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

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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. A Phillips curve analysis shows that global supply chain pressures contribute positively and significantly to inflation in the euro area. Furthermore, 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. Finally, a two-country New Keynesian model with 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

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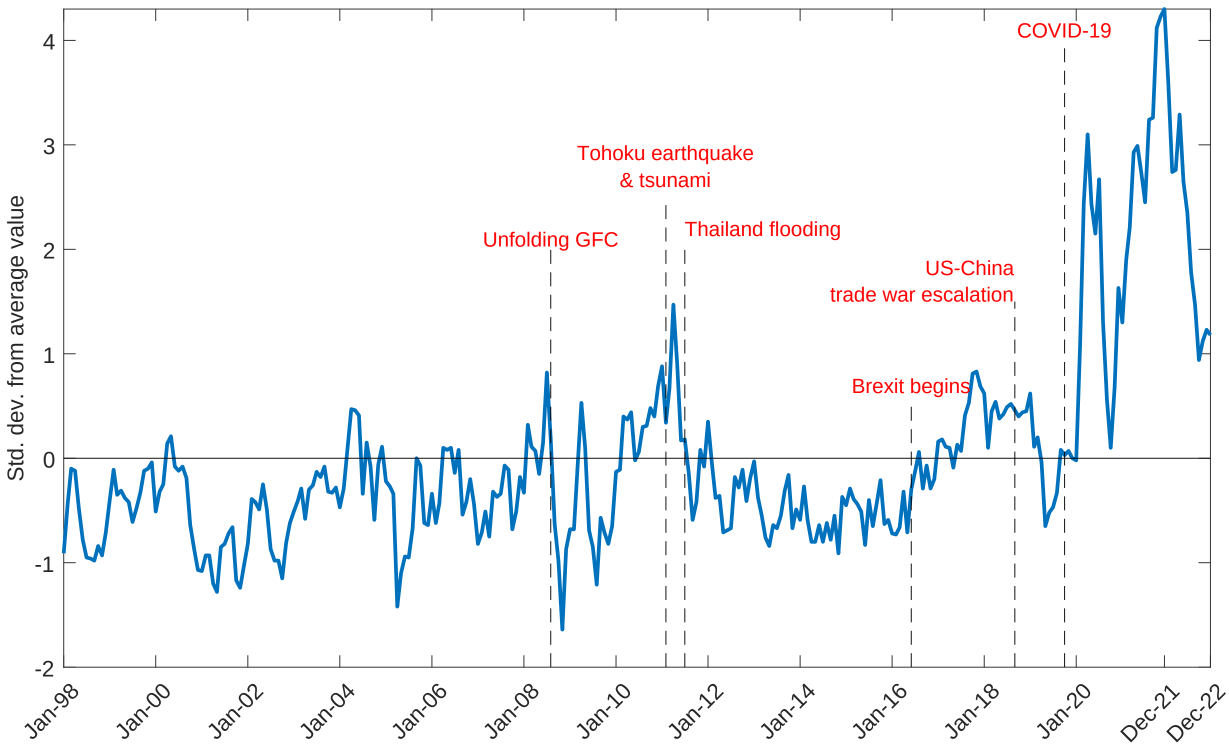
1 Introduction

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 fueled 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 an 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: Global supply chain pressures easing after historically high levels



Note: The figure displays the Global Supply Chain Pressure Index as computed by Benigno et al. (2022). The index is scaled by its standard deviation. The last observation is for December 2022. 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. As shown in Figure 1, 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 May 2022. At present, the GSCPI hovers around 1.2 standard deviations above its historical mean, indicating that supply bottlenecks remain elevated and continue to hamper production and fuel inflation.

In this paper, 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 second 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 tradeoff for monetary policy worsens and the Ramsey optimal policy calls for a less aggressive monetary policy response to avoid exacerbating the contraction in output.

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[1] 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

[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.

one-third to two-thirds of the recent surge in inflation to supply shocks (see e.g. Ferrante et al., 2022, Shapiro, 2022a, Shapiro, 2022b and di Giovanni et al., 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 pressures to euro area inflation. Related work by Carrière-Swallow et al. (2022) investigate 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), 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).[2] They also study optimal monetary policy in a two-country New Keynesian model with international trade in intermediate inputs, but focus primarily 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 (PPI) 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 of production.[3] 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 the upstream inflation rises relative to that on the final stage inflation. 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 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

[2] 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.

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

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 COVID-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 (2018) 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 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.[4] 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.[5]

We start by presenting several stylized facts about several 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 Phillips curve. Finally, in Section 2.3 we take a more structural approach and use

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

[5]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.

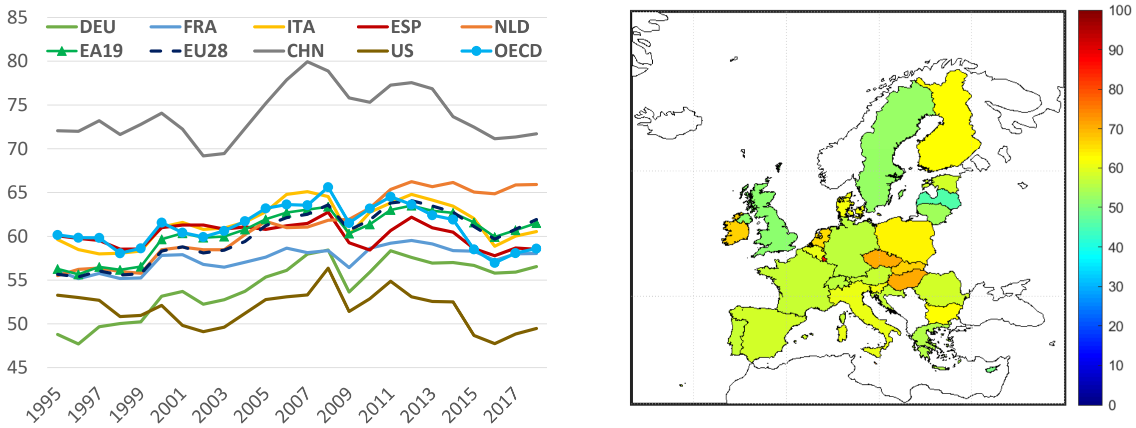
a Bayesian vector autoregressive (BVAR) model to identify shocks to global supply chain pressures and estimate their impact on euro area inflation.

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), as this determines by how much domestic prices are influenced by prices of imported intermediate inputs. 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 and 3, 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.

Figure 2: 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).

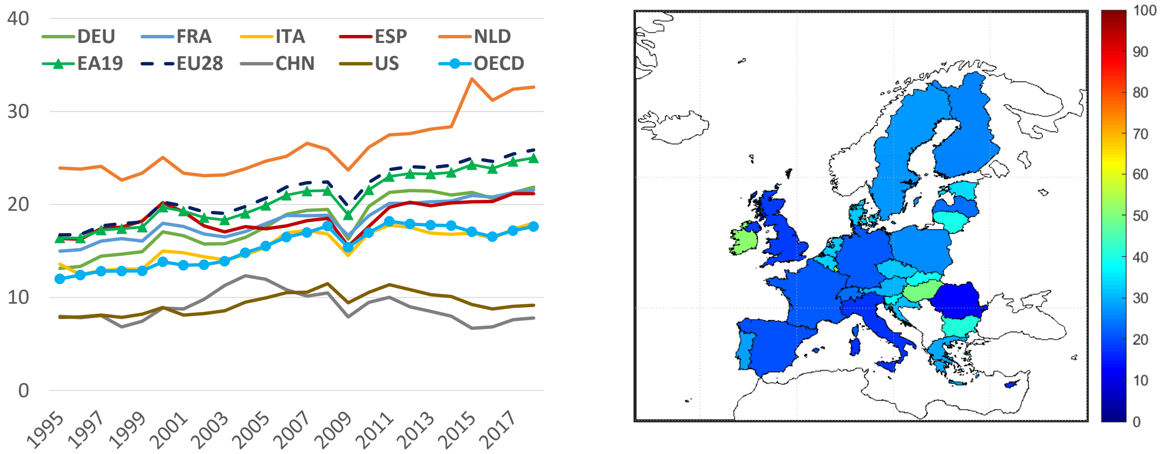
Both figures point to elevated participation in GVCs across advanced economies. Participation also appears to co-move strongly across countries, especially among euro area countries. Furthermore, participation trended upwards before the onset of the global financial crisis (GFC) and stabilized (or, in 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.[6] 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%. Note that we

[6] 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 3: Share of intermediate imports in total intermediate inputs (%)

