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Keywords

real exchange rates, euro area competitiveness, multi-country DSGE, Bayesian estimation

JEL Classification

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Shocks, Competitiveness, and Bilateral Real Exchange Rates in the Euro Area

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Abstract

This paper analyses the structural drivers of bilateral real exchange rate dynamics within the euro area and between the euro area and the United States over 1999–2025, using an estimated seven-country New Keynesian DSGE model of the world economy. The model features an ex ante identical structure across the country blocs and is estimated on a unified information set. International financial market shocks dominate the EA–US bilateral real exchange rate dynamics, with productivity differentials generating persistent euro appreciation pressure. Rising world demand and a secular decline in EA home bias exert partially offsetting euro depreciation pressure. Within the monetary union, the pre-crisis appreciation of France, Italy, and Spain relative to Germany reflects country-specific combinations of demand, supply, and trade disturbances that broadly unwind after 2008. Trend productivity differentials emerge as the dominant low-frequency driver, most starkly for Italy, where persistently slower trend productivity growth drives the bilateral real exchange rate through the sample. Model validation against empirical moments, exchange rate pass-through benchmarks, and off-model indicators confirms the empirical plausibility of the structural identification.

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1. Introduction

Within a monetary union, bilateral real exchange rates, constructed from relative price indices such as the GDP deflator, consumer prices, or unit labour costs, are the primary proxy of competitiveness: lacking the nominal exchange rate as an adjustment instrument, euro area (EA) member countries must rely on relative price and cost adjustments to absorb asymmetric shocks. Stylised facts show that between the launch of the euro in 1999 and the global financial crisis of 2008–09, France, Italy, and Spain experienced sustained real appreciations of five to fifteen percent relative to Germany, reflecting divergent wage and price dynamics. The sovereign debt crisis triggered a sharp reversal, followed by a decade of partial rebalancing. The post-pandemic period and the subsequent energy crisis have generated a new round of asymmetric macroeconomic adjustment across EA member states, renewing concerns about persistent competitiveness divergence within the monetary union. [Altieri et al. \(2024\)](#) document how pandemic supply disruptions, geopolitical tensions, and the 2022 energy shock affected EA external competitiveness asymmetrically relative to its main trading partners, exposing structural vulnerabilities in euro area market shares. These developments place the question of intra-EA cost and productivity gaps back at the centre of the policy debate, most prominently in the [Draghi \(2024\)](#) report, which identifies these divergences as a first-order threat to the long-run viability of the European growth model.

Understanding the structural drivers of these dynamics is important for two reasons. First, divergence in competitiveness lies at the heart of external imbalances. Second, the effectiveness of internal devaluation as the primary adjustment channel within the monetary union depends critically on structural parameters such as price rigidities and trade elasticities, and, crucially, on which shocks are responsible for the observed divergence. Demand-driven appreciation can, for example, be reversed by wage moderation or fiscal devaluation (e.g. [Hohberger and Kraus, 2016](#)); supply-side or terms-of-trade shocks may require structural reforms on the labour market and productivity improvements and operate over different horizons (e.g. [Pfeiffer et al., 2024](#)). A further layer of complexity arises from the external dimension. Shocks originating in the United States or the rest of the world affect the EUR/USD bilateral real exchange rate and transmit to individual EA member states asymmetrically. Because EA countries differ markedly in trade openness, commodity import intensity, and trade linkages, even a common external shock can generate asymmetric relative price responses across EA members. Separating the contribution of EA-external shocks from genuinely idiosyncratic intra-EA disturbances is therefore of particular interest to attribute observed competitiveness divergence to its structural sources.

This paper analyses the macroeconomic drivers of bilateral real exchange rate dynamics in the euro area through the lens of an estimated seven-region New Keynesian dynamic

stochastic general equilibrium (DSGE) model of the world economy. The model comprises Germany, France, Italy, Spain, the Rest of the Euro Area, the United States, and the Rest of the World, and is estimated using Bayesian methods on quarterly data from 1999Q1 to 2025Q4, a sample spanning the pre-crisis convergence boom, the global financial crisis, the sovereign debt episode, and the post-pandemic adjustment. All seven country blocs share an ex ante identical core structure and are subject to analogous exogenous disturbances, including preference and markup shocks, monetary policy surprises, and shocks to bilateral import demand and trade prices. The joint estimation on a unified information set identifies the main structural drivers of bilateral real exchange rate dynamics across the full EA–US–RoW nexus and provides a plausible and internally consistent narrative of intra-EA competitiveness divergence over the past quarter century. We decompose bilateral real exchange rate dynamics into a common EA-external layer and an intra-EA idiosyncratic layer, quantifying the contribution of each to the historical dynamics of the EA–US and intra-EA bilateral real exchange rates over 1999–2025. Despite abstracting from physical capital accumulation, fiscal policy, and an explicit commodity sector, the model replicates key business cycle patterns, and estimated shocks map closely onto off-model indicators of global supply chain pressures and energy prices, suggesting that the general equilibrium structure is sufficient to absorb the main exogenous drivers of international price dynamics in an empirically plausible way.

The EA–US bilateral real exchange rate is dominated by international financial market shocks, with EA–US productivity differentials accounting for the low-frequency trend and monetary policy divergence contributing visibly during 2015–2019. Within the monetary union, the pre-crisis competitiveness divergence reflects country-specific demand, supply, and trade disturbances that broadly unwind after 2008, compounded by asymmetric RoW demand conditions increasingly favouring German exports. Trend productivity differentials emerge as the dominant low-frequency driver of intra-EA bilateral real exchange rates, most starkly for Italy, where persistently slower trend productivity growth relative to Germany drives a cumulative real appreciation of approximately 15 percentage points over the sample.

The remainder of the paper is organised as follows. Section 2 reviews related literature. Section 3 documents the stylised facts on the EA–US external real exchange rate and the intra-EA bilateral real exchange rate dynamics over the sample period. Section 4 presents the model structure. Section 5 describes the Bayesian estimation strategy and discusses the posterior estimates of structural parameters. Section 6 validates the property of the model to replicate key business cycle patterns, examines dynamic responses to key structural shocks, discusses the historical shock decompositions of the EA–US and intra-EA bilateral real exchange rates, and assesses the model’s empirical plausibility with off-model indicators.

Section 7 concludes.

2. Related Literature

This paper sits at the intersection of three bodies of work: the empirical literature on intra-EA competitiveness, the theory and econometrics of real exchange rate determination, exchange rate pass-through, and trade pricing literature, and the family of multi-country estimated DSGE models for the euro area.

Intra-EA competitiveness and current account imbalances.

The pre-crisis divergence in competitiveness across EA countries has attracted a large body of empirical work. Early contributions by [Blanchard and Giavazzi \(2002\)](#) argued that current account deficits in the EA periphery were the natural counterpart of capital flows toward catching-up economies following financial integration. The sovereign debt crisis prompted a reassessment: [Spaventa and Giavazzi \(2010\)](#) show that imbalances matter even inside a monetary union when they reflect misallocation rather than orderly convergence, while [Chen et al. \(2012\)](#) decompose EA external imbalances into a financial integration channel and an intra-EA competitiveness channel driven by wage and price rigidities. [Lane and Milesi-Ferretti \(2012\)](#) document that post-crisis adjustment in deficit countries was achieved mainly through demand compression rather than expenditure switching, and [Gaulier and Vicard \(2012\)](#) show that demand asymmetries rather than cost divergence per se are the primary driver of the divergence, and [Cardani et al. \(2022b\)](#) quantify the relative importance of domestic versus foreign drivers of EA trade imbalances within an estimated DSGE framework. [Tkacevs et al. \(2016\)](#) show that different deflator concepts (GDP deflator, CPI, and unit labour costs) can diverge substantially across EA member states, highlighting the importance of deflator choice for competitiveness assessment, while [Schmitz et al. \(2024\)](#) document the ECB’s methodology for harmonised competitiveness indicators across all three deflator concepts. [Altieri et al. \(2024\)](#) document asymmetric competitiveness losses across EA member states following recent global shocks, complementing the reduced-form evidence of [Coutinho and Licchetta \(2025\)](#) on post-pandemic inflation differentials. Relative to this strand of literature, which relies predominantly on reduced-form empirical approaches such as panel regressions and error correction models, our estimated DSGE framework offers a structural interpretation of bilateral real exchange rate dynamics by capturing general equilibrium feedback effects across all seven country blocs simultaneously.

Real exchange rate determination and pass-through.

The theoretical foundations of bilateral real exchange rate dynamics rest on two complementary mechanisms. The first is the productivity channel: [Berka et al. \(2018\)](#) provide em-

empirical support for an amended Balassa–Samuelson mechanism within the eurozone, showing that intra-EA real exchange rate variation closely tracks sectoral productivity differentials between tradable and non-tradable sectors. Since our model abstracts from non-tradable sectors, it cannot generate the Balassa–Samuelson effect through the relative price of non-tradables. The productivity channel in our framework operates exclusively through the cost side of the tradable sector, where higher labour productivity in one country lowers the price of domestic output relative to trading partners, generating a real depreciation through the cost-competitiveness channel rather than through sectoral price differentials. The second is the financial market channel: [Itskhoki and Mukhin \(2021\)](#) propose a general equilibrium model that resolves the main exchange rate puzzles by assigning a dominant role to risk premium shocks operating through segmented asset markets. This mechanism is directly related to the bond preference shock we identify as one of the main driver of EUR/USD real exchange rate fluctuations. On the pricing side, [Adolfson et al. \(2007\)](#) and [Gopinath et al. \(2020\)](#) establish that local-currency import price stickiness and dollar invoicing generate asymmetric pass-through across trading partners, motivating the country-specific import price elasticities and bilateral Rotemberg adjustment costs in our model. [Ortega and Osbat \(2020\)](#) provide cross-model benchmarks for exchange rate pass-through in the euro area using the price-to-exchange-rate ratio (PERR) concept, against which we validate the model’s implied pass-through dynamics in Section 6.1.

Multi-country estimated DSGE models for the euro area.

The multi-country DSGE tradition for the EA provides our most direct methodological antecedents. [Smets and Wouters \(2003\)](#) establish the single-region estimated DSGE benchmark specification for the aggregate EA. [Rabanal and Tuesta \(2010\)](#) estimate a Bayesian two-country DSGE for the euro-dollar real exchange rate, finding that demand and technology shocks dominate and that incomplete financial markets substantially improve model fit. [Gomes et al. \(2012\)](#) develop the EAGLE model, a four-region New Keynesian framework for EA policy and spillover analysis, later extended with banking and financial frictions by [Bokan et al. \(2018\)](#). The European Commission’s Global Multi-country model ([Albonico et al., 2019a](#)) represents an important contribution in this tradition, with applications examining commodity price shocks and trade balance adjustments ([Giovannini et al., 2019](#)), and a DSGE-based interpretation of the COVID-19 recession ([Cardani et al., 2022a](#)). Most recently, [Ifrim et al. \(2026\)](#) use an estimated two-region DSGE model to show that the persistent EA–RoW productivity growth differences is the key driver of the EA external dynamics. The present paper estimates a seven-region New Keynesian DSGE model of the world economy in which all country blocs are jointly estimated on a unified information set with an ex ante identical structure. Existing frameworks either cover fewer regions ([Giovan-](#)

nini et al., 2019; Hohberger et al., 2019; Ifrim et al., 2026), rely on calibration rather than full Bayesian estimation (Gomes et al., 2012), use semi-structural specifications (Angelini et al., 2025), or estimate individual country configurations separately rather than as a joint system (Albonico et al., 2019b; Cardani et al., 2022b).

3. Stylised facts

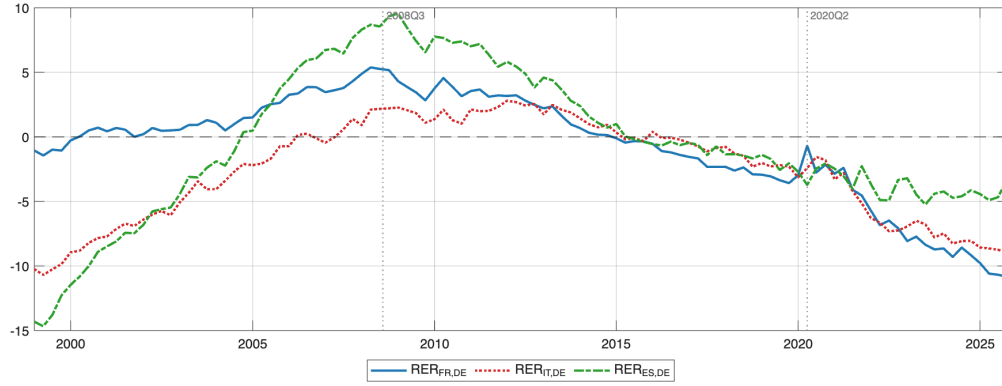
The stylised facts document three broad phases in intra-EA bilateral real exchange rate dynamics over 1999–2025 (Figure 1a). During the first decade of monetary union, France, Italy, and Spain appreciated in real terms against Germany: between 1999Q1 and the 2008Q3 peak, the cumulative appreciation amounted to approximately 24% for Spain, 12% for Italy, and 6% for France. The global financial crisis and the sovereign debt crisis triggered a reversal, with all three bilateral real exchange rates depreciating through the early 2010s and returning to their 2015 reference levels. Since 2015, the depreciation has continued, amounting to approximately 11%, 9%, and 5% for France, Italy, and Spain, respectively, by end-2025. Over the full EMU period, this implies a cumulative real depreciation of roughly 10% for France against Germany, while Italy’s bilateral real exchange rate is close to its 1999 level and Spain’s remains around 9% above it. Germany’s relative price level has thus risen against all three countries since 2015, reversing much of the relative price adjustment of the early EMU years.

The external real exchange rate between the US and the EA exhibits a distinct, more volatile cycle (Figure 1b). Following a sharp dollar appreciation in the early 2000s (peak of +25% in 2001-2002), the USD depreciated steeply against the EUR through 2008, bottoming out at approximately −30%. Post-crisis, the external real exchange rate oscillated within a broad range with a slight dollar appreciation trend, bringing the US-EA real exchange rate by the end of 2025 closely back to its starting value in 1999.

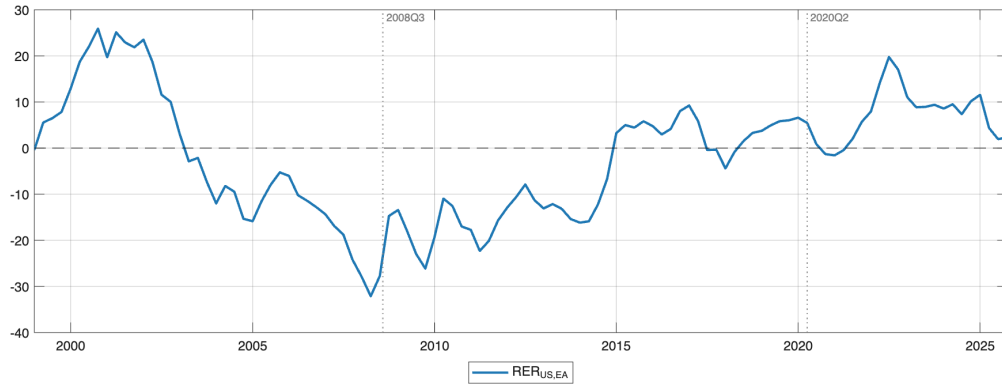
4. The model

The model is a multi-region DSGE model of the world economy and comprises seven regions: Germany (DE), France (FR), Italy (IT), Spain (ES), the Rest of the Euro Area (REA), the United States (US), and the Rest of the World (RoW). This model version keeps the individual country blocs deliberately parsimonious, abstracting from fiscal policy and physical capital accumulation, while remaining interconnected through rich bilateral trade linkages. The parsimony is intentional: given the seven-region setup, adding additional structural features, and hence, additional observables and corresponding shocks, would substantially

Figure 1: Bilateral real exchange rates (1999 - 2025).



(a) Bilateral intra-EA real exchange rates (relative to DE, in %)



(b) Bilateral real exchange rate between US and EA (in %)

Note: Bilateral real exchange rates are constructed from GDP deflator indices (2015 = 100) and shown as percent deviations from their 2015 level (1 on the y-axis corresponds to 1%). An increase denotes a real appreciation of the first-named country (FR, IT, ES in panel a; US in panel b) relative to the second. Sources: Eurostat, BEA.

increase the computational burden during estimation.¹

The representative household in each country k maximises expected lifetime utility over consumption subject to external habit formation. Preferences are subject to two disturbances: a stationary demand shock that shifts the time-varying discount factor, and a heteroscedastic (one-off) consumption shock that serves as an outlier correction for the COVID-19 lockdowns (Cardani et al., 2022a; Hohberger, 2025). The household holds a domestic risk-free bond and a single internationally traded bond denominated in RoW currency. The UIP conditions include structural bond premia: a common EA shock capturing shifts in in-

¹The focus of this paper is on disentangling domestic from foreign demand and supply shocks and international trade spillovers rather than on the composition of domestic demand components, for which structurally richer but less geographically comprehensive frameworks are better suited (Cardani et al., 2022b; Ifrim et al., 2026).

vestor appetite for euro assets, and an independent US shock capturing the global safe-haven premium on dollar-denominated assets.

In the production sector, monopolistically competitive firms produce differentiated goods, with price dynamics governed by a New Keynesian Phillips curve that relates inflation to the output gap and a cost-push shock. Domestic value added is then combined with oil, imported exclusively from RoW, by perfectly competitive firms using a CES production function to produce total gross output. In the trade block, perfectly competitive import retailers purchase goods from each foreign region and assemble them into bilateral import bundles, subject to Rotemberg quadratic price adjustment costs that generate incomplete exchange rate pass-through. These bilateral import bundles are then combined with domestic gross output by final good packagers via a CES aggregator, to create final consumption and export demand components. Similarly, exporters in each country face bilateral Rotemberg export price adjustment costs when setting destination-specific prices, generating a rich bilateral price-setting structure across all bilateral trade corridors.

The notation is structured as follows: X_k denotes the level of X in country k ; $M_{l,k}$ denotes imports of country k sourced from l ; $\mathbb{E}_t$ denotes the rational expectation operator conditional on date- t information.

4.1. Global block

4.1.1. Country sizes and aggregation

Each country k has an exogenous population size weight S_k which satisfies $\sum_k S_k = 1$. World aggregates of any variable X are computed as

$$X_{World} = \sum_k S_k X_k. \quad (1)$$

The EA aggregate is defined analogously over the subset $CO_{EMU} = \{DE, FR, IT, ES, REA\}$:

$$S_{EA} X_{EA} = \sum_{k \in CO_{EMU}} S_k X_k, \quad (2)$$

where $S_{EA} = \sum_{k \in CO_{EMU}} S_k$ is the EA population share in the world economy.

4.1.2. International bond and net foreign assets

There is a single internationally-traded nominal bond denominated in RoW currency, paying the nominal return i_t^{BW} between t and $t + 1$. Let $B_{k,t}^W$ denote the net holdings of this bond by residents of country k , expressed in RoW-currency units, and let $NFA_{k,t}$ be the

country's net foreign asset position in RoW units:

$$NFA_{k,t} = B_{k,t}^W. \quad (3)$$

Total household financial assets in domestic currency is $A_{k,t} = E_t^{\text{RoW},k} NFA_{k,t}$, where $E_t^{\text{RoW},k}$ is the nominal price of one unit of RoW currency in units of k currency. The world-wide bond market clearing condition is

$$\sum_k S_k NFA_{k,t} = 0. \quad (4)$$

4.1.3. Exchange-rate system

The US dollar serves as the numéraire, $E_t^{US,US} \equiv 1$. All EMU members share the euro, so for any $k \in CO_{EMU}$, $E_t^{US,k} = E_t^{US,EA}$, i.e. the dollar/euro exchange rate is common to DE, FR, IT, ES and REA. Bilateral nominal exchange rates are constructed from the US-numéraire prices via triangular arbitrage:

$$E_t^{l,k} = \frac{E_t^{US,l}}{E_t^{US,k}}, \quad \forall k, l \in CO, \quad k \neq l, \quad (5)$$

where k denotes the domestic country and l the foreign country. An increase in $E_t^{l,k}$ indicates an appreciation of the foreign currency l relative to the domestic currency k . The bilateral real exchange rate of foreign country l relative to domestic country k is defined as:

$$RER_{l,k,t} = E_t^{l,k} \cdot \frac{P_{l,t}^Y}{P_{k,t}^Y}, \quad (6)$$

where $E_t^{l,k}$ is the bilateral nominal exchange rate (units of k currency per unit of l currency) and $P_{l,t}^Y$ and $P_{k,t}^Y$ are the GDP deflators of countries l and k , respectively. In logarithms, $LRER_{l,k,t} = \log RER_{l,k,t} = \log E_t^{l,k} + \log P_{l,t}^Y - \log P_{k,t}^Y$. An increase in $RER_{l,k,t}$ indicates a real appreciation of country l relative to country k . The real effective exchange rate (REER) of country k is the trade-weighted average:

$$LRER_{k,t} = \sum_{l \neq k} s_{l,k}^M LRER_{l,k,t}, \quad (7)$$

where $s_{l,k}^M$ are the bilateral import shares from the trade matrix. Throughout the paper, the GDP deflator is used as the price deflator, consistent with the model's national accounts identity and the focus on domestic production cost dynamics ([Schmitz et al., 2024](#); [Tkacevs](#)

et al., 2016).

