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ChaMP

This paper contains research conducted within the network "Challenges for Monetary Policy Transmission in a Changing World Network" (ChaMP). It consists of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Central Banks (ESCB).

ChaMP is coordinated by a team chaired by Philipp Hartmann (ECB), and consisting of Diana Bonfim (Banco de Portugal), Margherita Bottero (Banca d'Italia), Emmanuel Dhyne (Nationale Bank van België/Banque Nationale de Belgique) and Maria T. Valderrama (Oesterreichische Nationalbank), who are supported by Melina Papoutsi and Gonzalo Paz-Pardo (both ECB), 7 central bank advisers and 8 academic consultants.

ChaMP seeks to revisit our knowledge of monetary transmission channels in the euro area in the context of unprecedented shocks, multiple ongoing structural changes and the extension of the monetary policy toolkit over the last decade and a half as well as the recent steep inflation wave and its reversal. More information is provided on its website.

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NATURAL GAS AND THE MACROECONOMY:
NOT ALL ENERGY SHOCKS ARE ALIKE

by Piergiorgio Alessandri* and Andrea Gazzani*

Abstract

How do shocks to the supply of natural gas affect output and inflation? To answer this question, we construct an instrument using daily news on the European gas market and employ it within a VAR model of the Euro Area. We find that negative supply shocks have sizable stagflationary effects and that they accounted for nearly 50 percent of the increase in core prices observed between 2021 and 2023. The propagation to core prices appears to be larger compared to oil shocks, suggesting that the structural differences between the two markets matter from an aggregate perspective.

JEL Classification: E31, E32, Q35, Q43.
Keywords: natural gas prices, inflation, narrative identification, Bayesian VAR.
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1. Introduction *

The procurement of natural gas has been a sticking point for European economies in recent years. The political tensions that built up in 2021, culminating in the Russian invasion of Ukraine in February 2022, triggered dramatic jumps in gas prices and a collapse in gas flows from Russia to Europe, precipitating Europe into the most dramatic energy crisis of the past few decades and turning a previously neglected commodity into a key issue on the media (Figure 1, left panel). The gas crisis was accompanied by a dramatic surge in Euro Area inflation (right panel), injecting new life into the debate on the inflationary role of energy shocks and their implications for monetary policy (see, for instance, Blanchard and Bernanke, 2024).

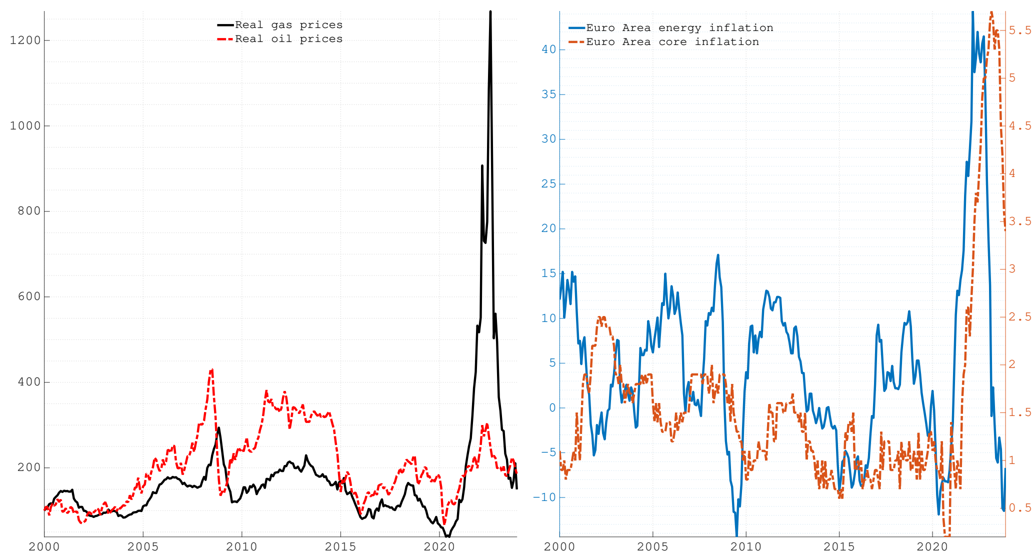

Figure 1: Gas prices and inflation in the Euro Area
Note. The left panel shows the dynamics of real natural gas (black line - Pinksheet series from the World Bank) and oil prices (red line - Brent price) rebased to 100 in January 200. The right panel displays Euro Area energy (blue line - left y-axis scale) and core (orange line - right y-axis scale) inflation.

Yet, unlike oil, gas represents an unknown from a macroeconomic perspective. There is scant evidence on how demand and supply factors affect gas prices or on the influence that gas prices have on inflation and economic activity. Furthermore, the gas market has several peculiar features that could in principle complicate the identification of exogenous supply or demand shocks and affect their propagation; these include

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geographical segmentation into regional markets, long-term contracts and regulations (that weaken the link between wholesale and retail prices), strong seasonality in consumption (which motivates buyers to maintain large storage capacities), and, in Europe, a tight relationship with the electricity market.[1]

This paper focuses on the role of supply-side factors, a likely culprit for the European energy crisis, analyzing the impact of gas supply shocks on inflation and economic activity and their implications for the conduct of monetary policy. We take up the identification challenge by combining two widely used tools in empirical macroeconomic studies: narrative identification and Bayesian VAR models. To identify supply shocks, we construct an instrument by parsing a large dataset of daily news about the European gas market over the 2010-2022 period. We focus on dates in which the prices of gas futures recorded large swings and resort to a careful line-by-line analysis of the underlying daily news to separate events that are clearly symptomatic of shifts in the supply of natural gas from those relating to changes in demand and other confounding factors. Our definition of supply disturbances encompasses changes in actual gas flows, news on future gas flows, and variations in risk about future supplies. We then use the change in prices in days driven by supply news as an external instrument or proxy in a medium-scale Bayesian VAR model of the Euro Area. The Bayesian setup allows us to (i) model the potentially 'long and variable' lags that separate shocks and economic responses despite the relatively small size of the sample; (ii) sterilize the confounding effect of the volatility caused by the Covid pandemic (following Lenza and Primiceri, 2022); and (iii) obtain estimates that are robust to the large price fluctuations observed in 2021 and 2022.

[1]See Hafner and Luciani (2022) and Ason (2022) for a review of the contractual features of the natural gas market.

We find that contractions in gas supplies are stagflationary. A 10% increase in gas prices leads to a 0.5% increase in core prices, and the large shocks that occurred in 2021-22 explain nearly 50 percent of the inflationary bout observed in the euro area after the end of the Covid pandemic. A varying degree of gas dependence gives place to significant differences among Euro Area members. We also find that, despite propagating more gradually, gas shocks have a larger impact on core inflation than oil shocks, reflecting the key role of gas in electricity production in Europe. The peak pass-through to core inflation, defined as the ratio between the cumulative responses of core and energy prices conditional on a given structural shock, is about 20% for gas shocks and 10% for oil shocks.

The findings are robust to various departures from the baseline setup, including the use of alternative VAR specifications, a factor-augmented VAR (FAVAR), local projections, and an identification scheme based on heteroskedasticity that does not require the instrument to be exogenous (Rigobon, 2003). Although our narrative instrument draws most of its power from the volatility caused by the conflicts between Russia and Ukraine, the results are also qualitatively similar in the pre-2022 period.

Related literature. Our work joins a debate on the relationship between energy markets and the macroeconomy that has recently gained significant visibility in both research and policy fora. As such, it draws on the large literature on the impact of oil prices and oil supply shocks (Hamilton, 1983; Kilian, 2009; Baumeister and Peersman, 2013; Baumeister and Hamilton, 2019; Caldara et al., 2019; Conflitti and Luciani, 2019; Känzig, 2021; Aastveit et al., 2023; Gagliardone and Gertler, 2023; Baumeister, 2023b). Since it can be used in daily VAR models, our instrument also allows policymakers to examine gas price fluctuations in quasi-real time, mimicking the strategy proposed by Gazzani, Venditti and Veronese (2024) for the oil market. Motivated by the recent energy crisis, Casoli et al. (2022), Boeck and Zörner (2023), Adolfsen et al. (2024) and Guntner et al. (2024) specifically analyzed the impact of gas shocks in Europe using monthly VAR models identified through sign (and zero) restrictions on the impact matrix.[2] The key advantage of our approach is that, by constructing an instrument based on daily news, we can isolate the shock at a higher frequency and avoid prior restrictions on the impact that disruptions to gas supplies may have on the economy. Both factors are likely to be important in light of the identification challenges associated with the peculiar nature of the gas market (see Section 2).

Our results can also guide research efforts that consider the implications of energy prices from a broader perspective. Several theoretical and empirical studies treat fluctuations in energy prices as homogeneous, without discriminating between different commodity markets (see respectively Chan et al., 2022; Pieroni, 2023; Auclert et al., 2023 and Blanchard and Bernanke, 2023; Arce et al., 2024; De Santis and Tornese, 2023; Neri, 2024). The glaring heterogeneity that we document in the transmission of oil and gas supply shocks suggests that this level of aggregation can be misleading. Adopting a more granular approach may be particularly important when evaluating policy responses from a positive or normative perspective: our findings show that differences in the pass-through cause core prices to behave differently after gas and oil shocks even if the initial jump in energy prices is the same. In the case of energy, whether and how central banks should 'look through' supply shocks (Beaudry et al., 2023) appears to depend on the source of the shock.[3]

[2]See also Nick and Thoenes (2014) and Rubaszek et al. (2021), which analyze the drivers of natural gas markets rather than the macro-financial implications of gas supply shocks.

[3]Differences among energy commodities are likely to become increasingly important in the future. The transition towards a low-emission economy requires the intensive use of several critical minerals,

Last but not least, our paper contributes to the ongoing debate on the drivers of the post-pandemic inflation surge (for a review, see for instance Giannone and Primiceri, 2024). Researchers have alternatively emphasized the role of demand factors (Ascari et al., 2023; Giannone and Primiceri, 2024) or supply factors (Blanchard and Bernanke, 2023; Gagliardone and Gertler, 2023) in explaining inflation dynamics. Our results corroborate the conclusion that energy shocks played a key role in the Euro Area, especially compared to the US (Di Giovanni et al., 2023; Bergholt et al., 2023; Blanchard and Bernanke, 2024; Dao et al., 2024), and shed light on the specific implications of gas supply shocks.

