Global supply chain pressures, inflation, and implications for monetary policy*

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February 6, 2024

Abstract

How should policymakers respond to the recent surge in inflation? This paper examines the impact of global supply chain pressures on euro area inflation and the implications for monetary policy. Results from a Bayesian structural vector autoregressive model show that shocks to global supply chain pressures were the dominant driver of euro area inflation in 2022, and that these shocks have a highly persistent and hump-shaped impact on inflation. Furthermore, a two country New Keynesian model with international trade in intermediate goods shows that the optimal monetary policy response to global-supply-induced inflation is a non-linear function of the degree of global value chain participation.

Keywords: inflation, global supply chain pressures, optimal monetary policy, Phillips curve, vector autoregression, Bayesian techniques, DSGE

JEL Classification: E30, E31, E32, E37, E50

*We thank Maurice Bun, Elena Bobeica, Fabio Canova, Peter van Els, Gavin Goy, Jakob de Haan, Oleksiy Kryvtsov, Christiaan van der Kwaak, Zheng Liu, Kostas Mavromatis, Thuy Lan Nguyen, Peter Tillmann, Kerem Tuzcuoglu and Sweder van Wijnbergen for helpful discussions and suggestions, and to participants at the 2023 Asia Economic Policy Conference, ICEA conference on Pandemics, Labour Markets and Inflation, CEBRA 2023 Annual Meeting, EcoMod2023 International Conference on Economic Modeling and Data Science, ERMAS 2023 and National Bank of Romania's research seminar for helpful comments. The views expressed are those of the authors and do not necessarily represent the views of De Nederlandsche Bank or the Eurosystem.

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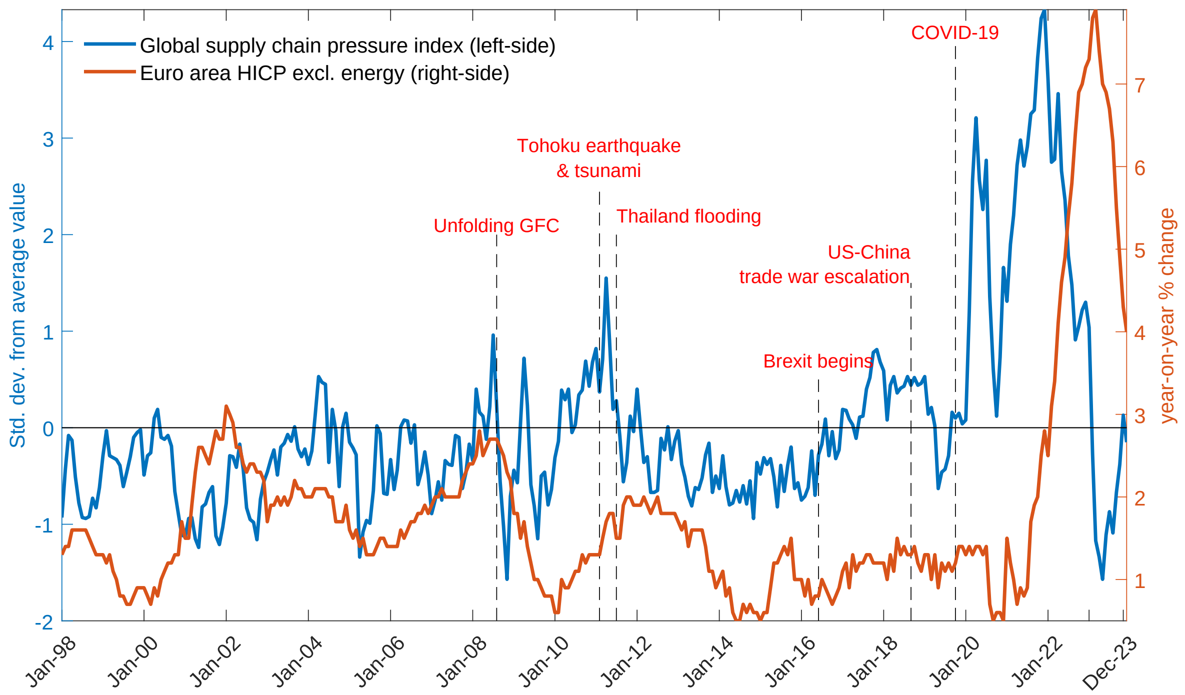
1 Introduction

As the global economy recovered from the COVID-19 pandemic, supply chain disruptions intensified, exerting upward pressure on prices. Many firms struggled to keep up with surging consumer demand – which has been fuelled by excessive savings and pent-up demand – amid broad-based supply shortages and delivery delays. Supply-demand imbalances arising from the COVID-19 health shock led to a critical shortage of raw materials and container transportation, which in turn led to increases in their prices. These developments, and their impact on inflation, were exacerbated by congested international ports and factories, labor shortages, low inventory levels and production delays attributable to COVID-19 containment measures. While a rather rare event before the COVID-19 pandemic, disruptions in global supply chains have become increasingly common across many countries.

Figure 1.1: Global supply chain pressures easing after historically high levels



Note: The figure displays the Global Supply Chain Pressure Index (GSCPI), as computed by Benigno et al. (2022), together with euro area core inflation (HICP excluding energy). The GSCPI is scaled by its standard deviation. The last observation is for December 2023. Several episodes stand out: (i) a fall and swift rebound during the global financial crisis; (ii) a surge in 2011, associated to two natural disasters, i.e. the Tōhoku earthquake (and resulting tsunami) and the Thailand flooding; (iii) a rise during the China-US trade disputes of 2017-18, during which many firms had to adjust their global procurement strategies; and (iv) a number of unprecedented spikes attributable to the unfolding COVID-19 pandemic.

The newly constructed Global Supply Chain Pressure Index (GSCPI) by Benigno et al. (2022), which combines a comprehensive set of indicators of global transportation costs and supply bottlenecks, shows that pandemic-related events led to historically high and volatile global supply chain pressures. In Figure 1.1, we display the GSCPI's evolution alongside euro area core inflation (as proxied by HICP excluding energy) to set the stage for our analysis. The GSCPI jumped at the onset of the pandemic, reflecting the lockdown measures imposed by China, and declined briefly thereafter as world production started to resume around mid-2020. Against the background of a new wave of COVID-19 cases in the winter of 2021, global supply chain pressures started to intensify again, only to slowly recede in the second part of 2022 (from its peak value of +4.3 in December 2021). At present, the GSCPI hovers around 1 standard deviation below its historical mean, indicating that supply bottlenecks have been easing substantially. In most developed economies, inflation has surged as economic activity started to rebound from the pandemic-induced recession, and euro area inflation was no exception (see Figure 1.1). During the recovery phase that started in late 2020, inflation rose markedly.[1]

Against this background, in this paper we ask how policymakers should respond to the recent surge in inflation. To address this question, we quantify empirically how much global supply chain pressures contribute to euro area inflation and examine theoretically what they imply for the conduct of monetary policy. First, we estimate the relationship between global supply chain pressures and inflation using a Phillips curve that features the GSCPI as an additional explanatory variable. We find that global supply chain pressures contribute positively and significantly to euro area inflation and that augmenting the Phillips curve with the GSCPI yields a more significant and larger estimate of the Phillips curve slope. Second, we estimate a Bayesian structural vector autoregressive model with both sign and narrative restrictions to identify shocks to global supply chain pressures. We find that these shocks were the dominant driver of the surge in euro area inflation in the first half of 2022, and that their impact on inflation is highly persistent and hump-shaped. This result suggests that global supply disruptions tend to gradually feed through to domestic prices, are potentially amplified by second-round effects that further raise aggregate prices and will continue to drive up inflation long after the initial shock to global supply chain pressures has faded out.

Third, we study the implications of global supply chain pressures for optimal monetary policy using a two-country New Keynesian model along the lines of Benigno (2009). Following Eyquem and Kamber (2014) and Gong et al. (2016), the model features the use of foreign intermediate goods in the production of domestic final goods. This feature captures, in a stylized way, a country's participation in global value chains and implies that firms' marginal costs are directly subject to changes in relative international prices. We show that, at low degrees of global value chain participation, a shock to global supply chain pressures has similar characteristics as that of a domestic demand shock, with output and inflation moving in the same direction. The Ramsey optimal policy then implies a monetary policy tightening to contain inflationary pressures. However, when global value chain participation is relatively high, global supply chain pressure shocks resemble a domestic supply shock, moving output and inflation in opposite directions. As a result, the inflation-output stabilization trade-off for monetary policy worsens and the Ramsey optimal policy calls for a less aggressive monetary policy response to avoid exacerbating the contraction in output.

[1] A DNB Analysis (2021) – "Euro area inflation and the pandemic" – discusses at length all the potential forces that might have contributed to this sharp increase.

Related literature. Our work is connected to various strands of the literature. First, the massive surge in inflation that followed the rebound from the pandemic-induced recession triggered renewed interest among both policymakers and academics into the relative importance of supply- and demand-side factors of inflation. Much recent work on this topic is focused on the US and subscribe between one-third to two-thirds of the recent surge in inflation to supply shocks (see e.g. Ferrante et al., 2023, Shapiro, 2022a, Shapiro, 2022b, di Giovanni et al., 2023, Kabaca and Tuzcuoglu, 2023, and di Giovanni et al., 2022 for euro area estimates). We add to this body of work by quantifying empirically the contribution of global supply chain pressure shocks to euro area inflation. Another related empirical contribution by Finck and Tillmann (2022) finds that a global supply chain shock leads to a significant increase in inflation and a drop in economic activity, using euro area data.[2] A more recent empirical study by Banbura et al. (2023) shows that global supply chains and gas price shocks have exhibited a much larger influence on euro area inflation during the COVID-19 pandemic than in the past.[3] Focusing on a panel of 29 countries in sub-Saharan Africa, Andriantomanga et al. (2022) study the impact of global supply chain pressures on domestic inflation and find that during the 2020-22 period they accounted for 45 and 55 percent of headline and tradable core inflation, respectively. Related work by Carrière-Swallow et al. (2022) investigates the impact of shocks to global shipping costs, as captured by the Baltic Dry Index (BDI), on domestic prices for a large panel of 46 countries during the period 1992-2021. They find that BDI surges are followed by sizable increases in domestic inflation and inflation expectations.

Second, our theoretical framework builds on the literature on global supply chain disruptions and the implications for monetary policy. Work by Ozdagli and Weber (2017), Pastén et al. (2020) and Ghassibe (2021), among others, shows that the existence of input-output linkages in production networks amplifies the effects of monetary policy shocks. This is because the presence of production networks creates strategic complementarities in firms' price setting. Our theoretical model is closely related to Gong et al. (2016).[4] They also study optimal monetary policy in a two-country New Keynesian model with international trade in intermediate inputs, but focus on the role of various degrees of price stickiness across different stages of production. They show that targeting the intermediate-goods price index of producers should be preferred by monetary policymakers when the intermediate-good price is highly sticky. Recent work by Wei and Xie (2020) investigates the implications of global supply chains for the design of optimal monetary policy using a small open economy New Keynesian model with multiple stages

[2]Note that Finck and Tillmann (2022) only focus on identifying global supply chain disruption shocks, whereas we opt for a full identification to disentangle between the main driving forces of the recent inflation surge.

[3]The main difference between our approaches is that they use a medium-sized BVAR model with a factor structure for the residuals (identifying 8 shocks in a relatively data-rich system of 17 variables). The underlying assumption in their setting is that the factors are the structural shocks, which are identified using sign and zero restrictions only.

[4]Compared to Gong et al. (2016), our model differs along two important dimensions: (i) they assume an elasticity of substitution between home and foreign final goods equal to one, while we relax this assumption in line with empirical evidence (see Feenstra et al., 2018), and (ii) they assume complete international markets and perfect international risk sharing. Both the trade elasticity and degree of international risk sharing have important implications for optimal monetary policy, which is why we focus on a range of trade elasticities and incomplete asset markets.

of production.[5] Their results imply that targeting producer price inflation yields a smaller welfare loss than targeting CPI inflation alone, since as the economy becomes more open and the production chain becomes longer, the optimal weight on upstream inflation rises relative to that on final stage inflation. Also related is Andriantomanga et al. (2022) who find that central banks can stabilize inflation and output more efficiently by monitoring global supply chains and preemptively adjust the monetary policy stance before these disruptions have fully passed through into all inflation components. The intuition behind this result is that by acting early, central banks dampen the second-round effects on both non-tradable inflation and expectations.[6] Nevertheless, research on how global supply chain disruptions affect the transmission mechanism of monetary policy has received less attention. Based on a nonlinear local projection framework, Laumer and Schaffer (2022) find that greater pressure on supply chains amplifies the standard effects of monetary policy on key macroeconomic variables. The authors argue that this is due to credit costs reacting more strongly to monetary policy shocks during times of supply chain distress.

Third, our paper is related to the literature on the impact of globalization on inflation. Studies like Auer et al. (2017), Auer et al. (2019) and Forbes (2019), for instance, investigate how global supply chains (and other global factors) affect domestic inflation dynamics. Their results imply that domestic inflation has become more sensitive to global factors, which might affect the central banks' ability to achieve price stability. We contribute to this strand of the literature by studying the role of openness and interconnectedness (i.e. a country's dependence on foreign intermediate goods for the production of domestic goods) for the conduct of (optimal) monetary policy.

Finally, our paper builds on the literature that studies supply chains or input-output linkages as an amplification mechanism for shocks (see Acemoglu et al., 2016; Carvalho and Tahbaz-Salehi, 2019; Acemoglu and Tahbaz-Salehi, 2020, among others). Global value chains are a key transmission channel of supply-side shocks, as demonstrated by the recent adverse effects of pandemic-related supply disruptions (see Frohm et al., 2021; di Giovanni et al., 2022). The role of global value chains in the international propagation of shocks is largely associated with their sticky nature, as shown by Monarch and Schmidt-Eisenlohr (2023) and Antràs (2020a). Korniyenko et al. (2017) document that interconnected countries producing goods with a high degree of substitutability are better positioned to withstand global chain disruptions. Related papers study the link between pervasive supply linkages and the co-movement of business cycles across countries. For example, De Soyres and Gaillard (2022) claim that economic activity across countries becomes more synchronized when the content of their trade is tilted towards imported intermediate goods as opposed to final goods, while Frohm and Gunnella (2021) argue that it

[5] Wei and Xie (2020) build on previous work, such as Shi and Xu (2007), Huang and Liu (2007), Lombardo and Ravenna (2014) and Matsumura (2022).

[6] In other words, for central banks with low credibility it is preferable to tighten their stance early to mitigate as much as possible second-round effects, even though this comes at the expense of a negative output gap. The authors argue that a tighter monetary policy is particularly effective in low-income open economies, where the share of tradable goods in the consumption basket is typically high and second-round effects are more likely to arise.

is not input-output linkages per se that generate spillovers across countries, but rather the presence of large hubs in the global economy that connect otherwise unrelated sectors.

The rest of the paper is organized as follows. Section 2 provides novel empirical evidence on the importance of global supply chain pressures for euro area inflation dynamics. In Section 3, we introduce our two-country New Keynesian model with trade in intermediate goods and examine the implications of global supply chain pressures for the design of optimal monetary policy. Finally, Section 4 concludes.

2 Empirical evidence

In this section, we report novel empirical evidence on the importance of global supply chain pressures for the dynamics of euro area inflation.[7] To this end, we primarily make use of the comprehensive Global Supply Chain Pressure Index (GSCPI) from Benigno et al. (2022), which is based on a large set of commonly used metrics that monitor supply constraints and provides a comprehensive summary of potential disruptions affecting global supply chains.[8,9]

We start by presenting several stylized facts about European countries' participation in global value chains in Section 2.1 to get a sense of the euro area's exposure to global supply chain disruptions. In Section 2.2, we study the relationship between euro area inflation and global supply chain pressures through the lens of a standard Phillips curve. Finally, in Section 2.3 we take a more structural approach and use a Bayesian vector autoregressive (BVAR) model to identify shocks to global supply chain pressures and estimate their impact on euro area inflation.

2.1 Participation in global value chains

An economy's exposure to global supply chain snarls depends, among other things, on the extent to which a country is integrated into global value chains (GVCs). Therefore, we start by looking at the share of imported intermediate inputs in total imports and in total (domestic and foreign) intermediate inputs as two straightforward measures of a country's participation in GVCs. Figures 2.1 and 2.2, panel *a*, report these shares, and how they evolved over time, for a number of major euro area countries (Germany, France, Italy, Spain and the Netherlands), as well as the United States, China, the EU28 average (which includes the United Kingdom) and the OECD average.

Both figures point to elevated participation in GVCs across advanced economies. Participation also appears to co-move strongly across countries, especially among euro area countries. Furthermore, par-

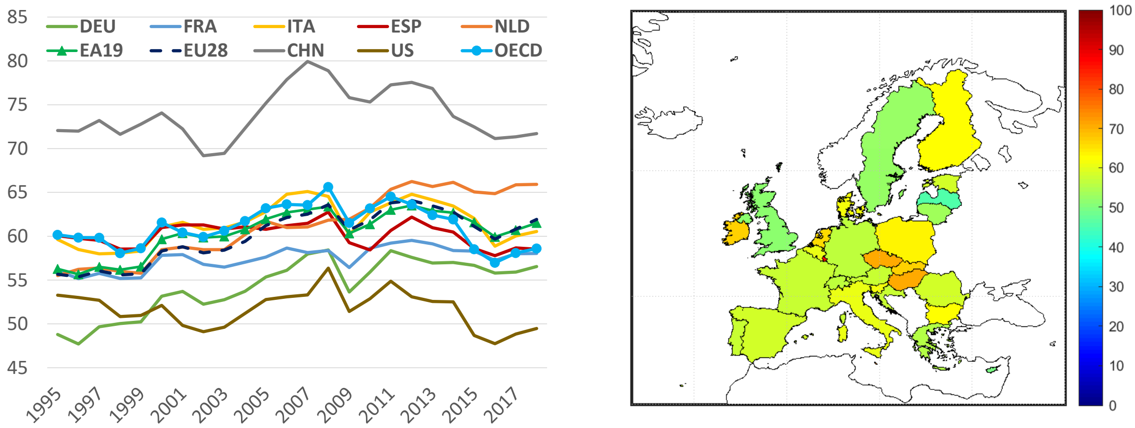
[7] Throughout, we use the terms 'global supply chain pressures', 'global supply disruptions' and 'supply bottlenecks' interchangeably.

[8] The GSCPI is based on two sets of indicators, which we briefly discuss in Appendix A. More details regarding the methodology and data used to construct the GSCPI are available at the Federal Reserve Bank of New York, using the following link.

[9] There are various approaches to proxy supply chain disruptions and therefore several alternative indices, based on, for example: (i) satellite data on congestion at container ports (Bai et al., 2023), (ii) Google searches (Bernanke and Blanchard, 2023), (iii) newspaper data (Burriel et al., 2023), (iv) shipping costs (Carrière-Swallow et al., 2023).

Figure 2.1: Share of intermediate imports in total imports (%)

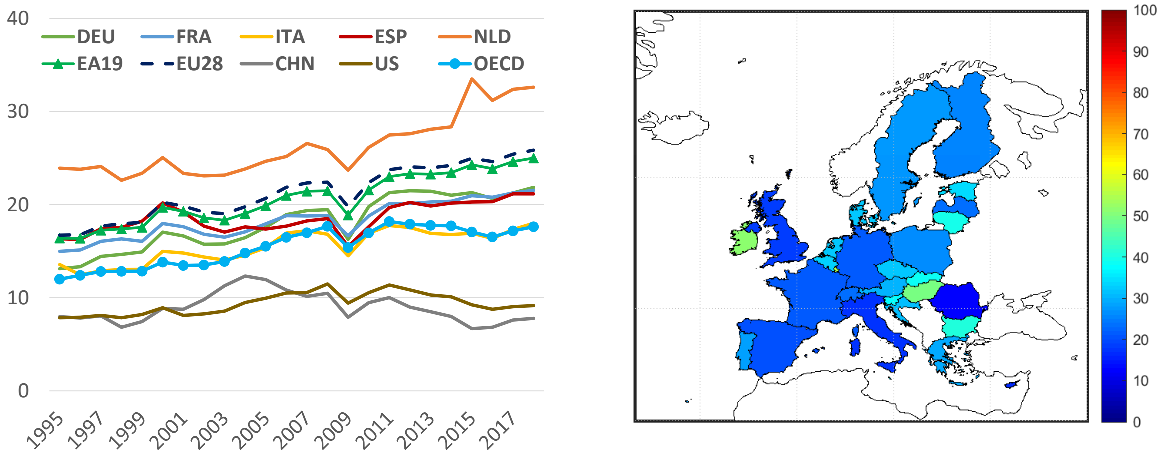
(a) Advanced economies, 1995-2018 **(b)** European countries, 2018



Source: OECD, TiVA 2021 edition (last year available is 2018).

