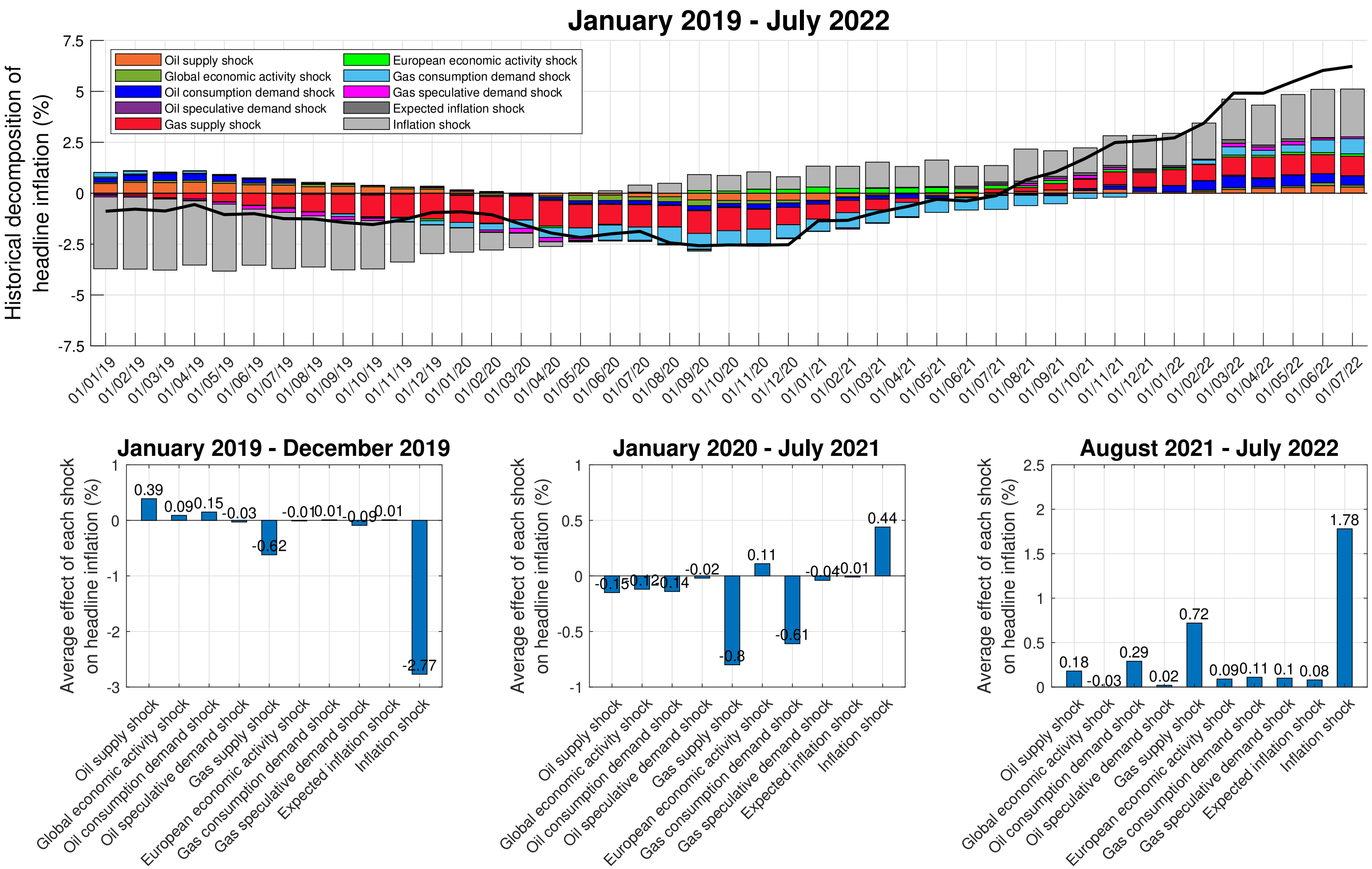

Figure 6: Historical decomposition of the headline inflation rate: pre, during and after Covid-19 periods

Note: top panel shows the de-meaned expected inflation (black line) and the corresponding historical decomposition (colored bars). Bottom panel reports the average contributions of each shock in three different periods.