4.2. Households

4.2.1. Preferences and budget constraint

The representative household in country k chooses sequences of consumption $C_{k,t}$, holdings of a domestic risk-free asset, and holdings of the international bond $B_{k,t}^W$ to maximise

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_{k,t} U(C_{k,t}, C_{k,t-1}).$$

The period utility function delivers a CRRA marginal utility with external habit formation.² Specifically, with θ_k the inverse of the intertemporal elasticity of substitution and $h_k \in [0, 1]$ the habit parameter, the marginal utility of consumption is

$$\Lambda_{k,t} = (C_{k,t} - \epsilon_{k,t}^{tC} - h_k C_{k,t-1} - \epsilon_{k,t-1}^{tC})^{-\theta_k}, \quad (8)$$

where $\epsilon_{k,t}^{tC}$ is a heteroscedastic (one-off) shock to consumption, capturing a forced saving shock imposed through the COVID-19 lockdowns (Cardani et al., 2022a; Hohberger, 2025). The time-varying discount factor is $\beta_{k,t} = \beta_k \exp(\varepsilon_{k,t}^C)$, where $\varepsilon_{k,t}^C$ is a transitory shock to the subjective rate of time preference (saving shock).

The budget constraint of the household, expressed in units of k currency, reads

$$\begin{aligned} P_{k,t}^C C_{k,t} + B_{k,t}^{rf} + E_t^{\text{RoW},k} B_{k,t}^W = \\ (1 + i_{k,t-1}) B_{k,t-1}^{rf} + (1 + i_{t-1}^{BW}) E_t^{\text{RoW},k} B_{k,t-1}^W \Phi_{k,t} + \Omega_{k,t}, \end{aligned} \quad (9)$$

where $B_{k,t}^{rf}$ are holdings of the domestic risk-free bond paying nominal interest $i_{k,t}$, $P_{k,t}^C$ is the consumer price index, and $\Omega_{k,t}$ collects firms' profits (taken as exogenous to the household's optimisation problem).³ Following Schmitt-Grohe and Uribe (2003), holdings of the international bond carry a country-specific portfolio adjustment cost that ensures a unique non-stochastic steady state. The wedge is defined as

$$\Phi_{k,t} = 1 - \left(\alpha_{0,k}^{BW} + \alpha_{1,k}^{BW} \frac{E_t^{\text{RoW},k} B_{k,t}^W}{P_{k,t}^Y Y_{k,t}} \right) - \varepsilon_{k,t}^{BW}, \quad (10)$$

²The utility function abstracts from labour supply, consistent with the linear production setting (Section 4.3) that treats the active labour force as an observable input and approximates real marginal cost through the output gap rather than a wage Phillips curve. This reduced-form treatment of the labour market preserves tractability at the seven-region scale.

³Aggregate output, consumption and the trade balance are linked through the national-accounts identity in Section 4.5.

where $\alpha_{0,k}^{BW}$ is a country-specific constant calibrated to match the steady-state net foreign asset position, and $\alpha_{1,k}^{BW}$ governs the debt-elastic component of the risk premium. The shock $\varepsilon_{k,t}^{BW}$ is a country-specific UIP risk premium shock, specified asymmetrically across blocs as described in Section 4.2.3.

4.2.2. Derivation of the consumption Euler equation

Let $\lambda_{k,t}$ be the Lagrange multiplier attached to the period- t budget constraint. The first-order condition with respect to $C_{k,t}$ yields

$$\beta_{k,t} U_C(C_{k,t}, \cdot) = \lambda_{k,t} P_{k,t}^C,$$

which, after substituting the CRRA marginal utility and normalising by $P_{k,t}^C$, defines $\Lambda_{k,t} = \lambda_{k,t}/(\beta_{k,t})$. The FOC with respect to the domestic risk-free bond equates the marginal rate of intertemporal substitution to the inverse real return:

$$1 = \beta_{k,t} \mathbb{E}_t \left[\frac{\Lambda_{k,t+1}}{\Lambda_{k,t}} \frac{P_{k,t}^C}{P_{k,t+1}^C} (1 + i_{k,t} - \iota_{k,t}^{\text{sp}}) \right], \quad (11)$$

where $\iota_{k,t}^{\text{sp}}$ is a country-specific interest rate spread capturing the wedge between the EA policy rate and the effective borrowing cost driven by the debt-elastic NFA premium in equation (14). Equation (11) is the consumption Euler equation that determines the dynamics of the real interest rate and consumption trade-off in each country.

4.2.3. Derivation of the UIP condition

The FOC with respect to international bond holdings $B_{k,t}^W$ requires that the household be indifferent between holding the domestic bond at return $1 + i_{k,t}$ and the international bond, after accounting for expected currency returns and the portfolio adjustment cost (10). Substituting the stochastic discount factor $SDF_{k,t,t+1} \equiv \beta_{k,t} \Lambda_{k,t+1}/\Lambda_{k,t} \cdot P_{k,t}^C/P_{k,t+1}^C$ yields:

$$\mathbb{E}_t \left[SDF_{k,t,t+1} \left[(1 + i_t^{BW}) \frac{E_{t+1}^{\text{RoW},k}}{E_t^{\text{RoW},k}} - \varepsilon_{k,t}^{BW} - \left(\alpha_{0,k}^{BW} + \alpha_{1,k}^{BW} \frac{E_t^{\text{RoW},k} B_{k,t}^W}{P_{k,t}^Y Y_{k,t}} \right) \right] \right] = 1. \quad (12)$$

Up to a first-order approximation, equation (12) implies

$$i_t^{BW} - i_{k,t} \approx \mathbb{E}_t \left[\Delta \log E_{t+1}^{\text{RoW},k} \right] - \alpha_{1,k}^{BW} \widehat{nfa}_{k,t} - \varepsilon_{k,t}^{BW},$$

where $\widehat{nfa}_{k,t}$ denotes the deviation of the NFA-to-GDP ratio from its steady state and $\alpha_{0,k}^{BW}$ vanishes at the linearisation point. The international-domestic interest rate differential is

equated by expected currency depreciation, a debt-elastic risk premium that falls with the NFA position, and a UIP shock $\varepsilon_{k,t}^{BW}$. Since all five EMU member states share the exchange rate $E_t^{\text{RoW,EA}}$ and the union policy rate $i_{EA,t}$, the UIP holds at the aggregate level:

$$(1 + i_t^{BW}) \mathbb{E}_t \left[\frac{E_{t+1}^{\text{RoW,EA}}}{E_t^{\text{RoW,EA}}} \right] = (1 + i_{EA,t}) + \varepsilon_{EA,t}^{BW} + \alpha_{0,EA}^{BW} + \alpha_{1,EA}^{BW} \frac{E_t^{\text{RoW,EA}} B_{EA,t}^W}{P_{EA,t}^Y Y_{EA,t}}, \quad (13)$$

where a positive $\varepsilon_{EA,t}^{BW}$ raises the effective return on euro-denominated assets, attracting capital inflows and generating an impact appreciation of the euro. The bond premium shock $\varepsilon_{k,t}^{BW}$ is specified differently across blocs: for all EA member states $k \in CO_{EMU}$ it is replaced by the common shock $\varepsilon_{EA,t}^{BW}$, which captures EA-specific financial conditions such as shifts in investor appetite for euro assets or changes in aggregate sovereign risk, while for the US, $\varepsilon_{US,t}^{BW}$ is an independent structural shock capturing the global safe-haven premium on dollar-denominated assets. RoW has no separately identified bond premium shock. RoW has no separately identified bond premium shock. The within-EA cross-country FOC for member $k \in CO_{EMU}$ becomes a no-arbitrage condition with the union rate:

$$(1 + i_{EA,t}) - \alpha_{1,k}^{BW} \frac{E_t^{\text{RoW,EA}} B_{k,t}^W}{P_{k,t}^Y Y_{k,t}} = 1 + i_{k,t}. \quad (14)$$

The wedge $i_{k,t} - i_{EA,t} = -\alpha_{1,k}^{BW} \frac{E_t^{\text{RoW,EA}} B_{k,t}^W}{P_{k,t}^Y Y_{k,t}}$ captures an endogenous intra-EA interest rate spread driven by NFA positions, providing a structural foundation for sovereign risk differentials within the monetary union.

4.3. Production, total output and the New Keynesian Phillips curve

4.3.1. Production technology and potential output

Domestic value added in country k is produced from labour-augmenting productivity through a linear production function that abstracts from physical capital accumulation:

$$Y_{k,t} = A_{k,t}^Y N_{k,t}, \quad (15)$$

where $A_{k,t}^Y$ captures labour-augmenting productivity rather than total factor productivity in the Cobb-Douglas sense, and $N_{k,t} = Actr_{k,t} \cdot Pop_{k,t}$ is the active labour force, with $Actr_{k,t}$ the

labour force participation rate and $Pop_{k,t}$ total population.⁴ Trend output is accordingly:

$$Y_{k,t}^{pot} = A_{k,t}^Y \cdot Pop_{k,t}, \quad (16)$$

growing at the combined rate of trend labour productivity and population growth along the balanced growth path. Since productivity follows a non-stationary process, the model distinguishes two technology disturbances. The growth rate of productivity evolves as

$$\log A_{k,t}^Y - \log A_{k,t-1}^Y = \varepsilon_{k,t}^{AY} + \overline{\epsilon}_{k,t}^{AY}, \quad (17)$$

where $\overline{\epsilon}_{k,t}^{AY}$ is an i.i.d. shock to the productivity growth rate that generates a one-off permanent shift in the productivity level, and $\varepsilon_{k,t}^{AY}$ is the time-varying trend growth rate following an AR(1) process around its steady-state trend growth rate $\bar{g}^{AY}$:

$$\varepsilon_{k,t}^{AY} = \rho_k^{AY} \varepsilon_{k,t-1}^{AY} + (1 - \rho_k^{AY}) \bar{g}^{AY} + \epsilon_{k,t}^{AY}, \quad (18)$$

with $\epsilon_{k,t}^{AY}$ a stationary i.i.d. innovation. Both shocks generate permanent shifts in the productivity level: $\overline{\epsilon}_{k,t}^{AY}$ through a one-off jump, and $\epsilon_{k,t}^{AY}$ through cumulative persistence in $\varepsilon_{k,t}^{AY}$. A positive $\epsilon_{k,t}^{AY}$ therefore permanently raises country k 's productivity level relative to trading partners, lowering domestic prices and generating a permanent real depreciation through the cost-competitiveness channel.⁵

4.3.2. Total output as a composite of value added and oil

Total output, $O_{k,t}$, is produced by perfectly competitive firms combining value added, $Y_{k,t}$, and oil, $OIL_{k,t}$, using a CES production function with elasticity of substitution σ_k^O :

$$O_{k,t} = \left[(1 - s_k^{OIL})^{1/\sigma_k^O} Y_{k,t}^{\frac{\sigma_k^O - 1}{\sigma_k^O}} + (s_k^{OIL})^{1/\sigma_k^O} OIL_{k,t}^{\frac{\sigma_k^O - 1}{\sigma_k^O}} \right]^{\frac{\sigma_k^O}{\sigma_k^O - 1}}, \quad (19)$$

⁴Given the simplified production setting without capital, the model abstracts from a labour FOC defining the real marginal cost, a wage Phillips curve, and the Tobin-Q investment decision. The production function (15) therefore serves as a reduced-form mapping between labour input, productivity and value added, with the output gap, $\log(Y_{k,t}/Y_{k,t}^{pot})$, as the relevant driver of inflation in the Phillips curve (24).

⁵The distinction between permanent and transitory productivity shocks is central to the analysis of [Ifrim et al. \(2026\)](#), who show that the persistent EA-RoW productivity growth differences is a key driver of EA external dynamics. Our framework complements their two-region analysis by decomposing this channel across all seven country blocs.

where s_k^{OIL} is the steady-state oil share in total output. The composite $O_{k,t}$ is split into consumption and export bundles $O_{k,t}^C$ and $O_{k,t}^X$, introduced in Section 4.4. The price of the composite, $P_{k,t}^O$, is defined by the value identity:

$$O_{k,t} P_{k,t}^O = P_{k,t}^Y Y_{k,t} + OIL_{k,t} P_{k,t}^{OIL}. \quad (20)$$

so that $P_{k,t}^O$ is an implicit price index that aggregates the value-added deflator $P_{k,t}^Y$ and the oil price $P_{k,t}^{OIL}$. Profit maximisation subject to (19) delivers the conditional input-demand schedules:

$$Y_{k,t} = (1 - s_k^{OIL}) \left(\frac{P_{k,t}^Y}{P_{k,t}^O} \right)^{-\sigma_k^O} O_{k,t}, \quad (21)$$

$$OIL_{k,t} = s_k^{OIL} \left(\frac{P_{k,t}^{OIL}}{P_{k,t}^O} \right)^{-\sigma_k^O} O_{k,t}. \quad (22)$$

Oil is imported exclusively from RoW, so domestic firms take the oil price as given. The domestic oil price is:

$$P_{k,t}^{OIL} = E_t^{RoW,k} P_{RoW,t}^{OIL} + \tau^{OIL} P_{k,t}^Y, \quad (23)$$

where $E_t^{RoW,k}$ is the bilateral exchange rate (domestic currency units per unit of RoW currency), $P_{RoW,t}^{OIL}$ is the world oil price denominated in RoW currency, and $\tau^{OIL} = 0.3$ is a calibrated globally uniform excise duty, capturing taxes, transport costs, and distribution margins that drive a wedge between the world oil price and the domestic delivered price.

4.3.3. Reduced-form New Keynesian Phillips curve

The price setting equation follows a hybrid New Keynesian Phillips curve (NKPC), where $sf p_k$ is the share of forward-looking price-setters. When $sf p_k = 1$, the NKPC reduces to its standard purely forward-looking form:

$$\begin{aligned} \pi_{k,t}^Y - \bar{\pi} = & \beta_{k,t} \frac{\Lambda_{k,t+1}}{\Lambda_{k,t}} \left[sf p_k (\pi_{k,t+1}^Y - \bar{\pi}) + (1 - sf p_k) (\pi_{k,t}^Y - \bar{\pi}) \right] + \phi_k^Y \log \left(\frac{Y_{k,t}}{Y_{k,t}^*} \right) + \varepsilon_{k,t}^Y, \end{aligned} \quad (24)$$

where $\pi_{k,t}^Y = \log(P_{k,t}^Y/P_{k,t-1}^Y)$ is the GDP-deflator, $\bar{\pi}$ is the steady-state trend inflation rate, ϕ_k^Y is the slope coefficient on the output gap. $\varepsilon_{k,t}^Y$ is a cost-push markup shock following the AR(1) process $\varepsilon_{k,t}^Y = \rho_k^Y \varepsilon_{k,t-1}^Y + \epsilon_{k,t}^Y$. The household's stochastic discount factor,

$\beta_{k,t}\Lambda_{k,t+1}/\Lambda_{k,t}$, couples the inflation block to the consumption Euler equation (11).⁶

4.4. International linkages: imports, exports and bilateral demand

The cross-border block governs how domestic final demand and exports are split between domestic and imported goods, and how bilateral trade flows respond to relative prices, exchange rates, and shifts in bilateral trade patterns. The block features two stages. First, perfectly competitive import retailers purchase goods from each foreign region and assemble them into bilateral import bundles. Second, perfectly competitive final good packagers combine domestic output with these import bundles to produce the consumption and export components of aggregate demand.

4.4.1. CES aggregation of domestic and imported intermediates

The final consumption bundle, $O_{k,t}^C$, and export bundle, $O_{k,t}^X$, are assembled by perfectly competitive final good packagers that combine domestic total output, $O_{k,t}$, with imported goods, $M_{k,t}^C$ and $M_{k,t}^X$, using a CES aggregator. For $D \in \{C, X\}$, where $D = C$ denotes the consumption bundle demanded by households and $D = X$ the export bundle, the aggregator is:

$$D_{k,t} = \left[(1 - s_k^{MD} \varepsilon_{k,t}^M)^{1/\sigma_k^D} (O_{k,t}^D)^{\frac{\sigma_k^D - 1}{\sigma_k^D}} + (s_k^{MD} \varepsilon_{k,t}^M)^{1/\sigma_k^D} (M_{k,t}^D)^{\frac{\sigma_k^D - 1}{\sigma_k^D}} \right]^{\frac{\sigma_k^D}{\sigma_k^D - 1}}, \quad (25)$$

where σ_k^D is the elasticity of substitution between domestic and imported goods (the Armington elasticity σ_k^C when $D = C$), s_k^{MD} is the steady-state sector-specific import share, and $\varepsilon_{k,t}^M$ is a shock to the import demand share capturing structural shifts in trade patterns. The nominal value identity:

$$P_{k,t}^D D_{k,t} = P_{k,t}^O O_{k,t}^D + P_{k,t}^M M_{k,t}^D, \quad (26)$$

implicitly defines $P_{k,t}^D$ as the unit cost of the aggregate bundle. Cost minimisation of (25) delivers the input demand schedules:

$$O_{k,t}^D = (1 - s_k^{MD} \varepsilon_{k,t}^M) \left(\frac{P_{k,t}^O}{P_{k,t}^D} \right)^{-\sigma_k^D} D_{k,t}, \quad (27)$$

$$M_{k,t}^D = s_k^{MD} \varepsilon_{k,t}^M \left(\frac{P_{k,t}^M}{P_{k,t}^D} \right)^{-\sigma_k^D} D_{k,t}, \quad (28)$$

⁶Despite the reduced-form NKPC, equation (24) retains the same micro-foundation interpretation as the canonical Calvo or Rotemberg NKPC, with ϕ_k^Y summarising the combined effect of markup curvature and nominal price stickiness (Smets and Wouters, 2003).

with the CES price index:

$$P_{k,t}^D = \frac{1}{\varepsilon_{k,t}^D} \left[(1 - s_k^{MD} \varepsilon_{k,t}^M) (P_{k,t}^O)^{1-\sigma_k^D} + (s_k^{MD} \varepsilon_{k,t}^M) (P_{k,t}^M)^{1-\sigma_k^D} \right]^{\frac{1}{1-\sigma_k^D}}, \quad (29)$$

where $\varepsilon_{k,t}^D$ is a sector-specific price shock to the final good basket.⁷ Total non-oil imports of country k are the sum of the consumption and export components:

$$M_{k,t} = M_{k,t}^C + M_{k,t}^X. \quad (30)$$

4.4.2. Bilateral import demand

Total imports of country k are sourced from the other regions l according to a second CES nest with price elasticity σ_k^{FM} and bilateral steady-state import shares $s_{l,k}^M$:

$$M_{l,k,t} = s_{l,k}^M \varepsilon_{l,k,t}^M \left(\frac{P_{l,k,t}^M}{P_{k,t}^M} \right)^{-\sigma_k^{FM}} \frac{S_k}{S_l} M_{k,t}, \quad (31)$$

where $\varepsilon_{l,k,t}^M$ is a bilateral import demand shock that captures structural trade-pattern shifts, such as supply chain reconfiguration, or deglobalisation episodes, and S_k/S_l is a size adjustment that scales bilateral flows by the relative population weights of the importing and exporting country to ensure global market clearing. Note that $\varepsilon_{l,k,t}^M$ is distinct from the aggregate import share shock $\varepsilon_{k,t}^M$ in equation (25): the former shifts the sourcing composition within the import basket, while the latter shifts the overall import propensity of country k . The aggregate import price index $P_{k,t}^M$ is defined implicitly by the value identity:

$$P_{k,t}^M M_{k,t} = \sum_{l \neq k} \frac{S_l}{S_k} P_{l,k,t}^M M_{l,k,t}, \quad (32)$$

which states that total import expenditure equals the sum of bilateral import expenditures across all source countries.