Structure of the paper. The remainder of the paper is organized as follows. In Section 2 we discuss the institutional features of the European gas market and the construction of the instrument. In Section 3, we discuss the properties of the instrument and several diagnostic exercises. In Section 4 we move to the VAR analysis. Section 5 explores alternative empirical specifications. Section 6 focuses on the comparison between gas and oil supply shocks. Section 7 concludes the paper. A detailed description of the data employed in the paper is provided in the Online Appendix.

2. Identification

In Section 2.1, we describe the institutional features of the European gas market, illustrating how it differs from the oil market and why the differences matter from an identification perspective. Section 2.2 describes the construction of our instrument for gas supply shocks and presents a range of diagnostic test on the validity of the instrument.

and taking into account the unique physical and contractual features of the underlying markets may be crucial to gauge the relations between these commodities and the business cycle.

2.1. *The natural gas market*

The physical characteristics of the commodities make trade significantly more expensive for natural gas than oil. Consequently, while oil has been traded on a relatively efficient and global market for decades, gas trading has traditionally occurred in regional segmented markets. International gas trade typically relied on pipelines that featured large upfront investments and lack of fungibility, forcing buyers and sellers to rely mostly on long-term contracts. Because of this, the gas market has not produced reliable price benchmarks for a long time. In Europe, long-term gas contracts used to be indexed to (a lagged moving average of) the price of oil products.[4]

The European market underwent radical changes starting from the 1990s with the development of techniques that allowed the production of *liquified natural gas* (LNG), dramatically increasing fungibility and global integration, the market liberalization promoted by European institutions, and the increase in gas demand and market size.[5] As a result of these changes, several trading hubs for spot and short-term trades arose across Europe, allowing a gradual decoupling of gas pricing from oil prices.[6] The Dutch *Title Transfer Facility* (TTF), set up in 2003, acquired prominence over the years and now provides the European wholesale gas price benchmark. TTF futures gas contracts are among the most liquid ones in the world (European Commission, 2018); in 2019, the TTF platform accounted for 79% of total traded volumes in the continent.[7]

[4]See Hafner and Luciani (2022) for a deeper discussion of the features of oil and gas markets.

[5]Key regulatory changes about market liberalization were Directives 1998/30/EC, 2003/55/EC, and 2009/73/EC. Between 1960 and 2020, global gas consumption increased twice as much compared to oil and coal consumption (Emiliozzi et al., 2023).

[6]This process gained momentum after 2010 and gradually spread to long-term contracts. As of today, oil indexing of long-term gas contracts is residual.

[7]The TTF is a virtual gas-trading hub that provides a trading platform defined through a transnational pipeline grid consisting of interconnected pipelines with no point of origin or end. Virtual trading hubs are typically adopted by countries or areas that mainly rely on imported natural gas, whereas physical hubs are more common in producing countries like the US. All gas within the virtual hub can be traded irrespective of its actual location.

Some institutional features are particularly important when considering the identification and transmission of gas supply shocks. First, long-term contracts (nowadays mainly indexed to the TTF wholesale price) force buyers to pay for a minimum quantity of gas irrespective of their needs (*Take-or-Pay* clause, see Masten and Crocker, 1985). As the price in these contracts is typically a lagged moving average of the spot price, arbitrage opportunities may arise between the spot market and long-term trades, implying that quantities provide noisy information on demand, and using them to disentangle demand and supply shocks is problematic (see for instance OIES, 2022). Second, the retail market is heavily regulated, and retail prices typically follow wholesale (hub) prices with a lag of a few months (see for the Italian case Alpino et al., 2023). These contractual frictions are likely to slow down the transmission of gas supply shocks, causing troubles in identification strategies that rely on contemporaneous sign restrictions. Third, a strong seasonality characterizes natural gas consumption, and buyers maintain large storage capacities. Fourth, gas prices have a crucial role in determining electricity prices as a result of the so-called *merit order* in force in the EU electricity system: gas is typically the marginal fuel of production for electricity generation, being the most expensive one (Fabra, 2023).[8] This tight gas-electricity link may significantly affect their propagation of gas supply shocks.

2.2. Construction of the instrument

To construct our instrument for gas supply shocks, we examine a rich sample of daily news spanning the period between January 1st, 2010, and November 30th, 2022. By using a relatively long sample, we reduce our reliance on the volatility caused by

[8] For a broad overview of the electricity market design in the EU, see European Parliament - 2016 briefing.

the Russian invasion of Ukraine in 2022. The period we consider includes the conflict between Russia and Ukraine in 2014, as well as phases of greater political and financial stability prior to 2014 and between 2016 and 2021.[9] We cut the sample in November 2022 because, on December 3rd, the European Union agreed to cap the price of natural gas to reduce the volatility created by the conflict. This unprecedented intervention altered the market in non-trivial ways, rendering the subsequent observations not directly comparable to the historical data.

In exploiting changes in gas prices around key dates for identification, we follow the logic used by Känzig (2021, 2022) for shocks to oil supply and carbon prices. The key idea is that exogenous shifts in supply drive these fluctuations in prices and are not related to changes in business cycle conditions. Like Wu and Cavallo (2012), we exploit daily news to interpret the drivers of the observed fluctuations in commodity prices. We construct the instrument in two steps.

The first step consists of isolating days characterized by quantitatively significant fluctuations in TTF futures. Defining what 'significant' means is not trivial because gas prices are much more volatile in the last part of our sample. Table A1 reports the results of a non-parametric test of constant variance for the TTF daily growth rate before and after 2019. The null hypothesis of constant variance is overwhelmingly rejected; the standard deviations of the series in the two sub-samples are about 2 and 5.8 percentage points.[10] Based on this evidence, we pick all the dates for which the absolute value of the daily percentage change in the front-month TTF future exceeds a threshold of,

[9]Russia and Ukraine officially ended the conflict by signing the Minsk II agreements on February 12th, 2015. The agreement included *inter alia* the withdrawal of heavy weapons from the front line and an OECD-observed unconditional ceasefire from February 15th.

[10]The break in December 2019 allows us to account for the Covid pandemic as well as a significant escalation in the political tensions between Russia and Ukraine; Ukraine was granted NATO Enhanced Opportunity Partner status on 12 June 2020, and President Zelensky approved a new national security plan with the explicit aim of joining NATO on 14 September 2020.

respectively, 5% in the pre-2019 data and 10% in the post-2019 data. We thus employ a set of 110 trading days that were characterized by price shifts of two standard deviations or more within each regime.[11]

In the second step, we collect and carefully vet the news about the gas market associated with each date. We begin by extracting from Refinitiv all news in English whose titles contain the strings "TTF", "LNG" (for Liquified Natural Gas) and/or "GAZP" (for Gazprom; excluding this keyword has little impact on the results). The search returns over 8,000 news. Upon removing noisy information – such as generic and non-factual commentaries on the market outlook – the total drops to 4,290 news, with a mean and median of respectively 39 and 29 news per date. The frequency of gas-related news displays large fluctuations over time, with a maximum of 150 entries (on September 7th, 2022), a minimum of 2 entries (on August 28th, 2014), and a standard deviation of about 30. We then examine the news individually, considering the body as well as the title of each entry, and assign a "demand" or "supply" flag to the items with a clear interpretation. All remaining news are marked as ambiguous or irrelevant; this residual category includes *e.g.* a large number of wires that merely comment on data released in previous days, or report minor updates on the routes followed by LNG tankers. This process isolates 55 daily supply shocks. The remaining dates are classified as (i) not sufficiently relevant, (ii) dominated by demand shocks, or (iii) characterized by an ambiguous mixture of demand and supply shocks and excluded from the analysis. The classification is deliberately conservative: we exclude all dates

[11] In order to focus on persistent changes in price levels, we exclude 15 dates in which price fluctuations are large, but the one-day ahead, front-month, and one-year ahead futures move in different directions. This filter may somewhat weaken the power of the instrument, but it allows us to focus on shocks that affect the level (rather than slope or curvature) of the future curve and are perceived to be persistent by market operators. Hevia et al. (2018) document the quantitative relevance of level, slope, curvature, and stochastic seasonality in futures on heating oil and soybean; Garratt and Petrella (2022) fit a similar multi-factor model to over 20 commodities, including natural gas.