The bottom panel of Figure 5 reports the average contributions of each shock to expected inflation during the three sub-periods. During the pre Covid-19 period the most relevant energy shock affecting the evolution of annual inflation expectations is coming from the natural gas supply. In general, inflation expectations are relatively low because of the strong supply within the Euro area. During the Covid-19 period, energy shocks become overall predominant, especially those related to natural gas market fundamentals, namely gas supply and consumption demand shocks. Conversely, the role of the oil market shocks is rather marginal. It is interesting to note that, within the pandemic period, inflation expectations are mostly expained by energy shocks rather than inflation shocks. Finally, the post Covid-19 period, a relevant portion of inflation expectations is driven by both inflation and expected inflation shocks. However, whereas during the pre Covid-19 period Eurozone supply is stronger than aggregate demand, in the post Covid-19 period supply is sluggish and it is further threatened by the large increase in energy prices and in input costs. Finally, gas supply shocks, followed by oil consumption demand and supply shocks, are also important drivers of expected inflation. Our findings are in line with the results of Arora et al. (2013), who show that the role of past inflation in forming consumers expectations becomes relevant in presence of energy price peaks.

5.5.2 Headline inflation

The historical decomposition of the headline inflation rate is showed in the top panel of Figure 6. The pre-pandemic period is characterized by solid economic conditions, since after the recovery from the sovereign debt crisis, supply has recovered and a high level of synchronization across the different countries is observed (Binici et al., 2022). Inflation is relatively low within these months, driven by low aggregate demand and the strong aggregate supply.

In the Covid-19 outbreak, inflation further decreases. During this phase, our results show that the demand-driven deflationary effects are negligible if compared with the upward pressure on prices pushed by the negative supply shocks and when properly controlling for the Covid-19 pandemic. Our findings are confirmed by Gonçalves et al.

(2022), who suggest that supply factors have played a major role in determining inflation during the early-2021. Our results are different from the conclusions by Ascari et al. (2023), who find that negative demand shocks have a predominant role with respect to negative supply shocks in causing deflationary effects.

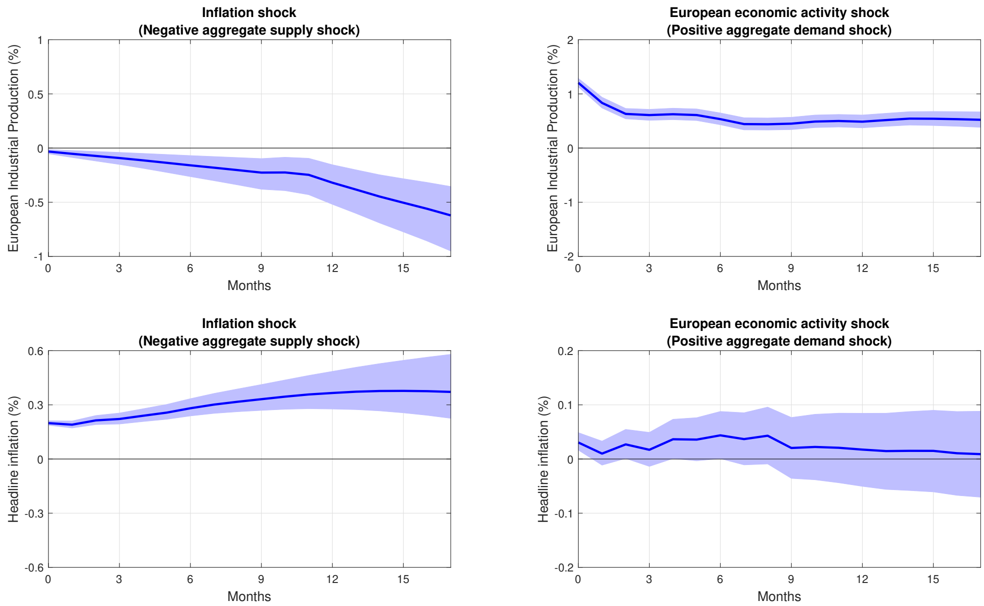

Figure 7: Impulse response functions of the Euro area aggregated demand and supply
Note: blue lines denote the median responses and shaded areas correspond to the relative density at 68% credibility levels.

