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Lucia López, Florens Odendahl,
Susana Parraga Rodriguez,
Edgar Silgado-Gómez

The pass-through to inflation of gas price shocks

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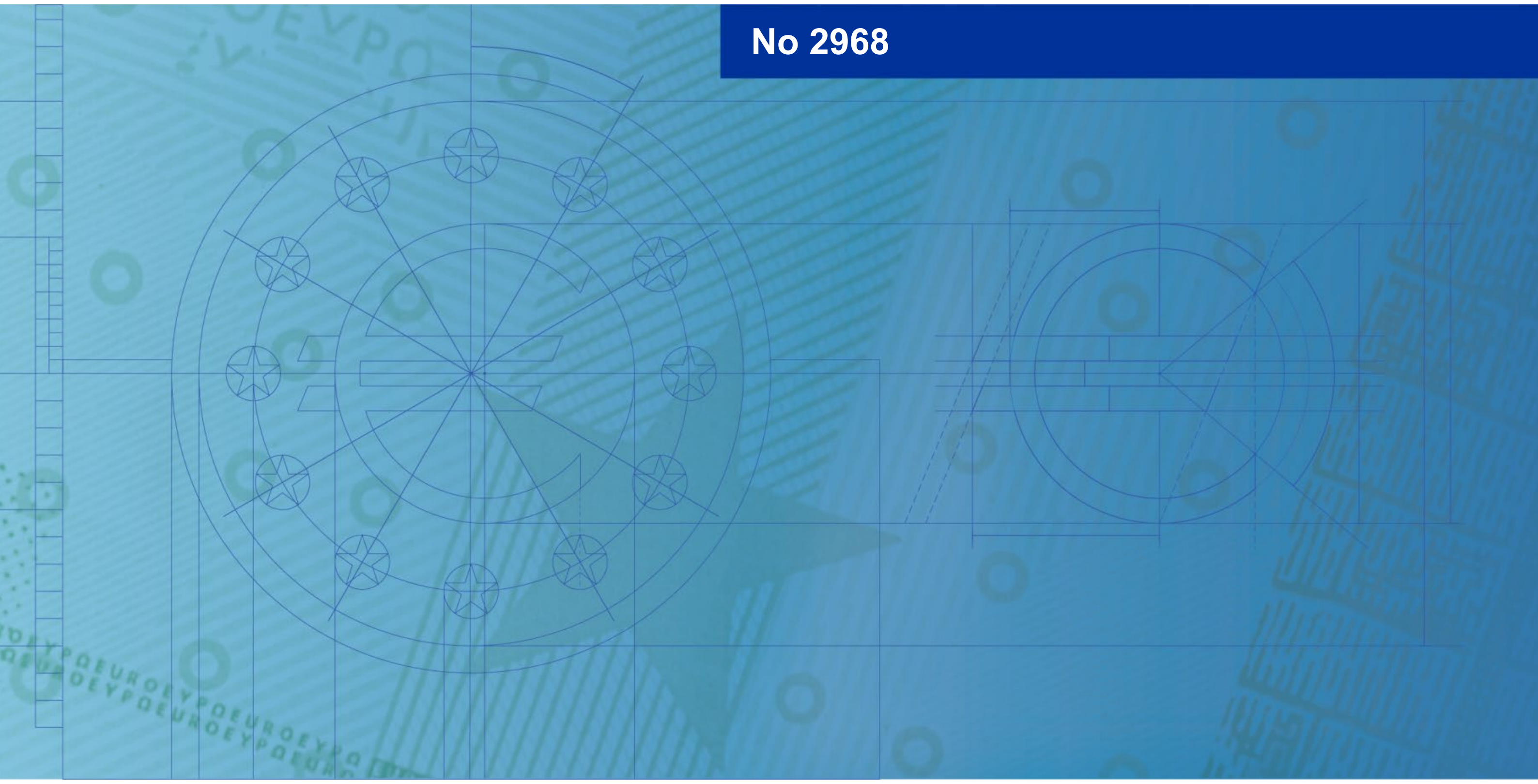

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Abstract

This paper analyses the pass-through of gas shocks to inflation in the euro area. First, it uses a Bayesian Structural Vector Autoregressive (BSVAR) framework to estimate the effects of gas supply shocks on headline inflation in the euro area and its four largest economies. A gas supply shock that increases gas prices by 10% raises euro area headline inflation by 0.6 percentage points after one year. The transmission of gas supply shocks is driven by direct and indirect effects, i.e. by households consuming gas products and by second-round effects through production costs. We document cross-country heterogeneity arising from differences in reliance on energy commodities across consumption and production, as well as from variation in the regulation of retail energy prices. Second, we build a New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model augmented with energy and show that indirect effects account for approximately 75% of the cumulative response of headline inflation after three years.

JEL Classification: C11, C32, E31, Q41.

Keywords: Gas Shocks; Headline Inflation; Bayesian VARs; New Keynesian DSGE.

Non-technical summary

The recent inflation surge in the euro area was significantly influenced by energy prices, particularly gas following Russia's invasion of Ukraine in February 2022. While past studies have largely focused on the impact of oil prices on inflation, this research shines a light on the role of gas prices.

This paper estimates empirically the pass-through of gas supply shocks to consumer prices in the euro area, including the largest economies in the region: Germany, France, Italy, and Spain. The sample period goes from January 1997 to December 2024. We also develop a theoretical model to gain deeper insights into how gas supply shocks influence consumer prices differentiating between their direct and indirect effects. Direct effects include basically increased spending on gas products like home heating, while indirect effects involve gas usage in the production processes.

Overall, the paper shows how gas supply shocks feed into euro area inflation. Our estimates suggest that a 10% increase in gas prices raises headline inflation by about 0.6 percentage points after one year, with most of the impact coming through indirect channels, as gas is a key input in production. The effects also vary across countries: Germany, Italy and Spain show stronger responses due to higher energy use and faster adjustment of retail prices, while France's highly regulated energy markets dampen the impact. To better understand these findings, we use an economic model that highlights the importance of indirect effects, which account for about three quarters of the total inflation response after three years. The model also helps explain recent inflation dynamics in the euro area, showing that gas supply shocks played a large and lasting role.

1 Introduction

Energy prices have been a key driver of the recent inflation surge in the euro area. Precisely, Russia's invasion of Ukraine in February 2022 triggered an unprecedented spike in gas prices, placing gas at the center of European energy markets. Yet, the inflationary effects of gas price shocks remain relatively unknown because the literature has focused on oil price shocks (see, for example, Blanchard and Galí, 2007; Clark and Terry, 2010; Kilian and Lewis, 2011; Baumeister and Peersman, 2013; Gao et al., 2014; Choi et al., 2018; Baumeister and Hamilton, 2019; Känzig, 2021; Cai et al., 2022) or the relation between oil and gas prices (see, for example, Brigida, 2014; Zhang and Ji, 2018; Szafranek and Rubaszek, 2023).

This paper instead provides a comprehensive study of the effects of gas shocks on consumer price inflation. Our contribution to the literature is twofold. First, we provide empirical evidence on the pass-through of gas supply shocks to inflation in the euro area. Second, we rationalize these findings by embedding gas in a New Keynesian Dynamic Stochastic General Equilibrium model (NK-DSGE).

We use a Bayesian Structural Vector Autoregressive (BSVAR) model to estimate the pass-through of international wholesale gas supply shocks into the Harmonised Index of Consumer Prices (HICP) inflation in the euro area and its four largest economies: Germany, France, Italy and Spain. The dataset of monthly observations spans from January 1997 to December 2024. Because not all commodity shocks are alike (Kilian, 2008), we focus on supply-side gas shocks and exploit the large gas supply disruptions in the latest part of the sample to complement the identification of the BSVAR with the narrative sign restrictions methodology introduced by Antolín-Díaz and Rubio-Ramírez (2018). To properly identify gas supply shocks, the baseline BSVAR controls for aggregate demand developments. Because of the historical relationship between oil and gas prices, our baseline specification also controls for oil supply shocks. Robustness exercises show that our identified gas supply shocks are not contaminated by other commodities shocks, including gas demand shocks, or other supply-side shocks related to production bottlenecks.

We further contribute to a better understanding of the dynamic effects of gas supply shocks by breaking down the estimated total effects into *direct* and *indirect* effects. In terms of consumer prices, direct effects of gas price increases can be measured via the HICP component CP0452, which summarises consumer prices for gas for cooking, home heating and hot water. Indirect effects capture the downstream impact of using gas as an input in production processes. The importance of the latter depends on whether gas is used intensively during the production processes or whether gas prices influence the pricing of other inputs such as electricity or heat production (Pacce et al., 2021). The effects of the gas price changes on electricity prices can be measured via the HICP component CP0451, which summarises electricity prices for consumers. Other indirect effects can be measured as the HICP headline inflation response that cannot be explained by movements in CP0451 or CP0452.

We find that gas supply shocks have significant inflationary effects: a gas supply shock that increases gas prices by 10% leads to a gradual increase of headline inflation that peaks at about 0.6 percentage points after one year. The *pass-through*, measured as the cumulative inflation response divided by the cumulative response of the gas price, builds up over time and reaches a maximum of 0.05 about 20 months after the shock. Country-level estimates indicate that economies with stronger inflationary responses to gas supply shocks, Germany, Italy and Spain, tend to be more intensive users of energy commodities in their production structures or consumption baskets or, as in the case of Spain, use an electricity market regulation that allows for a faster transmission of prices from wholesale to retail. In turn, France displays the smallest inflationary response to the gas supply shock as a result of using less gas for electricity production and having highly regulated gas and electricity retail markets with sticky price contracts.

On the theoretical side, we develop a NK-DSGE model augmented with energy, which is a complementary input for intermediate goods firms and a complementary good for households. In this framework, the energy bundle is composed of gas and oil. In this way, and similarly to the empirical section, we also account for oil fluctuations when identifying the gas shocks.

Our baseline NK-DSGE model performs well matching the IRFs of the BSVAR analysis. We obtain the same qualitative results with some quantitative differences. Our findings here highlight the importance of indirect channels in shaping inflationary dynamics after gas shocks. In particular, a large share of the overall inflationary response, around 75% after three years, is explained by second-round effects operating through production cost adjustments rather than direct price translations.

A recent but still scant literature is building up evidence about the pass-through of gas price shocks in Europe. Lan et al. (2022) estimate the direct pass-through of international gas prices on

German HICP gas inflation. Günter et al. (2024) apply the oil market model pioneered by Kilian (2008) to the German gas market. Both papers thus focus on a single European economy. Casoli et al. (2024) extend the oil market model with additional blocks for the gas market and inflation in Europe, but the contemporaneous relationship between gas and oil prices in their model might cast doubt on the estimates of the pass-through of gas prices. Adolfsen et al. (2024) use estimated structural gas shocks from an empirical gas market model to analyse the pass-through to euro area inflation of demand-driven, supply-driven and expectations-driven structural gas shocks using local projections. Different from their work, we provide evidence on the pass-through of gas supply shocks in different euro area countries. Alessandri and Gazzani (2025) construct an instrument for gas supply shocks to identify their effects on euro area core inflation. Different from their work, we rely on narrative sign restrictions for identification of the effects of gas supply shocks. Further, we look into different HICP items and extend the sample to the four largest European economies. Moreover, and most importantly, we rationalise our empirical findings with a theoretical model. Bańbura et al. (2023) develop a large BVAR to identify a large number of shocks via sign and zero restrictions, including an oil demand, oil supply and *gas price* shock. Different from Bańbura et al. (2023), we identify a *gas supply* shock by using both sign and *narrative sign* restrictions, in particular, by focussing on narrative episodes of gas supply shocks.

Among the most closely related theoretical work, Gagliardone and Gertler (2023) develop a New Keynesian model aimed at accounting for the recent sudden and persistent rise in inflation in the US economy. Their model places particular emphasis on the role of oil shocks. Instead, we account for both oil and gas fluctuations in the euro area.

The remainder of the paper is organised as follows. Section 2 summarizes the development of the European gas market and the narrative episodes used to identify the empirical model outlined in Section 3. Section 4 contains an NK-DSGE model with energy inputs to rationalize the empirical results. Section 5 offers concluding remarks.

2 Institutional Framework

2.1 A Brief History of the European Gas Market

The creation of the European gas market took off in the late 1990s. Figure 1 presents a timeline with key dates in its development. European Directives in 1998 and 2003 set the benchmark to expand the internal EU gas market. The Directives aimed at breaking vertical integration in the gas industry and introducing competition. A third Gas European Directive in 2009 promoted the integration of the European gas market and introduced incentives for launching trading hubs (Bastianin et al., 2019).

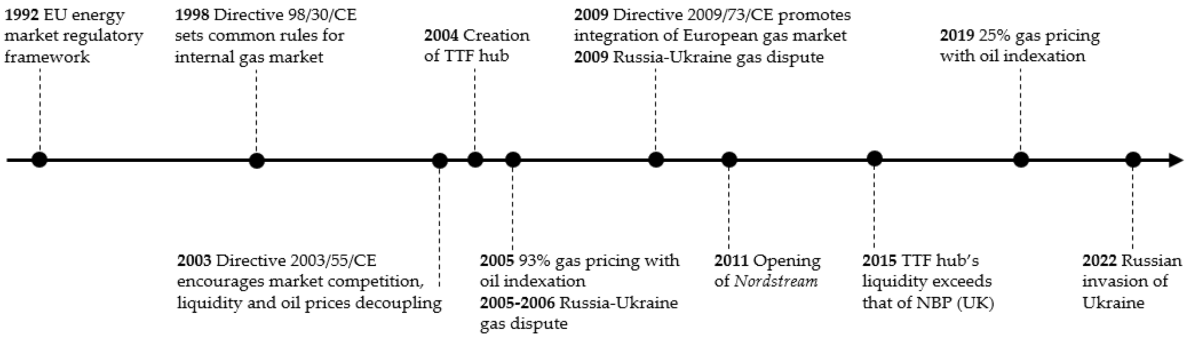

Figure 1: Timeline of the European Gas Market

In the early stages of the European gas market, openness and competitiveness were difficult because long-term contracts linked to oil prices predominated; a system also known as *oil indexation*. Oil indexation provided the necessary stability to develop gas infrastructures, but prices did not necessarily reflect the supply and demand fundamentals of the gas market. Over the last two decades, gas prices have moved away from oil indexation to spot pricing. International Energy Agency (IEA) data shows that oil-indexed contracts went from accounting for 93% of the European gas imports pricing mechanism in 2005 to 25% in 2019.[1] This transition to spot pricing accelerated after the 2008 financial crisis amid loose market conditions, the ending of contracts or the renegotiation of their terms to include spot pricing terms, as well as a new round of EU energy market legislation to improve the operation of the internal energy market.[2]

Over time, liberalisation promoted deep and liquid wholesale gas trading hubs such as the Title Transfer Facility (TTF) gas market, operative since 2004. The TTF has become the most liquid gas market in Europe, overcoming traded volumes in the UK National Balance Point (NBP) market around the mid-2010s (see, for example, European Commission, 2018). Currently, the TTF constitutes a benchmark for gas prices in Europe and worldwide, together with the US Henry Hub.