(a) Advanced economies, 1995-2018

(b) European countries, 2018



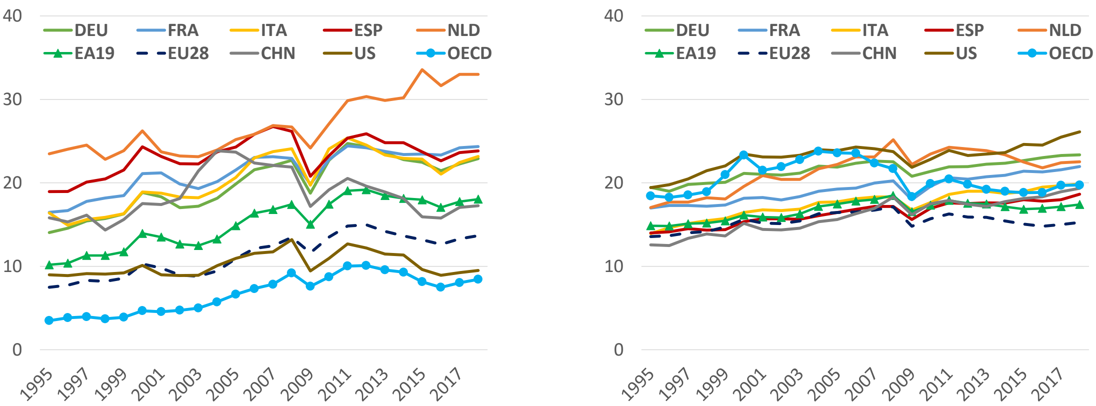
Source: OECD, TiVA 2021 edition (last year available is 2018).

use this latter measure to inform the calibration of our key parameter, γ, which captures the share of foreign intermediate goods used in domestic production in our theoretical model, see Section 3.1.5.

Figure 4: 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.

In Figure 4, we consider two alternative measures of participation in GVCs. Panel *a* reports the 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.[7]

2.2 Global supply chain pressures and inflation dynamics

We quantify the relationship between global supply chain pressures and euro area inflation by estimating a 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 2004M1-2022M11.[8]

Table 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. Near the end of 2021, these pressures contributed to around 1.5 percentage points to core inflation. Second, while

[7] 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.

[8] 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.

Table 1: Estimates of the euro area Phillips curve

Dependent variable	(1) Headline HICP	(2) Core HICP	(3) Headline HICP	(4) Core HICP
Industrial production	0.009***	0.004**	0.01***	0.053***
	[0.003]	[0.002]	[0.003]	[0.006]
1-year ahead inflation expectations	0.011	-0.004	0.054	0.456***
	[0.044]	[0.024]	[0.044]	[0.091]
GSCPI			**0.077*****	**0.291*****
			[0.02]	[0.042]
Adjusted R-squared	0.978	0.975	0.979	0.903
BIC	53.45	-186.7	39.05	367.33
Obs.	212	212	212	212

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 2004M1-2022M11.

the slope of the Phillips curve is positive and significant in all specifications, it is estimated to be almost flat in the baseline without the GSCPI, and much steeper in the alternative specification with the GSCPI. 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 ten-year OIS rate (as an indicator for the ECB's effective monetary policy stance) and the real effective exchange rate (with respect to the euro area's 42 main trading partners). 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 covering the period 2000M1-2022M11.[9]

Following the approach proposed by Antolín-Díaz and Rubio-Ramírez (2018), we use both sign and narrative restrictions to identify global supply chain pressure shocks and distinguish them from domestic supply and demand (and other) shocks.[10] This exercise thereby helps us to obtain novel estimates of the response of euro area inflation to global supply shocks, which is the main focus of this paper, but also to

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

[10] Our identification of global supply chain pressure shocks may be contaminated by exogenous movements in energy prices. Therefore, as a robustness exercise, we estimate an alternative version of our BVAR model in which we also identify an energy price shock. The corresponding results are provided in Appendix B.

inform about the relative importance of these 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 and narrative restrictions

The reduced-form VAR model follows the common specification:

$$y_t = a + \sum_{k=1}^{L} A_k y_{t-k} + \varepsilon_t, \quad t = 1, 2, ..., T \tag{1}$$

where y_t represents the vector of endogenous variables described earlier and ε_t the residual term. We set $L = 12$ and rely on Bayesian techniques to estimate the model.

We use the model to identify five shocks: a domestic demand shock, a domestic supply shock, a global supply shock, a monetary policy shock and an exchange rate shock. The sign restrictions that we impose (on impact) to identify these shocks are in line with economic theory and shown in Table 2. 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 real exchange rate appreciation. A negative shock to global supply implies a rise in both the GSCPI and core inflation, and a fall in industrial production.[11]

A contractionary monetary policy shock leads to a fall in core inflation. Finally, a positive shock to the real exchange rate (i.e. an appreciation) lowers both industrial production and core inflation.

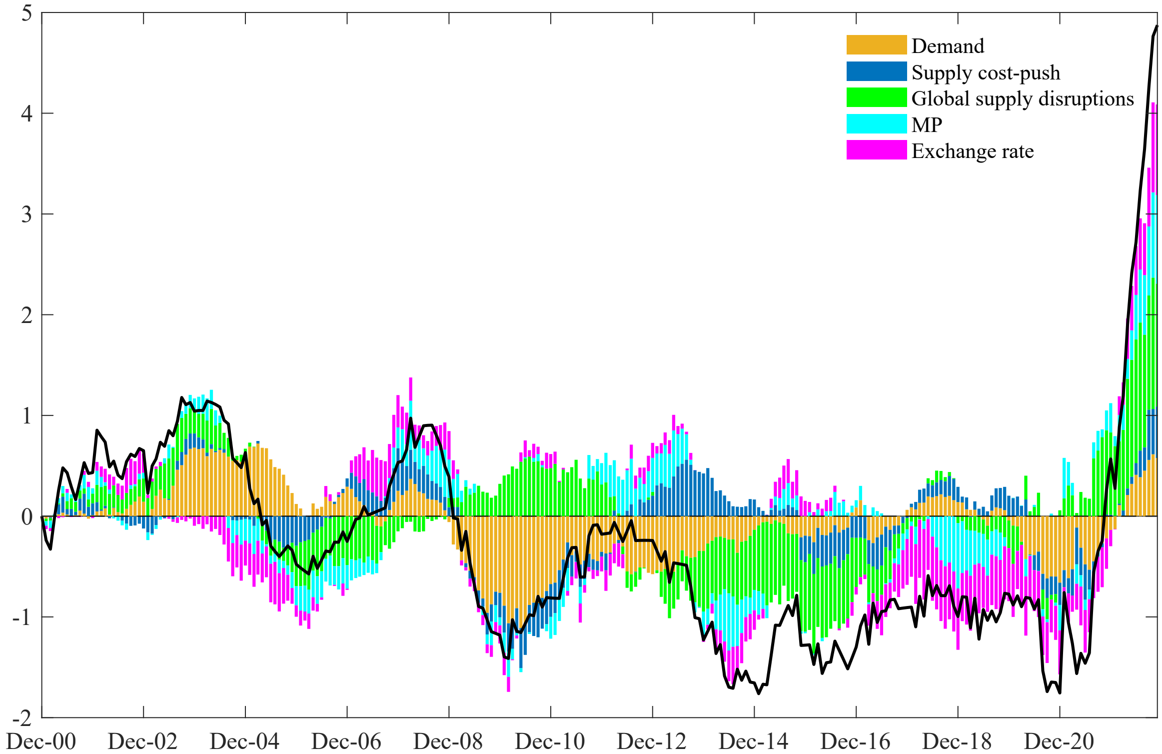
Table 2: Sign (on impact) and narrative restrictions imposed to identify the structural shocks

I. Sign restrictions	Demand	Supply cost-push	**Global supply**	Monetary policy	Exchange rate
Industrial production (y-o-y % change)	+	−	−		−
HICP excl. energy (y-o-y % change)	+	+	+	−	−
GSCPI (std. dev from mean)			+		
10Y OIS rate (%)	+			+	
REER 42 partners (y-o-y % change)		+			+
II. Narrative restrictions	Demand	Supply cost-push	**Global supply**	Monetary policy	Exchange rate
Largest contribution to					
1. 10Y OIS forecast errors				January 2015	
2. GSCPI forecast errors			April 2020 & November 2021		
Sign of shocks					
3. Demand	− March-April 2020				

In addition to these sign restrictions, we impose three narrative restrictions to further discipline the parameter space (see Table 2). First, the largest contribution to the forecast errors of the ten-year OIS rate in January 2015 is attributed to monetary policy shocks. This is motivated by the ECB's Asset Purchasing Program (APP) announcement on 22 of January 2015. This narrative restriction helps better identify monetary policy shocks, while also capturing the quantitative easing (QE) effects of monetary policy. Second, for the GSCPI in April 2020 and November 2021, shocks to global supply chain pressures

[11] 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 and 3, 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.

