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Gas price shocks and euro area inflation

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Abstract

This paper develops a Bayesian VAR model to identify three structural shocks driving the European gas market: demand, supply and inventory shocks. We document how gas price fluctuations have a heterogeneous pass-through to euro area prices depending on the underlying shock driving them. The pass-through is stronger and more persistent when gas prices are driven by aggregate demand or supply pressures, while inventory shocks have a weaker impact. Supply shocks, moreover, are found to pass through to all components of euro area inflation – producer prices, wages and core inflation, which has implications for monetary policy. We finally document how the response of gas prices to shocks is non-linear and is significantly magnified in periods of low unemployment.

Keywords: Gas Price, Pass-through, Price, Euro Area

JEL Codes: C50, C54, E30, E31, Q43

Non-technical summary

The European gas market changed markedly when the global economy recovered from the Covid-19 pandemic and Russia invaded Ukraine. Due to a combination of recovering demand and severe constraints in supply, European gas prices increased to historically high levels after remaining broadly stable for more than a decade. As natural gas is widely used in energy production, energy became much more expensive for firms and households. The surge in gas prices explained part of the unprecedented rise in inflation in Europe during 2022, thereby contributing to the challenges faced by monetary policy makers.

Due to these events, the relationship between energy prices, inflation and the real economy stepped into the spotlight. How do gas price shocks feed through to euro area inflation, and is the pass-through shock-dependent? What does it imply for monetary policy? So far, few studies have touched upon these questions – in contrast to the extensive analysis on oil, the literature on the European gas market is still sparse.

This paper helps plugging that gap. We analyse the importance of gas price shocks for euro area inflation in two steps. First, we develop a novel Bayesian VAR model to analyse key structural drivers of the Title Transfer Facility (TTF) gas prices. An extensive literature on oil has showed that the economic effects of oil shocks depend on whether they are demand- or supply-driven, and it is reasonable to assume that this applies to the gas market as well. We identify three structural shocks driving European gas prices, inspired by the literature on oil but tailored to the European gas market: (i) a gas supply shock, which reduces the supply of natural gas to the European market, increases the gas price and lowers gas inventories; (ii) an economic activity shock, which lifts demand for gas due to higher economic production, and finally (iii) a shock to gas inventories, when gas prices are driven by precautionary demand by gas companies. While these three factors should capture most of the fluctuations in gas prices over our sample, other possibly relevant drivers are captured by a fourth unrestricted shock. In a second step, we use the estimated structural gas shocks in a local projections setting to analyse the transmission to euro area inflation in detail, and explore possible non-linearities in the pass-through.

Our results point to three interesting findings. First, all three identified shocks are important drivers of gas price dynamics, but they differ in how persistently they push

up gas prices. When gas prices rise due to disruptions in gas supply, they can remain significant up to 12 months, which is also the case when they are triggered by positive demand shocks that follow higher economic growth. But when gas prices are driven by inventory demand shocks, the price effect typically dies out within one quarter. The unprecedented rise in gas prices in recent years was indeed – according to our model – mostly driven by a combination of recovering demand following the pandemic and supply-side disruptions following the war in Ukraine; the high persistence in gas prices that followed proved a major challenge for the euro area economy in particular.

Second, the pass-through to euro area inflation depends importantly on the factors driving gas prices higher. The effect on euro area HICP of a shock to gas supply is more persistent and somewhat higher than when gas prices are driven by economic activity shocks. In both cases, however, the peak increase in inflation goes above and beyond what is mechanically implied by the (small) weight of gas in the HICP expenditure basket, which indicates that important indirect effects are present. Indeed, these two types of gas market shocks are found to spill over significantly to core inflation. By contrast, due to the short-lived nature of gas inventory shocks, they do not persistently feed through aggregate price indices.

When analysing the transmission in more detail, we find that negative shocks to gas supply mainly work through lifting producer prices, likely reflecting the importance of gas as an input into production. Wages also rise following a supply-induced gas price increase, though less than proportional to aggregate prices which implies that real wages fall. Part of the costs of adjustment therefore seems carried by workers through lower purchasing power. At the same time, firms' margins are found to expand, possibly as less efficient firms are driven off the market due to higher production costs, leading to more efficient production on average.

A final key finding is that the pass-through of gas market shocks to euro area inflation appears non-linear. We test whether the transmission differs in periods of low unemployment, high inflation or after large shocks, and find that the labor market in particular matters for the transmission of gas supply shocks. In periods of low unemployment where the labor market tends to be tight, supply shocks have up to a 50% stronger impact on prices. Non-linearities related to the size of the shock or the level of inflation are less relevant according to our estimates.

These findings shed new light on the relationship between gas prices and inflation, and carry important lessons for policy makers. The unprecedented volatility of gas prices contributed to the inflation problem in the euro area, with the gas price shocks feeding through producer prices, wages and persistently lifting core inflation. This transmission was likely reinforced by a tight labor market. Due to this persistent pass-through, monetary policy cannot “look through” these types of energy shocks. Part of the price pressures come from demand shocks, but our results indicate that also gas supply shocks can morph into forces that persistently lift core inflation. Understanding what drives gas prices is crucial to determine which policy reaction is most appropriate, as not all gas shocks are alike. This paper provides a framework to analyse this for the European gas market.

1 Introduction

The European gas market changed markedly when the global economy recovered from the Covid-19 pandemic and Russia invaded Ukraine. Due to a combination of recovering demand and severe constraints in supply, gas prices in Europe peaked at an unprecedented level of 235.5 euros/MWh. This was more than 40 times the standard deviation of the price in the years before, see [Figure 1](#).¹ Natural gas is widely used in energy production, accounting for 20% of energy generation in the EU-27 in 2020, and the surge sparked a broad-based increase in the cost of energy for firms and households. More expensive energy contributed substantially to the rise in inflation in Europe during 2022.²

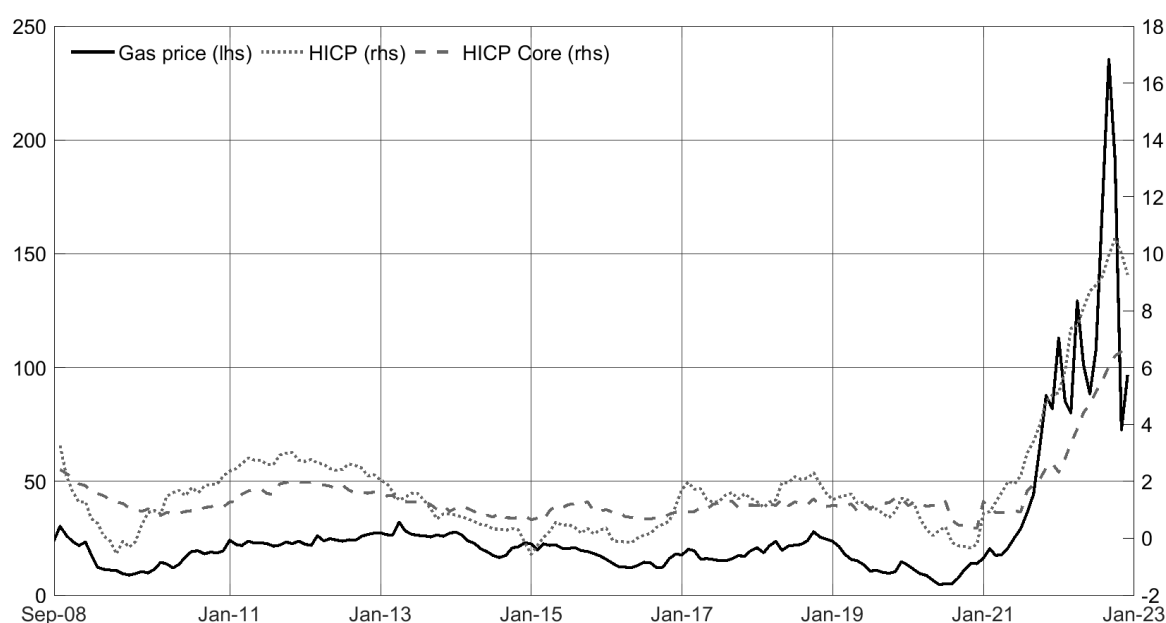


Figure 1: Gas price and euro area Harmonized Index of Consumer Prices.

Notes: The charts shows the Title Transfer Facility (TTF) gas price expressed in euros/MWh on the left-hand scale, and euro area HICP and HICP Core in year-on-year percentage changes on the right-hand scale.

Due to these events, the relationship between energy prices, inflation and the real economy stepped into the spotlight. How do gas price shocks feed through to euro area inflation, and is the pass-through shock-dependent? Is the transmission different given the tight labour market? Should monetary policy makers look through these type of

¹Between 2007 and 2021 the standard deviation of the TTF price averaged at about 19 euros/MWh with a standard deviation of 5.8 euros/MWh. After 2021 the average price was 123.6 with a standard deviation of 50.6.

²Mechanical calculations, which do not account for general equilibrium effects, imply that the energy component accounted for about one-half of annual HICP inflation in the euro area, see [Koester et al. \(2023\)](#).

energy shocks?

These questions have been studied extensively for oil prices. This literature has shown that the economic effects differ depending on what is driving oil prices (e.g. [Kilian, 2009](#); [Baumeister and Hamilton, 2019](#); [Caldara et al., 2019](#); [Känzig, 2021](#)), and that higher oil prices can feed through core inflation (e.g. [Peersman and Van Robays, 2009](#)), which challenges the role of monetary policy. Fewer contributions have analyzed the implications of gas price shocks so far; two examples are [Rubaszek and Uddin \(2020\)](#) for the US gas market and [Casoli et al. \(2022\)](#) for Europe.

There are similarities to oil in how to think about the economic implications of gas price shocks. Gas prices are driven by supply and demand factors, and the driving force likely matters for its effects on the economy.³ Also the pass-through to inflation might be multi-faceted. As is the case for oil, natural gas is a key input in production; it is widely used as an energy source and in several chemical processes.⁴ Rising energy costs might prompt firms to revisit pricing strategies, thereby affecting broader inflation. Economic theory indeed suggests that commodity prices driven by expansionary demand shocks affect inflation by more than the weight of commodities in the consumption basket, as the output gap is positive and higher demand leads to broad-based price increases ([Nakov and Pescatori, 2010](#)). On the contrary, if commodity prices are driven by contractionary forces such as supply shocks, the pass-through should be weaker. These differences have implications for monetary policy. In the case of supply shocks, it has been argued that central banks should “look through” them ([Blanchard and Galí, 2007](#)), whereas this might be less obvious in the case of second round effects to inflation ([Peersman and Van Robays, 2009](#)).

However, there are characteristic specific to gas markets that justify separate attention, and prevent us from simply applying what we know about oil to gas. First, gas prices have increasingly decoupled from other energy products and display own dynamics. The decreasing indexation of gas contracts to oil prices is a case in point.⁵ Gas prices increasingly reflect (regional) factors specific to gas markets, rather than global dynamics that shape oil prices. For instance, about 75% of gas imports to the euro area arrives through pipelines, making gas imports difficult to substitute and gas markets subject to

³See for example the evidence by [Rubaszek and Uddin \(2020\)](#) for the US economy.

⁴Natural gas, for example, accounted for about 20% of total EU-27 power generation in 2020, see [Italian Institute for International Political Studies \(November 2022\)](#).

⁵See [Adolfson et al. \(2022\)](#).

idiosyncratic developments.⁶ Second, natural gas is generally easier to substitute with other energy sources than oil as power plants can often switch between natural gas and coal.⁷ Finally, retail gas prices are often determined by contracts between the gas distributors and consumers implying rigidity in the pass-through from wholesale to retail prices in comparison to changes in crude oil prices. As a result of these differences, gas price shocks might transmit differently than oil price shocks. That would leave several questions about the impact of gas shocks on inflation unanswered.

This paper helps plugging that gap. We analyse the importance of gas price shocks for euro area inflation in two steps. First, we develop a novel Bayesian VAR model to analyse key structural drivers of the Title Transfer Facility (TTF) gas prices – the benchmark gas price in Europe. We identify three structural shocks driving European gas prices, inspired by the literature on oil but tailored to the European gas market: (i) a gas supply shock, which reduces the supply of natural gas to the European market, increases the gas price and lowers gas inventories; (ii) an economic activity shock, which lifts demand for gas due to higher economic production, and finally (iii) a shock to gas inventories, when gas prices are driven by precautionary demand by gas companies. While these three factors should capture most of the fluctuations in gas prices over our sample, other possibly relevant drivers are captured by a fourth unrestricted shock.⁸ In a second step, we use the estimated structural gas shocks using local projections following [Jordà \(2005\)](#) to analyse the transmission to euro area inflation in detail, while also exploring possible non-linearities related to the size of the shocks, the level of unemployment and inflation. We do this by using state-dependent local projections à la [Cloyne et al. \(2023\)](#).