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[1] See IEA, Evolution of Europe's gas import pricing mechanisms: from oil- to hub-indexation, https://www.iea.org/data-and-statistics/charts/evolution-of-europe-s-gas-import-pricing-mechanisms-from-oil-to-hub-indexation.

[2] See International Gas Union Wholesale Price Reports for different years at www.igu.org.

2.2 Narrative Episodes of Supply-Driven Gas Price Disruptions

Another unique characteristic of the European gas market is its dependency on imports from Russia. Figure 2 shows that Russia was the single largest provider of gas to the euro area.[3] Moreover, Ukraine was a major corridor for the transit of Russian gas to Europe. To bypass Ukraine's quasi-monopoly in the gas transit to Europe, Russia made several attempts to construct new pipelines traversing either to the south or to the north of Ukraine. These efforts were marked by numerous gas disputes, the most remarkable in terms of European gas flows being the 2005-2006 and 2009 gas crises, while in 2011 they led to the opening of the gas pipeline *Nord Stream*. Conversely, following the Russian invasion of Ukraine in 2022 gas flows from Russia plummeted.

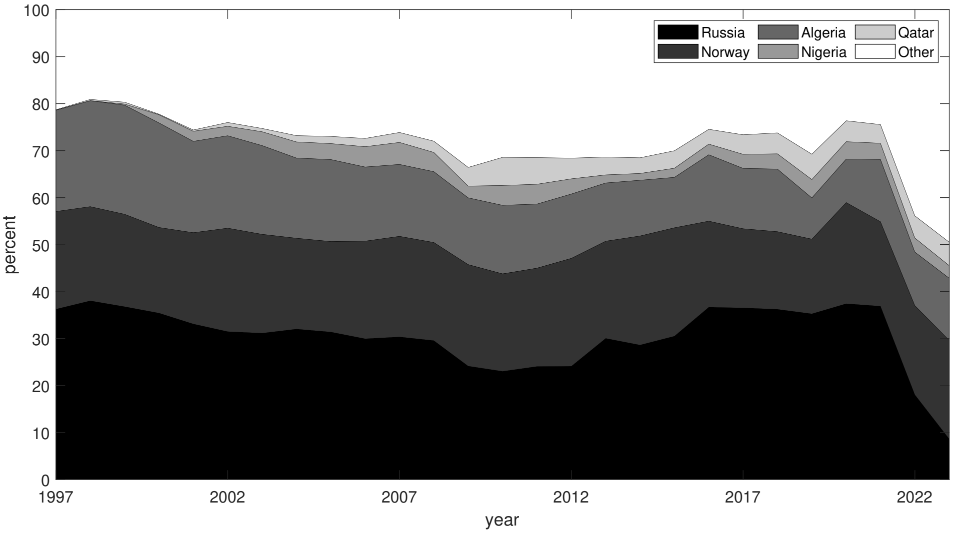

Figure 2: Euro Area Gas Imports by Origin. 1997-2023

Figure 3 highlights the episodes of gas supply shocks in 2005-2006 ("1st Gas Dispute"), in 2009 ("2nd Gas Dispute"), in 2011 ("Nord Stream") and in 2022 ("Russian Invasion of Ukraine"). The figure further plots high commodity prices π_t calculated following Hamilton (2003):

$$\pi_t = \max\left\{0, \frac{p_t}{\bar{p}_t^{3yr}} - 1\right\}, \tag{1}$$

with p_t the commodity price in month t and $\bar{p}_t^{3yr}$ the average price during the preceding 3 years. The figure also shows that oil price increases used to lead gas price increases until the 2010s. Next, we describe each episode in detail.

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[3] The latest available data point is 2023. See https://doi.org/10.2908/NRG_TI_GAS for details.

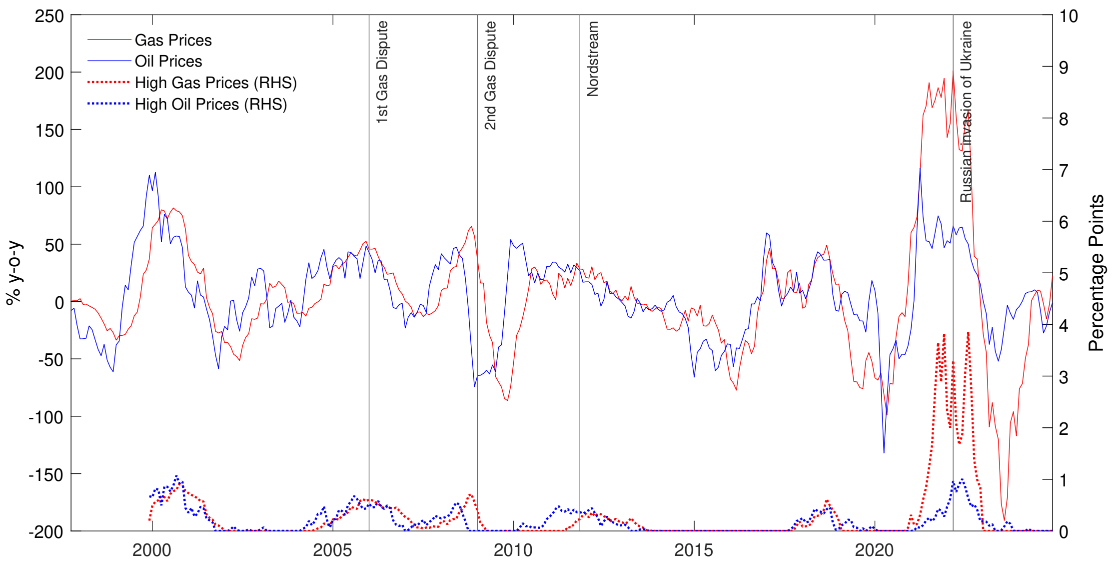

Figure 3: Episodes of Exogenous Gas Supply Shocks

Stern (2006) and Pirani et al. (2009) document that the deterioration in Russian-Ukrainian relations during 2005 led to a short-lived but significant dispute during 1-3 January 2006 (1st gas dispute).[4] The Russian demands to update the long-term contracts with Ukraine to charge higher prices were continuously rejected by Ukraine, preferring instead an extended transition period before paying higher prices. As a result, Russia cut off gas supplies to Ukraine and, in turn, Ukraine diverted volumes destined for the rest of Europe. By January 2, Hungary reported to have lost up to 40% of its Russian supplies; Austrian, Slovakian, and Romanian supplies were said to be down by one-third, France by 25-30%, and Poland by 14%. Italy reported having lost around 25% of deliveries during January 1-3. German deliveries were also affected but no further details are known. On 4 January 2006, a preliminary agreement was achieved, and gas flows were restored. At the same time, relatively mild weather and the halt in production of gas-intensive industrial producers during the New Year holiday period are evidence that this episode of high gas prices was supply-side driven. Therefore, we assume that the 1st Russia-Ukraine gas dispute constitutes a negative supply gas shock.

In 2009 another significant gas dispute took place between Russia and Ukraine (2nd gas dispute). Pirani et al. (2009) document how the accumulation of debt that Ukraine owed to Russia led to a new crisis from January 1 to 22, 2009. By January 6 Russian gas deliveries to Europe were drastically reduced and cut off on January 7. Gas was cut off completely to countries

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[4] See also “Russia vows to end gas shortage”, January 2, 2006, *BBC News Website*.

in south-eastern Europe which were very dependent on Russian imports, and partially to other countries, for 13 days. Supplies to Europe had never been halted before, as during the 2006 episodes the shortfalls in supplies to Europe resulted not from European supplies being halted, but from Ukraine diverting a proportion of European volumes for its own use. On 19 January two new long-term contracts for supply and transit between Russia and Ukraine were signed and gas flows to Europe were restored the following day. Again, we assume that the 2nd Russia-Ukraine gas dispute constitutes a negative supply gas shock.

In 2011, several new gas facilities were developed, including pipelines from Algeria and Russia (IEA, 2012). In November 2011, the *Nord Stream* pipeline was officially inaugurated. Its construction was part of Russia's politically motivated strategy to limit the influence of transit countries such as Ukraine, while increasing Europe's energy dependence on Russia (Solum Whist, 2008). The opening of *Nord Stream* increased the gas supply to Europe, and the new route became one of the most significant gas corridors from Russia (McWilliams, 2021). By 2014, Russia was delivering 33 billion cubic meters (bcm) of gas via *Nord Stream*, slightly more than the 31 bcm of gas routed via Ukraine/Slovakia (Erbach, 2016). Therefore, we assume a positive gas supply shock occurred in the month of the opening of *Nord Stream*.

More recently, Russia's invasion of Ukraine in February 2022 resulted in restrictions on the volume of energy imports from Russia, which generated tensions in the European wholesale natural gas markets. The conflict put further pressure on already tight European energy markets, as evidenced by diminished gas storage levels compared to historical averages and a substantial decline in Russian pipeline gas imports (see, for example, IEA, 2022). Keliauskaitė et al. (2025) show reduced gas transit from Russia in March 2022, where gas supply via the *Yamal* pipeline to Germany effectively dropped to zero in March. As a reaction to EU financial sanctions, Russia started to demand payments for Russian gas to be made in Russian rubles, which the EU rejected. Ultimately, Russia unilaterally cut deliveries through *Yamal* and *Nord Stream* in the months to follow. Seasonally adjusted month-on-month (nominal) gas prices increased by 60% from February 2022 to March 2022, the largest monthly increase in the sample from 1997m1 to 2024m12.[5] The large month-on-month change in gas prices, together with the narrative evidence regarding the

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[5] Comparing this episode to the recent literature, Alessandri and Gazzani (2025) document a concentration of daily news about gas market disruptions linked to fears on Russian supply to the EU in March 2022 and their gas supply shock instrument, based on daily changes of the one-month TTF futures, suggests an aggregate gas price change due to supply side surprises in the month of March 2022 of 68%.

Russian invasion of Ukraine, and the drastic drop in European imports of Russian gas leads us to impose two narrative sign restrictions for March 2022. First, the sign of the gas supply shock is negative in March 2022 and, second, that the gas supply shock is the overwhelming contributor to the gas price variation in the same period.

Finally, we do not use periods with disruptions in the European gas prices that appeared to be led by developments in other commodity markets, such as coal or oil. For instance, our reading of IEA reports at the time suggests that rising oil and coal prices drove up European hubs' gas prices in September 2018. Further, we also do not use periods for the narrative sign restrictions with a potentially sizeable contribution of demand factors or where it was not possible to determine whether demand or supply factors dominated. For example, early in 2018, a cold wave in UK and Ireland triggered an outstanding increase in seasonal demand while the severe weather conditions damaged key elements of the infrastructure in March 2018. We decided against using this period for narrative restrictions because it is not straightforward to determine whether demand or supply factors dominated. We also did not use gas price disputes around the Russian invasion of Crimea in 2014, as they did affect the gas supply to Ukraine but did not affect the transit flow of gas to the rest of Europe.

3 The Empirical Framework

Consider the standard Vector Autoregressive (VAR) model

$$\mathbf{y}_t = c + \sum_{j=1}^{12} A_j \mathbf{y}_{t-j} + \beta \mathbf{X}_t + \mathbf{u}_t, \tag{2}$$

where $\mathbf{y}_t$ represents the $n \times 1$ vector of endogenous variables, c is the intercept, A_j denotes the $n \times n$ matrices of lagged coefficients and $\mathbf{X}_t$ contains exogenous control variables. The innovations $\mathbf{u}_t = \mathbf{B}\epsilon_t$ correspond to a linear combination of the structural shocks ϵ_t. We use 12 lags according to the Akaike information criteria and the conservative upper bound set by Kilian and Lütkepohl (2017). The VAR model is estimated using Bayesian methods adopting a non-informative conjugate uniform-normal-inverse Wishart prior (Antolín-Díaz and Rubio-Ramírez, 2018).

We use a combination of sign and narrative restrictions to identify economically meaningful impulse responses. We impose restrictions on the sign of the effect that the different shocks have *on impact* on the variables, shown in Table 1. Note that whenever we refer to gas prices, we actually refer to the real price of gas as defined below. A gas supply shock increases the gas price, decreases activity and increases inflation. We separately identify a demand shock, for which gas prices, activity and general inflation increase. We *complement* the traditional sign restrictions with narrative sign restrictions (Antolín-Díaz and Rubio-Ramírez, 2018), i.e. for a few selected episodes, discussed in Section 2, we argue that we can impose the sign (or relevance relative to other shocks) of the gas supply shock.[6] Table 1 summarises the episodes when, based on historical knowledge of the gas market and its development at the time, unexpected and significant gas supply changes occurred and the direction of the changes is known.

Our key identifying assumption is that the gas supply shocks have the respective sign in any of the selected narrative periods and that, in March 2022, the gas supply shock explains more of the gas price variation than all the other shocks combined. Again, we consider four episodes for the narrative sign restrictions: i) gas disputes of January 2006; ii) gas disputes of January 2009; iii) opening of Nord Stream in November 2011; and iv) Russian invasion of Ukraine in March 2022. The 2006 and 2009 episodes constitute a negative gas supply shock, and the 2011 episode a positive gas supply shock. For the 2022 episode, we impose that the negative gas supply shock also constitutes the main contributor to the gas price variation in that month. As described before, the exceptional events surrounding the supply of gas to Europe via Russia in March 2022 lead us to use this period as our baseline narrative sign restrictions, while leaving to the robustness checks exploring alternative restrictions based on the other episodes.

The dataset includes monthly observations from 1997m1 to 2024m12 for the euro area, and, respectively, the four largest economies in the region: France (FR), Germany (DE), Italy (IT) and Spain (ES). The vector $\mathbf{y}_t$ contains gas prices and the harmonised consumer price index (HICP), as well as control variables for the general level of economic activity and the stance of monetary policy. Long historical series of country-level gas prices are not available because European gas hubs developed late (see Section 2). We overcome this shortcoming using gas prices for Europe from the World Bank's pink sheet data; note that the correlation between the European gas prices and the available individual countries' series is very high. We convert gas

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[6] Following the recommendations of Antolín-Díaz and Rubio-Ramírez (2018) and An et al. (2021) we set the number of draws and resampling weights to have approximately 1000 unique posterior draws that satisfy both the sign and narrative restrictions.