⁷In the current model specification, this shock is only estimated for the export bundle ($D = X$), where it captures exogenous shifts in the competitiveness of domestically produced goods within the export basket. For the consumption bundle ($D = C$), $\varepsilon_{k,t}^C$ is not estimated and is instead set to its steady-state value of one, so the consumer price index $P_{k,t}^C$ reduces to a purely structural object, mechanically determined each period by $P_{k,t}^O$ and $P_{k,t}^M$ via equation (29). Since $C_{k,t}$ is not itself an observable, real consumption is instead implicitly identified as a residual from the national accounts identity, $C_{k,t} = (P_{k,t}^Y Y_{k,t} - TB_{k,t})/P_{k,t}^C$, given observed output, the GDP deflator, the trade balance, and the model-implied $P_{k,t}^C$.

4.4.3. The “internal” export price

Producers in country k assemble the export composite $X_{k,t}$ from domestic and imported components at unit cost $P_{k,t}^{X,int}$, the internal (pre-shipment) export price, defined implicitly by the cost-of-production identity:

$$P_{k,t}^{X,int} X_{k,t} = P_{k,t}^O O_{k,t}^X + P_{k,t}^M M_{k,t}^X, \quad (33)$$

so that $P_{k,t}^{X,int}$ represents the marginal cost faced by exporters of country k . This internal price serves as the cost benchmark against which exporters set their destination-specific prices $P_{l,k,t}^X$ in the bilateral price-setting block described in Section 4.4.4.

4.4.4. Bilateral price-setting with Rotemberg adjustment costs

For each ordered pair of countries (l, k) with $l \neq k$ there are two distinct monopolistically-competitive intermediaries: an importer in k who buys variety l abroad and resells it domestically, and an exporter in l who ships its product to destination k . Both face Rotemberg quadratic costs of changing their price, and both discount future profits with the household’s stochastic discount factor (Section 4.2). Since both problems share the same Rotemberg quadratic structure, we derive the importer’s first-order condition in detail and state the exporter’s by analogy.

The importer’s problem. The importer in country k of goods from origin l purchases from the foreign exporter at the destination-specific export price $P_{k,l,t}^X$, expressed in l -currency. After exchange-rate conversion at the bilateral rate $E_t^{l,k}$, the landed cost (unit purchase cost) faced by the importer in k currency is

$$P_{l,k,t}^{M1} = E_t^{l,k} P_{k,l,t}^X, \quad (34)$$

i.e. the price the exporter in l charges for shipments to destination k , converted to the importer’s currency. The importer resells at the bilateral import price $P_{l,k,t}^M$ subject to a Rotemberg quadratic adjustment cost,

$$\Xi_{l,k,t}^{PM} = \frac{\gamma_{l,k}^{PM}}{2} \left(\frac{P_{l,k,t}^M}{P_{l,k,t-1}^M} \frac{P_{k,t-1}^O}{P_{k,t}^O} - 1 \right)^2 M_{l,k,t} \frac{P_{l,k,t}^M}{P_{k,t}^Y}, \quad (35)$$

expressed as a fraction of GDP at market prices. The adjustment-cost argument is indexed to the total output deflator $P_{k,t}^O$, implying that importers can re-price for free when they keep up with domestic output inflation, and only pay for relative price changes. Faced with the bilateral demand schedule from (31), the importer chooses the sequence $\{P_{l,k,t+s}^M\}_{s \geq 0}$ to

maximise the present discounted value of real profits:

$$\max_{\{P_{l,k,t+s}^M\}_{s \geq 0}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta_k^s \frac{\Lambda_{k,t+s}}{\Lambda_{k,t}} \frac{1}{P_{k,t+s}^Y} [P_{l,k,t+s}^M M_{l,k,t+s} - P_{l,k,t+s}^{M1} M_{l,k,t+s} - P_{k,t+s}^Y \Xi_{l,k,t+s}^{PM}] . \quad (36)$$

The first-order condition with respect to $P_{l,k,t}^M$ delivers the bilateral import-price equation:

$$P_{l,k,t}^M = P_{l,k,t}^{M1} - \gamma_{l,k}^{PM} \Psi_{l,k,t}^{PM} + \mathbb{E}_t \left[\beta_{k,t} \frac{\Lambda_{k,t+1}}{\Lambda_{k,t}} \gamma_{l,k}^{PM} \Phi_{l,k,t+1}^{PM} \right] , \quad (37)$$

where $\Psi_{l,k,t}^{PM}$ is the static Rotemberg adjustment term that captures the current-period marginal cost of the price change:

$$\Psi_{l,k,t}^{PM} = \frac{(P_{l,k,t}^M)^2}{P_{l,k,t-1}^M} \frac{P_{k,t-1}^O}{P_{k,t}^O} \left(\frac{P_{l,k,t}^M}{P_{l,k,t-1}^M} \frac{P_{k,t-1}^O}{P_{k,t}^O} - 1 \right) , \quad (38)$$

and $\Phi_{l,k,t+1}^{PM}$ is the forward-looking term that captures the future marginal saving from today's price adjustment:

$$\Phi_{l,k,t+1}^{PM} = \frac{M_{l,k,t+1}}{M_{l,k,t}} \exp(-\pi_{k,t+1}^Y) \frac{(P_{l,k,t+1}^M)^2}{P_{l,k,t}^M} \frac{P_{k,t+1}^O}{P_{k,t}^O} \left(\frac{P_{l,k,t+1}^M}{P_{l,k,t}^M} \frac{P_{k,t+1}^O}{P_{k,t}^O} - 1 \right) . \quad (39)$$

The factor $\exp(-\pi_{k,t+1}^Y)$ deflates the future nominal import price by current GDP inflation, converting the forward-looking term into real units consistent with the GDP-deflated profit objective. In the absence of nominal frictions ($\gamma_{l,k}^{PM} = 0$), equation (37) collapses to the law of one price, $P_{l,k,t}^M = P_{l,k,t}^{M1}$, implying full and immediate exchange rate pass-through from the landed cost to the destination import price.

The exporter's problem. Exporters in country k shipping to destination l buy the export composite at the internal price $P_{k,t}^{X,int}$ from (33) and sell at the destination-specific export price $P_{l,k,t}^X$, expressed in destination l currency. They face a Rotemberg cost whose argument is the gross growth rate of the export price expressed in source-currency terms:

$$\Xi_{l,k,t}^{PX} = \frac{\gamma_{l,k}^{PX}}{2} \left(\frac{P_{l,k,t}^X}{P_{l,k,t-1}^X} \frac{E_t^{k,l}}{E_{t-1}^{k,l}} - \exp(\bar{\pi}) \right)^2 M_{k,l,t} , \quad (40)$$

benchmarked against the steady-state trend inflation rate, $\bar{\pi}$. The term $P_{l,k,t}^X E_t^{k,l} / E_{t-1}^{k,l}$ re-expresses destination-currency price growth in source-currency terms: exporters can leave destination prices stable when their own currency depreciates without incurring an adjustment cost, but pay for any deviation from source-currency trend inflation. Solving the

analogous profit-maximisation problem and taking the FOC with respect to $P_{l,k,t}^X$ yields the bilateral export-price equation:

$$P_{l,k,t}^X = P_{k,t}^{X,int} \exp(\varepsilon_{l,k,t}^{PX}) - \gamma_{l,k}^{PX} \Psi_{l,k,t}^{PX} + \mathbb{E}_t \left[\beta_{k,t} \frac{\Lambda_{k,t+1}}{\Lambda_{k,t}} \gamma_{l,k}^{PX} \Phi_{l,k,t+1}^{PX} \right], \quad (41)$$

where $\Psi_{l,k,t}^{PX}$ and $\Phi_{l,k,t+1}^{PX}$ are the static and forward-looking Rotemberg adjustment terms, defined analogously to (38)–(39) with export prices and exchange rates replacing import prices. The shock $\varepsilon_{l,k,t}^{PX}$ shifts the desired export markup over the internal cost $P_{k,t}^{X,int}$ on the bilateral export route. In the current specification, this shock is identified only for exports originating from RoW ($k = RoW$), capturing exogenous shifts in global export pricing conditions that affect the price of RoW goods arriving in each country bloc. Intra-EA and EA–US bilateral export price dynamics are governed exclusively by the Rotemberg adjustment cost mechanism without an additional markup shock.

The real per-period profits of importers and exporters are rebated lump-sum to domestic households via $\Omega_{k,t}$ in equation (9), ensuring that all monopolistic-competition rents are returned to households. Total exports of country k aggregate bilateral flows across all destinations:

$$X_{k,t} = \sum_{l \neq k} M_{k,l,t}, \quad P_{k,t}^X X_{k,t} = \sum_{l \neq k} P_{l,k,t}^X M_{k,l,t}. \quad (42)$$

Relation to pricing-to-market. The combined friction described in this subsection generates incomplete short-run exchange-rate pass-through to local import prices, observationally similar to the local-currency-pricing (LCP) and pricing-to-market (PTM) frameworks of [Krugman \(1987\)](#) and [Betts and Devereux \(2000\)](#). The underlying mechanism is structurally different, however: exporters set a producer-currency price (the Rotemberg cost in equation (40) penalises deviations from trend inflation in the source currency), so that incomplete pass-through to local import prices arises from two complementary layers of nominal friction: importer-side stickiness in the destination currency (35) and exporter-side adjustment costs in the source currency (40). For exports originating from RoW, destination-specific export pricing is additionally captured through the bilateral export price shock $\varepsilon_{cc,RoW}^{PX}$, which allows the RoW source-currency export price to differ across destination regions, introducing a reduced-form analogue of pricing-to-market at the shock level. For intra-EA and EA–US bilateral corridors, export price dynamics are governed exclusively by the Rotemberg adjustment cost mechanism.

4.4.5. World oil market

The world oil price $P_{RoW,t}^{OIL}$ is exogenous and denominated in RoW currency:

$$P_{RoW,t}^{OIL} = \frac{\bar{P}_t^Y}{A_{RoW,t}^{POIL}}, \quad (43)$$

where $\bar{P}_t^Y = (1 + \bar{\pi})\bar{P}_{t-1}^Y$ is the deterministic nominal price trend growing at the steady-state quarterly inflation rate $\bar{\pi}$, ensuring that the real oil price is stationary in steady state. $A_{RoW,t}^{POIL}$ is an exogenous oil-specific supply technology whose decline raises the real cost of oil production and hence the world oil price. The global oil market clears when RoW supplies its oil endowment to all importing regions:

$$OIL_{RoW,t} = \sum_{k \neq RoW} \frac{S_l}{S_{RoW}} OIL_{k,t}. \quad (44)$$

4.5. Monetary policy, trade balance and market clearing

4.5.1. Taylor rules

The central banks of the EA, the US, and RoW each follow a Taylor-type interest rule:

$$i_{k,t} - \bar{i}_k = \rho_k^i (i_{k,t-1} - \bar{i}_k) + (1 - \rho_k^i) [\eta_k^\pi (\pi_{k,t}^C - \bar{\pi}) + \eta_k^y (y_{k,t} - y_{k,t}^{pot})] + \epsilon_{k,t}^i, \quad (45)$$

where $\bar{i}_k$ is the steady-state nominal interest rate, $\bar{\pi}$ is the inflation target, $\pi_{k,t}^C$ is the annualised quarter-on quarter CPI inflation rate, and $y_{k,t} \equiv \log Y_{k,t}$ and $y_{k,t}^{pot} \equiv \log Y_{k,t}^{pot}$ denote log output and log potential output, respectively. The policy parameters $(\rho_k^i, \eta_k^\pi, \eta_k^y)$ capture interest rate inertia and the policy response coefficient to inflation and the output gap, respectively. $\epsilon_{k,t}^i$ is an i.i.d. monetary policy shock.⁸

4.5.2. Trade balance and balance of payments

For a non-RoW country k , the nominal trade balance is

$$TB_{k,t} = P_{k,t}^X X_{k,t} - \sum_{l \neq k} \frac{S_l}{S_k} E_t^{l,k} P_{k,l,t}^X M_{l,k,t} - E_t^{RoW,k} P_{RoW,t}^{OIL} OIL_{k,t}, \quad (46)$$

where the first term is total export revenue, the second is total non-oil import expenditure converted to domestic currency, and the third is oil import expenditure. The balance-of-

⁸The EA and US nominal interest rate $i_{k,t}$ is matched to shadow rate data during the zero lower bound period to account for unconventional monetary policy measures following [Hohberger et al. \(2023\)](#).

payments identity accumulates net foreign assets:

$$E_t^{RoW,k} B_{k,t}^W = (1 + i_{t-1}^{BW}) E_t^{RoW,k} B_{k,t-1}^W + TB_{k,t} + ITR_{k,t} P_{k,t}^Y Y_{k,t}, \quad (47)$$

where $ITR_{k,t}$ is a calibrated international transfer (expressed as a share of nominal GDP) that accommodates non-zero steady-state trade balances across country blocs.

4.6. Aggregate resource constraint

Abstracting from investment and government spending, the national accounts identity in market prices is

$$P_{k,t}^Y Y_{k,t} = P_{k,t}^C C_{k,t} + TB_{k,t}. \quad (48)$$

For RoW, the constraint includes oil export revenues, with $P_{l,RoW,t}^{OIL} = E_t^{RoW,l} P_{RoW,t}^{OIL}$ denoting the world oil price converted to country l currency:

$$P_{RoW,t}^Y Y_{RoW,t} + \sum_{l \neq RoW} \frac{S_l}{S_{RoW}} OIL_{l,t} P_{l,RoW,t}^{OIL} = P_{RoW,t}^C C_{RoW,t} + TB_{RoW,t}. \quad (49)$$

5. Model solution and econometric approach

5.1. Model solution

The first-order perturbation solution of the model takes the form of a linear state space system:

$$y_t^{obs} = \Psi_1(\Theta) S_t, \quad (50)$$

$$S_t = \Psi_2(\Theta) S_{t-1} + \Theta_\varepsilon(\Theta) \varepsilon_t, \quad (51)$$

where y_t^{obs} is the vector of observables at time t , S_t is the vector of state variables, $\Psi_1(\Theta)$ is the observation matrix linking state variables to observables, $\Psi_2(\Theta)$ is the state transition matrix governing the dynamics of S_t , $\Theta_\varepsilon(\Theta)$ is the shock impact matrix, ε_t is the vector of exogenous structural shocks, and Θ denotes the full vector of structural parameters.

5.2. Data

The model is estimated at quarterly frequency using data from 1999Q1 to 2025Q4. Quarterly data for the individual EA Member States and EA aggregate are taken from Eurostat. Quarterly data for the US come from the Bureau of Economic Analysis (BEA) and the Federal Reserve. Annual data for RoW are constructed from the IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases. Quarterly observations for RoW are obtained by interpolating annual data. Following [Hohberger et al.](#)

(2023), we replace the nominal short-term interest rate with estimated shadow rates from Wu and Xia (2016, 2017) when the economy operates at the effective lower bound, capturing the stance of unconventional monetary policy.⁹ The estimated model uses 53 observed series. The full list of observables is provided in Appendix B.

5.3. Estimation procedure

A subset of parameters is calibrated to match historical long-run properties such as steady-state trade shares. The remaining parameters and shock processes are estimated using data over 1999Q1–2025Q4. A key identification feature of the estimation is the inclusion of trend output $Y_{k,t}^{pot}$ in equation (16), constructed from IMF and ECB potential output estimates, as direct observables for all seven country blocs. Observing the trend alongside actual output allows the Kalman filter to separately identify permanent productivity shocks from cyclical disturbances and pin down the low-frequency component of bilateral real exchange rate divergence, analogous to the identification strategy of Ifrim et al. (2026). We estimate 54 exogenous shocks, plus one heteroscedastic lockdown shock per country bloc.¹⁰ Posterior distributions are sampled using Gibbs sampling, specifically the slice sampler (Neal, 2003).¹¹

5.4. Calibrated parameters and posterior estimates

Table A.1 in Appendix A provides an overview of the calibrated parameters. Steady-state ratios are calibrated to match their average historical counterparts over the sample period. The steady-state shares of DE, FR, IT, ES, REA, US, and RoW in world GDP are 5.2%, 3.7%, 2.9%, 1.9%, 4.6%, 26.2%, and 55.4%, respectively. The trade-related parameters, specifically the degree of openness and the bilateral import propensities $s_{i,k}^M$, reflect the average import content of demand components as computed by Bussière et al. (2013). The consumption import shares s_k^{MC} are derived as a residual $s_k^{MC} = (M_k - s_k^{MX} X_k)/C_k$ rather than taken directly from Bussière et al. (2013). Since the model abstracts from government

⁹Shadow rate data are available at: <https://sites.google.com/view/jingcynthiawu/shadow-rates>. They are derived from term structure models and align with short-term policy rates under normal conditions, but turn negative when the ELB binds. For further discussion on the substitutability between policy rates and shadow rates, see Hohberger et al. (2023).

¹⁰The lockdown shocks are jointly estimated alongside the other structural parameters using a diffuse and heteroskedastic Kalman filter. Examples of incorporating pandemic-related heteroscedastic shocks in DSGE models can be found in Cardani et al. (2022a); Hohberger (2025).

¹¹The posterior is approximated using the slice sampler with 6 parallel chains of 50 iterations each, yielding 40 draws per chain for inference after a burn-in of 10 iterations. Computations are performed in parallel using Dynare 6.5 (Adjemian et al., 2024). The slice sampler has been shown to offer superior mixing properties compared to the Metropolis-Hastings algorithm (Calés et al., 2017) and has been applied in multi-country DSGE estimation by, among others, Giovannini et al. (2019), Hohberger et al. (2023), and Ifrim et al. (2026).

spending and investment, all non-export imports are attributed to consumption, mechanically raising s_k^{MC} above its raw input-output counterpart. For Germany, $s_{DE}^{MC} \approx 0.30$ against $s_{DE}^{MC,obs} \approx 0.21$, with the difference of approximately 0.09 reflecting the import content of government spending and investment weighted by their GDP shares. This residual derivation ensures import market clearing holds in steady state. Bilateral import shares $s_{i,k}^M$ are based on trade shares from the GTAP trade matrices for trade in goods and services.¹² Given that oil quantities are not directly observed in estimation, the elasticity of substitution between value added and oil σ_k^O is calibrated to 0.4, implying relatively inelastic substitution between domestic value added and oil inputs, consistent with [Bodenstein et al. \(2011\)](#). The global trend growth rate of real variables, the trend inflation rate, and population growth are calibrated to 1.38%, 2%, and 0.28% per year, respectively, ensuring a balanced growth path with a well-defined non-stochastic steady state around which the system is linearised. The steady-state nominal interest rate is implied by the intertemporal discount factor and trend inflation. With $\beta_k = 0.9985$ and 2% trend inflation, this implies a steady-state nominal interest rate of approximately 2.60% and a real rate of 0.60% per year.

Table [A.2](#) reports prior and posterior estimates for selected structural parameters. The monetary policy parameters suggest a strong response to inflation relative to the output gap and relatively high interest rate inertia. Habit persistence is estimated around 0.80 for the large EA member states, implying a slow adjustment of consumption to income changes. The elasticity of substitution between domestic goods and imports, σ^C , is estimated slightly above unity for the four large EA blocs.¹³ The import source substitution elasticity, σ^{FM} , governs how strongly import demand responds to relative price changes across source countries. Posterior estimates are heterogeneous across blocs, ranging from 0.26 (RoW) to 3.24 (DE), suggesting that import demand in DE and FR is more price-responsive across source countries than in the US and RoW. The estimated share of forward-looking price setters sfp is close to unity across all country blocs, confirming that the purely forward-looking New Keynesian Phillips curve provides an adequate description of inflation dynamics in the estimated model. Phillips curve slopes, ϕ^Y , are flat across all country blocs, consistent with recent evidence on the flattening of the Phillips curve in the euro area ([Beschinn et al.](#),

¹²The resulting 7×7 bilateral trade matrix covers DE, FR, IT, ES, REA, US, and RoW, with REA and RoW constructed as residual aggregates of the remaining EA and non-EA economies respectively (Table [A.1](#)). Each row is normalised to sum to unity across source countries. The matrix is consistent with a 3×3 EA–US–RoW aggregation in which the sum of intra-EA bilateral flows matches the EA diagonal of the aggregated matrix.