Our results point to three interesting findings. First, all three identified shocks are important drivers of gas price dynamics, but they differ in how persistently they push up gas prices. When gas prices rise due to disruptions in gas supply, they can remain significant up to 12 months, which is also the case when they are triggered by positive demand shocks that follow higher economic growth. But when gas prices are driven by inventory demand shocks, the price effect typically dies out within one quarter. The unprecedented rise in gas prices in recent years was indeed – according to our model

⁶See [European Council Infographic - Where does the EU's gas come from?](#).

⁷The substitution elasticity of gas is very low in some industrial sectors ([Albrizio et al., 2022](#)).

⁸These factors could include swings in temperature or global demand for other countries (which affects demand through LNG imports, which currently account for about 25% of supply but historically have been negligible).

– mostly driven by a combination of recovering demand following the pandemic and supply-side disruptions following the war in Ukraine; the high persistence in gas prices that followed proved a major challenge for the euro area economy in particular.

Second, the pass-through to euro area inflation depends importantly on the drivers of gas prices. The effect on euro area HICP of a shock to gas supply is more persistent and somewhat higher than the effect of an economic activity shock, being 0.85% and 0.66% respectively following a 10% impact increase in gas prices. In both cases, the peak increase in inflation goes beyond what is mechanically implied by the (small) weight of gas in the HICP expenditure basket, which indicates that important indirect effects are present. Indeed, these two types of gas market shocks are found to spill over significantly to core inflation, lifting core HICP at peak by 0.45% and 0.34% after a supply and economic demand shock respectively. By contrast, due to the short-lived nature of gas inventory shocks, they do not persistently feed through aggregate price indices.

When analysing the transmission in more detail, we find that negative shocks to gas supply mainly work through lifting producer prices, likely reflecting the importance of gas as an input into production. Wages also rise following a supply-induced gas price increase, though less than proportional to aggregate prices which implies that real wages fall. Part of the costs of adjustment therefore seems carried by workers through lower purchasing power. At the same time, firms' margins are found to expand, possibly as less efficient firms are driven off the market due to higher production costs in line with the hypothesis of “creative destruction” by [Schumpeter \(1942\)](#), leading to more efficient production on average.

A final key finding is that the pass-through of gas market shocks to euro area inflation appears non-linear. We test whether the transmission differs in periods of low unemployment, high inflation (such as in [Dias et al., 2007](#)) or after large shocks (similar to [Golosov and Lucas, 2007](#)), and find that the labor market in particular matters for the transmission of gas supply shocks. In periods of low unemployment where the labor market tends to be tight, supply shocks have up to a 50% stronger impact on prices. Non-linearities related to the size of the shock or the level of inflation are less relevant according to our estimates.

The volatility in economic variables triggered by the Covid-19 pandemic and the Russian invasion of Ukraine – including in gas prices and inflation – challenges empirical

models. There are reasons to believe that our conclusions do not rely on that episode alone, however. As expected, the reactions are somewhat smaller when excluding the last two years of data from our sample, but our qualitative results on transmission hold.⁹ The model is also robust to the down-weighting of observations around the Covid-19 shock as in [Lenza and Primiceri \(2022\)](#).

Our findings shed new light on the relationship between gas prices and inflation, and carry important lessons for policy makers. The unprecedented volatility of gas prices contributed to the inflation problem in the euro area, with the gas price shocks feeding through producer prices, wages and persistently lifting core inflation. This transmission was likely reinforced by a tight labor market. Due to this persistent pass-through, monetary policy cannot “look through” these types of energy shocks. Part of the price pressures come from demand shocks, but our results indicate that also gas supply shocks can morph into forces that persistently lift core inflation. Understanding what drives gas prices is crucial to determine which policy reaction is most appropriate, as not all gas shocks are alike.

The remainder of the paper is structured as follows: [Section 2](#) reviews related literature, while [Section 3](#) presents the data, the methodology and the historical decomposition of the European gas price, partially as a model validation. [Section 4](#) details the transmission of gas shocks to inflation and investigates potential non-linearities of gas supply shocks related to the size of the shock, the level of unemployment and the level of inflation. [Section 5](#) concludes.

2 Literature review

Our paper relates to two main strands in the literature: the one modeling energy markets and the one that analyses the economic impact of commodity price shocks.

Modeling of energy markets: the literature on energy markets has mostly focused on the oil market due to its role as the most important energy input in the global economy. Several studies used VAR models to identify drivers of oil price fluctuations, either via sign restrictions or structural identification schemes (e.g. [Peersman and Van Robays, 2009](#);

⁹The limited amount of data constrains our flexibility in addressing potential biases, certainly when using local projections, as local projections estimates for the future horizon k implies the loss of the first k data points.

Kilian and Murphy, 2012; Baumeister and Hamilton (2015); Baumeister and Hamilton (2019)), or through narrative analysis with instrumental variable regressions (Caldara et al., 2019). The literature on identifying gas market shocks is less rich, although recently new research has focused on this energy segment as gas and oil prices increasingly diverged following the shift from oil-indexation to “gas-on-gas” pricing as documented by Adolfsen et al. (2022). Most of the existing contributions are however focused on the US; Rubaszek et al. (2021) use a model in the spirit of Baumeister and Hamilton (2019) to identify structural drivers of the US gas price while Wiggins and Etienne (2017) perform a similar exercise using sign restrictions as in Kilian and Murphy (2012). Importantly, lessons from the US market cannot be extended to Europe as the two markets are structurally different. The US is a net-exporter of natural gas, with production greatly exceeding domestic demand, while extraction of gas in the EU is still very limited.¹⁰ As such, our paper contributes to this literature by setting up a model specific to European gas price dynamics.

The economic impact of commodity price shocks: the literature on the economic impact of commodity price shocks has also mainly focused on oil and the US economy.¹¹ Similarly to our paper, the empirical literature has mostly exploited sign restrictions to identify oil price shocks, see Kilian and Zhou (2022) and Aastveit et al. (2021), while more recently Känzig (2021) has proposed a strategy based on asset price movements around OPEC announcement. Papers considering the euro area energy markets, De Santis and Tornese (2023) and Neri et al. (2023), also typically employ sign restrictions finding that supply shocks increase HICP energy by 1.1% and HICP by 0.1%.

The literature on the economic impact of gas shocks is instead more limited. To our knowledge, Chan et al. (2022) are the only ones to use a micro-founded model to study the real economic effects of higher gas prices. Bachmann et al. (2022) use instead input-output data to show that lower exports from Russia during 2022 contributed to lower GDP in Germany by between 0.5% and 3%.¹²

More closely related to our work, López Muñoz et al. (2022) estimate the pass-through

¹⁰In 2022, the EU’s external natural gas dependency remained high at 97%, despite a fall in total demand of natural gas by about 13% relative to the previous year (see Eurostat Natural gas supply statistics).

¹¹See Nakov and Pescatori (2010), Filardo et al. (2020), Balke and Brown (2018) and Hou et al. (2016) for theoretical models.

¹²Albrizio et al. (2022) and Di Bella et al. (2022) also use similar approaches to simulate the impact on the European economy of the lower gas supply from Russia during 2022.

of higher gas prices to euro area prices through reduced-form regressions.¹³ Casoli et al. (2022) and Alessandri and Gazzani (2023) identify gas supply shocks using VAR models, finding that gas price shocks lead to persistent increases in headline inflation.¹⁴ Bańbura et al. (2023) find positive effects of gas price shocks on core inflation in a BVAR for the euro area that includes one type of gas shock along a longer list of macroeconomic shocks. The main difference to our paper is that we identify a wider range of structural shocks in the gas market giving a more comprehensive explanation of recent and historical price movements. Our setting also allows to estimate the non-linear effects of gas market shocks to prices.

This paper sits at the cross-roads of these two fields of research focusing on the transmission of different energy shocks to the European economy. We build on the oil price literature to identify shocks specific to the European gas market through sign restrictions as in Kilian and Murphy (2012) and Peersman and Van Robays (2009). As highlighted by Jadidzadeh and Serletis (2017), these shocks are specific to the energy market and are likely not captured by models of the global economy. We use the identified shocks and estimate their effects on inflation. Similar to the oil literature (Kilian, 2009), we show that not all gas shocks are alike.

3 Data and methodology

Our empirical strategy is twofold. In a first step, we build a parsimonious model of the European gas market to identify three structural shocks driving the European gas price: a gas supply shock, an economic activity shock and a precautionary gas inventory shock. The model focuses only on the gas market to identify shocks specific to this energy segment (Jadidzadeh and Serletis, 2017; Nguyen and Okimoto, 2019) and to avoid imposing unnecessary restrictions on other macro variables. In the second step, similarly to Georgiadis (2016), Dedola et al. (2017) and Iacoviello and Navarro (2019), we use

¹³They find that a 10% increase in the gas price leads to a peak reaction of inflation by 0.19% after 19 months. However as highlighted in the literature on the exchange rate pass-through, Forbes et al. (2018) and Ferrari Minesso and Gräb (2022), reduced-form models may not fully account for endogeneity and they do not distinguish between different types of shocks which are likely to imply different dynamics.

¹⁴Casoli et al. (2022) estimate that a one standard deviation in gas demand or supply increases headline inflation by 0.24 and 0.20% respectively after one year while Alessandri and Gazzani (2023) estimate that a 5% increase in the gas price leads to a 0.2% increase in core prices after about two years, however the gas price reaction turns negative at longer horizons.

the identified shocks to compute the pass-through to consumer prices in the euro area using local projections. We keep the empirical framework tractable to avoid imposing assumptions on the sign and the size of the reaction of aggregate price indices to shocks originating in the gas market. We further exploit the local projection setting to investigate key non-linearities in the propagation of gas market shocks, in particular related to unemployment, the inflation level as well as the size of the shock.

3.1 Data

For the gas market BVAR model, we use gas quantities, gas prices, gas inventories and euro area industrial production, as displayed in [Figure 2](#). Gas quantity is defined as gas imports plus domestic production minus gas exports from European countries.¹⁵ As a benchmark for European gas prices, we use the day-ahead price of the Dutch Title Transfer Facility (TTF), which functions as a benchmark hub for wholesale gas prices in European countries.

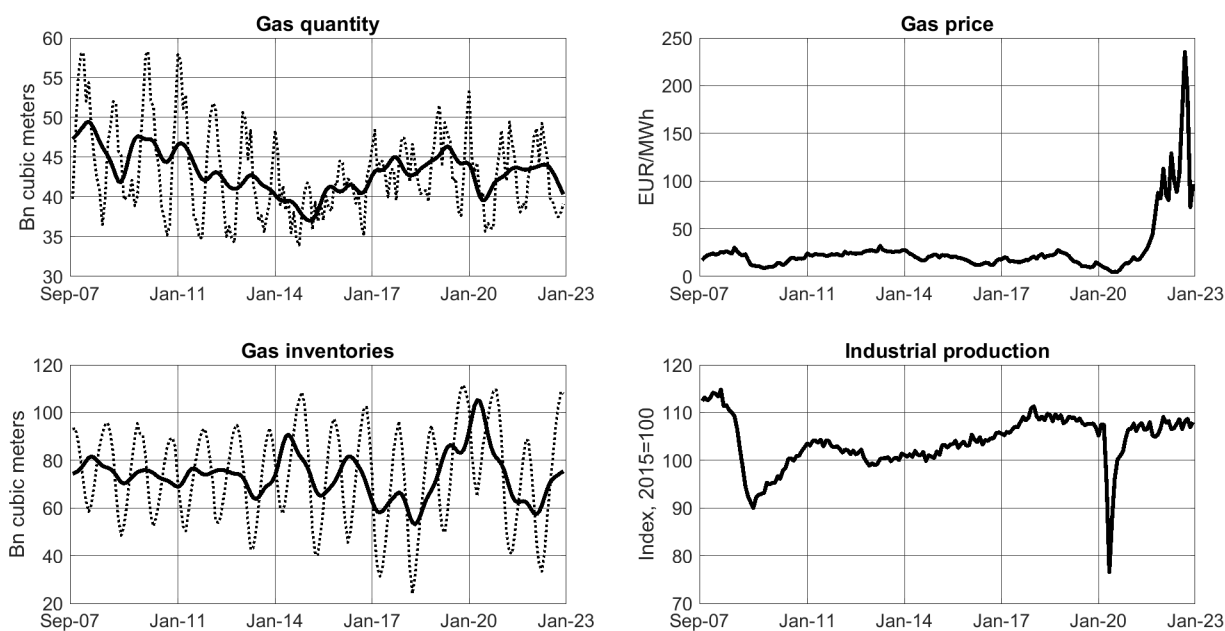


Figure 2: Input variables.

Notes: The chart shows the four input variables entering the Bayesian VAR model described in [Equation \(1\)](#). For gas quantity and inventories solid lines show the seasonally adjusted data as it enters the model; dotted lines show the non-seasonally adjusted data.

For the local projection exercise, the dependent variables are the gas price, euro area

¹⁵The countries considered are: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

consumer prices (headline HICP, HICP core and HICP energy), producer price indices (PPI), wages and profit margins. As controls we include Brent crude oil prices, the VIX as a proxy for global risk sentiment, the euro area unemployment rate and euro area industrial production.

Because of high seasonality tracking the European heating season, we seasonally adjust gas quantities and inventories using the U.S. Bureau of the Census X-13-ARIMA Seasonal Adjustment method, while macro time-series are seasonally adjusted by Eurostat. [Table 1](#) reports summary statistics and the sample coverage for the data we use.