Figure 2.2: Share of intermediate imports in total intermediate inputs (%)

(a) Advanced economies, 1995-2018 **(b)** European countries, 2018



Source: OECD, TiVA 2021 edition (last year available is 2018).

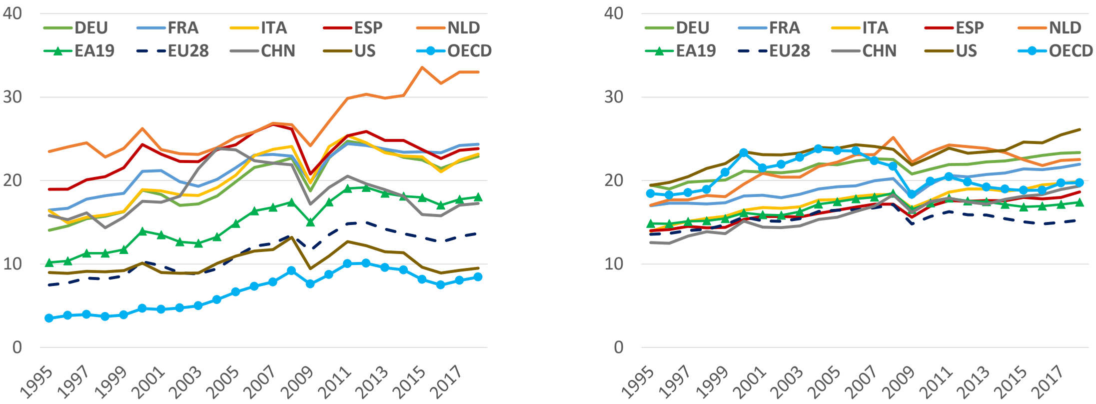
ticipation trended upwards before the onset of the global financial crisis (GFC) and stabilized (or, in some cases, slightly declined) thereafter. This trend break could reflect a rise in labor costs observed in key emerging market economies and firms' re-evaluation of risks associated with long supply chains.[10] In panel b of both figures, we zoom in on the European countries in 2018, the most recent year for which data is available. On average across these countries, the share of imported intermediate inputs in total imports is 61%, indicating significant exposure to global supply disruptions. Similarly, the European average share of imported intermediate inputs in total intermediate inputs is around 26%. These figures will inform us later on when we calibrate the trade parameters of the two-country New Keynesian model.

In Figure 2.3, we consider two alternative measures of participation in GVCs. Panel a reports the

[10]The notable decline in China's participation in GVCs can partly be explained by a gradual shift in demand towards services, which are generally less trade-intensive than goods.

Figure 2.3: Alternative measures of participation in Global Value Chains

(a) Backward Global Value Chain participation (%)   **(b)** Forward Global Value Chain participation (%)



Notes: Panel *a* represents the foreign value added embodied in exports, as a share of total gross exports of the exporting country (often referred to as backward or downstream GVC participation). Panel *b* captures domestic value added embodied in foreign exports, as a share of total gross exports of the value added source country (frequently referred to as forward or upstream GVC participation). *Source*: OECD, TiVA 2021 edition (last year available is 2018), own computations.

foreign value added content of exports (as a share of total gross exports of the exporting country), which is typically referred to as backward or downstream GVC participation. Panel *b* shows the domestic value added content of exports (as a share of total gross exports of the value added source country), which can be used as a measure of forward or upstream GVC participation. While stronger backward GVC linkages suggest higher exposure to foreign supply shocks, affecting vendors of raw materials and intermediates along the GVC, stronger forward GVC linkages typically indicate greater exposure to demand shocks originating from final consumers or distributive services abroad.

There appears to be more heterogeneity across countries in terms of backward GVC participation than forward GVC participation, with the euro area economies being more vulnerable to foreign supply shocks than the other advanced economies in our sample. Again, both alternative measures of GVC participation exhibit an upward trend before the GFC and a leveling off thereafter. Two natural disasters in 2011 (i.e. the Tōhoku earthquake and Thailand flooding) triggered supply chain bottlenecks in the car manufacturing sector and exposed the vulnerabilities of long supply chains and a lack of transparency along these value chains. Consequently, some companies shortened their supply chains in an attempt to limit (risks to) supply chain bottlenecks, which led to a reduction in GVC participation (OECD, 2013). However, foreign value added in trade actually increased between 2016 and 2018, suggesting that this 'GVC shrinkage' was temporary. We therefore conclude that global supply chains currently remain economically meaningful, especially within the euro area, which warrants closer examination into how shocks to global supply chain disruptions are transmitted to the domestic economy.[11]

[11] We should note that the unprecedented global supply chain disruptions unleashed by the COVID-19 pandemic (and possibly exacerbated by the Russian invasion of Ukraine) could lead to a reduction in GVC participation, as firms might reassess and reduce their exposure to supply chain risks (Antràs, 2020b). Nevertheless, as argued by Miroudot (2020) and Eppinger et al. (2021), reducing participation in GVCs does not necessarily imply increased robustness of supply chain arrangements.

Table 2.1: Estimates of the euro area Phillips curve

Dependent variable	(1) Headline HICP	(2) Core HICP	(3) Headline HICP	(4) Core HICP
Industrial production	0.011***	0.004**	0.012***	0.05***
	[0.004]	[0.002]	[0.004]	[0.008]
1-year ahead inflation expectations	0.06	0.038	0.109**	0.79*
	[0.049]	[0.03]	[0.049]	[0.102]
GSCPI			**0.095*** **	**0.379*** **
			[0.023]	[0.049]
Adjusted R-squared	0.976	0.95	0.978	0.885
BIC	122.94	-62.45	105.67	473.38
Obs.	221	221	221	221

Notes: Core HICP is proxied by HICP excluding energy. All variables expressed as y-o-y % changes, except for the GSCPI (standard deviation from mean). *, ** and *** indicate significance at 10%, 5% and 1%. Standard errors reported in brackets. Estimates of the constant and the coefficient on the lags of the dependent variable are omitted. The estimation sample is 2005M4-2023M8.

2.2 Global supply chain pressures and inflation dynamics

We quantify the relationship between global supply chain pressures and euro area inflation by estimating an otherwise standard Phillips curve that includes the GSCPI as an additional explanatory variable. This approach can be thought of as isolating the impact on domestic inflation of changes in relative international prices due to global supply chain disruptions. In that sense, our version of the Phillips curve relates to that of an open economy New Keynesian model in which foreign intermediate goods are used in the production of domestic goods, as in Eyquem and Kamber (2014) and Gong et al. (2016) (see also Section 3).

As our dependent variable, we consider both the headline Harmonized Index of Consumer Prices (HICP) and core HICP, which excludes energy prices. The explanatory variables are industrial production (as a measure for economic slack), the 1-year-1-year inflation swap rate (as a measure of inflation expectations) and three lags of the dependent variable. All variables are expressed as year-over-year percent changes, except for the GSCPI, which is scaled by its standard deviation. The data is monthly and covers the period 2005M4-2023M8.[12]

Table 2.1 reports our estimates of the euro area Phillips curve, with and without the GSCPI. Two results stand out. First, the coefficient on the GSCPI is positive and statistically significant, suggesting that global supply disruptions are an important factor driving euro area inflation. Since the GSCPI, despite it being a global factor, might endogenously respond to changes in euro area economic conditions, we stress that we do not claim to have found a causal relationship, but merely that we find evidence of a strong co-movement between the GSCPI and euro area inflation. Second, while the slope of the Phillips curve for core inflation is positive and significant in both specifications, it is estimated to be

[12] Our results are robust to using alternative measures for economic slack (i.e. the PMI) and inflation expectations (i.e. 1-year ahead consumer inflation expectations or the 5-year-5-year inflation swap rate), alternative lag structures, adding commodity prices, oil prices, the real effective exchange rate or the world industrial production index as additional controls, restricting the coefficients on the lags of the dependent variable to sum up to 1, and running the estimations on the pre-COVID-19 sample.

almost flat in the baseline without the GSCPI and much steeper in the alternative specification which includes the GSCPI.[13] This suggests that controlling for global supply chain pressures, and potentially other external factors, can lead to a more accurate identification of the relationship between domestic inflation and domestic demand pressures, and thereby prevent the erroneous conclusion that the Phillips curve has flattened (Forbes, 2019).

2.3 The effects of global supply chain pressure shocks

In addition to the (short-run) relationship between global supply chain pressures and inflation, as captured by the Phillips curve, we are also interested in the effects of shocks to global supply chain pressures on inflation. We identify these shocks using a structural BVAR model. The model is estimated using the following aggregate euro area variables: industrial production, core inflation (based on the HICP excluding energy), the Krippner's shadow rate estimate (as an indicator for the European Central Bank's effective monetary policy stance),[14] the real effective exchange rate (with respect to the euro area's 42 main trading partners) and the real price of oil Brent (deflated with HICP). This set of endogenous variables is augmented with the GSCPI time series to help us account for (shocks to) global supply chain pressures. All variables are expressed as year-over-year percent changes, except for the interest rate (which is included in levels) and the GSCPI (which is scaled by its standard deviation). We use monthly data starting in January 2000 until July 2023.[15]

Following the approach proposed by Antolín-Díaz and Rubio-Ramírez (2018), we use sign, zero and narrative sign restrictions to identify global supply chain pressure shocks and distinguish them from domestic supply and demand (and other) shocks. This exercise thereby helps us to obtain novel estimates of the euro area inflation response to global supply shocks, which is the main focus of this paper, but also to inform about the relative importance of these shocks versus that of other shocks in driving the recent burst in euro area inflation. The latter is a key input in the design and evaluation of monetary policy.

2.3.1 A Bayesian VAR model with sign, zero, and narrative restrictions

Following Antolín-Díaz and Rubio-Ramírez (2018)'s notation, we are interested in the structural vector autoregression (SVAR) with the following general specification

$$\mathbf{y}_t'\mathbf{A}_0 = \sum_{\ell=1}^{p} \mathbf{y}_{t-\ell}'\mathbf{A}_\ell + \mathbf{c} + \varepsilon_t' \quad \text{for } 1 \leq t \leq T, \tag{2.1}$$

where $\mathbf{y}_t$ is our $n \times 1$ vector of endogenous variables (with $n = 6$), ε_t is an $n \times 1$ vector of structural

[13]The results from the Phillips curve analysis are robust to removing the pandemic era and subsequent high-inflation episode from the sample.

[14]Our results are robust to using the 10 years OIS rate as an alternative measure for the ECB's monetary policy stance.

[15]Appendix A provides a detailed description of the data.

shocks, $\mathbf{A}_\ell$ is an $n \times n$ matrix of parameters for $0 \leq \ell \leq p$, $\mathbf{c}$ is a $1 \times n$ vector of parameters, p is the lag length and T is the sample size. $\mathbf{A}_0$ is an invertible $n \times n$ matrix which contains the contemporaneous relationships among the endogenous variables. Conditional on past information and the initial conditions $\mathbf{y}_0, \ldots, \mathbf{y}_{1-p}$, the vector ε_t is assumed to follow a Normal distribution with mean zero and covariance matrix $\mathbf{I}_n$ (the identity matrix of size n). The model described in equation (2.1) can be rewritten in compact form as follows

$$\mathrm{y}'_t \mathbf{A}_0 = \mathrm{x}'_t \mathbf{A}_+ + \varepsilon'_t \quad \text{for } 1 \leq t \leq T, \tag{2.2}$$

where $\mathbf{x}_t$ is a $(np+1) \times 1$ vector defined as $\mathbf{x}'_t = \left[1, \mathbf{y}'_{t-1}, \ldots, \mathbf{y}'_{t-p}\right]$ for $1 \leq t \leq T$ and $\mathbf{A}'_+ = \left[\mathbf{c}' \ \mathbf{A}'_1 \cdots \mathbf{A}'_p\right]$ of dimension $(np+1) \times n$. The reduced-form VAR model that we estimate follows the common specification:

$$\mathbf{y}'_t = \mathrm{x}'_t \mathbf{B} + \mathbf{u}'_t \quad \text{for } 1 \leq t \leq T, \tag{2.3}$$

where $\mathbf{B} = \mathbf{A}_+ \mathbf{A}_0^{-1}, \mathbf{u}'_t = \varepsilon'_t \mathbf{A}_0^{-1}$ and $E\left[\mathbf{u}_t \mathbf{u}'_t\right] = \left(\mathbf{A}_0 \mathbf{A}'_0\right)^{-1} = \mathbf{\Sigma}$. Note that matrices $\mathbf{B}$ and $\mathbf{\Sigma}$ contain the reduced-form parameters, while $\mathbf{A}_0$ and $\mathbf{A}_+$ contain the structural parameters, summarized by $\Theta = (\mathbf{A}_0, \mathbf{A}_+)$.

The data-driven VAR model is estimated using 12 lags ($p = 12$), a constant and Bayesian techniques.[16] In particular, we use standard Minnesota priors, which are commonly used in the literature.

The SVAR model in equation (2.1) is not identified and, therefore, we have to impose restrictions on the structural parameters to solve the identification problem.[17] We identify six shocks: a domestic demand shock, a domestic supply shock, a global supply shock, a monetary policy shock, an exchange rate shock and an oil price shock. Our identification strategy relies on sign, zero and narrative restrictions, which we discuss below.

Sign restrictions (imposed on impact): The sign restrictions, that we impose on the impact responses only, are in line with economic theory and shown in Table 2.2 (see first panel). A positive domestic demand shock is identified as a shock that raises industrial production growth, core inflation and the interest rate. A negative domestic (cost-push) supply shock lowers industrial production growth, raises core inflation and leads to a decline in the real price of oil. A negative shock to global supply implies a rise in both the GSCPI and core inflation, and a fall in industrial production.[18] A contractionary monetary policy shock leads to a fall in both industrial production and core inflation. A positive shock to the real exchange rate (i.e. an appreciation) lowers both industrial production and core inflation, while

[16] Our results are robust to using an alternative 6 lag structure.

[17] For a comprehensive discussion on using only sign restrictions to deal with the identification problem, see Section 3 in Antolín-Díaz and Rubio-Ramírez (2018).

[18] As we discuss in Section 3, a shock to global supply chain pressures could result in an expansion of domestic output if GVC participation is sufficiently low. However, given the evidence presented in Figures 2.1 and 2.2, we think it is reasonable to assume that euro area GVC participation is large enough for global supply chain pressure shocks to exert a negative impact on domestic output (see Banbura et al. (2023) for a similar conjecture for euro area data).

Table 2.2: Restrictions imposed to identify the structural shocks

I. Sign/Zero restrictions (on impact)	Demand	Supply cost-push	**Global supply**	Monetary policy	Exchange rate	Oil
Industrial production (y-o-y % change)	+	−	−	−	−	−
HICP excl. energy (y-o-y % change)	+	+	+	−	−	
GSCPI (std. dev from mean)	0	0	+	0		
Shadow rate (%)	+			+	−	
REER 42 partners (y-o-y % change)					+	
Real oil price (y-o-y % change)		−				+

Notes: An entry with +/-/0 denotes a positive/negative/no contemporaneous response of the variable (rows) to the specific structural shock (columns). An empty cell implies an unrestricted response.

II. Narrative sign restrictions	Demand	Supply cost-push	**Global supply**	Monetary policy	Exchange rate	Oil
Sign of shocks						
1. Demand	− March-April 2020					
2. Global supply			+ March 2011 & March 2021 & April 2022			
3. Oil						+ March 2003 & February 2011 & March 2022
Largest contribution to						
4. GSCPI forecast errors			March 2011 & April 2020 & November 2021			
5. Real oil price forecast errors						March 2022

the monetary authority reacts by cutting the short term interest rate to stabilize the economy. Finally, we conjecture that the real price of oil increases and industrial production falls following an adverse oil supply shock.[19] We deliberately leave the impact response of HICP excluding energy unrestricted, since we believe that an increase in oil prices might affect core inflation with a lag through second-round effects.

Zero restrictions: Moreover, we add three zero restrictions, i.e. the GSCPI does not react contemporaneously following a domestic demand shock, domestic supply cost-push or a monetary policy shock.[20] These restrictions are justified by the global nature of the GSCPI.

Narrative restrictions: In addition to these sign restrictions, we impose 12 narrative restrictions to further discipline the parameter space and help sharpen inference (see Table 2.2, second panel). As explained by Antolín-Díaz and Rubio-Ramírez (2018), these narrative restrictions shrink the admissible set of structural parameters by ensuring that around several key historical events (e.g. the GFC, Tōhoku earthquake and COVID-19 pandemic) the structural shocks and historical decomposition align with the established narratives.

First, we assume that global supply chain shocks have a positive value in March 2011, March 2021 and April 2022. The first event is informed by the exogenous disruption to global supply chains following the Tōhoku earthquake and tsunami in Japan on March 11 (for more details, see Section 2.1). The other two events are related to the Suez Canal Obstruction on 23 of March 2021 and the Shanghai Backlog on 5 of April 2022 (for a detailed discussion, see Finck and Tillmann, 2022). We also use the natural disaster

[19] Note that we use additional narrative restrictions to properly distinguish between global supply chain pressures and oil price shocks (see below).

[20] As a robustness check, we additionally impose that a global supply chain shock has no contemporaneous impact on oil prices. This extra zero restriction ensures that the sign and zero restrictions are sufficient to distinguish global supply disruption shocks from oil-related forces. The impulse responses following a global supply chain pressure shock are reported and discussed in Appendix B (Figure B.2).

in Japan to impose that global supply chain shocks are the most important contributor to the observed unexpected movements in the GSCPI in March 2011. Specifically, the absolute value of the global supply chain shock's contribution is larger than the absolute value of the contribution of any other structural shock. Moreover, shocks to global supply chain pressures are also assumed to be the main driver of the unexpected GSCPI spikes in April 2020 and November 2021. Similarly, these restrictions imply that in these periods the absolute value of the global supply chain shock's contribution to the unexpected change in the GSCPI is larger than the absolute value of the contribution of any other structural shock. Choosing these two key pandemic-related events is motivated by the unprecedented surges in the GSCPI (see Figure 1.1), attributable to (i) the onset of the COVID-19 health crisis and (ii) the new wave of COVID-19 cases, in the winter of 2021, which further intensified the already wide-spread supply bottlenecks. Second, following Antolín-Díaz and Rubio-Ramírez (2018), we exploit disruptions in the oil market caused by geopolitical conflicts to pin down oil-related shocks. Therefore, we conjecture that oil shocks have a positive sign in March 2003 (outbreak of the Iraq War) and February 2011 (outbreak of the Libyan Civil War) and March 2022 (Russia's invasion of Ukraine). Furthermore, we also assume that oil shocks are the main driver of the unexpected oil price jump in March 2022, motivated by the Russia's invasion of Ukraine.[21] Finally, we conjecture that demand shocks have a negative sign in March and April 2020, motivated by the onset of the COVID-19 pandemic.

We show and discuss in Appendix B the key role played by the narrative restrictions to properly identify the global supply chain shocks (see Figure B.4).[22]

2.3.2 Responses to global supply chain pressure shocks

The responses of euro area core inflation to a negative global and domestic supply shock are shown in Figure 2.4. While both types of shocks have a positive impact on core inflation, we find that the response to the domestic supply shock (right panel) is rather short lived, whereas the response to the global supply shock (left panel) is more persistent and hump-shaped.[23] In particular, the effect of the domestic cost-push shock on core inflation is positive on impact, but gradually diminishes thereafter, becoming statistically insignificant (in Bayesian terms) after four months. Conversely, the positive effect of the global supply chain pressure shock slowly builds up, peaks after two years and persists for more

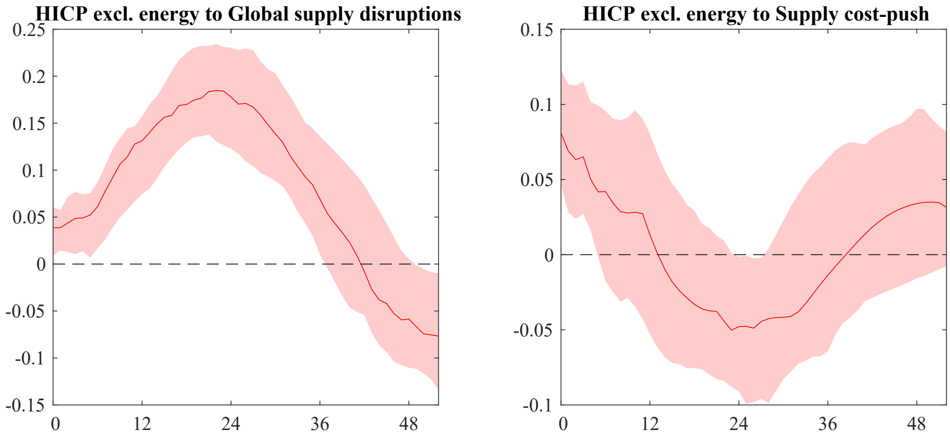
[21] This restriction implies that in March 2022 the absolute value of the oil shock's contribution to the unexpected change in the oil price is larger than the absolute value of the contribution of any other structural shock.