Table 1: BVAR Identification Restrictions

Variable	**Gas supply shock**	**Demand shock**
Sign Restrictions:		
Gas price$_{h=0}$	$+$	$+$
Activity$_{h=0}$	-	$+$
HICP$_{h=0}$	$+$	$+$
ECB rate$_{h=0}$	...	...
Narrative Sign Restrictions:		
01/2006	$\epsilon_t^{\text{gas supply}} < 0$	
01/2009	$\epsilon_t^{\text{gas supply}} < 0$	
11/2011	$\epsilon_t^{\text{gas supply}} > 0$	
03/2022	$\epsilon_t^{\text{gas supply}} < 0$, major contributor	

Notes: The table shows the sign and narrative sign restriction imposed to identify gas price and demand shocks. The sign restrictions refer to the sign of the IRF on impact. Dots imply that we do not impose any sign restrictions. The narrative sign restrictions refer to the sign of the gas supply shock in the respective month, denoted by $\epsilon_t^{\text{gas supply}}$. A negative (positive) $\epsilon_t^{\text{gas supply}}$ implies that the gas supply shock decreased (increased) gas supply in that month. "major contributor" refers to the *Type B overwhelming contributor* restriction of Antolín-Díaz and Rubio-Ramírez (2018).

prices into euros, seasonally adjust and deflate them by the seasonally adjusted HICP.[7] We use the Economic Sentiment Indicator (ESI) produced by the European Commission as the monthly indicator for economic activity. The ESI is a survey-based indicator that tracks GDP growth. Its coverage is wider than other monthly activity indicators like industrial production as it includes the sectors of industry, services, consumers, retail and construction. We use the short-term interbank interest rate for the euro area (Eonia for 1997-2004 and €STR since the end of 2022) to control for the monetary policy stance. However, as the standard interest rates cannot capture the non-conventional measures that the ECB has implemented since the 2008 financial crisis, we use instead the Wu and Xia (2016, 2020) euro area shadow rate from September 2004 to August 2022. The BSVAR is estimated on the month-on-month growth rates of all the variables except for the interest rate.

Due to the historical relationship between oil and gas prices, it is important to clean all series in $\mathbf{y}_t$ of oil shocks. Otherwise, the identified gas supply shocks could be contaminated by oil price shocks that might satisfy similar traditional sign restrictions as the gas supply shocks.

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[7] Headline HICP series for France, Italy and Spain are retrieved from Eurostat and seasonally adjusted by us, while the European Central Bank and the Bundesbank publish seasonally adjusted series for headline HICP in the euro are and Germany, respectively.

To address such concerns, $\mathbf{X}_t$ contains the exogenous oil supply news shocks of Känzig (2021). Moreover, we include exogenous monthly dummy variables to control for the Covid lockdowns and reopening disruptions between March 2020 and September 2020.

Finally, to decompose the total effect of gas supply shocks into different consumer price components, we also present results that distinguish between *direct* and *indirect* effects. Direct effects can be approximated by substituting the headline HICP in the BSVAR by the gas products HICP item (COICOP-0452, *Gas*). The *Gas* component measures the consumer prices paid for household purchases of gas for cooking, heating, and hot water. We separate the indirect effects into two parts. For the household prices for electricity, (COICOP-0451, *Electricity*), we estimate explicitly the effect of a gas supply shock. The remaining indirect effects are approximated by subtracting the response of *Gas* and *Electricity* from the total response of headline inflation. The BSVAR for the *Gas* and *Electricity* HICP items is estimated using the same specification and identification strategy as the baseline BSVAR but substituting the headline inflation variable by the respective HICP component.

3.1 The Pass-through of Gas Supply Shocks to Inflation

Figure 4 shows the impulse response (IRF) of the gas price (left panel), the impulse response of euro area headline HICP year-on-year inflation (middle panel), and the *pass-through* (right panel) to a gas supply shock that increases the gas price by 10%. Similarly to fiscal multipliers, the *pass-through* is computed as the cumulative inflation response divided by the cumulative response of the gas price. Precisely, the *pass-through* is computed as:

$$\textit{pass-through} = \frac{\sum_{h=0}^{H} \mathrm{IRF}_{\mathrm{HICP},h}}{\sum_{h=0}^{H} \mathrm{IRF}_{\mathrm{Gas\ Price},h}}$$

where H is the horizon under consideration and $\mathrm{IRF}_{\mathrm{HICP},h}$ and $\mathrm{IRF}_{\mathrm{Gas\ Price},h}$ are the respective month-on-month impulse response functions (IRFs) of HICP and gas prices after a gas supply shock.

The shaded areas report 68 percent credible intervals. Black lines represent the posterior median IRFs identified with traditional sign restrictions. Red lines show the posterior median IRFs identified using traditional sign restrictions and complementary narrative sign restrictions based on the episode of the Russian invasion of Ukraine in early 2022. Specifically, we assume a negative gas supply shock and that this gas supply shock is the overwhelming contributor to explaining the gas price dynamics in March 2022. To facilitate the interpretation of the results, we present annualized IRFs (the non-transformed IRFs are presented in Appendix A).

We find that the narrative sign restrictions reduce the width of the credible intervals such that the gas supply shock causes HICP inflation to increase for about 12 months with high posterior probability. Further, the posterior median of the inflation response is about 0.1 percentage points larger at its peak compared to traditional sign restrictions. In particular, at the posterior median, a gas supply shock that increases the price of gas by 10% increases year-on-year headline inflation by about 0.6 percentage points after 12 months, at which point the inflation response starts to decline and the credible intervals start to contain zero. The *pass-through* (right panel in Figure 4) builds up over time, reaching a maximum of about 0.05 around 20 months after the shock. Appendix A shows that the ESI falls following a gas price increase, while the interest rate increases. Our estimates are in line with Alessandri and Gazzani (2023), although they find slightly weaker inflationary effects on impact.

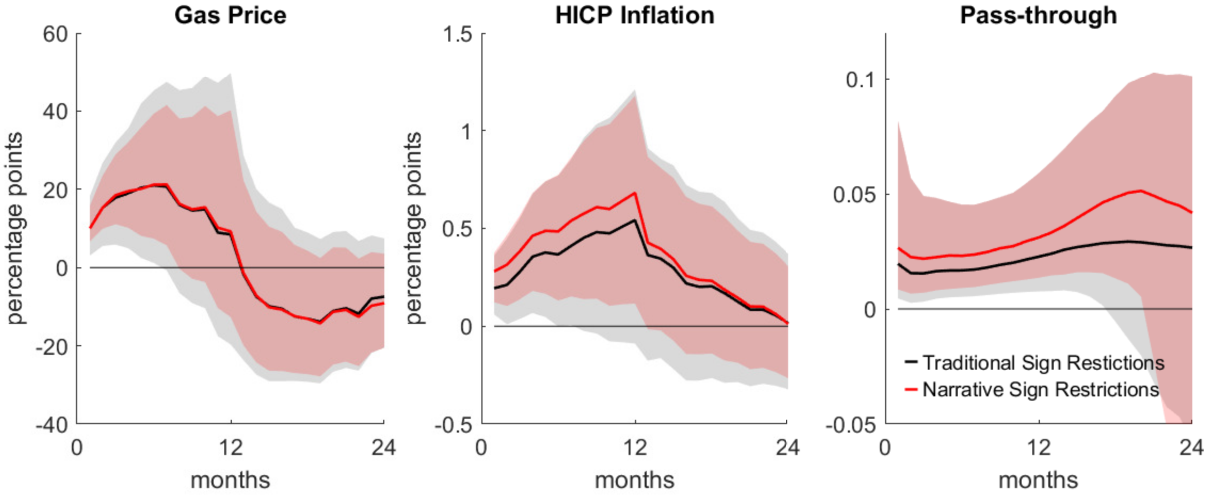

Figure 4: Impact of Gas Supply Shocks on Headline Inflation in the Euro Area

Notes: The figure shows year-on-year gas price and headline inflation posterior median impulse response functions (left and middle panel) and the *pass-through* (cumulative and standardised response of inflation; right panel) to a gas supply shock that increases the gas price by 10% identified with traditional sign restrictions (black lines) and sign and narrative sign restrictions (red lines). Shaded areas report 68% credible intervals. Sample 1997m1 to 2024m12.

Narrative sign restrictions are more relevant for identification when these restrictions can rule out a larger share of the potential set of structural parameter draws consistent with the baseline model.[8] The results indicate that the baseline narrative sign restrictions, based on the events in March 2022, are very relevant since only about 40% of the draws that satisfy the sign restrictions also satisfy the narrative sign restrictions. This result is driven by the narrative sign restriction about the contribution of the shock to the historical decomposition of the gas prices in March 2022.

While the narrative sign restrictions based on 2006m1 and 2009m1 lead to somewhat higher rejection probabilities, around 80% and 90%, respectively, Figure B.1 in the Appendix shows that the alternative narrative sign restrictions lead to similar posterior distributions. Notable differences are that the alternative restrictions based on the 2006m1 and 2009m1 periods produce somewhat smaller credible intervals and larger posterior medians for medium- to long-term inflationary effects.

A drawback of the restrictions based on 2006m1, 2009m1 and 2011m9, however, is that gas prices were still, to a large extend, oil-indexed at the time. Thus, our baseline specification is based on the period for which there is the strongest narrative evidence about gas supply shocks. Importantly, note that the alternative narrative sign restrictions do not invalidate the baseline findings that gas supply shocks have important inflationary effects but instead suggest that these effects might be even more persistent. In that sense, the results we report from the baseline specification are conservative estimates of the effects of a gas supply shock on headline inflation.

3.2 Robustness Analysis

This section discusses results when modifying the baseline model and identification strategy along several dimensions; please see Appendix C for the respective figures showing the robustness results.

First, if oil price shocks are not accounted for, the estimated effects of gas supply shocks on inflation could be upward-biased due to being contaminated by oil-driven inflationary pressures. Figure C.1 shows the posterior median of the baseline BSVAR plotted against the posterior median of a BSVAR that does not control for the oil supply shocks of Känzig (2021). As the figure shows, failing to control for oil supply shocks results in a small upward bias of the posterior median. The results are also robust to using alternative oil shock series from Baumeister and

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[8] Importantly, the rejection frequency is *not* a test of the external validity of the assumptions of the underlying sign restrictions; see Antolín-Díaz and Rubio-Ramírez (2018) for further details.

Hamilton (2019), who separately identify supply-, demand-, and inventory-driven components in the oil market (Figure C.1). Furthermore, the figure shows that the results are robust to controlling for food commodity prices, thereby ensuring that the estimated effect of gas supply shocks is not contaminated by inflationary effects from other volatile commodity markets.[9]

Second, to show that our gas supply shocks are not contaminated by gas demand shocks, we explicitly control for gas inventory shocks, a form of gas demand shocks arising from precautionary or seasonal stock-building, using the series of exogenous shocks of Adolfsen et al. (2024). These shocks can raise gas prices without the macroeconomic effects typically associated with aggregate demand shocks, and may be correlated with gas supply disturbances. Figure C.2 shows that results are very similar when including the series of gas demand shocks as an additional exogenous variable in the BSVAR, i.e. in $\mathbf{X}_t$. While credible intervals are somewhat larger for both the gas price and the headline inflation response, the overall point estimates are very similar for the first 12 months after the shock.

Third, explicitly controlling for other supply-side disruptions might be important when trying to isolate gas supply shocks. Therefore, we re-estimate the baseline BSVAR additionally including one at a time either of the following three proxies for supply side production bottlenecks: the euro area supply bottlenecks index based on newspaper data from Burriel et al. (2023), the global Purchasing Managers' Indices (PMIs) for suppliers' delivery times (SDT), as suggested by Attinasi et al. (2022), and the Global Supply Chain Pressures Index (GSCPI) of Benigno et al. (2022). Figure C.3 shows that results are similar to the baseline when any of these proxies is included as an additional exogenous regressor in the BSVAR.

Finally, the baseline results are also robust to using alternative controls for economic activity in the BSVAR. Figure C.4 shows that replacing the ESI with industrial production or monthly interpolated GDP growth leads to very similar estimates.[10]

3.3 Estimates for the Largest Euro Area Economies

This section presents estimates of the inflationary effects of gas supply shocks for the four largest economies in the euro area: Germany (DE), France (FR), Italy (IT) and Spain (ES).

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[9] For food commodities prices we use the euro area total farm-gate and wholesale market prices in euros.

[10] The monthly interpolation is based on a mixed-frequency factor model; details are available upon request.

The country-level analysis reveals differences that correlate with different productive structures, consumption baskets, and domestic regulations.

Figure 5 compares the IRFs by country with the baseline estimates for the euro area. As in the baseline, identification combines traditional sign restrictions with narrative sign restrictions based on the event of the Russian invasion of Ukraine. The posterior median IRFs show the response to an unexpected 10% increase in the gas price due to a gas supply shock. Shaded areas report 68 percent credible intervals.

Some cross-country differences emerge in terms of posterior medians. Germany's profile for the response of headline inflation is essentially identical to the euro area aggregate, likely reflecting that Germany contributes to around 30% to the aggregate for euro area inflation. Spain shows a large inflationary response on impact, 0.35 percentage points (pp), a result linked to its retail electricity market regulation, discussed below in detail, that allows for a fast transmission of wholesale energy prices to retail energy prices. Italy's inflationary response is somewhat smaller on impact but otherwise has a similar profile to Germany's. France shows the weakest response to gas supply shocks, with the smallest point estimates and credible intervals that include zero after a few periods, likely reflecting highly regulated energy markets and a small overall weight of gas in the consumers consumption basket (see Figure D.1a).

To further document these differences, we break down the total inflationary response into the contributions of *direct* and *indirect* effects. The direct effect is measured as the contribution of the gas products HICP item (COICOP-0452, *Gas*), that is, the price index component for household purchases of gas for cooking, heating, and hot water. We separate the indirect effects into two parts. For the household prices for electricity, (COICOP-0451, *Electricity*), we estimate explicitly the effect of a gas supply shock. The remaining indirect effects are approximated by subtracting the response of *Gas* and *Electricity* from the total response of headline inflation. The BSVAR for the *Gas* and *Electricity* HICP items is estimated using the same specification and identification strategy as in the baseline BSVAR but substituting the headline inflation variable by the respective HICP component.