Table 1: Summary statistics

	Mean	Standard deviation	Unit	Start date	End date	Source
Gas quantity ¹	43.17	2.63	Billion cubic meters	Sep 2007	Nov 2022	IEA ⁶
Gas price	27.14	29.9	EUR/MWh	Sep 2007	Nov 2022	Refinitiv
Gas inventories ²	73.58	9.5	Billion cubic meters	Sep 2007	Nov 2022	IEA ⁶
Euro area IP	103.84	5.37	Index, 2015=100	Sep 2007	Nov 2022	Eurostat
Oil price	76.04	26.09	USD/barrel	Oct 2008	Nov 2022	EIA ⁷
VIX	20.3	9.23	Index	Oct 2008	Nov 2022	Haver
HICP	100.98	6.13	Index, 2015=100	Oct 2008	Nov 2022	Eurostat
HICP Core	100.49	5.19	Index, 2015=100	Oct 2008	Nov 2022	Eurostat
HICP Energy	105.75	15.57	Index, 2015=100	Oct 2008	Nov 2022	Eurostat
PPI Energy	114.23	36.15	Index, 2015=100	Oct 2008	Nov 2022	Eurostat
PPI Food	101.83	8.47	Index, 2015=100	Oct 2008	Nov 2022	Eurostat
Wages ^{2,3}	100.13	6.95	Index, 2015=100	Oct 2008	Nov 2022	ECB, Bundesbank
Profit margins ⁴	9.3	1.42	Percent	Oct 2008	Nov 2022	Refinitiv
Unemployment	9.57	1.67	Percent	Oct 2008	Nov 2022	Eurostat
Inflation ⁵	1.76	2.05	Percent	Oct 2008	Nov 2022	Eurostat

Notes: ¹Defined as European gas imports plus domestic production minus gas exports. Mean and standard deviation are of the seasonally adjusted data. ²Mean and standard deviation are of the seasonally adjusted data. ³The wage index is the negotiated wage index for Germany excl. one-off payments from the Bundesbank extrapolated by annual negotiated wage rate changes excl. one-off payments for the euro area. ⁴Defined as Ebit over Sales for the 1,399 largest publicly listed firms in the euro area. ⁵Defined as year-on-year HICP percentage change. ⁶International Energy Agency. ⁷U.S. Energy Information Administration.

3.2 A VAR model for the European gas market

The reduced-form representation of the estimated VAR model is:

$$Y_t = A_0 + \sum_{l=1}^L A_l Y_{t-l} + B\varepsilon_t \quad (1)$$

where A_l is a matrix of lagged coefficients and B a matrix that rotates the reduced-form residuals into structural shocks ε . We use 12 months as lags and data from September 2007 to November 2022. The model is estimated with Bayesian methods using standard Minnesota priors with hyper-parameters selected as in [Giannone et al. \(2015\)](#) to optimize

the posterior distribution.¹⁶ The vector Y includes the European gas quantity proxy, gas inventories, the European gas price benchmark and euro area industrial production. All variables enter the model in log first differences.

We impose sign restrictions on the matrix B , reported in [Table 2](#), to identify three structural shocks in the European gas market: a supply shock, an economic activity shock and a gas inventory shock. These restrictions are drawn from the oil literature, similar in spirit to [Kilian and Murphy \(2012\)](#) and [Peersman and Van Robays \(2009\)](#) among many others. First, a gas supply shock reduces the quantity of gas available in the European market. We assume this supply shock to lower gas quantities and inventories as less gas is supplied to Europe, leading gas prices to increase. We leave the reaction of industrial production unrestricted to avoid imposing the shock to be contractionary.¹⁷ Second, the economic activity shock captures changes in the demand for gas driven by business cycle fluctuations. This shock is characterized by an expansion of industrial production that leads to higher gas consumption. As demand for gas increases, the gas price also rises while inventories fall as agents use gas in storage to partially satisfy higher demand. Finally, a gas inventory shock reflects higher demand for gas driven by precautionary motives. Therefore, we impose inventories, gas quantities and gas prices to increase as more gas is demanded to fill up storages ahead of a potential tightening in the gas market in the future. A fourth shock is left unrestricted to capture other potential fundamental drivers of gas demand and supply (e.g. changing weather conditions or global shocks that pass-through to the European market).¹⁸ All restrictions are imposed on impact.

3.3 Gas market dynamics

[Figure 3](#) reports the impulse responses to the different types of gas price shocks. Gas supply shocks, on average over the sample, tend to trigger larger gas price reactions on impact (of about 8% following a one standard deviation shock), compared to gas

¹⁶Results are robust to accounting for the extreme observations during the Covid-19 pandemic. [Figure A.1](#) in the Appendix reports the correlation between structural shocks extracted from the baseline model and from an alternative model estimated applying the [Lenza and Primiceri \(2022\)](#) correction. [Figure A.2](#) compares the impulse responses across the two models. Identified shocks are strongly correlated across the two VARs, in particular the supply shock, and impulse responses are overlapping.

¹⁷Imposing a restriction on industrial production would also, mechanically, condition the correlation between supply shocks and prices, which is of main interest to the paper.

¹⁸Notice however that LNG imports, which are subject to global shocks, account for 25% of gas supply to Europe, and were historically seen much less important.

Table 2: Sign restriction table

	Gas supply shock	Econ. activity shock	Gas inventory shock	Unrestricted shock
Gas quantity	–	+	+	
Gas price	+	+	+	
Gas inventories	–	–	+	
Euro area IP		+		

Notes: “+” indicates a positive response of the variable to the shock, “–” a negative response and empty cells indicate unrestricted responses. All restrictions are imposed on impact.

price shocks driven by economic activity or inventory demand (of around 5%). While the responses evidently reflect the sign restrictions imposed, there are interesting differences in the persistence of the gas price reactions. After a gas supply shock the price impact peaks at around two-three months and then remains stable – the impulse response becomes statistically insignificant after one quarter, implying that, on average, the price remains stable thereafter. An economic activity shock lifts gas prices even more persistently; the response plateaus only after about seven months. By contrast, gas inventory shocks are on average short-lived. Gas quantities follow a similar pattern to prices. Shocks to gas quantities driven by gas supply or inventory shocks tend to revert to pre-shock levels after around five to seven months, while economic activity shocks lead to a more long-lived increase in gas demand.¹⁹ Dynamics in gas inventories are more similar across shocks.

Despite all shocks rising gas prices, the impact on industrial production is only significant in response to an economic activity shock, as shown in the last column of [Figure 3](#). For the other two shocks, where this variable is not restricted, the reactions are more noisy and statistically insignificant.²⁰ This result likely reflects that, historically, shocks specific to the gas market have not been large enough to significantly affect the European business cycle. However, supply shocks do point to a fall in industrial production on average, signaling that they tend to be contractionary in nature.²¹

Taken together, these impulse responses highlight the different nature of the three underlying shocks in terms of persistence and economic impact – which can have important

¹⁹Notice that the responses of gas quantities reported in [Figure 3](#) change sign after five to seven months after a gas supply or inventory shock. That implies that the underlying series *in levels* is reverting towards long-run trend.

²⁰This result is however similar to [Alessandri and Gazzani \(2023\)](#).

²¹The impact of inventory shocks is more ambiguous which might reflect its precautionary nature, i.e. gas demand increases on *expectations* of potentially higher demand in the future. If risks to gas demand do not materialize, higher inventory levels would decrease prices in the future, leading to an ambiguous reaction of industrial production.

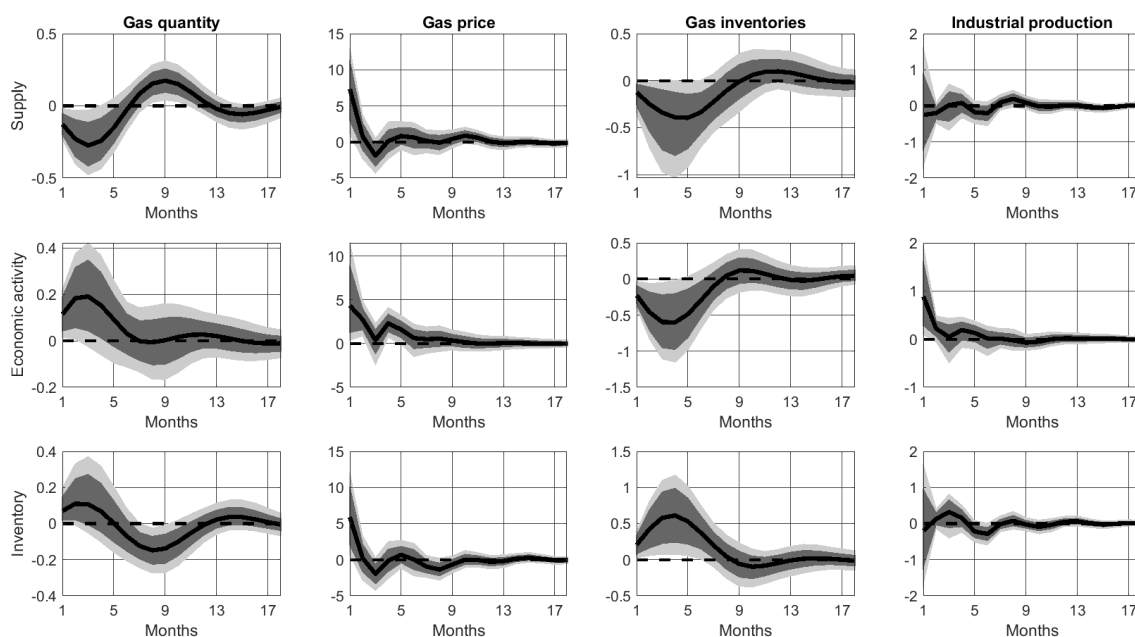


Figure 3: Impulse response functions.

Notes: The charts show monthly impulse responses in percent. Shaded areas show 68% and 90% confidence intervals, which are based on the posterior distribution of the model, while the black solid line is the median response.

implications for the pass-through to inflation as we analyze in [Section 4](#).

3.4 Historical events in the European gas market

Before analysing the transmission of the different types of gas shocks to euro area prices, we show how the model interprets the unprecedented gas price rise in 2022 in terms of driving factors, and compare it with previous historical episodes of heightened gas price volatility as a way of validating the model. The results are summarized in [Figure 4](#). The complete historical decomposition for the gas market variables is reported in the Appendix, see [Figure A.3](#) to [Figure A.6](#).

The Covid-19 recovery & the invasion of Ukraine: the top left panel in [Figure 4](#) shows the historical decomposition of the European gas price since June 2019. The model reads the decline in gas prices following the outbreak of the pandemic in late 2019 and the subsequent rebound as being mainly driven by demand due to changes in economic activity (yellow bars). Since the summer of 2021, supply and inventory shocks played a more prominent role (blue and red bars, respectively). The higher contribution from supply in the second half of 2021 reflects the reduction in Russian gas exports to the EU

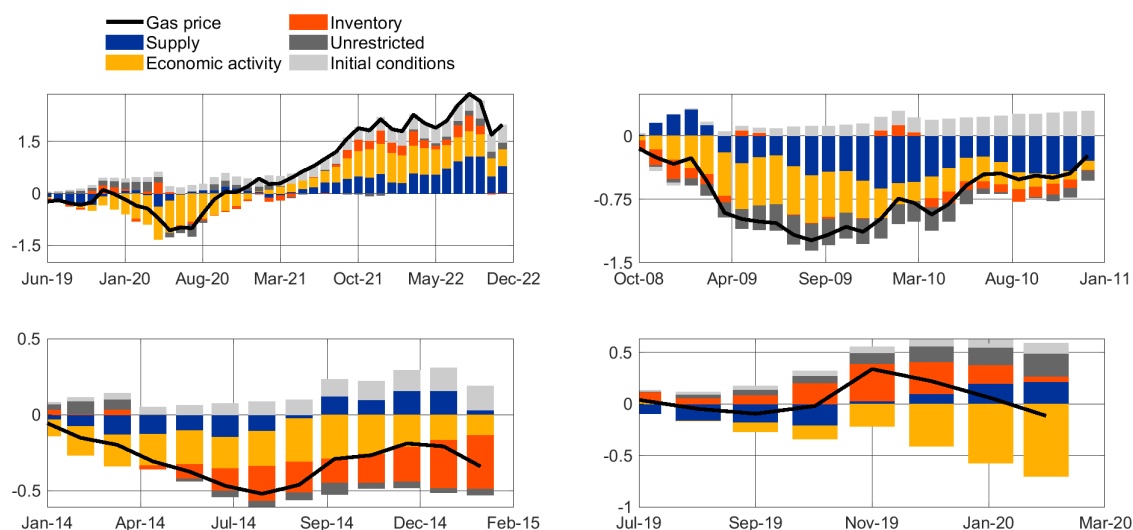


Figure 4: Historical decomposition around main events in the European gas market. **Notes:** The chart reports the historical decomposition of accumulated log-differences of the euro area gas price. The decomposition is based on the Bayesian VAR model described in Equation (1) where shocks are identified by sign restrictions as reported in Table 2 and the median rotation is used. Initial conditions include the contribution of the constant term A_0 .

ahead of the invasion of Ukraine. After the onset of the war, Russia gradually cut off other gas deliveries, for example by shutting down the Nord Stream 1 pipeline, leaving EU gas imports from Russia 20% below 2019 levels. However, lower Russian supply was partly compensated by increasing LNG imports, which limited the upward contribution of gas supply shocks to the European gas price.²² Slightly less relevant than gas supply shocks were shocks to gas inventories following from the filling of gas storage ahead of the 2022-23 winter to levels above the new EU gas storage target.²³ Taken together, supply and inventory shocks accounted for more than two-thirds of the record-increase in the gas price in 2022. These findings highlight the unprecedented sequence of shocks hitting the European gas market during the past years.