Figure 5: Historical shock decomposition of euro area core inflation



Notes: Core inflation measured by y-o-y % change of HICP excluding energy. Units expressed in deviations from mean.

are assumed to be the main contributors to the forecast errors. Choosing these two key historical events is motivated by the unprecedented surges in the GSCPI (see Figure 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. Third, demand shocks have a negative sign in March and April 2020, motivated by the onset of the COVID-19 pandemic.

2.3.2 Decomposing euro area inflation

Figure 5 displays the historical shock decomposition of core inflation, expressed in deviations from the unconditional mean. Several episodes stand out. First, in the run-up to the GFC, 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 most cases was driven by all five shocks. In response, the European Central Bank moved its key policy rate below zero (up to -0.5% in September 2019) in an attempt to stimulate aggregate demand. However, our results show that, on the back of a globalization trend (that lasted until the China-US trade disputes of 2017-18), positive global supply shocks played an important role in driving down euro area inflation. This result is consistent with the narrative that the effect of expansionary 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.[12]

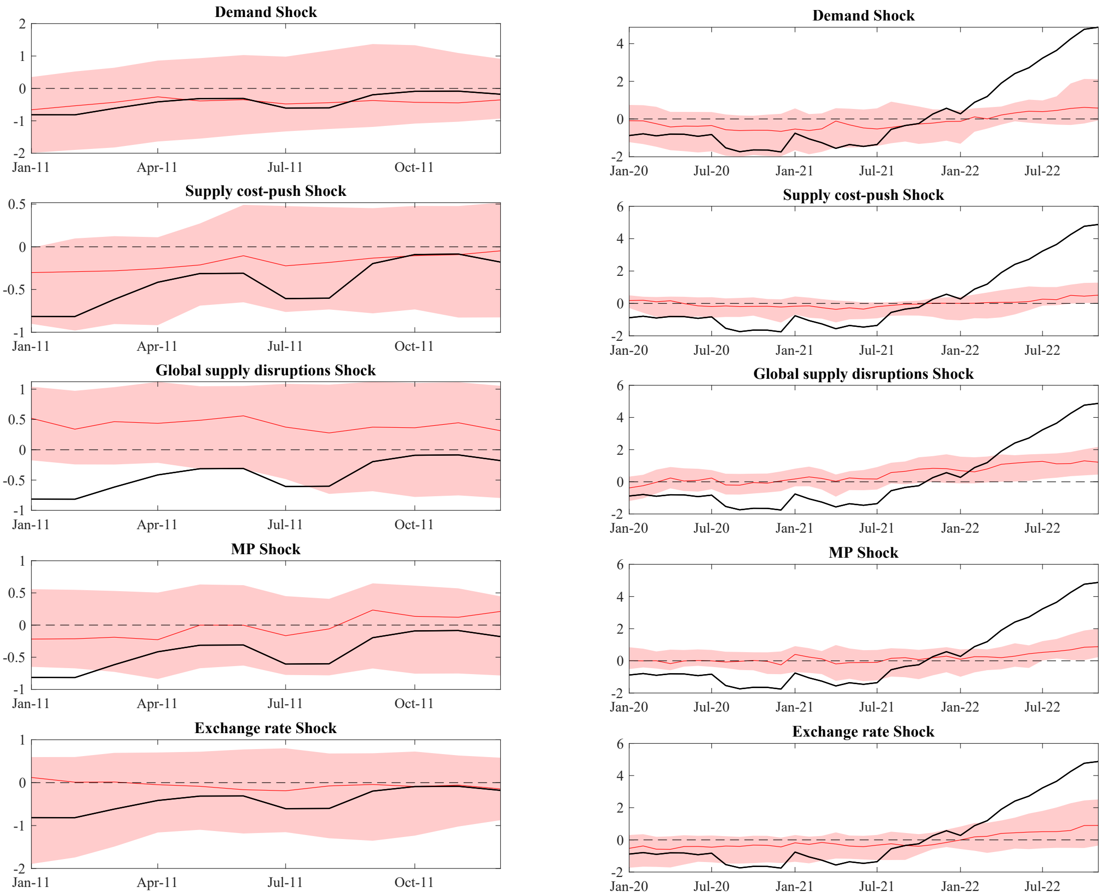
Third, the COVID-19 pandemic unfolded as a combination of supply and demand shocks rippling through the global economy in overlapping waves. Following the health crisis, supply chain disruptions and production bottlenecks became a major challenge for the global economy. The interplay of lockdowns, mobility restrictions, broad-based factory closures and, eventually, a strong rebound in global demand for manufacturing goods resulted in bottlenecks, shipping costs surges and prolonged delivery times. Our model suggests that since August 2021, shocks to global supply chain pressures had a steady and growing positive contribution to core inflation dynamics. This contribution mounted to 51% in 2022Q2 on average. In line with the observed decline in the GSCPI near the end of 2022 (see Figure 1), the contribution of global supply chain pressure shocks to inflation gradually diminished to 31% in October and November 2022. However, despite this reduction, global supply chain pressure shocks continued to exert a dominant influence on inflation compared to other shocks. Inflation dynamics were also significantly influenced by domestic supply shocks, which accounted for approximately 10% of the overall inflation increase in 2022Q3, owing to soaring food prices and tight labor market conditions. Inflationary pressures in 2022 also stemmed from 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. Finally, monetary policy has been contributing positively to inflation as well, implying a looser than expected monetary stance.

Next, we focus on two selected episodes during which the GSCPI surged, i.e. 2011 and 2020-2022, and report the observed unexpected fluctuations in core inflation attributed to each of the structural shocks. Figure 6, panel *a*, zooms in on the year 2011, which witnessed two natural disasters: (i) the Tōhoku earthquake (and subsequent tsunami), 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. Even though we did not impose any narrative restrictions on this episode, shocks to global supply disruptions seem to have played an important role in driving euro area core inflation dynamics. Throughout 2011, fluctuations in core inflation attributed to global supply chain pressure shocks alone amounted, on average, to about 0.4 percentage points (see third plot in

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

Figure 6: Historical decomposition of core inflation around two selected episodes

(a) Two natural disasters **(b)** COVID-19 pandemic



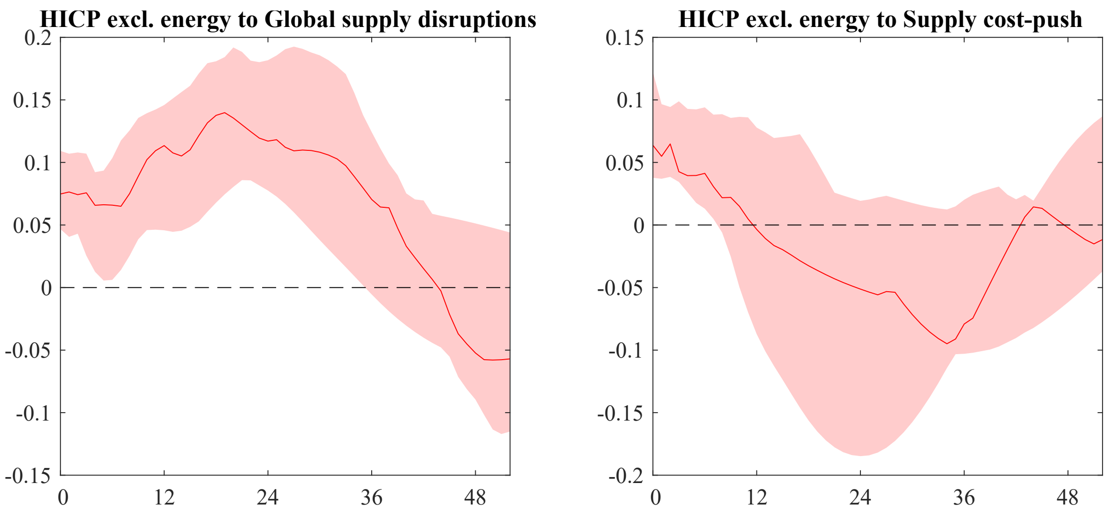
Notes: The two panels display the observed unexpected fluctuations in core inflation attributed to each of the structural shocks for two selected historical episodes: (i) two natural disasters which occurred in 2011, i.e. the Tōhoku earthquake (and the resulting tsunami) and the Thailand flooding (panel *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 identification (sign and narrative) restrictions, while the pink shaded area represents the 68% (point-wise) probability bands.

panel *a*). 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 has 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. Further, note that in the second half of 2022, all shocks have exerted upward pressures on euro area inflation.