event date	*key headline*	%ΔTTF
06-May-2010	Russia's proposal to merge gas network rebuked by Ukraine	5.6
04-Jun-2010	Oman and Quatar LNG facilities down for climatic events	5.4
20-Jul-2010	ENI pushes forward pipeline project in Azerbaijan; LNG tankers diverted from Mexico to EU	-6.1
31-Mar-2011	Internal political tensions in Russia; Russian gas facility delayed by 3 months; worries on LNG supply for EU market	6.0
03-Mar-2014	Tensions piling up between Russia and Ukraine	9.5
04-Mar-2014	Gazprom says Russian gas flows to Europe via Ukraine not affected by tensions	-5.6
07-Apr-2014	Deadline for Ukraine to pay Gazprom expires without transactions	5.0
28-Aug-2014	EU Commissar Oettinger cannot rule out disruptions in gas flows from Russia	5.2
29-Aug-2014	Gazprom accuses Ukraine of stealing gas	15.9
22-Jan-2016	Dispute between Gazprom and Naftogas	7.0
21-Apr-2016	Russia starts providing gas to China	5.9
26-Apr-2016	Gazprom unavailable to discuss its monopoly position	7.8
28-Apr-2016	Gazprom hopes Nord Stream 2 avoids problems with Brussels faced by predecessor	-9.6
13-Dec-2017	Yamal starts exporting LNG	-5.1
05-Apr-2019	Reduce supply from Norway to EU and UK	12.3
10-Sep-2019	EU court ruling against Gazprom on Opal Pipeline; Putin suggests diverting gas from EU to China	17.7
29-Jun-2020	US threaten to sanction EU on NS2	19.0
30-Jul-2020	Pompeo makes strong declaration against Nord Stream 2	15.6
03-Aug-2020	Tensions between Poland and Gazprom	12.9
20-Sep-2021	Gazprom is not booking gas transit via Ukraine - Ukraine to reconfigure gas transmission system	15.7
05-Oct-2021	Putin declaration: "Gazprom will prioritize domestic market"	20.0
28-Oct-2021	Gazprom declares it can pump gas into EU storage	-10.9
29-Oct-2021	Gazprom reaches agreement with ENI and Moldova	-16.1
03-Nov-2021	Increasing uncertainty over Russian supply to EU	13.2
16-Nov-2021	Nord Stream 2 certification halted by German authorities	17.8
14-Dec-2021	Talk of Western sanctions on Russia	10.5
21-Dec-2021	Russian is not booking gas volume towards EU but increase flows to Turkey; Yamal flowing eastbound	22.7
23-Dec-2021	Russian news agencies: gas to EU increased in 2021; LNG tankers diverted from Asia towards EU	-23.3
03-Jan-2022	Gazprom draws on storage but misses 2021 export target to Europe	14.3
13-Jan-2022	IEA chief Birol: "Russia worsened EU gas crisis"; US congress discuss Nord Stream 2 sanction bill	13.7
17-Jan-2022	Gazprom increase gas output	-11.4
23-Feb-2022	Biden announces sanctions on Nord Stream 2	11.4
24-Feb-2022	Russia invades Ukraine	51.1
25-Feb-2022	Reassurances from Gazprom on gas flows	-30.7
01-Mar-2022	Several EU gas companies severe ties with Gazprom	23.4
02-Mar-2022	Yamal stops; Sanctions on EU-Russian gas joint-ventures	36.1
04-Mar-2022	Nord Stream 2 holding files for bankruptcy; fears on Russian supply to EU	19.7
07-Mar-2022	Talk of EU sanctions on Russian gas	18.0
09-Mar-2022	Gazprom books Yamal transit	-27.3
10-Mar-2022	Regular Gazprom supply to EU; new LNG projects approved worldwide	-18.9
16-Mar-2022	Norway can provide more gas to EU; new LNG projects approved in the US	-11.1
23-Mar-2022	Gazprom will require payments in rubles	18.5
30-Mar-2022	EU-Russia tensions over ruble gas payments	10.6
01-Apr-2022	US is exporting more gas to EU	-10.9
14-Jun-2022	Nord Stream 1 limited capacity due to turbine stuck in Canada	16.4
15-Jun-2022	Nord Stream 1 volumes drop further; implications of Freeport LNG Fire Continue to Grow	24.0
04-Jul-2022	Gazprom may ask for rubles payment also for LNG exports; Norway flows drop by 13% due to strike	10.3
25-Jul-2022	Gazprom announced Nord Stream flows cut due to renew dispute on Siemens turbine	10.5
26-Jul-2022	Nord Stream flows drop to 20% of capacity	13.2
22-Aug-2022	Three days stop to Nord Stream announced	13.2
25-Aug-2022	Gazprom states that turbines are not being repaired in Canada	10.0
29-Aug-2022	Flows to Ukraine increase; Yamal flows regularly	-19.6
02-Sep-2022	Data signals Nord Stream 1 flows to resume	-11.7
05-Sep-2022	New halt to Nord Stream1 flows	14.7
21-Oct-2022	Italy approves new LNG terminal; Mozambique starts exporting LNG to EU	-10.7

Table 1: Natural gas supply events

for which supply-side events might be polluted by concurrent changes in demand to preserve the validity of the instrument.

The instrument is defined as $z_t^d = \mathsf{TTF}_t - \mathsf{TTF}_{t-1}$, where t denotes the days with supply news and TTF_t denotes the price of the one-month TTF contract. The instrument is set equal to zero on all remaining dates. We employ the one-month contract because gas futures are less liquid at longer maturities. In any case, when using a principal component extracted from contracts with multiple maturities, we obtain a series that is highly correlated to our baseline instrument (0.95) and delivers very similar responses in the VAR (see Section 5). Futures prices generally incorporate risk premia (Baumeister, 2023a), but these are unlikely to vary substantially at the daily frequency (Kuttner, 2001; Faust et al., 2004; Piazzesi and Swanson, 2008; Hamilton, 2009; Nakamura and Steinsson, 2018).

Table 1 reports all dates for which $z_t^d \neq 0$, showing for each day the key news and the observed daily percentage change in one-month TTF future. Negative supply shocks (corresponding to positive price changes) include several events linked to Russia, such as the US government's threat to sanction North Stream 2 (June 2020), the invasion of Ukraine (February 2022), the shutdown of the Yamal pipeline (March 2022) and Gazprom's decision to accept only payments in roubles (March 2022). A sequence of restrictive shocks also occurs between June and August 2022, in relation to the continuous decline in Nord Stream gas flows. Other events concern the global supply of LNG, such as when a main facility in the US (Freeport) was hit by a fire (June 2020), or the supply from other sources, such as when Norway's supply to Europe fell due to strikes (July 2020). Positive supply shocks (and declines in gas prices) are often associated with conciliatory statements by Gazprom or unexpected pickups in pipeline flows. As the table makes clear, we do not discriminate between actual changes in gas flows, news on future flows, and changes in the uncertainty about future flows. These shocks are likely to have fairly similar effects on macroeconomic outcomes. Discriminating among them could be interesting in principle, but would require a larger database and a more subtle (and potentially contentious) interpretation of the news.

Figure 2 shows a simple monthly average of the TTF percentage price changes observed around the selected dates. The largest shocks take place in the build-up and aftermath of the Russian invasion of 2022, but there are a number of significant episodes in the sample that predates Covid (2014-2019) and the Crimean conflict (2010-2014).

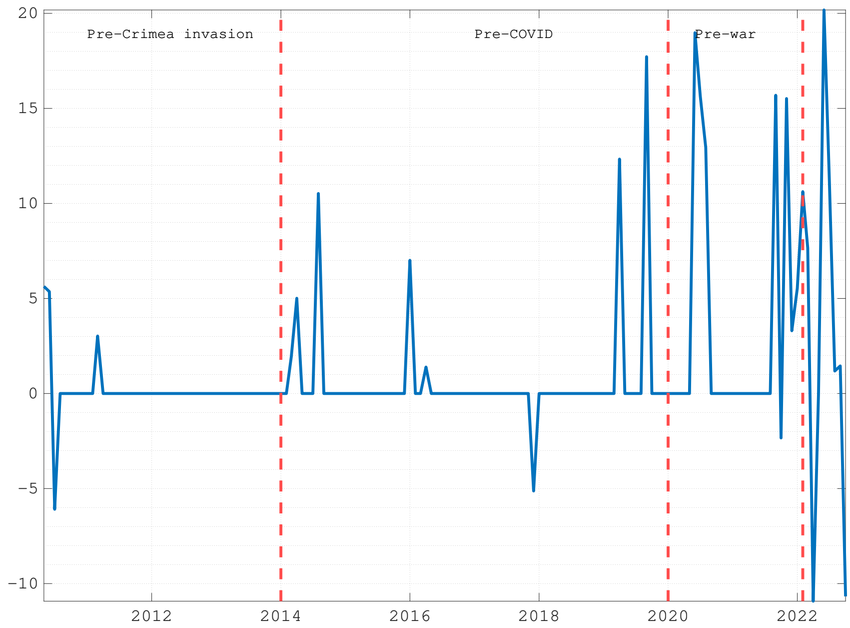


Figure 2: MONTHLY INSTRUMENT
Note. The figure shows the monthly average of the daily gas supply IV (as % change) obtained through narrative identification.

There are clear trade-offs in constructing the instrument: an algorithm-based textual analysis would allow us to expand the sample quantitatively while focusing on relatively few dates allows us to study the news in greater depth. We choose depth over width because the noisy nature of the news, combined with the lack of predefined, recurrent announcements (like the OPEC announcements on oil production), creates a significant risk that automated procedures would misclassify the shocks.

3. Validation

Our news-based instrument should ideally capture genuine gas supply shocks and be orthogonal to other structural shocks. In Sections 3.1-3.3 we present statistical evidence supporting these properties. In Section 3.4 we use daily local projection models (Jordà, 2005) to show that gas supply shocks – as captured by our instrument – cause asset and commodity price movements that are consistent with what one would expect on economic grounds.

3.1. Volatility ratios

Our first test looks at how the volatility of gas prices and other commodity and asset price indicators change around dates dominated by news on gas supplies. If (i) our identification picks up shocks that truly originate in the gas market (as opposed to generic macro-financial disturbances), and (ii) these shocks have a larger impact on gas prices than on the other indicators, then on supply shock dates the variance of the TTF should increase more than the variance of the other series. Table 2 reports the ratio between the volatility of TTF on shock- and no-shock dates (column 1) and a range of analogous ratios computed using oil prices, coal prices, wheat prices, equity prices, the VSTOXX volatility index, the 3-month Euribor rate and the geopolitical risk index (GPR, from Caldara and Iacoviello, 2022) (columns 2 to 7). The volatility of TTF futures is 25 times larger on shock dates. No other indicator displays a comparable increase in variance except for the coal price. However, since coal is a partial substitute of natural gas for power generation in Europe, volatility could arise in this case precisely as a response to gas supply shocks.[12] The conclusion holds in the pre- and post-2020 samples: in both cases the TTF is the only indicator for which volatility is one order of magnitude larger on shock dates.

The results are particularly interesting for the oil price and the GPR index. Oil prices

[12]See for instance Di Bella et al. (2022), OIES Quarterly Review 19 and OIES Energy Insight no.117. Wheat prices display a significant increase in variance too, but this is one order of magnitude smaller than for gas prices and confined to the 2020-2022 time window

are actually 40% less volatile around the shock dates in 2020-2022, confirming that gas and oil markets followed largely different patterns over this period and that the risk of capturing combinations of energy shocks of different kinds is low. The potential overlap between gas and geopolitical shocks is another potentially important concern, as the conflict between Russia and Ukraine certainly caused a widespread increase in uncertainty and a deterioration in business conditions after 2022. However, the volatility of the GPR index also turns out to be lower on shock dates, suggesting that, at the daily frequency, geopolitical events are not systematically synchronized with (what we identify as) changes in gas supply.

