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Summary

We develop a Bayesian Structural VAR (SVAR) model to study the relationship between different kinds of energy shocks and inflation dynamics in Europe. Specifically, we include in our specification two separate energy markets (oil and natural gas) and two target macroeconomic variables, measuring inflation expectations and the realized headline inflation. Our results demonstrate that, during the last year, inflation in the Euro area is more affected from energy price shocks, particularly those coming from the natural gas sector. The high peaks of the Eurozone inflation are mainly associated with gas consumption demand shocks and, to a lesser extent, to oil and gas supply shocks.

Keywords: Energy shocks, Oil and gas markets, Inflation, Bayesian Structural VARs

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 (SVAR) model to study the relationship between different kinds of energy shocks and inflation dynamics in Europe. Specifically, we include in our specification two separate energy markets (oil and natural gas) and two target macroeconomic variables, measuring inflation expectations and the realized headline inflation. Our results demonstrate that, during the last year, inflation in the Euro area is more affected from energy price shocks, particularly those coming from the natural gas sector. The high peaks of the Eurozone inflation are mainly associated with gas consumption demand shocks and, to a lesser extent, to oil and gas supply shocks.

Keywords: Energy shocks; Oil and gas markets; Inflation; Bayesian Structural VARs.
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1 Introduction

The socio-economic environment in Europe is currently characterized by a large amount of uncertainty. The post-pandemic recovery has been weakened by the beginning of the Russian-Ukrainian conflict. The war scenario is additionally exacerbated by two exceptional and related events: energy prices are at their historical record and inflation is

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remarkably increasing after some decades of moderate growth. The Eurozone prices from September 2021 to September 2022 have increased by 9.9% (and this rate has gone up to 10.9% considering the whole European Union), an increase that is even higher than the 9.1% registered in August this year. Notice that on September 2021 the inflation rate was at 3.4%.[1] Uncovering the factors behind the current high inflation and disentangling the nexus with the energy markets is essential in order to determine the ECB monetary policy, which may opt for high interest rates in the forthcoming periods.

The European phenomenon is not an isolated case: the UK annual inflation rate reached 10.1% in September 2022, while in the US it was 8.2%.[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 the headline and core inflation rates in the US and the Euro area, it emerges that, whereas the high inflation in the US is pushed by an overall increasing demand, in the Eurozone it is most likely the result of an increasing pressure by the energy sector. Energy is the most important contributor to Euro area HICP annual inflation, with a share of 4 percentage points in 2022, compared with the 1.4 percentage points registered one year ago.

Given the relevance of the topic, an increasing amount of studies is focusing on the energy-inflation pass-through. The relationship between inflation, inflation expectations and oil market in the recent period 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), studying the impact of gasoline prices on US inflation and inflation expectations, conclude that the burden of rising energy prices is not expected to have a persistent impact on the two target variables. However, gasoline price shocks account on average for the 42% of the variation in inflation expectations, and the US increase in expected inflation during the period spanning from 2009 to 2013 is almost exhaustively explained by rise in gasoline prices (Kilian and Zhou, 2022b).

Despite this, there is still lack of a comprehensive analysis for the European case, which requires a particular setup.[3] The European energy sector is highly dependent on natural gas, whose market, contrary to oil, cannot be considered *global*, since it is typically characterized by local frictions, although there are signs of a remarkable and increasing level of integration in the European gas market (see Bastianin et al., 2019; Broadstock et al., 2020; Papież et al., 2022, as examples).

[1]Source: Eurostat.

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

[3]Clerides et al. (2022) is one of the few exceptions. They analyze the European case considering world crude oil and gasoline prices impacts on consumers sentiment.

In this article we develop a model in which both the global oil market and the European local gas market are taken into account and related to the macroeconomy, via expected and realized inflation rates. To our knowledge, Rubaszek et al. (2021) are the first to describe the natural gas market distinguishing among different kind of shocks in a SVAR setup,[4] whereas the SVAR model of Jadidzadeh and Serletis (2017) is one of the few considering interdependence between the oil and the gas markets. However, it is worth noting that 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 through a gas price equation, without a structural distinction among the different types of shocks affecting the market.

We build a Bayesian SVAR model that consists of an oil market block and an inflation block, augmented with a full extra block modeling natural gas fundamentals, and estimate the whole three-blocks specification with European data. From a methodological point of view, it is not straightforward to estimate and identify the causal relationships among two energy markets and two inflation rates. The forward looking behavior of expected inflation captures all the contemporaneous available information, but at the same time it implies that changes in consumers' expectations immediately affect their economic behavior.[5] The endogeneity of inflation and its expectations requires to depart from standard identification setups, such as the canonical Cholesky orthogonalization of the variance-covariance matrix of the model residuals. We rely on Bayesian SVAR models to examine the energy-inflation pass-through, accounting for the fact that inflation and its expectations instantaneously affect each other. As shown in Baumeister and Hamilton (2019, 2022), Bayesian inference can be thought as a less restrictive way to impose restrictions on the structural parameters of the VAR, as it allows to include uncertainty to the otherwise stronger prior beliefs.

The rest of the article is structured as follows. Section 2 introduces the main literature on energy prices effect on inflation and expected inflation. Section 3 describes the dataset. Section 4 focuses on the model, the identification scheme, the estimation procedure and the prior distributions. Section 5 presents and discusses the results of the analysis, while Section 6 concludes.

[4]Their model is developed in the spirit of the SVAR literature on oil price shocks, as in Kilian (2009); Baumeister and Hamilton (2019).

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

2 Literature review

Although there is increasing attention in studying the dynamics of the gas markets, literature is traditionally focused on the global oil market and inflation relationship. Whereas oil is the most important energy commodity worldwide in terms of market size, natural gas is becoming increasingly important, especially in the Euro area, when it is the primary energy source in terms of consumption for the industrial sector. Most of the gas market growth can be attributed to the efforts aimed at removing 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 include both when analyzing the effects of energy shock on inflation, and there are no reasons to expect that the channels of transmissions from oil prices to inflation should not apply also for natural gas price shocks, considering the substitution relation linking these two energy commodities.

Overall there is consensus that increases in oil prices lead to higher inflation rates. Choi et al. (2018) find that, for both developed and developing economies, this effect is asymmetric, with positive oil price shocks having larger effects than negative shocks. 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.

Energy price shocks can affect inflation through two different channels. The first relates to costs, as increased energy prices reflect directly a push in input costs. The second is the indirect effect of wage bargaining and price setting, arising from an increase in inflation expectations (Wong, 2015). 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, influence (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 different historical periods characterized by high (or low) inflation rates are coupled with different oil price levels (Barsky and Kilian, 2001, 2004). Blanchard and Gali (2007), although not distinguishing among different kinds of oil shocks, provide evidence for the fact that the propagation from oil prices to macroeconomic fluctuations in the 1970s and in the 2000s are difficult to compare, given the different nature of the shocks. 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. Therefore, it is not surprising 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.[6]

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 67 USD per barrel. When disentangling among different types of oil shocks, results are mixed. Güntner and Linsbauer (2018), for instance, provide evidence that only aggregate demand shocks affect inflation expectations, with a positive effect estimated for the first few months and a negative one thereafter. On the contraty, 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 reacts to higher oil prices, regardless of the type of the 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 the price of oil, and demonstrate that increases in fuel prices do cause inflation expectations to rise, as found by Coibion and Gorodnichenko (2015), but the effect is temporary and disappear after 5 months.

