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The COVID-19 recession on both sides of the Atlantic: A model-based comparison*

Roberta Cardani[1], Philipp Pfeiffer[2], Marco Ratto[3], and Lukas Vogel[2,4]

[1]ESM
[2]European Commission, DG ECFIN
[3]European Commission, JRC
[4]IRES, UC Louvain

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Abstract

This paper compares the COVID-19 recession in the euro area (EA) and the US using an estimated multi-region New Keynesian macroeconomic model. To capture quarterly dynamics from 2020 onwards, we introduce relevant extensions such as 'forced' savings, extensive versus intensive employment margins, and trade in commodities as inputs to production and final demand. Transitory ('forced') savings are central to account for the behaviour of economic activity in both regions during the pandemic, which was strongly driven by private consumption, alongside shocks to domestic demand and foreign activity. The model highlights the importance of demand recovery and rising commodity prices for the inflation acceleration during 2021-22. EA inflation has a stronger supply component (including commodity prices) compared to a stronger demand component in the US.

JEL classification: C11, E1, E20
Keywords: DSGE model, Bayesian estimation, COVID-19, Euro Area, United States, Inflation, Business cycles

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1 Introduction

This paper compares the COVID-19 recession and recovery in the Euro Area (EA) and the United States (US), using an estimated three-region dynamic stochastic general equilibrium (DSGE) model (EA, US, RoW). The model is a variant of the European Commission's Global Multi-country (GM) model (Albonico et al. (2019)), augmented by COVID-specific shocks (Cardani et al. (2022)), an explicit distinction between the intensive and extensive margins of employment, and an enriched representation of commodity use (input to production and component of final demand) and trade, in which the US is a commodity supplier along with the RoW.

Combining ex-ante identical EA and US blocks (except for the difference in commodity endowment) in a multi-country setting and estimating them jointly on the same set of observable variables provides an appropriate framework for cross-country comparison. The model captures many possible demand-side and supply-side drivers of GDP growth and inflation, including private domestic demand, monetary and fiscal policy, foreign activity and trade, wage and price setting, productivity, and commodity prices, and jointly assesses their quantitative importance in the estimation.

Our model is a fairly rich but standard estimated one-sector multi-region DSGE model in the New Keynesian tradition. It incorporates additional macro shocks to accommodate COVID-period data, a distinction between employment in persons and hours worked, and a richer structure of commodity supply and use. The setup includes an endogenous and occasionally binding effective lower bound (ELB) on nominal short-term interest rates.

Additional features of relevance during the pandemic, such as the multi-sector structure of production (with contact-intensive and other activities), or an explicit interaction between economic activity and the spread of the virus, are omitted. However, evidence from different models and empirical work at different levels of aggregation is helpful for a more structural interpretation of some of the model shocks.

The model is estimated on data over the period 2020q1-2022q4. It covers the COVID-19 pandemic and recovery as well as the energy crisis in 2021-22 and other early economic consequences of Russia's war of aggression against Ukraine.

The analysis attributes an important role to transitory consumption ('forced' savings) shocks in accounting for the volatility (contraction and recovery) of EA and US economic activity at quarterly frequency in 2020-21. More persistent consumption and investment shocks, as well as shocks to foreign activity and trade, have also played a role. Fiscal policy has stabilised aggregate activity during the pandemic. Rising inflation in 2021-22 has been driven by recovering domestic and foreign demand and rising commodity prices.

Fiscal policy also added to price pressure. Appreciation (depreciation) pressure on the USD (euro) dampened (added to) inflation in the US (EA). Particularly for the EA, the estimation also points to inflation from retail price shocks. Overall, the results align with the hypothesis that inflation in 2021-22 had a stronger supply-side component in the EA and a more substantial demand-side component in the US.

The paper proceeds as follows. Section 2 presents stylised macro facts for the EA and the US macroeconomic adjustment to the COVID-19 shock. Section 3 discusses the connections to the literature with respect to modelling pandemic-specific developments and empirical literature on the COVID shock and its macroeconomic repercussions. Section 4 outlines the main elements of the model. Section 5 describes the econometric approach and reports parameter estimates. The propagation of COVID-specific and other important model shocks is analysed in more detail in Section 6. Section 7 discusses the main drivers of EA and US growth and inflation during and after the pandemic on the basis of shock decompositions. Section 8 provides additional off-model evidence for the plausibility of the estimated COVID-specific shocks. Section 9 discusses robustness checks concerning the role of fiscal and monetary policy (fiscal multipliers and unconventional monetary policy). Finally, Section 10 concludes.