2.3.3 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 7. 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. In particular, the effect of the domestic cost-push shock on core inflation is positive on impact, but quickly diminishes thereafter, becoming statistically insignificant after about seven months. Conversely, the positive effect of the global supply chain pressure shock slowly builds up, peaks after two years and persists for nearly three years. 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 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 are receding, they may continue to add to inflationary pressures for some time.

Figure 7: Response of core inflation to global and domestic supply shocks

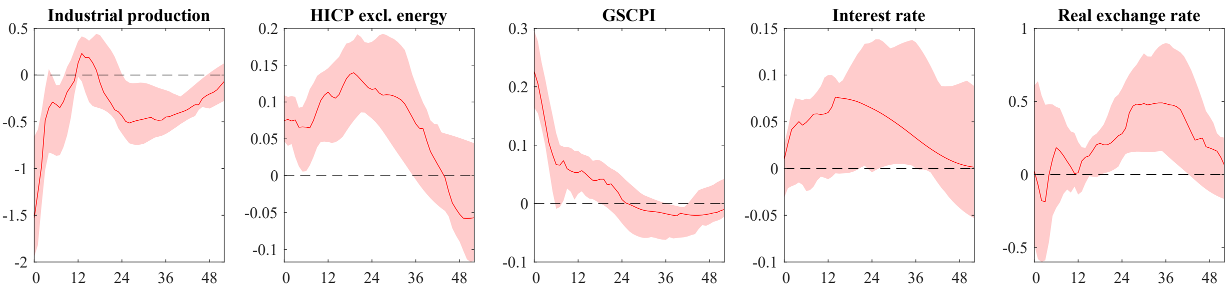


Notes: The figure shows the response of euro area core inflation (based on the HICP excluding energy) to a one standard deviation global supply chain pressure shock (left panel) and to a one standard deviation domestic supply cost-push shock (right panel). The solid red line reports the median response.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

Finally, Figure 8 reports the responses of the other endogenous variables following a global supply chain pressure shock.[13] The real exchange rate gradually appreciates over time, 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 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 external shocks. The response of the ten-year OIS rate is positive (although mostly not significant), 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 tradeoff between stabilizing inflation and output.

[13]For completeness, we report the responses to the other shocks in Appendix C.

Figure 8: 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.

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.[14] 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, $c_{F,t}$:

$$c_t = \left[(1-\mu)^{\frac{1}{\eta}} (c_{H,t})^{\frac{\eta-1}{\eta}} + \mu^{\frac{1}{\eta}} (c_{F,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

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

[14] The full model is presented in Appendix D.

price index (CPI) P_t are given by:

$$c_{H,t} = (1-\mu)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} c_t, \tag{3}$$

$$c_{F,t} = \mu\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} c_t, \tag{4}$$

$$P_t = \left[(1-\mu) P_{H,t}^{1-\eta} + \mu P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{5}$$

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 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 $i \in [0,1]$:

$$c_{H,t} = \left[\int_0^1 c_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{6}$$

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

$$c_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} c_{H,t}, \tag{7}$$

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

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:

$$E_0 \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{1+\varphi}}{1+\varphi}\right), \tag{8}$$

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:

$$P_t c_t + B_{H,t} + e_t B_{F,t} = R_{t-1} B_{H,t-1} + e_t R^*_{t-1} B_{F,t-1} + W_t n_t + P_t \Gamma_t + P_t \Gamma_{f,t} - \frac{\kappa_D}{2} e_t P^*_t \left(\frac{B_{F,t}}{P^*_t} - \bar{b}_F \right)^2 . \quad (9)$$

The last term on the right-hand side of (9) 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 (8) subject to (9) and an appropriate transversality condition yields the following first-order conditions:

$$\lambda_t = c_t^{-\sigma}, \quad (10)$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t}{\pi_{t+1}} \right), \quad (11)$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R^*_t}{\pi^*_{t+1}} \frac{q_{t+1}}{q_t} \right) - \kappa_D \left(b_{F,t} - \bar{b}_F \right), \quad (12)$$

$$\kappa_L n_t^{\varphi} = \lambda_t w_t, \quad (13)$$

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:

$$x_t = z_{A,t} n_t, \quad (14)$$

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

$$\ln z_{A,t} = (1 - \rho_A) \ln z_A + \rho_A \ln z_{A,t-1} + \varepsilon_{A,t}, \quad (15)$$

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:

$$y_{H,t}(i) = \left[(1-\gamma)^{\frac{1}{\phi}} \left(x_{H,t}(i) \right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(x_{F,t}(i) \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \tag{16}$$

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:

$$MC_t(i) = MC_t = \left[(1-\gamma) \left(\frac{W_t}{z_{A,t}} \right)^{1-\phi} + \gamma \left(e_t \frac{W_t^*}{z_{A,t}^*} \right)^{1-\phi} \right]^{\frac{1}{1-\phi}}. \tag{17}$$

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

$$x_{H,t}(i) = (1-\gamma) \left(p_{H,t}^{-1} \frac{w_t / z_{A,t}}{mc_t} \right)^{-\phi} y_{H,t}(i), \tag{18}$$

$$x_{F,t}(i) = \gamma \left(q_t p_{H,t}^{-1} \frac{w_t^* / z_{A,t}^*}{mc_t} \right)^{-\phi} y_{H,t}(i), \tag{19}$$

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 $\overline{\pi}$, a-la Rotemberg (1982):

$$AC_t(i) = \frac{\kappa_P}{2} \left(\frac{P_{H,t}(i)}{P_{H,t-1}(i)} - \overline{\pi} \right)^2 P_{H,t} y_{H,t}, \tag{20}$$

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 (7) and (18)-(20). The corresponding first-order condition is given by:

$$(\pi_{H,t} - \overline{\pi}) \pi_{H,t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} (\pi_{H,t+1} - \overline{\pi}) \pi_{H,t+1} \frac{p_{H,t+1}}{p_{H,t}} \frac{y_{H,t+1}}{y_{H,t}} \right] + \frac{\varepsilon}{\kappa_P} \left(mc_t - \frac{\varepsilon - 1}{\varepsilon} \right), \tag{21}$$

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:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\overline{\pi}} \right)^{\phi_\pi} \left(\frac{gdp_t}{gdp} \right)^{\phi_y} \right]^{1-\rho_R}, \tag{22}$$

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:

$$y_{H,t} = (1-\mu) p_{H,t}^{-\eta} c_t + \left(\frac{1-s}{s} \right) \mu^* p_{H,t}^{*-\eta} c_t^* + \frac{\kappa_P}{2} (\pi_{H,t} - \overline{\pi})^2 y_{H,t}. \tag{23}$$

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:

$$x_t = (1-\gamma) \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)} \right]^{\frac{\phi}{1-\phi}} y_{H,t} + \gamma^* \rho_{r,t} \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi} \right]^{\frac{\phi}{1-\phi}} y_{F,t}^*. \tag{24}$$

The resource constraint is given by

$$c_t + tb_t = gdp_t \left[1 - \frac{\kappa_P}{2} (\pi_{H,t} - \overline{\pi})^2 \right], \tag{25}$$

where tb_t denotes the trade balance:

$$tb_t = b_{H,t} + q_t b_{F,t} - \frac{R_{t-1}}{\pi_t} b_{H,t-1} - q_t \frac{R^*_{t-1}}{\pi^*_t} b_{F,t-1} \\ + \frac{\kappa_D}{2} q_t \left(b_{F,t} - \bar{b}_F\right)^2 - \frac{1-s}{s}\frac{\kappa_D}{2}\left(b^*_{H,t} - \bar{b}^*_H\right)^2 - w_t n_t \left(1 - \frac{x_{H,t}}{x_t}\right) + q_t w^*_t n^*_t \frac{x_{F,t}}{x^*_t}. \tag{26}$$

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

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 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 3). The euro area average share (around 25%) falls within this range, with some notable differences across countries.[15] The elasticity of substitution between Home and Foreign intermediate goods, ϕ, is set to 5, which comes close to the estimated (aggregate) trade elasticity of Caliendo and Parro (2015). 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. Finally, we fix trade openness to $\omega = 0.4$ and calibrate μ to be proportional to $\omega - \gamma$ and the relative size of Home with respect to Foreign, i.e. $\mu = (\omega - \gamma)(1 - s)$.