[22] For example, see similar discussions for the euro area and the US in related empirical work by Finck and Tillmann (2022) and Kabaca and Tuzcuoglu (2023), respectively. Moreover, we check ex-post if the estimated GSCPI shock is correlated with euro area demand or supply shocks, since this is relevant for our proposed identification strategy. The corresponding correlation coefficients between the estimated median value of global value chain shocks and domestic demand and supply shocks are very low: 0.06 and 0.028, respectively.

[23] Using a BVAR model for euro area, De Santis (2024) also finds that the impact of adverse supply chain disruption shocks on core HICP is rather strong and persistent, while the effect is muted and transitory following energy supply shocks (in line with our results, see Figure B.3). Moreover, a similar result for US headline PCE inflation has been obtained (using a local projection model) by staff research at the Federal Reserve Bank of San Francisco, see link.

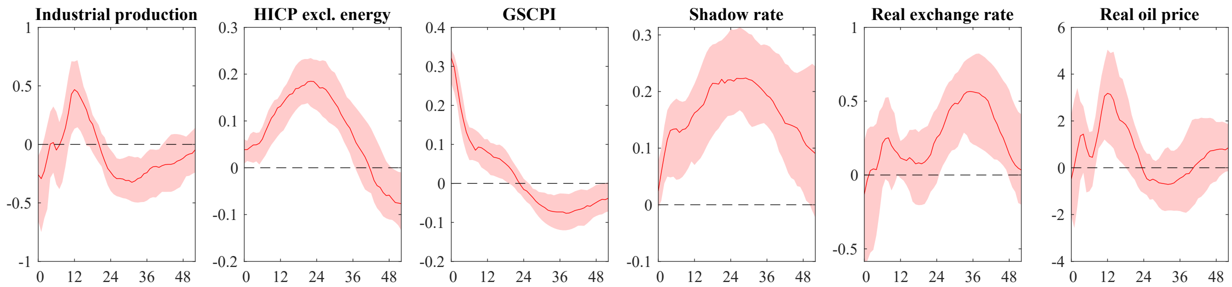
than three years.[24] These dynamics can be attributed to the slow response to global supply bottlenecks of prices along the different stages of production (see Gong et al., 2016). Moreover, firms' limited ability to establish new supply chains in the short term (and at low cost) and the presence of second-round effects that further raise input costs at the aggregate level cause global supply bottlenecks to strongly feed through to domestic inflation over time. The highly persistent nature of global supply chain pressure shocks implies that, even as global supply disruptions have been receding, they may continue to add to inflationary pressures for some time.

Figure 2.4: Response of core inflation to global and domestic supply shocks



Notes: The figure shows the response of euro area core inflation (based on the HICP excluding energy) to a one standard deviation global supply chain pressure shock (left panel) and to a one standard deviation domestic supply cost-push shock (right panel). The solid red line reports the median response. Shaded areas represent the 68% probability bands. The horizontal axis is time, measured in months.

Figure 2.5: Macroeconomic responses following global supply chain pressure shocks



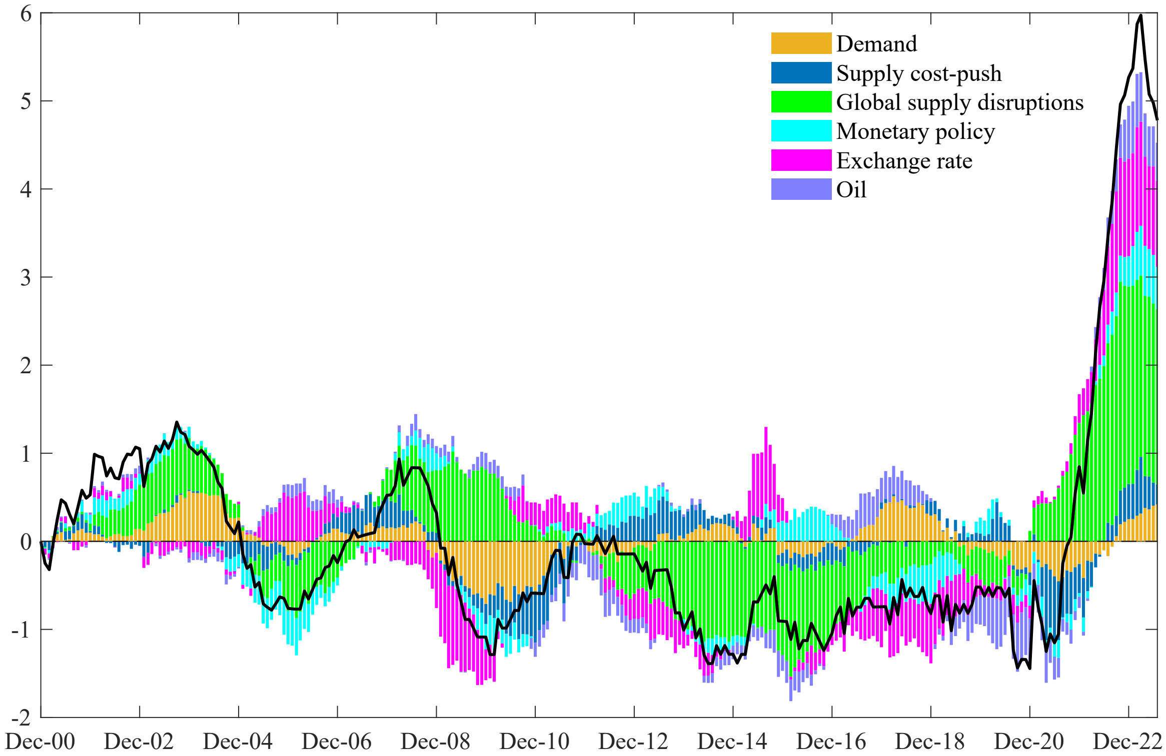
Notes: The figure shows the responses to a one standard deviation global supply chain pressure shock. The solid red line reports the median response. Shaded areas represent the 68% probability bands. The horizontal axis is time, measured in months.

Figure 2.5 reports the responses of the other endogenous variables following a global supply chain pressure shock.[25] The real exchange rate gradually appreciates over time, likely reflecting an expenditure-switching effect towards domestically produced goods as imported goods become relatively more expensive due to the global supply shock. Although this effect positively impacts domestic output, industrial

[24] Given the heterogeneity across euro area countries in terms of their reliance on global value chains, we report in Appendix D the response of core inflation to global and domestic supply shocks for two European countries which are differently exposed to GVCs, i.e. Germany and the Netherlands, and show that they are similar to our baseline results based on the aggregate EA economy (see Figure D.1).

[25] For completeness, we report the macroeconomic responses to the other structural shocks in Appendix B (see Figure B.1).

Figure 2.6: Historical shock decomposition of euro area core inflation



Notes: The bars show the contributions (percentage points) of the identified shocks to core inflation over time. Core inflation measured by y-o-y % change of HICP excluding energy. Units expressed as deviations from mean.

production (our proxy for economic activity) undergoes a significant (in Bayesian terms) and pronounced decline, mainly owing to the euro area's high degree of participation in GVCs and exposure to foreign supply shocks.[26] The response of the shadow interest rate is positive, implying that monetary policy tightens in response to global supply chain pressures and the ensuing rise in inflation, despite the contraction in economic activity. In section 3, we investigate theoretically the optimal monetary policy response to inflation induced by global supply chain disruptions, exploring the factors that determine the trade-off between stabilizing inflation and output. Finally, the real oil price's response is positive (in the short run), which could reflect shortages in the European energy markets as a result of global supply disruptions, such as natural disasters. We show in Appendix E that our results are robust to removing the COVID-related period and the subsequent high-inflation episode from the estimation sample (see Figure E.1).

2.3.3 Decomposing euro area core inflation

Figure 2.6 displays the contributions of the identified shocks to core inflation over time, expressed in deviations from its unconditional mean.[27] Several episodes stand out. First, in the run-up to the GFC,

[26]In Appendix C, we use a local projection model to estimate the response of euro area aggregate unemployment to the global supply chain pressure shocks obtained from our baseline BVAR model. We find that unemployment rises in response to the global supply chain pressure shock, but only in the long run.

[27]We report and discuss the historical shock decomposition of euro area industrial production in Appendix C, which provides supportive evidence that the estimated global supply chain pressure shocks resemble supply shocks.

while most shocks pushed euro area inflation above its mean, shocks to global supply chain pressures contributed negatively and thereby mitigated the buildup of inflationary pressures. In the aftermath of the GFC and during the European sovereign debt crisis, we observe the opposite, with demand shocks exerting significant downward pressures on inflation and global supply chain disruptions raising inflation. The latter most likely reflects the consequences of a collapse in international trade, the ensuing decline in GVC participation and two natural disasters that occurred in 2011 (i.e. the Tōhoku earthquake and Thailand flooding) that resulted in supply chain bottlenecks in the auto and electronics manufacturing sectors.

Second, during much of the post-crisis period (from 2014 to 2019), inflation persistently fell below the ECB's medium-term target, which in various cases was driven by most of the structural shocks. In response, the ECB moved its key policy rate below zero (up to -0.5% in September 2019) in an attempt to stimulate aggregate demand. Our results show that, on the back of a globalization trend (that lasted until the China-US trade disputes of 2017-18), favorable shocks to global supply chains played an important role in driving down euro area inflation. This result is consistent with the narrative that the effects of expansionary (domestic) monetary policy on inflation may have been partially offset by structural external forces that drove down inflation and which were outside the central bank's (immediate) control.[28]

Third, the COVID-19 pandemic unfolded as a combination of supply and demand shocks rippling through the global economy in overlapping waves. During the health crisis, supply chain disruptions and production bottlenecks became a major challenge for the global economy. The interplay between lockdowns, mobility restrictions, broad-based factory closures and, eventually, a strong rebound in global demand for manufacturing goods resulted in bottlenecks, shipping cost surges and prolonged delivery times. Our model suggests that since December 2020, shocks to global supply chain pressures had a steady and growing positive contribution to core inflation dynamics. This contribution mounted to 65% in April 2022 (its peak), reflecting the persistent effects of global supply chain pressure shocks. Starting with mid-2022, the global supply chain pressures index has been gradually easing (see Figure 1.1), reaching its lowest value in May 2023 (primarily driven by significant downward contributions from Great Britain backlogs and Taiwan delivery times). Since June 2023, the GSCPI has been fluctuating around 1 standard deviation below its historical mean. As a result of these developments, the contribution of global supply chain pressure shocks to inflation steadily diminished to about 40% by mid-2023. However, despite this reduction, global supply chain pressure shocks continue to exert a dominant influence on inflation compared to other shocks. Inflation dynamics were also significantly influenced by adverse oil shocks, which feature prominently in the decomposition of euro area core inflation. They explain about 12% of non-energy inflation fluctuations towards the end of 2022, as energy prices in Europe surged in the

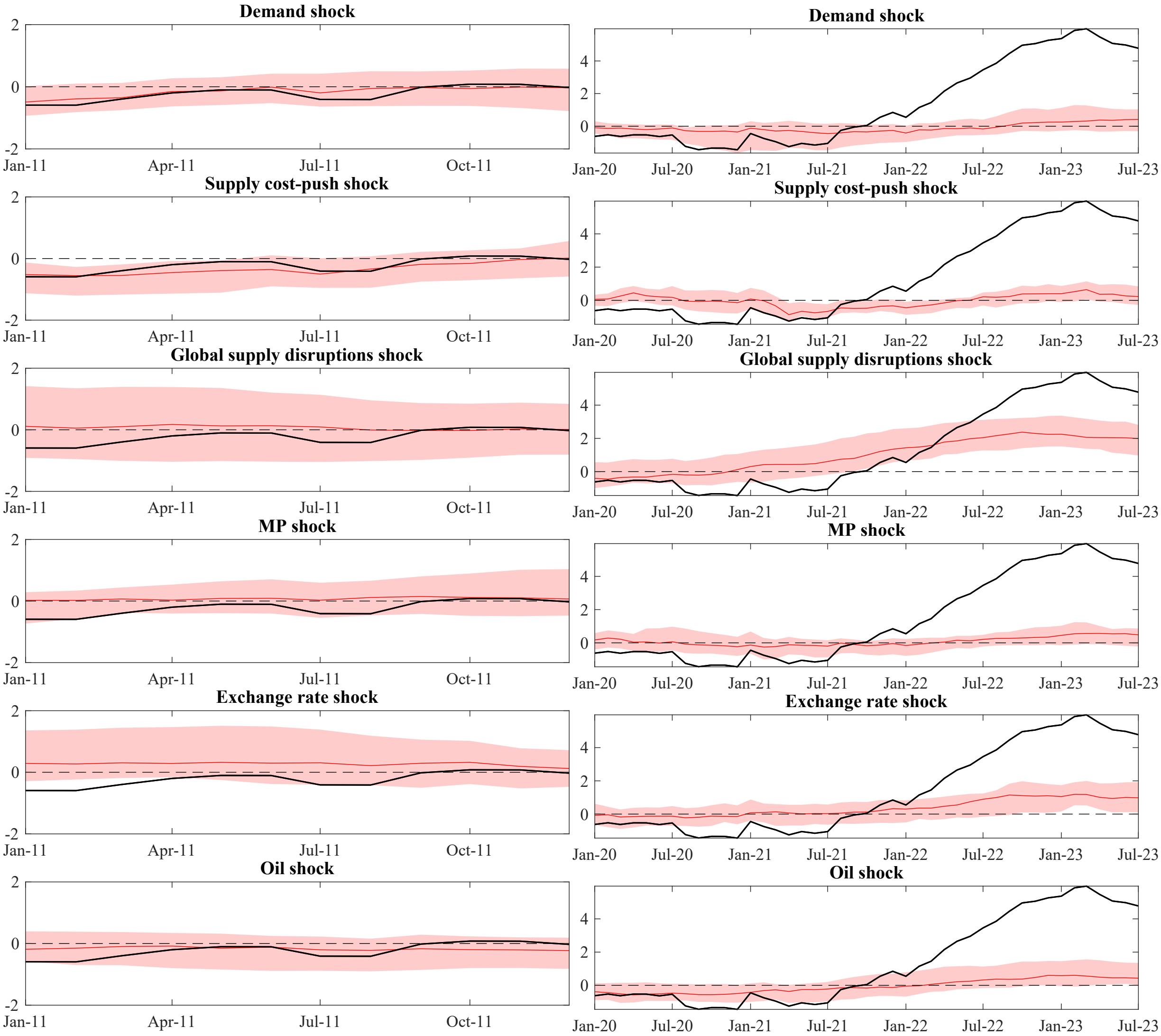
[28] See for example Auer et al. (2017), Auer et al. (2019) and Forbes (2019), among others.

context of the Russian invasion of Ukraine (with Russia's decision to suspend gas deliveries to several EU member states further amplifying this problem).[29] Inflationary pressures in 2022 also stemmed from sizeable negative shocks to the exchange rate (i.e. a depreciation of the euro) and positive aggregate demand shocks, as lockdowns and containment measures were lifted, consumer demand recovered and many sectors resumed their activities. The contribution of domestic supply shocks, which accounted for about 10% of the overall core inflation increase (above its unconditional mean) towards end-2022 and early-2023, owing to soaring food prices and relatively tight labor market conditions, has been steadily declining thereafter.

Figure 2.7: Historical decomposition of core inflation around two selected episodes

(a) Two natural disasters

(b) COVID-19 pandemic



Notes: The two panels display the observed unexpected fluctuations in core inflation attributed to each of the structural shocks for two selected historical episodes: (i) two natural disasters which occurred in 2011, i.e. the Tōhoku earthquake (and the resulting tsunami) in March and the Thailand flooding (panel *a*), and (ii) the COVID-19 pandemic (panel *b*). The observed unexpected change is represented by the solid black line. The solid red lines report the median for our baseline identification (sign, zero and narrative) restrictions, while the pink shaded area represents the 68% (point-wise) probability bands.

[29] Russia's invasion of Ukraine in early 2022 further fuelled commodity prices, leading to an unprecedentedly high euro area energy inflation rate of 44.3% year-on-year in March 2022.

Next, we focus on two selected episodes during which the GSCPI surged, i.e. 2011 and 2020-2023, and report the observed unexpected fluctuations in core inflation attributed to each of the structural shocks.

Figure 2.7, panel *a*, zooms in on the year 2011, which witnessed two natural disasters: (i) the Tōhoku earthquake (and subsequent tsunami) in March, which impaired production networks in Japan and surrounding regions that served as a crucial hub for automobile manufacturing, and (ii) the Thailand flooding, which affected seven of the country's largest industrial estates and disrupted the global production chains of the auto and electronics industries. As discussed previously, we imposed two narrative restrictions around the Tōhoku earthquake (and the resulting tsunami) in March 2011 (see Table 2.2, second panel). Shocks to global supply disruptions seem to have exerted upward pressure on euro area core inflation. During that period, fluctuations in core inflation attributed to global supply chain pressure shocks alone amounted, on average, to about 0.1-0.2 percentage points (see third plot in panel *a*), although not statistically significant (in Bayesian terms), and fading towards the second half of 2011. Except for the real exchange rate depreciation, which added to the inflationary pressures, all other shocks had a negative or relatively muted contribution to core inflation fluctuations throughout 2011.

In panel *b*, we examine the COVID-19 pandemic. The structural shock capturing global supply disruptions was a particular strong driver of euro area inflationary pressures once economic activity started to resume in 2021 and consumption (mostly oriented towards goods) rebounded on the back of excess savings. Broad-based supply shortages and disruptions in the logistics industry made it difficult for many goods producers to keep up with the surge in consumer demand, resulting in bouts of supply-driven inflation. Towards the end of 2022, fluctuations in non-energy inflation attributed to global supply chain pressure shocks alone amounted, to about 2.4 percentage points (see third plot in panel *b*). As expected, the adverse oil shock in the context of Russia's military invasion of Ukraine shows prominently as an important driver in explaining non-energy inflation fluctuations. Further, note that since September 2022, through the lens of our BVAR model, all shocks exerted upward pressure on euro area inflation.

3 Implications for monetary policy

We further examine the effects of global supply chain pressures on domestic inflation and their implications for (optimal) monetary policy using a New Keynesian model for two countries, **H**ome and **F**oreign, in the spirit of Benigno (2009). The population size of Home relative to Foreign is governed by the parameter $s \in [0, 1]$. Following Eyquem and Kamber (2014) and Gong et al. (2016), we allow for foreign intermediate goods to be used as inputs in the production of domestic final goods, in addition to domestic intermediate goods. We consider the share of foreign intermediate inputs used in domestic production as a (reduced-form) measure of the country's participation in GVCs and, thereby, its exposure to global supply chain disruptions. In section 3.1, we provide more details on the building blocks of the model. For brevity, we only focus on the Home country, and denote Foreign variables with an asterisk superscript.[30] In section 3.2, we perform numerical simulations and discuss the implications of global supply chain pressures for the conduct of monetary policy.

3.1 Model description

3.1.1 Households

Household consumption, c_t, is a bundle of domestically produced Home final goods, $c_{H,t}$, and imported Foreign final goods, $c_{F,t}$:

$$c_t = \left[(1-\mu)^{\frac{1}{\eta}} (c_{H,t})^{\frac{\eta-1}{\eta}} + \mu^{\frac{1}{\eta}} (c_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{3.1}$$

where $\mu \in [0,1]$ denotes the import share in consumption expenditures, which is related to the size of Home relative to Foreign and the degree of home bias, and $\eta > 1$ the elasticity of substitution between Home and Foreign final goods. The demand schedules corresponding to $c_{H,t}$ and $c_{F,t}$, and the consumer price index (CPI) P_t are given by:

$$c_{H,t} = (1-\mu)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} c_t, \tag{3.2}$$

$$c_{F,t} = \mu\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} c_t, \tag{3.3}$$

$$P_t = \left[(1-\mu) P_{H,t}^{1-\eta} + \mu P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{3.4}$$

where $P_{H,t}$ and $P_{F,t}$ denote the producer price index (PPI) of Home and Foreign (denominated in Home currency). Let $q_t \equiv e_t P_t^* / P_t$ be the real exchange rate, with e_t the nominal exchange rate (i.e. the price of one unit of Foreign currency in terms of Home currency). Assuming the law of one price holds then implies $P_{H,t} = e_t P_{H,t}^*$ and $P_{F,t} = e_t P_{F,t}^*$. The domestically produced final consumption good, $c_{H,t}$, is a composite of different varieties, $c_{H,t}(i)$, that are produced by monopolistically competitive final good firms, indexed by $i \in [0,1]$:

$$c_{H,t} = \left[\int_0^1 c_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3.5}$$

where $\varepsilon > 1$ denotes the elasticity of substitution between varieties of the same origin. The demand schedule corresponding to $c_{H,t}(i)$ is given by

$$c_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} c_{H,t}, \tag{3.6}$$

[30] The full model is presented in Appendix F.

with $P_{H,t}(i)$ the price set by firm i (see below). Analogous expressions apply for the imported consumption goods.