3.2. Relation with macroeconomic surprises and monetary decisions

The second test examines the correlation between our instrument and European or global macroeconomic surprises or monetary policy events. The Citigroup Economic Surprise Index (CESI), in either its global or any regional version, does not display any explanatory power for our instrument (Table A3). Furthermore, there is no overlap between supply shock dates and the US monetary policy surprises computed by Jarociński and Karadi (2020). There are four days on which the instrument overlaps with ECB Governing Councils (6 May 2010, 21 April 2016, 28 October 2021, 10 March 2022). However, monetary surprises on those dates are very small (0.20, 0.04, 0.01, and 0.36 standard deviations, respectively), and they have no explanatory power for the instrument: the regression has an F statistic of 0.05 with a p-value 0.83 at the daily frequency and 1.73 with p-value 0.19 at the monthly frequency. The variance of the Euribor rate does not change significantly on shock dates (see Table 2). Additional evidence comes from our local projection and VAR analyses. The estimated response of interest rates or shadow rates to gas supply shocks is extremely delayed, both at the daily frequency (see Section 3.4) and at the monthly frequency (see Section 4). This lack of contemporaneous comovements between gas prices and interest rates corroborates the conclusion that the contamination of our IV by monetary policy disturbances, if any, is quantitatively negligible.

3.3. *Relation with other structural shocks*

In our third test, we compute correlations between our instrument and other structural shock estimates available in the literature, focusing on energy and geopolitical risk shocks. The results are reported in Table 3. The correlations between the instrument and oil, carbon, or geopolitical risk shocks are both small and statistically insignificant.

Sample	TTF	Brent	Coal	Wheat	EuroStoxx	VStoxx	Euribor	GPR
2010-2022	25.4*	1.5	23.5*	2.7*	2.4*	1.8*	3.3*	0.72
2010-2019	14.3*	2.6	1.6	1.2	1.4	1.8	0.4	0.78
2020-2022	12.6*	0.6	11.3*	2.7*	2.2*	1.5	1.5	0.60

Table 2: Changes in volatility around dates with gas supply shocks

For each indicator, the table reports the ratio between the volatility observed on days with gas supply shocks and the volatility observed on ordinary trading days. The indicators are gas prices (TTF, col.1), oil, coal and wheat prices (cols.2-4), the Eurostoxx equity price index and its implied volatility (cols.5-6), the 3-month Euribor rate (col.7) and the geopolitical risk index (col.8). The ratios are computed over the full sample as well as the 2010-2019 and 2020-2022 subsamples. Stars denote ratios that are statistically different from one at the 1% level based on a Levene test.

	Corr.	P-value	Obs.
Kanzig (2021) oil supply shocks	0.001	0.98	156
Kanzig (2022) carbon policy shocks	0.12	0.21	120
Baumeister and Hamilton (2019) oil supply shocks	-0.14	0.13	156
Baumeister and Hamilton (2019) demand shocks	-0.03	0.74	156
Caldara and Iacoviello (2022) GPR global - AR(1) residual	0.07	0.37	156
Caldara and Iacoviello (2022) GPR Russia - AR(1) residual	0.09	0.22	156

Table 3: Correlation with other shocks in the literature.

3.4. *The financial effects of gas supply shocks*

As a final validation exercise, we estimate the impact of gas prices on various financial indicators using local projection (LP) models based on daily data. The LP coefficients measure the conditional correlations between gas futures and other asset or commodity prices at various horizons. As such, they capture both the impact of gas shocks on those prices and the common response of the indicators to unobserved shocks of a different nature. One can use economic theory and common sense to discriminate between the two and check that the coefficients only or mostly reflect causality going from the gas market to the rest of the economy. For each indicator we estimate a daily LP model of the following form:

$$y_{t+h} - y_{t-1} = \alpha_h + \beta_h lTTF_t + \delta_h X_{t-1} + \epsilon_t \quad h = 0, .., 90 \tag{1}$$

where $lTTF_t$ is the log of the TTF one-month contract instrumented with the supply swing series z_t^d, X is a vector of controls containing 10 lags of y and $lTTF$, and ϵ_t is a standard error term. The first-stage regression is extremely strong, with an F statistic of 624 and an R-squared coefficient of 0.46, confirming that the IV inference is reliable.

Figure 3 display the impulse-response functions. On impact, an increase in gas prices (TTF, top left corner) is associated to a drop in equity prices (Eurostoxx), a rise in implied volatility (VSTOXX), and a rise in the prices of Asian LNG and UK gas and electricity. The adverse supply shock causes a repricing of risk in the equity market that reflects the higher energy costs faced by households and firms in the economy. Oil prices (Brent) barely move, whereas coal prices respond strongly and rise along with the TTF. This is consistent with gas and coal being highly substitutable in contrast with oil and gas, as discussed in Section 3. Like oil prices, the VIX index and the Geopolitical Risk Index remain virtually unchanged, suggesting no overlap with broader business cycles or uncertainty shocks. Over time, the gas supply shock is also followed by increased US gas prices and a drop in carbon emission prices, potentially pointing

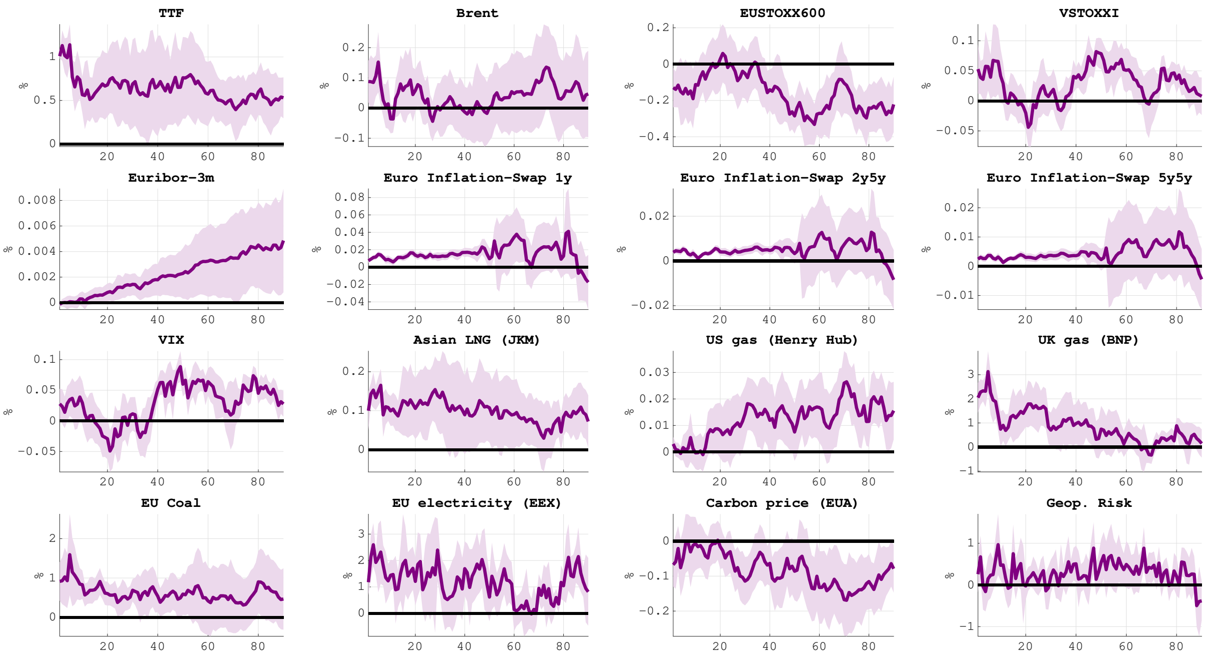


Figure 3: DAILY IRFS FROM LP-IV ESTIMATION

Note. The coefficients (β) are estimated by a set of bivariate local projections at the daily frequency that include gas price, instrumented with our narrative proxy, and the variable of interest (with 10 lags of the two variables as controls). All variables enter as log-level but for interest rates and inflation swaps. Standard error are computed following Newey-West. Sample: 2010-2022.

to pressures on US supplies and a slowdown of carbon-intensive activities. Finally, the shock elicits an increase in the short-term interest rate and inflation swaps, which implicitly measure inflation expectations (second row of the figure). All in all, the tests consistently corroborate the conclusion that the shocks captured by the instrument are exogenous, unexpected, and specific to the gas market.

4. The macroeconomic effects of gas supply shocks

To study the nexus between the gas market and the macroeconomy, we resort to a VAR model. We describe the structure and estimation of the model in Sections 4.1-4.2 and illustrate our main results in Section 4.3.

4.1. *Econometric framework*

Consider the standard VAR model:

$$\mathbf{y}_t = \mathbf{a} + \mathbf{A}_1 \mathbf{y}_{t-1} + \cdots + \mathbf{A}_p \mathbf{y}_{t-p} + \mathbf{u}_t \tag{2}$$

where p is the lag order, $\mathbf{y}_t$ is a $n \times 1$ vector of endogenous variables, $\mathbf{u}_t$ is a $n \times 1$ vector of reduced-form innovations with covariance matrix $\text{Var}(\mathbf{u}_t) = \mathbf{\Sigma}$, $\mathbf{a}$ is a $n \times 1$ vector of constants, and $\mathbf{A}_1, \ldots, \mathbf{A}_p$ are $n \times n$ matrices. The innovations $\mathbf{u}_t$ can be expressed as a linear combination of the structural shocks ε_t under the assumption of invertibility:

$$\mathbf{u}_t = \mathbf{B}\boldsymbol{\varepsilon}_t$$

$\text{Var}(\boldsymbol{\varepsilon}_t) = \mathbf{\Omega}$ is diagonal as the structural shocks are by construction uncorrelated. Conversely, $\mathbf{\Sigma} = \mathbf{B\Omega B}'$ is not diagonal as, generally, the reduced-form residuals are correlated. We are interested in estimating the causal impact of a unique shock in the system, i.e. the gas supply shock $\varepsilon_{1,t}$. The task involves recovering a single column $\mathbf{b}_1$ of the impact matrix $\mathbf{B}$.