The global financial crisis and the 2009 tensions over Ukrainian gas transit: in late 2008 and early 2009 tensions between Russia and Ukraine over their gas transit deal led to a two-week Russian cut-off of gas supply to Europe through Ukraine. Russian gas exports were quickly re-established once the conflict was resolved. As the top-right panel in Figure 4 shows, supply shocks peaked between December and January when Russia

²²Higher LNG imports enter the model as a positive supply shock which weighs on European gas prices. As such, the supply shock components are a combination of negative supply shocks from Russia and positive supply shocks reflecting higher LNG imports.

²³The EU introduced a gas storage target of 80% by end-October 2022 following the Russian invasion of Ukraine.

blocked exports through the Ukrainian pipeline (blue bars). The shock was however short-lived as the two countries reached an agreement within a few weeks. The recession induced by the global financial crisis was instead a more dominant driver of gas price fluctuations during 2009, as illustrated by the contribution of the economic activity shock (yellow bars).

Russian invasion of Crimea: in February 2014, Russia took military action in Crimea but there were no immediate disruptions of gas flows to Europe through Ukraine. However, Russian gas exports to Europe were significantly reduced in the second half of 2014.²⁴ As the bottom-left panel in [Figure 4](#) shows, the supply component (blue bars) indeed increased substantially in that period, adding upward pressure to the gas price. Release of inventories (red bars) eased the effect of the shock somewhat. The negative contribution of economic activity is likely caused by spillovers to the gas market from the European sovereign debt crisis. Finally, Russia started to raise gas exports from 2015, which led to a steady reduction of the supply contribution in the first month of 2015.

Negotiations on the Russia-Ukraine gas transit deal: between 2015 and 2019 negotiations on the gas transit deal between Russia and Ukraine caused concerns that Russia would again reduce gas supplies to Europe via Ukraine. These tensions culminated in the beginning of the winter of 2019-20 and coincided with a cold spell of temperatures in Europe in November which led to expectations of a cold winter.²⁵ The lower-right panel of [Figure 4](#) illustrates that the risks of failure to reach a new gas transit deal between Russia and Ukraine combined with expectations of colder weather conditions drove gas companies to build up inventories in order to establish a gas storage buffer. The inventory building exerted upward pressure on the gas price (red bars).²⁶ Eventually, Russia and Ukraine reached an agreement on a new gas transit deal and the winter turned out to be mild implying that the impact of the inventory shock quickly dissipated in early 2020, when the outbreak of the Covid-19 pandemic started leaving its trace on the global economy and the gas market as well (yellow bars).

²⁴Gas transit through Ukraine went down by 50% compared to the first half of 2014.

²⁵Temperatures in Northwestern Europe were 0.7 degrees below the past 10 years average in November 2019.

²⁶EU gas storages stood at 88% of capacity at the end of the year, which was the highest level reached in 8 years.

Average importance of different gas shocks: on average over the full sample, gas supply shocks have been the most relevant driver of the European gas market. These shocks account for about 38% of the volatility of gas quantities and 31% of the volatility of the gas price (see [Table 3](#)). The economic activity shock comes second, explaining around one-fifth of gas quantity and one-fourth of gas price fluctuations. Inventory shocks play a slightly smaller role, accounting for 17% of gas quantity and 23% of gas price fluctuations while the residual component (i.e. the unrestricted shock and the initial conditions) drive about 15% of the variability in both variables. Gas shocks also explain a sizable part of the variation in industrial production (i.e. 59%) with, as expected, activity-driven gas demand shocks explaining the largest part.

Table 3: Average shock contribution to the historical decomposition

	Gas supply shock	Econ. activity shock	Gas inventory shock	Residual
Gas quantity	38%	20%	17%	25%
Gas price	31%	24%	23%	22%
Gas inventories	23%	27%	26%	24%
Euro area IP	17%	26%	16%	41%

Notes: The table reports the average contribution of shocks to the historical decomposition of the four endogenous variables in [Equation \(1\)](#). The residual includes the unrestricted shock and the initial conditions.

These results provide two insights. First, the model captures past dynamics of the European gas market well; it provides an intuitive explanation of the driving factors of gas market dynamics despite the different constellation and persistence of the shocks over time. Second, the comparison with previous gas market disruptions also emphasizes how unprecedented the gas price spike of 2022 was. A unique sequence of large, positive price shocks lifted gas prices to historically high levels that were maintained for a prolonged period of time. In the past, supply shocks were typically short-lived. This might have implications for the pass-through of these shocks to inflation – and indicate that the transmission might be non-linear.

4 Pass-through of gas price shocks to consumer prices

The pass-through of gas price shocks to inflation is likely to be multi-faceted. Natural gas only accounts for about 1.9% of the expenditure weight in the euro area Harmonized

Index of Consumer Prices (HICP).²⁷ But as an important part of production costs, steep rises in gas prices might induce price pressures that go well beyond its HICP weight. Multiple, possibly counteracting factors are at play in determining how an increase in gas prices might affect aggregate inflation.

First, as discussed already, the pass-through to inflation likely depends on the type of shock driving gas prices higher. As [Figure 3](#) showed, the driving force determines how persistently high gas prices might remain, with possible implications for how firms and households react to the initial gas price increase. If the shock is short-lived, for example, firms may decide not to pass on higher energy costs entirely to consumers as a consequence of “menu costs” ([Mankiw, 1985](#)). Besides differences in persistence, the state of the economy also likely matters. [Figure 3](#) indicates that different gas price shocks are paired with different dynamics in economic activity. If the underlying shock is contractionary, the effect on HICP should be less than proportionate to the weight of gas in the HICP expenditure basket, as the fall in economic activity would reduce demand and weigh on prices of other goods ([Nakov and Pescatori, 2010](#); [Filardo et al., 2020](#)). By contrast, if the underlying shock is expansionary in nature, the price of other goods might rise as well on the back of stronger demand, thereby generating stronger inflationary pressures. Also the existence of possible second round effects might depend both on the persistence of the gas price increase and the economic environment. It is plausible that the prevailing level of inflation and the size of the gas price shocks might matter for the ultimate impact, too.

A second factor determining the extent of pass-through are possible government interventions. As observed in 2022, governments might intervene to reduce the social costs of higher commodity prices by subsidizing firms and households. This was the case in 2022 when European governments invested a total of 646 billion euros to alleviate the economic consequences of higher gas prices ([Sgaravatti et al., 2023](#)). These support measures might lead to a lagged transmission of gas prices, and, arguably, a more contained pass-through as long as these measures are in place.

The net effect of these counteracting forces is an empirical question. In the remainder of this section, we investigate the pass-through of gas price shocks to HICP aggregates in detail using local projection methods, allowing also for potential non-linearities in the

²⁷See the [Eurostat HICP methodology](#).

effects, as suggested by [De Santis and Tornese \(2023\)](#). Specifically, we test whether the inflation impact depends on the level of unemployment, the inflation level and the size of the underlying shock.

4.1 Unconditional pass-through of different types of gas shocks

4.1.1 Local projections

We estimate the spillover of gas market shocks to price aggregates through local projections as in [Jordà \(2005\)](#) and [Cloyne et al. \(2023\)](#). Specifically, we estimate the following equation recursively:

$$y_{t+k} = \alpha^k + \beta^k \hat{S}_t + \bar{X}_t \Gamma^k + \hat{S}_t \otimes \bar{X}_t \Delta^k + \zeta^k y_{t-1} + \varepsilon_{t+k} \quad (2)$$

where y is a price index, \hat{S} is one of the three identified shocks in [Equation \(1\)](#) and \bar{X} is a set of lagged control variables, expressed in log-deviation from the sample average. Local projections are particularly suited for this exercise as they do not require specific assumptions on the sign or magnitude of the reaction of y to the shock considered. Additionally, local projections do not impose linearity assumptions on the relationship between shocks and outcome variables and they can easily be extended to account for interaction terms. Our two-step procedure is similar to [Dedola et al. \(2017\)](#) and [Iacoviello and Navarro \(2019\)](#). [Figure A.5](#) in the Appendix reports the estimated shocks.

We first consider four outcome variables y : the European gas price, euro area HICP, core HICP and energy HICP. The vector of control variables \bar{X} includes three lags of global oil²⁸ and European gas prices, euro area industrial production and the VIX-index. β^k captures the response of variable y to shock \hat{S} at horizon k , that is the *direct effect*. $\bar{X} \Delta^k$ is an estimate of the *indirect effect* of the shock conditional on specific levels of the control variables \bar{X}_t denoted by \bar{X} .²⁹ Because \hat{S} is a generated regressor, standard errors are biased by construction as they do not account for uncertainty in [Equation \(1\)](#). Hence, we construct confidence intervals as in [Swanson \(2021\)](#) based on 1,000 random draws from the posterior distribution of the structural shocks.³⁰

²⁸Crude oil is traded globally with less regional price divergence than gas. Hence, we use Brent crude oil prices as a representation of global oil prices.

²⁹If $\bar{X} = 0$ then the interaction term is not relevant; in other words, when control variables are at the sample mean, there is no additional interaction effect.

³⁰[Swanson \(2021\)](#) constructs confidence intervals with a simulation method. In a nutshell, N draws

4.1.2 Impact on main HICP components

Figure 5 shows the baseline impulse responses of euro area prices to the different types of gas shocks. The findings highlight a set of interesting results.

A first finding is that most, yet not all gas price shocks are inflationary. Focusing on the response of headline HICP in the euro area, Figure 5 shows that when gas prices are induced by supply disruptions, or by higher gas demand in context of economic activity, they feed through to inflation. These two types of shocks combined however explain more than half of the average gas price variability in our sample, see Table 3. When gas prices rise due to higher demand for inventories, by contrast, no significant pass-through to inflation is found, despite a mechanical link between gas prices and euro area inflation through the HICP energy component, of which gas accounts for about one-third. This likely reflects differences in the persistence of the gas price increase following these shocks, as mentioned in the previous section and also illustrated in Figure 5.

A second finding is that – when gas price shocks feed through inflation – it takes time for gas prices to transmit, and the transmission is not always complete. Following gas shocks driven by supply, for instance, the impulse response for headline HICP becomes significant after about three months and it takes around a year for the effect to reach its maximum impact. In the initial months following the shock, dynamics in headline HICP mostly mimic the reaction in the energy component. Whereas the initial response of overall HICP reflects the weight of gas in the expenditure basket³¹, the reaction of the energy component is less than proportional. This indicates that the initial shift in wholesale gas prices is not fully passed on to consumers, or that prices of other energy commodities fall in response to the gas price increase. Government interventions aimed at limiting the energy price increase could also explain the lagged and contained impact. At its peak impact after 12 months, HICP energy still remains below the mechanical impact, increasing by 4.6%.³² Also following gas price shocks driven by economic activity, it is

are taken from the posterior distribution of shocks and one regression is estimated for each of the N draws. Confidence intervals are computed from the moments of the distributions of the N estimated coefficients.

³¹After three months, the gas price has increased by 9% which would imply a mechanical increase of headline HICP by 0.17% which is broadly in line with our estimate.

³²After 12 months, the gas price stands at 23.9% above pre-shock levels, which would mechanically imply a pass-through of about 19%. The mechanical effect from HICP energy to headline HICP is smaller than the estimated effect, ruling out that the results for headline HICP are driven by spillovers from gas prices to other energy prices incl. electricity prices.

clear that the pass-through from wholesale to retail energy costs is incomplete and lagged as general equilibrium effects take time to manifest.

Third, depending on the driving factor, gas price increases can pass through to core inflation in the euro area. Core HICP – which is not mechanically impacted by higher gas prices – reacts positively and significantly following gas supply shocks and economic activity shocks, which further contributes to the delayed impact on inflation, see [Figure 5](#).³³ A supply shock in the gas market leads to a peak reaction of core HICP by about 0.45% around one year following the shock. Slow pass-through from wholesale to retail prices, rigidities in price settings by firms ([Stiglitz, 1999](#)), and government policies might explain why it takes time for core prices to adjust.³⁴ For overall HICP, when reaching its peak impact after 14 months, the increase by 0.85% following a gas supply shock adds to more than twice the mechanical effect as natural gas prices are part of the HICP basket.³⁵ Again, gas price shocks induced by changes in economic activity trigger similar dynamics as shocks to gas supply, whereas gas inventory shocks are found to not affect inflation.