¹³Parameter uncertainty with values slightly below unity point to the international elasticity puzzle documented, for example, by [Ruhl \(2008\)](#) and [Fontagné et al. \(2018\)](#) who show that high-frequency exchange rate variation activates the intensive margin of trade slowly, generating systematically lower macro elasticities than tariff-based estimates ([Bajzik et al., 2020](#)).

2025). Import price adjustment costs, γ^{PM} , range from 3.65 (ES) to 11.09 (FR), implying moderate-to-high import price stickiness. Export price adjustment costs, γ^{PX} , are substantially smaller, implying that exchange rate shocks are absorbed primarily on the import price side.

The estimated shock processes for all regions are reported in Table A.3 in Appendix A. The EA bond premium shock, capturing shifts in investor appetite for euro-denominated assets, and the EA monetary policy shock are common to all EMU member states, while the US bond premium shock captures the global safe-haven premium on dollar-denominated assets. The bilateral trade shocks represent exogenous shifts in each country’s import and export price vis-à-vis RoW, with the bilateral subscript indicating the source country. The posterior estimates of the pandemic-specific lockdown shock are in line with Hohberger (2025); Cardani et al. (2022a), with Spain (7.32%) and Italy (6.38%) recording the largest estimates, consistent with their severe early pandemic restrictions.

6. Estimation results

This section presents the main estimation results in four steps. We first validate the estimated model by comparing model-implied moments to their empirical counterparts and assessing exchange rate pass-through (ERPT) dynamics. We then characterise the impulse response dynamics of key macro-financial variables to selected structural shocks, distinguishing between the symmetric transmission of external shocks and the asymmetric bilateral divergence generated by country-specific disturbances. We decompose the historical dynamics of the EA–US bilateral real exchange rate and the intra-EA bilateral real exchange rates of France, Italy, and Spain relative to Germany into contributions from structurally identified shock groups, quantifying the drivers of competitiveness divergence over 1999–2025. Finally, we provide off-model validation of key structural shocks by comparing smoothed shock estimates to external indicators.

6.1. Model validation

Table 1 compares selected sample and model-implied moments for DE, FR, IT, ES, and the US, covering the volatility, persistence and cross-correlation with GDP growth of real GDP growth, the GDP deflator, export and import price inflation, export and import growth, and the trade balance-to-GDP ratio. We use quarter-on-quarter growth rates for all variables except the trade balance-to-GDP ratio, for which we use first differences. The model tends to mildly overstate the volatility of most series relative to the data, most visibly for GDP growth and the trade balance-to-GDP ratio, while the high export and import growth volatilities are matched fairly closely. Persistence in GDP growth is well captured: the countries display

Table 1: Theoretical moments and model fit.

	Std (%)		AR(1)		Corr(x,GDP)	
	Data	Model	Data	Model	Data	Model
Germany (DE)						
GDP growth	1.50	1.56	-0.14	-0.10	1.00	1.00
GDP deflator	0.51	0.52	0.39	0.19	-0.38	-0.18
Export price inflation	0.86	0.96	0.72	0.10	0.24	0.10
Import price inflation	0.93	0.85	0.75	0.58	0.16	0.07
Export growth	3.68	3.76	-0.00	-0.08	0.87	0.75
Import growth	3.16	3.22	0.01	-0.05	0.70	0.68
Trade balance-to-GDP	0.69	0.79	-0.01	0.17	0.43	0.28
France (FR)						
GDP growth	2.05	2.12	-0.24	-0.31	1.00	1.00
GDP deflator	0.58	0.60	-0.11	0.17	-0.75	-0.48
Export price inflation	1.14	1.18	0.65	0.17	0.21	0.09
Import price inflation	0.95	0.83	0.66	0.54	-0.22	-0.21
Export growth	3.86	3.93	-0.05	-0.09	0.87	0.80
Import growth	3.06	3.34	-0.03	-0.15	0.84	0.81
Trade balance-to-GDP	0.55	0.63	-0.10	0.22	0.37	0.18
Italy (IT)						
GDP growth	2.09	2.26	-0.11	-0.27	1.00	1.00
GDP deflator	0.50	0.57	0.09	0.20	-0.26	-0.10
Export price inflation	0.82	0.85	0.63	0.20	0.33	0.08
Import price inflation	1.10	1.03	0.73	0.63	0.19	0.15
Export growth	4.65	4.56	-0.08	-0.09	0.92	0.72
Import growth	3.65	3.75	0.13	-0.15	0.84	0.76
Trade balance-to-GDP	0.62	0.70	0.01	0.11	0.31	0.02
Spain (ES)						
GDP growth	2.58	2.75	-0.19	-0.32	1.00	1.00
GDP deflator	0.70	0.75	0.32	0.20	0.17	0.11
Export price inflation	1.26	1.32	0.39	0.18	0.21	0.07
Import price inflation	1.27	1.24	0.69	0.57	0.20	0.16
Export growth	4.94	4.85	-0.13	-0.10	0.94	0.74
Import growth	4.95	4.81	-0.11	-0.16	0.89	0.78
Trade balance-to-GDP	0.65	0.71	0.13	0.18	0.04	-0.12
United States (US)						
GDP growth	1.27	1.37	-0.16	-0.25	1.00	1.00
GDP deflator	0.40	0.45	0.69	0.12	0.32	0.19
Export price inflation	1.56	1.68	0.40	-0.01	0.45	0.23
Import price inflation	0.91	1.07	0.65	0.52	0.20	0.13
Export growth	3.41	3.68	0.07	-0.04	0.84	0.63
Import growth	3.71	3.69	0.07	-0.10	0.72	0.56
Trade balance-to-GDP	0.33	0.36	0.16	0.15	-0.06	0.05

negative first-order autocorrelation in both data and model. The model understates price inflation persistence relative to the data, particularly for export price inflation, where the data show higher autocorrelation than the model implies. Import price inflation persistence is captured more closely. On cross-correlations, the model reproduces the strong positive co-movement of export and import growth with GDP growth found in the data. Notably, the model correctly replicates the sign of the correlation between the GDP deflator and GDP growth in all countries, negative for DE, FR, and IT, and positive for ES and the US, matching a pattern that is not imposed by calibration. The trade balance-to-GDP ratio is positively correlated with GDP growth for DE, FR, and IT, while for ES and the US the correlation is close to zero in both the data and the model.

We validate the model's ERPT dynamics using the price-to-exchange-rate ratio (PERR) concept introduced by [Ortega and Osbat \(2020\)](#), defined as the ratio of the impulse response of a price variable to the impulse response of the nominal exchange rate, conditional on a

Table 2: Price-to-Exchange-Rate Ratios (PERR).

Shock	Country	Import price (border)		Consumer price	
		Quarter I	Quarter IV	Quarter I	Quarter IV
Bond premium (EA)	DE	0.21	0.66	0.11	0.33
	FR	0.19	0.63	0.10	0.32
	IT	0.20	0.64	0.09	0.26
	ES	0.28	0.82	0.12	0.35
	REA	0.21	0.66	0.13	0.40
	US	0.21	0.66	0.03	0.07
	<i>OO(2020) median</i>	<i>0.38</i>	<i>0.80</i>	<i>0.04</i>	<i>0.10</i>
Mon. policy (EA)	DE	0.20	0.79	0.13	0.57
	FR	0.20	0.83	0.15	0.65
	IT	0.20	0.77	0.11	0.48
	ES	0.28	0.97	0.16	0.65
	REA	0.19	0.73	0.13	0.51
	US	0.17	0.53	0.02	0.04
	<i>OO(2020) median</i>	<i>0.40</i>	<i>0.80</i>	<i>0.10</i>	<i>0.30</i>
Mon. Policy (US)	DE	0.15	0.44	0.04	0.09
	FR	0.15	0.45	0.03	0.08
	IT	0.16	0.46	0.03	0.08
	ES	0.30	0.73	0.07	0.15
	REA	0.23	0.62	0.11	0.29
	US	0.17	0.61	0.08	0.34
	<i>OO(2020)</i>	<i>US monetary policy shock not reported</i>			

Note: Quarter I and Quarter IV refer to the PERR on impact and after four quarters, respectively. The exchange rate is defined such that an increase denotes a depreciation. *OO(2020) median* refers to the cross-model median from Tables 3 and 4 of [Ortega and Osbat \(2020\)](#).

given structural shock:

$$PERR_h^z = \frac{\text{IRF of price}_h^z \mid \text{shock } s}{\text{IRF of exchange rate}_h \mid \text{shock } s}, \quad z \in \{M, C\}, \quad (52)$$

where $z = M$ denotes import prices at the border and $z = C$ denotes consumer prices (proxied by the CPI deflator), and h indexes the horizon. Unlike the shock-invariant ERPT, the PERR is shock-conditional and therefore captures the general equilibrium feedback through which monetary policy and bond premium shocks transmit differentially to prices. [Ortega and Osbat \(2020\)](#) document, based on a cross-model comparison, that approximately 38% of a given exchange rate movement passes through to EA border import prices on impact, and approximately 4% to total consumer prices.

Table 2 reports the model-implied PERRs for three structural shocks, the EA bond premium shock, the EA monetary policy shock, and the US monetary policy shock, at impact (Quarter I) and after four quarters (Quarter IV). The model-implied PERRs are broadly consistent with the [Ortega and Osbat \(2020\)](#) benchmarks. Border PERRs on impact (0.19–0.28 across EA countries) are somewhat below the cross-model median of 0.38, reflecting the

estimated import price adjustment costs that generate sluggish initial pass-through, while 4-quarter PERRs (0.63–0.82) closely match the benchmark of 0.80. The EA monetary policy shock generates slightly higher PERRs than the bond premium shock after four quarters. Consumer price PERRs exceed the benchmark at four quarters for both EA shocks, consistent with the absence of an explicit retail distribution sector that would otherwise create an additional wedge between border and consumer price adjustment. The US monetary policy shock provides a novel perspective on ERPT not covered by [Ortega and Osbat \(2020\)](#), who focus exclusively on aggregate EA shocks. A US monetary policy tightening appreciates the dollar against the euro, raising import costs across EA member states. The border PERR for EA countries ranges from 0.15 to 0.30 on impact, and from 0.44 to 0.73 at four quarters. The cross-country heterogeneity is more pronounced than for the EA-origin shocks, which reflects the interaction between each country’s dollar-invoiced import share and its estimated import price elasticity. For the US, the PERR on impact (0.17) and at four quarters (0.61) are somewhat lower than those of the EA countries.

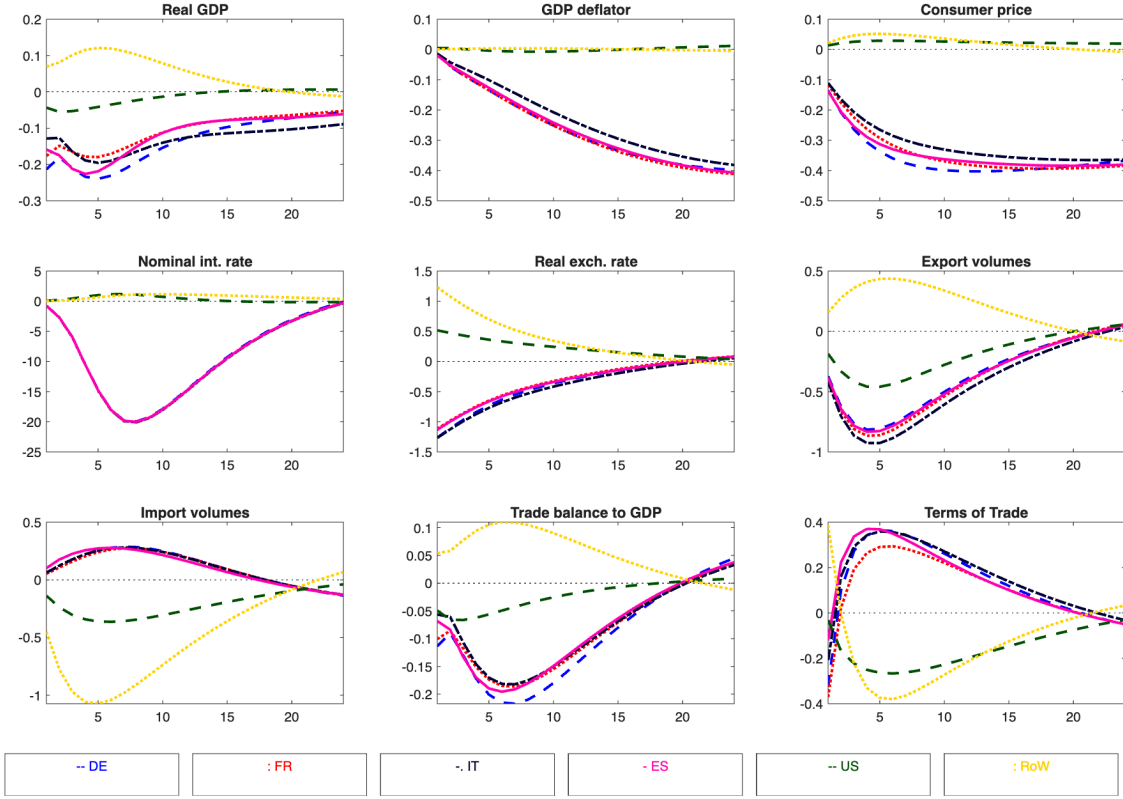
6.2. *Dynamic transmission of shocks*

This subsection presents the dynamic responses to four selected estimated disturbances: (i) a positive EA bond premium shock, (ii) a positive shock to DE’s import share, (iii) a negative terms-of-trade shock to DE, and (iv) a negative shock to IT’s trend productivity growth rate. All shocks are simulated using one estimated standard deviation. Each panel illustrates the dynamic responses of real GDP, the GDP deflator, consumer prices, nominal interest rates, the real exchange rate, real export and import volumes, the trade balance-to-GDP ratio, and the terms of trade (measured as the export-to-import-price ratio). Real variables are expressed as percent deviations from steady state; the nominal interest rate as annualised basis point deviations; and the trade balance-to-GDP ratio as percentage point deviations. An increase in the real exchange rate indicates a real appreciation. For the terms-of-trade shock, we additionally report posterior impulse responses with 90% uncertainty bands in [Figure A.2](#) of [Appendix A](#) to account for parameter uncertainty.

Positive EA bond premium shock

[Figure 2](#) presents the dynamic responses to a positive EA bond premium shock ϵ_{EA}^{BW} , capturing an exogenous increase in the required return on euro-denominated assets. The shock triggers a capital inflow into the EA, appreciating the real exchange rates for the EA member states on impact. The appreciation improves the terms of trade by lowering import prices and increases imports while compressing export demand, deteriorating the trade balance. Both the GDP deflator and consumer prices fall and GDP contracts as net exports decline. The EA monetary policy rate falls in response to the disinflationary output

Figure 2: Dynamic responses to a positive EA bond premium shock.



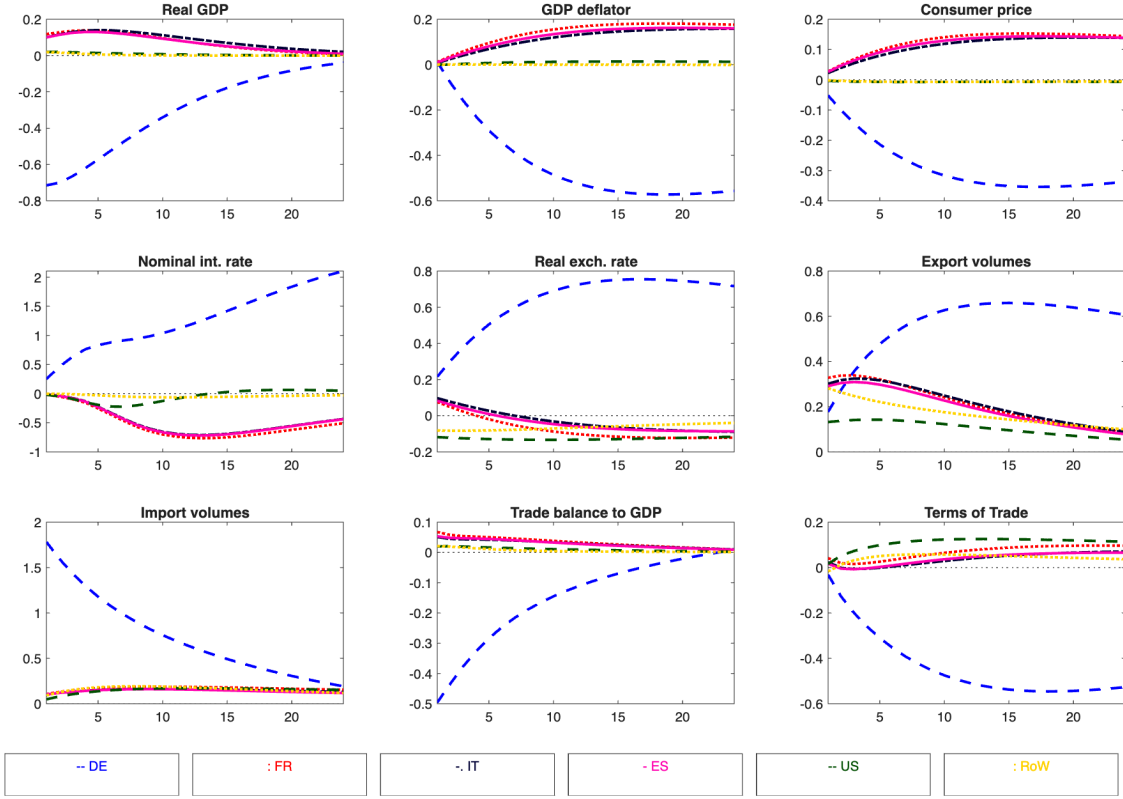
Note: Impulse responses to an estimated one-standard-deviation shock. The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

contraction, partially cushioning the appreciation and generating the gradual mean reversion. Since the shock is common to all EA member states, it generates broadly homogeneous dynamics, leaving intra-EA competitiveness positions largely unchanged.

Positive shock to Germany's import share (home bias)

Figure 3 presents the dynamic responses to a positive shock to aggregate import propensity of DE, ϵ_{DE}^M , capturing an exogenous reduction in DE home bias. Import volumes rise, substituting away from domestically produced goods and lowering GDP. Both the GDP deflator and CPI fall as domestic demand weakens. Import prices rise as higher DE demand puts upward pressure on import prices, while falling domestic costs lower export prices and deteriorate the terms of trade. However, the export response is insufficient to offset the import increase, so the trade balance-to-GDP ratio deteriorates. The DE real exchange rate depreciates as domestic prices fall relative to trading partners. This produces a combination of trade balance deterioration and real depreciation, as the volume effects of the import

Figure 3: Dynamic responses to a positive shock to the DE import share.