Due to the large fluctuations in our relatively short sample related in particular to the Covid pandemic and the energy crisis, we employ Bayesian methods to estimate the VAR model in Eq.(2). We impose a standard Minnesota prior on the parameters of the BVAR according to which all univariate equations behave as a random walk. To fix the break in volatilities induced by the Covid shock, we re-scale the size of the reduced form residuals in March, April, and May 2020 as suggested in Lenza and Primiceri (2022). The hyper-parameters that control the prior and the scaling factors for the residuals are determined by jointly optimizing the marginal data density.[13] Our results are virtually identical if we do not model breaks in volatility as a result of lack of exogenous supply shifts in our IV during the Covid.

Underlying the VAR identification via external instruments lies the assumption that the instrument z_t has two properties:

$$\begin{aligned} \mathbb{E}\left[z_t \varepsilon_{1,t}\right] &= \alpha \neq 0 \qquad \textit{(relevance)} \\ \mathbb{E}\left[z_t \varepsilon_{2:n,t}\right] &= 0 \qquad\quad \textit{(exogeneity)} \end{aligned} \tag{3}$$

where $\varepsilon_{1,t}$ is the gas supply shock and $\varepsilon_{2:n,t}$ are the remaining structural shocks. Under those conditions, the column $\mathbf{b_1}$ is correctly estimated, up to scale and sign, as:

$$\mathbf{b}_1 \propto \frac{\mathbb{E}\left[z_t \mathbf{u}_t\right]}{\mathbb{E}\left[z_t \mathbf{u}_{1,t}\right]'} \tag{4}$$

We employ the narrative series of gas supply shifts described in Section 2.2 as an external instrument following Mertens and Ravn (2013).

4.2. *Baseline specification*

Our baseline specification is a medium-scale monthly VAR for the Euro Area that includes gas prices (*gas*), energy consumer prices (*energy hicp*), core consumer prices (*core hicp*), industrial production (*ip*), stock prices (*sp*), the shadow short-term rate (*srate*) and the 10-year Bund rate (*10yr*). Using a mix of macroeconomic and financial indicators is important to fully capture the effects of gas supply shocks, which spread quickly through financial markets (see Section 3.4) but are likely to propagate slowly

[13] A similar approach to optimize the scaling factors for the Covid is proposed by Cascaldi-Garcia (2022).

and gradually to the real economy (see Section 2.1). All variables except interest rates enter in growth rates and the VAR includes 12 lags. *gas* is the *Pinksheet* World Bank series for European natural gas prices, available for a much longer sample than TTF prices, deflated by headline consumer prices. *energy hicp* and *core hicp* are the month-on-month inflation rates (the estimates are similar albeit less accurate for year-on-year growth rates). *sp* is the *Eurostoxx 600* equity index similarly deflated. *srate* is the monetary policy short-term rate computed by Krippner (2013), which allows us to control for the Euro Area monetary policy stance during the zero-lower bound period too. *gas*, *energy hicp*, and *core hicp* are seasonally adjusted using the Census X13.

The monthly instrument z_t is obtained by simply averaging the daily instrument z_t^d within each calendar month. The first-stage regression of the *gas* VAR residual on z_t delivers an F statistic of 40.6 (with a p-value < 0.001 and a R^2 of 0.2). The instrument comfortably passes the invertibility test (Plagborg-Møller and Wolf, 2021; Noh, 2018): the p-value for the null hypothesis of no Granger causality from the VAR residuals to the proxy is 0.99. To fully exploit the data, we estimate the reduced-form parameters using a 2000-2023 sample; we then identify the impact matrix using the sub-period over which our instrument is available, namely 2010-2022. For instance, a similar strategy is adopted in Gertler and Karadi (2015).

4.3. Main results

Figure 4 reports the IRFs of the endogenous variables to a gas supply shock identified via the external instrument approach. *gas* displays a strong and persistent response to the shock, confirming the strength of the instrument. *energy hicp* and *sp* are the only other variables that respond on impact to the shock, although their peak response occurs after several months too. *core hicp* and *ip* respond with a long delay to the gas supply

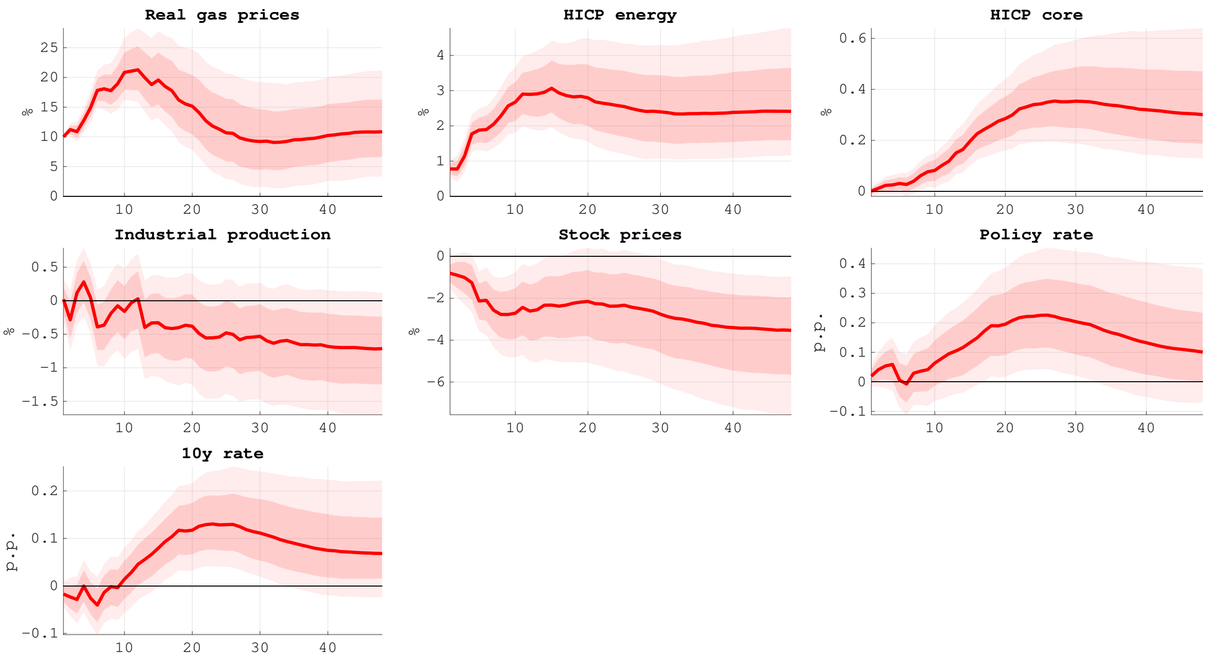


Figure 4: IRFs to gas supply shocks - baseline VAR model

Note. The figure reports the IRFs from the baseline VAR (cumulated for variables in growth rates). The VAR is estimated under a Minnesota prior with 12 lags. The solid line represents the median posterior IRF, whereas the bands report 68% and 90% credible sets. Estimation sample: 2000-2023; identification sample 2010-2022.

shock. This lagged response is consistent with the institutional characteristics of the EU gas market (see Section 2.1), and it could easily invalidate alternative identification approaches. For instance, sign restrictions that postulate contemporaneous responses of these variables would not be sound in this context. The *energy hicp* response peaks after about one year, *core hicp* peaks after more than two years; the negative response of *ip* takes even more time to build. At the peak, a 10% increase in *gas* leads to a 3% increase in *energy hicp*, an almost 0.4% increase for *core hicp*, and a 0.6% fall in *ip*. The path of the shadow rate indicates that monetary policy responds slowly and gradually to the shock, tracking the response of inflation. The relatively sharp rise in interest rates observed one year after the shock is consistent with the idea that central banks may optimally ignore supply shocks for a while and then pivot to a hawkish stance when prices accelerate beyond a given threshold (Beaudry et al., 2023).

Figure A1 displays the contribution of gas supply shocks to the variance of the variables. The forecast error variance decomposition (FEVD) suggests that supply shocks have a strong explanatory power for *gas* in the short run (about 80 percent), whereas demand and supply factors are equally important in the long run. Gas supply shocks also explain a statistically significant share of the variance of *energy hicp*, *core hicp*, *ip*, but the shares – ranging between 10 and 20 percent – indicate that they are not a dominant driver of the Euro Area business cycle. Prices appear more sensitive to gas supply fluctuations than production, in line with the survey evidence from Italian firms reported in Corsello et al. (2023).

4.4. Historical contribution

Figure 5 shows the historical contribution of gas supply shocks to the dynamics of *gas* in levels.[14] Panel (a) displays the whole estimation sample; panel (b) zooms on the post-Covid phase, showing the results for inflation and output as well as gas prices. Our identification strategy appears to successfully disentangle supply episodes from demand-driven fluctuations. The supply component does not explain, for instance, the boom-and-bust cycle around the Global Financial Crisis – which was indeed demand-driven – nor the fall in prices that accompanied the Covid pandemic. Conversely, it captures meaningful supply episodes in the EU gas market. In 2005-2006, several unplanned outages at LNG plants worldwide and delays in new production facilities generated a squeeze in LNG supply, while Gazprom curtailed supplies to Western Europe due to a prolonged commercial dispute (IEA, 2006). In 2009, Europe was hit by what the International Energy Agency (IEA) described – with hindsight, somewhat optimistically – as "the worst gas crisis in IEA history" (IEA, 2009). Disputes between