The representative household decides on how much to consume, how many hours to work, n_t, and how many bonds to hold (or issue) to maximize expected lifetime utility:

$$E_0 \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{1+\varphi}}{1+\varphi} \right), \tag{3.7}$$

with $\beta \in (0,1)$ the discount factor, $\sigma > 0$ the risk aversion coefficient, κ_L a parameter that pins down steady-state hours worked and $\varphi > 1$ the inverse Frisch elasticity. The household has access to two types of internationally traded, one-period non-state contingent nominal bonds: a Home bond, $B_{H,t}$, which is denominated in Home currency and offers a gross nominal return of R_t, and a Foreign bond, $B_{F,t}$, denominated in Foreign currency and yielding a return R_t^*. Furthermore, the household earns a nominal wage, W_t, on each hour worked and receives profits, Γ_t, as lump-sum dividends from domestic final good firms (which the household owns). The period budget constraint of the Home household can be stated as follows:

$$P_t c_t + B_{H,t} + e_t B_{F,t} = R_{t-1} B_{H,t-1} + e_t R_{t-1}^* B_{F,t-1} + W_t n_t + P_t \Gamma_t + P_t \Gamma_{f,t} - \frac{\kappa_D}{2} e_t P_t^* \left(\frac{B_{F,t}}{P_t^*} - \bar{b}_F \right)^2. \tag{3.8}$$

The last term on the right-hand side of (3.8) represents a financial intermediation cost, paid to the Foreign household, which the Home household incurs when it alters its external debt position, with $\kappa_D > 0$ governing the size of this cost. Similarly, Foreign households pay financial intermediation costs to the Home household, $\Gamma_{f,t}$, when changing their holdings of Home bonds.

Maximizing (3.7) subject to (3.8) and an appropriate transversality condition yields the following first-order conditions:

$$\lambda_t = c_t^{-\sigma}, \tag{3.9}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t}{\pi_{t+1}} \right), \tag{3.10}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t^*}{\pi_{t+1}^*} \frac{q_{t+1}}{q_t} \right) - \kappa_D \left(b_{F,t} - \bar{b}_F \right), \tag{3.11}$$

$$\kappa_L n_t^{\varphi} = \lambda_t w_t, \tag{3.12}$$

with λ_t the Lagrange multiplier on the period budget constraint, $\pi_t \equiv P_t/P_{t-1}$ gross inflation, $w_t \equiv W_t/P_t$ the real wage and $b_{F,t} \equiv B_{F,t}/P_t^*$ real Foreign bond holdings.

3.1.2 Firms

In each country, two types of firms characterize the production sector: intermediate goods firms and final goods firms. This implies a two-stage production process. At the first stage, perfectly competitive intermediate goods firms use domestically supplied labor to produce intermediate goods, x_t, using the following linear production function:

$$x_t = z_{A,t} n_t, \tag{3.13}$$

where $z_{A,t}$ denotes a productivity shock that evolves according to a stationary AR(1) process:

$$\ln z_{A,t} = (1 - \rho_A) \ln z_A + \rho_A \ln z_{A,t-1} + \varepsilon_{A,t}, \tag{3.14}$$

with $\rho_A \in [0, 1]$ and $\varepsilon_{A,t} \sim \mathcal{N}\left(0, \sigma_A^2\right)$. The Foreign intermediate goods producer faces a similar production function, with productivity shock $z_{A,t}^*$. The price of the intermediate good is set equal to its nominal marginal cost.

At the second stage, final goods firms produce variety $y_{H,t}(i)$ using both Home and Foreign intermediate goods according to the following technology:

$$y_{H,t}(i) = \left[(1-\gamma)^{\frac{1}{\phi}} \left(x_{H,t}(i)\right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(x_{F,t}(i)\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}, \tag{3.15}$$

where $x_{H,t}(i)$ and $x_{F,t}(i)$ are intermediate goods produced in Home and Foreign, and demanded by firm i in Home. A key parameter of interest is $\gamma \in [0, 1]$, which measures the share of Foreign intermediate goods used in Home production. When $\gamma > 0$, the economy relies on global supply chains as there is cross-border trade in intermediate goods along the production process. One can therefore think of γ as measuring the country's participation in GVCs (see Section 2.1): the higher is γ, the higher is GVC participation. Another key parameter is the elasticity of substitution between Home and Foreign intermediate goods, $\phi \geq 0$, which governs the ability of firms to substitute away from imported intermediate goods toward domestically produced intermediate goods, and thereby their ability to overcome global supply chain pressures.

Taking the price of intermediate goods as given, cost minimization yields the following expression for the final good firms' nominal marginal costs:

$$MC_t(i) = MC_t = \left[(1-\gamma)\left(\frac{W_t}{z_{A,t}}\right)^{1-\phi} + \gamma\left(e_t \frac{W_t^*}{z_{A,t}^*}\right)^{1-\phi}\right]^{\frac{1}{1-\phi}}. \tag{3.16}$$

Note that, when $\gamma > 0$, changes in the relative price of Foreign intermediate goods directly affect domestic inflation through marginal costs. Eyquem and Kamber (2014) show that the presence of this so-called 'cost channel' generates a more empirically plausible share of foreign shocks in the variance decomposition of domestic output. The optimal demand schedules for intermediate goods are given by

$$x_{H,t}(i) = (1-\gamma)\left(p_{H,t}^{-1}\frac{w_t/z_{A,t}}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{3.17}$$

$$x_{F,t}(i) = \gamma\left(q_t p_{H,t}^{-1}\frac{w_t^*/z_{A,t}^*}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{3.18}$$

where $p_{H,t} \equiv P_{H,t}/P_t$ and $mc_t \equiv MC_t/P_{H,t}$.

Final good firms set their price, $P_{H,t}(i)$, at a markup over marginal costs and are subject to a cost, $AC_t(i)$, whenever they adjust their price relative to the benchmark $\overline{\pi}$, à la Rotemberg (1982):

$$AC_t(i) = \frac{\kappa_P}{2}\left(\frac{P_{H,t}(i)}{P_{H,t-1}(i)} - \overline{\pi}\right)^2 P_{H,t}y_{H,t}, \tag{3.19}$$

where $\kappa_P \geq 0$ measures the size of the price-adjustment cost. The firm seeks to maximize current and future expected discounted profits (expressed in terms of domestic CPI):

$$E_t\sum_{k=0}^{\infty}\beta^k\frac{\lambda_{t+k}}{\lambda_t}\left[\frac{P_{H,t+k}(i)}{P_{t+k}}y_{H,t+k}(i) - \frac{w_{t+k}}{z_{A,t+k}}x_{H,t+k}(i) - q_{t+k}\frac{w_{t+k}^*}{z_{A,t+k}^*}x_{F,t+k}(i) - \frac{AC_{t+k}(i)}{P_{t+k}}\right],$$

subject to (3.6) and (3.17)-(3.19). The corresponding first-order condition is given by:

$$(\pi_{H,t} - \overline{\pi})\pi_{H,t} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(\pi_{H,t+1} - \overline{\pi})\pi_{H,t+1}\frac{p_{H,t+1}}{p_{H,t}}\frac{y_{H,t+1}}{y_{H,t}}\right] + \frac{\varepsilon}{\kappa_P}\left(mc_t - \frac{\varepsilon-1}{\varepsilon}\right), \tag{3.20}$$

where $\pi_{H,t} \equiv P_{H,t}/P_{H,t-1}$.

3.1.3 Monetary policy

A standard Taylor-type rule characterizes monetary policy and relates the nominal interest rate to deviations of CPI inflation and GDP, $gdp_t \equiv p_{H,t}y_{H,t}$, from their respective targets:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R}\left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi}\left(\frac{gdp_t}{gdp}\right)^{\phi_y}\right]^{1-\rho_R}, \tag{3.21}$$

where $\rho_R \in (0,1)$ measures the degree of interest rate smoothing and where $\phi_\pi > 1$ and $\phi_y \geq 0$ denote the monetary policy response to inflation and output, respectively. Variables without a t-subscript denote steady-state values.

3.1.4 Market clearing

The goods market clearing condition aggregates Home and Foreign demand for final consumption goods, and the resources lost due to price adjustments:

$$y_{H,t} = (1-\mu)\, p_{H,t}^{-\eta} c_t + \left(\frac{1-s}{s}\right) \mu^* p_{H,t}^{*-\eta} c_t^* + \frac{\kappa_P}{2} \left(\pi_{H,t} - \overline{\pi}\right)^2 y_{H,t}. \tag{3.22}$$

Defining the intermediate goods terms of trade by $\rho_{r,t} \equiv (w_t / z_{A,t}) \left(q_t w_t^* / z_{A,t}^*\right)^{-1}$, we can derive the global demand for Home intermediate goods:

$$x_t = (1-\gamma) \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)}\right]^{\frac{\phi}{1-\phi}} y_{H,t} + \gamma^* \rho_{r,t} \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi}\right]^{\frac{\phi}{1-\phi}} y_{F,t}^*. \tag{3.23}$$

The resource constraint is given by

$$c_t + tb_t = gdp_t \left[1 - \frac{\kappa_P}{2} \left(\pi_{H,t} - \overline{\pi}\right)^2\right], \tag{3.24}$$

where tb_t denotes the trade balance:

$$\begin{aligned} tb_t = {} & b_{H,t} + q_t b_{F,t} - \frac{R_{t-1}}{\pi_t} b_{H,t-1} - q_t \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1} \\ & + \frac{\kappa_D}{2} q_t \left(b_{F,t} - \overline{b}_F\right)^2 - \frac{1-s}{s} \frac{\kappa_D}{2} \left(b_{H,t}^* - \overline{b}_H^*\right)^2 - w_t n_t \left(1 - \frac{x_{H,t}}{x_t}\right) + q_t w_t^* n_t^* \frac{x_{F,t}}{x_t^*}. \end{aligned} \tag{3.25}$$

Finally, bond market clearing implies $s b_{H,t} + (1-s)\, b_{H,t}^* = 0$ and $s b_{F,t} + (1-s)\, b_{F,t}^* = 0$.

3.1.5 Calibration

We calibrate the model parameters assuming a quarterly frequency for t. Most of the parameters are assigned commonly-used values found in the literature. Table 3.1 reports an overview of the baseline calibration, which assumes symmetry across the two countries (with $s = 0.5$), a zero-external-debt steady state and a 2% inflation target set by the central bank. Furthermore, we normalize steady-state Home GDP to $gdp = 1$ and set steady-state Home hours worked equal to $n = 1/3$.

As a benchmark, we set $\gamma = 0$, in which case there is no international trade in intermediate inputs, and consider values of γ up to 0.3, which is consistent with the average share of foreign intermediate inputs (% of total intermediate inputs) across the 66 countries covered by OECD's TiVA database, which amounts to 26.6% in 2018 (see Figure 2.2). The euro area average share (around 25%) falls within this range, with some notable differences across countries.[31] The elasticity of substitution between Home and Foreign intermediate goods, ϕ, is set to 5, which comes close to the average trade elasticity of

[31] For example, while for Germany, France and Spain, this share lies within the 21-22% range, much higher values are found for the Netherlands (32.6%), the Baltic states (32.8%) and Luxembourg (55.9%).

intermediates estimated by Caliendo and Parro (2015) and which is also used by di Giovanni et al. (2022) in their model of global input-output linkages. Since this parameter helps domestic firms to alleviate strains arising from global supply chain pressures, we shall also consider alternative values for ϕ in the numerical simulations below.[32] Finally, we calibrate the imported share of final goods to $\mu = 0.2$ using the average value obtained from the OECD's TiVA database.

Table 3.1: Baseline calibration

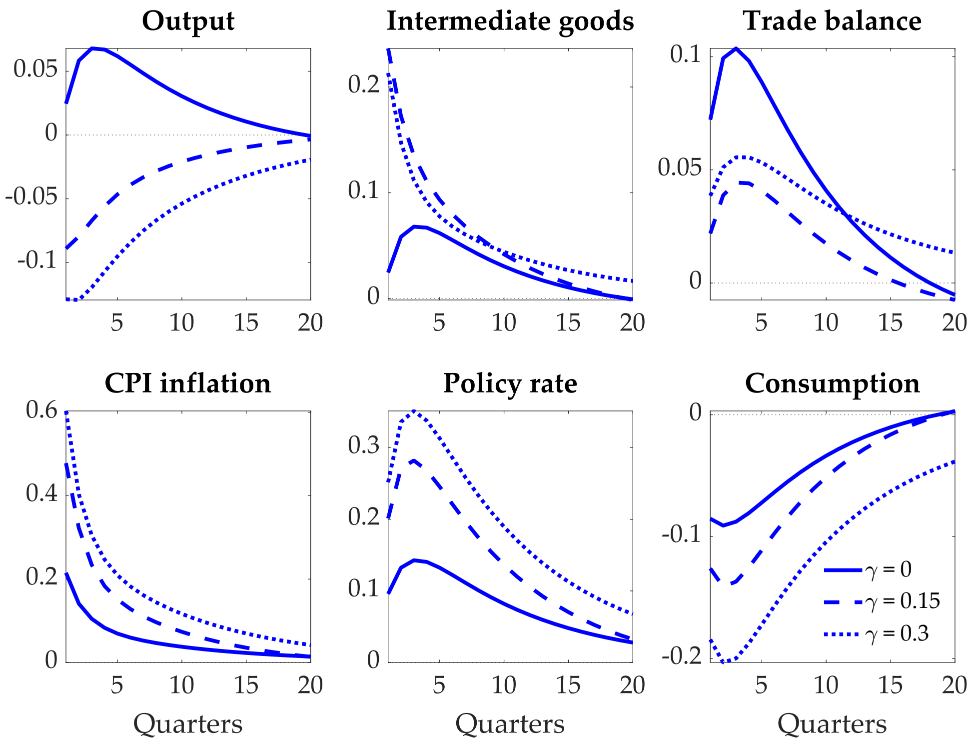
Parameter	Description	Value
β	Discount factor	0.99
σ	Relative risk aversion coefficient	2
φ	Inverse Frisch elasticity of labor supply	2
ϵ	Elasticity of substitution between intermediate goods from the same country	6
ϕ	Elasticity of substitution between intermediate goods from different countries	5
η	Elasticity of substitution between Home and Foreign final goods	2
κ_P	Rotemberg parameter	58.25
κ_D	Risk premium parameter	0.005
s	Relative population size of Home	0.5
ρ_R	Interest rate smoothing	0.7
ϕ_π	Monetary policy response to inflation	1.5
ϕ_y	Monetary policy response to output	0.125
ρ_A	Persistence of productivity shock	0.9
μ, μ^*	Import share of consumption	0.2
Steady state assumptions		
$\overline{\pi}$, $\overline{\pi}^*$	Inflation target	1.02
gdp	Steady-state Home GDP	1
n	Steady-state Home hours worked	1/3

3.2 Numerical simulations and Ramsey optimal policy

Before examining the implications of global supply chain pressures for monetary policy, we first use the model to better understand the propagation mechanism of a shock to global supply chain pressures. The latter is approximated by a negative shock to Foreign productivity, $z^*_{A,t}$, that reduces the supply of Foreign intermediate inputs available for the production of Home goods. The severity of such global supply chain disruptions is determined, inter alia, by the parameter γ which measures the degree of GVC participation. Note that this type of global supply chain disruption may differ in nature from that considered in the empirical framework in which we rely on the GSCPI to identify the shocks and which captures, not only sudden shortages in critical foreign intermediate inputs, but also increases in shipping

[32] Note that, while most of the international business cycle literature uses a trade elasticity closer to or even below 1, this elasticity applies to *final* consumption goods produced in different countries, which are often characterized by a stronger degree of differentiation (such as automobiles and medical equipment). Intermediate goods produced in different countries, on the other hand, typically have a much higher elasticity of substitution. Moreover, changes in tariffs and shipping costs are often found to have a stronger impact on trade in intermediates than on total trade and on trade in final consumption goods. Intuitively, compared to final goods, intermediate goods are often less differentiated and so firms can more easily substitute between different suppliers of the same intermediate good across different countries, resulting in a higher elasticity of demand. However, we acknowledge that some results would change if one uses a much lower value of ϕ, as close to 1. Specifically, the results shown in Figures 3.1 and Figure 3.2 would require a higher value of γ if ϕ is lower.

Figure 3.1: Responses of Home variables to a global supply chain pressure shock



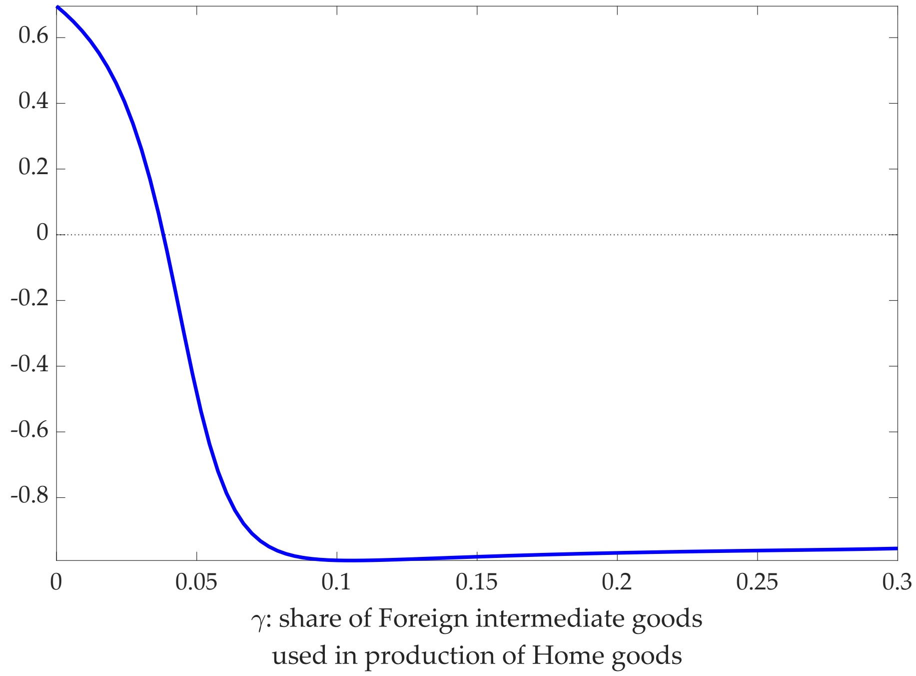
Notes: The figure plots the responses to a 1% negative Foreign productivity shock, which we use as a proxy for a global supply chain pressure shock. The importance of global supply chains is governed by γ, which measures the share of Foreign intermediate goods used in the production of Home goods. Units are expressed as percentage point deviation from steady state, except for CPI inflation and the policy rate which are expressed in annualized percentage points.

costs, import tariffs and other impediments to global trade. In that sense, our modelling choice implies that the type of global supply chain disruption that we consider in the model is asymmetric, because it only affects the imports of intermediate goods produced abroad, but does not directly affect the exports of domestically produced intermediate goods.

Figure 3.1 plots the impulse responses to the global supply chain pressure shock. When $\gamma = 0$, global supply chains are absent and the shock prompts an increase in Home output and inflation due to an expenditure-switching effect: as the negative Foreign supply shock raises the price of Foreign goods, consumers switch their expenditures toward relatively less expensive Home goods. The latter leads to an increase in Home production, an improvement of the trade balance and subsequently to a rise in marginal costs which pushes up inflation. The central bank, when following a conventional Taylor rule, responds by raising the nominal interest rate to dampen the surge in inflation and output, which leads to a decline in consumption.