Note: Impulse responses to an estimated one-standard-deviation shock. The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

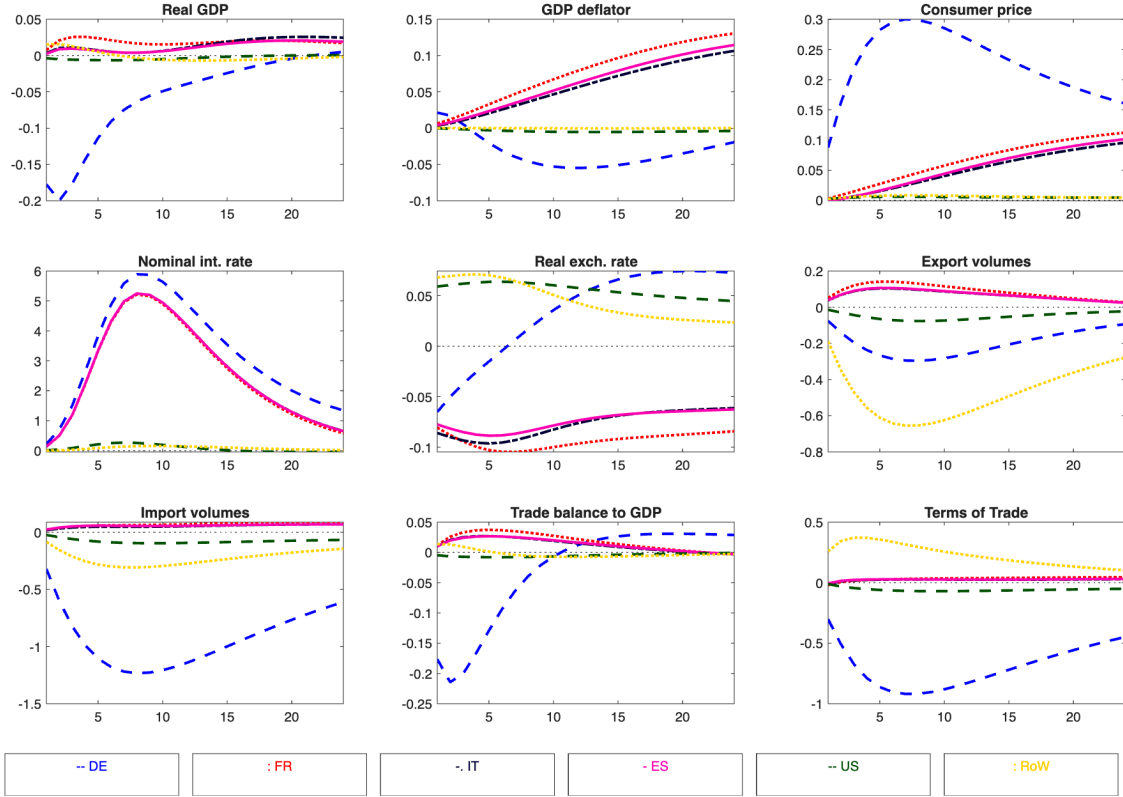
demand shock dominate the price adjustment channel.¹⁴ Nominal interest rates across EA member states diverge marginally through the debt-elastic risk premium: DE's deteriorating net foreign asset position raises its effective borrowing cost slightly while the positive demand spillover to France, Italy, and Spain compresses their intra-EA spreads. The resulting bilateral real exchange rate appreciation of FR, IT, and ES relative to DE illustrates the idiosyncratic channel through which country-specific import demand shocks can generate intra-EA competitiveness divergence. Figure A.1 in Appendix A presents the corresponding posterior IRFs with 90% uncertainty bands to account for parameter uncertainty.

Negative terms-of-trade shock for Germany

Figure 4 presents the dynamic responses to a negative terms-of-trade shock for DE, mod-

¹⁴This pattern distinguishes the import share shock from a standard negative saving shock, which would also raise imports but would simultaneously raise domestic prices and appreciate the real exchange rate. Since the two shocks generate opposite real exchange rate responses, they are clearly distinguishable in the data and can be separately identified by the likelihood during the estimation process.

Figure 4: Dynamic responses to a negative terms-of-trade shock for Germany.

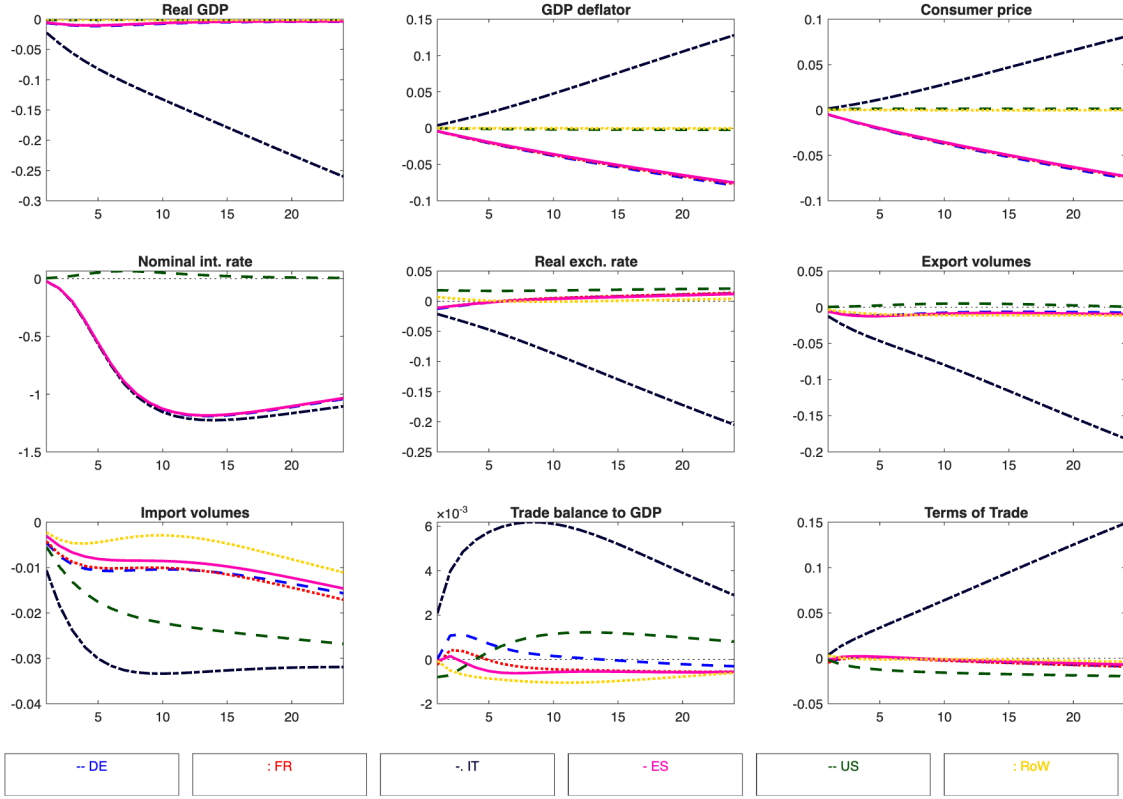


Note: Impulse responses to an estimated one-standard-deviation shock. The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

elled as a positive shock to the bilateral export price from RoW to DE, $\epsilon_{DE,RoW}^{PX}$. Higher DE import prices from RoW reduce import volumes, compressing domestic demand and lowering GDP. While domestic output prices remain broadly unchanged, consumer prices rise as the higher import costs pass through to the consumption basket. Real exchange rates across EA member states diverge due to output prices differentials, accompanied by a deterioration of the trade balance-to-GDP ratio in DE. The shock generates a stagflationary pattern, i.e. falling output while consumer prices rise, reflecting that the shock raises the cost of living without directly affecting domestic production costs. The shock therefore serves as a structural proxy for global supply chain disruptions and external cost-push pressures. Figure A.2 in Appendix A presents the corresponding posterior IRFs with 90% uncertainty bands, confirming that the stagflationary pattern is robust to parameter uncertainty. Additionally, Section 6.4 provides off-model validation of this shock by comparing the estimated smoothed shock series with the Global Supply Chain Pressure Index of Benigno et al. (2022).

Negative shock to the trend productivity growth rate in Italy

Figure 5: Dynamic responses to a negative trend productivity growth rate shock in Italy.



Note: Impulse responses to an estimated one-standard-deviation shock. The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

Figure 5 presents the dynamic responses to a negative shock to the trend productivity growth rate in IT, ϵ_{IT}^{AY} . As discussed in Section 4.3, even a transitory negative shock to the growth rate generates a permanent downward shift in the productivity level via the accumulation equation, lowering trend output and GDP. Domestic prices rise relative to trading partners, generating a persistent real appreciation through the cost-competitiveness channel. The terms of trade improve as IT export prices increase, while the trade balance-to-GDP remains broadly unchanged: the deterioration in export volumes is largely offset by the rise in export prices, and import demand stays stable due to sluggish consumption adjustment driven by habit formation. Since the shock is Italy-specific, it does not trigger a response from the common EA monetary policy rate, leaving the appreciation uncushioned and amplifying the persistent intra-EA competitiveness divergence documented in Section 6.3.

6.3. Estimated drivers of bilateral real exchange rate adjustments

Historical shock decompositions (SDs) offer a quantitative evaluation of the main structural drivers of bilateral real exchange rate dynamics. We present SDs for two comple-

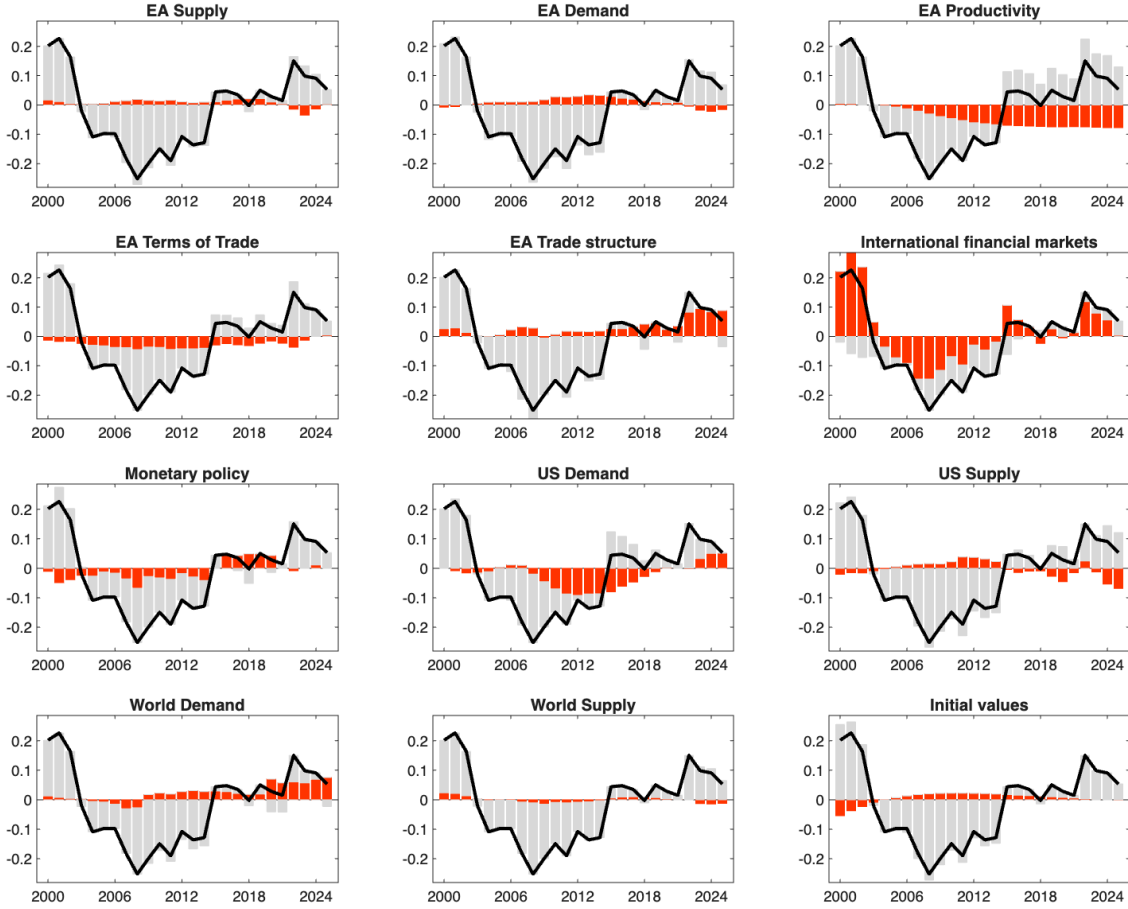
mentary sets: First, Figure 6 presents the SD of the EA–US bilateral real exchange rate over 2000–2025, capturing the external dimension of EA competitiveness vis-à-vis the US. Second, Figures 7–9 exhibit the SDs of the bilateral real exchange rate dynamics of FR, IT, and ES relative to DE over the same period, capturing the intra-EA competitiveness dimension. In all figures, the continuous black line represents the historical bilateral real exchange rate data. The vertical red bars illustrate the contribution of each shock group to the series, while stacked light grey bars summarise the contributions of all remaining shocks. Bars above the horizontal axis represent positive shock contributions, contributing to a real appreciation of country i relative to Germany, while bars below the horizontal axis indicate negative contributions, contributing to a real depreciation.

The shock grouping differs slightly between the two decompositions: for the EA–US real exchange rate, shocks are grouped by origin (EA, US, and world), while for the intra-EA real exchange rates they are expressed as differentials between the respective country and Germany. Hence, for each shock group in Figures 7–9, the plotted red bars reflect the difference between the shock’s contribution to country i ’s real exchange rate and its contribution to Germany’s real exchange rate. A positive contribution from, for example, the supply differential group therefore means that supply shocks (e.g. price markup) have raised country i ’s price level relative to Germany’s, generating a real appreciation of country i vis-à-vis Germany. The shock groups for the intra-EA real exchange rate SDs are: (i) supply differentials (price markup shocks); (ii) demand differentials (preference shocks); (iii) productivity differentials (shocks to the trend output growth rate); (iv) terms-of-trade differentials (bilateral export and import price shocks vis-à-vis RoW, including oil price shocks); (v) trade structure differentials (home bias and to bilateral import shares); (vi) common shocks (EA bond premia and EA monetary policy shocks); (vii) non-EA differentials (US and RoW demand, supply, and monetary policy shocks); (viii) EA differentials (shocks from other EA member states); and (ix) initial values. The sum of all contributions equals the observed bilateral data in each period by construction.

6.3.1. The EA-US bilateral real exchange rate

Figure 6 presents the historical SD of the bilateral real exchange rate between the US and the EA over 2000–2025, where an increase indicates a real appreciation of the dollar vis-à-vis the euro. The EA–US bilateral real exchange rate exhibits a period of dollar strength in the early 2000s, followed by a prolonged dollar depreciation through 2002–2008; a gradual reversal and renewed dollar appreciation following the global financial crisis and during the European sovereign debt crisis of 2012–2013; and a post-pandemic episode of euro depreciation that has since partially unwound toward pre-pandemic levels.

Figure 6: Bilateral real exchange rate between US and EA



Note: The bilateral real exchange rate is shown in percentage-point deviations from steady state. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

International financial market shocks, captured through the estimated bond premium shocks, emerge as the dominant driver of the EA–US real exchange rate throughout the sample, consistent with [Itskhoki and Mukhin \(2021\)](#), who show that financial market shocks are the primary driver of bilateral real exchange rate fluctuations across all major currency pairs. Monetary policy shocks, combining EA and US Taylor rule disturbances, contribute visibly to euro depreciation during 2015–2019, capturing the divergence between the ECB’s unconventional monetary policy stance and the contemporaneous Fed normalisation cycle ([Hohberger et al., 2023](#)). US demand shocks generate a notable negative contribution in the aftermath of the global financial crisis, consistent with a period of post-crisis deleveraging ([Greaney and Walsh, 2023](#)). World demand shocks contribute positively and with growing importance from 2012 onward, reflecting the dollar’s dominant role in global trade and the tendency for global demand expansions ([Gopinath et al., 2020](#)).

EA-origin shocks (supply, demand, productivity, terms-of-trade, and trade structure) contribute modestly to the EA–US real exchange rate throughout the sample with two exceptions: First, EA trend productivity shocks make an increasingly negative contribution to the EA–US bilateral real exchange rate from the global financial crisis onward, exerting persistent euro appreciation pressure through the cost-competitiveness channel. The shock to the trend output growth rate generates permanent cumulative shifts in the productivity level and hence in relative prices. Unlike cyclical markup shocks, these disturbances do not mean-revert and therefore account for the low-frequency, persistent component of the real exchange rate divergence: a negative contribution reflects slower EA trend productivity growth relative to the US, which raises EA prices and appreciates the euro in real terms through the cost-competitiveness channel. Second, EA trade structure shocks contribute increasingly to euro depreciation after 2017 due to a decline in EA goods home bias.¹⁵

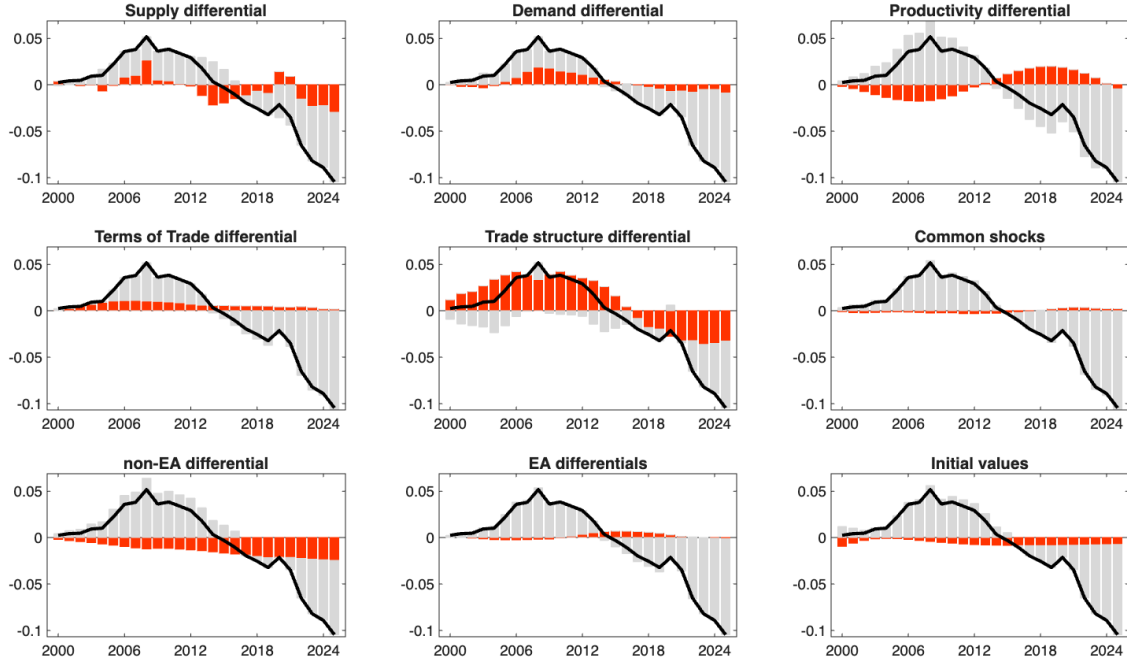
6.3.2. Intra-EA bilateral exchange rates

France–Germany

The FR/DE bilateral real exchange rate exhibits a moderate FR appreciation of approximately 5% during 2000–2008, followed by a persistent depreciation of approximately 15% through 2025 (Figure 7). The pre-crisis appreciation is driven by a combination of demand, terms-of-trade, and trade structure differentials, reflecting stronger FR domestic demand and price dynamics compared to DE in the pre-crisis boom. Within the trade structure group, a reduction in DE aggregate home bias (DE is sourcing more of its demand from abroad) compresses DE domestic prices and contributes positively to FR appreciation during 2000–2009. From 2012 onward, this contribution is increasingly offset by asymmetric bilateral RoW demand shocks that disproportionately benefit DE exports, appreciating the DE real exchange rate relative to FR and generating a growing negative net trade structure contribution through 2025. Productivity differentials contribute negatively during 2002–2012, reflecting higher productivity growth in FR relative to DE over this period. Higher potential output widens the output gap for given actual output, dampening FR inflation relative to DE and depreciating the FR real exchange rate. This contribution dissipates from 2012 onward and reverses to a positive contribution, suggesting that DE productivity growth began outpacing FR, consistent with the delayed materialisation of efficiency gains from DE’s structural labour market reforms of the mid-2000s (Kollmann et al., 2015; Cardani et al., 2022b), though the model identifies this through trend output dynamics rather than

¹⁵Initial conditions account for a sizeable contribution in the early part of the sample that dissipates by 2008, consistent with the model’s convergence from its 1999Q1 starting values toward the steady state.