The finding that gas price shocks can feed through to core inflation has important policy implications. Following economic activity shocks, which represent a more broad-based pick-up in the demand for a wide range of goods, wider price pressures can be expected, and the role of monetary policy is clear. But following disruptions in gas supply – which can trigger broad-based price changes while weighing on economic activity – this might be less evident.

To test whether these results do not only follow from the exceptional gas market dynamics observed since 2020, we cut the sample used to end in 2019 to avoid that the post-pandemic period affect local projection results. [Figure A.13](#) in the Appendix compares the resulting impulse responses against our baseline estimates. When including 2020 to 2022 data, price reactions to gas market shocks are unsurprisingly stronger, suggesting that the latest juncture might represent a break in the relation between the gas market and aggregate euro area prices. However, the qualitative results remain similar meaning that not all dynamics come from the most recent data. There is an insufficient

³³A reaction of core inflation also explains why, despite having incomplete pass-through to HICP energy, the overall HICP impact is overall in line with the weight of gas in the expenditure basket.

³⁴Indeed governments tend to implement measures to sterilize the effects of higher energy prices. During 2022, for example, in the EU about 646 billion euros have been spent by national governments to reduce the economic downfall of higher gas prices, see [Sgaravatti et al. \(2023\)](#).

³⁵After 14 months our estimates imply a 21% increase in the gas price which mechanically translates into a 0.40% increase in the price aggregate when applying the HICP weight.

amount of data points to formally test this hypothesis, but it is an important venue for future research once more data become available.³⁶

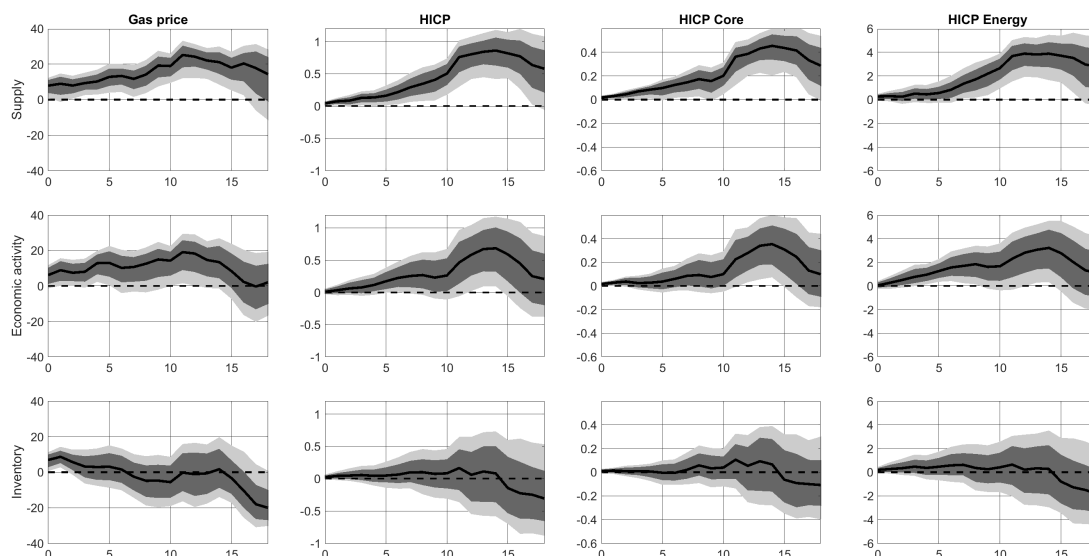


Figure 5: Unconditional effect of gas price shocks.

Notes: The figure shows impulse responses in percent of the four price indices to the three gas shocks identified in the model up to 18 months after the shock. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (2) cover the period October 2008 to November 2022.

4.1.3 Channels of transmission

To better understand core inflation dynamics, Figure 6 digs deeper into the pass-through channels of a gas shocks to inflation. We consider a set of key producer price indices (PPI), wages³⁷ as well as profit margins³⁸ to assess the relevance of so-called “second round” effects, i.e. the reaction of firms and workers to higher gas input prices.

³⁶This is as we use local projections which implies the loss of the last $K = 18$ data points.

³⁷Data for compensation per employee or per hour are only available on a quarterly frequency. We therefore use monthly negotiated wages excluding one-off payments for the euro area. However, as we calculate impulse response functions in monthly percentage changes and negotiated wages for the euro area are only available in year-on-year growth rates, to estimate the local projections, we construct a wage index based on a monthly negotiated wage index for Germany from the Bundesbank before our data sample starts and extrapolate that index with negotiated wage changes for the euro area in the period of our data sample. We seasonally adjust the wage index to correct for seasonality in wages. As a seasonally-adjusted version of the wage index we use is not available, we rely on the same seasonal adjustment method as for other variables. Yearly changes in the index are strongly correlated with negotiated wage data for the euro area with a correlation coefficient of 0.93.

³⁸There are several ways to measure profits (Hahn, 2023). We use a stock market based measure as it is available on a monthly frequency.

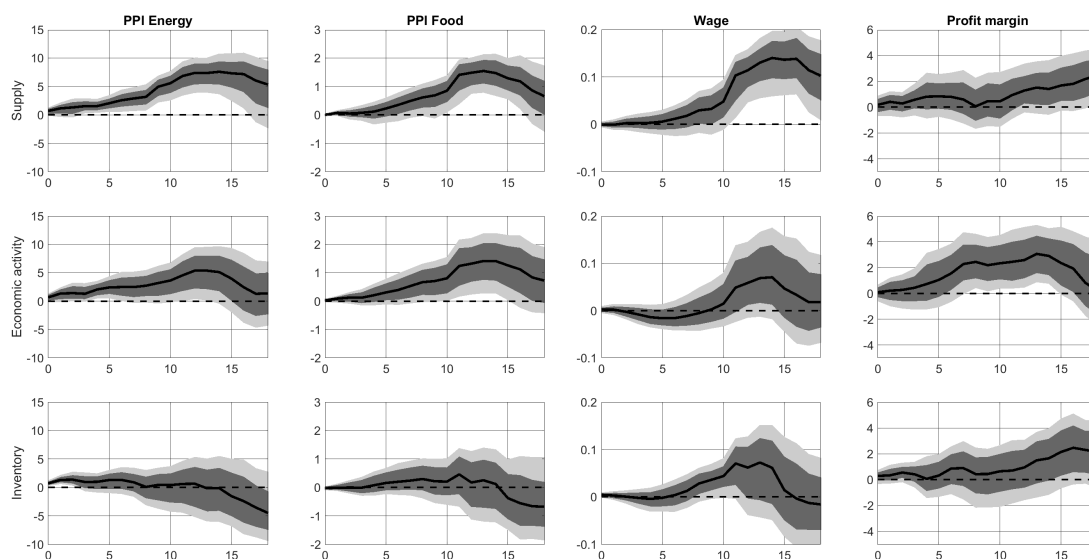


Figure 6: Unconditional response of PPI, wages and profit margins.

Notes: The figure shows impulse responses of the four outcome variables to the three gas shocks identified in the model up to 18 months after the shock. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (2) span from October 2008 to November 2022.

The results show that both energy and food producer prices respond significantly to gas supply and economic activity shocks. Following a shock in supply, for example, energy producer prices peak at 7.6%, which increases production costs of firms more widely and are in part passed on to consumers. Noticeably, the energy PPI increases more than HICP energy after a supply shock, which may reflect price containment measures aimed at shielding consumers from energy price increases.³⁹ Also food producer prices rise significantly, by about 1.5% at the peak, which reflects the role of gas as a key input in food production through its use for the production of fertilizers (for which natural gas is a key input) as well as in electricity production and transportation.⁴⁰

Wages in the euro area are also found to react to gas supply shocks, with a lag of about nine months. Once higher gas prices spill over to inflation more broadly, workers demand higher compensation with nominal rigidities in wage setting potentially explaining why the increase in wages is delayed. The peak increase in wages amounts to about 18% of

³⁹PPI energy increases by almost 10% above average at the peak, while HICP energy increases by less than 5%.

⁴⁰Fertilizer prices increase at peak by 7.5% following a gas supply shock. Electricity prices follow gas prices closely in Europe due to the marginal-pricing system, see Adolfsen et al. (2022) for further details, while prices on fuels may also increase to some extent amid energy substitution taking place after a gas supply shock.

the peak rise in headline inflation, suggesting that real wages fall and workers face losses in purchasing power.

Finally, profit margins are also found to adjust, increasing with a considerable delay of around 12 months after a gas supply shock which lifts gas prices. The increase in profit margins might reflect the “cleansing effect” of recessions, by which negative gas supply shocks force less efficient firms off the market and, therefore, increase average productivity and profits, see [Schumpeter \(1942\)](#).⁴¹ Firms may also raise prices disproportionately to the increase in input costs due to the menu costs associated with changing prices frequently, therefore leading to higher profits, which has often been discussed in policy circles⁴², although this would not fully explain the delayed reaction of margins. In any case, higher overall profit margins would contribute further to upward pressures on core inflation from gas supply shocks.

These results underline that higher gas prices induced by shocks to gas supply can have far-reaching implications when it comes to inflation. Persistently higher gas prices do not only feed through the energy component of the consumption basket, but affect inflation more broadly through food prices and wages. In contrast to what is established for standard commodity supply shocks, the presence of these additional transmission channels suggest that monetary policy cannot entirely look through supply-driven gas price increases.

4.2 State dependency in the effects of gas supply shocks

As gas supply shocks are found to affect core inflation dynamics on average, it is worth questioning whether there might be relevant non-linearities in place. For example, the high contribution of the 2022 gas price spike to euro area inflation happened following very large gas price shocks, in an already high inflation environment and when the euro area labor market was tight – all factors that might have reinforced incentives of firms to pass on higher gas input costs, and workers to demand higher wages.

[De Santis and Tornese \(2023\)](#) indeed show that economic effects of energy shocks depend on the state of the economy, suggesting that non-linearities could apply for gas price shocks as well. Consumer prices, for example, could react stronger to gas price

⁴¹This has also been documented by [Caballero and Hammour \(1991\)](#), [Davis and Haltiwanger \(1992\)](#) and [Osotimehin and Pappadà \(2017\)](#).

⁴²[Brainard \(2023\)](#), [Panetta \(2023\)](#) and [Schnabel \(2023\)](#).

fluctuations when the economy already operates at capacity and the labor market is tight, because price pressures are already high. The price response may also depend on the level of inflation: in periods of high inflation it is easier for firms to pass higher prices on to consumers, see [Bruine de Bruin et al. \(2023\)](#), [Nakamura et al. \(2018\)](#), [Alvarez et al. \(2019\)](#) and [Dias et al. \(2007\)](#). Finally, because of menu costs, firms might update prices after large shocks but look through small ones, see [Mankiw \(1985\)](#), [Golosov and Lucas \(2007\)](#) and [Karadi and Reiff \(2019\)](#).

4.2.1 State-dependent local projections

We test these hypotheses with conditional local projections, focusing on gas supply shocks as these are arguably the most exogenous.⁴³ Specifically, we augment [Equation \(2\)](#) with additional interactions terms as in [Cloyne et al. \(2023\)](#):

$$y_{t+k} = \alpha^k + \beta^k \hat{S}_t + \gamma_t I_t + \delta^k \hat{S}_t \otimes I_t + \bar{X}_t \Gamma^k + \hat{S}_t \otimes \bar{X}_t \Delta^k + \zeta^k y_{t-1} + \varepsilon_{t+k} \quad (3)$$

where y , \hat{S} and \bar{X} are defined as before, and I is an additional control variable on which we condition the non-linear reaction of price aggregates to shocks. We consider three additional controls in I : the euro area unemployment rate⁴⁴, a dummy variable equal to one if the euro area inflation rate⁴⁵ is larger than 2%, and a dummy variable equal to one if the absolute shock, \hat{S}_t , is larger than one standard deviation. These variables enter separately in [Equation \(3\)](#) to maintain sufficient degrees of freedom.⁴⁶ If the sequence, $\{\delta^k\}_{k=0}^K$, is statistically different from zero, then there are non-linearities in the reaction of y to the shocks conditional on the channel captured by I . The coefficient $\beta^k + \delta^k \bar{I}$ captures the response of consumer prices conditional on the control variable, I_t , being at the level \bar{I} . In what follows, we test possible non-linearities in the pass-through depending on the unemployment rate, the prevailing level of inflation and the size of the shocks.

⁴³When gas prices are driven by economic activity, by comparison, the transmission to inflation might be influenced by factors which are difficult to disentangle from the dynamics that are set in train by the higher gas prices specifically.

⁴⁴The usual labor market tightness indicator would be the ratio between vacancies and unemployed persons. However, this measure is not available at a monthly frequency for the euro area.

⁴⁵Defined as year-on-year HICP percentage change.

⁴⁶When using the unemployment rate, I_t is the de-meaned unemployment rate, $I_t - E(I)$. When a dummy enters as the state variable, no de-meaning is used.