Finally, the pass-through from energy price shocks to inflation expectations may differ from the one 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 could suggest that high energy prices make the correlation between the expected and actual inflation rates stronger, whereas in some phases core inflation may be dominant in explaining headline inflation.[7] Aastveit et al. (2021) estimate that the effect of inflation expectations on actual inflation is stronger than the effect of observed inflation on expected inflation, in line with the findings of Coibion et al. (2018, 2020). Kilian and Zhou (2022b) find that a positive shock to core CPI has negligible effects on expected inflation, whereas, in contrast, a positive shock to inflation expectations raises both the expected and headline inflation rates.

3 Data

Our dataset is constructed by combining data on a monthly basis from different sources. For the oil market we mainly rely on EIA data, whereas data for the gas market mostly

[6]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.

[7]Giri (2022), for instance, shows that energy inflation is correlated with the headline inflation rate on a short-term horizon, whereas there is evidence that the correlation between headline and core inflation is weakening since the mid-90s.

comes from the JODI database. We download macroeconomic data from multiple sources, namely the OECD, Eurostat and Fred databases.

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	natural gas monthly database: stock changes
Expected inflation	π^e	OECD monthly index of consumer opinion survey on consumer prices (inflation): future tendency (1 year after)	OECD expected inflation
Inflation rate	π	annualized monthly rate of change (log difference) in the EA HICP consumer price index, deseasonalized	Euro Area HICP

Notes: 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 saving the residuals of a regression against monthly dummies.

It is worth stressing that, whereas it is relatively easy to proxy expected inflation in the US, this is not straightforward for Europe, given the absence of series properly measuring the expected inflation rate with a monthly frequency. We rely on the OECD index of consumer opinion survey on the future tendency of consumer prices, as it is the only available variable option: However this index has a more qualitative perspective than the US Michigan Survey of Consumers and, crucially, it is not bounded between 0 and 100.[8] Table 1 describes the dataset, listing the sources of raw data and how we compute

[8]We noted however the very high correlation between this index and the quarterly inflation forecasts, made by professional forecasters and provided by the ECB.

the final endogenous variables entering in the model. Data span from February 2010 to August 2022, as there are no previous data for the gas market. We end up with $n = 10$ endogenous variables for a total of $T = 149$ time observations.

4 Methodology

We model oil and gas markets as two independent energy blocks interacting with expected and realized inflation in a Bayesian structural setup. The oil market specification we reference to is proposed by 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.[9] The same specification has been proposed for the natural gas market by Rubaszek et al. (2021), and extended to include inflation and its expectations by Aastveit et al. (2021). Our model consists on a total of 11 equations, that is 5 referred to the global oil market (inbcluding the measurement error equation, that does not count as an additional endogenous variable), 4 relative to the European natural gas market and 2 describing inflation and its expectations.

4.1 A Bayesian SVAR model for energy and inflation

The structural form of the VAR model is given by:

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

in which $\boldsymbol{y_t}$ denotes the vector of the 10 endogenous variables, $\boldsymbol{A}$ and $\boldsymbol{B_l}$ are the matrices of structural contemporaneous and lagged coefficients and $\boldsymbol{v_t} \sim \mathcal{N}(0, D)$ is the vector collecting the structural shocks, with $\boldsymbol{D}$ a 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), which should capture the business cycle length, proxied by global industrial production, and all possible residual autocorrelation.

By writing the reduced form representation of the model as:

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

with $\boldsymbol{\beta}_0 = \boldsymbol{A}^{-1}\boldsymbol{b_0}$, $\boldsymbol{\mathcal{B}_l} = \boldsymbol{A}^{-1}\boldsymbol{B_l}$, $\boldsymbol{u_t} = \boldsymbol{A}^{-1}\boldsymbol{v_t}$ and assuming that the reduced form errors

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

$\boldsymbol{u_t}$ 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 (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.

Our identification scheme consists on the $\boldsymbol{A}$ matrix of contemporaneous structural parameters specified as:

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

The structural form of model (1) can be written as a system of equations consisting in three blocks, which will be discussed in the next sections.

4.1.1 Structural equations for the global market of crude oil

The first block represents the oil market, which is described as:

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

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

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

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

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

The term $\boldsymbol{x}_{t-1} \equiv [\boldsymbol{y}_{t-1}', \ldots, \boldsymbol{y}_{t-12}']'$ denotes a vector containing all the lags of $\boldsymbol{y}_t'$, while $\boldsymbol{b_i'}$ contains the structural parameters of the lagged variables, with $i = 1, \ldots, n$. All the four oil market endogenous variables depend at time t by *all* the lagged variables, whereas the contemporaneous relationships reflect the identification scheme proposed in the literature by Baumeister and Hamilton (2019); Aastveit et al. (2021). Equation (3a) represents the global oil supply, where oil production is contemporaneously affected by its own price. The parameter $\alpha_{q^o p^o}$ thus represents the short-run oil supply own price elasticity. 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". The second equation, (3b), describes the impact effects of real oil price on world real economic activity, via the parameter $\alpha_{y^o p^o}$, so that the structural innovation v^*_{2t} can be interpreted as a "global economic activity shock". Equation (3c) relates the global oil consumption demand with the real oil price, the global industrial production, through the structural coefficients $\beta_{q^o p^o}$ and $\beta_{q^o y^o}$, respectively, and the change in oil inventories. The term $\beta_{q^o p^o}$ is thus the short-run own price elasticity of oil demand, while $\beta_{q^o y^o}$ represents the income elasticity of the oil demand curve. The resulting structural shock, v^*_{3t}, denotes an "oil specific consumption demand shock". Finally, equation (3d) states that the oil inventory demand depends on the oil produced quantities and real price, with v^*_{4t} denoting a separate structural shock to inventory demand, thus called an "inventory (or speculative) demand shock", while equation (3e) accounts for a measurement error (e_t), since the true quantity of global oil stocks is not available. On this respect, we can use equation (3e) to rewrite the equations for oil-consumption demand and oil-inventory demand in terms of observed variables, that is:

$$q^o_t = b_3 + \beta_{q^o p^o} p^o_t + \beta_{q^o y^o} y^o_t + -\chi^{-1} \Delta i^o_t + \boldsymbol{b'_3 x}_{t-1} + v^*_{3t} - \chi^{-1} e_t \tag{4a}$$

$$\Delta i^o_t = b_4 + \psi_1 q^o_t + \psi_3 p^o_t + \boldsymbol{b'_4 x}_{t-1} + \chi v^*_{4t} + e_t \tag{4b}$$

where $\psi^o_1 = \chi \psi^{*o}_1$ and $\psi^o_3 = \chi \psi^{*o}_3$. 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 simultaneous correlated, due to the assumptions of the measurement error. Therefore, uncorrelated structural shocks can be obtained by pre-multiplying the system made by equations (3a), (3b), (4a) and (4b) by the following 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 $\rho = \frac{\chi^{-1}\sigma^2_e}{d^*_{33} + \chi^{-2}\sigma^2_e}$, whereas d^*_{33} and σ^2_e represent the structural variances of the oil consumption-demand equation and measurement error, respectively.