Figure 7 shows the responses of headline inflation and the European industrial production index to inflation and European economic activity shocks. Our model identifies the aggregate demand and supply shocks and allows into disentangling the two opposite effects. An inflation shock has a negative and persistent effect on the Eurozone industrial production consistent with the view that firms are subject to higher costs and reduce output. As a consequence, this shock produces a rise in headline inflation. On the contrary, a European economic activity shock can be interpreted as a positive aggregate demand shock, which raises both European industrial production and headline inflation. The overall drop in inflation can be understood by considering the negative energy price shocks, which more than offset the supply-side inflation shocks. Negative energy shocks are consistent with an increase in output, due to lower input costs, and consequent lower inflation.

The role of energy shocks, of paramount relevance during the pandemic period, is also crucial during the recovery phase. Within the post Covid-19 period, we assist at a persistent rise in the Euro area inflation rate, pushed by a combination of positive energy shocks and inflation shocks. As highlighted by Eickmeier and Hofmann (2022), the major contributing factor to the prices rise comes from the supply side. The Russia-Ukraine war further exacerbates the supply effect, indeed, starting from March 2022, energy shocks play an increasing role in driving headline inflation. Surprisingly, the pass-through from inflation expectations to inflation is almost absent from all the considered periods. This finding suggests that inflation is more likely explained by higher input costs (direct effects) than by a wage-price factor through inflation expectations (indirect effects). We conclude that the Euro area inflation surge is due to constraints coming from the energy supply, also related to the war in act, rather than being the result of a large expansion in demand as the US economy has experienced.

The bottom panels of Figure 6 report the average shocks importance for each period. We observe that energy shocks and inflation shocks, measuring supply-side effects, are the most relevant contributors to headline inflation. During the post Covid-19 period, energy and inflation shocks affect headline inflation by 1.6% and 1.9%, respectively. It is worth noting that, the most important role is played by the natural gas supply shock, followed by shocks in the oil market fundamentals. This result is of paramount importance because it highlights how much the Euro area economy is dependent from natural gas production and imports.

Our findings demonstrate that inflation in the Eurozone is pushed by supply-driven factors, namely input costs and energy shocks. Specifically, the combination of oil and gas supply shocks has an average effect on headline inflation of 0.9%. Moreover, the gas supply shock is more important than its oil counterpart and economic activity shocks, when explicitly accounting for Covid-19, are rather marginal. Finally, although there is a substantial feedback from inflation shocks to inflation expectations, the effects of expected inflation shocks on headline inflation are less significant.

6 Conclusions

The Euro area has recently faced a turbulent period, characterized by high energy prices, especially in the natural gas market, geopolitical instability, due to the current Russian-Ukrainian war, and a boost in both the expected and headline inflation. In order to design the most suitable monetary policy mix, one of the main challenges consists in the determination of the causes of the current increasing inflation rate. Inflation could be triggered by a cost factor, pushed by energy shocks, or by an aggregate demand pressure, with different monetary policy implications. Specifically, it is crucial to determine how energy price shocks are transmitted to expected and headline inflation, how these two macroeconomic variables interact with each other, and if in the most recent period the phenomenon is in some way different from the past. Moreover, it is fundamental to understand which energy shocks are predominant in explaining the inflation dynamics.