Figure 6 shows the contribution of the *Gas* HICP item, *Electricity* HICP item and other indirect effects to the response of headline inflation to a 10% increase in gas prices by country. We calculate these contributions in two steps. First, for headline inflation, the *Gas* and the

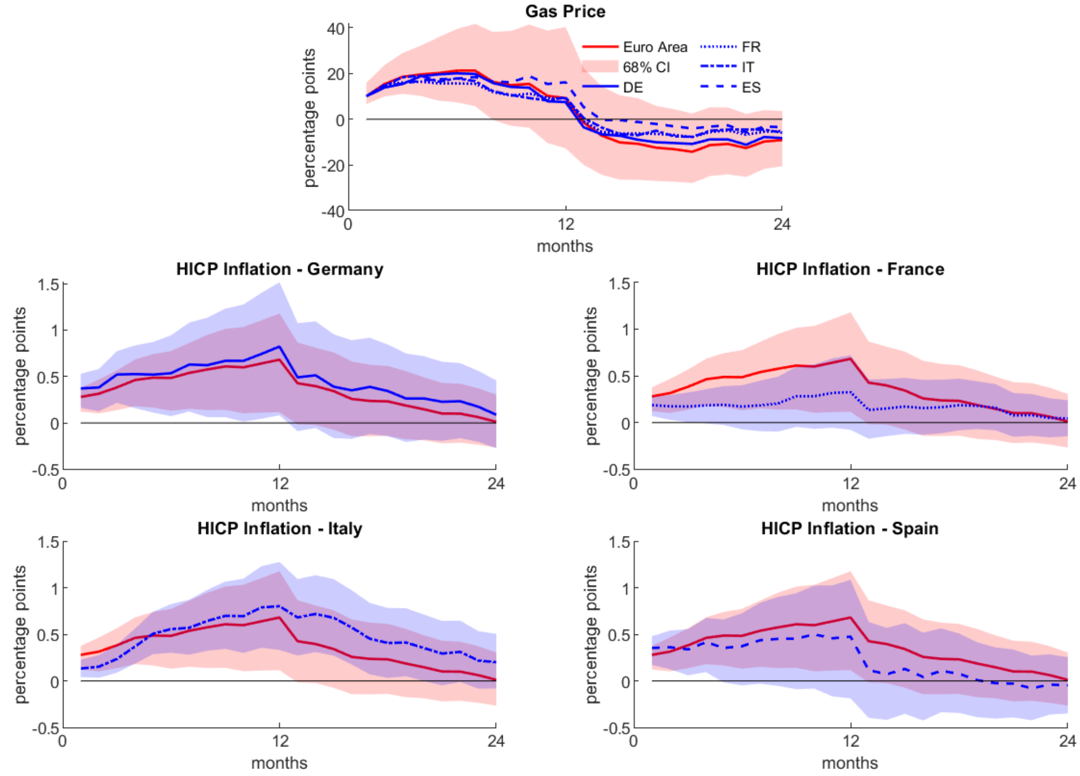

Figure 5: Impact of Gas Supply Shocks on Headline Inflation by Country

Notes: The figure shows posterior median impulse response functions to a gas supply shock that increases gas prices by 10%, identified with sign and narrative sign restrictions. Shaded areas report 68% credible intervals. The sample ranges from 1997m1 to 2024m12.

Electricity item, we compute the *pass-through*. That is, the cumulative response of the price index divided by the cumulative change in the gas price. Second, the contributions of each item can be calculated as the ratio of the individual items' *pass-through* to the total *pass-through*.[11]

Cross-country patterns in the *pass-through* of gas supply shocks reflect primarily two factors: the intensity in gas usage in the production processes and electricity generation, and the speed at which wholesale energy price changes are transmitted to retail energy prices. The latter largely depends on the energy market regulation. In Spain, the fast *pass-through* for electricity reflects the *PVPC* regulated tariff, in place since 2014 for small consumers, which links hourly retail prices directly to wholesale prices and, thereby, amplifies volatility (Pacce et al., 2021). This effect is reinforced by the relatively high weight of electricity in Spain's consumption basket

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[11] To have all variables in units of the headline HICP and adjust for the larger volatility of individual HICP items relative to the headline index, we scale the individual items' *pass-through* with their respective HICP weight by country.

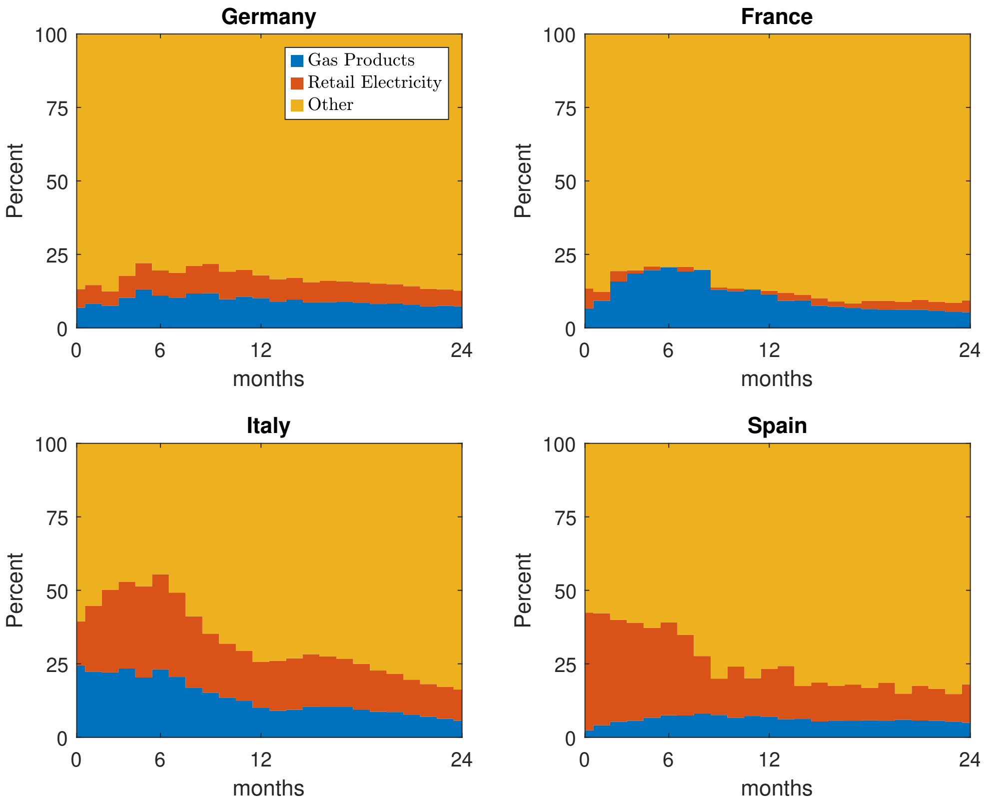

Figure 6: Contribution of Selected HICP Items to the Response of Headline Inflation to a Gas Supply Shock by Country

Notes: Contributions of the gas products (COICOP-0452) and electricity (COICOP-0451) item to the headline inflation response, calculated as the ratio of each items' *pass-through* to the total *pass-through*, and other indirect effects (residual) to the response of headline inflation to a gas supply shock that increases gas prices by 10%. Sample 1997m1 to 2024m12.

(see Figure D.1b in the Appendix). Consistent with these results, the quarterly report by the European Commission (2023) shows that in Spain the transmission of wholesale price changes to retail price changes from April 2021 to the peak prices in 2022 was very fast and all but complete. By contrast, the direct gas effect is muted, as gas accounts for the smallest household budget share, together with France, among the four countries considered (see Figure D.1a in the Appendix). In Italy, instead, large direct effects arise from the relatively high weight of gas products in the household consumption. That the sizeable contribution of electricity builds up over the first months following the gas supply shock reflects the quarterly update (monthly since October 2022) of electricity prices in the Italian regulated market (Colabella et al., 2025).[12] In line with the

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[12] In the Italian regulated market (*maggior tutela*), electricity prices are updated quarterly (monthly since October 2022) by the national regulator (*ARERA, Autorità di Regolazione per Energia Reti e Ambiente*) based on the conditions in the wholesale market. In the free market (*mercato libero*), households choose their electricity supplier among competing private companies, who can set their own offers (prices, discounts, contract terms, etc.);

market description of the Italian electricity market and our results, calculations in the quarterly report of the European Commission (2023) show that Italian electricity retail price changes in the recent period peaked around two months after the wholesale prices, with an essentially complete adjustment, suggesting a quick transmission to consumers. France and Germany both exhibit a slow *pass-through* to retail energy prices, reflecting regulatory lags (Kuik et al., 2022). In France, this is further mitigated by the large nuclear share in electricity generation, together with energy price controls and subsidies, which likely dampen the impact of energy price shocks on consumers' energy prices (IMF, 2023).[13] Finally, in Germany, the sizeable "other indirect" effects most likely stem from its energy-intensive industrial base, as the size of the German industrial sector stands out from the other euro area economies. According to Eurostat, Germany is a substantial producer of basic metals, fabricated metal products, and the top exporter of chemicals. These industries use gas intensively in the production process, face limited possibilities of input substitution, and have strong linkages with other downstream industries. We further discuss the role of gas in the production structure in Section 4.

4 The Theoretical Framework

This section presents a theoretical model to rationalize the empirical findings in the previous sections. It helps to understand how gas price shocks propagate through the economy, capturing the main underlying mechanisms.[14] The analysis is based on a canonical New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model augmented with energy, which is a complementary input for intermediate firms and a complementary good for households. The whole economy is populated by households, intermediate producers, a final good sector, energy firms, and a monetary authority. Next we detail the agents' decision problems.

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in the free market, households tend to prefer fixed-term contract with a duration of 12 months or more (CEER, 2024). Since 2007, Italy has experienced a gradual switching from the regulated market to the free market. For example, in 2023, household supplier switches were 150% larger in Italy than in Germany (CEER, 2023). In 2023, still about 1/3 of households remain in the regulated tariff.

[13] Figure E.1 in the Appendix shows that despite similar contributions by country, the inflationary impact for gas products in France is one of the smallest and null for electricity. More details on the energy sources in electricity production can be found in IEA's country reports.

[14] Note that a fully comprehensive model for the transmission of energy price shocks would require further elements, such as a more detailed representation of the electricity market. We leave these extensions for future research.

4.1 Households

There is a continuum of households indexed by j. The households maximize their utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ ln(c_{jt} - \kappa c_{jt-1}) - \xi \frac{l_{jt}^{1+\psi}}{1+\psi} \right\}, \tag{3}$$

subject to the resource constraint

$$c_{jt} + i_{jt} + \frac{b_{jt+1}}{p_t} = R_{t-1} \frac{b_{jt}}{p_t} + w_{jt} l_{jt} + \Xi_t + T_t, \tag{4}$$

where β is the subjective discount factor, ψ is the inverse of the Frisch elasticity of labour supply and κ denotes the degree of habit persistence. Households invest in government bonds, b_{jt}, and receive a nominal gross interest rate, R_t. They also supply labour, l_{jt}, in exchange for the real wage rate w_{jt}. Through their ownership of firms, households receive the profit Ξ_t. Moreover, they are subject to lump-sum taxes T_t.

Household total consumption is denoted by c_{jt}. Specifically, households consume a composite final good, which is made of energy, $c_{e,jt}$, and a consumption good excluding energy, $c_{x,jt}$

$$c_{jt} = \left(\nu_c^{\frac{1}{\mu_c}} (c_{e,jt})^{\frac{\mu_c - 1}{\mu_c}} + (1-\nu_c)^{\frac{1}{\mu_c}} (c_{x,jt})^{\frac{\mu_c - 1}{\mu_c}} \right)^{\frac{\mu_c}{\mu_c - 1}}, \tag{5}$$

where $c_{e,jt}$ is given by

$$c_{e,jt} = \left(\nu_e^{\frac{1}{\mu_e}} (c_{g,jt})^{\frac{\mu_e - 1}{\mu_e}} + (1-\nu_e)^{\frac{1}{\mu_e}} (c_{o,jt})^{\frac{\mu_e - 1}{\mu_e}} \right)^{\frac{\mu_e}{\mu_e - 1}}, \tag{6}$$

where ν_c represents the weight of energy in the consumption bundle and μ_c is the elasticity of substitution between energy and non-energy consumption goods. A low value for the latter would imply that energy and consumption goods excluding energy are not easy to substitute in the total consumption basket. In other words, the total consumption basket for the household would clearly reflect the dependence on energy consumption when a negative shock to commodity prices hits the economy. Similarly, ν_e represents the weight of gas in the energy bundle and μ_e is the elasticity of substitution between gas, $c_{e,jt}$, and oil, $c_{o,jt}$.

Expenditure minimization yields the demand equations for gas, oil, total energy, and the consumption good excluding total energy

$$c_{x,jt} = (1-\nu_c)\left(\frac{p_{x,t}}{p_t}\right)^{-\mu_c} c_{jt}, \qquad c_{e,jt} = \nu_c \left(\frac{p_{e,t}}{p_t}\right)^{-\mu_c} c_{jt}, \tag{7}$$

$$c_{g,jt} = \nu_e \left(\frac{p_{g,t}}{p_{e,t}}\right)^{-\mu_e} c_{e,jt}, \qquad c_{o,jt} = (1-\nu_e)\left(\frac{p_{o,t}}{p_{e,t}}\right)^{-\mu_e} c_{e,jt}, \tag{8}$$

where $p_{e,t}$ is the price of total energy and $p_{x,t}$ the price of the consumption good excluding energy.[15] The aggregate (headline) price index is then defined as

$$p_t = \left(\nu_c {p_{e,t}}^{1-\mu_c} + (1-\nu_c)\, {p_{x,t}^{1-\mu_c}}\right)^{\frac{1}{1-\mu_c}}, \tag{9}$$

with

$$p_{e,t} = \left(\nu_e p_{g,t}^{1-\mu_e} + (1-\nu_e)\, p_{o,t}^{1-\mu_e}\right)^{\frac{1}{1-\mu_e}}, \tag{10}$$

where $p_{g,t}$ is the price of gas and $p_{o,t}$ stands for the price of oil.

Denoting by λ_{jt} the Lagrange multiplier, the optimality conditions for the household's maximization problem with respect to bond holdings and total consumption are

$$\lambda_{jt} = \beta \mathbb{E}_t \lambda_{jt+1} \frac{R_t}{\Pi_{t+1}}, \quad \text{with} \quad \Pi_{t+1} = \frac{p_{t+1}}{p_t} \tag{11}$$

$$(c_{jt} - \kappa c_{jt-1})^{-1} - \kappa \beta \mathbb{E}_t (c_{jt+1} - \kappa c_{jt})^{-1} = \lambda_{jt} \tag{12}$$

Wages are determined following a Calvo's staggered nominal setting, i.e., in each period, households are only allowed to reset their wage with probability $1-\theta_w$, regardless of the time elapsed since they last adjusted their wage contracts. Thus, in each period a measure $1-\theta_w$ of households optimally reset their wages at the same rate, $\widetilde{w}_t = \widetilde{w}_{jt}$. Those households that do not re-optimize are allowed to update their wages according to the following indexation rule

$$w_{jt} = (\Pi_{t-1})^{\chi_w} \Pi^{1-\chi_w} w_{jt-1} \tag{13}$$

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[15] We normalise to one the price of the composite consumption good when solving the model.

where Π is the steady-state (headline) inflation and wage indexation is controlled by the parameter χ_w.