4.1.2 Structural equations for the European market of natural gas

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

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

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

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

$$\Delta i_t^g = b_8 + \psi_1 q_t^g + \psi_2 y_t^g + \psi_3 p_t^g + \Delta i_t^g + \boldsymbol{b_8'} \boldsymbol{x}_{t-1} + v_{8t}. \tag{5d}$$

Equation (5a) corresponds to the natural gas supply curve and is specular to the oil supply one represented in equation (3a). Therefore, $\alpha_{q^g p^g}$ represents the natural gas own price supply elasticity and structural innovation v_{5t} is an unexpected shock in gas supply, which can be associated to decrements in gas production or changes of the import-export mix in and from the Euro area. Equation (5b) models the dynamics of the European aggregate economic activity, depending contemporaneously on the real price of gas. The structural shock v_{6t} corresponds to a "European economic activity shock", reflecting shifts on the Eurozone business cycle. Equation (5c) relates the impact of the real price of gas and all the other gas-related endogenous variables, denoting the natural gas European demand curve. The structural parameters $\beta_{q^g p^g}$ and $\beta_{q^g y^g}$ represent the own price demand elasticity and the demand income elasticity. The demand curve is also dependent directly from changes in natural gas stocks. The innovation term v_{7t} can be interpreted as a structural unexpected change in natural gas demand for consumption, which we label as "gas specific consumption demand shock". Finally, the dynamics of natural gas inventories in the Eurozone are described by equation (5d). Stock changes immediately respond to gas supply and price, as in the equivalent oil storage equation (3d). As in Rubaszek et al. (2021), we do not assume that inventories come with a measurement error, since data for the Euro area natural gas stocks are quite accurate.

Notice that the oil and Eurozone natural gas markets are considered completely independent on impact, via the exclusion restrictions set on matrix $\boldsymbol{A}$. This reflects the idea that interdependence between the two markets does exist, but is not instantaneous. Rather, it takes about 1 month to manifest.

4.1.3 Structural equations for expected inflation and actual inflation

Finally, the last block of equations models the macroeconomic dynamics of European price changes. It is worth noting that the energy equations from equation (3a) to equation (5d) are predetermined with respect to the inflation variables, as it is expected that inflation takes more than one month to impact the oil and natural gas prices, quantities and inventories. The inflation block consists in two equations, modeling the evolution of inflation expectations and the headline inflation rate of the Eurozone.

$$\begin{aligned}\pi^e = b_9 + \lambda_{\pi^e q^o} q_t^o + \lambda_{\pi^e y^o} y_t^o + \lambda_{\pi^e p^o} p_t^o + \\ \lambda_{\pi^e q^g} q_t^g + \lambda_{\pi^e y^g} y_t^g + \lambda_{\pi^e p^g} p_t^g + \lambda_{\pi^e \pi} \pi + \boldsymbol{b_9'} \boldsymbol{x}_{t-1} + v_{9t}\end{aligned} \tag{6a}$$

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

Equation (6a) allows for interactions with both oil and natural gas supply and demand curves, global and European real economic activity and inflation. Similarly, equation (6b) relates the monthly inflation rate of the Euro area to the energy markets and the expected inflation rate. The structural innovations v_{9t} and v_{10t} denote idiosyncratic shocks to expected and realized inflation.

4.2 Estimation algorithm

Estimation of model (1) requires some sequential steps, which we summarize as follows:[10]

1. Rewrite model (1) as:

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

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

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

   - denote with $p(\boldsymbol{A})$ the joint prior distribution, obtained as the product of all the elements of $\boldsymbol{\alpha}$, since they are assumed independent;
   - defining d_{ii} as the element in $\boldsymbol{D}$ on the i^{th} row and column, specify these priors as:

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

[10]For a detailed description of the main algorithm and all the technicalities, we refer the reader to Baumeister and Hamilton (2015).

with $d_{ii}^{-1} \sim \Gamma(\kappa, \tau_i)$, κ/τ_i is the expected value of the Gamma distribution and κ/τ_i^2 denotes the 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 $\boldsymbol{y_t}$;

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

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

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

3. Conditioning on the sample data $\boldsymbol{Y}_T$,, construct the joint posterior distribution of the parameters, that is:

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

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

4.3 Priors on the contemporaneous structural parameters

To set priors on the matrices of structural coefficients $\boldsymbol{A}$, we rely on economic theory and empirical literature on energy markets and inflation.

We specify our prior beliefs for the coefficients of $\boldsymbol{A}$ as Student t distributions, with mode, scale and degrees of freedom as reported in Table 2. Although there is plenty of literature providing estimates of many of the coefficients we focus on, we rely on prior beliefs proposed by the literature using similar Bayesian settings. Since studies documenting the gas shocks impacts on both inflation expectations and inflation are virtually absent, we impose for the coefficients of interest the same priors specified for the oil market counterpart. We further restrict the coefficients in sign when economic theory is able to justify positive or negative effects.

Table 2: Prior t distributions for the contemporaneous structural coefficients in $\boldsymbol{A}$

Parameter	Prior				Main sources
	mode (c)	scale (σ)	d.o.f. (ν)	sign restriction	
$\alpha_{q^o p^o}$	0.1	0.2	3	+	Baumeister and Hamilton (2019)
$\alpha_{y^o p^o}$	-0.05	0.1	3	−	Baumeister and Hamilton (2019)
$\beta_{q^o y^o}$	0.7	0.2	3	+	Baumeister and Hamilton (2019)
$\beta_{q^o p^o}$	-0.1	0.2	3	−	Baumeister and Hamilton (2019)
ψ_1^o	0	0.5	3	none	Baumeister and Hamilton (2019)
ψ_3^o	0	0.5	3	none	Baumeister and Hamilton (2019)
$\alpha_{q^g p^g}$	0.1	0.2	3	+	Rubaszek et al. (2021)
$\alpha_{y^g p^g}$	-0.05	0.05	3	−	Rubaszek et al. (2021)
$\beta_{q^g y^g}$	0.5	0.3	3	+	Rubaszek et al. (2021)
$\beta_{q^g p^g}$	-0.3	0.3	3	−	Rubaszek et al. (2021)
ψ_1^g	0	0.5	3	none	Rubaszek et al. (2021)
ψ_3^g	0	0.5	3	none	Rubaszek et al. (2021)
$\lambda_{\pi^e q^o}$	-0.1	10	3	−	Aastveit et al. (2021)
$\lambda_{\pi^e y^o}$	0.1	10	3	+	Aastveit et al. (2021)
$\lambda_{\pi^e p^o}$	0.02	1	3	+	Aastveit et al. (2021)
$\lambda_{\pi^e q^g}$	-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	+	Aastveit et al. (2021)
$\lambda_{\pi q^o}$	-0.1	10	3	−	Aastveit et al. (2021)
$\lambda_{\pi y^o}$	0.25	1	3	+	Aastveit et al. (2021)
$\lambda_{\pi p^o}$	0.04	1	3	+	Aastveit et al. (2021)
$\lambda_{\pi q^g}$	-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	+	Aastveit et al. (2021)

5 Estimation results and discussion

We provide results from estimating model (1) in terms of comparison of the posterior distributions with our prior beliefs , impulse response functions and historical decompositions. In the remainder of this section we will discuss the main findings of our analysis.

5.1 Prior vs posterior distributions of the elements of $\boldsymbol{A}$

We compare the prior distributions of the structural parameters in $\boldsymbol{A}$ with the posterior distributions we get after estimation of model (1). Figures 1, 2 and 3 show the prior distributions (green lines) and the posterior distributions (blue histograms) for the main parameters of interest.