When $\gamma > 0$, the response of Home inflation to the global supply chain pressure shock is again positive, yet the response of Home output becomes *negative*. Intuitively, the fact that Home firms rely on Foreign intermediate goods implies that they directly feel the brunt of a negative Foreign supply shock, as the rise in Foreign intermediate goods prices immediately pass through to their marginal costs. Consequently, Home goods become more expensive and aggregate demand declines, which results in a contraction of Home output and a more muted response of the trade balance compared to the benchmark

Figure 3.2: Correlation between Home output and inflation under global supply chain pressures



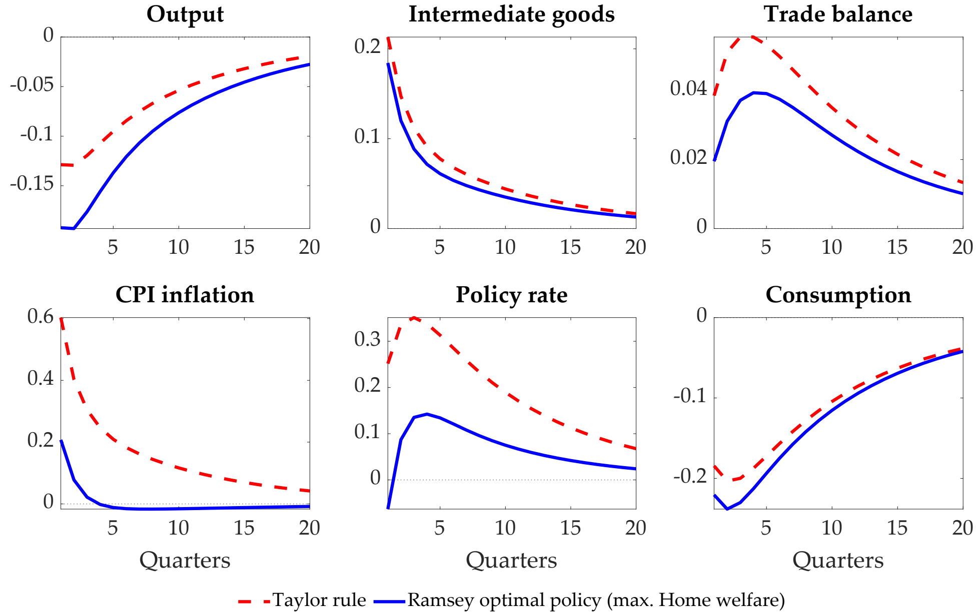
Notes: The figure plots the correlation between Home output and Home consumer price inflation after simulating (a second-order approximation of) the model for 1,000 periods, conditional on the world economy facing only random (positive and negative) Foreign productivity shocks.

without international trade in intermediate inputs. The greater is GVC participation, i.e. the higher is γ, the stronger is this cost channel and so the larger is the contraction in output following the global supply chain pressure shock. A stronger cost channel also implies a more prominent rise in inflation and, correspondingly, more aggressive tightening of monetary policy.

The counteracting responses of output and inflation resemble those to a traditional adverse domestic supply shock and similarly pose a trade-off to monetary policy between stabilizing inflation and output. As the central bank raises the nominal interest rate to lower inflation, the decline in output is aggravated by a reduction in consumption. The higher is γ, the more unfavorable this monetary policy trade-off becomes. Figure 3.2, which plots the correlation between Home output and inflation after simulating (a second-order approximation of) the model for 1,000 periods conditional on the economy being subject to random Foreign productivity shocks, confirms that higher values of γ are associated with a less positive or negative correlation between output and inflation, and thereby with a less favorable inflation-output stabilization trade-off for monetary policy. The size of γ, therefore, represents an important input in the design of optimal monetary policy, as it shapes the characteristics of adverse foreign supply shocks: when γ is low, such shocks resemble domestic demand shocks, in that they move output and inflation in the same direction, whereas when γ is high, they are more akin to domestic supply shocks, pushing output and inflation in opposite directions.

So how *should* monetary policy respond to global-supply-induced inflation? We answer this question by examining the implied path of the Home policy interest rate following a global supply chain pressure

Figure 3.3: Responses of Home variables to a global supply chain pressure shock under conventional Taylor rule and Ramsey optimal policy ($\gamma = 0.3$)



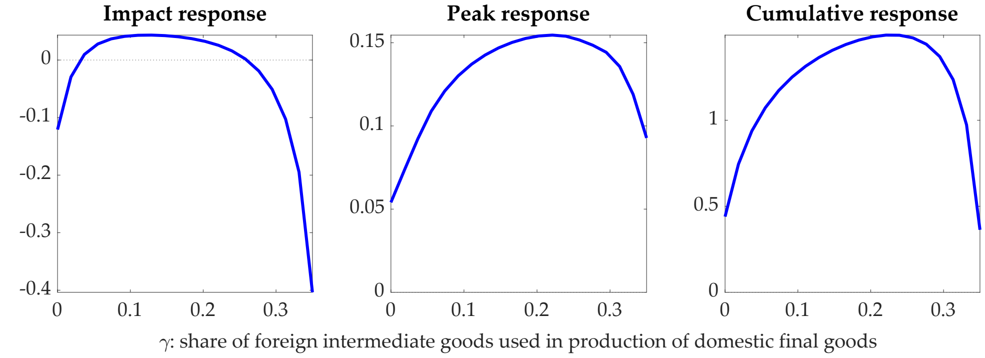
Notes: The figure plots the responses to a 1% negative Foreign productivity shock, which we use as a proxy for a global supply chain pressure shock. The importance of global supply chains is governed by γ, which measures the share of Foreign intermediate goods used in the production of Home goods. Units are expressed as percentage point deviation from steady state, except for CPI inflation and the policy rate which are expressed in annualized percentage points.

shock under Ramsey optimal policy. We consider a non-cooperative policy in which the Ramsey policy-maker aims to maximize the welfare of only Home households, which is proxied by their expected lifetime utility shown in equation (3.7). Figure 3.3 shows the responses under Ramsey optimal policy (solid blue lines) for the case with $\gamma = 0.3$, along with the corresponding responses under the conventional Taylor rule (dashed red lines) as shown in Figure 3.1. Optimal policy implies a monetary policy *easing* on impact, followed by a monetary tightening that is much less aggressive than implied by the Taylor rule. The initial easing can be explained by the contraction in output induced by the adverse external supply shock. The more sticky are prices, the larger will be the output contraction and the more pronounced will be the initial monetary easing. Nevertheless, a subsequent monetary tightening is required, at the cost of lower aggregate demand, to mitigate the buildup of inflationary pressures arising from global supply chain pressures. Correspondingly, following an initial jump, CPI inflation remains roughly stable around the inflation target.[33]

One of our key findings is that the monetary policy response to a global supply chain pressure shock should not be too aggressive when GVC participation is relatively high. This is because higher GVC participation results in a worsening of the inflation-output stabilization trade-off in the event of an adverse external supply shock. We illustrate this result in Figure 3.4, which shows the impact, peak and cumulative response (over 20 quarters) of the Home policy rate to the global supply chain pressure shock under Ramsey optimal policy for different values of γ. Up to a certain threshold, higher values of γ are

[33]The results are qualitatively very similar when we shut down international trade in final goods by setting $\{\mu, \mu^*\} = 0$. This implies that the propagation mechanism of adverse external supply shocks works mainly through the international trade of intermediate goods, which is consistent with De Soyres and Gaillard (2022).

Figure 3.4: Response of Home policy rate to a global supply chain pressure shock under Ramsey optimal policy



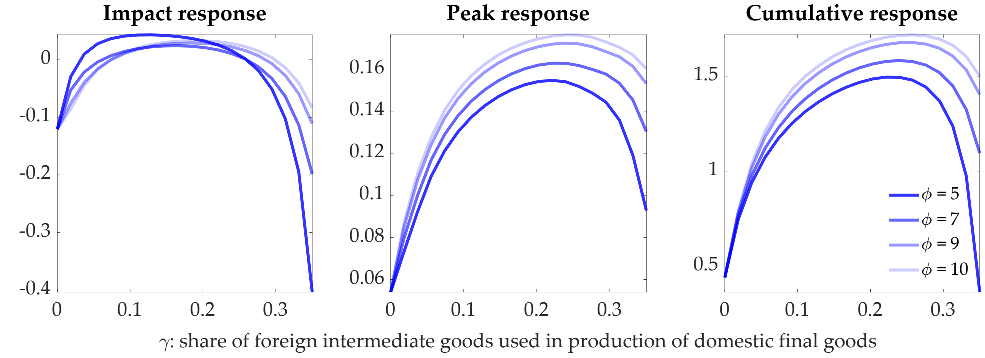
Notes: Units are expressed as annualized percentage points. The cumulative response is measured over 20 quarters.

associated with a more aggressive monetary policy response, as the global supply chain pressure shock will have a larger (direct and indirect) impact on Home inflation, which the Ramsey policymaker aims to contain. However, beyond this threshold, the optimal amount by which the central bank should raise the policy rate becomes *negatively* related with γ. This result follows immediately from our earlier discussion on how the inflation-output stabilization trade-off turns less favorable under higher GVC participation. In that case, a more aggressive monetary policy response to global-supply-induced inflation could end up reducing welfare by exacerbating the contraction in output and consumption too much.

To build some additional intuition behind the non-linear relationship between, on the one hand, the optimal monetary policy response to global-supply-induced inflation and, on the other hand, the degree of GVC participation, we again examine the optimal response of the Home policy rate to a global supply chain pressure shock as a function of γ, yet this time considering alternative calibrations of several other key parameters. In Figure 3.5, we vary the elasticity of substitution between Home and Foreign intermediate goods, ϕ, across a range of five values: 5 (baseline), 7, 9 and 10. Everything else equal, a higher elasticity implies that firms can more easily substitute away from imported intermediate goods toward domestically produced intermediate goods and set up new supply chains, which helps dampen the adverse effects arising from global supply chain disruptions on Home production in the very short term. Consequently, we find that, for a given value for γ, a higher value of ϕ allows for a more aggressive monetary policy response to adverse external supply shocks.

In Figure 3.6, we consider higher values for the elasticity of substitution between Home and Foreign final goods, η, which we raise from its baseline value of 2 to 4, 5 or 6. A higher trade elasticity also improves the inflation-output stabilization trade-off, in a similar vein as does a higher value for ϕ, as an increase in the price of foreign final goods due to an adverse external supply shock leads to a lower decline in aggregate demand for domestic goods through a more powerful expenditure switching channel. Therefore, higher values for the trade elasticity between final goods permits a more aggressive monetary policy response to the global chain pressure shock, for a given share of foreign intermediate goods used

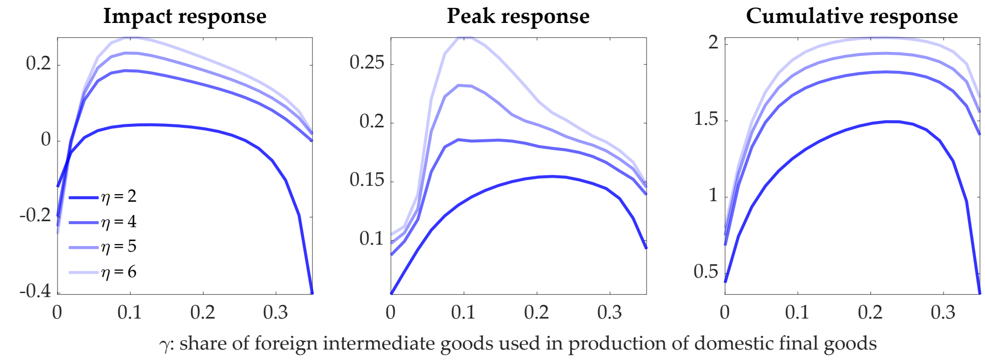
Figure 3.5: Response of Home policy rate to a global supply chain pressure shock under Ramsey optimal policy, alternative calibrations of the elasticity of substitution between Home and Foreign intermediate goods



Notes: Units are expressed as annualized percentage points. The cumulative response is measured over 20 quarters. For each line, we vary the elasticity of substitution between Home and Foreign intermediate goods (ϕ, baseline = 5) and leave the other parameters at their baseline calibration shown in Table 3.1.

in domestic production.

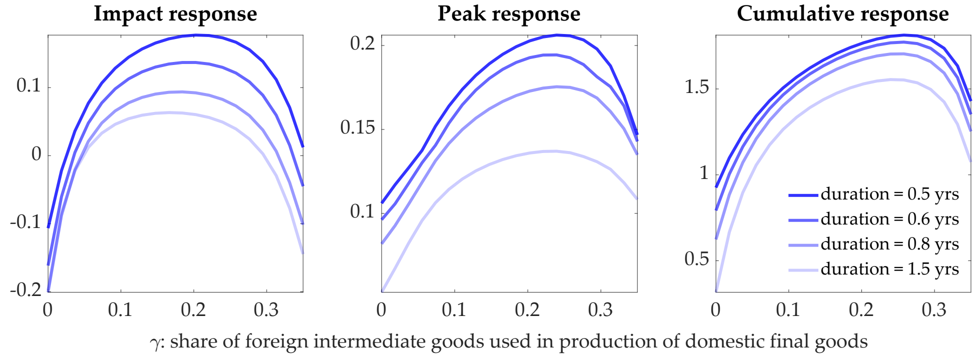
Figure 3.6: Response of Home policy rate to a global supply chain pressure shock under Ramsey optimal policy, alternative calibrations of the elasticity of substitution between Home and Foreign final goods



Notes: Units are expressed as annualized percentage points. The cumulative response is measured over 20 quarters. For each line, we vary the elasticity of substitution between Home and Foreign final goods (η, baseline = 2) and leave the other parameters at their baseline calibration shown in Table 3.1.

Finally, in Figure 3.7, we consider different degrees of price stickiness by varying the parameter κ_P from 10 to 143. The baseline value ($\kappa_P = 58$) implies a fixed price contract with expected duration of 1 year, while the alternative values correspond to a contract with expected duration of 0.5, 0.6, 0.8, and 1.5 years, respectively. A higher degree of price stickiness worsens the inflation-output stabilization trade-off as Home firms will be forced to curtail production by more in response to changes in aggregate demand, which renders a tightening of monetary policy more costly in terms of welfare losses. As a consequence, a less aggressive monetary policy response to global supply chain pressure shocks is warranted when γ is relatively large. Conversely, more flexible prices help alleviate the inflation-output stabiliziation trade-off, allowing for a more aggressive monetary policy response.

Figure 3.7: Response of Home policy rate to a global supply chain pressure shock under Ramsey optimal policy, alternative calibrations of the price-adjustment cost parameter



Notes: Units are expressed as annualized percentage points. The cumulative response is measured over 20 quarters. For each line, we vary the price-adjustment cost parameter (κ_P, baseline = 58, which corresponds to a price contract with expected duration of 1 year) and leave the other parameters at their baseline calibration shown in Table 3.1.

4 Concluding remarks

Strains in global supply chains have been a major factor driving inflation dynamics in most advanced economies since late 2020. Our paper quantifies empirically how much global supply chain pressures contribute to euro area inflation and studies theoretically what these shocks imply for optimal monetary policy.

Our empirical evidence supports the view that global supply chain pressures matter for domestic inflation dynamics. We first show that global supply chain pressures contribute positively and significantly to euro area inflation, relying on a standard estimated Phillips curve which includes the GSCPI as an additional regressor. Next, using a Bayesian structural VAR model with sign and narrative restrictions, we find that shocks to global supply chain pressures play a dominate role in driving the recent surge in euro area inflation. This exercise also reveals that the effects of a shock to global supply chain pressures on inflation are highly persistent and hump-shaped. This result implies that, although strains in global supply chains have been easing recently, supply bottlenecks are still expected to add to inflationary pressures for some time.

Finally, we investigate the implications of global supply chain pressures for monetary policy using a two-country New Keynesian model. A key feature of the model is that firms use both domestic and foreign intermediate inputs in the production of domestic final goods. This feature captures, in a stylized way, the degree of the economy's participation in global value chains (GVCs) and implies that firms' marginal costs are directly influenced by changes in relative international prices. According to the model, the impact of shocks to global supply pressures on inflation and output depend on the degree of GVC participation, which in turn has important implications for the design of optimal monetary policy. When GVC participation is low, global supply chain pressure shocks raise both domestic inflation and output, which implies a monetary policy tightening under Ramsey optimal policy. However, at higher levels of GVC participation, the global supply pressure shock leads to a rise in inflation, but a decline in output, which worsens the monetary policy trade-off between stabilizing inflation and output. Consequently, the Ramsey optimal policy calls for a less aggressive monetary policy tightening. This non-linear relationship between the optimal monetary policy response to global-supply-induced inflation and GVC participation depends, among other things, on the elasticity of substitution between imported and domestically produced goods and the degree of price stickiness.

We conclude with two promising avenues for future research, which focus on the role of fiscal policy in the presence of global supply disruptions. One open question is how fiscal policy could support monetary policymakers in the face of external supply shocks. Related, another line of research might consider exploring the distributional consequences of global supply shocks and to what extent fiscal policy can alleviate (or even avoid) the corresponding welfare losses.

References

Acemoglu, D., Akcigit, U., and Kerr, W. (2016). Networks and the macroeconomy: An empirical exploration. *NBER Macroeconomics Annual*, 30(1):273–335.

Acemoglu, D. and Tahbaz-Salehi, A. (2020). Firms, failures, and fluctuations: the macroeconomics of supply chain disruptions. Technical report, National Bureau of Economic Research, Working Paper Series No. 27565.

Andriantomanga, Z., Bolhuis, M. A., and Hakobyan, S. (2022). Global supply chain disruptions: Challenges for inflation and monetary policy in Sub-Saharan Africa.

Antolín-Díaz, J. and Rubio-Ramírez, J. F. (2018). Narrative sign restrictions for SVARs. *American Economic Review*, 108(10):2802–29.

Antràs, P. (2020a). Conceptual aspects of global value chains. *The World Bank Economic Review*, 34(3):551–574.

Antràs, P. (2020b). De-globalisation? Global value chains in the post-COVID-19 age. Technical report, National Bureau of Economic Research, Working Paper Series No. 28115.

Auer, R., Borio, C. E., and Filardo, A. J. (2017). The globalisation of inflation: The growing importance of global value chains. Technical report, CEPR Discussion Paper No. DP11905.

Auer, R. A., Levchenko, A. A., and Sauré, P. (2019). International inflation spillovers through input linkages. *Review of Economics and Statistics*, 101(3):507–521.

Bai, X., Fernández-Villaverde, J., Li, Y., and Zanetti, F. (2023). The causal effects of global supply chain disruption on macroeconomic outcomes: Theory and evidence. *mimeo*.

Banbura, M., Bobeica, E., and Hernández, C. M. (2023). What drives core inflation? The role of supply shocks. Technical report, ECB Working Paper No. 2023/2875.

Benigno, G., di Giovanni, J., Groen, J. J., Noble, A. I., et al. (2022). A new barometer of global supply chain pressures. Technical report, Federal Reserve Bank of New York Liberty Street Economics, January 4, 2022.

Benigno, P. (2009). Price stability with imperfect financial integration. *Journal of Money, Credit and Banking*, 41:121–149.

Bernanke, B. S. and Blanchard, O. J. (2023). What caused the US pandemic-era inflation? Technical report, National Bureau of Economic Research, Working Paper Series No. 31417.

Burriel, P., Kataryniuk, I., Moreno Pérez, C., and Viani, F. (2023). A new supply bottlenecks index based on newspaper data. Technical report, Banco de Espana Working Paper No. 2304, 2023.

Caliendo, L. and Parro, F. (2015). Estimates of the trade and welfare effects of NAFTA. *The Review of Economic Studies*, 82(1):1–44.

Carrière-Swallow, Y., Deb, P., Furceri, D., Jiménez, D., and Ostry, J. D. (2022). Shipping costs and inflation. Technical report, International Monetary Fund, Working Paper No. 61.

Carrière-Swallow, Y., Deb, P., Furceri, D., Jiménez, D., and Ostry, J. D. (2023). Shipping costs and inflation. *Journal of International Money and Finance*, 130:102771.

Carvalho, V. M. and Tahbaz-Salehi, A. (2019). Production networks: A primer. *Annual Review of Economics*, 11:635–663.

De Santis, R. A. (forthcoming 2024). Supply chain disruption and energy supply shocks: Impact on euro-area output and prices. *International Journal of Central Banking*.

De Soyres, F. and Gaillard, A. (2022). Global Trade and GDP Comovement. *Journal of Economic Dynamics and Control*, page 104353.

di Giovanni, J., Kalemli-Özcan, á., Silva, A., and Yildirim, M. A. (2022). Global supply chain pressures, international trade, and inflation. Technical report, National Bureau of Economic Research, Working Paper Series No. 30240.

di Giovanni, J., Kalemli-Özcan, á., Silva, A., and Yildirim, M. A. (2023). Quantifying the inflationary impact of fiscal stimulus under supply constraints. Technical report, National Bureau of Economic Research, Working Paper Series No. 30892.

Eppinger, P., Felbermayr, G. J., Krebs, O., and Kukharskyy, B. (2021). Decoupling global value chains. Technical report, CESifo Working Paper No. 9079.

Eyquem, A. and Kamber, G. (2014). A note on the business cycle implications of trade in intermediate goods. *Macroeconomic Dynamics*, 18(5):1172–1186.