4.2.2 Non-linear impact on main HICP components

Figure 7 reports the impulse response functions of the gas price, HICP and its main components estimated from Equation (3) using the unemployment rate as an interaction variable.⁴⁷ To illustrate indirect effects of lower-than-average unemployment rates – akin to expansion periods – we invert the sign of the interaction coefficient, δ^k , which is reported in the middle row of Figure 7. The results show that the interaction term is significant after about 10 months and generally positive. This means that when unemployment is low, the impact of gas supply shocks on aggregate consumer prices and its components is disproportionately high. The difference is also economically significant; when unemployment is one standard deviation below its historical average, the reaction of inflation is roughly 50% higher, as shown in the bottom row of Figure 7. Similar results apply to HICP core and HICP energy. The transmission to producer prices also displays non-linearity depending on the unemployment level, although the differences are more contained, see Figure A.10 in the Appendix.

There are several explanations why the pass-through could be more pronounced in times of low unemployment. The stronger price adjustment could simply reflect larger gas price increases which triggers a more wide-spread rise in other prices as well, see the middle left panel in Figure 7. Alternatively, firms might adjust retail prices by more when balance sheets of firms and households are stronger, allowing a better absorption of higher energy costs. Wages might also react stronger – at peak – to gas supply shocks in periods of low unemployment. When the job market is tight, workers have more bargaining power to negotiate wage deals to offset losses in purchasing power. The results hint in that direction, with the average response of wages 0.05 pp higher when unemployment is one standard deviation below average (see Figure A.10), but the estimates are surrounded by some uncertainty. By contrast, the profit margin channel is more muted in an economic upturn, and is not likely to be behind the non-linearity found. But this finding would support the “cleansing effect” interpretation of dynamics in profit margins: in periods of low unemployment, higher energy input costs could be less contractionary as consumer demand is more robust, which might force fewer low-productivity firms to leave the market, and could prevent average productivity to increase significantly (thereby containing profit margins).

⁴⁷The results are robust when controlling for changes in supply chain pressures, see Figure A.7.

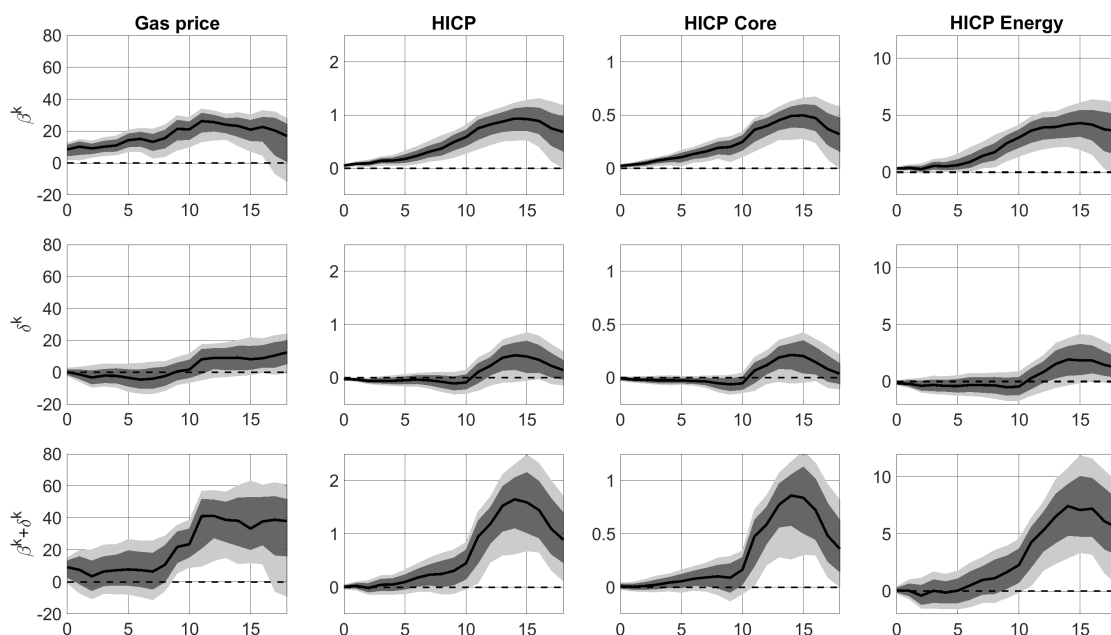


Figure 7: Impulse responses to a supply shock conditional on the unemployment level. **Notes:** The figure shows impulse responses in percent of the four price indices to a gas supply shock identified in the model up to 18 months after the shock and conditional on controlling for the unemployment rate in Equation (3). The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \bar{I}\delta^k$, where \bar{I} is set to have unemployment one standard deviation below average. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

While there is a clear non-linearity depending on the level of unemployment, we do not find state dependency in the effect for different levels of inflation, in contrast to De Santis and Tornese (2023). This is shown in Figure A.8 in the Appendix. Also for large gas price shocks, the transmission is not significantly different to average-sized shocks, see Figure A.9. According to our estimates, it is mostly labour market conditions that might matter for the extent to which core inflation dynamics are affected following gas price shocks.

5 Conclusion

Major shocks to gas markets have challenged monetary policy makers in their fight against inflation in recent years. The challenge was two-fold; gas supply disruptions added to already accelerating inflation that followed from the pandemic recovery, while the supply nature of the shock caused doubt on how persistent the disruptions would be, and how

these would feed through inflation.

This paper presents a novel BVAR model for the European gas market that provides empirical evidence on these aspects. Our model – inspired by the oil literature but tailored to the European gas market – captures historic events well and demonstrates how an unusual combination of supply and demand factors caused gas prices to spike to unprecedented levels in 2022.

The results underline that gas price shocks can have important implications for inflation in the euro area – depending on the driving factor of higher gas prices. Disruptions in gas supply, as observed during the invasion of Russia in Ukraine in 2022, tend to persistently lift gas prices, and more so than when gas prices rise due to inventory rebuilding. The persistent nature of these gas supply shocks cause the impact on inflation to be broad-based. Our estimates indicate that gas supply shocks not only affect energy inflation, but also feed through to core inflation due to persistent effects on producer prices and wages. These indirect effects on core inflation might even be magnified notably in times when unemployment is low – as observed in recent years. Similar dynamics are found when gas prices are driven by changes in economic activity, whereas shocks to gas inventory demand are not found to be inflationary. Results are robust to formally accounting for the Covid-19 pandemic, the exclusion of post-2019 data and controlling for supply bottle necks.

These findings have important implications for monetary policy. Due to possible broad-based effects on inflation, monetary policy cannot simply “look through” these types of energy shocks, even when the shock is partly driven by supply factors. Similar to what is known for oil ([Kilian, 2009](#)); not all gas price shocks are alike. Understanding what drives gas prices is key to determine which monetary policy reaction is most appropriate. This paper provides a framework to understand the driving forces of the European gas market and its implications for the euro area economy.

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Appendix

A Figures

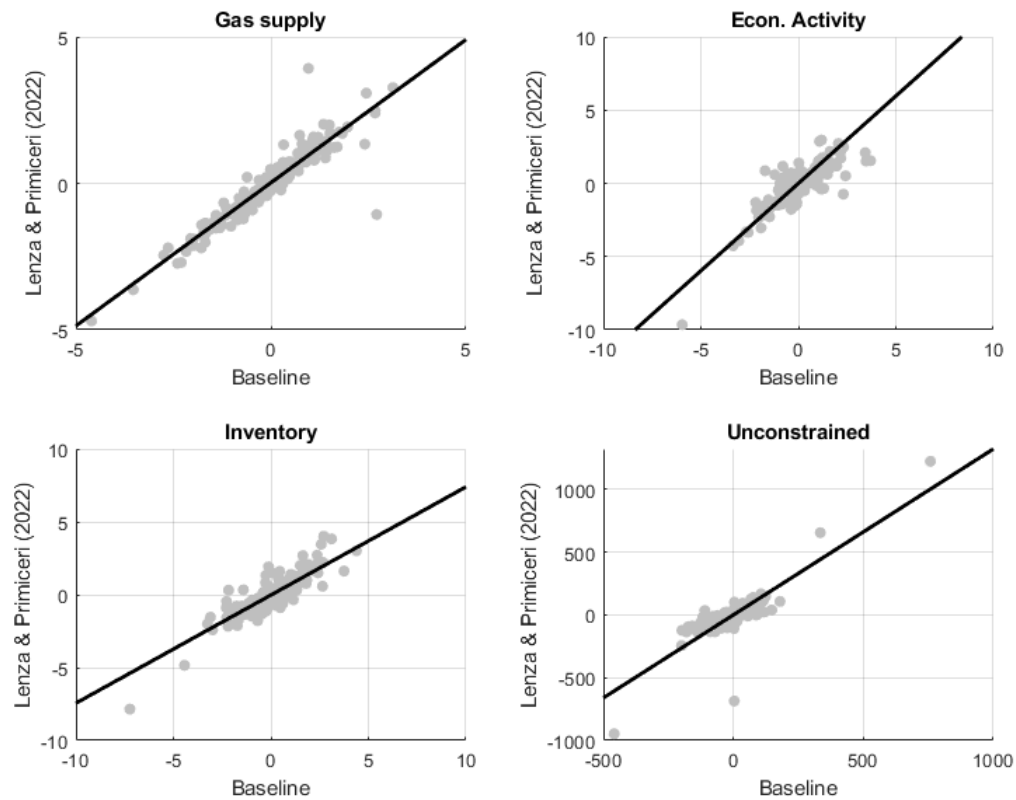


Figure A.1: Correlation in identified shocks.

Notes: The chart reports the correlation of (median) identified shocks between the baseline model and an alternative model estimated using the correction by [Lenza and Primiceri \(2022\)](#) for the observations around the Covid-19 outbreak. Specifically, observations between February and July 2020 are down-weighted.

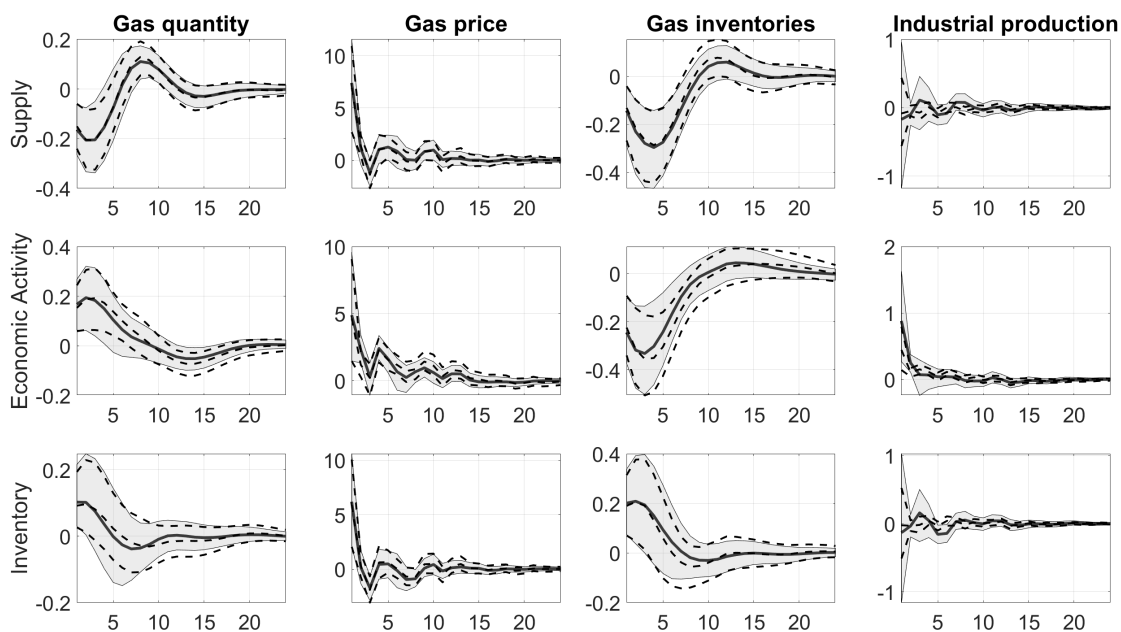


Figure A.2: Impulse responses accounting for the Covid-19 pandemic.

Notes: The chart reports median impulse responses from the baseline model (solid black line) and an alternative model (black dashed lines) estimated using the correction by [Lenza and Primiceri \(2022\)](#) for the observations around the Covid-19 outbreak. 68% confidence interval are also reported via grey shaded areas (baseline) and dashed black lines ([Lenza and Primiceri \(2022\)](#)).