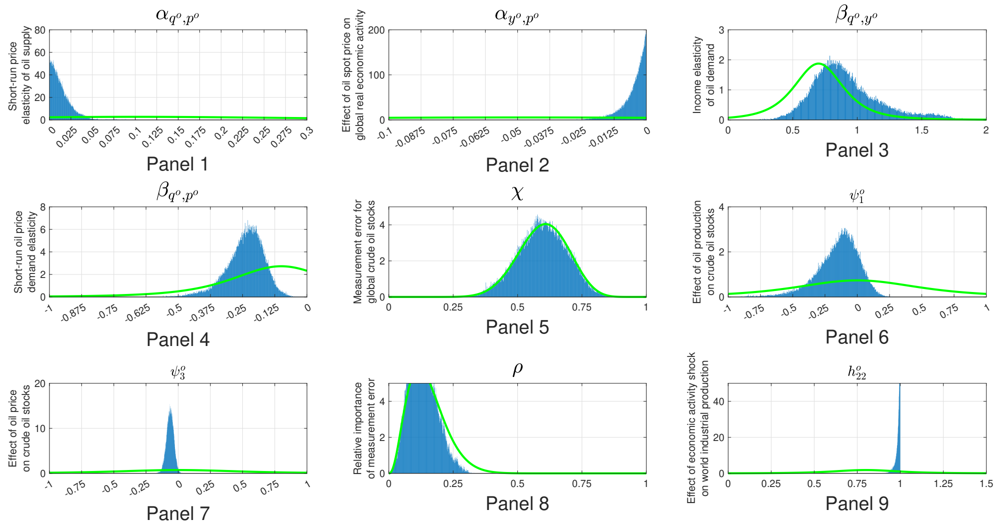

Figure 1: Prior and posterior distributions for the contemporaneous structural coefficients of the oil block

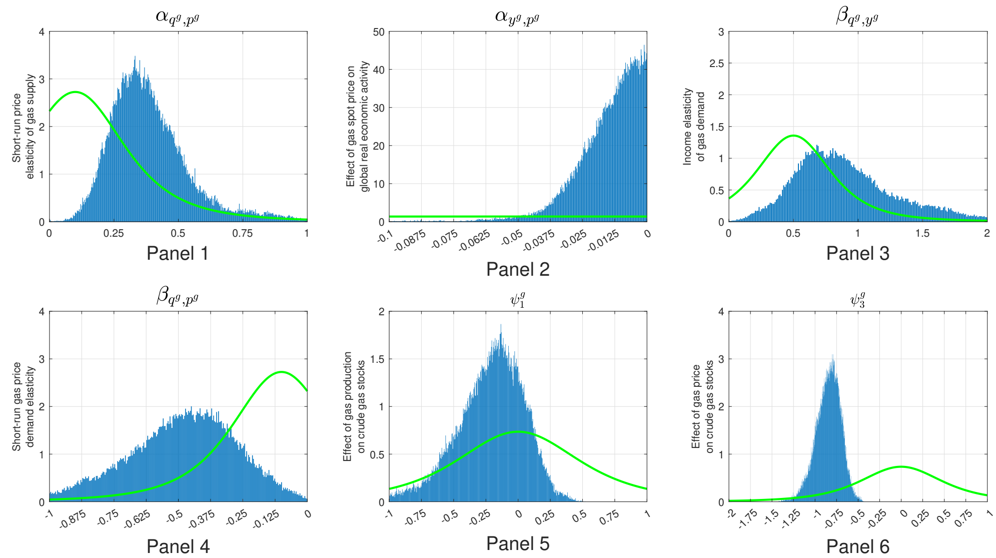

Figure 2: Prior and posterior distributions for the contemporaneous structural coefficients of the gas block

Panel 1 of Figure 1 reports the estimated short-run elasticity of oil supply. We notice that the prior distribution of $\alpha_{q^o p^o}$ is flat relatively to the posterior distribution, furthermore it exhibits a larger variance, suggesting that our data are revising and updating our prior beliefs, as well as reducing uncertainty. The posterior median of $\alpha_{q^o p^o}$ is equal to

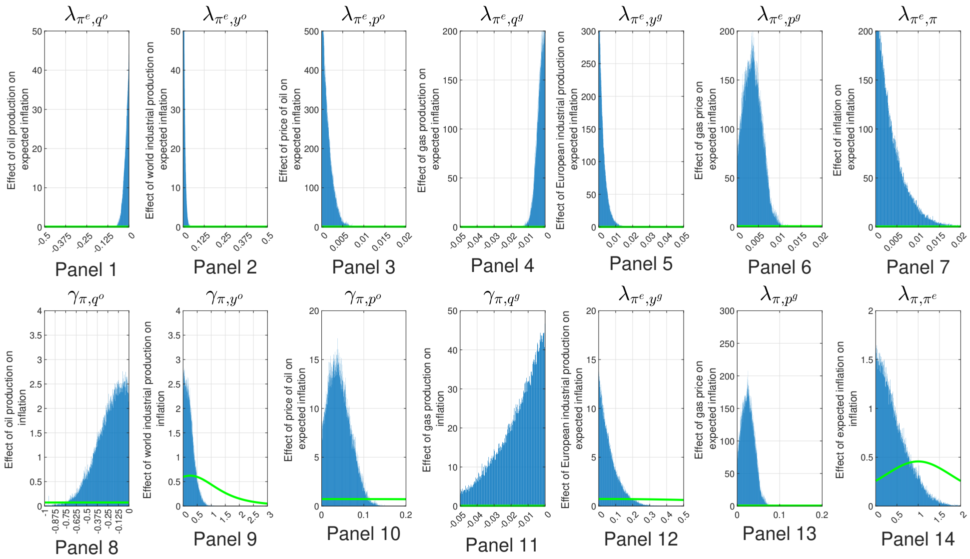

Figure 3: Prior and posterior distributions for the contemporaneous structural coefficients of the inflation block

0.01%, consistent with the empirical literature (see for example Kilian and Murphy (2014), Caldara et al. (2019), Coglianese et al. (2017) and Herrera and Rangaraju (2020)). Panel 2 depicts the short run price demand elasticity for the oil market, and we notice that the mass of the posterior distribution is more concentrated to the left with respect to the prior. The prior is revised negatively, and the median is equal to -0.23%, again similarly to what is found in the gasoline and crude oil markets literature (see among others, Levin et al. (2017), Baumeister and Hamilton (2019) and Valenti (2022)).

Moving to the natural gas market, we focus on the distributions of $\alpha_{q^g p^g}$ and $\beta_{q^g p^g}$, that is the short-term own price elasticities for European supply and demand curves, respectively. These are shown in Panels 1 and 3 of Figure 2. Both the two posteriors are revised if confronted with the prior distributions, with medians equal to 0.36% in the case of supply elasticity and -0.48% in the case of demand. By comparing these results with the findings obtained in the literature for EU or US natural gas market, two main conclusions emerge. First, the median is much larger for the European case with respect to the the US gas market estimated by Rubaszek et al. (2021). This suggests that the Eurozone gas market has a more elastic supply curve with respect to the US counterpart. Second, the gas supply elasticity is much larger with respect to the oil market supply elasticity, suggesting again a greater elasticity for the supply curve. These two facts can be easily explained by noting that the European natural gas supply is an aggregate including also net imports, in addition to the produced quantity. The own-price elasticity of natural gas demand is quite sizeable if compared with other analyses, although this finding can be rationalized with the same motivation used above. Asche et al. (2008), focusing on natural gas demand in the European household sector, find a statistically significant demand curve elasticity only if the model is estimated with fixed effects, equal to -0.24, with significant heterogeneity among countries. Erias and Iglesias (2022) estimate a yearly average short-run price demand elasticity for many European economies ranging from -0.3 to -0.14.