Feenstra, R. C., Luck, P., Obstfeld, M., and Russ, K. N. (2018). In search of the Armington elasticity. *Review of Economics and Statistics*, 100(1):135–150.

Ferrante, F., Graves, S., and Iacoviello, M. (2023). The inflationary effects of sectoral reallocation. *Journal of Monetary Economics*, 140:S64–S81.

Finck, D. and Tillmann, P. (2022). The macroeconomic effects of global supply chain disruptions. Technical report, BOFIT Discussion Papers.

Forbes, K. J. (2019). Has globalization changed the inflation process? Technical report, BIS Working Paper No. 791.

Frohm, E. and Gunnella, V. (2021). Spillovers in global production networks. *Review of International Economics*, 29(3):663–680.

Frohm, E., Gunnella, V., Mancini, M., Schuler, T., et al. (2021). The impact of supply bottlenecks on trade. *ECB, Economic Bulletin Boxes*, Issue 6/2021.

Ghassibe, M. (2021). Monetary policy and production networks: An empirical investigation. *Journal of Monetary Economics*, 119:21–39.

Gong, L., Wang, C., and Zou, H.-f. (2016). Optimal monetary policy with international trade in intermediate inputs. *Journal of International Money and Finance*, 65:140–165.

Huang, K. X. and Liu, Z. (2007). Business cycles with staggered prices and international trade in intermediate inputs. *Journal of Monetary Economics*, 54(4):1271–1289.

Kabaca, S. and Tuzcuoglu, K. (2023). Supply drivers of US inflation since the pandemic. Technical report, Bank of Canada, Staff Working Paper 2023-19.

Korniyenko, M. Y., Pinat, M., and Dew, B. (2017). Assessing the fragility of global trade: The impact of localized supply shocks using network analysis. Technical report, International Monetary Fund, Working Paper WP/17/30.

Krippner, L. (2013). Measuring the stance of monetary policy in zero lower bound environments. *Economics Letters*, 118(1):135–138.

Laumer, S. and Schaffer, M. (2022). Monetary policy transmission under supply chain pressures: Prepandemic evidence from the US. Technical report.

Lombardo, G. and Ravenna, F. (2014). Openness and optimal monetary policy. *Journal of International Economics*, 93(1):153–172.

Matsumura, M. (2022). What price index should central banks target? An open economy analysis. *Journal of International Economics*, 135:103554.

Miroudot, S. (2020). Resilience versus robustness in global value chains: Some policy implications. In *COVID-19 and trade policy: Why turning inward won't work*, volume 2020, pages 117–130. CEPR Press London.

Monarch, R. and Schmidt-Eisenlohr, T. (2023). Longevity and the value of trade relationships. *Journal of International Economics*, 145:103842.

OECD (2013). Interconnected Economies: Benefiting from GVCs.

Ozdagli, A. and Weber, M. (2017). Monetary policy through production networks: Evidence from the stock market. Technical report, National Bureau of Economic Research, Working Paper Series No. 23424.

Pastén, E., Schoenle, R., and Weber, M. (2020). The propagation of monetary policy shocks in a heterogeneous production economy. *Journal of Monetary Economics*, 116:1–22.

Rotemberg, J. J. (1982). Sticky prices in the United States. *Journal of Political economy*, 90(6):1187–1211.

Shapiro, A. H. (2022a). Decomposing supply and demand driven inflation. Federal Reserve Bank of San Francisco Working Paper 2022-18.

Shapiro, A. H. (2022b). How much do supply and demand drive inflation? *FRBSF Economic Letter*, 15.

Shi, K. and Xu, J. (2007). Optimal monetary policy with vertical production and trade. *Review of International Economics*, 15(3):514–537.

Stock, J. H. and Watson, M. W. (2002). Macroeconomic forecasting using diffusion indexes. *Journal of Business & Economic Statistics*, 20(2):147–162.

Wei, S.-J. and Xie, Y. (2020). Monetary policy in an era of global supply chains. *Journal of International Economics*, 124:103299.

Appendix

A Data set

Table A.1: Data description

	Variable	Description
1	Industrial production	Volume index of production, Mining and quarrying; manufacturing; electricity, gas, steam and air conditioning supply; Annual rate of change, logarithmic first difference; Calendar adjusted data, not seasonally adjusted data.
2	Non-energy inflation rate	Consumer inflation measured by HICP excluding energy; Annual rate of change, logarithmic first difference. Neither seasonally nor working day adjusted.
3	Real oil price	Brent oil price (euros per barrel) deflated by HICP; Annual rate of change, logarithmic first difference. Neither seasonally nor working day adjusted.
4	GSCPI	Global Supply Chain Pressure Index Index scaled by its standard deviation; Computed by Benigno et al. (2022).
5	Euro area shadow interest rate	A measure to capture the ECB's effective monetary policy stance; Computed by Krippner (2013).
6	Real effective exchange rate	With respect to euro area's 42 main trading partners.

Note: The data set has monthly frequency and it covers the period January 2000 until July 2023. The sources of the data are Eurostat, ECB Statistical Data Warehouse, FRED database, and EIA.

Macroeconomic aggregate data. The industrial production data is taken from Eurostat and for the estimation of the model we use its monthly year-on-year growth rate (i.e. logarithmic first-difference). This time series includes the following sectors: (i) mining and quarrying, (ii) manufacturing, and (iii) electricity, gas, steam and air conditioning supply. We do not include the construction sector as this is highly volatile. The data is calendar adjusted and not seasonally adjusted, since this is not necessary because we compute year-on-year growth rates. We think that industrial production represents a good proxy for the aggregate economic activity. Nevertheless, we acknowledge its limitation in capturing services, as these account for a substantial share of euro area output.

Next, we use monthly consumer core inflation, measured by the logarithmic first-difference in HICP excluding energy prices and the real price of oil Brent (deflated by HICP), measured by the logarithmic first-difference. The source of the two HICP time series is ECB's Statistical Data Warehouse and the price of oil Brent is taken from the US Energy Information Administration (EIA).

To study the global supply side of inflationary pressures, we use the Global Supply Chain Pressure Index (GSCPI) as proposed by Benigno et al. (2022). This measure is based on a set of commonly used metrics and aims to provide a comprehensive summary of potential disruptions affecting global supply chains. The first set of indicators is focused on cross-border transportation costs, which are measured by employing data on sea shipping costs. For this the authors use data from the Baltic Dry Index (BDI) and the Harpex index, as well as the United States Bureau of Labor Statistics airfreight cost indices for freight flights between Asia, Europe, and the United States. The second set of indicators is based on country-level manufacturing data from the Purchase Manager Index (PMI) surveys. In particular, they use three supply chain-related indicators – "delivery times", "backlogs", and "purchased stocks" – from the Purchasing Managers' Index (PMI) surveys for manufacturing firms across seven interconnected economies: the euro area, China, Japan, South Korea, Taiwan, the United Kingdom, and the US.

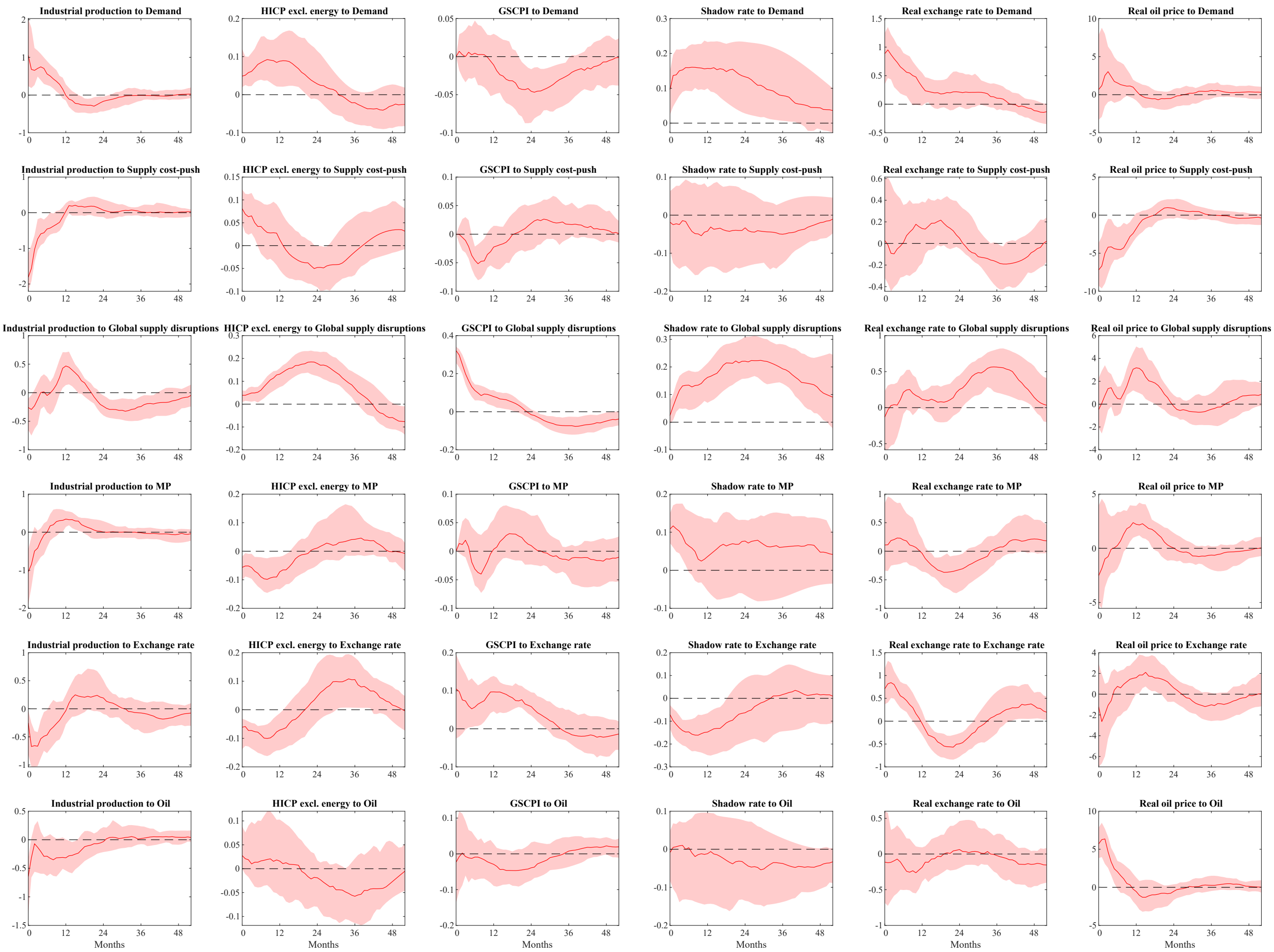
To summarize, the estimated GSCPI measure is based on information covering twenty-seven variables: (i) two global shipping rates, (ii) four price indices which capture airfreight costs between the United States, Asia, and Europe, and (iii) three country-specific supply chain variables for the seven economies included in their estimation sample. The authors claim that all these variables are corrected to the largest possible extent for demand effects. This is carried out by projecting the PMI supply chain components on the "new orders" component from the corresponding PMI surveys and, similarly, the global transportation cost measures that are projected onto the GDP-weighted "new orders" and "inputs purchased" components across the seven PMI surveys. This is highly important for the empirical analysis, as the aim is to distinguish between supply and demand factors in driving inflation dynamics. In order to estimate a common (global) component from these time series, the authors follow Stock and Watson (2002) and use a principal component analysis.

Financial data. To capture the ECB's effective monetary policy stance, we use the euro area shadow rate estimate, as computed by Krippner (2013), to account for both conventional and unconventional monetary policy measures deployed by the ECB.

B Macroeconomic effects following various shocks

This section discusses the macroeconomic effects following demand, supply cost-push, monetary policy, exchange rate, and oil shocks, based on our estimated Bayesian VAR model. Figure B.1 reports the IRFs following each of the structural shocks (row-wise).

Figure B.1: Impulse responses using our baseline identification strategy



Notes: The solid red line reports the median response and the corresponding light red shaded area represents the 68% probability bands using sign, zero and narrative restrictions (our baseline identification strategy, see Table 2.2). The horizontal axis is time, measured in months.

First row of Figure B.1 shows that following a *positive demand shock* industrial production and core inflation both increase, and therefore the monetary authority reacts by rising its policy rate. On impact the GSCPI does not respond, reflecting our zero restriction. In the short to medium run, the GSCPI's response is negative (although not significant for most of the horizon, in Bayesian terms), implying an easing in global supply pressures, to some degree also reflecting the decline in economic activity. The real exchange rate appreciates, reflecting a higher aggregate demand for domestic goods. As expected, (real) oil prices increase in the short term, on the back of higher industrial production, and then gradually start to fall, adjusting to the dampened economic activity (although the response is not significant).

Following an *adverse (domestic) supply cost-push shock* (second row of Figure B.1), as expected, economic activity falls, while core inflation increases. As a result, the monetary policy reacts by increasing its short-term policy rate (although the response is not significant in Bayesian terms). On impact the GSCPI does not respond, reflecting our zero restriction. The GSCPI declines in the short run, implying that global supply chain pressures tend to ease. This result can be partly rationalized via a prevailing indirect effect stemming from the fall in aggregate demand, which in turn exerts less pressure on global supply chains. However, over the medium run, the GSCPI raises (although the response is not significant), most likely as a result of global drivers and to a lower degree to the rebound in the domestic economic activity.

A *contractionary monetary policy shock* leads to a decline in industrial production in the very short term, followed by a relatively short-lived boost, which then gradually dissipates in the medium term (forth row of Figure B.1). As expected, core inflation falls. The GSCPI does not respond on impact, reflecting our zero restriction. In the short to medium run, the global supply chain pressures are first easing, then tightening, and then easing again after more than two years (although the response is not significant in Bayesian terms). These swings are reflecting multiple forces pulling in different directions, as well as the fact that domestic monetary policy has little influence on global supply chain pressures. The interest rate increase results in a real exchange rate appreciation in the very short term (although not significant), followed by a depreciation in the medium term. The (real) oil price falls in the short term, while slowly increasing in the medium term, reflecting partly the impact of tighter monetary policy on aggregate demand.

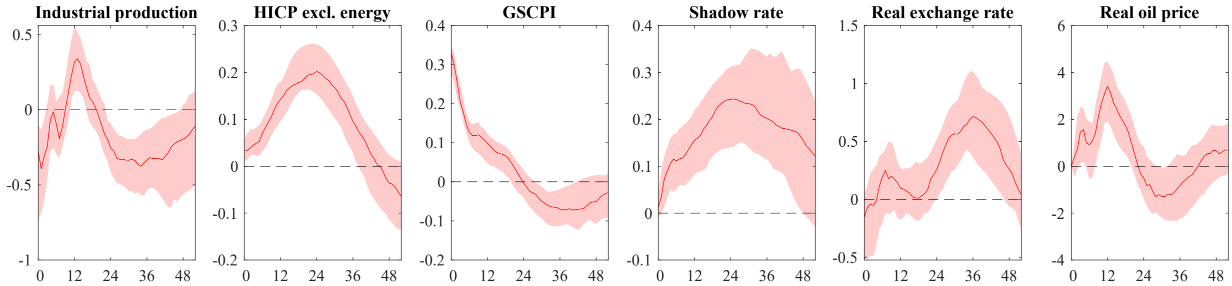
Fifth row of Figure B.1 reports the macroeconomic effects following a *positive shock to the real exchange rate* (i.e. an appreciation). This shock lowers both industrial production and core inflation, while it has a tightening impact on the GSCPI (although the response is not significant on impact). The real exchange rate appreciation leads to a short-lived fall in the real price of oil, which reverses after about six months.

Finally, according to our model, an *adverse oil shock* (last row of Figure B.1) leads to a short-lived spike in the real price of oil. As a result, industrial production falls, while core inflation raises, although the impact is rather small. Note that we did not impose any sign restrictions on core inflation in this case and let the data speak.

One might worry that it is difficult to separately identify the GSCPI shock and the oil supply shock. Nevertheless, we use the narrative restrictions to help us in disentangling these two shocks. The qualitative differences between the responses to a GSCPI shock and an oil shock provide evidence that we indeed identify two different types of supply shocks. While both shocks generate a decline in economic activity and a rise in core inflation on impact, the latter is more muted and less persistent, as well as not significant, in case of the response to an oil price shock. The central bank response is different too, and consistent with the responses of industrial production and inflation. Specifically, the shadow rate increases gradually – and statistically significantly so – following a global supply chain pressure shock, while it falls after an adverse oil price shock, although the response is not statistically significant. This difference could be explained by the central bank taking on a looking-through approach following an oil price shock, given its more muted and transitory impact on core inflation. Another key difference across the responses to the two shocks is the GSCPI response, which is positive following a global supply chain pressure shock, yet negative and relatively small following an oil price shock – and again not significant. The latter can be explained by the fact that there are two opposing forces affecting the GSCPI following an increase in oil prices: on the one hand, a positive oil price shock increases transportation costs raising the GSCPI (since these are determinants of the GSCPI), while on the other hand, it causes a reduction in aggregate demand and thereby easing supply chain pressures (such as backlogs, port congestions, shortages of truck drivers or containers, etc.).

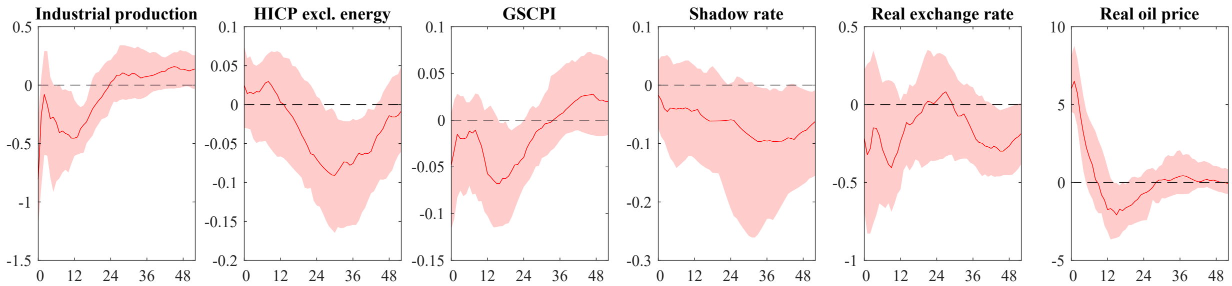
As a robustness check, we additionally impose that a global supply chain shock has no contemporaneous impact on oil prices. As argued by Banbura et al. (2023), supply chain disruptions often originate in the product market, reflecting increases in shipping costs other than those linked to energy. Figures B.2 and B.3 display the impulse responses following a global supply chain shock and an oil price shock based on this alternative identification strategy. These responses are in line with those from our baseline identification, yet they seem slightly more precisely estimated (i.e. they have narrower 68% probability bands). Also in this case the monetary authority response is different, highlighting that understanding which supply forces hit the economy is key for policymakers. Note that, compared to our baseline results (without the additional zero restriction described above), the response of the GSCPI to the oil price shock is now much more negative.

Figure B.2: Responses following a global supply chain pressure shock (extra zero restriction)



Notes: The figure shows the responses to a one standard deviation global supply chain pressure shock. The solid red line reports the median response. Shaded areas represent the 68% probability bands. The horizontal axis is time, measured in months.

Figure B.3: Responses following an oil shock (extra zero restriction)



Notes: The figure shows the macroeconomic responses to a one standard deviation oil shock. The figure reports the median response (red solid line) and a 68% probability bands. The horizontal axis is time, measured in months.

Finally, we show that the narrative restrictions further discipline the parameter space and help sharpen inference (generating overall narrower credible sets).[34] Figure B.4 reports the IRFs following each shock (row-wise) and compares those generated with narrative restrictions (red line) and without narrative restrictions (blue line). This exercise thus helps clarify the usefulness of adding the narrative restrictions. We find that, compared to the case where we rely only on sign and zero restrictions to identify the structural shocks, most of the 68% credible sets for the IRFs become narrower.