Figure 7: Bilateral real exchange rate between France and Germany (aoa)



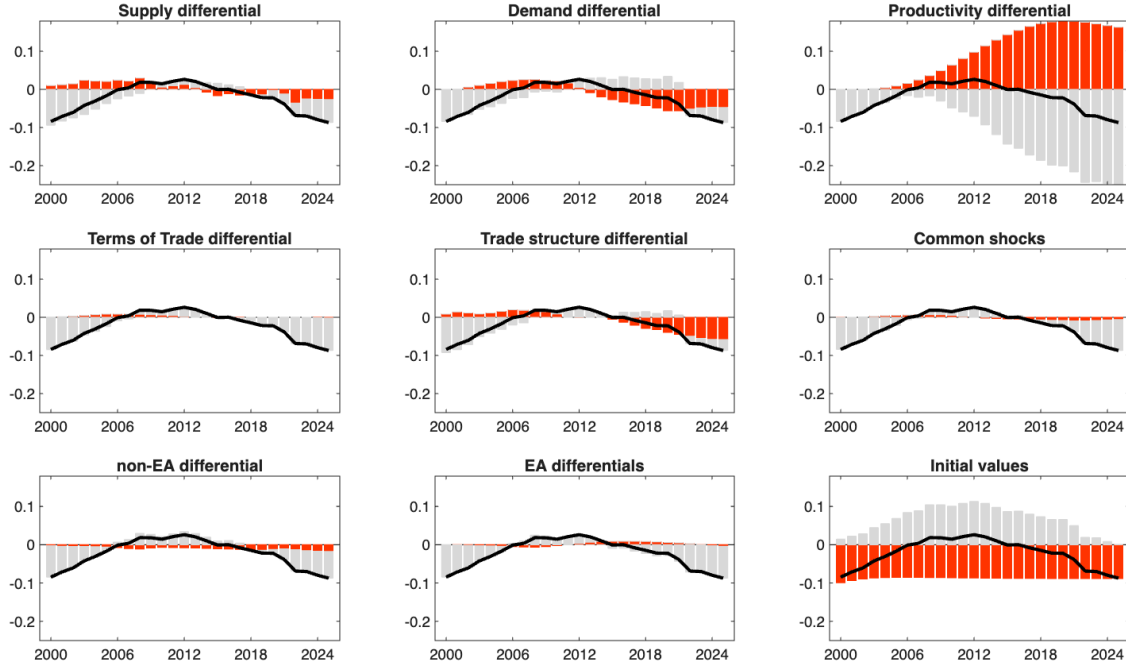
Note: The bilateral real exchange rate is shown in percentage-point deviations from steady state. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

directly through a labour productivity channel. Supply differentials contribute negatively from 2012 onward, driven by stronger cost-push markup shocks in DE relative to FR, amplified post-pandemic by the 2022 energy price surge, which raised DE prices relative to FR and contributed to DE appreciation. Additionally, the persistent negative contribution from non-EA differentials is driven primarily by non-EA productivity shocks that exert stronger appreciation pressure on DE. Common shocks remain near zero throughout, consistent with the symmetric transmission of EA-wide monetary policy and bond premium shocks.

Italy–Germany

IT experienced an appreciation of approximately 10% during the first decade of EMU relative to DE, before entering a sustained depreciation of similar magnitude that continued through 2025 (Figure 8). In contrast to the FR/DE decomposition, where multiple shock groups contribute to the bilateral real exchange rate dynamics, the IT/DE real exchange rate is dominated by the productivity differential, which rises from near zero in 2005 to approximately 15% by 2025. Slower trend productivity growth in IT relative to DE dampens the negative output gap, putting upward pressure on IT prices relative to DE prices and generating persistent real appreciation vis-à-vis DE. This structural productivity divergence points to a supply-side misalignment supported by the empirical literature: [Calligaris et al. \(2018\)](#)

Figure 8: Bilateral real exchange rate between Italy and Germany (aoa)



Note: The bilateral real exchange rate is shown in percentage-point deviations from steady state. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

estimate that IT aggregate productivity in 2013 would have been 18% higher had resource misallocation remained at its 1995 level, while [International Monetary Fund \(2025\)](#) documents a cumulative labour productivity shortfall of approximately 30% relative to European peers by the mid-2020s. Our structural decomposition provides a general equilibrium quantification of the real exchange rate consequences of this productivity gap. Demand, supply, and trade structure differentials contribute negatively from 2012 onward, reflecting weaker domestic and foreign demand for IT goods, stronger DE cost competitiveness, and asymmetric RoW demand conditions favouring DE exports. These forces mostly offset the appreciation pressure from the productivity differential, while external and common shocks contribute negligibly.¹⁶

¹⁶The persistent negative contribution of initial values to the IT/DE bilateral real exchange rate throughout the sample reflects the gap between the IT real exchange rate position at euro adoption in 1999Q1 and the model's estimated steady-state IT/DE bilateral real exchange rate, calibrated to the full-sample average. IT entered EMU with a relatively depreciated real exchange rate, a legacy of the 1992–93 ERM crises and lira devaluations, which lies below the model's steady state for most of the sample. The slow dissipation of this initial condition reflects the high persistence of the trend productivity shock process, which generates sluggish mean reversion in all state variables and prevents the initial deviation from dying out within the 25-year estimation horizon. This does not affect the structural interpretation of the shock contributions but

Spain–Germany

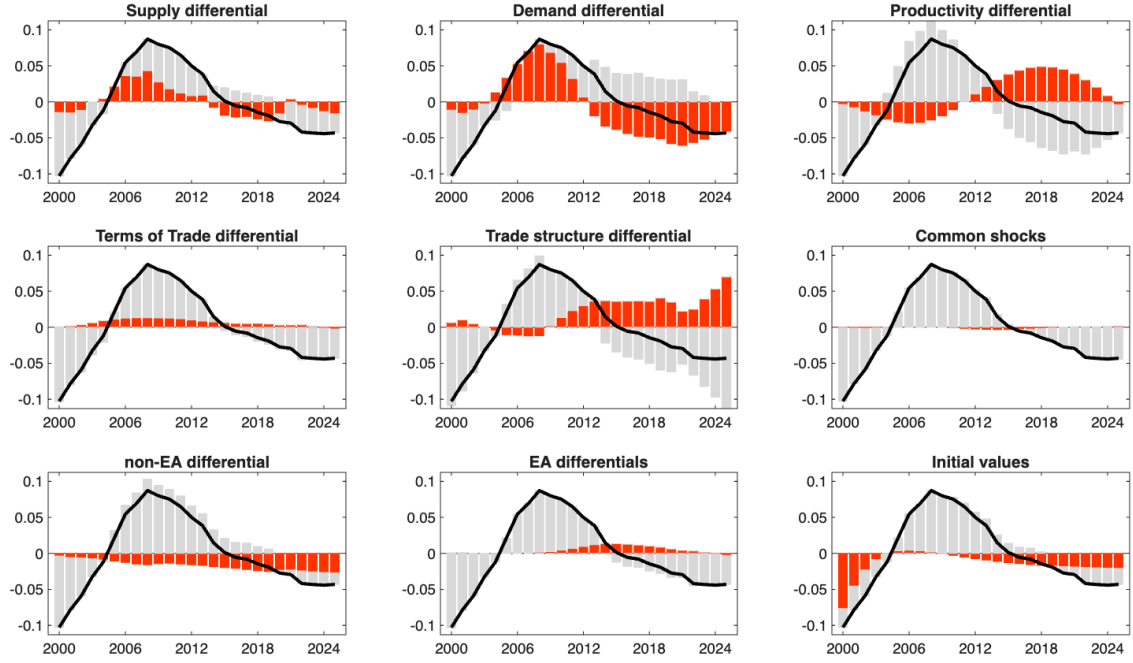
Figure 9 presents the historical SD of the ES/DE bilateral real exchange rate, which exhibits the classic pre-crisis boom-and-bust pattern most clearly among the three bilateral pairs. The real exchange rate appreciates by approximately 20% during 2000–2008, before reversing by approximately 15% through 2025. Unlike the FR/DE and IT/DE decompositions, the pre-crisis appreciation is driven simultaneously by supply, demand, and terms-of-trade differentials, reflecting the ES pre-crisis boom characterised by strong domestic demand, rising wages and prices, and improving terms of trade relative to DE (Lane and Milesi-Ferretti, 2012; Gaulier and Vicard, 2012). Trend productivity differentials contribute negatively during 2002–2008, reflecting above-trend ES potential output growth consistent with the structural convergence trajectory of a catching-up economy, which partially moderated the appreciation pressure from demand and supply differentials. This contribution fades and gradually reverses from 2008 onward as ES potential growth normalised toward the common steady-state rate.¹⁷ In the most recent years, the productivity differential turns slightly negative again, consistent with Germany’s post-pandemic productivity deterioration (German Council of Economic Experts, 2024; Kemp, 2026). (German Council of Economic Experts, 2024; Kemp, 2026). The post-2012 real exchange rate reversal is driven by the unwinding of the pre-crisis drivers. Trade structure differentials contribute negatively until 2012, partially offsetting the appreciation pressure, before turning positive and contributing to ES appreciation thereafter. Within that group, positive shocks to DE’s aggregate import propensity, reflecting episodes of rising German home bias reduction that compress DE domestic prices relative to ES, offset the negative contribution from asymmetric bilateral RoW demand shocks that disproportionately raise DE exports and appreciate the DE real exchange rate relative to ES. Non-EA differentials contribute negatively throughout, driven primarily by RoW productivity shocks that exert stronger appreciation pressure on DE than on ES. Common shocks contribute negligibly throughout.

As an additional robustness check confirming the coherence of the model’s structural interpretation across multiple dimensions, Figures A.3–A.5 in Appendix A present the historical SDs of real GDP growth for four EA member states, DE, FR, IT, ES, and the US.

implies that the model attributes part of the observed IT/DE level to pre-sample initial conditions rather than to identified structural shocks.

¹⁷This may appear counter-intuitive given that measured labour productivity per hour in Spain was low during this period, depressed by rapid employment expansion in low-productivity sectors such as construction and tourism. The distinction arises because the model’s productivity concept captures the smooth low-frequency component of output per worker identified from potential output series, rather than the average output per hour across all employed workers including those in cyclically expanded sectors. These two measures can diverge substantially during boom-bust episodes characterised by large compositional shifts in employment.

Figure 9: Bilateral real exchange rate between Spain and Germany (aoa)



Note: The bilateral real exchange rate is shown in percentage-point deviations from steady state. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

The shock grouping follows the same thematic categories as the bilateral real exchange rate decompositions (demand, supply, productivity, trade, monetary policy, financial markets, and external shocks) but applied to country-level output rather than bilateral differentials, so that each country's GDP growth is decomposed into contributions from its own domestic shocks alongside trade and world demand and supply disturbances. Demand shocks emerge as the dominant driver of GDP growth fluctuations at business cycle frequencies across all country blocs, while supply shocks contribute notably during specific episodes such as the post-pandemic period. Productivity shocks contribute to low-frequency trend deviations in output growth, consistent with their role as the dominant driver of the IT/DE real exchange rate divergence. World demand and international trade shocks reflect global demand spillovers. Notably, EA monetary policy shocks contribute visibly and positively to output growth across the EA member states during 2015–2019, consistent with the estimated stimulative effects of ECB unconventional monetary policy documented by [Hohberger et al. \(2019\)](#), [Hohberger et al. \(2023\)](#), and [Garcia-Revelo et al. \(2025\)](#). This contribution reverses from 2022 onward, as the ECB's monetary tightening in response to the post-pandemic inflation surge generates a negative monetary policy contribution to output growth.

6.4. Off-Model Validation

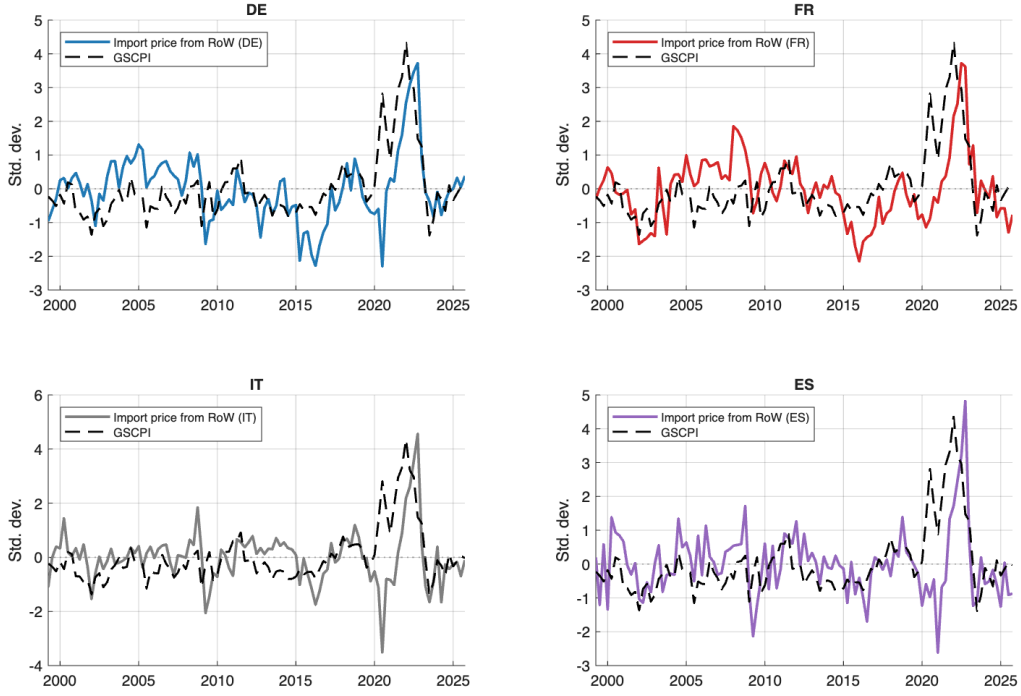
To assess the empirical plausibility of selected structural shocks and validate their economic interpretation, we compare the smoothed shock estimates to observable external indicators not used in estimation (Figure 10). We focus on two external supply shocks that play a central role in the historical decomposition: the bilateral import price shock $\varepsilon_{cc, RoW}^{PX}$ and the RoW supply shock ε_{RoW}^Y . Despite the model’s abstraction from explicit commodity sectors and international production networks, we assess whether the estimated shock processes nevertheless capture the dynamics of global supply chain disruptions and energy price pressures, providing indirect evidence on the empirical reach of the parsimonious shock structure.

Figure 10a plots the smoothed bilateral import price shocks for the four EA member countries alongside the Global Supply Chain Pressure Index (GSCPI) of [Benigno et al. \(2022\)](#). The estimated shock series track the GSCPI fairly well across the four EA member states, capturing the major supply chain disruption episodes, particularly the sharp spike in 2021–2022 following the COVID-19 pandemic and Russia’s invasion of Ukraine as well as the subsequent normalisation through 2023–2024. This co-movement is consistent with the structural interpretation as a bilateral terms-of-trade shock illustrated in Figure 4, where a positive shock raises import costs from RoW that generates a stagflationary pattern of declining output and rising consumer prices.

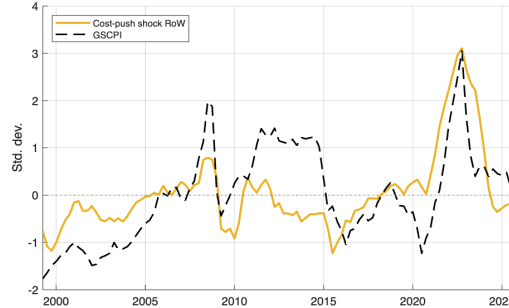
Figure 10b plots the smoothed RoW cost-push markup shock alongside the Global Price of Energy Index published by the IMF. This shock enters the RoW Phillips curve and therefore absorbs broad-based production cost pressures in RoW, including energy price dynamics. Both series co-move at cyclical frequencies, capturing part of the 2008 oil price spike, the post-crisis correction, the renewed energy price surge of 2021–2022, and its subsequent partial unwinding, with a correlation of 0.58 between the two series. Although the model includes the Brent crude oil price as a direct observable, with a corresponding oil price shock that explicitly absorbs crude oil price fluctuations, it abstracts from broader energy and commodity markets, including industrial supplies and natural gas. Fluctuations in these wider energy cost components are therefore not explicitly modelled but may be partially absorbed by the RoW markup shock.

The two validation exercises suggest that the estimated external supply shocks identified by the model map onto economically meaningful off-model counterparts. This does not imply that the estimated shocks exclusively capture global supply chain disruptions and energy price dynamics, both shocks absorb all exogenous cost-push pressures not explained by the model’s other structural components, but provides evidence that these economic phenomena are at least partially reflected in the estimated shock series, without explicit modelling of

Figure 10: Off-model indicators and estimated model shocks.



(a) Global Supply Chain Pressure Index



(b) Global price of energy index

Note: In Panel a), the model shocks (solid lines) represent the estimated smoothed bilateral import price shock from RoW. The data for the Global Supply Chain Pressure Index (GSCPI) are taken from the NY Fed website based on [Benigno et al. \(2022\)](#). In Panel b), the model shock (yellow solid line) represents the estimated smoothed RoW cost-push shock. The data used is the IMF's Global price of energy index (dashed line). Both data have been adjusted using a linear transformation to align the mean and standard deviation of the adjusted series with the corresponding moments of the estimated model shocks.

commodity markets or international production networks.

6.5. Robustness

We assess the sensitivity of the main results to alternative model specifications.

Latent potential output. To assess the identification role of the observed potential output series, we remove potential GDP as an observable and the corresponding trend productivity shock $\varepsilon_{k,t}^{AY}$ from the measurement equation, hold all parameters at their baseline posterior mode, and re-run the Kalman smoother. The resulting output gaps are reported in Figure A.6 in Appendix A. Without the observed potential output series, persistent deviations of trend productivity growth from the calibrated trend growth rate $\bar{g}^{AY}$ cannot be absorbed by the corresponding shock and are instead attributed to the output gap, generating a downward-trending gap for IT and an upward-trending gap for the US, suggesting trend productivity growth runs persistently below and above $\bar{g}^{AY}$, respectively. The counterfactual suggests that the observed potential output series plays an essential identification role, anchoring the trend-cycle decomposition and allowing the model to separately identify permanent shifts in trend productivity from cyclical output fluctuations.¹⁸

CPI-deflated IT/DE bilateral real exchange rate. The baseline results use GDP deflators to construct bilateral real exchange rates, consistent with the model’s price block. Figure A.7 in Appendix A presents the IT/DE bilateral real exchange rate as an illustrative example, confirming that the main patterns, namely the pre-crisis appreciation, the post-crisis reversal, the persistent real exchange rate divergence, as well as the dominant structural drivers identified in the historical shock decomposition are robust to replacing the GDP deflator with the CPI (Schmitz et al., 2024; Tkacevs et al., 2016).

7. Conclusion

This paper develops and estimates a seven-region New Keynesian DSGE model of the world economy to identify the structural drivers of bilateral real exchange rate dynamics within the euro area and between the euro area and the United States over 1999–2025. Jointly estimating all seven country blocs on a unified information set with an ex ante identical structure allows us to disentangle the contributions of domestic and external disturbances within a single, internally consistent general equilibrium framework.

The historical shock decompositions reveal a two-layer structure of real exchange rate determination. At the EA–US level, the external value of the euro is driven predominantly by international financial market conditions rather than EA macroeconomic fundamentals. Monetary policy divergence between the ECB and the Federal Reserve contributed visibly to euro depreciation during 2015–2019, before largely offsetting each other as both central

¹⁸A full re-estimation without observed potential output would partially mitigate these dynamics through parameter adjustment, but at the cost of losing the structural interpretation of trend productivity as a distinct driver of bilateral real exchange rate divergence.

banks tightened simultaneously in response to the post-pandemic inflation surge. Slower EA trend productivity growth generates persistent euro appreciation pressure, while rising world demand and a secular decline in EA home bias exert partially offsetting depreciation pressure from 2012 onward. The pre-crisis intra-EA appreciations decompose into distinct country-specific drivers: demand and trade structure differentials dominate the FR/DE pair, broad-based supply, demand, and terms-of-trade disturbances drive the ES/DE pair. Post-2008, these contributions unwind, with trade structure differentials playing an increasingly important role. These reflect two opposing forces common to all three pairs: a secular decline in DE home bias exerts depreciation pressure, while rising RoW demand for DE exports exerts appreciation pressure. The net effect differs across pairs depending on the bilateral partner’s own home bias and export demand dynamics. For FR and IT, a gradual reduction in home bias from 2012 onward and declining RoW demand for their exports generate a growing negative net trade structure contribution through 2025, implying bilateral competitiveness gains relative to DE. For ES, a comparatively stable home bias and recovering post-pandemic RoW export demand yield a positive net trade contribution, implying a bilateral competitiveness loss relative to Germany. Trend productivity differentials constitute the dominant low-frequency driver across all three pairs, becoming the defining feature of the IT/DE bilateral real exchange rate. Slower trend productivity growth in both IT and ES relative to DE generates persistent real appreciation pressure, deepening through the sovereign debt crisis and peaking around 2020. Thereafter the two pairs diverge: ES productivity differential narrows sharply, driven by both a recovery in ES trend productivity and a post-pandemic deterioration in DE productivity, while IT differential remains broadly stable, with the modest post-2020 narrowing reflecting primarily the same DE productivity deterioration rather than an IT catch-up.