The impact effects of energy variables on inflation and inflation expectations are depicted in Panels 1 to 14 of Figure 3. The effects of oil and natural gas prices on expected inflation exhibit posterior distributions with smaller variances with respect to the priors. Specifically, in the case of the global oil price, the distribution for the effect $\lambda_{\pi^e p^o}$ is more concentrated around zero if compared with the distribution of $\lambda_{\pi^e p^g}$. We find that the median is higher for the natural gas price, suggesting that European households revise their expectations about the future by looking more at the natural gas price movements than the oil price fluctuations.[11] Interestingly, we estimate a similar effect if considering how the two prices impact the actual inflation, even if lower in magnitude, suggesting that the pass-through is stronger via the expectations channel. However, it is crucial to stress that this comparison has to be carried out with care, as our proxy for inflation expectations is not a pure expected inflation rate (i.e., it is not scaled from 0 to 100). The two medians associated with $\lambda_{\pi p^o}$ and $\lambda_{\pi p^g}$ are equal to 0.04% and 0.01%. Finally, we focus on the distributions of the parameters $\lambda_{\pi^e \pi}$ and $\lambda_{\pi \pi^e}$. Whereas in the former case the posterior distribution is completely revised from the prior distribution (which is relatively flat) and its mass is concentrated on 0, in the latter case the prior is informative and influencing the posterior distribution. The estimated median for the effect of expected inflation on realized inflation is 0.36%, much lower than the unity prior we have imposed. Similarly, we obtain a median effect from inflation to its expected value of 0.003, smaller than the prior mode.

5.2 Impulse response analysis

5.2.1 Energy price shocks and inflation

We illustrate in Figure 4 the dynamic responses of the two target inflation variables to each energy shock. Each plot shows the median of the posterior distributions (blue lines) and the relative density at 68% credibility level (light blue shaded ares). Each shock is standardized to represent a one unit standard deviation shock. Overall our results are smoother in the case of the expected inflation, whereas the effects on headline inflation

[11] The two medians imply effects equal to 0.11% and 0.36% for the gas and oil prices, respectively.

are exhibiting more noise. This could reflect our choice to measure the inflation rate as the annualized monthly rate of growth. We expect that the responses should become smoother if we switch to the annual inflation rate on a monthly basis.[12]

A negative oil supply shock causes an increase in both expected and actual inflation rates, on impact. The effect of an oil supply disruption on the two target macroeconomic variables is persistently positive after 16 months (even though it reverts towards zero in the case of actual inflation in the first 3 months). A positive global economic activity shock induces a simultaneous and small increase in the expected inflation rate. The dynamic response is overall positive, with a peak registered after 9 months. The contemporaneous impact on headline inflation is positive and stronger in magnitude, but more uncertain in the dynamics. A positive oil consumption demand shock raises inflation expectations both instantaneously and dynamically, but the effect reverts to zero after the 15th horizon. The effect on inflation is more uncertain. An oil speculative demand shock has a negligible effect on both inflation variables on impact and it fluctuates around zero at all horizons. Moving to the European gas market, a gas supply disruption affects positively the expected and actual inflation, and the effect is persistent for most of the horizons. Surprisingly, a European economic activity shock has a much small impact on both inflation expectations and realized inflation rate. Gas consumption demand shocks are the most interesting, as they strongly positively impact expected inflation, even if it takes about 4 months for the effect to manifest; there is no sign of reversion after 16 months. The effect on inflation is more stable and short-lived, as the credible regions include the zero value for some of the horizons. Finally, a natural gas speculative demand shock has an unclear effect for the inflation measures, both on impact and dynamically, as the credible bands often are including the zero value.

From these results, some interesting considerations emerge. First, on our sample, whereas the European expected inflation is more affected from oil price increases coming from oil supply and aggregate global demand, at the same time it is more sensitive to gas shocks coming from supply or consumption demand, whereas the effect of European aggregate demand is less important. This suggests that consumer sentiment is more influenced by energy consumption coming from the gas sector rather than the oil one, which is consistent with the share of gas used in both industrial and household activities, and that the inflationary pressure in the examined time span is pushed from energy price shocks, rather than European aggregate demand. Second, the pass-through from energy price shocks to inflation expectations is stronger and more persistent than the transmission to headline inflation.

[12]We opted for the annualized rate of growth to make a comparison with the results obtained by Aastveit et al. (2021). Further extensions of the model will address this point.

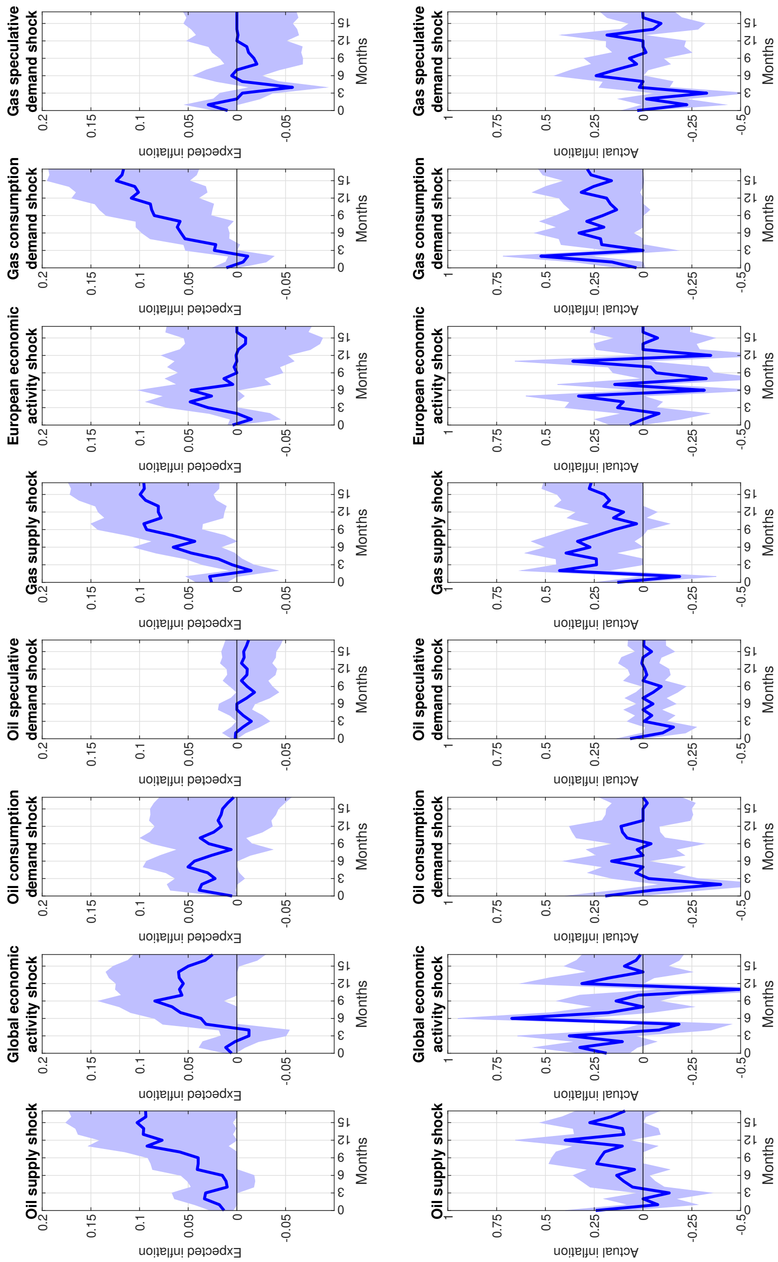

Figure 4: Impulse response functions of oil and natural gas market specific shocks on expected (top panel) and actual (bottom panel) inflation

5.2.2 Energy price shocks: spillovers between oil and natural gas markets

Since the interaction between the two energy markets of crude oil and natural gas in a structural perspective is a novelty, this section is dedicated to discussion these results.