[15] For example, while for Germany, France, and Spain this share lies within the 21-22% range, close to the average, for the Netherlands (32.6%), the Baltic states (32.8%, on average), or Luxembourg (55.9%) is much higher.

Table 3: 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
ω, ω^*	Trade openness	0.4
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

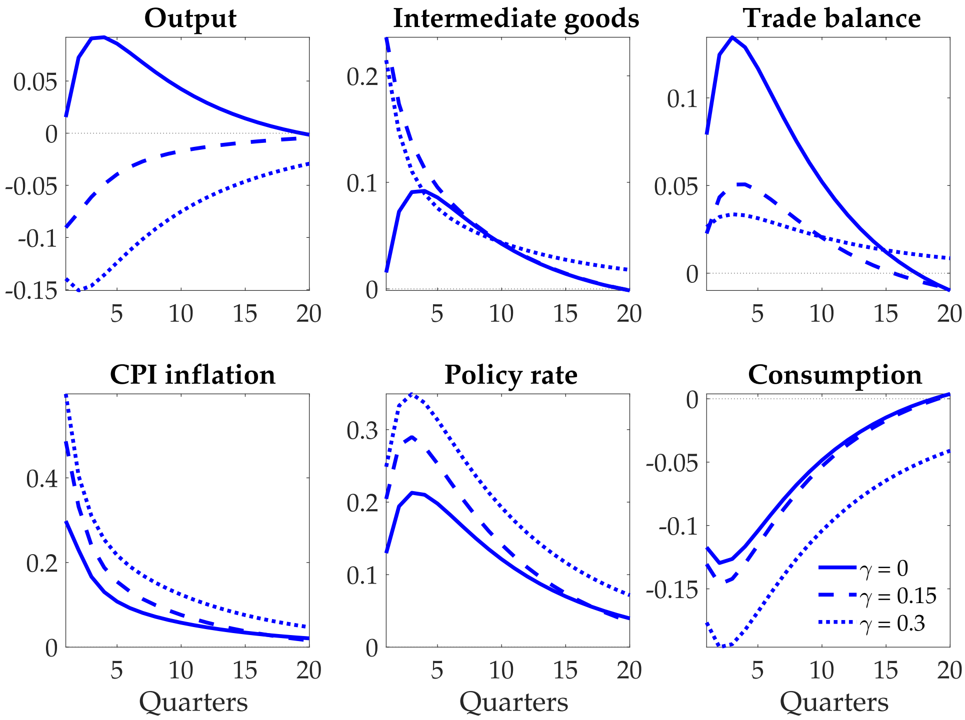
3.2 Numerical simulations and Ramsey optimal policy

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.

Figure 9 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.

Figure 9: Responses of Home variables to a global supply chain pressure shock

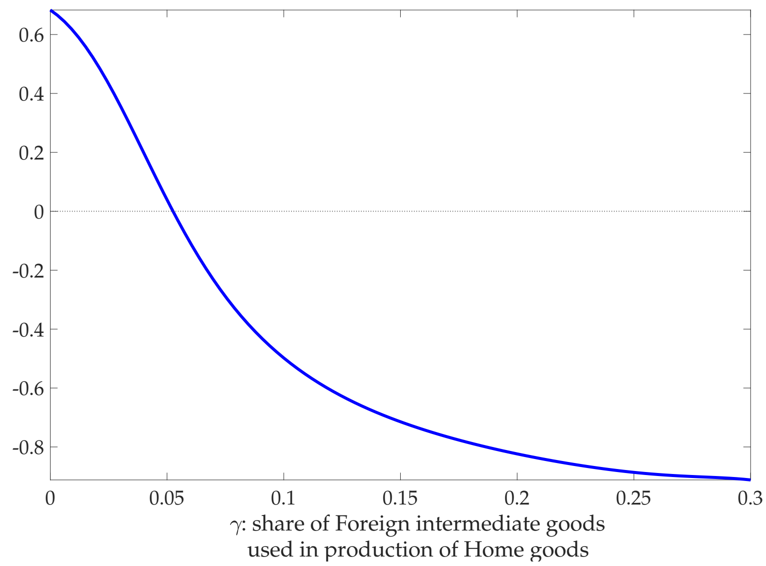


Notes: The figure plots the responses to a 1% negative Foreign productivity shock, which we use as a proxy for a global supply chain pressure shock. The importance of global supply chains is governed by γ, which measures the share of Foreign intermediate goods used in the production of Home goods. Units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

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 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 tradeoff 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 tradeoff becomes. Figure 10, 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 tradeoff for monetary policy. The size of γ, therefore, forms 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

Figure 10: 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.

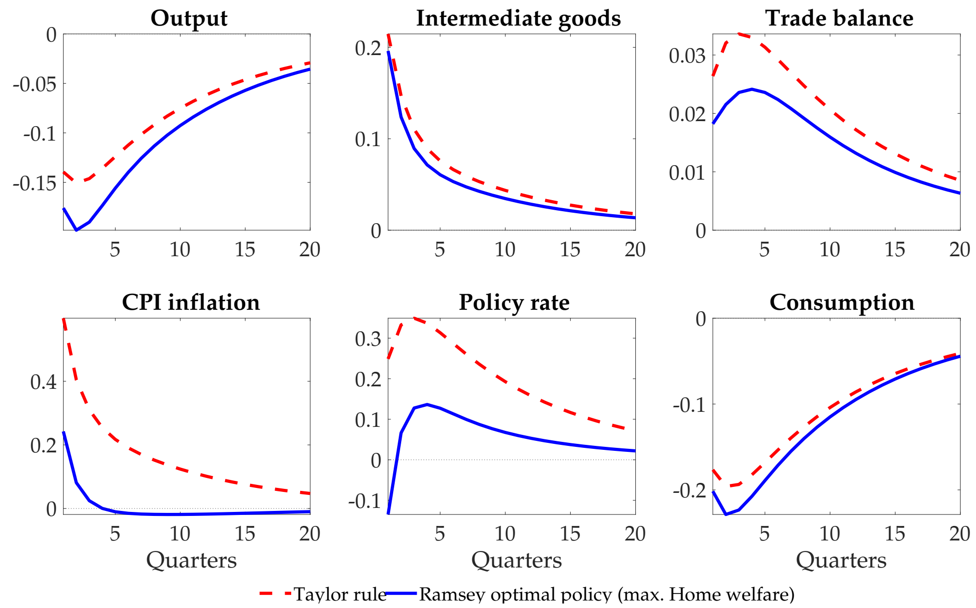
inflation in opposite directions.

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 shock under Ramsey optimal policy. We consider a non-cooperative policy in which the Ramsey policymaker aims to maximize the welfare of only Home households, which is proxied by their expected lifetime utility shown in (8). Figure 11 shows the responses under Ramsey optimal policy (solid blue lines) for the case where $\gamma = 0.3$, along with the corresponding responses under the conventional Taylor rule (dashed red lines) as shown in Figure 9. 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.[16]

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 tradeoff in the event of an adverse external supply shock. We illustrate this result in Figure 12, which shows the impact, peak and

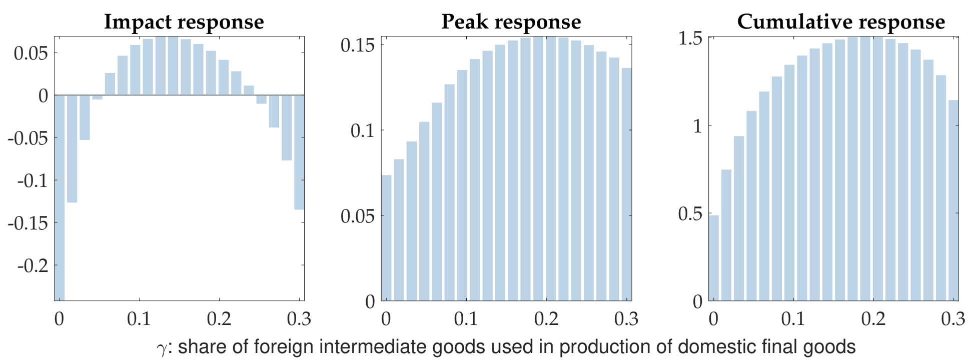
[16]The results are qualitatively very similar when we shut down international trade in final goods by setting $\{\mu, \mu^*\} = 0$. This implies that the propagation mechanism of adverse external supply shocks works mainly through the international trade of intermediate goods, which is consistent with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

Figure 11: 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.

Figure 12: 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.