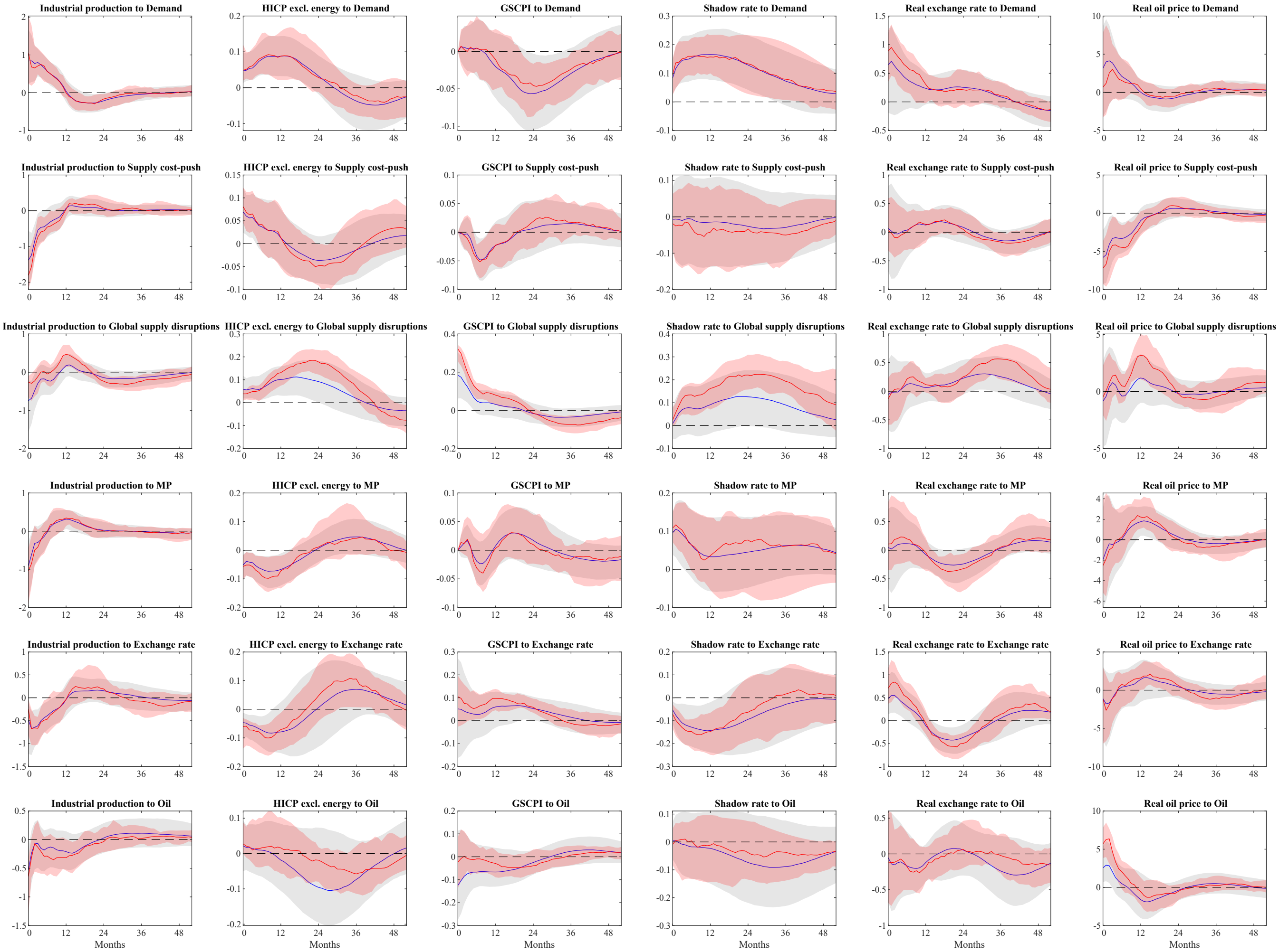
C Historical decomposition and effects of GSCPI shocks on unemployment

Figure C.1 and Figure C.2 display the historical shock decomposition of industrial production (our proxy for economic activity) and core inflation, respectively. In the aftermath of the global financial crisis (GFC), global supply chain pressure shocks acted as a drag on euro area economic activity (while they were adding to inflationary pressures in the euro area), given the collapse in international trade at the time. Subsequently, two natural disasters in Japan in March 2011 resulted in supply chain bottlenecks in the car manufacturing sector, which propagated across the global economy via production networks and dampened industrial production in the euro area. Afterwards, on the back of the globalization trend, GSCPI shocks were overall favorable and boosted economic activity up until 2019. At the onset of the COVID-19 pandemic, lockdowns, mobility restrictions and broad-based factory closures triggered global supply disruptions which further depressed production, while pushing inflation upwards. Combined, these results provide supporting evidence that our estimated global supply chain pressure shocks resemble supply shocks.

For a detailed discussion on the historical shock decomposition of core inflation see Section 2.3.3. Here we only briefly discuss several key events. In the run-up to the GFC, shocks to global supply

[34] As explained in Antolín-Díaz and Rubio-Ramírez (2018), these narrative restrictions shrink the admissible set of structural parameters by ensuring that, around several key historical events, the structural shocks and historical decomposition align with the established narratives.

Figure B.4: Macroeconomic responses with (red) and without (blue) narrative restrictions



Notes: The solid red line reports the median response and the corresponding light red shaded area represents the 68% probability bands using sign, zero and narrative restrictions (our baseline identification strategy). The solid blue line and its corresponding grey shaded area depict the median response and the 68% credible sets if no narrative restrictions are used. The horizontal axis is time, measured in months.

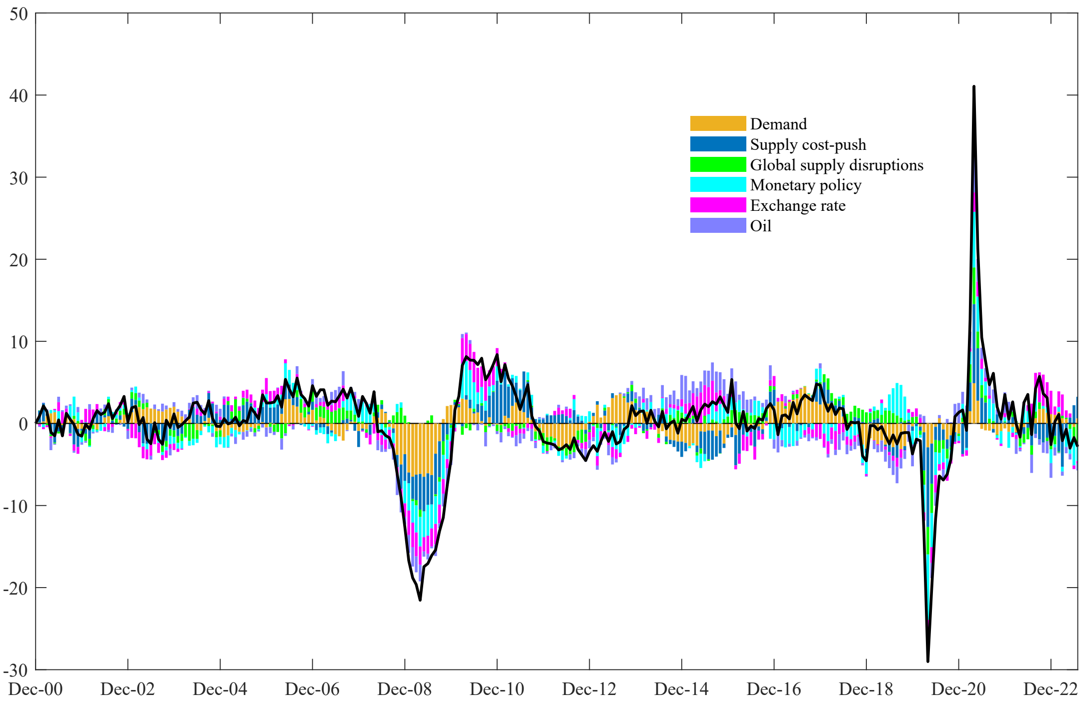
chain pressures contributed negatively and thus alleviated the buildup of inflationary pressures, while most shocks pushed euro area inflation above its mean. In the aftermath of the GFC and during the European sovereign debt crisis, we witnessed the opposite: global supply chain disruptions raising inflation, while demand shocks exerting significant downward pressures on inflation.[35] Then, during much of the post-crisis period (2014-2019), inflation persistently fell below the ECB's medium-term target, which in numerous cases was driven by many of the considered structural shocks. Our results imply that favorable shocks to global supply chains played an important role in driving down euro area inflation, most likely as a result of the globalization trend (that lasted until the China-US trade disputes of 2017-18). Finally, the COVID pandemic triggered supply chain disruptions and production bottlenecks, which became a major challenge for the global economy. Through the lens of our BVAR model, since December 2020, shocks to global supply chain pressures had a steady and growing positive contribution to core inflation dynamics, peaking to 65% in April 2022, reflecting the highly persistent impact of global supply chain pressure shocks.

Figure C.3 shows the response of euro area unemployment to the global supply chain pressure shocks, as estimated by our baseline BVAR model, which we obtained by means of a standard local projection model that regresses unemployment on the global supply chain pressure shock, 10 of its own lags and 10 lags of the shock. The figure shows that unemployment does not respond significantly in the short run

[35] The former most likely captures the consequences of a collapse in international trade, the ensuing decline in GVC participation and two natural disasters that occurred in 2011 (i.e. the Tōhoku earthquake and Thailand flooding) that resulted in supply chain bottlenecks in the auto and electronics manufacturing sectors.

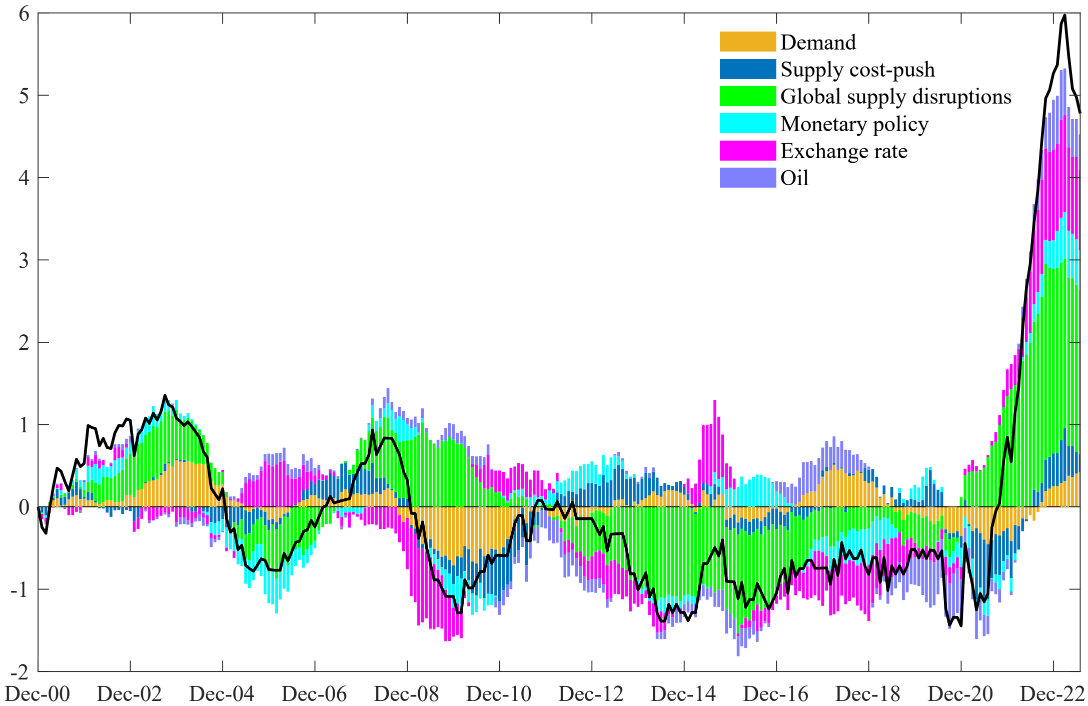
following the shock, or even in the medium run. Only in the very long run do we observe a statistically significant positive response of unemployment.

Figure C.1: Historical shock decomposition of euro area industrial production



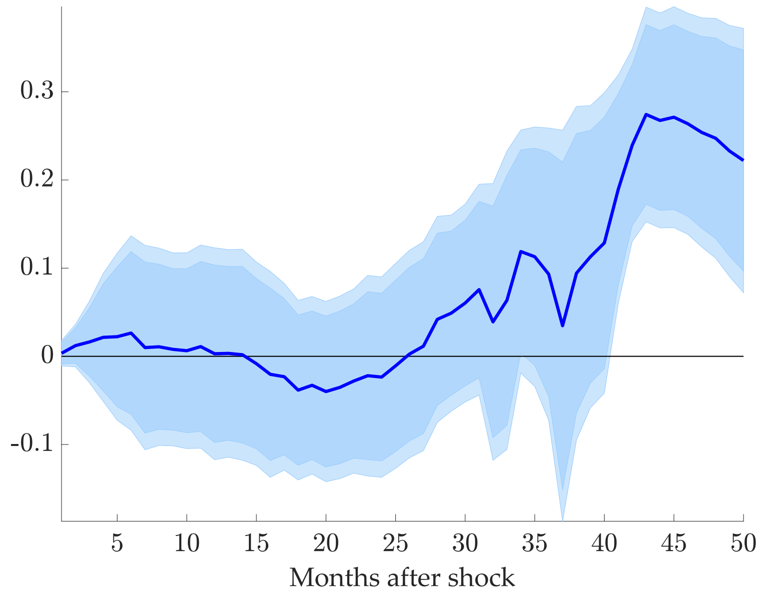
Notes: The bars show the contributions (percentage points) of the identified shocks to industrial production over time. Industrial production (our proxy for economic activity in the euro area) measured by y-o-y % change. Units expressed in deviations from mean.

Figure C.2: Historical shock decomposition of euro area core inflation



Notes: The bars show the contributions (percentage points) of the identified shocks to core inflation over time. Core inflation measured by y-o-y % change of HICP excluding energy. Units expressed as deviations from mean.

Figure C.3: Response of euro area unemployment rate to global supply chain pressure shock



Notes: Shaded (light shaded) area corresponds to the 95% (90%) confidence interval.

D GSCPI shocks and European economies: The Netherlands versus Germany

Our conjecture that EA shocks (i.e., aggregate demand, domestic supply and monetary policy) do not affect contemporaneously the GSCPI might seem too restrictive, given that the EA is a large economic block which could potentially affect global supply chains. Moreover, there could be heterogeneity across euro area countries in terms of their reliance on global value chains (GVCs). Here, we conduct the same BVAR exercise (using our baseline identification strategy of the shocks summarized in Table 2.2) for (i) The Netherlands, which is a small open economy and (ii) Germany, which is the largest European economy. While both of these European economies rely on GVCs (see Figures 2.1, 2.2 and 2.3 in the main paper) and are both exposed to foreign supply shocks, The Netherlands seems more vulnerable than Germany given its high measure of backward- and downstream GVC participation (Figure 2.3, panel a).

The response of core inflation to global and domestic supply shocks in both countries are in line with our baseline results based on the aggregate EA economy (see Figure D.1). As expected, since The Netherlands is more exposed to global supply chain pressures, the peak response of core inflation to this shock is relatively larger when compared to the response of German core inflation.

E Sensitivity to the COVID period

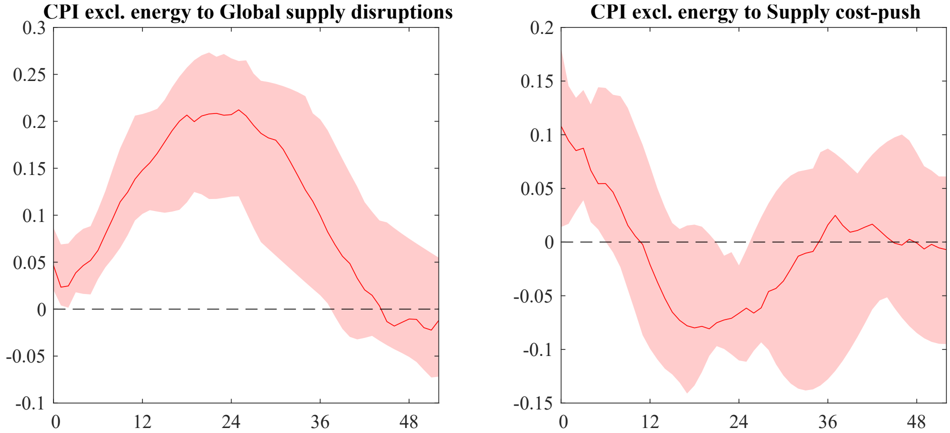
Here we report that our results are robust to the exclusion of the COVID period from the sample.

Specifically, when estimating the Phillips curve using data up until December 2019, see Table E.1, we find that the coefficients do not change much quantitatively compared to our baseline results. Importantly, the coefficient on the GSCPI remains positive and statistically significant. Furthermore, we find that, for core inflation, the slope of the Phillips curve is greater when augmented with the GSCPI, consistent with our baseline results.

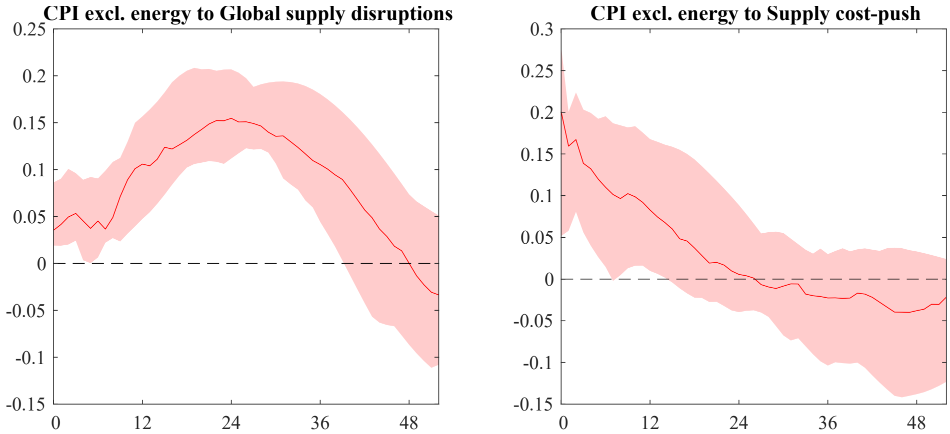
Figure E.1 reports below the IRFs to a global supply chain pressure shock based on our baseline BVAR model, but estimated on the pre-COVID sample. In this case, we only make use of the natural disaster in Japan to better identify the global supply chain pressure shock. As in our baseline estimation, we assume that global supply chain pressure shocks have a positive value in March 2011 and that they are the most important contributor to the observed unexpected movements in the GSCPI in that period. Moreover, we also keep the oil-related narrative sign restrictions, namely we impose that oil price shocks have a positive sign in March 2003 (outbreak of the Iraq War) and February 2011 (outbreak of the Libyan Civil War). The IRFs reveal that once we exclude the COVID period from the sample, the impact of global

Figure D.1: Response of core inflation to global and domestic supply shocks

(a) The Netherlands



(b) Germany



Notes: The figure shows the response of core inflation (based on the CPI excluding energy) to a one standard deviation global supply chain pressure shock (left panel) and to a one standard deviation domestic supply cost-push shock (right panel). The solid red line reports the median response. Shaded areas represent the 68% probability bands. The horizontal axis is time, measured in months.

supply chain pressure shocks on euro area core inflation is more muted and less persistent compared to our baseline results.[36] Already after one quarter, the response becomes insignificant (in Bayesian terms), rendering this impact highly uncertain.[37] Hence, while the COVID pandemic plays an important role in accurately identifying the effects of a global supply chain pressure shock on inflation quantitatively, excluding the COVID period does not alter the qualitative result that global supply chain pressure shocks are inflationary.

[36] Moreover, the contribution of global supply chain pressure shocks to core inflation becomes smaller when considering only the pre-COVID period.

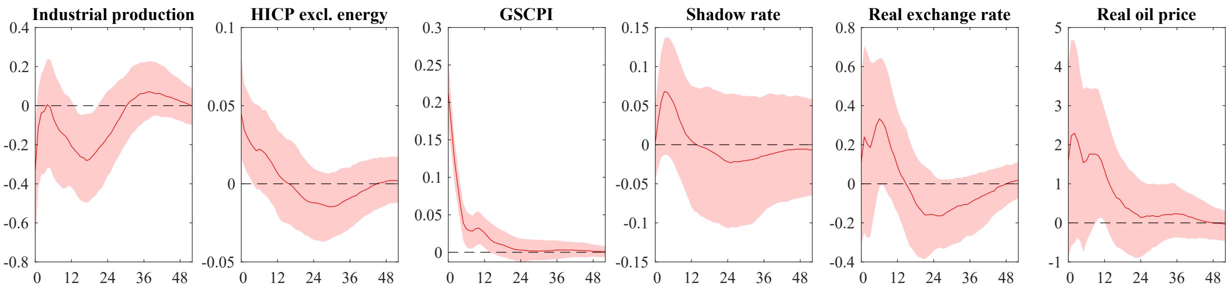
[37] We obtain similar results if we were to add two more narrative sign restrictions on the global supply chain pressure shocks, motivated by the expansion of the Suez and Panama canals in August 2015 and June 2016, respectively (implying favorable or easing GSCPI shocks).