First, we find that global oil market effects on the real price of oil and oil inventories are consistent with the results of Baumeister and Hamilton (2019) (the results are illustrated in Figure 5).

Second, pheraps not surprisingly, the gas market specific shocks effects on real price of gas and European gas stocks are similar to the oil shocks, apart from the economic activity shock. European aggregate demand shocks seem to have less impact on natural gas market. A negative gas supply shock of one standard deviation causes an increase in the real gas price, with a persistent and statistically significant effect. At the same time, it causes a drop in gas stock changes, and the effect is stronger on impact with respect to a global oil negative supply shock on inventories. European economic activity shocks affect positively the real spot price of gas on impact, but the effect reverts to negative values after three months. The effect on gas inventories is overall uncertain. A positive gas consumption demand shock has a positive and persistent effect on the real price of gas and a negative and persistent effect on stocks, with broader effects if compared with the specular oil market shocks. Finally, natural gas speculative demand shocks are in line with theory and cause both the real price and inventories change to increase. This is shown in Figure 6.

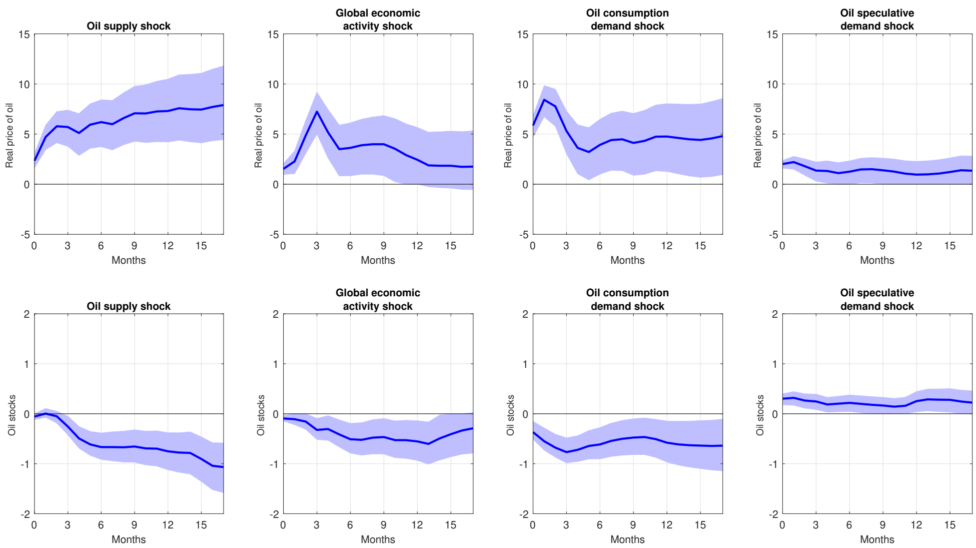

Figure 5: Impulse response functions of oil market shocks to oil price and inventories

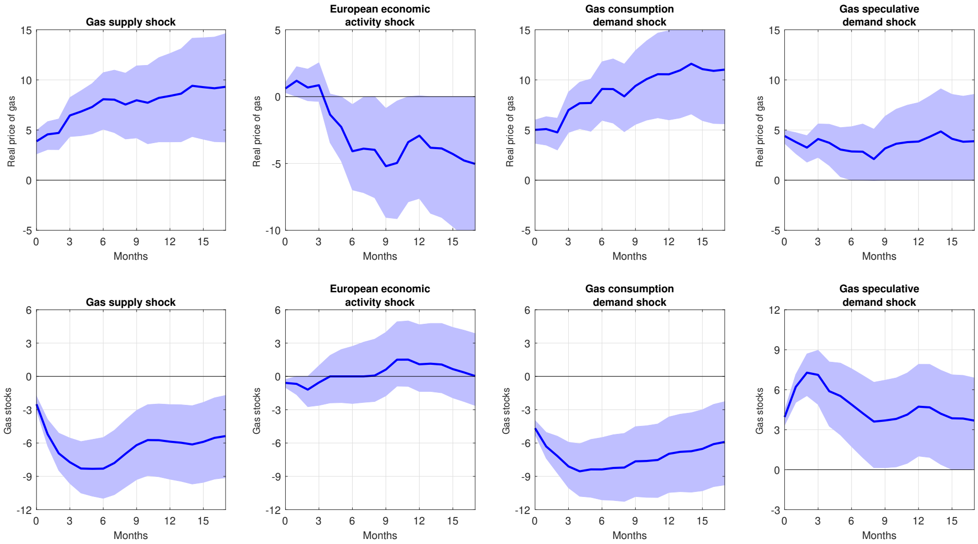

Figure 6: Impulse response functions of natural gas market shocks to gas price and inventories

We move now to the analysis of how oil global market shocks impact the real $TTFpriceofgasandEur$

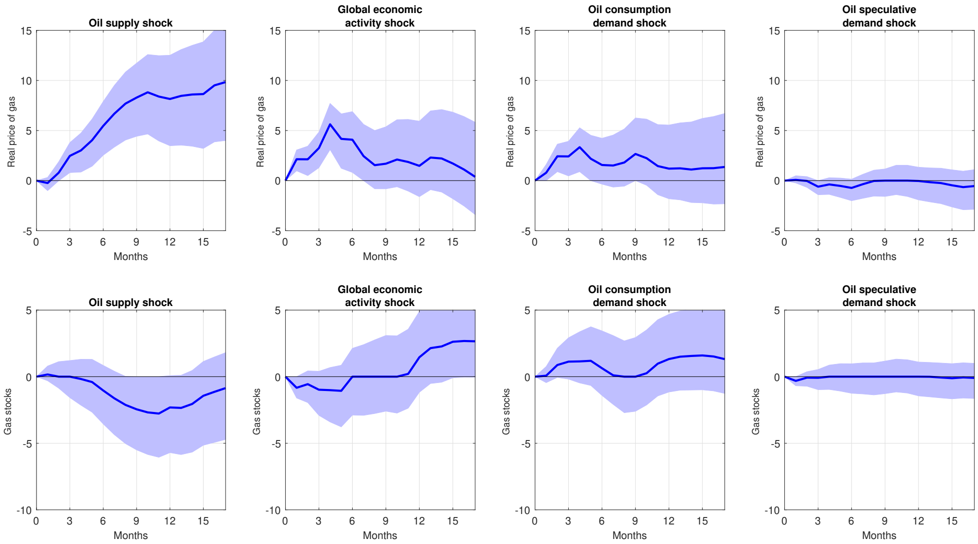

Figure 7: Impulse response functions of oil market shocks to gas price and inventories

[13] We remind that all the cross-market effects are restricted to be zero in matrix $\boldsymbol{A}$.