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 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 tradeoff 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 a few key parameters. In the figures shown in the top row of Figure 13 we assume that the elasticity of substitution between Home and Foreign intermediate goods, ϕ, is twice as large as its baseline value of 5. This 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 to dampen the adverse effects arising from global supply chain disruptions on Home production. Therefore, a higher elasticity of substitution improves the inflation-output stabilization tradeoff and allows for a more aggressive monetary policy response to the global supply chain pressure shock, even for relatively high values of γ.

In the second row, we consider a higher elasticity of substitution between Home and Foreign final goods, η, which we raise from its baseline value of 2 to 6. This higher trade elasticity worsens the inflation-output stabilization tradeoff, as an increase in the price of domestic goods due to an adverse external supply shock will, compared to the baseline, trigger a sharper decline in aggregate demand for domestic goods through the expenditure switching channel, and more so when γ is relatively large.

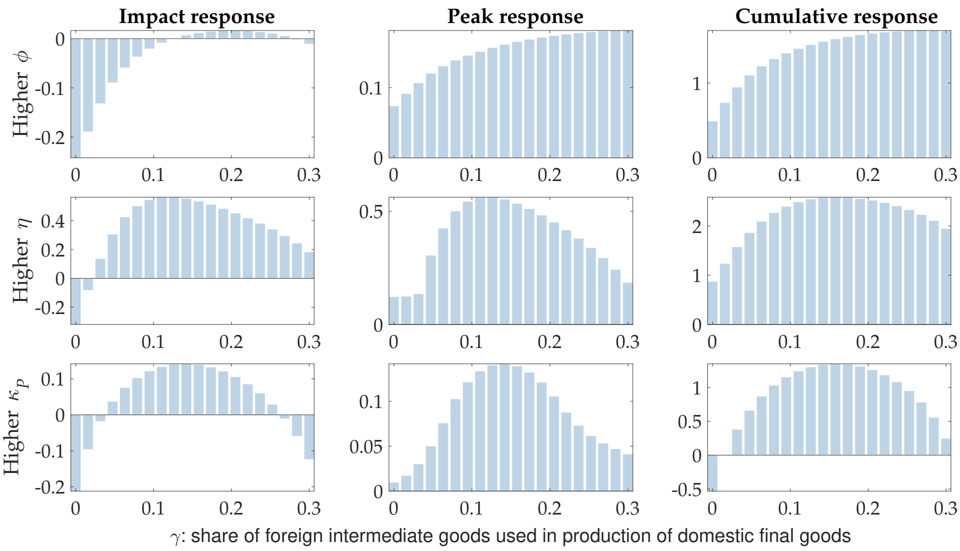
Finally, in the bottom row, we consider a stronger degree of price stickiness by raising the parameter κ_P from 58 to 1597. The baseline value implies a fixed price contract with expected duration of 1 year, whereas the alternative value corresponds to a contract with expected duration of 5 years. A higher degree of price stickiness worsens the inflation-output stabilization tradeoff as Home firms will, compared to the baseline, 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.

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 an estimated Phillips curve which includes the GSCPI as an additional regressor. Next, using a Bayesian structural VAR (BVAR) model with sign and narrative

Figure 13: Response of Home policy rate to a global supply chain pressure shock under Ramsey optimal policy, alternative calibrations



Notes: Units are expressed as annualized percentage points. The cumulative response is measured over 20 quarters. In each row, we change one parameter and leave the other parameters at their baseline calibration shown in Table 3. In the top row, we set the elasticity of substitution between Home and Foreign intermediate goods equal to $\phi = 10$ (baseline $= 5$); in the second row, we set the elasticity of substitution between Home and Foreign final goods equal to $\eta = 6$ (baseline $= 2$); in the bottom row, we set the price-adjustment cost parameter equal to $\kappa_P = 1597$, which implies a fixed price contract with expected duration of 5 years (baseline $= 58$, which corresponds to a price contract with expected duration of 1 year).

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 tradeoff 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 intermediate 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 can fiscal policy support monetary policymakers in the face of such shocks. Related, another line of research might consider exploring the distributional consequences of global supply shocks and to what extent can fiscal policy alleviate (or even avoid) the corresponding welfare losses. Tackling these questions could provide useful insights for policymakers and help inform the current policy debate.

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A Data set

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 inflation measured by the logarithmic first-difference in HICP excluding energy. The source of this time series is ECB's Statistical Data Warehouse.

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 United States.

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 ten-year OIS rate as the policy interest rate.

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	Core inflation rate	Consumer inflation measured by HICP excluding energy; Annual rate of change, logarithmic first difference. Neither seasonally nor working day adjusted.
3	GSCPI	Global Supply Chain Pressure Index Index scaled by its standard deviation; Computed by Benigno et al. (2022).
4	10-year OIS rate	A measure to capture the ECB's effective monetary policy stance;
5	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 November 2022. The sources of the data are Eurostat, ECB Statistical Data Warehouse, and FRED database.

B Extending the VAR data set

In this section we consider an extension of our empirical Bayesian VAR model, to also account for energy shocks. We add HICP energy (y-o-y % change) to our data set, and we impose two additional sign restrictions to identify a negative energy shock. In particular, we conjecture that HICP energy increases and industrial production falls. Note that we leave the HICP excluding energy unrestricted on impact, since we believe that an increase in energy prices has second-round effects on core inflation, which feed through with some lag.

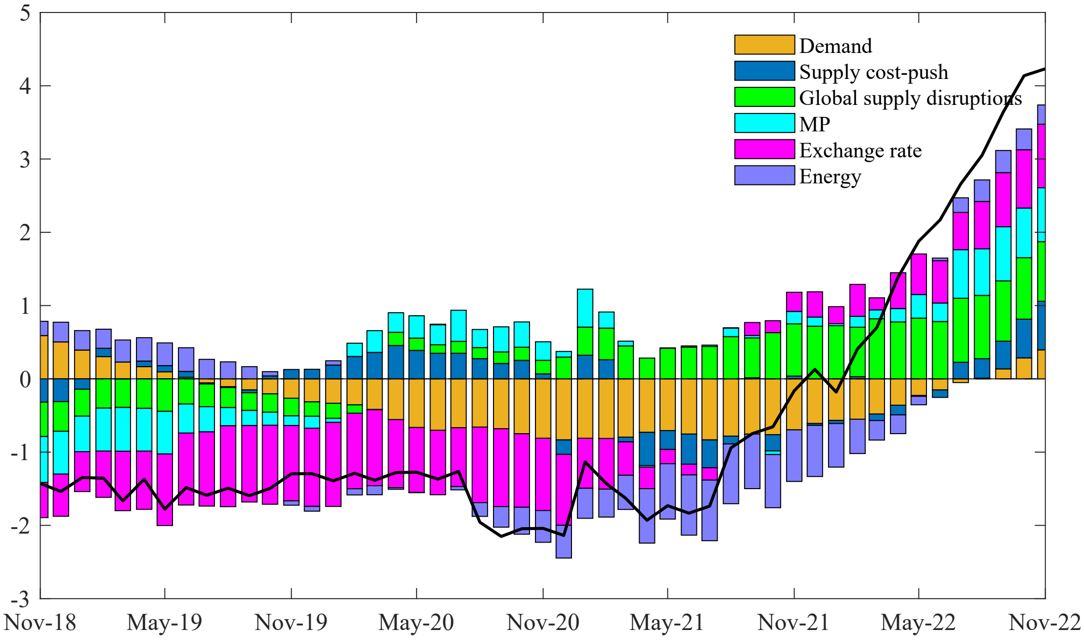
We report the corresponding historical shock decomposition in Figure B.1. As expected, changing the structure of the Bayesian VAR model by enlarging the information set has implications for the historical shock decomposition. Nevertheless, focusing on the recent surge in euro area inflation, the benchmark VAR and this alternative specification convey a very similar narrative in terms of the shocks that drive inflation dynamics, with shocks to global supply pressures playing a relatively large role in the most recent period. Unsurprisingly, the adverse energy shock ripples through the economy and, through second-round effects, features quite prominently in the decomposition of euro area core inflation.

C Macroeconomic effects following various shocks

This section reports the macroeconomic effects following demand, supply cost-push, monetary policy, and exchange rate shocks, based on our estimated Bayesian VAR model.

Figure C.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. The response of GSCPI is positive (although not significant, in Bayesian terms, for more than one year), implying that

Figure B.1: Historical shock decomposition of euro area core inflation



Notes: Core inflation measured by y-o-y % change of HICP excluding energy. Units expressed in deviations from mean.