Model validation supports the empirical plausibility of the estimation results. Model-implied moments match observed data pattern well. Exchange rate pass-through dynamics are broadly consistent with cross-model benchmarks. The smoothed bilateral export price shock tracks the Global Supply Chain Pressure Index closely, while the RoW supply shock co-moves with global energy price developments, confirming that the parsimonious shock structure captures the main exogenous drivers of international price dynamics without explicit modelling of commodity markets. Finally, sensitivity checks confirm that observing potential output is essential for credible trend-cycle identification.

Three natural extensions emerge from the current analysis. Incorporating fiscal policy and sovereign risk differentials would allow a structural identification of the sovereign debt channel in intra-EA real exchange rate dynamics, particularly for the 2010–2012 episode. Extending the model to include an explicit non-tradable sector would allow for a structural

assessment of the Balassa–Samuelson mechanism alongside the cost-competitiveness channel identified here. Finally, incorporating an explicit commodity and energy sector would sharpen the identification of global supply shocks and their asymmetric transmission across EA member states, a dimension that has gained particular prominence in light of the 2022 energy price surge and the ongoing restructuring of global energy markets.

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Appendix A. Additional results

Table A.1: Selected calibrated structural parameters.

		Country / Region						
		DE	FR	IT	ES	REA	US	RoW
Preferences and technology								
Intertemporal discount factor	β	0.999	0.999	0.999	0.999	0.999	0.999	0.999
Total import share	s^M	0.411	0.346	0.305	0.348	0.701	0.156	0.117
Import share in consumption	$s^{M,C}$	0.301	0.265	0.220	0.238	0.501	0.143	0.097
Import share in exports	$s^{M,X}$	0.220	0.227	0.253	0.296	0.258	0.094	0.176
Oil share in output	s^{Oil}	0.025	0.025	0.025	0.025	0.023	0.025	–
Oil price elasticity	σ^O	0.40	0.40	0.40	0.40	0.40	0.40	–
Steady-state ratios								
Trade balance share	TB/Y	0.052	–0.006	0.011	0.003	0.052	–0.032	–
Size (% of world GDP)	$size$	5.2	3.7	2.9	1.9	4.6	26.2	55.4
Bilateral import shares: share of exporter j (columns) in imports of importer i (rows)								
Importer ↓ / Exporter →		DE	FR	IT	ES	REA	US	RoW
DE	–	0.083	0.053	0.036	0.303	0.066		0.459
FR	0.174	–	0.073	0.075	0.257	0.076		0.345
IT	0.147	0.099	–	0.052	0.205	0.052		0.445
ES	0.140	0.134	0.068	–	0.193	0.052		0.413
REA	0.186	0.083	0.048	0.040	–	0.117		0.527
US	0.067	0.027	0.022	0.010	0.063	–		0.811
RoW	0.144	0.077	0.061	0.041	0.290	0.386		–

Note: Panel A reports country-level preference and steady-state parameters. β is uniform across all blocs. Oil share (s^{Oil}) and steady-state ratios are not separately calibrated for RoW (–). Country sizes are expressed as shares of world GDP based on model sample averages. Panel B reports bilateral import shares: each row sums to one.

Table A.2: Prior and posterior distribution of key estimated model parameters.

				Prior		Posterior (90% HPD interval)						
				Distr	Mean / St.Dev	DE	FR	IT	ES	REA	US	RoW
Monetary Policy												
Interest rate persistence	ρ^i	B	0.85 0.05					0.853 (0.833, 0.872)			0.887 (0.866, 0.904)	0.975 (0.968, 0.980)
Response to inflation	$\eta^{i,\phi}$	G	2.00 0.20					1.534 (1.330, 1.666)			1.862 (1.586, 2.087)	1.729 (1.489, 1.953)
Response to GDP	$\eta^{i,y}$	G	0.05 0.02					0.017 (0.003, 0.028)			0.063 (0.033, 0.094)	0.064 (0.042, 0.088)
Preferences												
Habit persistence	h	B	0.70 0.10		0.792 (0.753, 0.832)	0.802 (0.765, 0.839)	0.802 (0.762, 0.845)	0.812 (0.774, 0.856)	0.769 (0.707, 0.834)	0.822 (0.790, 0.852)	0.868 (0.856, 0.883)	
Elasticity of domestic demand	σ^C	G	1.50 0.30		1.048 (0.923, 1.168)	1.195 (0.931, 1.387)	1.135 (0.849, 1.354)	1.115 (0.866, 1.335)	1.151 (0.889, 1.499)	1.221 (0.982, 1.505)	2.487 (1.924, 3.079)	
Import price elasticity	σ^{FM}	G	2.00 1.00		3.243 (1.304, 5.424)	3.140 (1.122, 4.547)	1.987 (0.467, 3.608)	1.580 (0.644, 2.971)	1.290 (0.663, 2.319)	1.101 (0.352, 2.122)	0.263 (0.089, 0.434)	
Share of forward-looking price setters	sfp	N	1.00 0.15		0.922 (0.813, 0.999)	0.925 (0.834, 0.999)	0.927 (0.850, 0.997)	0.926 (0.864, 0.997)	0.935 (0.856, 0.998)	0.918 (0.806, 1.000)	0.945 (0.848, 1.000)	
Phillips curve slope	ϕ^y	G	0.025 0.01		0.012 (0.007, 0.018)	0.015 (0.009, 0.023)	0.008 (0.003, 0.012)	0.012 (0.008, 0.018)	0.006 (0.003, 0.009)	0.016 (0.009, 0.023)	0.001 (0.000, 0.002)	
Nominal frictions												
Import price adj. cost	γ^{PM}	G	5.00 2.00		9.133 (4.707, 13.089)	11.090 (6.119, 16.425)	8.689 (4.230, 13.041)	3.649 (1.729, 5.616)	8.341 (4.283, 12.188)	8.906 (3.913, 13.169)	8.234 (3.996, 12.417)	
Export price adj. cost	γ^{PX}	G	5.00 2.00		0.771 (0.458, 0.992)	0.932 (0.651, 1.367)	0.427 (0.271, 0.612)	0.427 (0.181, 0.662)	1.776 (0.559, 3.375)	0.154 (0.079, 0.236)	2.289 (1.870, 2.676)	

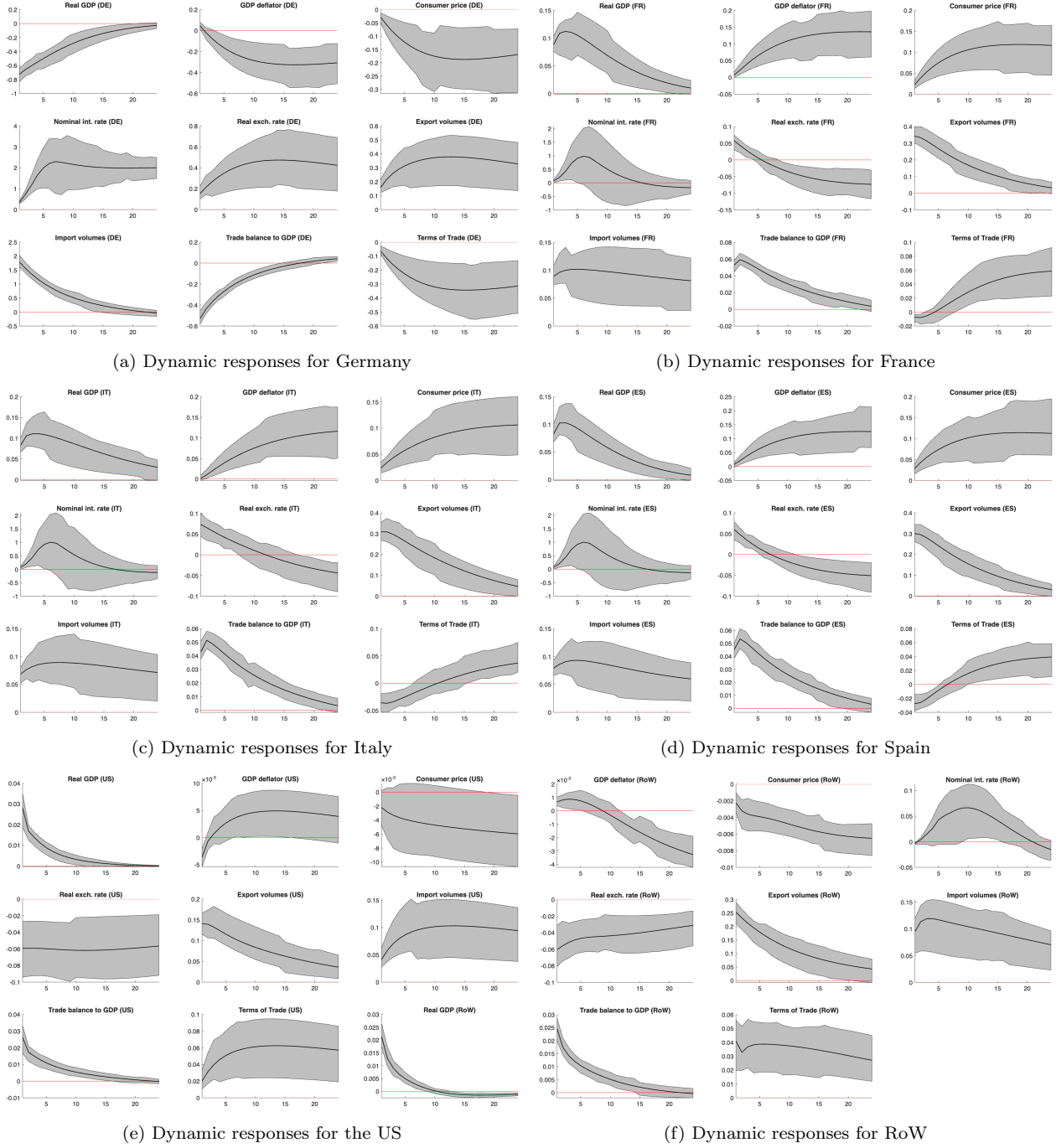
Note: Cols. (1)–(2) list model parameters and symbols. Cols. (3)–(4) indicate the prior distribution (B: Beta; G: Gamma; N: Normal) with prior mean and standard deviation. Monetary policy parameters (ρ^i , $\eta^{i,\phi}$, $\eta^{i,y}$) are common to all EA countries; separate Taylor rules are estimated for the US and RoW. Cols. (5)–(11) show the posterior mode and 90% HPD interval for each country bloc.

Table A.3: Prior and posterior distribution of estimated exogenous shock processes.

		Prior		Posterior (90% HPD) — EA					Non-EA	
		Distr	Mean / St.Dev	DE	FR	IT	ES	REA	US	RoW
Autocorrelations of forcing variables										
Subjective discount factor	ρ^C	B	0.70 0.10	0.786 (0.709, 0.854)	0.800 (0.738, 0.883)	0.871 (0.813, 0.913)	0.894 (0.848, 0.938)	0.951 (0.929, 0.976)	0.816 (0.767, 0.860)	0.926 (0.895, 0.954)
Import share	ρ^M	B	0.75 0.10	0.960 (0.941, 0.977)	0.964 (0.948, 0.979)	0.964 (0.943, 0.983)	0.902 (0.860, 0.955)	— —	0.860 (0.791, 0.926)	0.915 (0.883, 0.947)
Productivity trend growth	ρ^{AY}	B	0.85 0.05	0.975 (0.966, 0.984)	0.970 (0.965, 0.977)	0.983 (0.978, 0.986)	0.972 (0.965, 0.981)	0.967 (0.957, 0.976)	0.977 (0.972, 0.983)	0.934 (0.920, 0.946)
Intl. bond preference	ρ^{BW}	B	0.50 0.20	— —	— —	0.940 (0.930, 0.949)	— —	— —	0.892 (0.875, 0.900)	— —
Export price	ρ^{PX}	B	0.75 0.10	0.944 (0.923, 0.968)	0.878 (0.827, 0.916)	0.932 (0.903, 0.959)	0.860 (0.804, 0.914)	— —	0.928 (0.906, 0.962)	— —
Bilateral trade share vs. RoW	$\rho^{M,RoW}$	B	0.75 0.10	0.901 (0.868, 0.932)	0.952 (0.924, 0.979)	0.962 (0.930, 0.986)	0.885 (0.830, 0.937)	— —	0.864 (0.780, 0.948)	— —
Bilateral export price vs. RoW	$\rho^{PX,RoW}$	B	0.75 0.10	0.940 (0.922, 0.961)	0.941 (0.916, 0.964)	0.879 (0.838, 0.926)	0.777 (0.692, 0.886)	— —	0.924 (0.883, 0.956)	— —
Standard deviations (%) of innovations to forcing variables										
Subjective discount factor	ϵ^C	G	1.00 0.40	1.224 (0.625, 1.643)	1.048 (0.648, 1.414)	0.791 (0.442, 1.191)	0.778 (0.367, 1.095)	0.315 (0.157, 0.464)	0.768 (0.521, 1.028)	0.275 (0.148, 0.399)
Price mark-up	ϵ^Y	G	2.00 0.80	0.455 (0.372, 0.522)	0.547 (0.458, 0.641)	0.528 (0.446, 0.605)	0.723 (0.616, 0.840)	0.503 (0.418, 0.604)	0.398 (0.327, 0.463)	0.966 (0.839, 1.129)
Import share	ϵ^M	G	1.00 0.40	1.903 (1.629, 2.122)	1.541 (1.364, 1.751)	1.891 (1.668, 2.125)	2.106 (1.904, 2.371)	— —	2.596 (2.339, 2.900)	3.317 (2.924, 3.737)
Productivity trend growth	ϵ^{AY}	G	0.02 0.01	0.009 (0.008, 0.010)	0.006 (0.005, 0.006)	0.014 (0.012, 0.015)	0.015 (0.013, 0.017)	0.014 (0.012, 0.016)	0.011 (0.009, 0.012)	0.115 (0.110, 0.118)
Intl. bond preference	ϵ^{BW}	G	1.00 0.40	— —	— —	0.243 (0.202, 0.283)	— —	— —	0.471 (0.393, 0.579)	— —
Export price	ϵ^{PX}	G	1.00 0.40	0.936 (0.752, 1.080)	1.424 (1.179, 1.653)	0.772 (0.632, 0.909)	1.214 (0.945, 1.480)	— —	1.289 (1.092, 1.432)	— —
Bilateral trade share vs. RoW	$\epsilon^{M,RoW}$	G	2.00 0.80	3.230 (2.830, 3.563)	3.483 (3.171, 3.846)	4.161 (3.609, 4.546)	5.287 (4.835, 5.851)	— —	1.396 (1.096, 1.629)	— —
Bilateral export price vs. RoW	$\epsilon^{PX,RoW}$	G	2.00 0.80	4.347 (3.754, 4.938)	5.494 (4.791, 6.176)	6.903 (6.117, 7.764)	8.764 (7.652, 9.848)	— —	4.478 (4.050, 5.022)	— —
Monetary policy	ϵ^i	G	1.00 0.40	— —	— —	0.157 (0.136, 0.178)	— —	— —	0.133 (0.119, 0.149)	0.048 (0.043, 0.053)
Productivity level	$\epsilon^{\overline{AY}}$	G	0.10 0.04	0.002 (0.001, 0.003)	0.001 (0.001, 0.002)	0.003 (0.001, 0.004)	0.003 (0.002, 0.004)	0.003 (0.002, 0.005)	0.002 (0.001, 0.003)	0.022 (0.010, 0.033)
Lockdown shock										
COVID lockdown	ϵ^{tC}	G	5.00 2.00	3.703 (2.271, 5.391)	5.635 (3.289, 7.463)	6.377 (3.979, 9.269)	7.319 (4.880, 9.714)	4.399 (1.720, 6.457)	4.430 (2.724, 6.539)	1.323 (0.447, 2.416)

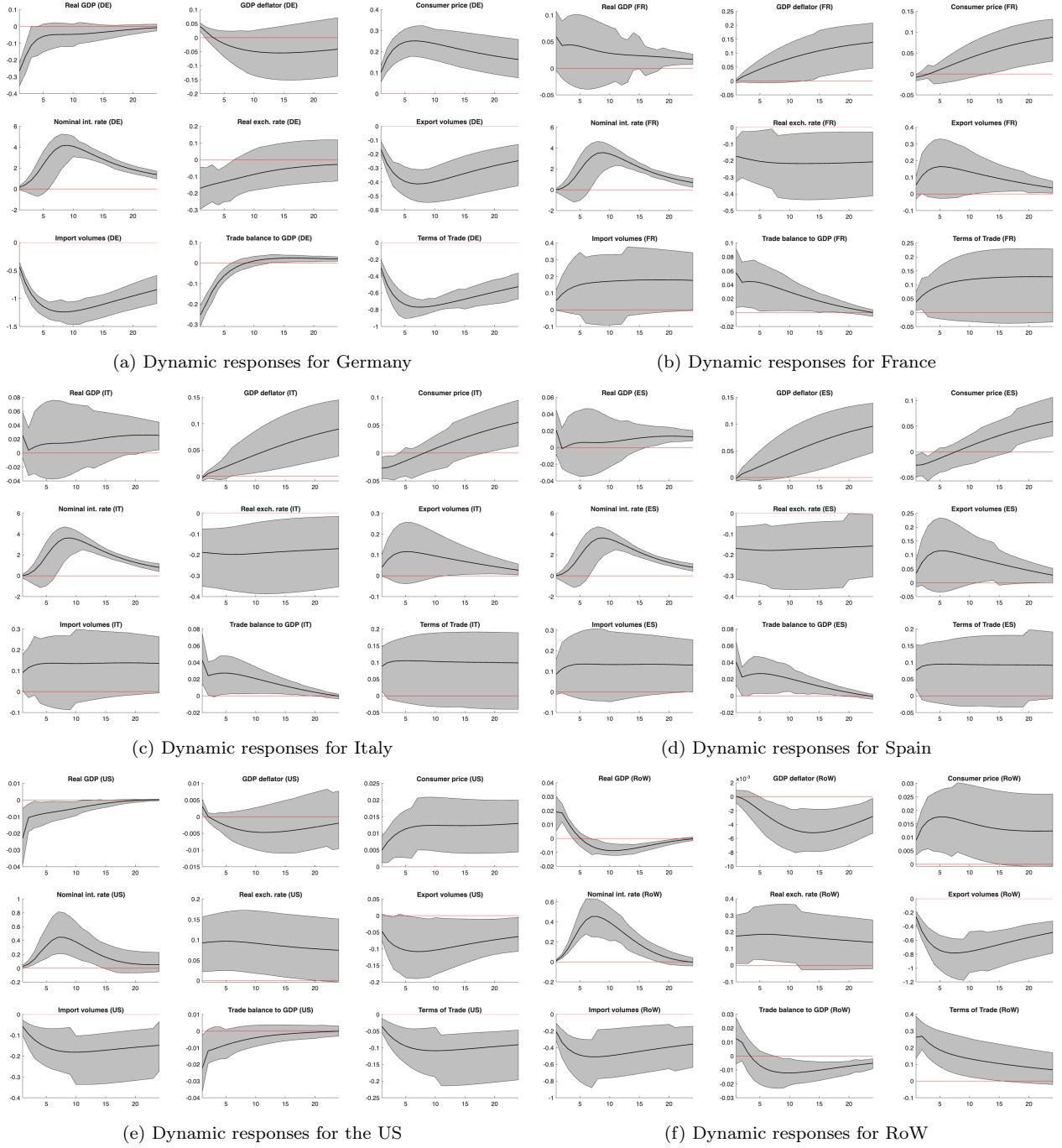
Note: Cols. (1)–(2) list shock parameters. Cols. (3)–(4) indicate the prior distribution (B: Beta; G: Gamma). Cols. (5)–(11) report country posteriors. ρ_{EA}^{BW} , ϵ_{EA}^{BW} , and ϵ_{EA}^i are common to all EA countries. Bilateral trade shares are bilateral shocks to each country's trade share and export price vis-à-vis RoW. Standard deviations reported in percent (%).