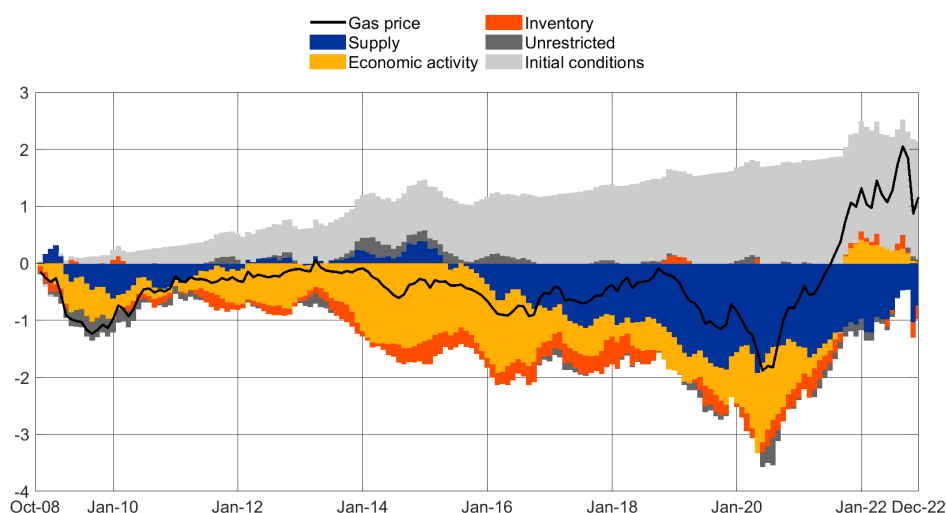


Figure A.3: Historical decomposition of the gas price over the full sample.

Notes: The chart reports the historical decomposition of cumulated log-differences of the euro area gas price. The decomposition is based on the Bayesian VAR model described in [Equation \(1\)](#) where shocks are identified using sign restrictions as reported in [Table 2](#) and the median rotation is used. Initial conditions include the contribution of the constant term A_0 .

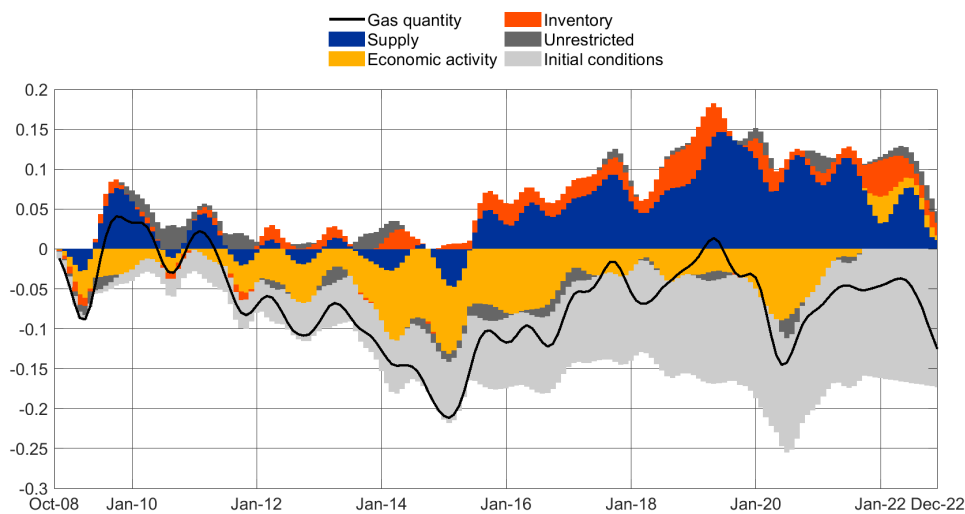


Figure A.4: Historical decomposition of the gas quantity over the full sample.

Notes: The chart reports the historical decomposition of cumulated log-differences of the euro area gas quantity. The decomposition is based on the Bayesian VAR model described in Equation (1) where shocks are identified using sign restrictions as reported in Table 2 and the median rotation is used. Initial conditions include the contribution of the constant term A_0 .

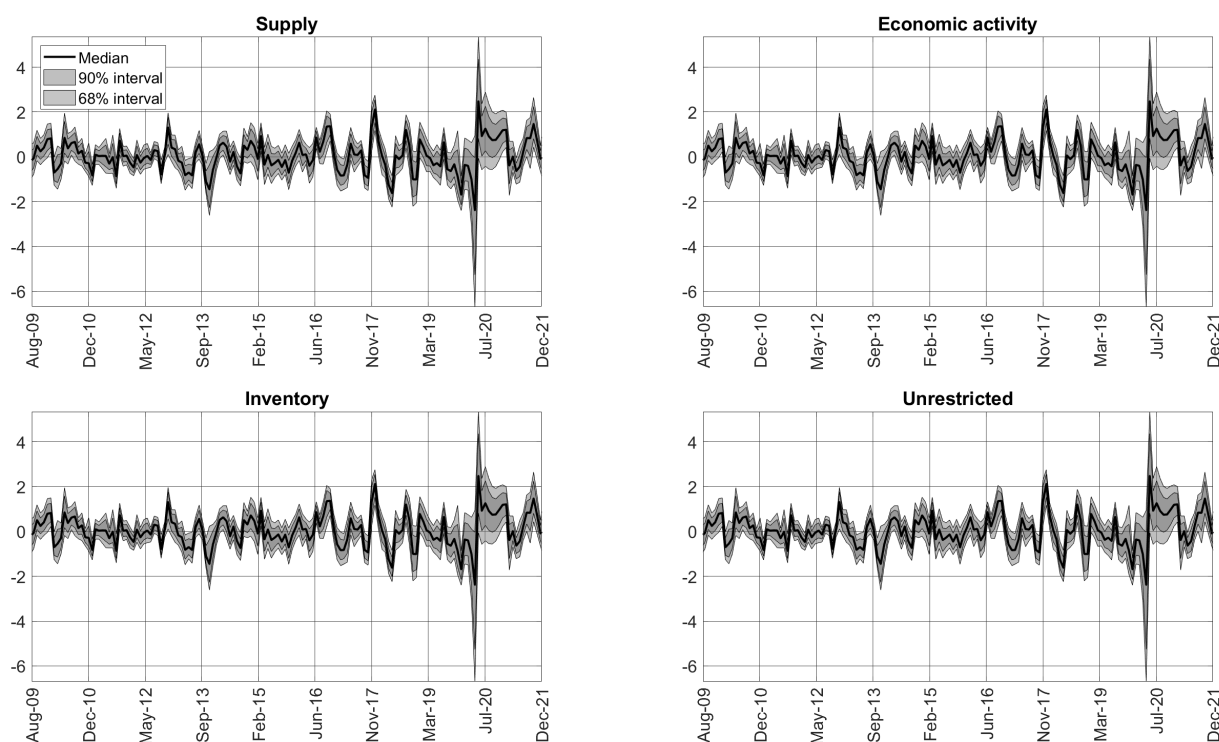


Figure A.5: Estimated shocks.

Notes: The chart reports the estimated shocks from Equation (1). The black solid line is the median shock across 10,000 rotations of the model and the shaded areas report the 68 and 90 percentile shocks from the distribution.

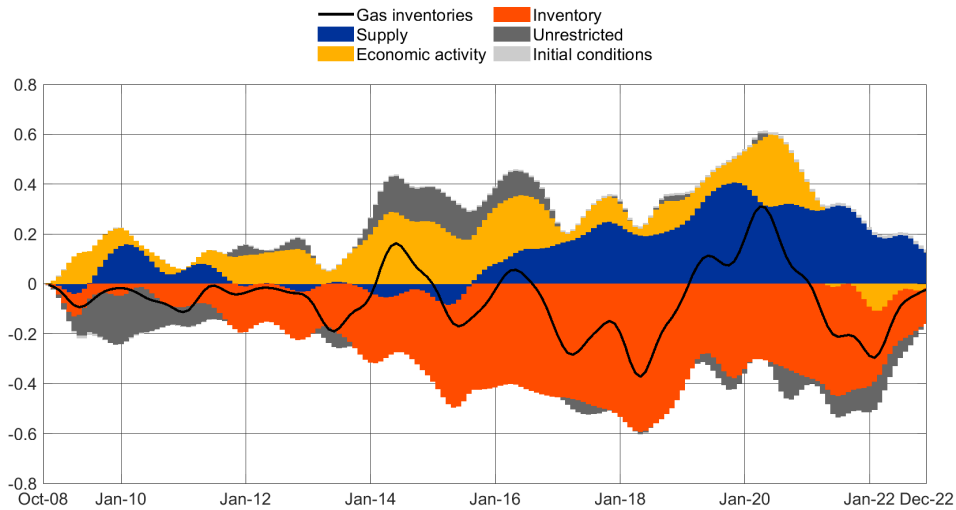


Figure A.6: Historical decomposition of gas inventories over the full sample.

Notes: The chart reports the historical decomposition of cumulated log-differences of euro area gas inventories. The decomposition is based on the Bayesian VAR model described in Equation (1) where shocks are identified using sign restrictions as reported in Table 2 and the median rotation is used. Initial conditions include the contribution of the constant term A_0 .

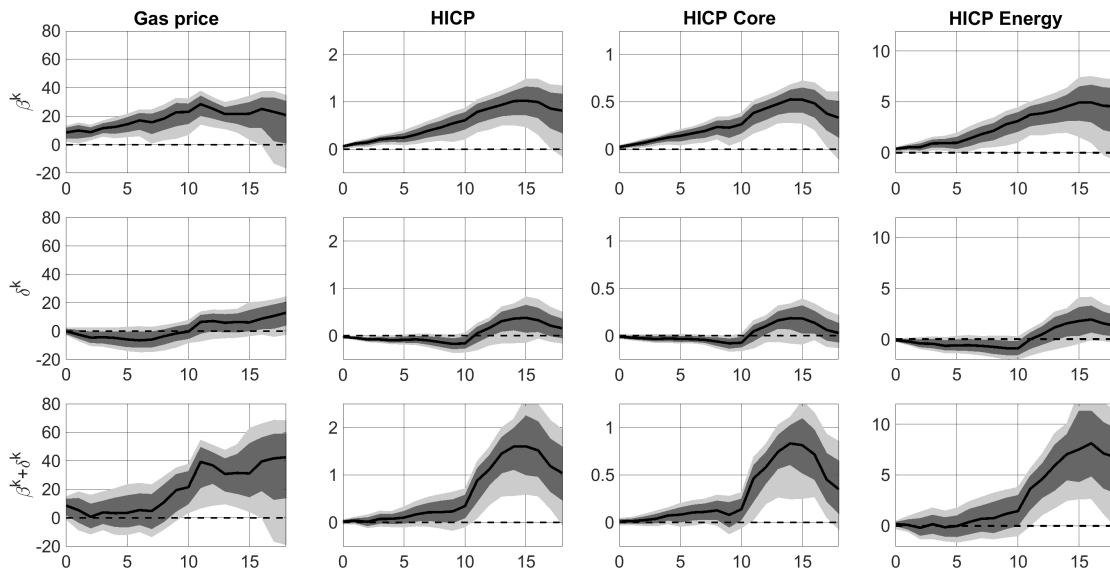


Figure A.7: Impulse responses to a supply shock conditional on the unemployment level after controlling for changes in supply chain pressures.

Notes: The figure shows impulse responses in percent of the four price indices to a gas supply shock identified in the model up to 18 months after the shock and conditional on controlling for the unemployment rate in Equation (3). Changes in supply chain pressures, proxied by PMI supply delivery times in the euro area, have been added to the control variables, \bar{X} . The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \bar{I}\delta^k$, where \bar{I} is set to have unemployment one standard deviation below average. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

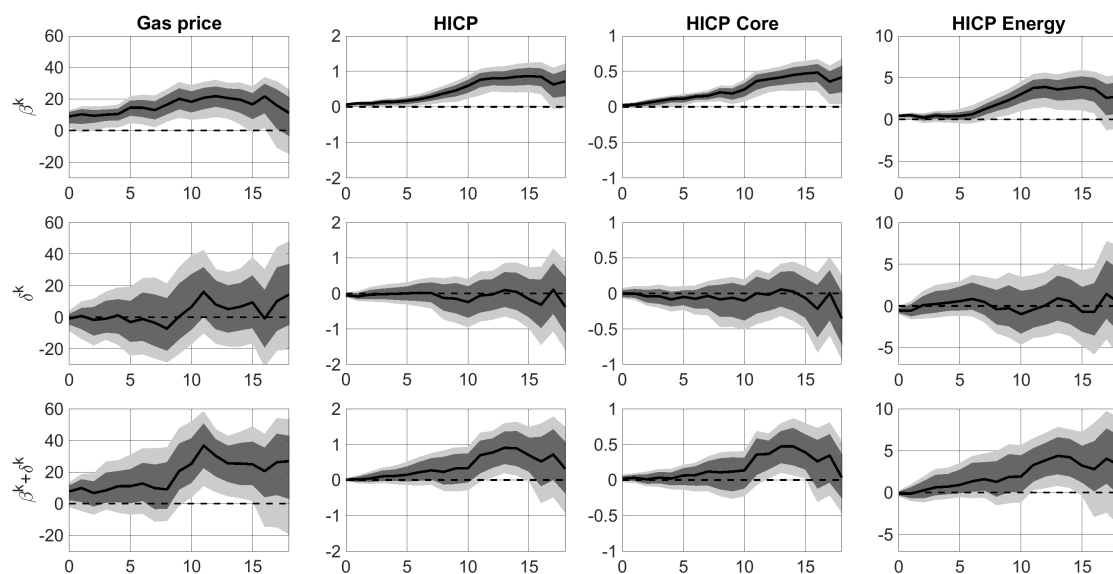


Figure A.8: Impulse responses to a supply shock conditional on the level of inflation.
Notes: The figure shows impulse responses in percent of the four price indices to a gas supply shock identified in the model up to 18 months after the shock and conditional on controlling for a dummy equal to one if HICP inflation is above 2% in Equation (3). The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \bar{I}\delta^k$, where \bar{I} is set to have inflation above 2%. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