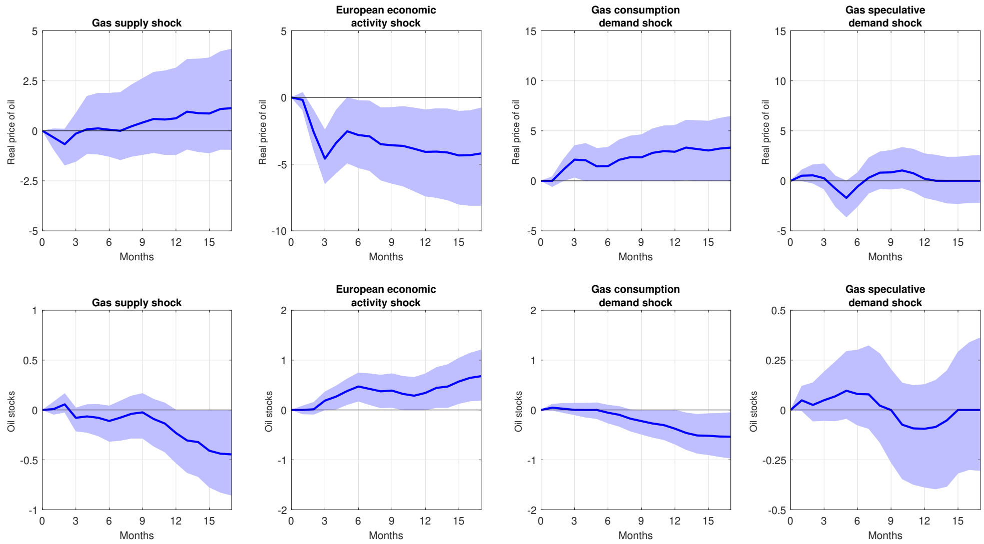

Figure 8: Impulse response functions of natural gas market shocks to oil price and inventories

The results from the cross energy shocks analysis demonstrate that there is interconnection between crude oil and natural gas prices, and this is more persistent in the direction from crude oil to natural gas. The literature considers the relationship between oil and gas markets weakest in the US than in Europe (Wei et al., 2022). The US decoupling of the two markets has started with the introduction of new technologies (such as the shale revolution), as stated in Batten et al. (2017). However, Zhang et al. (2017) find that, whereas the US gas price is linked to the volatility indexes, the European gas price is associated with the price of Brent, suggesting that the interaction between the two markets may be stronger in Europe. We find evidence in support of this finding, that is also in line with Jadidzadeh and Serletis (2017), who show the importance of structural supply and demand shocks in the oil market for explaining the US real price of gas.

5.3 Historical decomposition

Although impulse response analysis is useful to assess the importance of different kinds of shocks to the endogenous variables, it is also crucial to examine the relevance of shocks during specific time spans. With this aim, we compute the historical decompositions of the two measures of inflation during the last three years of the sample. This include a pre-Covid-19 subsample, the 2020-2021 period characterized by the pandemic wave, and the last year in which both the war scenario and the post-Covid-19 recovery are in act. Figures 9 and 10 report the historical decomposition in the selected periods for expected and actual inflation, respectively.

5.3.1 Expected inflation

The top panel of Figure 9 shows that expected inflation has been characterized by different dynamics according to the historical situation. During the pre-Covid-19 period (June 2019 to May 2020), inflation expectations were negative and overall mainly driven by natural gas supply shocks and by expected inflation shocks (see also the bottom panel, reporting the average historical decompositions by shocks contribution during the three subsamples). After the Covid-19 outbreak, the consumer sentiment dropped and economic activity shocks became more relevant in explaining the inflation expectations drop. Finally, during the last period we assist at both the economic recovery and the creation of geopolitical tensions caused by the Russian invasion of Ukraine. Interestingly, here the energy shocks are predominant. During all the three sub-periods, the most relevant shock driving the dynamics of inflation expectation is a shock "coming from itself", suggesting that consumer expectations about the future tend to self-feed. This is especially evident during the last two years, characterized by more economic uncertainty. At the same time, the relative importance of headline inflation in explaining inflation expectation is higher in the last year, which is also the one characterized by higher energy prices. This finding is in line with the results of Arora et al. (2013), showing that past inflation role in forming consumers expectations gains in terms of importance when there are peaks of energy prices.

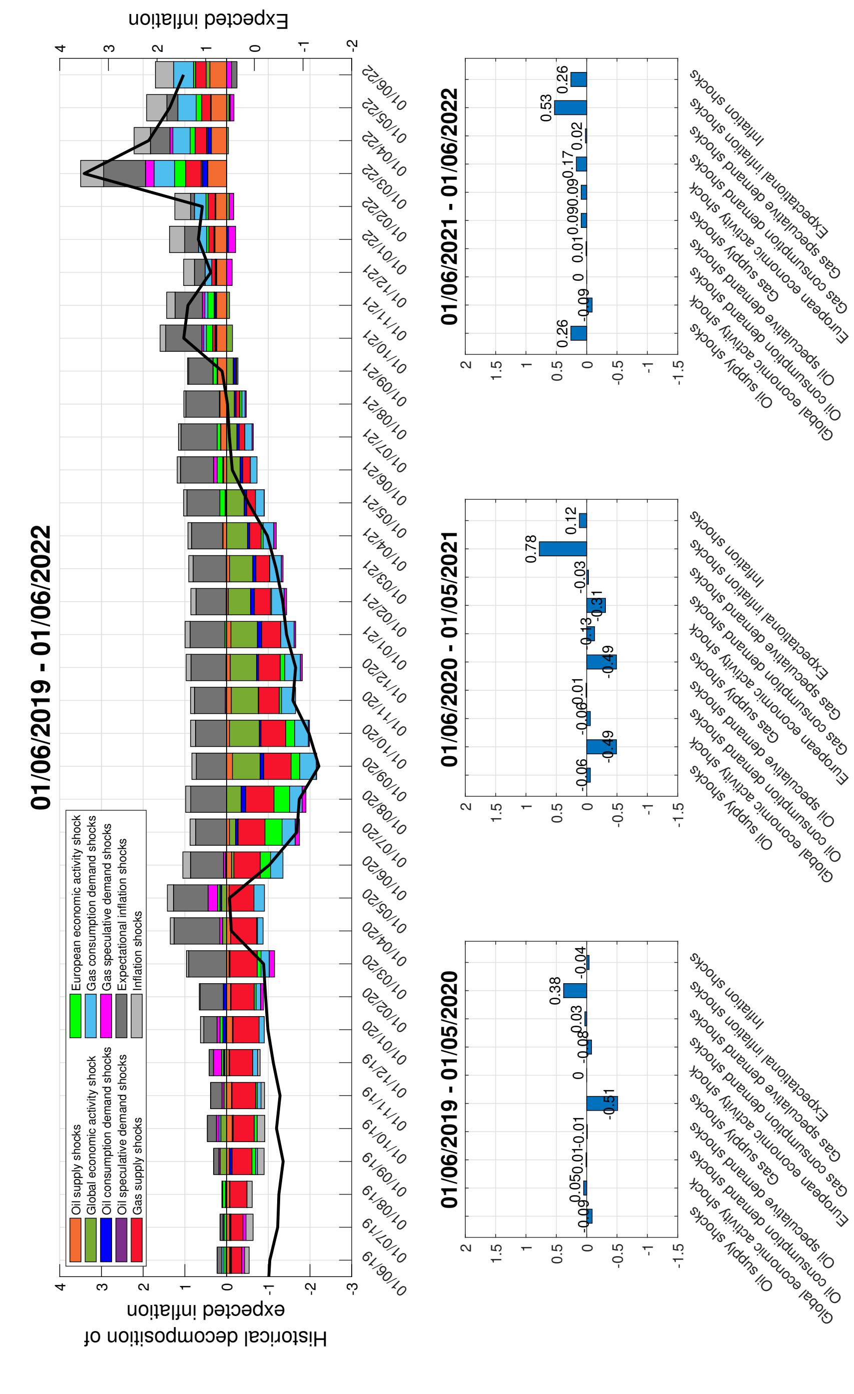

Figure 9: Historical decomposition of the expected inflation: pre, during and after Covid-19 periods