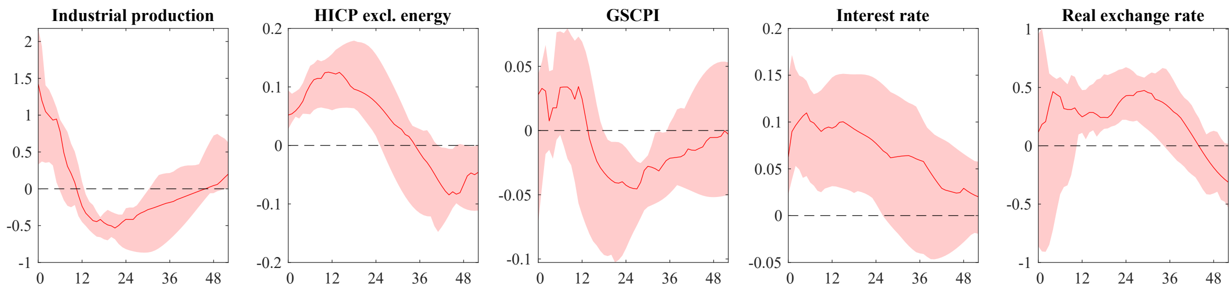
stronger demand leads to a rise in global supply chain pressures. The real exchange rate appreciates, reflecting a higher demand.

Following an adverse (domestic) supply cost-push shock (Figure C.2), as expected, economic activity falls, while core inflation increases (at least in the short term). As a result, the monetary policy reacts by increasing its short-term rate (although the response is not significant). Surprisingly, the GSCPI declines, implying that global supply chain pressures tend to ease. This result can be partly rationalized via an indirect effect stemming from the fall in aggregate demand, which in turn exerts less pressure on global supply chains.

A contractionary monetary policy shock leads to a fall in both industrial production (although short lived) and core inflation (Figure C.3). Note that we did not impose any sign restrictions on industrial production in this case. The GSCPI's response seems somewhat erratic, and not statistically significant, 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 short-lived appreciation of the real exchange rate.

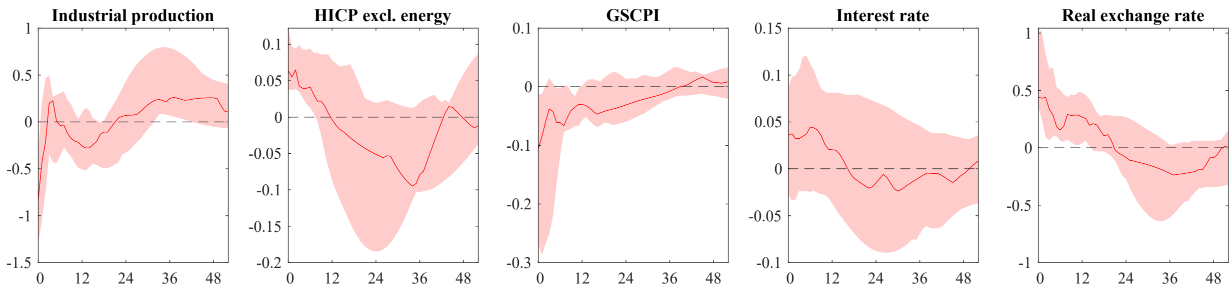
Finally, Figure C.4 reports the macroeconomic effects following a positive shock to the real exchange rate (i.e. an appreciation). This shock lowers both industrial production and core inflation, while it has a relatively muted impact on the GSCPI (although the response is not significant).

Figure C.1: Macroeconomic responses following demand shocks



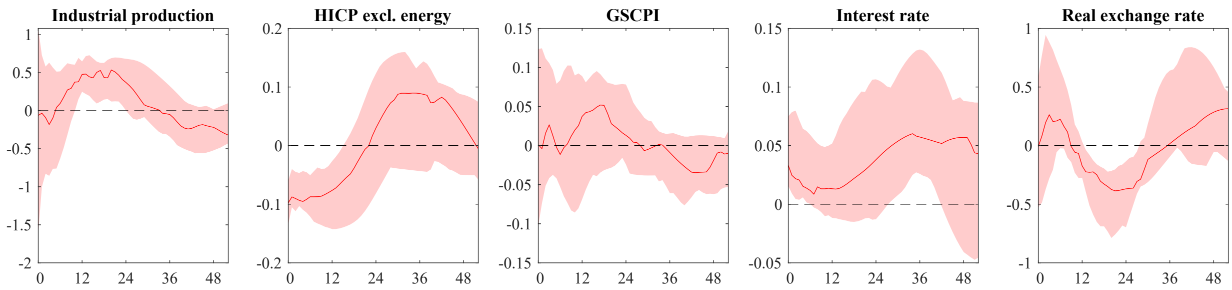
Notes: The figure shows the macroeconomic responses to a one standard deviation demand shock. The figure reports the median response (red solid line) and a 68% probability bands. The horizontal axis is time, measured in months.

Figure C.2: Macroeconomic responses following supply cost-push shocks



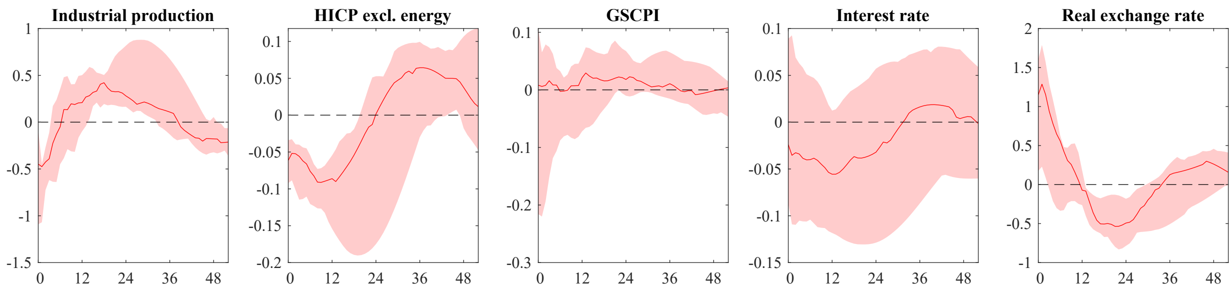
Notes: The figure shows the macroeconomic responses to a one standard deviation supply cost-push shock. The figure reports the median response (red solid line) and a 68% probability bands. The horizontal axis is time, measured in months.

Figure C.3: Macroeconomic responses following monetary policy shocks



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

Figure C.4: Macroeconomic responses following exchange rate shocks



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

D 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.

D.1 Households

D.1.1 Intratemporal problem

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

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

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

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

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

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

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:

$$p_{H,t} = q_t p^*_{H,t}, \tag{27}$$

$$p_{F,t} = q_t p^*_{F,t}, \tag{28}$$

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 $P^*_{F,t}$).

D.1.2 Intertemporal problem

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

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{1+\varphi}}{1+\varphi} \right), \tag{29}$$

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

$$P_t c_t + B_{H,t} + e_t B_{F,t} = R_{t-1} B_{H,t-1} + e_t R^*_{t-1} B_{F,t-1} + W_t n_t + P_t \Gamma_t + P_t \Gamma_{f,t} - \frac{\kappa_D}{2} e_t P^*_t \left(\frac{B_{F,t}}{P^*_t} - \bar{b}_F \right)^2, \tag{30}$$

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 (30) 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:

$$\lambda_t = c_t^{-\sigma}, \tag{31}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t}{\pi_{t+1}} \right), \tag{32}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R^*_t}{\pi^*_{t+1}} \frac{q_{t+1}}{q_t} \right) - \kappa_D \left(b_{F,t} - \bar{b}_F \right), \tag{33}$$

$$\kappa_L n_t^{\varphi} = \lambda_t w_t, \tag{34}$$

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:

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{c_{t+k}^{*1-\sigma}}{1-\sigma} - \kappa_L \frac{n_{t+k}^{*1+\varphi}}{1+\varphi} \right), \tag{35}$$

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

$$\lambda_t^* = c_t^{*-\sigma}, \tag{36}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{R_t^*}{\pi_{t+1}^*} \right), \tag{37}$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{R_t}{\pi_{t+1}} \frac{q_t}{q_{t+1}} \right) - \kappa_D \left(b_{H,t}^* - \bar{b}_H^* \right), \tag{38}$$

$$\kappa_L n_t^{*\varphi} = \lambda_t^* w_t^*. \tag{39}$$

D.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

$$y_{H,t}(i) = \left(\frac{p_{H,t}(i)}{p_{H,t}} \right)^{-\varepsilon} y_{H,t}. \tag{40}$$

Similarly, for Foreign:

$$y_{F,t}^*(i) = \left(\frac{p_{F,t}^*(i)}{p_{F,t}^*} \right)^{-\varepsilon} y_{F,t}^*. \tag{41}$$

D.3 Firms

D.3.1 Intermediate goods producers

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

$$x_t = z_{A,t} n_t, \tag{42}$$

$$x_t^* = z_{A,t}^* n_t^*, \tag{43}$$

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:

$$\ln z_{A,t} = (1 - \rho_A) \ln z_A + \rho_A \ln z_{A,t-1} + \varepsilon_{A,t}, \tag{44}$$

$$\ln z_{A,t}^* = (1 - \rho_A) \ln z_A^* + \rho_A \ln z_{A,t-1}^* + \varepsilon_{A,t}^*, \tag{45}$$

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.