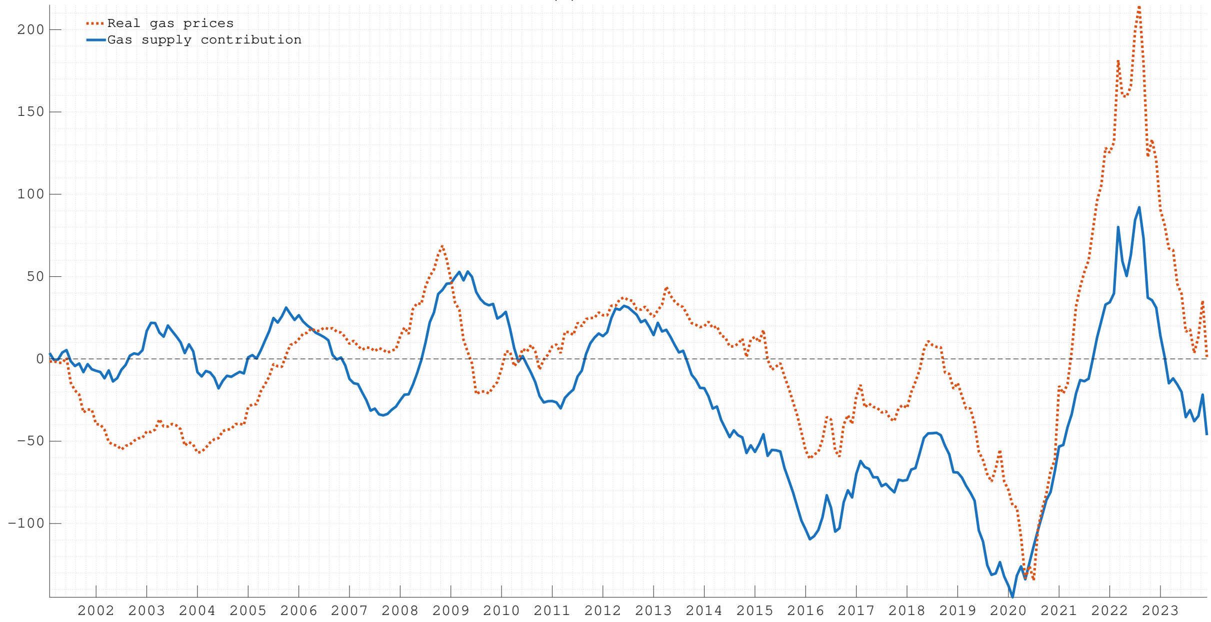
[14]Figure A2 reports the historical decomposition of gas prices in growth rates and the series of gas supply shocks extracted from the VAR.

Russia and Ukraine significantly reduced imports to Western Europe in January. Some countries reacted by drawing on their reserves; others, mainly in southern and eastern Europe, lacked adequate storage capacity and suffered severe supply shortfalls. Gas supplies from North Africa (particularly from Libya to Italy) declined steadily from 2011 onwards due to the political turmoils that culminated with the 'Arab Spring'. The bombing of the Arab Gas Pipeline in September 2011 also caused output shortfalls throughout the Middle East, particularly in Syria. A combination of factors tightened supply in 2012-13 (IEA, 2012, 2013). During winter, Gazprom delivered volumes that were 10% below buyers' requests for several days to meet an unexpected cold weather spell in Russia. The effects of this shortfall reverberated through the European gas supply system, causing reported national shortages varying between 8% and 50% of demand. After 2013 and until the Covid pandemic of 2020, supply-side factors made a significant contribution to a steady decline in gas prices. The growth of LNG trade stimulated the convergence between international wholesale gas prices, including the TTF (ACER, 2016). Furthermore, a sizable shift from traditional long-term contracts to hub-based trading rendered the European gas market more efficient.

In the aftermath of the Covid pandemic, rising tensions between Russia and Western countries – first on the approval of the Nord Stream 2 pipeline, then on Ukraine – led to a fast surge in gas prices (see also Table 1). Panel (b) of Figure 5 shows that, according to our estimates, the price rise was mostly driven by supply shocks and had important repercussions for inflation. The energy component of HICP tracked gas prices closely, while the core component rose later and in a more gradual fashion, in line with the timing of the IRFs displayed in Figure 4. All in all, gas supply shocks accounted for about half of the increase in core prices registered in 2023.[15] In a decomposition based on year-on-year inflation rates rather than the price level, gas supply shocks explain about one-third of the rise in core inflation (see Figure A3).

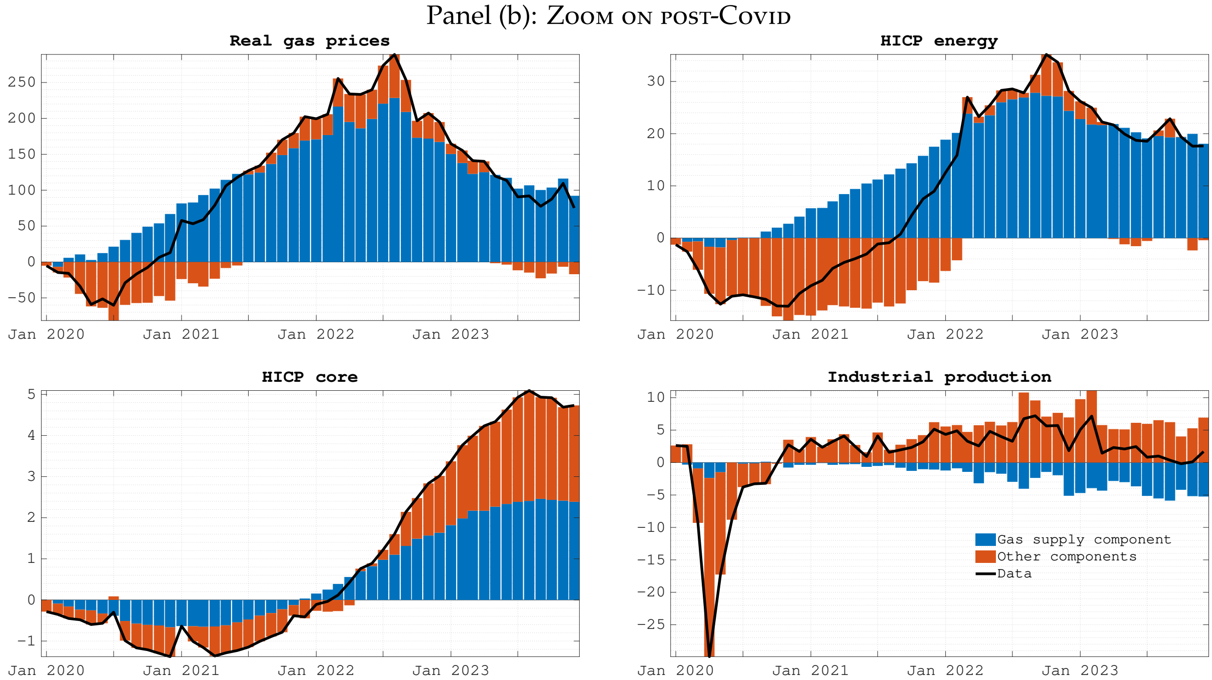
[15] Di Giovanni et al. (2023) find that energy shocks contributed more to inflation in the Euro Area than in the US. The US economy is generally less exposed to volatility in gas prices. Furthermore, prices rose more in Europe than in the US due to the segmentation of regional markets determined by infrastructural constraints.

Panel (a): Full sample



Note. The figure reports the historical contribution of gas supply shocks to the level of gas prices (in deviation from the sample average) in the whole estimation sample 2000-2023.

Panel (b): Zoom on post-Covid



Note. The figure reports the historical contribution of gas supply shocks to selected endogenous variable in the VAR since January 2020.

Figure 5: Historical decomposition

4.5. Cross-country effects

In this section, we investigate the inflationary effects of gas supply shocks on single countries within the Euro Area, similarly to the analysis of oil supply shocks in Baumeister (2023b). For each country, we estimate the VAR specified in Section 4.2, including national consumer prices and industrial production instead of the Euro Area aggregate series.

The country-level responses of *energy hicp* and *core hicp* are homogeneous in terms of signs but display a marked dispersion in terms of size (Figure A4). Unsurprisingly, the responses are much stronger in countries with a higher dependence on natural gas. Figure 6 displays the relation between the magnitude of the responses of core and energy inflation (horizontal axis) and the intensity of gas usage (vertical axis) across countries.[16] The correlation is strongly positive (about 0.4), and the inflationary impact of the shocks can be two times larger in gas-intensive economies (such as Italy) than in economies that are at the lower end of the intensity scale (such as France). It is important to stress that this correlation cannot, by construction, be too high because the GDP gas-intensity measure only captures the direct exposure to gas supply shocks. Other indirect channels are at play, including spillovers from gas to electricity prices (see Section 6) or higher coal prices due to substitution effects. Moreover, the propagation of the shocks was clearly affected by national policy responses, including, for instance, the nature and size of the (highly heterogeneous) fiscal measures adopted after 2020 in response to Covid or the energy crisis itself (Emiliozzi et al., 2023).

[16]We define gas intensity as the gas contribution to energy consumption divided by GDP. These statistics come from Eurostat data for 2021. We employ the "Complete energy balances" (code *NRG_BAL_C__custom_7474239*). We exclude Cyprus from the scatterplot because it makes no use of natural gas at all. The responses for Cyprus are small, poorly estimated, and presumably linked to international spillovers and indirect general equilibrium effects.

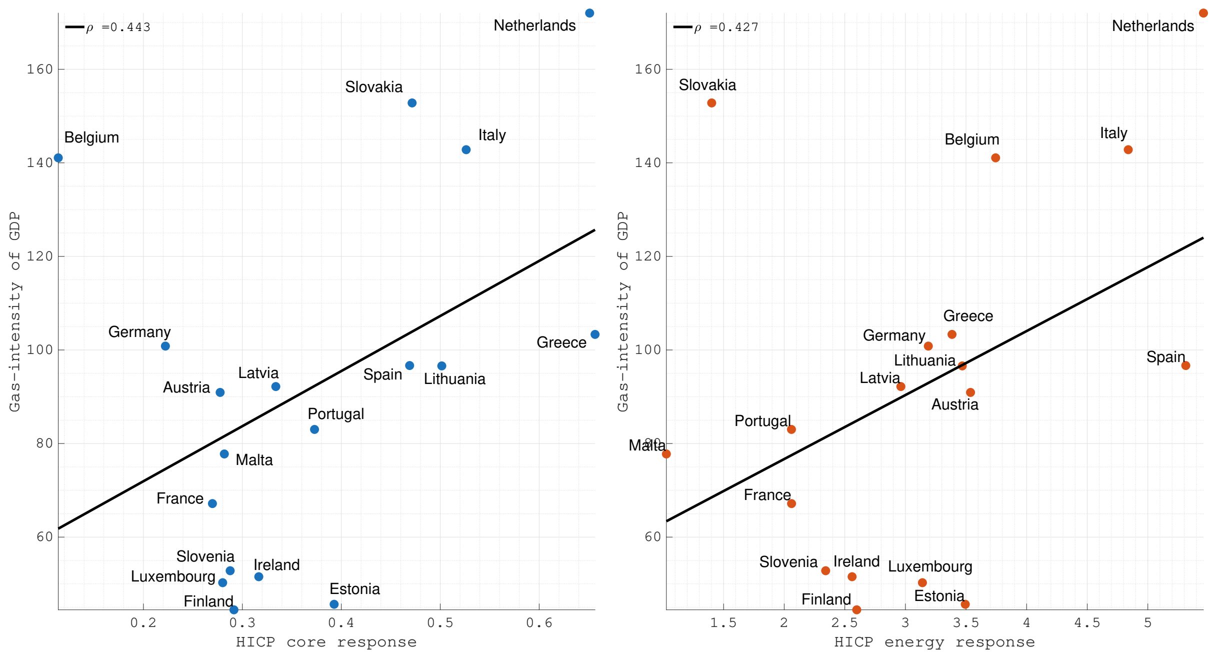


Figure 6: Inflation response and gas-intensity of GDP

Note. The figure displays a scatter of the response of core (left panel) - energy inflation (right panel) to a gas supply shock and the gas intensity of GDP.