The first-order condition of the households that optimize their wage reads as follows

$$\mathbb{E}_t\left[\sum_{k=0}^{\infty}(\beta\theta_w)^k\left(\lambda_{jt+k}\frac{\widetilde{w}_t}{p_{t+k}}\left(\frac{p_{t+k-1}}{p_{t-1}}\right)^{\chi_w}\Pi^{(1-\chi_w)k}-\xi\frac{\eta_w}{\eta_w-1}l_{jt+k}^{\psi}\right)l_{jt+k}\right]=0 \tag{14}$$

The previous equation comes from maximizing the household's utility function subject to the indexation rule, the budget constraint, and the demand for its differentiated labour services, $l_{jt}=\left(\frac{w_{jt}}{w_t}\right)^{-\eta_w}l_t^d$, where l_t^d is the aggregate labour demand and η_w is the elasticity of substitution among different types of labour.[16]

4.2 Final Good Sector

The final good is produced by a perfectly competitive sector which assembles a continuum of intermediate goods using the aggregate CES function

$$y_t=\left(\int_0^1 y_{it}^{\frac{\eta_p-1}{\eta_p}}\,di\right)^{\frac{\eta_p}{\eta_p-1}}, \tag{15}$$

where η_p is the elasticity of substitution. Given the previous aggregator, the demand function faced by each firm i is

$$y_{it}=\left(\frac{p_{x,it}}{p_{x,t}}\right)^{-\eta_p}y_t. \tag{16}$$

4.3 Intermediate Firms

The indirect effects of supply shocks from energy commodities are incorporated into the model introducing an additional energy input in the production function of the intermediate producers. In particular, each firm i combines energy with labour services

$$y_{it}=z_t\left(\nu_y^{\frac{1}{\mu_y}}\left(e_{it}\right)^{\frac{\mu_y-1}{\mu_y}}+(1-\nu_y)^{\frac{1}{\mu_y}}\left(l_{it}^d\right)^{\frac{\mu_y-1}{\mu_y}}\right)^{\frac{\mu_y}{\mu_y-1}}, \tag{17}$$

with

$$e_{it}=\left(\nu_{ey}^{\frac{1}{\mu_{ey}}}\left(e_{g,it}\right)^{\frac{\mu_{ey}-1}{\mu_{ey}}}+(1-\nu_{ey})^{\frac{1}{\mu_{ey}}}\left(e_{o,it}\right)^{\frac{\mu_{ey}-1}{\mu_{ey}}}\right)^{\frac{\mu_{ey}}{\mu_{ey}-1}}, \tag{18}$$

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[16] See Gomes et al. (2012) for detailed derivations.

where e_{it} is the quantity of energy used and l_{it}^d is the amount of the "packed" labour input rented by the intermediate firm i. The elasticity of substitution between the utilization of energy and labour is represented by μ_y, and ν_y determines the share of energy in the production technology. The aggregate variable z_t represents the productivity level.

The objective of each intermediate firm is to maximize profits. By solving the intermediate firms' program, we get the following optimality conditions

$$e_{it} = \nu_y \left(\frac{p_{e,t}}{z_t mc_t} \right)^{-\mu_y} \frac{y_{jt}}{z_t}, \tag{19}$$

$$l_{it}^d = (1 - \nu_y) \left(\frac{w_t}{z_t mc_t} \right)^{-\mu_y} \frac{y_{jt}}{z_t}, \tag{20}$$

with

$$mc_t = z_t^{-1} \left(\nu_y p_{e,t}^{1-\mu_y} + (1 - \nu_y) w_t^{1-\mu_y} \right)^{\frac{1}{1-\mu_y}}, \tag{21}$$

Notice that marginal costs are the same across intermediate good firms since all producers face the same input prices. The variable mc_t is the marginal cost of producing a unit of the intermediate good.

The intermediate good producers set their prices in a staggered fashion following Calvo (1983). With probability $1 - \theta_p$ they maximise the discounted sum of their expected nominal profits. Thus, in each period t a measure $1 - \theta_p$ of intermediate firms update their prices at the same rate, $\widetilde{p}_{x,t} = \widetilde{p}_{x,it}$. Those firms that do not re-optimize reset their prices according to the following indexation scheme

$$p_{x,it} = (\Pi_{x,t-1})^{\chi_p} {\Pi_x}^{1-\chi_p} p_{x,it-1}, \tag{22}$$

where $\Pi_{x,t-1}$ is the intermediate firms inflation rate and price indexation is controlled by the parameter χ_p.

The implied (symmetric) first-order condition is[17]

$$\mathbb{E}_t \left[\sum_{k=0}^{\infty} (\theta_p)^k \left(\lambda_{t,t+k} \prod_{s=1}^{k} \Pi_{x,t+s-1}^{\chi_p} \Pi_x^{(1-\chi_p)} \widetilde{p}_{x,t} - \frac{\eta_p}{\eta_p - 1} mc_{t+k} \right) y_{it+k} \right] = 0 \tag{23}$$

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[17] See Gomes et al. (2012) for a detailed derivation.

And the intermediate price index, $p_{x,t}$ evolves as

$$p_{x,t} = \left(\theta_p \left(\Pi_{x,t-1}^{\chi_p} \Pi_x^{(1-\chi_p)} p_{x,t-1}\right)^{1-\eta_p} + (1-\theta_p)(\widetilde{p}_{x,t})^{1-\eta_p}\right)^{\frac{1}{1-\eta_p}} \tag{24}$$

4.4 Energy Firms

Energy firms transform crude energy into refined or processed energy employing a simple Leontief production function. Firms in this section set their prices in a staggered fashion following Calvo (1983). On the one hand, firms producing gas/electricity maximize the discounted sum of their expected nominal profits with probability $1-\theta_g$. Consequently, in each period t a measure $1-\theta_g$ of firms update their prices at the same rate. On the other hand, refined oil firms also optimally change their price with probability $1-\theta_o$. The resulting (linearized) New Keynesian Phillips curves for these set of firms are

$$\pi_{g,t} = \beta \pi_{g,t+1} + \frac{(1-\theta_g)(1-\beta\theta_g)}{\theta_g}(p_{ng,t} - p_{g,t}) \tag{25}$$

and

$$\pi_{o,t} = \beta \pi_{o,t+1} + \frac{(1-\theta_o)(1-\beta\theta_o)}{\theta_o}(p_{co,t} - p_{o,t}), \tag{26}$$

where $p_{ng,t}$ is the price of natural gas and $p_{co,t}$ is the price of crude oil.

The inclusion of energy firms supplying refined energy captures important channels that can delay the transmission of energy price shocks. In the estimation section, we quantify the magnitude of this transmission for both sets of firms.

4.5 Monetary Policy and Resource Constraints

The monetary authority adjusts the nominal interest rate according to the following Taylor rule

$$(R_t)^{12} = \phi_R (R_{t-1})^{12} + (1-\phi_R)\left(\bar{R}^{12} + \phi_\pi \left[\left(\frac{p_t}{p_{t-12}}\right) - \bar{\Pi}\right] + \phi_y \left[y_{gr3,t} - 1\right]\right) + \epsilon_{R,t}, \tag{27}$$

where $\epsilon_{R,t}$ is the monetary policy shock, $\bar{\Pi}$ denotes the monetary authority's (gross) inflation target, $\bar{R}^{12}$ is the annualized (gross) equilibrium nominal interest rate, and $y_{gr3,t}$ is the (q-o-q) growth rate of real GDP, which is defined as

$$GDP_t = \frac{1}{p_t}\Big(p_{x,t}y_t - p_{e,t}c_{e,t}\Big). \tag{28}$$

In order to close the model, we assume that the supply of nominal bonds is set to zero and that the prices of natural gas and crude oil are exogenous.[18]

4.6 Calibration

The model is solved by means of a first-order perturbation method. We calibrate several model's parameters using euro area data pre-Covid or from the previous literature, and estimate the structural shocks of the model with Bayesian methods for the period January 1997 to December 2024.[19] The estimation is based on 6 observables: real (Brent) oil price inflation (in terms of HICP, in euros), real natural gas price inflation (in terms of HICP, in euros), real GDP growth, compensation per-employee growth, the shadow rate from Wu and Xia (2020) and HICP inflation, using the same data as in the BSVAR when applicable.

Table 2 summarises the (monthly) calibration of the model. We set the household discount factor and the Inverse of Frisch labour supply elasticity to $0.992^{\frac{1}{3}}$ (matching the annualized real interest rate of 3 percent in steady-state) and 2, respectively. The habit persistence parameter is set to $0.45^{\frac{1}{3}}$, which is consistent with the microeconomic literature (see Havranek et al., 2017). We set the Calvo wage parameter to $0.75^{\frac{1}{3}}$, as in Gomes et al. (2012). Regarding prices, we calibrate the price stickiness parameter to $0.75^{\frac{1}{3}}$, implying a quarterly value similar to Alvarez et al. (2006). For monetary policy, we set the reaction to annual inflation and the quarterly output growth to 1.50 and 0.1, respectively, as in Coenen et al. (2023) and Gomes et al. (2012).

We now turn to energy. We follow Coenen et al. (2023) and set both the elasticity of substitution between energy and labour, and the elasticity of substitution between the consumption of energy and the consumption good excluding energy to 0.4. These small values imply low substitution among the consumption goods and between inputs in the production function.

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[18] We model the exogenous prices as AR(2) processes.

[19] We also estimate the Calvo parameters for refined energy firms (θ_g and θ_o), which allows us to assess the delay in the transmission of crude energy price shocks to the processed energy sector. Appendix F presents these results, along with the estimated structural shocks. As shown, the higher Calvo parameter for gas/electricity firms suggests a slower adjustment in their prices compared to refined oil firms. This is consistent with the fact that petrol prices respond more quickly to crude oil shocks, while gas/electricity prices tend to adjust more gradually due to price regulations or longer-term contracts.

Table 2: Model Parameters

	Firms		
μ_y	Elast. of subst. between energy and labour	0.4	Coenen et al. (2023)
ν_y	Quasi-share of energy in the production of interm. goods	0.0527	To match $e/y = 0.0441$
η_p	Elast. of subst. between differentiated goods	6	Markup of 1.2
θ_p	Price stickiness	$0.75^{\frac{1}{3}}$	Alvarez et al. (2006)
	Households		
β	Discount rate	$0.992^{\frac{1}{3}}$	Real interest rate of 3%
ψ	Inverse of Frisch labour supply elasticity	2	Gomes et al. (2012)
κ	Habit persistence	$0.45^{\frac{1}{3}}$	Havranek et al. (2017)
μ_c	Elast. of subst. between consumption goods	0.4	Coenen et al. (2023)
ν_c	Quasi-share of energy in the consumption basket	0.0342	To match $c_e/c = 0.0314$
η_w	Elast. of subst. among different types of labour	4.3	Markup of 1.3
θ_w	Wage stickiness	$0.75^{\frac{1}{3}}$	Gomes et al. (2012)
	Monetary Policy		
ϕ_π	Inflation coefficient TR	1.50	Coenen et al. (2023)
ϕ_y	Output growth coefficient TR	0.1	Gomes et al. (2012)
ϕ_R	Interest rate inertia	0.87	Gomes et al. (2012)
Π	Inflation target	1.02	Gomes et al. (2012)

Regarding the share of energy in the household's consumption basket, we set the quasi-share parameter to 0.0342, implying a steady-state share of energy in the household's consumption basket of $c_e/c = 0.0314$. This share is obtained combining the information conveyed by Coenen et al. (2023) and Eurostat's energy statistics. The former sets the total energy share in the consumption bundle to 0.055 out of the three energy producing sectors in the input-output tables from the 2018 of the OECD TiVA database, i.e., mining, petroleum products, and the conglomerate of gas, electricity, steam and air conditioning supply. We adjust this value to account only for the gas and oil components using their contribution in Eurostat's gross energy balances, around 22% and 35%, respectively.

Similarly, we set ν_y to 0.0527 in order to match the share of gas and oil in the production of the intermediate goods $e/y = 0.0441$. Again, this value applies Eurostat's gas and oil contributions in the gross energy balances to the total dirty energy share of Coenen et al. (2023) calculated as $0.071 \times 0.717 = 0.0509$. It is worth noting that our approach captures well all the uses of gas as an energy source. Eurostat's gross energy balances inform of different primary energy sources in the production and imports of total energy, and do not distinguish whether gas is used for electricity production, heat production, in manufacturing processes or directly in household consumption. Implying the calibration of the share of gas in conjunction with its downstream uses such as electricity and heat production.

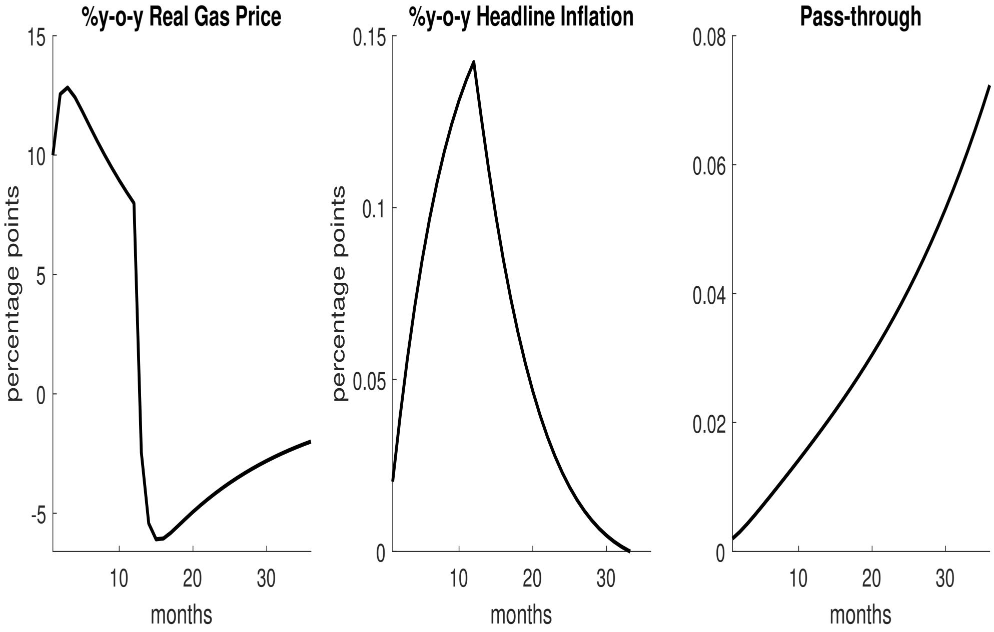

Figure 7: IRFs to a 10% increase in the real gas price

Regarding the split between gas and oil at the household and firm levels, ν_e is set to 0.39 ($1 - \nu_e = 0.61$), and ν_{ey} to 0.31 ($1 - \nu_{ey} = 0.69$), reflecting their respective shares in the gross energy balances of both inputs. Finally, the elasticities of substitution between gas and oil are set to 0.9, in line with the values used in Golosov et al. (2014).