5.3.2 Actual inflation

The historical decomposition of the actual inflation rate is more puzzling. By looking at the top panel of Figure 10, we note that there is more fragmentation in the shocks contribution to the observed inflation fluctuations. Energy inflation, which can be thought as the sum of the inflation portion explained by the sum of all the energy shocks triggered by either oil or natural gas prices, seems predominant in both the first and the last periods (this is evident also from the bottom panel). During the Covid-19 pandemic, economic production is the main driver of the inflation rate, both on a global and European perspective. Also expected inflation contributes to the dynamics of headline inflation. Focusing on the last period, energy shocks dominate on economic activity, and also inflation expectations become marginal. In particular, gas market shocks are overall more important than oil market shocks, accounting for 2.08% of the total inflation rate (this is the sum of the shocks contributions coming from the supply and demand side, the latter including demand for inventories and consumption). In relative terms, gas consumption demand shocks are the most relevant ones, followed by oil and gas supply shocks. This result is of paramount importance, because it leads us to conclude that the recent inflationary tendency of the Euro area is not pushed by rising aggregate demand, rather it is triggered by energy inflation, in particular by the shocks originating in the European natural gas market.

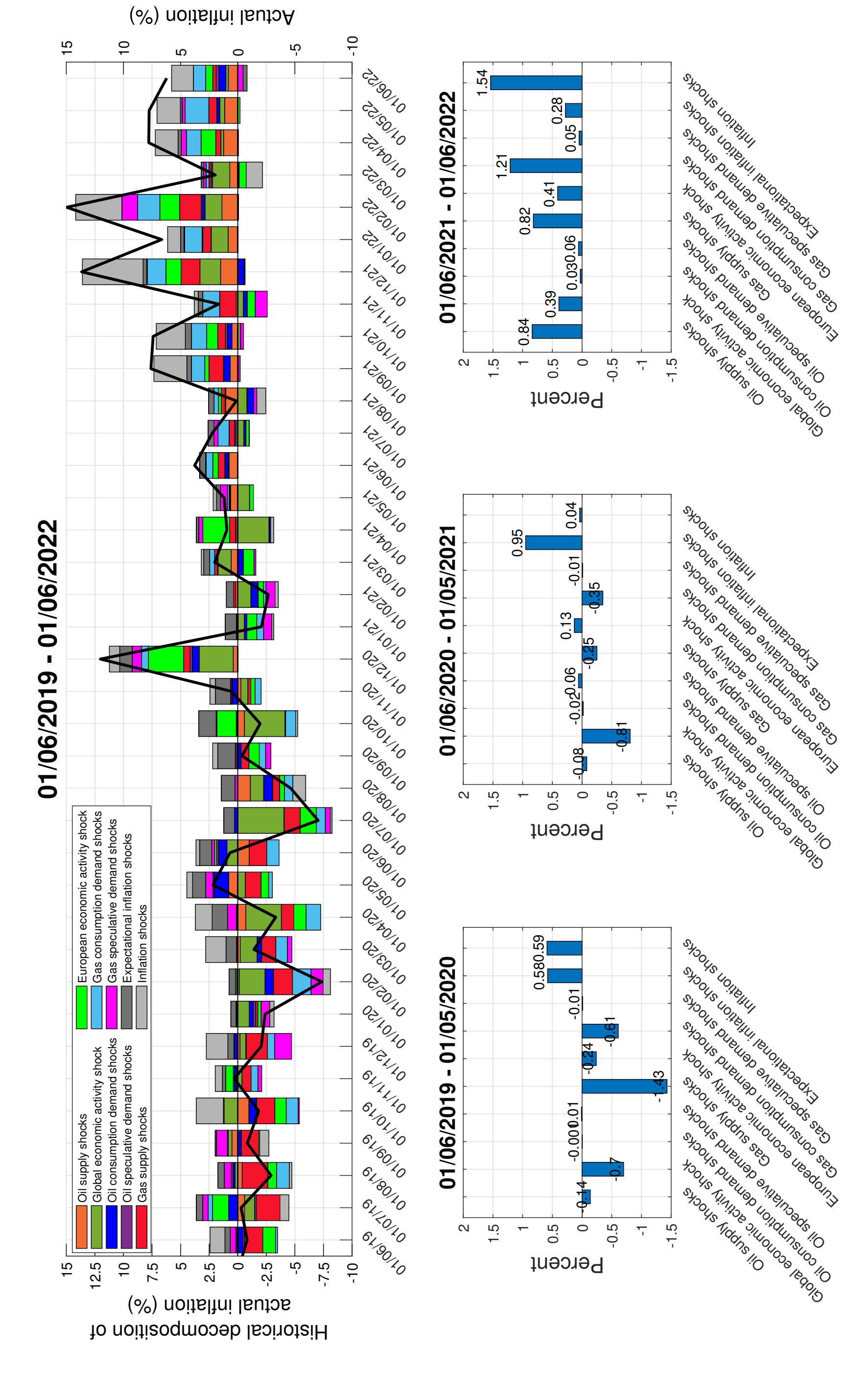

Figure 10: Historical decomposition of the actual inflation rate: pre, during and after Covid-19 periods

6 Conclusion

The Euro area is facing 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 expected and headline inflation. In order to design the most suitable monetary policy mix, it is of utmost importance to determine the *causes* of the current increasing inflation rate. This could be triggered by energy shocks or either by aggregate demand pressures, but the implications are different in terms of strategies. Specifically, it is crucial to assess how energy price shocks are transmitted to expected and realized inflation, how these two macroeconomic variables interact between each other, and if in the most recent period the phenomenon is somehow different fronm the past years. Moreover, it is fundamental to understand which kinds of energy shocks are predominant in explaining the inflation dynamics.

To address these questions, we design a Bayesian SVAR model in which we describe the interaction among two energy markets, the global oil market and the European natural gas market, as well as the pass-through fronm energy shocks to expected and actual inflation in the Eurozone. To our knowledge there are no precedent studies accounting for a structural specification for the European gas market, nor for the interaction between oil and gas markets modeled with separate equations for supply, consumption and inventories demand, and real economic activity.

We provide evidence that: (*i*) there is dynamic interdependence between the global oil market and the EU gas market, with the former having higher impact on the latter than viceversa; (*ii*) the effects of energy shocks on the inflation variables exhibit more persistence in the expected inflation, whereas the impulse responses of actual inflation are characterized by larger uncertainty; (*iii*) shocks in gas consumption demand and gas supply are most persistent when impacting the inflation expectations, together with global oil supply shocks; (*iiii*) the recent spike in the Euro area inflation is mainly driven by energy shocks rather than aggregate demand, whereas during the Covid-19 period economic activity was driving inflation.

We believe that these findings are relevant in order to design specific tools to mitigate inflationary pressures and to understand the relationship, and possible the propagation mechanism, of the current high inflation with the rest of the macroeconomy.

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