Figure A.1: Posterior IRFs to a positive shock to Germany's import share.



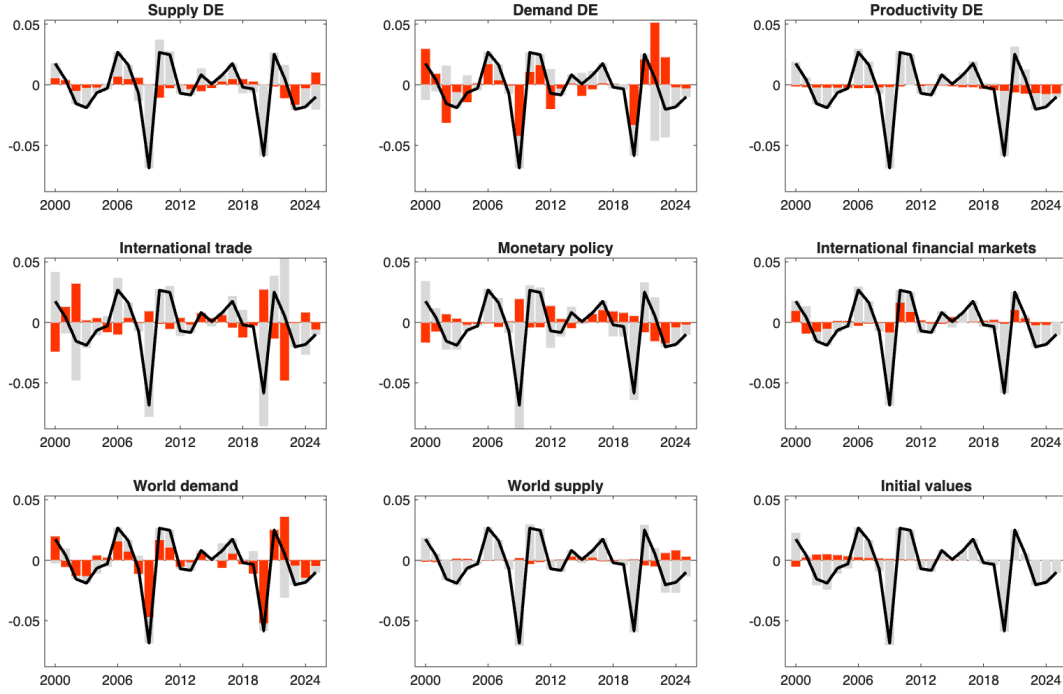
Note: Impulse responses with 90% posterior uncertainty bands to the estimated one-standard-deviation import share shock for Germany (reduction in home bias). The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

Figure A.2: Posterior IRFs to a negative terms-of-trade shock for Germany.

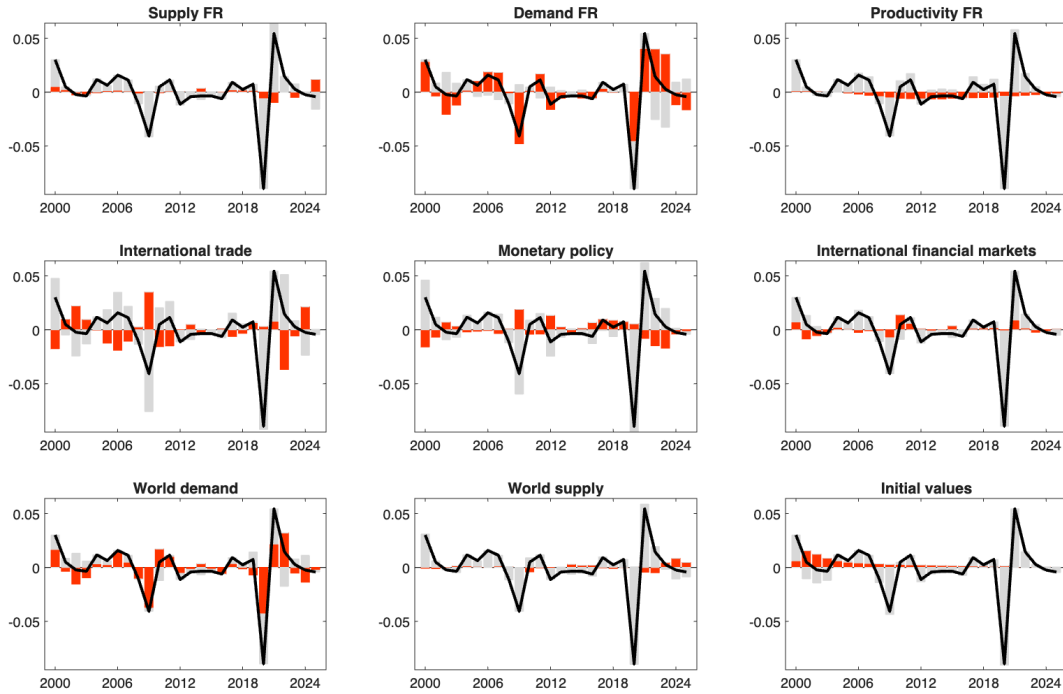


Note: Impulse responses with 90% posterior uncertainty bands to the estimated one-standard-deviation terms-of-trade shock for Germany. The trade balance (normalised by GDP) and the nominal interest rate (p.a.) are expressed as percentage point and basis point deviations from steady state, respectively. All other variables are percent deviations from steady state. Horizon in quarters.

Figure A.3: Historical shock decomposition of real GDP growth (aoa).



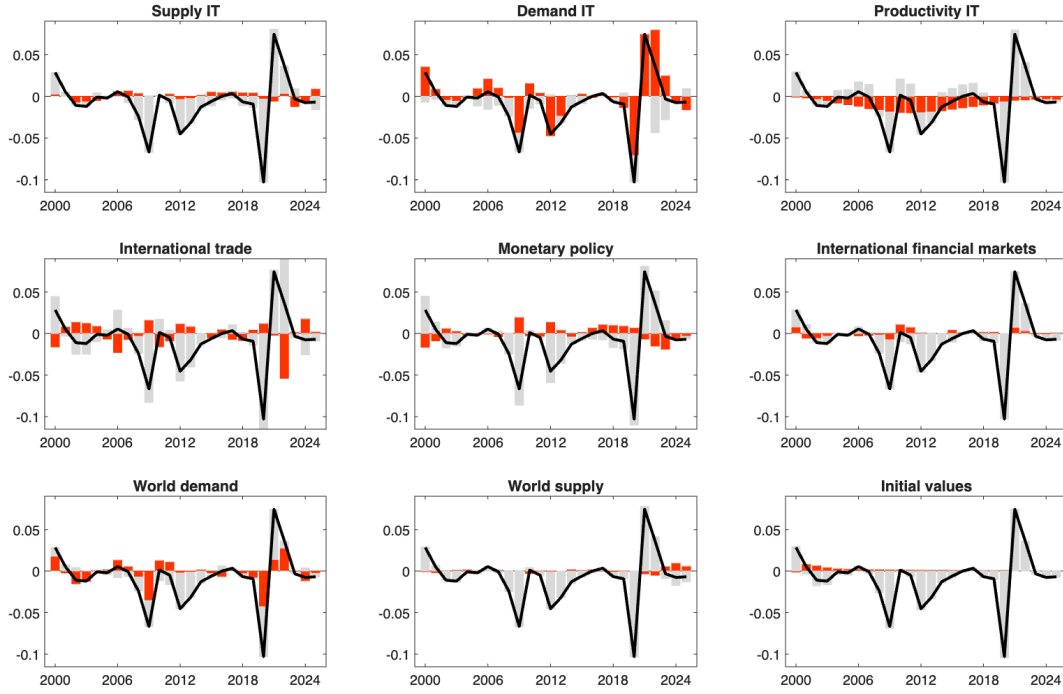
(a) Germany



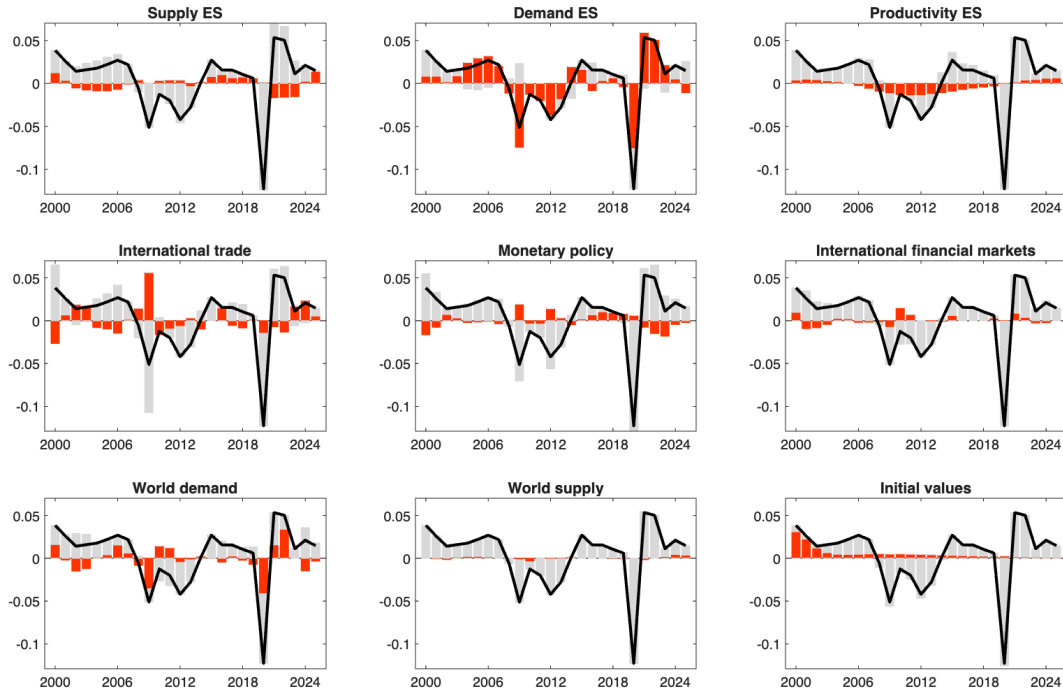
(b) France

Note: Real GDP growth is shown in percentage point deviations from steady state, which is calibrated to 1.38% per year. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

Figure A.4: Historical shock decomposition of real GDP growth (aoa).



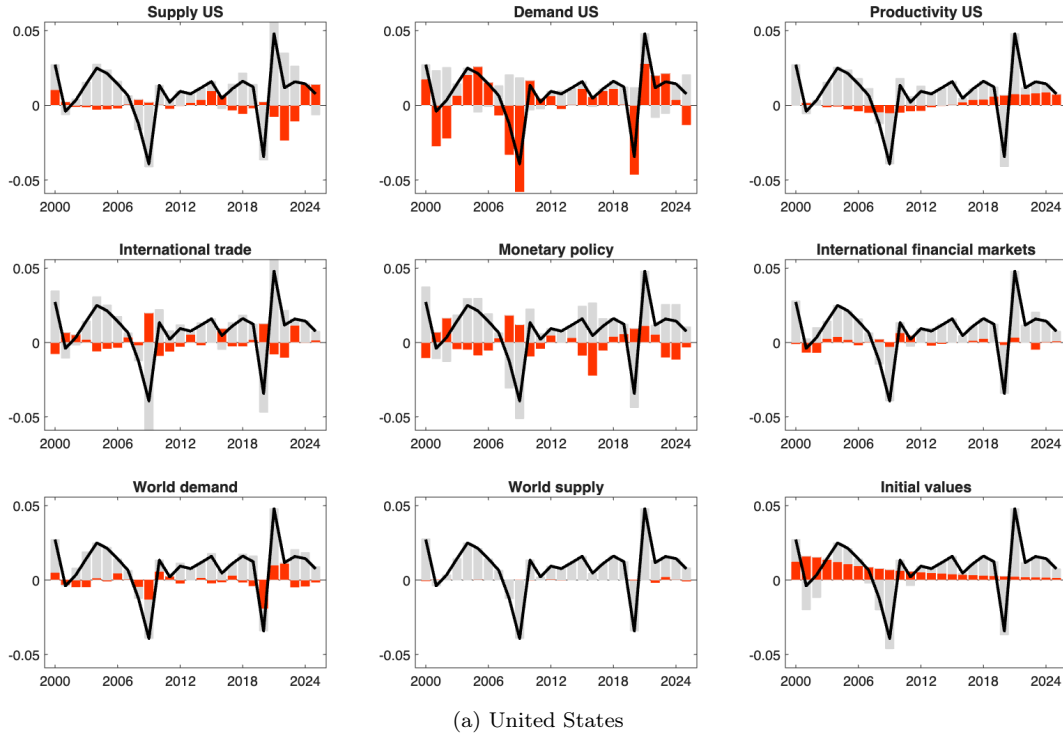
(a) Italy



(b) Spain

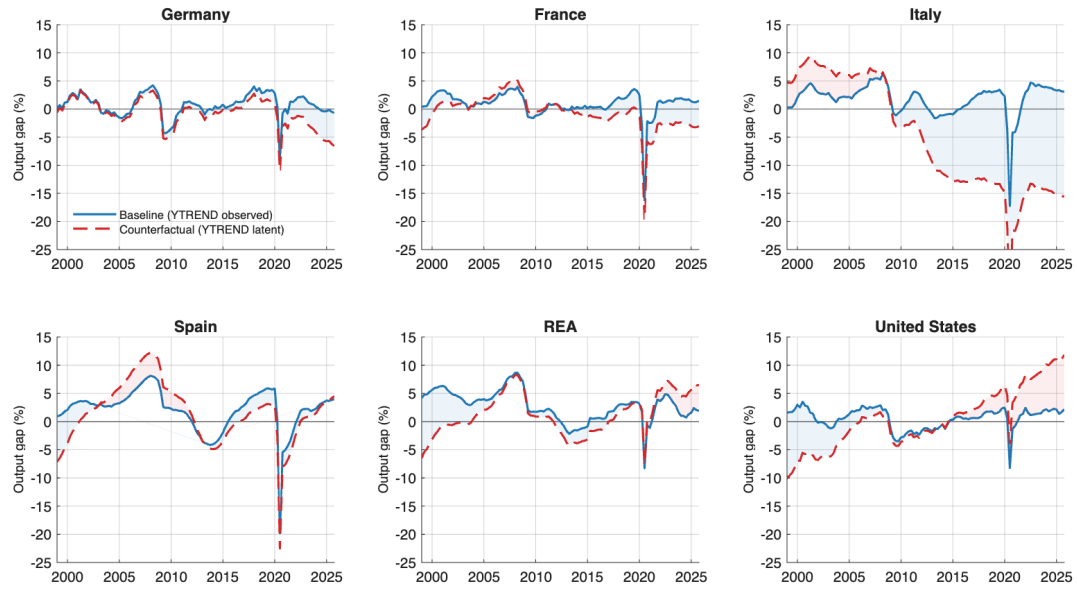
Note: Real GDP growth is shown in percentage point deviations from steady state, which is calibrated to 1.38% per year. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

Figure A.5: Historical shock decomposition of real GDP growth (aoa).



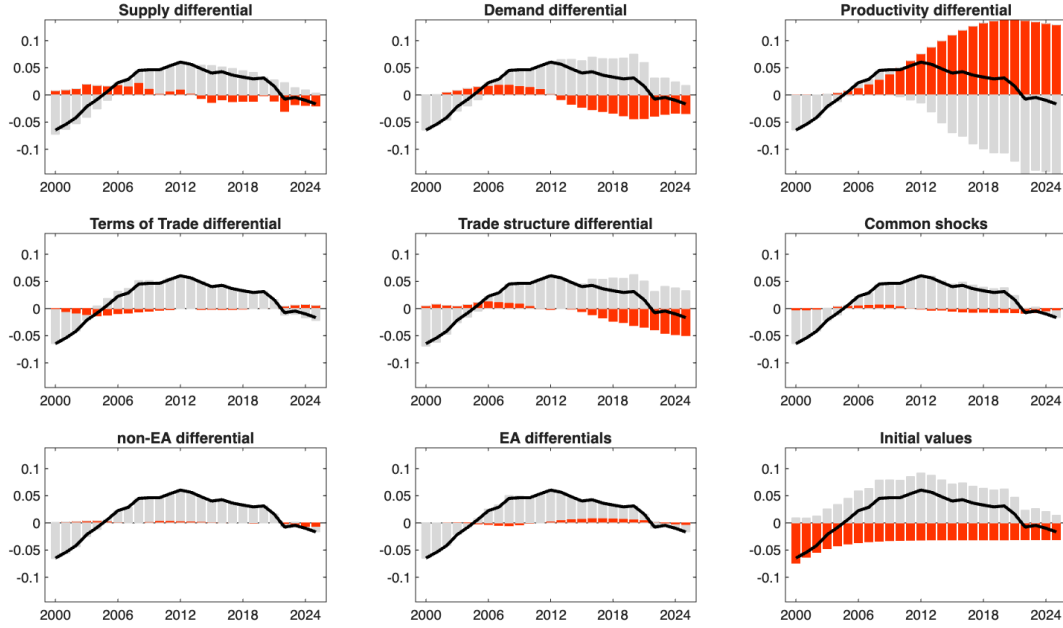
Note: Real GDP growth is shown in percentage point deviations from steady state, which is calibrated to 1.38% per year. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

Figure A.6: Observed and latent output gap across country blocs



Note: Output gap in percent deviations from potential output. Solid blue lines: baseline specification with potential GDP observed ($Y_{k,t}^{pot}$ as direct observable). Dashed red lines: counterfactual with potential GDP latent, holding all other parameters at their baseline posterior mode.

Figure A.7: CPI-based bilateral real exchange rate between Italy and Germany



Note: The bilateral real exchange rate is shown in percentage-point deviations from steady state. 0.1 on the y-axis corresponds to 10 pp. Continuous black lines represent the historical data. The vertical red bars illustrate the contribution of each respective (group of) exogenous shocks to the data, whereas stacked light grey bars summarise the contributions of all remaining shocks. The sum of the contributions equals the historical data.

Appendix B. Data source and observed time series

Data sources

Data for the four EMU Member States and EA (quarterly national accounts, quarterly interest and exchange rates) are taken from Eurostat. Corresponding data for the US comes from the Bureau of Economic Analysis (BEA) and the Federal Reserve. Annual data for RoW are constructed on the basis of the IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases. Bilateral trade flows are based on GTAP trade matrices, covering goods and services.

List of observables

The estimation uses the time series information for 53 endogenous variables. Table B.4 lists the observed time series. We apply logarithmic transformations to all observables, with the exception of the oil price (Brent) and nominal interest rates. GDP deflators and prices for exports and imports are computed as the ratios of the current-price value to the chain-indexed volume series. We observe EA aggregate variables and compute model-consistent REA variables given the aggregate size of the four largest EMU economies. Short-term interest rates for the EA and US are adjusted using shadow rate data from [Wu and Xia \(2016, 2017\)](#) as a measure of unconventional monetary policies (UMP) during the effective lower bound periods. The bilateral USD/EUR exchange rate and the nominal effective exchange rate are observed at the EA aggregate level.

Table B.4: Observed time series by country bloc.

	Individual EA Member States				EA	US	RoW
Observable	DE	FR	IT	ES			
<i>Real activity</i>							
GDP (nominal and real)	✓	✓	✓	✓	✓	✓	✓
Potential GDP	✓	✓	✓	✓	✓	✓	
Population	✓	✓	✓	✓	✓	✓	✓
<i>Trade flows</i>							
Exports (nominal and real)	✓	✓	✓	✓		✓	
Imports (nominal and real)	✓	✓	✓	✓		✓	
<i>Exchange rates and commodity prices</i>							
Nominal effective exchange rate					✓		
Bilateral USD/EUR exchange rate					✓		
Crude oil price (Brent, USD)							✓
<i>Monetary policy</i>							
Short-term nominal interest rate					✓	✓	✓

Note: ✓ indicates that the variable is used as an observable in the Bayesian estimation.