4.7 Results

Figure 7 exhibits the response of headline inflation to a gas price shock. We calibrate the shock to imply an increase of 10%, upon impact, in the real price of gas, as in the previous empirical sections. One can observe that the DSGE model performs well in matching the IRFs in Figure 4.[20] We obtain the same qualitative results, with some quantitative differences. Given the differing post-shock dynamics of the real gas price in the BSVAR and DSGE models, we compute the *pass-through* of this shock as in the empirical counterpart, again measured as the cumulative inflation response standardized by the cumulative change in the gas price. As observed, it also builds up over time, reaching approximately 0.07 percentage points about three years after the shock, which aligns closely with the predictions of the baseline BSVAR model.

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[20] In the Appendix, we further show how monetary policy can influence the effects of gas price shocks on inflation and provide a narrative for the recent contribution of several structural shocks to inflation and output fluctuations.

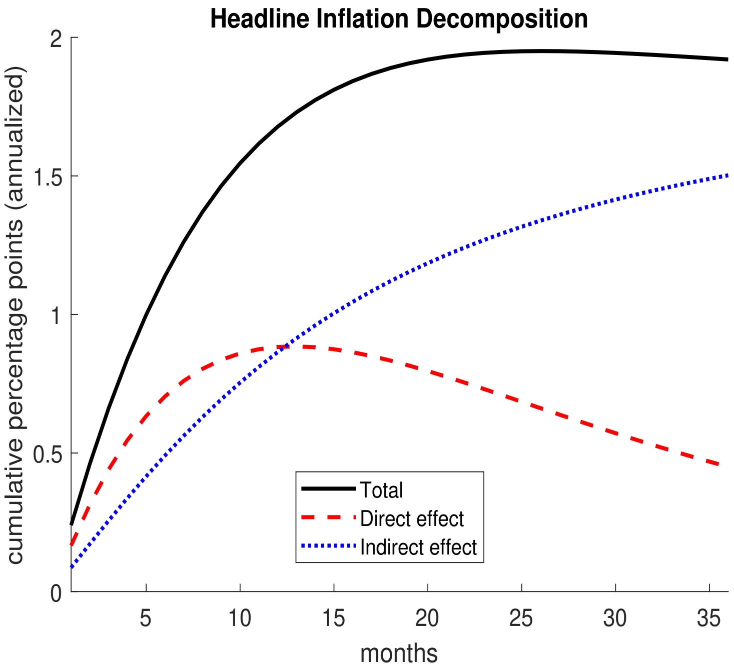

Figure 8: IRFs to a 10% increase in the real gas price: Direct vs. Indirect Effects

To better understand the propagation mechanisms of natural gas price shocks, we decompose the transmission into *direct* and *indirect* effects. In the DSGE model, the direct channel captures the immediate impact of higher gas prices on headline inflation, while the indirect channel includes the broader macroeconomic transmission via energy-intensive intermediate inputs and general equilibrium effects. A way to assess the direct and indirect effects is to examine the IRFs of the consumer gas price and the price of non-energy consumption goods, respectively. This exercise allows us to quantify the relative importance of both channels in shaping the overall inflationary response to an energy price shock.

Figure 8 illustrates the decomposition of the cumulative response of headline inflation to a 10% increase in the real gas price. It distinguishes between the total effect (solid black line), the direct effect (red dashed line), and the indirect effect (blue dotted line), with all responses reported in annualized percentage points over a 36-month horizon.

The results show that the total inflationary impact peaks at approximately 1.9 percentage points. The direct effect initially dominates the response, particularly within the first year, reflecting the immediate impact from higher gas prices to energy-related components of the consumption basket. Over time, however, the indirect effect becomes increasingly relevant, capturing second-round effects through production costs. After three years, more than 75% of the cumulative headline inflation response is attributable to indirect effects. This finding is consistent with the previous empirical evidence where the impact of gas price shocks were mainly transmitted to headline inflation through indirect effects. As we have previously argued, gas has become a key input for many production processes. On the other hand, the main direct impact of gas remains through home heating, which tends to have a lower HICP weight.

5 Conclusions

Gas has become an important energy commodity in the euro area and recent developments in the European gas markets increased the interest in studying the connection between unexpected gas price increases and HICP inflation. For instance, for the first time in 2023, the European Central Bank included the gas price explicitly as part of the technical assumptions in the macroeconomic projection exercise.

To assess the effects of gas supply shocks on inflation, we first estimate a structural BVAR identified with sign and narrative sign restrictions and find that a gas supply shock that increases gas prices by 10% leads to an increase in headline year-on-year inflation of roughly 0.6 percentage points at its peak after one year. The *pass-through*, measured as the cumulative inflation response divided by the cumulative response of the gas price, builds up over time and reaches a maximum of 0.05 about 20 months after the shock.

Cross-country patterns in the *pass-through* of gas supply shocks mainly reflect two factors: (i) the energy intensity of production structures and electricity generation, and (ii) the speed at which wholesale price changes are transmitted to retail energy prices, which depends largely on market regulation. Our results suggest gas supply shocks matter more for German, Spanish and Italian than for French headline inflation.

Finally, we develop a New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model augmented with energy, which is a complementary input for intermediate goods firms and a complementary good for households. Our model matches well the impulse responses of the empirical analysis. We also identify a prominent role for indirect effects, capturing second-round effects through production costs. After three years, approximately 75% of the cumulative headline inflation response is attributable to indirect effects. While the model can serve as a first tool to rationalize the transmission of gas price shocks, it would benefit from further elements to fully capture the complexities of energy price transmission to the macroeconomy. Addressing these limitations is left for future research.

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Appendix

A Additional Results

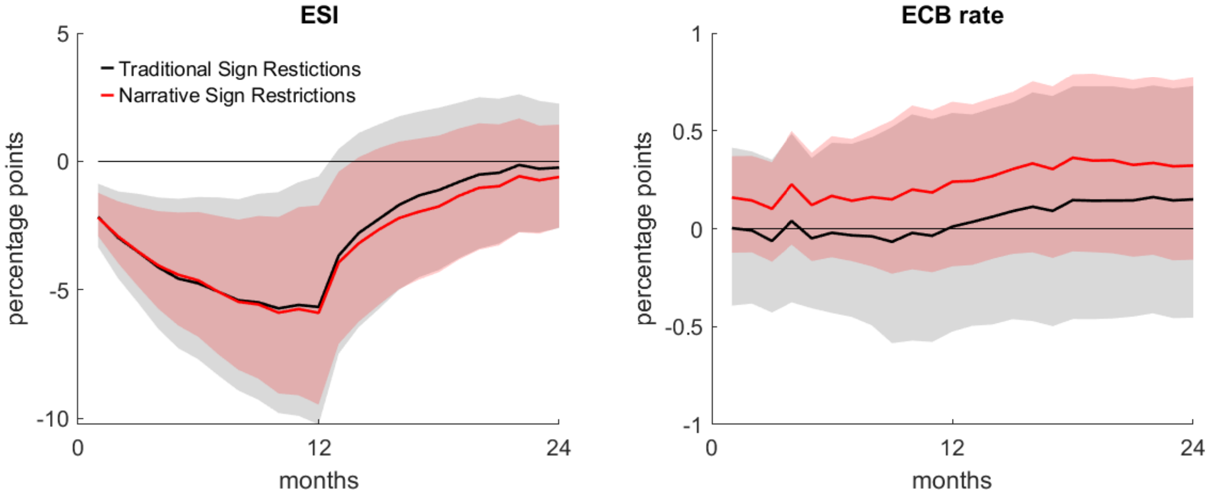


Figure A.1: Additional Baseline BSVAR Results

Notes: The figure shows year-on-year posterior median impulse response functions to a 10% increase in the price of gas. 68% credible intervals. Sample 1997m1 to 2024m12.

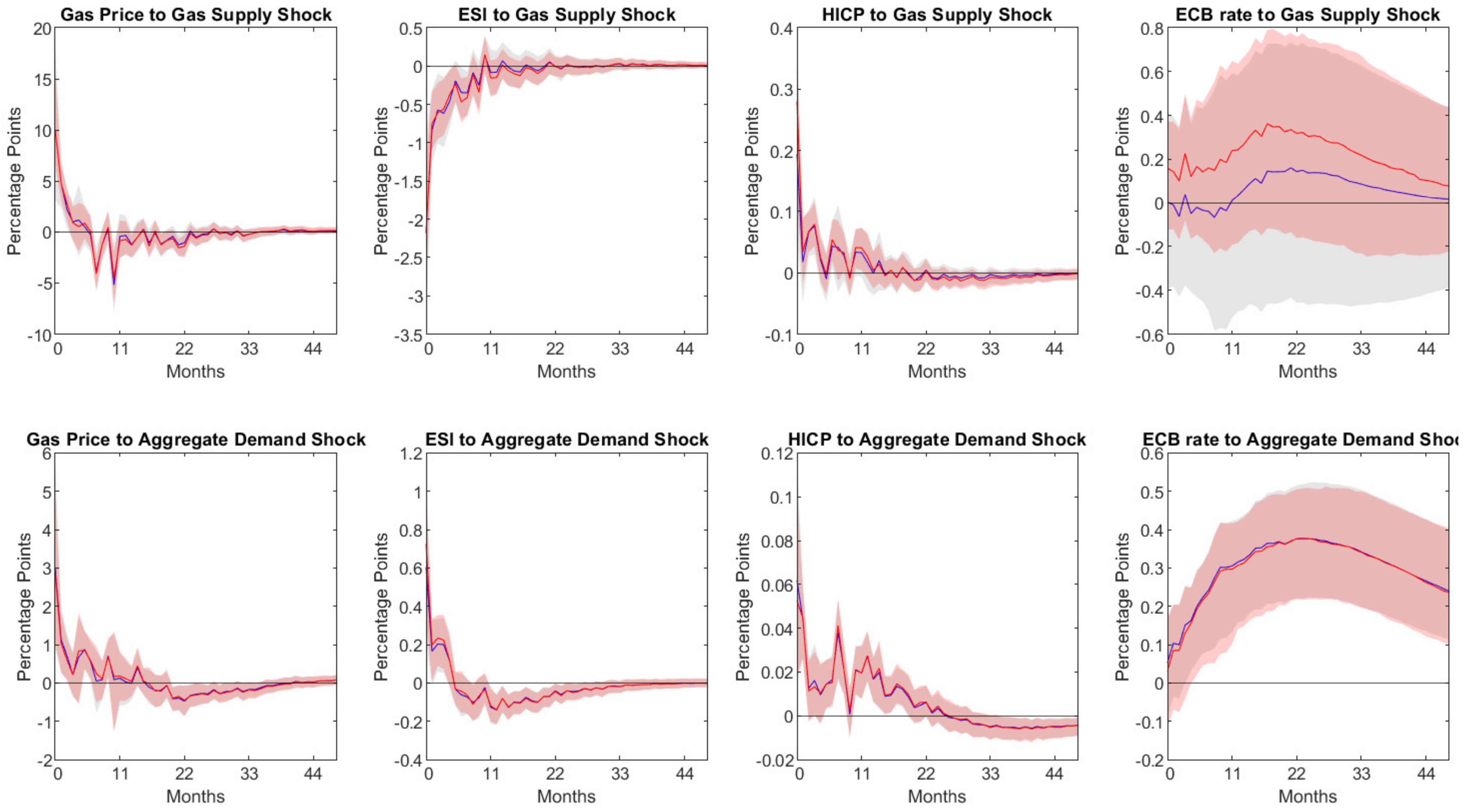


Figure A.2: Baseline BSVAR Results - month-on-month growth rates

Notes: The figure shows posterior median impulse response functions identified with narrative sign restrictions (red lines) and traditional sign restrictions (blue lines). Shaded areas report 68% credible intervals.

B Alternative Narrative Sign Restrictions

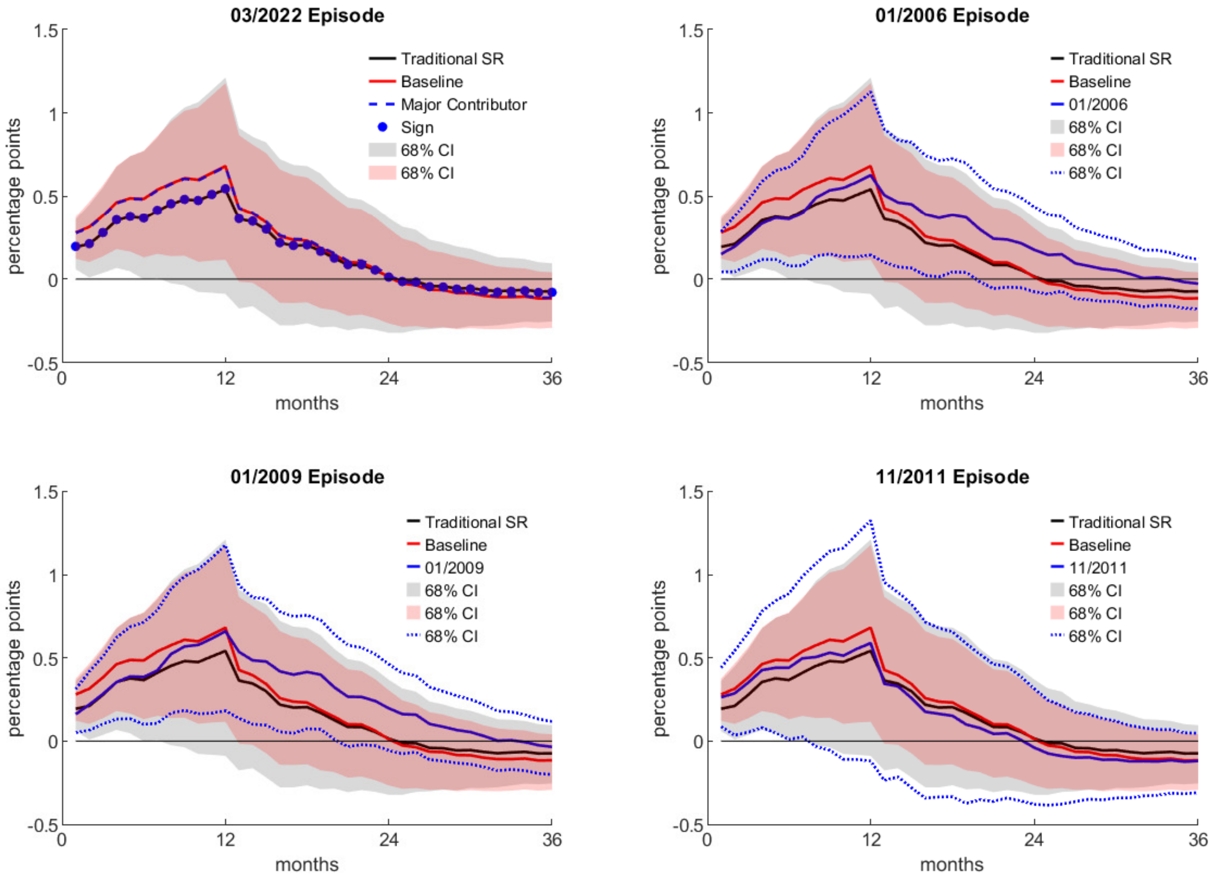


Figure B.1: HICP inflation response to an unexpected increase in gas prices in the Euro Area – Alternative Narrative Sign Restrictions

Notes: The figure shows year-on-year posterior median impulse response functions to a 10% increase in the price of gas. 68% credible intervals. Sample 1997m1 to 2024m12. “Traditional SR” refers to standard Sign Restrictions imposed on impact.