5. Robustness analysis

In this section, we replicate the analysis modifying our empirical strategy along various dimensions, including identification scheme, specification of the VAR model, sample period, treatment of the Covid-19 break, and estimation of the dynamic effects.

5.1. Identification via heteroskedasticity

Our results are virtually unchanged if we lift our assumption on the exogeneity of the instrument and employ instead an identification scheme based on heteroskedasticity. The assumption underlying this strategy is that the *relative variance* of supply and demand shocks changes over time (Rigobon, 2003; Rigobon and Sack, 2004; Känzig, 2021, 2022). More formally, suppose that – besides being a noisy proxy of gas supply shocks ($\varepsilon_{1,t}$), as commonly assumed in the literature – our external instrument is potentially contaminated by shocks that are not related to gas supply ($\varepsilon_{j,t}$):

$$z_t = \varepsilon_{1,t} + \sum_{j>1} \varepsilon_{j,t} + \nu_t \tag{5}$$

Although the exogeneity assumption is violated, we can still identify supply shocks by combining the external instrument approach with identification via heteroskedasticity. In essence, we compare the dates in which TTF swings are predominantly caused by shifts in supply (T) to a control group of dates in which prices move under the influence of demand factors or unknown combinations of demand and supply factors (C) (that, as such, are excluded in our baseline analysis). The identification assumption is that the ratio of the variances of supply and demand shocks varies between T and C:

$$\begin{aligned} &\frac{\sigma^2_{\varepsilon_1,T}}{\sigma^2_{\varepsilon_j,T}} \neq \frac{\sigma^2_{\varepsilon_1,C}}{\sigma^2_{\varepsilon_j,C}} \quad \text{for } j = 2, \dots, n \\ &\sigma^2_{\nu,C} = \sigma^2_{\nu,T} \end{aligned} \tag{6}$$

If this condition holds, the impact of gas supply shocks can be recovered as

$$\mathbf{b}_1 = \frac{\mathbb{E}_T\left[z_t \mathbf{u}_t\right] - \mathbb{E}_C\left[z_t \mathbf{u}_t\right]}{\mathbb{E}_T\left[z_t^2\right] - \mathbb{E}_C\left[z_t^2\right]} \tag{7}$$

Rigobon and Sack (2004) show that the coefficient can be equivalently recovered through an IV approach as $\mathbf{b}_1 = \left(\tilde{\mathbf{z}}'\mathbf{z}\right)^{-1}\left(\tilde{\mathbf{z}}'\mathbf{u}\right)$, where $\tilde{\mathbf{z}} = (\mathbf{z}'_T, -\mathbf{z}'_C)'$ and $\mathbf{z} = (\mathbf{z}'_T, \mathbf{z}'_C)'$. This procedure delivers virtually identical results to our baseline estimates (see Figure A5).

5.2. *Alternative VAR specifications*

Geopolitical risk. Accounting for geopolitical risks may be important when studying the transmission of gas supply shocks: several gas supply swings identified through our narrative approach concern political tensions between Russia, Ukraine and Europe. Table 2 strongly suggests that the contamination of our IV by geopolitical risk shocks is limited. In any case, replacing *10yr* with the GPR index in the VAR delivers IRFs that are very similar to the baseline, irrespective of whether we use the global or Russia-specific version of the index (Figure A6). The GPR itself displays a limited, short-lived response to gas supply shocks.

Alternative macroeconomic indicators. Our baseline specification employs month-on-month inflation rates, mainly because these are less affected by the base effects generated by Covid. Employing year-on-year inflation rates has no material influence on the results (Figure A7). Replacing *ip* with the unemployment rate makes little difference too. The inflationary impact of the shock is virtually unchanged. The unemployment rate increases in response to the shock, and the response is even slower than that of *ip*, consistently with the delayed adjustment of the labor market to many economic shocks (Figure A8). Daily regressions suggest that oil prices barely move in response to supply shocks in the European gas market (see Figure 3). Including Brent oil prices in the monthly VAR model confirms this conclusion: the oil price response is muted, and the overall macroeconomic effects of gas supply shocks are consistent with the baseline (Figure A9).

Bottlenecks. Strained supply chains and bottlenecks accompanied the post-pandemic recovery, with important implications for inflationary dynamics (Di Giovanni et al., 2022). To check whether this mechanism confounds our identification of gas shocks, we estimate a version of the VAR that includes the New York Fed Global Supply Chain Pressure Index (GSCPI) as an additional variable. The IRFs are unchanged (Figure A10).

Gas prices and quantities. In our baseline specification we employ real gas prices, deflating the nominal price of the one-month future with the headline HICP. Results are robust to using nominal gas prices directly in the VAR (Figure A11). Additionally, including gas quantities in the model does not alter the effects of gas supply shocks on the macroeconomy; gas consumption and imports fall, as one would expect after a negative supply shock (Figure A12).

Restricted sample period. A potential limitation of our approach is that most of the statistical power of our IV comes from 2022, a year in which the Russian invasion of Ukraine rendered the gas market exceptionally volatile. However, our key conclusions are confirmed in a smaller-scale VAR (with *gas*, *core hicp*, *ip*) estimated on a 2000-2021 sample. Gas supply shocks are stagflationary, and a 10% increase in prices causes a 0.4% increase in core inflation that takes about 2 years to fully materialize (Figure A13). We take this as evidence that, despite its exceptional nature, the war did not significantly distort the transmission mechanisms that operated in the previous two decades.

Multiple TTF future contracts. In our baseline, we employ the one-month contract because gas futures are less liquid at longer maturities. Nonetheless, when building the IV by using a principal estimate on the daily changes in the one-month, two-month, three-month, and one-year ahead contracts, we obtain a series that is highly correlated to our baseline instrument (0.95) and delivers very similar responses in the VAR (Figure A14).

5.3. *VAR priors and Covid pandemic*

In our baseline analysis, we estimate the VAR using the modified Minnesota prior suggested by Lenza and Primiceri (2022) to account for the Covid pandemic. It turns out that the results do not change much if we use a plain Minnesota prior without modeling explicitly the break in volatility induced by the pandemic (Figure A15). This stems from the fact that our news-based IV is always equal to zero during the Covid crisis, and even the structural shocks extracted from the VAR do not display abnormal values in that period (see Section 4). The model without breaks in volatility can also be estimated using a flat prior that imposes minimum constraints on the data. The results are again very similar to the baseline (Figure A16). Ng (2021) accounts for Covid by including the number of Covid cases and deaths as exogenous variables in the VAR. Baumeister and Hamilton (2023) drop the observations of the pandemic period (in our case, the whole of 2020). Our results are also robust to these alternative approaches to fixing the Covid break.

5.4. *Local projections*

Our instrument can be easily exploited in a local projection rather than a VAR setup. We do it in two alternative ways. First, we directly project the endogenous variables of interest on the gas supply shock extracted by the VAR. This direct LP approach has the advantage of exploiting the full 2000-2023 sample for estimation, so it is also more directly comparable with the VAR. Second, we use the instrument in a LP-IV setup (Jordà et al., 2015; Ramey and Zubairy, 2018), relying only on the 2010-2022 sample. In both cases, the results are qualitatively in line with those coming from the baseline VAR, although the IRFs are less precisely estimated and more erratic (see Figures A17-A18). It is worth noting that, in our setup, the bias-variance trade-off between VAR and LP estimators is likely to be particularly severe given the relatively short sample period and the potential occurrence of structural breaks (Plagborg-Møller and Wolf, 2021; Li et al., 2024).

5.5. FAVAR

Our benchmark model is the type of medium-scale VAR typically employed in the literature. The invertibility test of the IV (see Section 4) suggests that the information set in the VAR is adequate to capture gas supply shocks. Similar indirect evidence comes from the sensitivity analysis to alternative variable choice in Section 5.2. An additional, more demanding test can be implemented employing a Factor-augmented VAR model in the spirit of Bernanke et al. (2005). Following their example, we include 6 factors from 54 macro-financial time series that also span sector-specific price and production indicators. The variables of interest, namely *gas*, *energy hicp*, *core hicp*, and *ip*, are directly included in the VAR as endogenous variables. Despite the sizable expansion of the information set, the IRFs remain similar to those derived from the baseline VAR specification (Figure A19).

6. Are all energy shocks alike?

One important question is to what extent gas shocks resemble oil shocks in terms of impact and propagation mechanisms. Strong similarities would allow researchers and policymakers to focus on the 'big picture', overlooking the exact source of fluctuations in the cost of energy. Conversely, if the two shocks differ, macroeconomic models and policy responses should be based on a finer, more granular view of energy markets. After making the case that oil and gas markets are indeed structurally different in Section 6.1, we present new empirical evidence on the macroeconomic implications of those differences in Section 6.2.