Table E.1: Estimates of the euro area Phillips curve using pre-COVID sample

Dependent variable	(1) Headline HICP	(2) Core HICP	(3) Headline HICP	(4) Core HICP
Industrial production	0.013***	0.01***	0.012***	0.07***
	[0.004]	[0.002]	[0.004]	[0.009]
1-year ahead inflation expectations	0.073	0.024	0.082*	0.32***
	[0.049]	[0.029]	[0.049]	[0.102]
GSCPI			**0.085****	**0.416*****
			[0.04]	[0.082]
Adjusted R-squared	0.939	0.919	0.94	0.742
BIC	7.48	-183.16	2.91	260.91
Obs.	177	177	177	177

Notes: Core HICP is proxied by HICP excluding energy. All variables expressed as y-o-y % changes, except for the GSCPI (standard deviation from mean). *, ** and *** indicate significance at 10%, 5% and 1%. Standard errors reported in brackets. Estimates of the constant and the coefficient on the lags of the dependent variable are omitted. The estimation sample is 2005M4-2019M12.

Figure E.1: Responses to a global supply chain pressure shock, pre-COVID period



Notes: The figure shows the responses to a one standard deviation global supply chain pressure shock. The solid red line reports the median response. Shaded areas represent the 68% probability bands. The horizontal axis is time, measured in months. The estimation sample stops in December 2019.

F The full theoretical model

The model describes two countries, **H**ome and **F**oreign, and follows Benigno (2009). The relative population size of Home with respect to Foreign is governed by the parameter $s \in [0, 1]$. Foreign variables are denoted with an asterisk superscript.

F.1 Households

F.1.1 Intratemporal problem

The consumption bundles of Home households, c_t, and Foreign households, c_t^*, are given by the following aggregators:

$$c_t = \left[(1-\mu)^{\frac{1}{\eta}} \left(c_{H,t} \right)^{\frac{\eta-1}{\eta}} + \mu^{\frac{1}{\eta}} \left(c_{F,t} \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

$$c_t^* = \left[(1-\mu^*)^{\frac{1}{\eta}} \left(c_{F,t}^* \right)^{\frac{\eta-1}{\eta}} + \mu^{*\frac{1}{\eta}} \left(c_{H,t}^* \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

where $c_{H,t}$ and $c_{F,t}$ ($c_{H,t}^*$ and $c_{F,t}^*$) denote consumption by Home (Foreign) households of Home and Foreign final goods. The parameters $\mu \in [0, 1]$ and $\mu^* \in [0, 1]$ measure the import share in consumption, while η denotes the elasticity of substitution between Home and Foreign final goods. The optimal demand schedules for $c_{H,t}$ and $c_{F,t}$, and the consumer price index for Home are given by

$$c_{H,t} = (1-\mu)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} c_t,$$
$$c_{F,t} = \mu\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} c_t,$$
$$P_t = \left[(1-\mu)\, P_{H,t}^{1-\eta} + \mu P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}},$$

where $P_{H,t}$ and $P_{F,t}$ are the Home and Foreign producer price indices (PPI), denominated in Home currency, and P_t is the Home consumer price index (CPI) denominated in Home currency. Similarly, the optimal demand schedules for $c^*_{H,t}$ and $c^*_{F,t}$, and the Foreign consumer price index are given by

$$c^*_{H,t} = \mu^*\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta} c^*_t,$$
$$c^*_{F,t} = (1-\mu^*)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\eta} c^*_t,$$
$$P^*_t = \left[\mu^* P^{*1-\eta}_{H,t} + (1-\mu^*)\, P^{*1-\eta}_{F,t}\right]^{\frac{1}{1-\eta}}.$$

Define the real exchange rate as $q_t \equiv e_t P^*_t / P_t$,with e_t the nominal exchange rate (i.e. the price of one unit of Foreign currency in terms of Home currency). Assuming the law of one price holds then implies the following:

$$p_{H,t} = q_t p^*_{H,t}, \tag{A1}$$
$$p_{F,t} = q_t p^*_{F,t}, \tag{A2}$$

where we defined $p_{H,t} \equiv P_{H,t}/P_t$ and $p_{F,t} \equiv P_{F,t}/P_t$ (and similarly for $P^*_{H,t}$ and $P^*_{F,t}$).

F.1.2 Intertemporal problem

Home households The objective function of a representative household in Home is given by

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{1+\varphi}}{1+\varphi}\right), \tag{A3}$$

where κ_L is used to pin down the steady-state value of hours worked, n_t. The parameters $\beta \in (0,1)$, $\sigma > 0$ and $\varphi > 1$ denote the discount factor, relative risk aversion coefficient and inverse Frisch elasticity of labor supply, respectively. The household's budget constraint is given by

$$P_t c_t + B_{H,t} + e_t B_{F,t} = R_{t-1} B_{H,t-1} + e_t R^*_{t-1} B_{F,t-1} + W_t n_t + P_t \Gamma_t + P_t \Gamma_{f,t} - \frac{\kappa_D}{2} e_t P^*_t \left(\frac{B_{F,t}}{P^*_t} - \bar{b}_F\right)^2, \tag{A4}$$

where W_t denotes the nominal wage rate, Γ_t firm profits, and R_t and R^*_t the gross nominal return on, respectively, holdings of Home bonds (denominated in Home currency), $B_{H,t}$, and Foreign bonds (denominated in Foreign currency), $B_{F,t}$. The final term in Equation (A4) represents a quadratic financial intermediation cost of holding Foreign bonds, with $\kappa_D > 0$ governing the size of the financial intermediation cost, which is paid to the Foreign household. Conversely, Foreign households pay a financial intermediate cost, $\Gamma_{f,t}$, to Home households when adjusting their portfolio of Home bonds, $b^*_{H,t}$:

$$\Gamma_{f,t} = \frac{1-s}{s} \frac{\kappa_D}{2} \left(b^*_{H,t} - \bar{b}^*_H\right)^2.$$

Maximizing the objective function subject to the period budget constraint yields the following first-order conditions:

$$\lambda_t = c_t^{-\sigma}, \tag{A5}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t}{\pi_{t+1}} \right), \tag{A6}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t^*}{\pi_{t+1}^*} \frac{q_{t+1}}{q_t} \right) - \kappa_D \left(b_{F,t} - \bar{b}_F \right), \tag{A7}$$

$$\kappa_L n_t^{\varphi} = \lambda_t w_t, \tag{A8}$$

with λ_t the Lagrange multiplier on the period budget constraint and where $\pi_t \equiv P_t/P_{t-1}$, $w_t \equiv W_t/P_t$ and $b_{F,t} \equiv B_{F,t}/P_t^*$.

Foreign households The representative Foreign household faces a similar objective function:

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{*1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{*1+\varphi}}{1+\varphi} \right), \tag{A9}$$

and period budget constraint:

$$c_t^* + q_t^{-1} b_{H,t}^* + b_{F,t}^* = q_t^{-1} \frac{R_{t-1}}{\pi_t} b_{H,t-1}^* + \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1}^* + w_t^* n_t^* - \frac{\kappa_D}{2} q_t^{-1} \left(b_{H,t}^* - \bar{b}_H^* \right)^2 + \Gamma_t^* + \Gamma_{f,t}^*,$$

where

$$\Gamma_{f,t}^* = \frac{s}{1-s} \frac{\kappa_D}{2} \left(b_{F,t} - \bar{b}_F \right)^2.$$

The corresponding first-order conditions are given by

$$\lambda_t^* = c_t^{*-\sigma}, \tag{A10}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{R_t^*}{\pi_{t+1}^*} \right), \tag{A11}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{R_t}{\pi_{t+1}} \frac{q_t}{q_{t+1}} \right) - \kappa_D \left(b_{H,t}^* - \bar{b}_H^* \right), \tag{A12}$$

$$\kappa_L n_t^{*\varphi} = \lambda_t^* w_t^*. \tag{A13}$$

F.2 Final consumption goods

The Home final consumption good, $y_{H,t}$, is a composite of different varieties, $y_{H,t}(i)$, produced by domestic firm $i \in [0,1]$:

$$y_{H,t} = \left[\int_0^1 y_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

where $\varepsilon > 1$ denotes the elasticity of substitution between intermediate goods from the same country. The optimal demand for variety i is given by

$$y_{H,t}(i) = \left(\frac{p_{H,t}(i)}{p_{H,t}} \right)^{-\varepsilon} y_{H,t}. \tag{A14}$$

Similarly, for Foreign:

$$y_{F,t}^*(i) = \left(\frac{p_{F,t}^*(i)}{p_{F,t}^*} \right)^{-\varepsilon} y_{F,t}^*. \tag{A15}$$

F.3 Firms

F.3.1 Intermediate goods producers

Intermediate goods producers in Home and Foreign face the following production functions:

$$x_t = z_{A,t} n_t, \tag{A16}$$
$$x_t^* = z_{A,t}^* n_t^*, \tag{A17}$$

where x_t and x_t^* are the intermediate goods produced in Home and Foreign, respectively. Productivity shocks $z_{A,t}$ and $z_{A,t}^*$ evolve according to a stationary AR(1) process:

$$\ln z_{A,t} = (1 - \rho_A) \ln z_A + \rho_A \ln z_{A,t-1} + \varepsilon_{A,t}, \tag{A18}$$
$$\ln z_{A,t}^* = (1 - \rho_A) \ln z_A^* + \rho_A \ln z_{A,t-1}^* + \varepsilon_{A,t}^*, \tag{A19}$$

with $\rho_A \in [0, 1]$, $\varepsilon_{A,t} \sim \mathcal{N}\left(0, \sigma_A^2\right)$ and $\varepsilon_{A,t}^* \sim \mathcal{N}\left(0, \sigma_A^2\right)$. The intermediate goods producers operate under perfect competition and therefore set their prices equal to nominal marginal costs.

F.3.2 Final goods producers

Following Eyquem and Kamber (2014), final goods producers use Home and Foreign intermediate goods to produce the final good:

$$y_{H,t}(i) = \left[(1-\gamma)^{\frac{1}{\phi}} \left(x_{H,t}(i)\right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(x_{F,t}(i)\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}},$$
$$y_{F,t}^*(i) = \left[(1-\gamma^*)^{\frac{1}{\phi}} \left(x_{F,t}^*(i)\right)^{\frac{\phi-1}{\phi}} + \gamma^{*\frac{1}{\phi}} \left(x_{H,t}^*(i)\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}},$$

where $\gamma \in [0, 1]$ and $\gamma^* \in [0, 1]$ denote the share of imported intermediate goods used in the production of domestic final goods. As long as $\{\gamma, \gamma^*\} > 0$, final goods producers trade intermediate goods along the production process and we say the economy participates in GVCs. The parameter $\phi > 1$ measures the elasticity of substitution between intermediate goods from different countries. The firms' real marginal costs (expressed in terms of the domestic PPI) are given by

$$mc_t^{1-\phi} = (1-\gamma)\left(p_{H,t}^{-1} \frac{w_t}{z_{A,t}}\right)^{1-\phi} + \gamma \left(q_t p_{H,t}^{-1} \frac{w_t^*}{z_{A,t}^*}\right)^{1-\phi}, \tag{A20}$$
$$mc_t^{*1-\phi} = (1-\gamma^*)\left(p_{F,t}^{*-1} \frac{w_t^*}{z_{A,t}^*}\right)^{1-\phi} + \gamma^* \left(q_t^{-1} p_{F,t}^{*-1} \frac{w_t}{z_{A,t}}\right)^{1-\phi}, \tag{A21}$$

while the optimal demand schedules for the intermediate goods are given by

$$x_{H,t}(i) = (1-\gamma)\left(p_{H,t}^{-1} \frac{w_t / z_{A,t}}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{A22}$$
$$x_{H,t}^*(i) = \gamma^* \left(q_t^{-1} p_{F,t}^{*-1} \frac{w_t / z_{A,t}}{mc_t^*}\right)^{-\phi} y_{F,t}^*(i), \tag{A23}$$
$$x_{F,t}(i) = \gamma \left(q_t p_{H,t}^{-1} \frac{w_t^* / z_{A,t}^*}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{A24}$$
$$x_{F,t}^*(i) = (1-\gamma^*)\left(p_{F,t}^{*-1} \frac{w_t^* / z_{A,t}^*}{mc_t^*}\right)^{-\phi} y_{F,t}^*(i). \tag{A25}$$

Since final good firms operate in monopolistically competitive markets, they set the price of their own good at a markup over real marginal costs. Home firms pay quadratic adjustment costs, $AC_t(i)$, whenever they adjust their prices with respect to the benchmark $\overline{\pi}$, as in Rotemberg (1982):

$$AC_t(i) = \frac{\kappa_P}{2}\left(\frac{P_{H,t}(i)}{P_{H,t-1}(i)} - \overline{\pi}\right)^2 P_{H,t} y_{H,t},$$

where $\kappa_P \geq 0$ measures the size of the price-adjustment cost. The profit maximization problem of a generic firm i, expressed in terms of the domestic CPI, is the following:

$$\max_{P_{H,t}(i)} E_t \sum_{k=0}^{\infty} \beta^k \frac{\lambda_{t+k}}{\lambda_t} \left[\frac{P_{H,t+k}(i)}{P_{t+k}} y_{H,t+k}(i) - \frac{w_{t+k}}{z_{A,t+k}} x_{H,t+k}(i) - q_{t+k} \frac{w^*_{t+k}}{z^*_{A,t+k}} x_{F,t+k}(i) - \frac{AC_{t+k}(i)}{P_{t+k}} \right],$$

subject to

$$\begin{aligned} y_{H,t}(i) &= \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} y_{H,t}, \\ x_{H,t}(i) &= (1-\gamma) \left(p^{-1}_{H,t} \frac{w_t / z_{A,t}}{mc_t} \right)^{-\phi} y_{H,t}(i), \\ x_{F,t}(i) &= \gamma \left(q_t p^{-1}_{H,t} \frac{w^*_t / z^*_{A,t}}{mc_t} \right)^{-\phi} y_{H,t}(i). \end{aligned}$$

The corresponding first-order condition is given by

$$(\pi_{H,t} - \overline{\pi}) \pi_{H,t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} (\pi_{H,t+1} - \overline{\pi}) \pi_{H,t+1} \frac{p_{H,t+1}}{p_{H,t}} \frac{y_{H,t+1}}{y_{H,t}} \right] + \frac{\varepsilon}{\kappa_P} \left(mc_t - \frac{\varepsilon - 1}{\varepsilon} \right). \tag{A26}$$

Firm profits (deflated using the consumer price index, P_t) are given by

$$\Gamma_t = p_{H,t} y_{H,t} - \frac{w_t}{z_{A,t}} x_{H,t} - q_t \frac{w^*_t}{z^*_{A,t}} x_{F,t} - \frac{\kappa_P}{2} (\pi_{H,t} - \overline{\pi})^2 p_{H,t} y_{H,t}. \tag{A27}$$

Note that

$$\pi_{H,t} = \frac{p_{H,t}}{p_{H,t-1}} \pi_t. \tag{A28}$$

Similar conditions hold for Foreign:

$$(\pi^*_{F,t} - \overline{\pi}^*) \pi^*_{F,t} = \beta E_t \left[\frac{\lambda^*_{t+1}}{\lambda^*_t} (\pi^*_{F,t+1} - \overline{\pi}^*) \pi^*_{F,t+1} \frac{p^*_{F,t+1}}{p^*_{F,t}} \frac{y^*_{F,t+1}}{y^*_{F,t}} \right] + \frac{\varepsilon}{\kappa_P} \left(mc^*_t - \frac{\varepsilon - 1}{\varepsilon} \right). \tag{A29}$$

$$\Gamma^*_t = p^*_{F,t} y^*_{F,t} - \frac{w^*_t}{z^*_{A,t}} x^*_{F,t} - q^{-1}_t \frac{w_t}{z_{A,t}} x^*_{H,t} - \frac{\kappa_P}{2} (\pi^*_{F,t} - \overline{\pi}^*)^2 p^*_{F,t} y^*_{F,t}, \tag{A30}$$

$$\pi^*_{F,t} = \frac{p^*_{F,t}}{p^*_{F,t-1}} \pi^*_t. \tag{A31}$$

F.4 Monetary policy

Monetary policy in both countries is characterized by a standard Taylor-type rule that relates the nominal interest rate to deviations in CPI inflation and GDP with respect to their respective targets:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\overline{\pi}} \right)^{\phi_\pi} \left(\frac{gdp_t}{gdp} \right)^{\phi_y} \right]^{1-\rho_R}, \tag{A32}$$

$$\frac{R^*_t}{R^*} = \left(\frac{R^*_{t-1}}{R^*} \right)^{\rho_R} \left[\left(\frac{\pi^*_t}{\overline{\pi}^*} \right)^{\phi^*_\pi} \left(\frac{gdp^*_t}{gdp^*} \right)^{\phi^*_y} \right]^{1-\rho^*_R}, \tag{A33}$$

where $\{\overline{\pi}, \overline{\pi}^*\}$ are the inflation targets, $\{\rho_R, \rho^*_R\} \in [0,1]$ denote the interest rate smoothing parameter, $\{\phi_\pi, \phi^*_\pi\} > 1$ the monetary policy response to inflation and $\{\phi_y, \phi^*_y\} \geq 0$ the monetary policy response to output, and where

$$gdp_t = p_{H,t} y_{H,t}, \tag{A34}$$

$$gdp^*_t = p^*_{F,t} y^*_{F,t}. \tag{A35}$$

F.5 Market clearing

Goods market clearing implies:

$$y_{H,t} = (1-\mu)\, p_{H,t}^{-\eta} c_t + \left(\frac{1-s}{s}\right) \mu^* p_{H,t}^{*-\eta} c_t^* + \frac{\kappa_P}{2} \left(\pi_{H,t} - \overline{\pi}\right)^2 y_{H,t}, \tag{A36}$$

$$y_{F,t}^* = (1-\mu^*)\, p_{F,t}^{*-\eta} c_t^* + \left(\frac{s}{1-s}\right) \mu p_{F,t}^{-\eta} c_t + \frac{\kappa_P}{2} \left(\pi_{F,t}^* - \overline{\pi}^*\right)^2 y_{F,t}^*. \tag{A37}$$

Bonds market clearing implies:

$$s b_{H,t} + (1-s)\, b_{H,t}^* = 0, \tag{A38}$$

$$s b_{F,t} + (1-s)\, b_{F,t}^* = 0. \tag{A39}$$

Defining the intermediate goods terms of trade as

$$\rho_{r,t} = q_t^{-1} \frac{w_t / z_{A,t}}{w_t^* / z_{A,t}^*}, \tag{A40}$$

we obtain the following market clearing conditions for the Home and Foreign intermediate goods:

$$x_t = (1-\gamma) \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)}\right]^{\frac{\phi}{1-\phi}} y_{H,t} + \gamma^* \rho_{r,t} \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi}\right]^{\frac{\phi}{1-\phi}} y_{F,t}^*, \tag{A41}$$

$$x_t^* = (1-\gamma^*) \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi}\right]^{\frac{\phi}{1-\phi}} y_{F,t}^* + \gamma \rho_{r,t}^{-1} \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)}\right]^{\frac{\phi}{1-\phi}} y_{H,t}. \tag{A42}$$

The Home resource constraint is given by

$$c_t + tb_t = gdp_t \left[1 - \frac{\kappa_P}{2} \left(\pi_{H,t} - \overline{\pi}\right)^2\right], \tag{A43}$$

where the Home trade balance, tb_t, is given by

$$\begin{aligned} tb_t = {} & b_{H,t} + q_t b_{F,t} - \frac{R_{t-1}}{\pi_t} b_{H,t-1} - q_t \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1} \\ & + \frac{\kappa_D}{2} q_t \left(b_{F,t} - \overline{b}_F\right)^2 - \frac{1-s}{s} \frac{\kappa_D}{2} \left(b_{H,t}^* - \overline{b}_H^*\right)^2 - \Omega_t, \end{aligned} \tag{A44}$$

and $\Omega_t \equiv w_t n_t \left(1 - x_{H,t}/x_t\right) - q_t w_t^* n_t^* x_{F,t}/x_t$. The Foreign trade balance is given by

$$\begin{aligned} tb_t^* = {} & q_t^{-1} b_{H,t}^* + b_{F,t}^* - q_t^{-1} \frac{R_{t-1}}{\pi_t} b_{H,t-1}^* - \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1}^* \\ & - \frac{\kappa_D}{2} \frac{s}{1-s} \left(b_{F,t} - \overline{b}_F\right)^2 + q_t^{-1} \frac{\kappa_D}{2} \left(b_{H,t}^* - \overline{b}_H^*\right)^2 + \Omega_t. \end{aligned} \tag{A45}$$

By Walras' Law, the Foreign resource constraint is redundant.