C Robustness Checks

This Appendix includes several robustness checks. First, we checked that the results are robust to developments in other commodities prices. Failing to control for oil shocks in the BVAR would introduce a positive bias, although the results lie within the same credible intervals (Figure C.1). The same figure shows that the results are very similar using alternative exogenous oil shocks and extending the controls to developments in food commodity prices. Second, we checked the identified gas supply shocks do not confound specific demand-driven gas price dynamics, which restrictions on economic activity might not isolate (Figure C.2). Third, the estimated inflationary effects do not capture other supply-side shocks as proxied by indices of production bottlenecks (Figure C.3). Fourth, the results are robust to alternative variables to control for economic activity (Figure C.4).

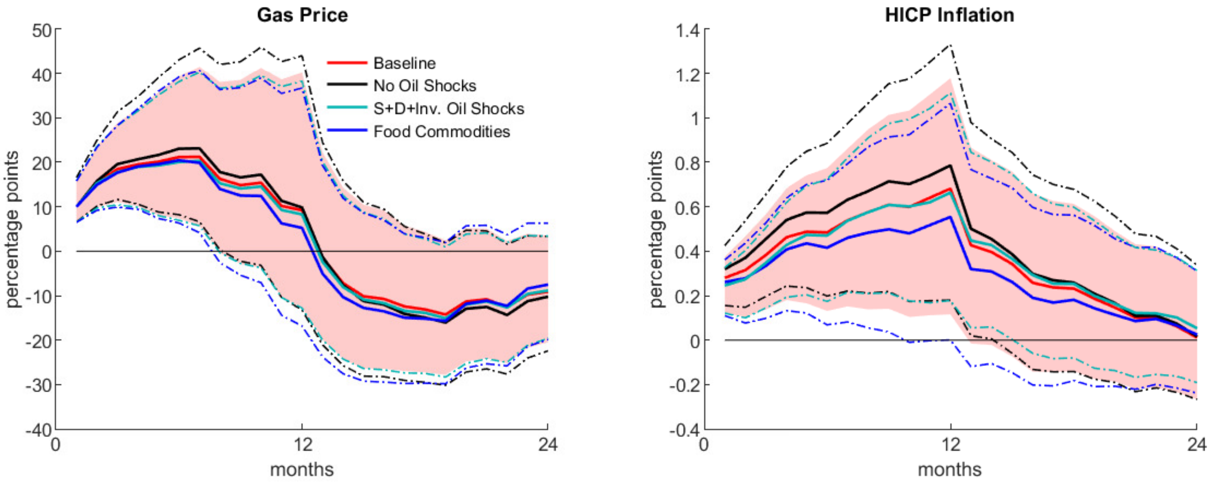


Figure C.1: Other commodities prices

Notes: The figure shows year-on-year posterior median impulse response functions to a 10% increase in the price of gas. Shaded area and dash-dotted lines report 68% credible intervals. Sample 1997m1 (Food commodities 2000m1) to 2024m12. “No Oil Shocks” specification excludes the exogenous oil shocks by Känzig (2021) from the BVAR; “S+D+Inv. Oil Shocks” specification replaces the Känzig (2021) series by oil supply-driven, demand-driven and inventory-driven shocks by Baumeister and Hamilton (2019); “Food Commodities” adds to the baseline BVAR an additional exogenous variable for farm-gate and wholesale market prices in the euro area.

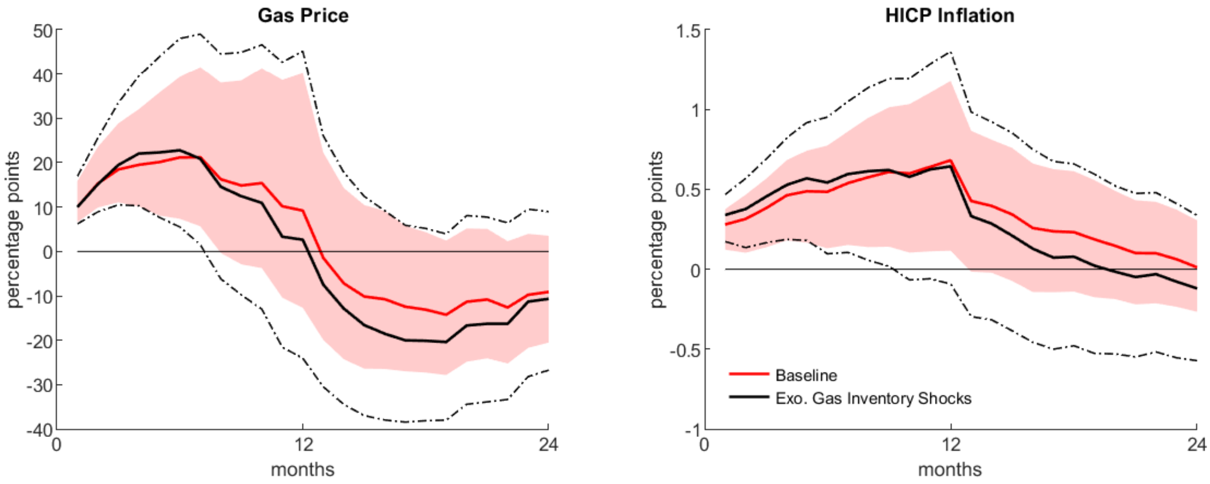


Figure C.2: Controlling for Gas Demand-driven Dynamics

Notes: The figure shows year-on-year posterior median impulse response functions to a 10% increase in the price of gas. Shaded area and dash-dotted lines report 68% credible intervals. Sample 1997m1 to 2024m12. “Exo. Gas Inventory Shocks” adds to the baseline BVAR an additional exogenous variable for specific demand-driven gas price dynamics by Adolfsen et al. (2024).

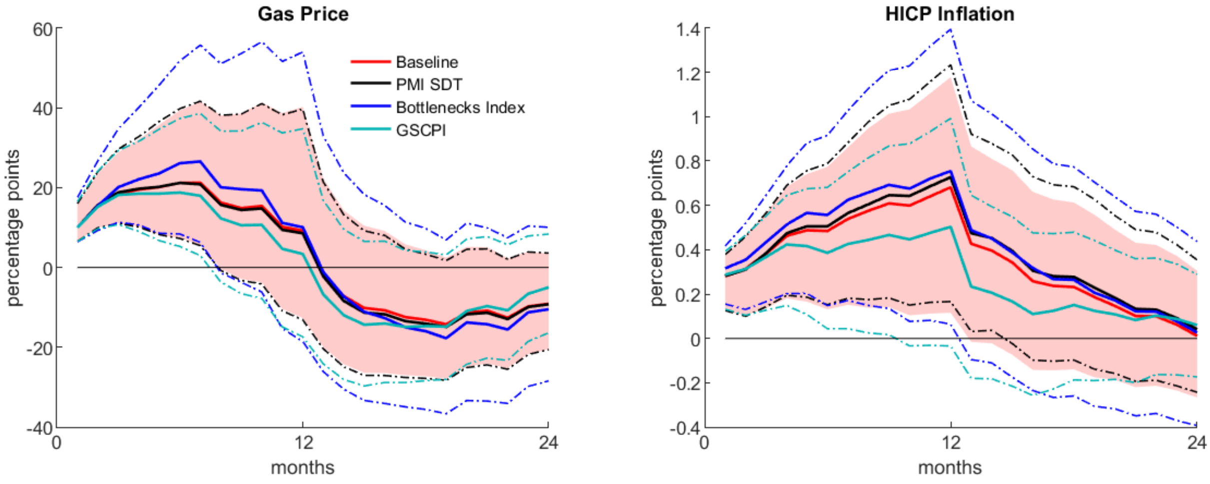


Figure C.3: Additional controls for supply shocks

Notes: The figure shows year-on-year posterior median impulse response functions to a gas supply shock that increases gas price by 10%. Shaded area and dash-dotted lines report 68% credible intervals. Sample 1997m1 (“PMI SDT” and “GSCPI” 1998m1, “Bottlenecks Index” 2007m1) to 2024m12. “PMI SDT”, “Bottlenecks Index” and “GSCPI” add to the baseline BVAR as exogenous variables, respectively, the purchasing managers’ index for suppliers’ delivery times in the euro area, the euro area’s supply bottlenecks index based on newspaper data of Burriel et al. (2023) and the global supply chain pressures index of Benigno et al. (2022).

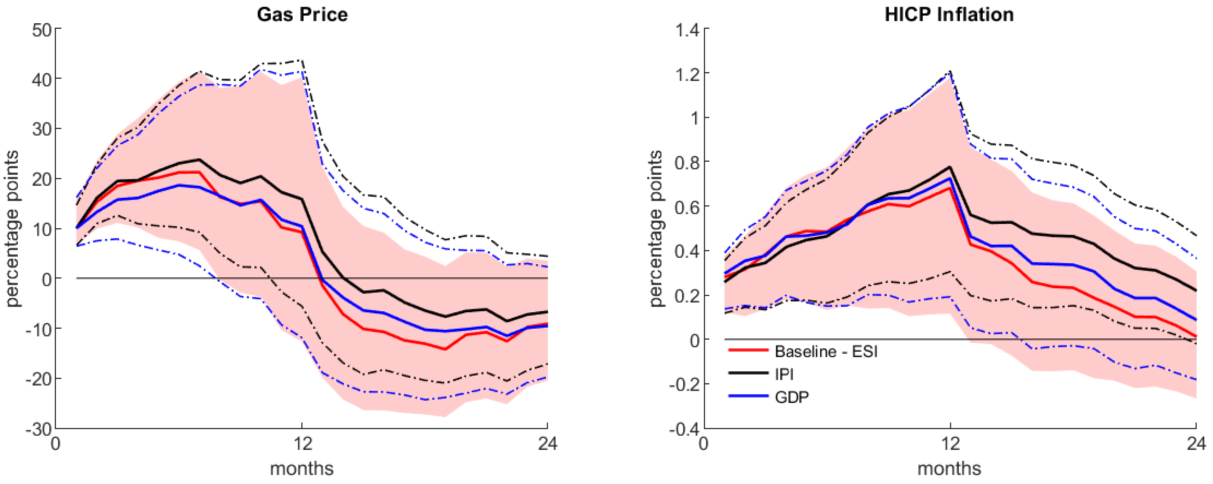
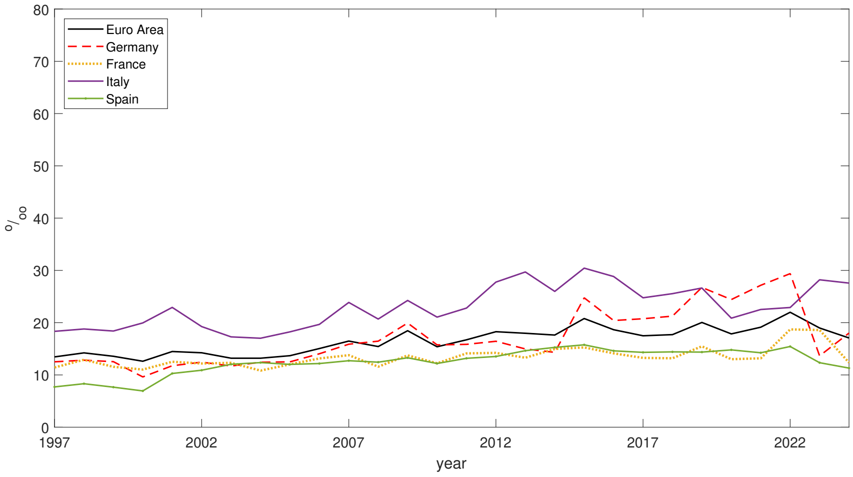


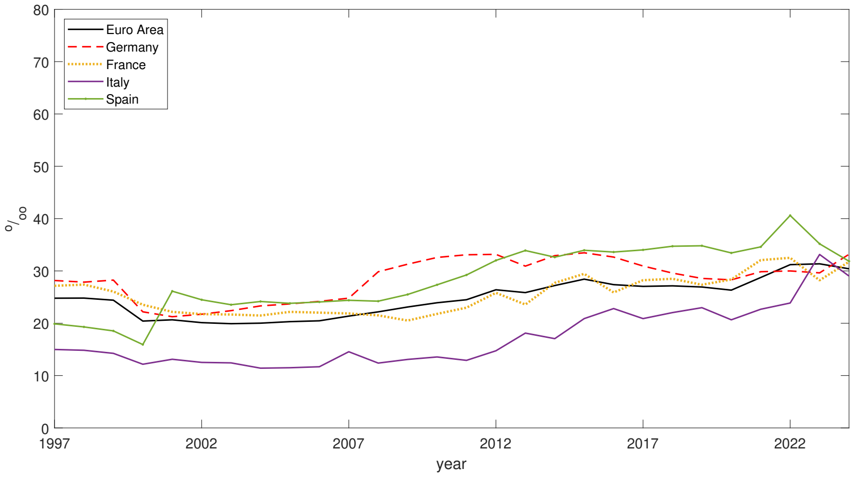
Figure C.4: Other Controls for Activity

Notes: The figure shows year-on-year posterior median impulse response functions to a 10% increase in the price of gas. Shaded area and dash-dotted lines report 68% credible intervals. Sample 1997m1 to 2024m12. “IPI” and “GDP” replace the ESI with the monthly series of industrial production and estimated GDP for the euro area, respectively.