6.1. A European overview of gas and oil markets

Several differences in both the market structure and the actual usage of oil and gas could in principle render the propagation of supply shocks different for the two commodities. As we noted in Section 2.1, in the gas market trading traditionally relied on long-term contracts indexed to past prices, and heavily regulated retail prices adjust slowly to changes in wholesale prices. The oil market is (and has been for decades) more efficient, it is typically based on spot and short-term contracts, and it features a strong link between crude and gasoline prices. Furthermore, the two commodities are employed in very different ways. The key difference is that gas is a crucial source of electricity production. Natural gas accounted for about 20% of EU electricity in 2021, while oil accounted for about 1% of it. Irrespective of its direct usage in electricity production, gas also determines the price of electricity because it represents the marginal fuel of production in the so-called *merit order* (Fabra, 2023).

These differences are clearly reflected in the data. According to Eurostat, oil and natural gas covered respectively 33% and 25% of primary energy consumption in the EU in 2021. For final energy consumption, the contributions of oil, gas, and electricity are respectively 10%, 33%, and 33%: oil products are mainly used for transportation, with gas and electricity taking the lion's share. Finally, in terms of weights in the EU HICP, fuels for transportation account for about 3.5%, gas for about 2%, and electricity for 3%. As we show next, these differences in market structure, usage, and inflation weights have interesting implications for the propagation of oil and gas shocks.

6.2. *VAR-based evidence*

To dissect more accurately the propagation of oil and gas shocks we slightly adapt our baseline VAR model. We drop the 10-year interest rate and include instead the energy producer price index (*energy ppi*), the HICP transportation fuels component (*trans. hicp*, which includes gasoline and similar products), and the price of electricity (*electr*, based on the main European benchmark, the EEX spot price, deflated by headline HICP). When estimating the effects of oil supply shocks, we simply replace gas prices with real oil prices (*oil*; the Brent front-future contracts deflated by Euro Area HICP price level). [17] Our news-based IV for captures both actual changes in supply and news on future supply in the gas market. To insure that the comparison is accurate, we need equally broad instruments for the oil market. We thus identify oil supply shocks in a multiple instrumental variable setup as in Ramey and Zubairy (2018). Specifically, we instrument *oil* using both the supply shocks extracted from the structural VAR model of Baumeister and Hamilton (2019), which capture actual changes in supply, and the oil supply news shocks identified by Känzig (2021), which exploit the variation in the price of oil futures around OPEC announcements.[18]

In order to summarize the differences between oil and gas shocks, we complement the standard IRFs with pass-through estimates that quantify the elasticity of core prices to energy prices conditional on a specific structural shock. More formally, the pass-through for shock s at horizon h is defined by the following equation:

$$PT_h^s = \frac{\sum_{1:h} IRF_h^s(\textit{core hicp})}{\sum_{1:h} IRF_h^s(\textit{energy hicp})} \tag{8}$$

[17]As in our baseline analysis, we exploit the 2000-2023 sample to estimate the reduced-form parameters and the 2010-2023 sample for identification.

[18]The first stage statistics are extremely strong - the details are available upon request.

The PTs are ratios of cumulative responses and can be readily computed using the VAR impulse-response functions. They fully capture the dynamics of both the energy and the core component of inflation, which may differ in non-trivial ways depending on the shock. And, through a simple normalization, they directly answer questions that routinely arise in policy circles: what is the core inflation cost of a 1% rise in energy prices? And does that depend on whether the rise in energy prices originates in the gas or the oil market?[19]

The results are displayed in Figure 7. We compare shocks that increase *oil* or *gas* by 10% on impact. The comparison reveals a number of interesting differences pertaining to the sectoral propagation and pass-through of oil and gas shocks to consumer prices.

Oil shocks hit the economy very quickly, mostly through a large and sudden increase in transportation costs (*trans hicp*). Second-round and general equilibrium effects take longer to materialize, implying that *energy hicp* and *core hicp* peak about 16 and 30 months after the shock, respectively. Gas shocks have a weak and only temporary effect on transportation costs, but cause a large contemporaneous increase in electricity prices, with *electr* rising three times more than after an oil shock (a direct implication of the *merit order* described in the previous subsection). In the medium term, electricity prices also rise in response to oil shocks, presumably because of the indexation of gas contract to oil prices that characterizes the first part of our sample (see Section 2.1). Nonetheless, the difference between the response of electricity prices to gas and oil supply shocks is sizable and statistically significant (Figure A20).[20] By the combined

[19] Elasticities based on ratios of impulse-responses have a long history in the literature on the 'fiscal multiplier', and have been recently used to study the implications of monetary policy shocks: see Barnichon and Mesters (2021, 2020) and Alessandri et al. (2023).

[20] Alternative specifications that include 24 lags or employ HICP electricity rather than the EEX wholesale price points to a similar, if not even larger, heterogeneity across gas and oil supply shocks (Figures A21-A22).

effect of *gas* and *elect*, *energy ppi* is slightly more responsive to gas than oil shocks. The pass-through dynamics in the bottom-right corner clarify the implications of these differences for core inflation. The two shocks lead to a similar response of *energy hicp*, but the impact on *core hicp* of a gas supply shock is much larger, specially over long horizons. Consequently, the estimated peak pass-through is 0.2 for gas shocks and 0.1 for oil shocks.[21] From a monetary policy perspective, this implies that a given shift in *energy hicp* may trigger a more gradual but ultimately stronger response if and when it originates in the gas market. This conclusion comes with an important caveat: our framework ignores by construction any non-linearities associated with the sign or size of the underlying shocks. If 'size matters', for instance, the results could be influenced by the fact that gas shocks are relatively larger than oil shocks in our sample. The oil shocks of the 1970s-80s, for instance, could in principle produce larger responses than those included in our analysis. We leave this question open for future research.[22]

[21] The difference is statistically significant. Figure A20 shows the distribution of the differences between the responses to gas and oil shocks obtained from a VAR that includes both gas and oil prices: this difference is close to zero for energy prices and statistically different from zero (based on the 68% credible set) at all horizons above one for both core prices and our pass-through measure.

[22] From a methodological perspective, it is worth noting that PT is somewhat more robust than the IRFs used to construct it: if the nonlinearity only affected the relation between the two shocks and *HICP energy*, then scaling the *HICP core* response by the *HICP energy* response (as we do when calculating PT) would render the comparison valid despite the linear structure of the VAR.

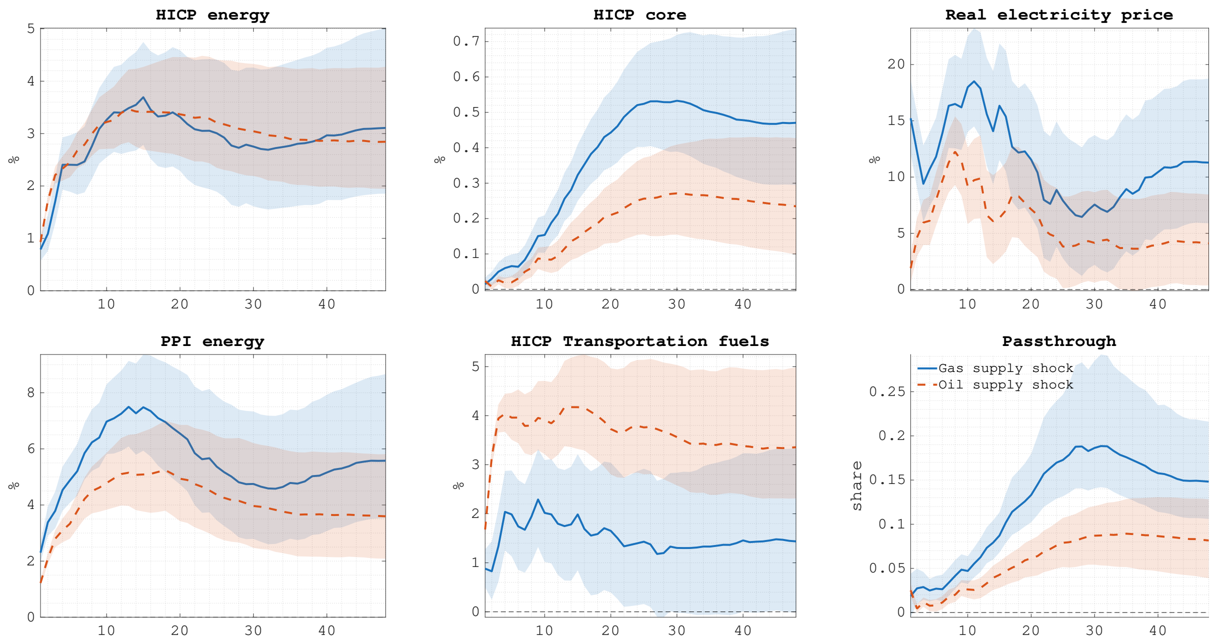


Figure 7: THE EFFECTS OF GAS AND OIL SUPPLY SHOCKS

Note. The figure displays the IRFs to gas (blue) and oil supply (orange) shocks with the respective 68% confidence bands. The estimation sample is 2000-2023.

7. Conclusions

The Russian invasion of Ukraine in February 2022 plunged European economies into a dramatic energy crisis, placing natural gas at the center of heated policy debates in Europe and elsewhere. It also revealed large gaps in economists' understanding of the relations between the natural gas market and the business cycle. We fill those gaps by providing new evidence on the macroeconomic implications of exogenous restrictions in gas supplies. We construct an instrument for gas supply shocks through a narrative approach and estimate their impact on Euro Area economies using a Bayesian VAR. Our empirical strategy is designed to cope with the specificity of the European gas market, where structural and contractual frictions complicate the identification of genuine supply shocks, and with a turbulent sample that includes the Covid pandemic and the Russia-Ukraine conflict. We find that negative shocks to gas supplies are stagflationary, leading to a drop in economic activity and a significant rise in both energy and core consumer prices. The impact varies significantly across euro area members depending on the degree of gas dependence. We also find that their influence is gradual but ultimately larger and more long-lasting than that of oil shocks, largely due to the crucial role of gas in the European electricity market. All in all, the shocks account for nearly 50 percent of the increase in core prices observed between 2021 and 2023. The evidence suggests that the European Central Bank, and monetary authorities in general, should take a granular view of energy markets and calibrate their policy responses considering the specific source of the shocks and the role of each commodity in their economies.

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