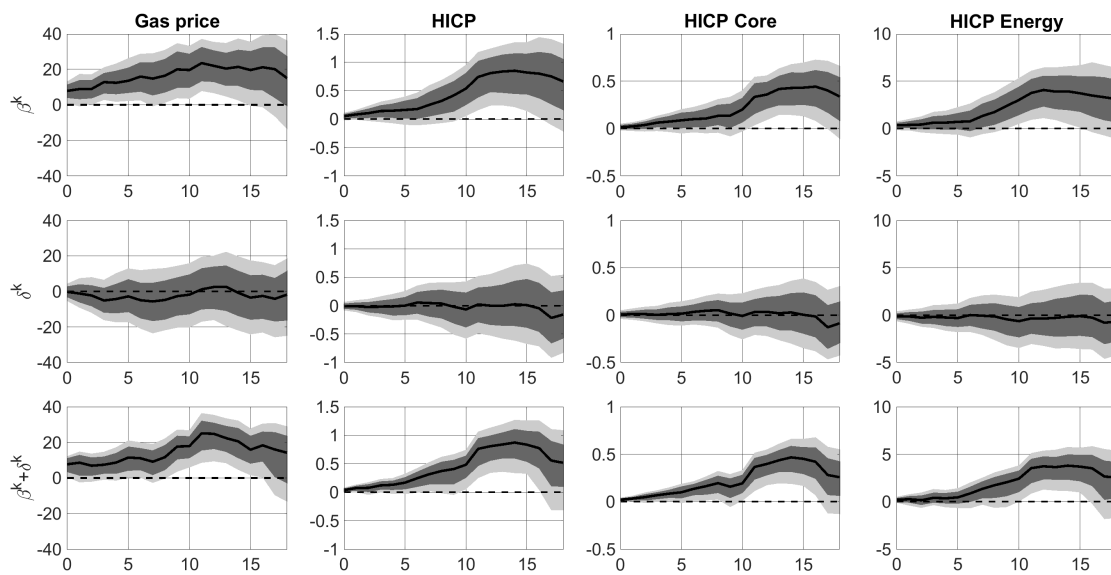


Figure A.9: Impulse responses to a supply shock conditional on the size of the shock.
Notes: The figure shows impulse responses in percent of the four price indices to a gas supply shock identified in the model up to 18 months after the shock and conditional on controlling for a dummy equal to one if shocks are larger than one standard deviation [Equation \(3\)](#). The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \bar{I}\delta^k$, where \bar{I} is set to have the shock one standard deviation above the average. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from [Equation \(1\)](#). The data used in [Equation \(3\)](#) cover the period October 2008 to November 2022.

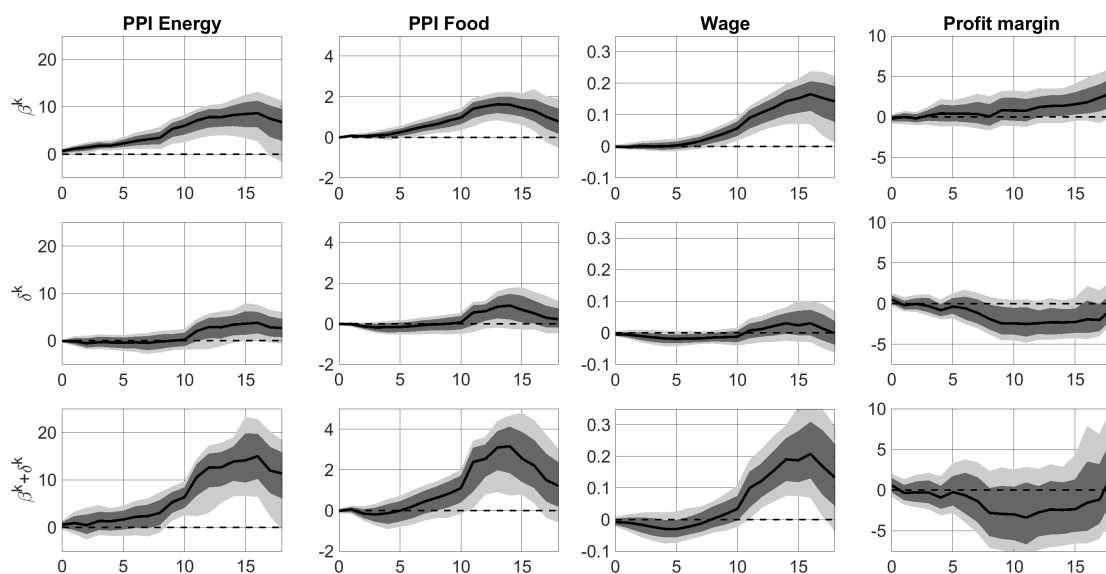


Figure A.10: Impulse response of PPI, wages and profit margins to a supply shock conditional on the unemployment level.

Notes: The figure shows impulse responses in percent of the four outcome variables to a gas supply shock identified in the model up to 18 months after the shock. The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \bar{I}\delta^k$, where \bar{I} is set to have unemployment one standard deviation below average. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

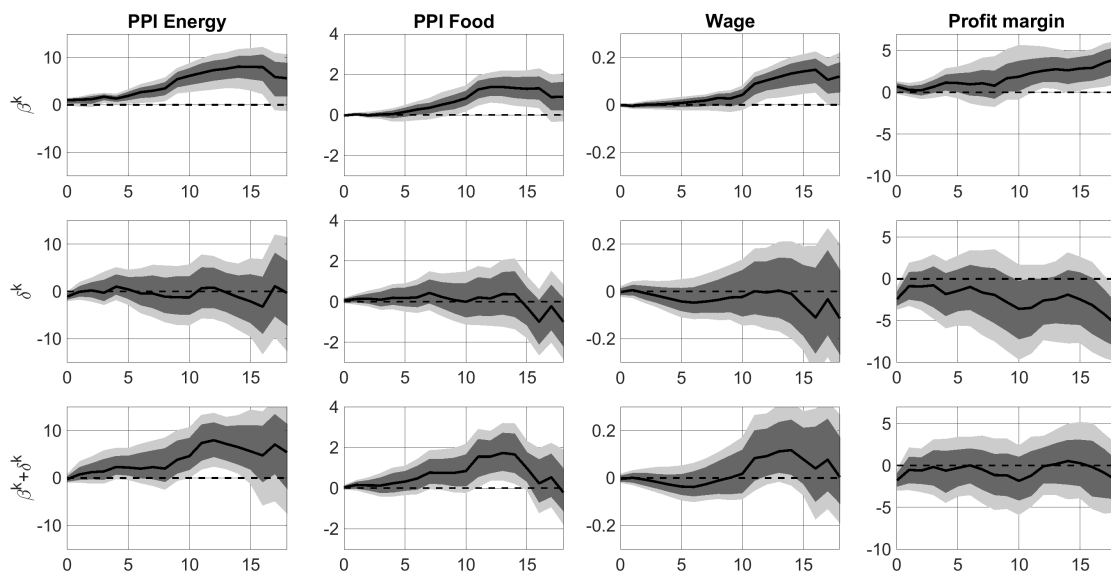


Figure A.11: Impulse response of PPI, wages and profit margins to a supply shock conditional on inflation.

Notes: The figure shows impulse responses in percent of the four outcome variables to a gas supply shock identified in the model up to 18 months after the shock. The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \delta^k$. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

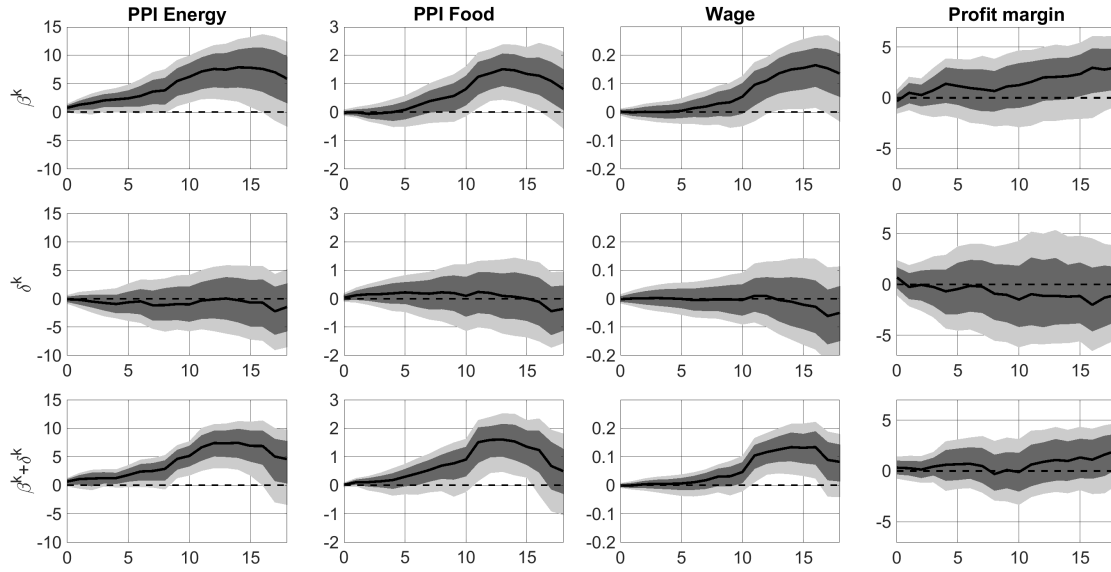


Figure A.12: Impulse response of PPI, wages and profit margins to a supply shock conditional on the size of the shock.

Notes: The figure shows impulse responses in percent of the four outcome variables to a gas supply shock identified in the model up to 18 months after the shock. The first row shows the direct effect of the shock β^k , the second row shows the interaction coefficient of interest δ^k , and the third row shows the sum of the direct and indirect effect $\beta^k + \delta^k$. The black solid line is the median response while shaded areas report 68% and 90% confidence intervals based on the posterior distribution of the shocks from Equation (1). The data used in Equation (3) cover the period October 2008 to November 2022.

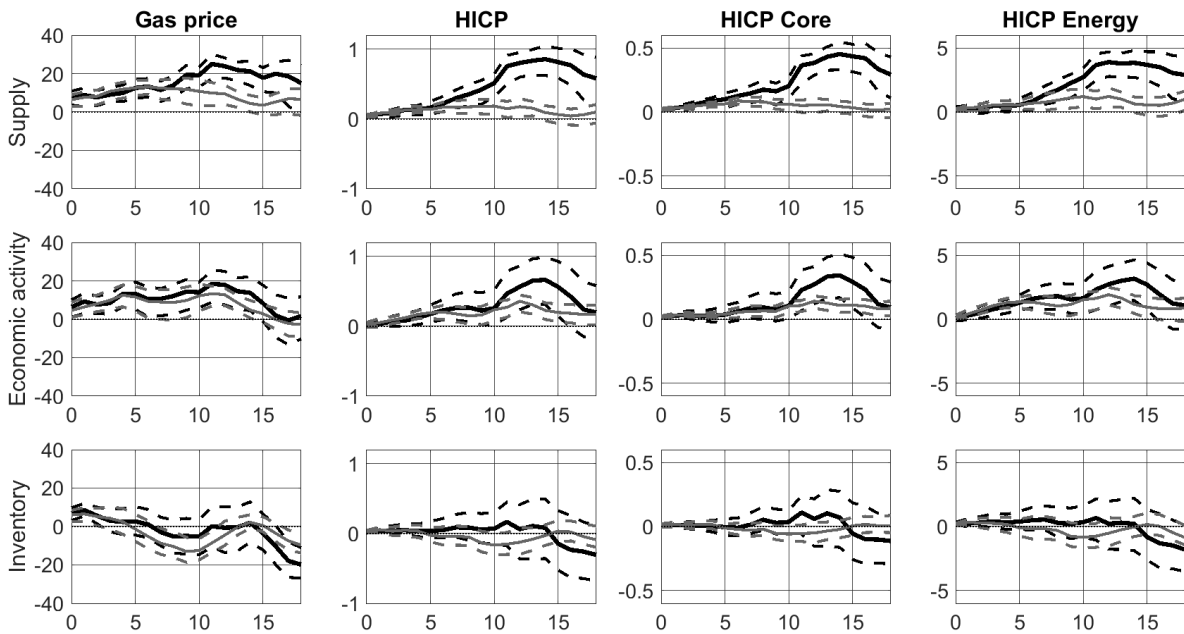


Figure A.13: Unconditional response for the full and restricted sample.

Notes: The figure shows impulse responses of the four price indices to the three gas shocks identified in the model up to 18 months after the shock. The black solid line refers to the full sample (October 2008 to November 2022), while the thinner gray line refers to the restricted sample (October 2008 to December 2020). Dashed lines show 68% confidence intervals, which are based on the posterior distribution of the model.

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