D HICP Energy Components Weights



(a) HICP Weight of Gas



(b) HICP Weight of Electricity

Figure D.1: HICP Weights for Energy Items

E Cumulative Inflationary Impact by Component and Country

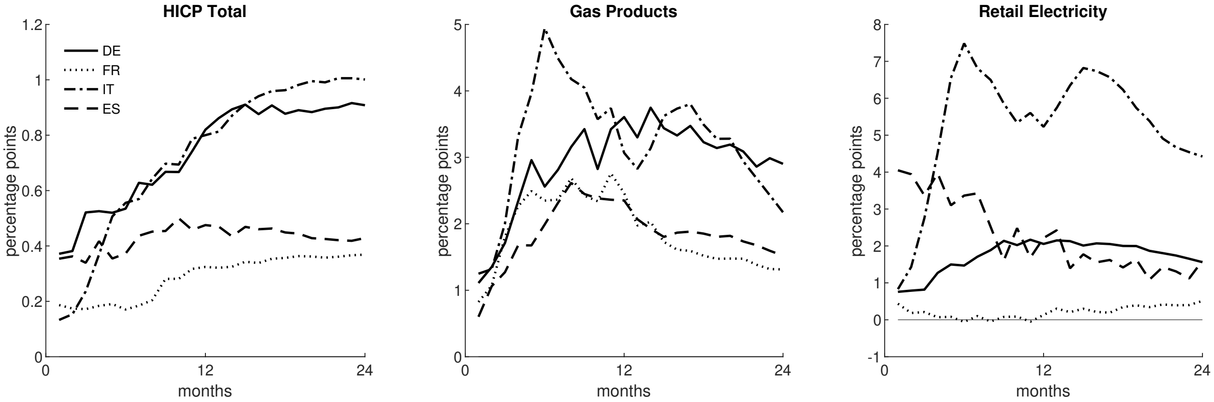


Figure E.1: Cumulative Impact by Component and Country

Notes: The figure shows the cumulative sum of the responses of m-o-m estimates for total HICP, gas products (COICOP-0452) and retail electricity (COICOP-0451) to a 10% increase in the price of gas. Sample 1997m1 to 2024m12.

F Bayesian Estimation Results

Table F.1: Estimation Results

Parameter	**Prior Type**	**Mean**	**S.D.**	**Post. Mean**	**90% Interval**	
					Lower	**Upper**
Estimated Parameters						
θ_o – Calvo refined oil firms	*beta*	0.70	0.15	0.59	0.51	0.66
θ_g – Calvo gas/elect. firms	*beta*	0.70	0.15	0.90	0.86	0.93
ρ_{co}^1 – root 1, crude oil	*beta*	0.60	0.15	0.89	0.86	0.93
ρ_{co}^2 – root 2, crude oil	*beta*	0.30	0.15	0.31	0.21	0.41
ρ_{ng}^1 – root 1, natural gas	*beta*	0.60	0.15	0.94	0.92	0.97
ρ_{ng}^2 – root 2, natural gas	*beta*	0.30	0.15	0.31	0.22	0.40
ρ_d – persistence preference	*beta*	0.60	0.15	0.56	0.50	0.63
ρ_z – persistence TFP	*beta*	0.60	0.15	0.97	0.96	0.98
ρ_w – persistence wage mark-up	*beta*	0.60	0.15	0.29	0.17	0.41
$\rho_{w,ma}$ – persistence wage mark-up (MA component)	*beta*	0.15	0.05	0.20	0.11	0.29
ρ_p – persistence price mark-up	*beta*	0.60	0.15	0.31	0.17	0.44
$\rho_{p,ma}$ – persistence price mark-up (MA component)	*beta*	0.15	0.05	0.18	0.09	0.27
Standard Deviation of Shocks						
σ_{co} – crude oil	*invg*	0.01	2.00	0.10	0.09	0.10
σ_{ng} – natural gas	*invg*	0.01	2.00	0.07	0.07	0.08
σ_d – preference	*invg*	0.01	2.00	0.05	0.04	0.05
σ_r – monetary policy	*invg*	0.01	2.00	0.01	0.00	0.01
σ_z – TFP	*invg*	0.01	2.00	0.01	0.00	0.01
σ_w – wage mark-up	*invg*	0.01	2.00	0.14	0.13	0.15
σ_p – price mark-up	*invg*	0.01	2.00	0.02	0.02	0.02

Notes: Results are reported at the posterior mean. 90% confidence intervals in parenthesis. Prior Type indicates the assumed distribution (beta or inverse-gamma).

G The Role of Monetary Policy

Figure G.1 shows how monetary policy can influence the effects of gas price shocks to inflation. It provides insights into the trade-off between output and inflation that monetary policy faces when the economy is hit by supply shocks. We explore two counterfactual scenarios: *i*) prioritising stabilising inflation, when the Taylor rule inflation coefficient is set to 50; and *ii*) focusing on stabilising output, implying that the Taylor rule inflation coefficient is set to 1.05. As observed, if the central bank strongly reacts to inflation, prioritising price stability over output, the peak response of headline inflation is one-fourth of what is observed in the benchmark scenario (red dashed line). However, achieving this outcome entails a substantial drop in real GDP, of approximately -2.15% in quarterly terms, in contrast to the baseline simulation, which exhibits a -0.23% decline. On the other hand, with an accommodating monetary policy the peak in inflation is slightly higher (blue dotted line), whereas real GDP now experiences a smaller drop compared to the benchmark case.

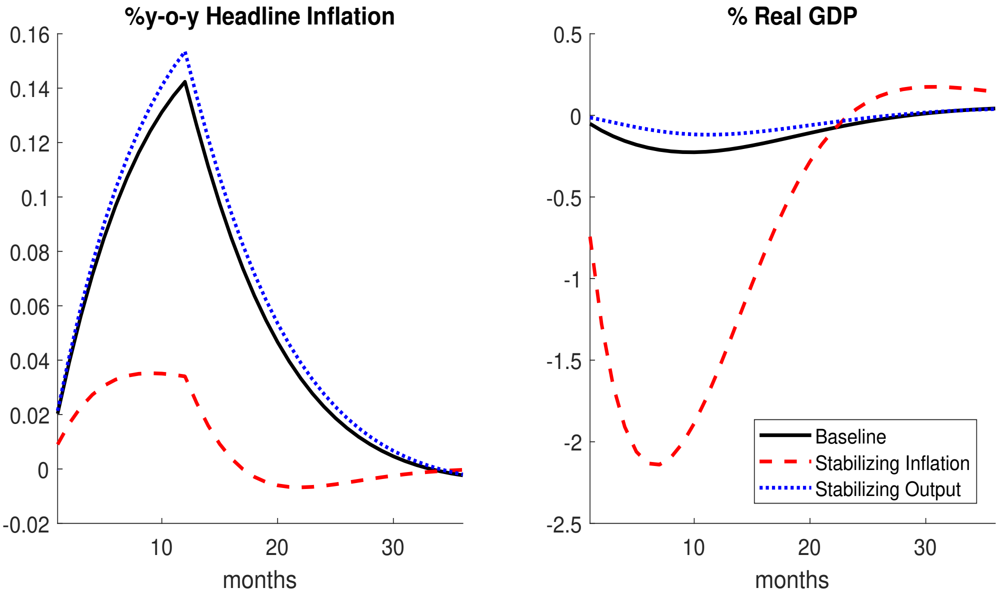


Figure G.1: IRFs to a 10% increase in the real gas price: The Role of Monetary Policy

H Contribution of Shocks to Headline Inflation and Real GDP Growth in the Euro Area

In this section, we explore the structural driving forces that have contributed to the recent inflation dynamics. We consider four key driving forces that are of relevance for inflation: gas and oil shocks, demand-side shocks and other supply-driven shocks (see Table F.1 for further details).

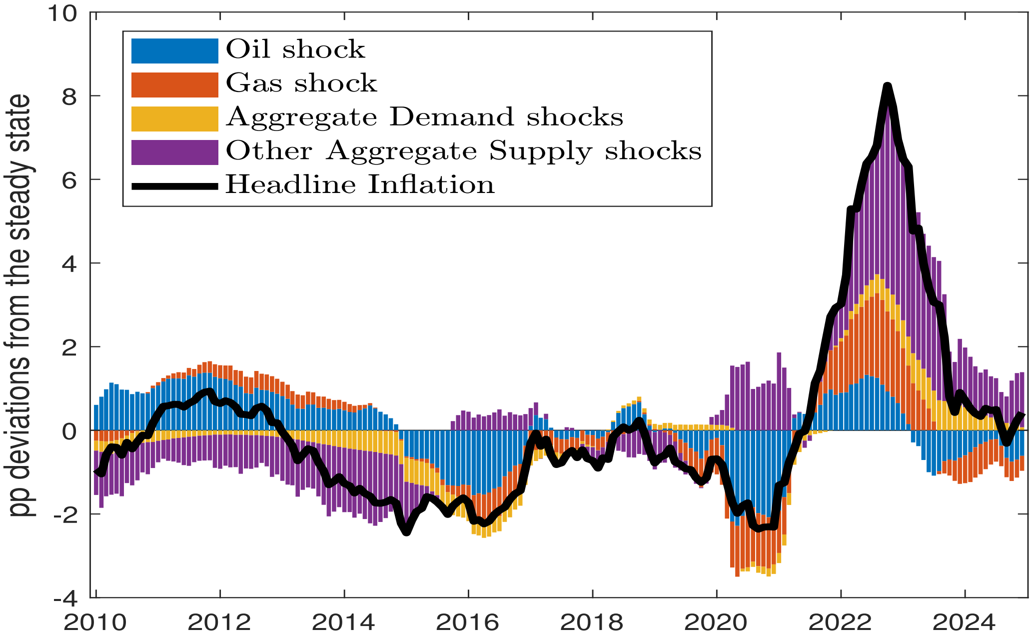


Figure H.1: Historical shock decomposition of headline inflation in the euro area

Note: Horizontal axis: months. Vertical axis: percentage-point deviations from the steady state.

Figure H.1 illustrates the historical shock decomposition of the year-on-year headline inflation rate spanning from January 2010 to December 2024.[21] One can notice several noteworthy features. First, the period before the Covid crisis is characterized by a low inflation regime. As observed, this reflects a combination of low energy prices, other aggregate supply shocks, and negative demand-side (preference-based) shocks. Second, after the Covid lockdown, the inflation surge was driven by energy shocks, with gas shocks making a larger and more persistent contribution than oil shocks, followed by aggregate demand and other supply shocks.

---

[21] We present the historical decomposition from 2010 to 2024 for better illustrative purposes.

Bearing in mind that a one-to-one comparison is not possible, our historical decomposition is in line with that of Bańbura et al. (2023). They employ a structural VAR model, identified with zero and sign restrictions, in order to account for the drivers of core inflation. They use a rich set of variables in their empirical framework and consider different supply and demand shocks that affected core inflation following Russia's invasion of Ukraine. Instead, we focused empirically on supply-driven gas shocks and relied on a micro-founded theoretical model to study the potential transmission channels. Nevertheless, we obtain similar results regarding the relative contribution of energy price shocks.

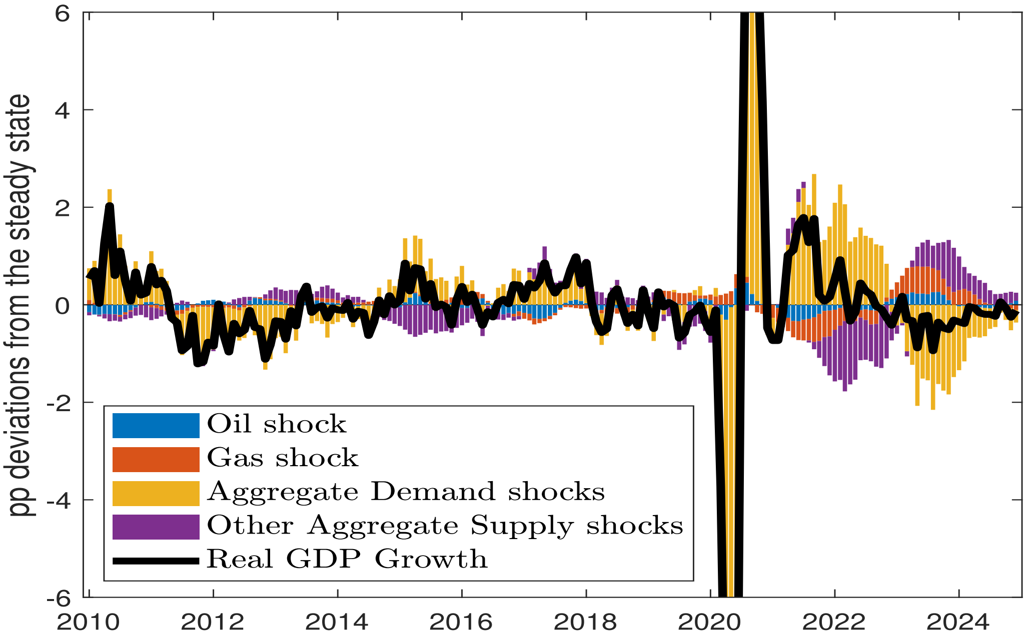


Figure H.2: Historical shock decomposition of real GDP growth in the euro area
Note: Horizontal axis: months. Vertical axis: percentage-point deviations from the steady state.

Finally, the historical shock decomposition for real GDP exhibits lower uncertainty from 2010 to 2020 (see Figure H.2). However, from 2020 onward, the contribution of different structural shocks to output dynamics is clearly more uncertain. On the one hand, we observe a positive contribution of aggregate demand shocks, potentially influenced by the reopening of the economies after the Covid lockdowns. At the same time, we note persistent and negative contributions from energy shocks (especially natural gas) and other aggregate supply shocks.

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Lucia López
Banco de España, Madrid, Spain; email: lucia.lopez@bde.es

Florens Odendahl
Banco de España, Madrid, Spain; Centro de Estudios Monetarios y Financieros, Madrid, Spain; email: florens.odendahl@bde.es

Susana Parraga Rodriguez
European Central Bank, Frankfurt am Main, Germany; email: susana.parraga_rodriguez@ecb.europa.eu

Edgar Silgado-Gómez
Banco de España, Madrid, Spain; email: edgar.silgado@bde.es

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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