To address these questions, we design a Bayesian SVAR model in which the interaction among two energy markets, the first for the global market of crude oil and the second for the European natural gas market, are considered to estimate the pass-through of energy shocks to expected and headline inflation in the Eurozone. To our knowledge there are no studies accounting for a structural specification for the European gas market, nor for the interaction between oil and gas markets. We provide evidence that: (*i*) there is dynamic interdependence between the oil and EU gas markets, which is important for the analysis of the pass-through from energy shocks to inflation; (*ii*) the responses of expected and headline inflation to energy supply and consumption demand shocks are relevant and persistent after more than one year; (*iii*) oil and gas speculative demand shocks are rapidly absorbed, while economic activity shocks cause a rise in both inflation rates but the effect is smaller if compared to energy shocks; (*iv*) the recent spike in the European inflation is mainly driven by energy shocks and aggregate supply rather than aggregate demand, (*v*) among the enegry shocks, the most important role is played by gas supply shocks, affecting headline inflation with a average of 0.7% during post-period Covid-19.

We believe these findings are relevant in order to design specific monetary instruments for the Euro area to mitigate inflationary pressure and to understand the possible propagation of high inflation to the rest of the macroeconomy.

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Appendix

A Estimation algorithm

Estimation of model (1) requires some sequential steps, which we summarize here. For a detailed description of the main algorithm and related technicalities, we refer the reader to Baumeister and Hamilton (2015).

1. Rewrite the model presented in (1) in a compact notation as:

$$\boldsymbol{A}\boldsymbol{y}_t = \boldsymbol{B}\boldsymbol{x}_{t-1} + \boldsymbol{v}_t, \tag{7}$$

   where $\boldsymbol{x}_{t-1}$ is a $(ln+3) \times 1$ vector containing the l lags of the endogenous variables, the constant and the exogenous variable, that is: $\boldsymbol{x}'_{t-1} = [\boldsymbol{y}'_{t-1}, \ldots, \boldsymbol{y}'_{t-l}, 1, \boldsymbol{x}^{*\prime}_{\boldsymbol{t}}]'$.

2. Specify the prior beliefs in the form of density functions for matrices $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{D}$. Collect in a vector $\boldsymbol{\alpha}$ all the unknown elements of $\boldsymbol{A}$, in addition to the prior assigned to the determinant $h_1 = det(\boldsymbol{A})$. The latter follows an asymmetric Student t distribution with positive domain. The priors assigned to the elements of matrix $\boldsymbol{A}$ will be further discussed in the next section.

   2.1. Denote with $p(\boldsymbol{A})$ the joint prior distribution, obtained as the product of all the elements of α assumed to be independent;

   2.2. defining d_{ii}^{-1} as the element on the i^{th} row and column of the inverse of $\boldsymbol{D}$, specify priors as:

$$p(\boldsymbol{d}|\boldsymbol{A}) = \prod_{i=1}^{n} p(d_{ii}|\boldsymbol{A}),$$

   with $d_{ii}^{-1} \sim \Gamma(\kappa, \tau_i)$, where κ/τ_i is the expected value of the Gamma distribution and κ/τ_i^2 denotes its second moment. The prior mean for the d_{ii}^{-1} elements is set to the reciprocal of the diagonal elements of matrix $\boldsymbol{A\Omega A'}$, with $\boldsymbol{\Omega}$ representing the variance-covariance matrix of the innovations obtained from running univariate autoregressive models with 12 lags for each endogenous variable in $\boldsymbol{y_t}$;

   2.3. specify priors for $\boldsymbol{B}$ conditional on $\boldsymbol{A}$ and $\boldsymbol{D}$:

$$p(\boldsymbol{B}|\boldsymbol{D}, \boldsymbol{A}) = \prod_{i=1}^{n} p(\boldsymbol{b'}|\boldsymbol{A}, \boldsymbol{D}).$$

   The prior information on $\boldsymbol{B}$ follows the conditional Normal distribution $\boldsymbol{b}_i|\boldsymbol{A}, \boldsymbol{D} \sim N(\boldsymbol{m}_i, d_{ii}\boldsymbol{M}_i)$, where $\boldsymbol{b}'_i$ denotes the i^{th} row of $\boldsymbol{B}$, $\boldsymbol{m}_i$ is the prior about $\boldsymbol{b}'_i$ and $\boldsymbol{M}_i$ is the prior variance-covariance matrix.