D.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

$$mc_t^{1-\phi} = (1-\gamma) \left(p_{H,t}^{-1} \frac{w_t}{z_{A,t}} \right)^{1-\phi} + \gamma \left(q_t p_{H,t}^{-1} \frac{w_t^*}{z_{A,t}^*} \right)^{1-\phi}, \tag{46}$$

$$mc_t^{*1-\phi} = (1-\gamma^*) \left(p_{F,t}^{*-1} \frac{w_t^*}{z_{A,t}^*} \right)^{1-\phi} + \gamma^* \left(q_t^{-1} p_{F,t}^{*-1} \frac{w_t}{z_{A,t}} \right)^{1-\phi}, \tag{47}$$

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

$$x_{H,t}(i) = (1-\gamma)\left(p_{H,t}^{-1}\frac{w_t/z_{A,t}}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{48}$$

$$x_{H,t}^{*}(i) = \gamma^{*}\left(q_t^{-1}p_{F,t}^{*-1}\frac{w_t/z_{A,t}}{mc_t^{*}}\right)^{-\phi} y_{F,t}^{*}(i), \tag{49}$$

$$x_{F,t}(i) = \gamma\left(q_t p_{H,t}^{-1}\frac{w_t^{*}/z_{A,t}^{*}}{mc_t}\right)^{-\phi} y_{H,t}(i), \tag{50}$$

$$x_{F,t}^{*}(i) = (1-\gamma^{*})\left(p_{F,t}^{*-1}\frac{w_t^{*}/z_{A,t}^{*}}{mc_t^{*}}\right)^{-\phi} y_{F,t}^{*}(i). \tag{51}$$

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

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

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

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

The corresponding first-order condition is given by

$$(\pi_{H,t} - \overline{\pi})\pi_{H,t} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(\pi_{H,t+1} - \overline{\pi})\pi_{H,t+1}\frac{p_{H,t+1}}{p_{H,t}}\frac{y_{H,t+1}}{y_{H,t}}\right] + \frac{\varepsilon}{\kappa_P}\left(mc_t - \frac{\varepsilon-1}{\varepsilon}\right). \tag{52}$$

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

$$\Gamma_t = p_{H,t} y_{H,t} - \frac{w_t}{z_{A,t}} x_{H,t} - q_t \frac{w_t^{*}}{z_{A,t}^{*}} x_{F,t} - \frac{\kappa_P}{2}(\pi_{H,t} - \overline{\pi})^2 p_{H,t} y_{H,t}. \tag{53}$$

Note that

$$\pi_{H,t} = \frac{p_{H,t}}{p_{H,t-1}}\pi_t. \tag{54}$$

Similar conditions hold for Foreign:

$$\left(\pi^*_{F,t}-\overline{\pi}^*\right)\pi^*_{F,t}=\beta E_t\left[\frac{\lambda^*_{t+1}}{\lambda^*_t}\left(\pi^*_{F,t+1}-\overline{\pi}^*\right)\pi^*_{F,t+1}\frac{p^*_{F,t+1}}{p^*_{F,t}}\frac{y^*_{F,t+1}}{y^*_{F,t}}\right]+\frac{\varepsilon}{\kappa_P}\left(mc^*_t-\frac{\varepsilon-1}{\varepsilon}\right). \tag{55}$$

$$\Gamma^*_t=p^*_{F,t}y^*_{F,t}-\frac{w^*_t}{z^*_{A,t}}x^*_{F,t}-q_t^{-1}\frac{w_t}{z_{A,t}}x^*_{H,t}-\frac{\kappa_P}{2}\left(\pi^*_{F,t}-\overline{\pi}^*\right)^2p^*_{F,t}y^*_{F,t}, \tag{56}$$

$$\pi^*_{F,t}=\frac{p^*_{F,t}}{p^*_{F,t-1}}\pi^*_t. \tag{57}$$

D.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:

$$\frac{R_t}{R}=\left(\frac{R_{t-1}}{R}\right)^{\rho_R}\left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi}\left(\frac{gdp_t}{gdp}\right)^{\phi_y}\right]^{1-\rho_R}, \tag{58}$$

$$\frac{R^*_t}{R^*}=\left(\frac{R^*_{t-1}}{R^*}\right)^{\rho_R}\left[\left(\frac{\pi^*_t}{\overline{\pi}^*}\right)^{\phi^*_\pi}\left(\frac{gdp^*_t}{gdp^*}\right)^{\phi^*_y}\right]^{1-\rho^*_R}, \tag{59}$$

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 $\left\{\phi_y,\phi^*_y\right\}\geq 0$ the monetary policy response to output, and where

$$gdp_t=p_{H,t}y_{H,t}, \tag{60}$$

$$gdp^*_t=p^*_{F,t}y^*_{F,t}. \tag{61}$$

D.5 Market clearing

Goods market clearing implies:

$$y_{H,t}=(1-\mu)\,p_{H,t}^{-\eta}c_t+\left(\frac{1-s}{s}\right)\mu^*p_{H,t}^{*-\eta}c^*_t+\frac{\kappa_P}{2}\left(\pi_{H,t}-\overline{\pi}\right)^2y_{H,t}, \tag{62}$$

$$y^*_{F,t}=(1-\mu^*)\,p_{F,t}^{*-\eta}c^*_t+\left(\frac{s}{1-s}\right)\mu p_{F,t}^{-\eta}c_t+\frac{\kappa_P}{2}\left(\pi^*_{F,t}-\overline{\pi}^*\right)^2y^*_{F,t}. \tag{63}$$

Bonds market clearing implies:

$$sb_{H,t}+(1-s)\,b^*_{H,t}=0, \tag{64}$$

$$sb_{F,t}+(1-s)\,b^*_{F,t}=0. \tag{65}$$

Defining the intermediate goods terms of trade as

$$\rho_{r,t} = q_t^{-1} \frac{w_t / z_{A,t}}{w_t^* / z_{A,t}^*}, \tag{66}$$

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

$$x_t = (1-\gamma) \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)} \right]^{\frac{\phi}{1-\phi}} y_{H,t} + \gamma^* \rho_{r,t} \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi} \right]^{\frac{\phi}{1-\phi}} y_{F,t}^*, \tag{67}$$

$$x_t^* = (1-\gamma^*) \left[(1-\gamma^*) + \gamma^* \rho_{r,t}^{1-\phi} \right]^{\frac{\phi}{1-\phi}} y_{F,t}^* + \gamma \rho_{r,t}^{-1} \left[(1-\gamma) + \gamma \rho_{r,t}^{-(1-\phi)} \right]^{\frac{\phi}{1-\phi}} y_{H,t}. \tag{68}$$

The Home resource constraint is given by

$$c_t + tb_t = gdp_t \left[1 - \frac{\kappa_P}{2} \left(\pi_{H,t} - \overline{\pi} \right)^2 \right], \tag{69}$$

where the Home trade balance, tb_t, is given by

$$\begin{aligned} tb_t = {} & b_{H,t} + q_t b_{F,t} - \frac{R_{t-1}}{\pi_t} b_{H,t-1} - q_t \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1} \\ & + \frac{\kappa_D}{2} q_t \left(b_{F,t} - \overline{b}_F \right)^2 - \frac{1-s}{s} \frac{\kappa_D}{2} \left(b_{H,t}^* - \overline{b}_H^* \right)^2 - \Omega_t, \end{aligned} \tag{70}$$

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

$$\begin{aligned} tb_t^* = {} & q_t^{-1} b_{H,t}^* + b_{F,t}^* - q_t^{-1} \frac{R_{t-1}}{\pi_t} b_{H,t-1}^* - \frac{R_{t-1}^*}{\pi_t^*} b_{F,t-1}^* \\ & - \frac{\kappa_D}{2} \frac{s}{1-s} \left(b_{F,t} - \overline{b}_F \right)^2 + q_t^{-1} \frac{\kappa_D}{2} \left(b_{H,t}^* - \overline{b}_H^* \right)^2 + \Omega_t. \end{aligned} \tag{71}$$

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