3. Find $\hat{\boldsymbol{\alpha}}$ that numerically maximizes the target function $q(\hat{\boldsymbol{\alpha}})$ to obtain a reasonable guess for the posterior mean of the target function. The elements collected in $\hat{\boldsymbol{\alpha}}$ inform the Metropolis-Hastings algorithm if they satisfy sign-restrictions consistent with economic theory. Otherwise, initial values for $\boldsymbol{A}$ are used to perform the random-walk Metropolis-Hastings algorithm in the subsequent step.

4. Conditioning on the sample data $\boldsymbol{Y}_T$, construct the joint posterior distribution of the structural parameters in $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{D}$:

$$p(\boldsymbol{A}, \boldsymbol{D}, \boldsymbol{B}|\boldsymbol{Y}_T) = p(\boldsymbol{A}|\boldsymbol{Y}_T)p(\boldsymbol{D}|\boldsymbol{A}, \boldsymbol{Y}_T)p(\boldsymbol{B}|\boldsymbol{A}, \boldsymbol{D}, \boldsymbol{Y}_T).$$

   with the help of the Metropolis-Hastings algorithm. The latter is used to generate $S = 10$ million draws $[\boldsymbol{A}(\boldsymbol{\alpha}^s), \boldsymbol{D}^s, \boldsymbol{B}^s]_{s=M+1}^{M+N}$ from the posterior distribution $p(\boldsymbol{A}, \boldsymbol{D}, \boldsymbol{B}|\boldsymbol{Y}_T)$, with 9 million draws of burn-in.

B Priors for the structural parameters: energy markets

B.1 Oil market

Priors for parameters of the oil supply equation. As reported in Table 2, our prior belief on $\alpha_{q^o p^o}$ is a Student t distribution with support restricted on the positive domain and prior mode equal to 0.1. The choice of the location parameter is consistent with the range of the empirical estimates of the short-run oil price supply elasticity available in the literature (e.g Kilian and Murphy, 2014; Juvenal and Petrella, 2015; Caldara et al., 2019; Bjørnland et al., 2021).

Priors for parameters of the global economic activity equation. The structural coefficient $\alpha_{y^o p^o}$ represents the effect of the real price of oil on the world industrial production. Since energy expenditure represents a small fraction of global GDP, we would not expect a large response of the global economic activity to oil price changes. For the structural parameter $\alpha_{y^o p^o}$, we specify a Student t prior distribution truncated to be negative with mode at $c_{\alpha_{y^o p^o}} = 0.05$, in line with Baumeister and Hamilton (2019) and Rühl and Erker (2021). As for the coefficient describing the response of world industrial production to changes in European industrial production, $\alpha_{y^o y^g}$, we rely on a Student t distribution with mode $c_{\alpha_{y^o y^g}} = 0$ and support restricted on the positive domain. This consistent with the view that an increase in the European economic activity boosts global economic growth within the month.

Priors for the oil consumption demand equation. The first structural coefficient of the global crude oil demand Equation (3c) is $\beta_{q^o y^o}$, which represents the income elasticity of oil demand. We form our prior beliefs about $\beta_{q^o y^o}$ based on studies available in this literature (e.g. Csereklyei et al. (2016) and Gately and Huntington (2002)). Thus, we assign a Student t prior distribution with mode at $c_{\beta_{q^o y^o}} = 0.7$ and support constrained to be non-negative. Moreover, the literature attempting to estimate the oil price demand elasticity is vast (e.g. Hausman and Newey, 1995; Gelman et al., 2016; Coglianese et al., 2017; Valenti, 2022). These contributions, using different sources of data and econometric methods, find that estimates for the short-term price elasticity of oil demand range between 0.4 and 0.1, in absolute value. Thus, for the structural coefficient $\beta_{q^o p^o}$, we use a Student t prior, with mode at -0.1 and truncated to be negative.

Priors for the oil inventory demand equation. We assign relatively uninformative Student t priors for ψ_1^o (the effect of oil production on crude oil inventories) and ψ_3^o (the response of crude oil inventories to oil price changes), with location parameter set at 0. These priors are consistent with the view that, on the one hand, a price increase might induce inventories to be drawn down for production (consumption) smoothing, while, on the other hand, it might also cause an increase in the demand for storage for speculative reasons (see for example Juvenal and Petrella, 2015; Valenti et al., 2022).

B.2 Gas market

Priors for parameters of the natural gas supply equation. The price elasticity of natural gas supply is quite rigid in the short-term. According to the theoretical model provided by Albrizio et al. (2022), the responsiveness of global gas producers to changes in gas price reflects the supply-side rigidities which are mainly motivated by frictions to infrastructure requirements for transportation (e.g. pipelines, LNG import, export terminals and storage facilities). For the price elasticity of gas supply, $\alpha_{q^g p^g}$, we specify a Student t positive truncated distribution, with mode at 0.1. The choice of the prior mode for $\alpha_{q^g pg}$ is consistent with the empirical estimate of gas supply elasticity reported by Krichene (2002).

Priors for parameters of the European economic activity equation. For the structural parameter $\alpha_{y^g p^g}$, we would expect a weak effect of gas price on European industrial production. This is motivated by a small share of natural gas rents to total GDP in Europe.[12] For the parameter $\alpha_{y^g y^o}$, we select the same mode used for $\alpha_{y^o y^g}$, that is, $c_{\alpha_{y^g y^o}} = 0$ and a positively restricted support domain. Finally, the structural coefficient $\alpha_{y^g \pi}$ is the effect of actual inflation on European industrial production. As anticipated,

[12]The natural gas rent (% of GDP) is the difference between the value of natural gas production and total costs of production. According to the World Bank, the average natural gas rent in Europe between 2010 and 2020 is 0.05%. See `https://data.worldbank.org/indicator/NY.GDP.NGAS.RT.ZS?locations=EU`.

this coefficient reflects the European aggregated demand elasticity, thus we restrict the Student t distribution to the negative domain. Since the inflation effect on economic output is typically estimated by considering the interest rate, absent in our specification, we opt for a relatively agnostic position and set the mode $c_{\alpha_{y^g\pi}} = 0$.

Priors for the natural gas consumption demand equation. The structural coefficients $\beta_{q^g y^g}$ and $\beta_{q^o p^o}$ represent the income and the consumption elasticities of natural gas demand, respectively. For the structural parameter $\beta_{q^g y^g}$, we use a relatively uninformative Student t prior distribution, with mode at $c_{\beta_{q^g y^g}} = 0.5$ and truncated to be positive (see Al-Sahlawi, 1989; Huntington et al., 2019; Asche et al., 2008). For the price elasticity of natural gas demand, $\beta_{q^o p^o}$, we specify a Student t prior distribution, centered at $c_{\beta_{q^g p^g}} = -0.3$, whose support is constrained to be negative. The location parameter and the sign restrictions are consistent with a large body of empirical studies, such as Labandeira et al. (2017); Rubaszek et al. (2021); Andersen et al. (2011).

Priors for the natural gas inventory demand equation. For the parameters describing the effects of production and price on gas stocks, namely ψ_1^g and ψ_3^g, we opt for relatively uninformative Student t prior distribution, with location parameters set at 0. Similarly to the oil inventory demand equation, we do not impose sign restrictions on ψ_1^g and ψ_3^g, since changes in natural gas stocks can be driven by both consumption (production) smoothing and speculative decisions, which are unknown a priori.

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