2 Stylised macro facts

Comparing macroeconomic time series for the EA and the US points to similarities and differences in response to the COVID-19 shock and the recovery. Figures 1 and 2 summarise six general observations that an estimated multi-region macro model has to account for.

The first observation is that economic activity (measured by real GDP per capita in Figures 1 and 2) fell in both regions in 2020 but more strongly in the EA. US activity had recovered to pre-pandemic levels by spring 2021, whereas EA activity reached the 2019q4 level only in autumn 2021. The sharp decline in private consumption in 2020 was an important driver of the pandemic recession, which contrasts with previous ('standard') recessions (including the 2008-09 financial crisis) that exhibit the opposite pattern, i.e. a more critical role for investment demand in the business cycle. Private consumption recovered faster in the US, where it was back to its 2019q4 level in 2021q1, whereas EA consumption reached the 2019q4 level only in 2022q3.

Second, EA and US inflation increased strongly after 2020. US CPI inflation accelerated early in the recovery and moderated in the second half of 2022. EA CPI inflation followed with some lag but remained elevated in the second half of 2022. Given that the

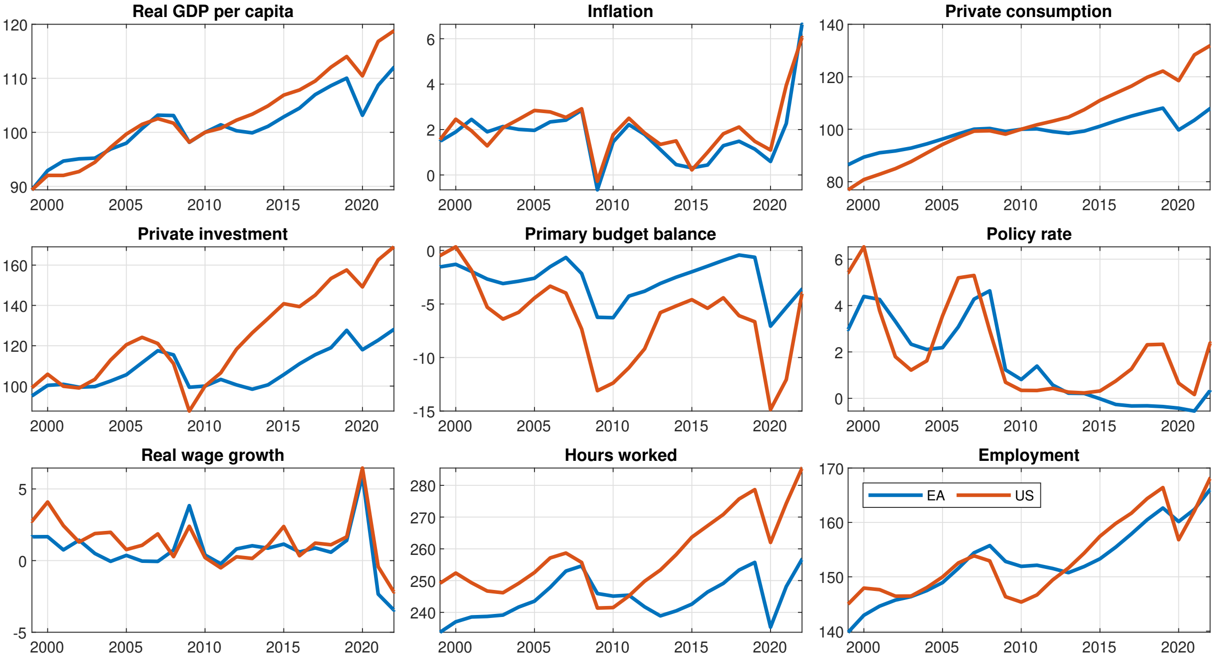

Figure 1: Macro time series for EA and US (1999-2022)

Notes: Annual series for GDP, consumption and investment are at constant prices (real terms) and normalised to 100 in 2010. Annual inflation (in %) refers to the HICP for the EA and the PCE index for the US. The policy rate and real wage growth are also expressed in % per year. The primary government balance is expressed in % of GDP. Hours are in billions, whereas employment is reported in millions (persons). *Sources:* AMECO, BEA, and Eurostat.

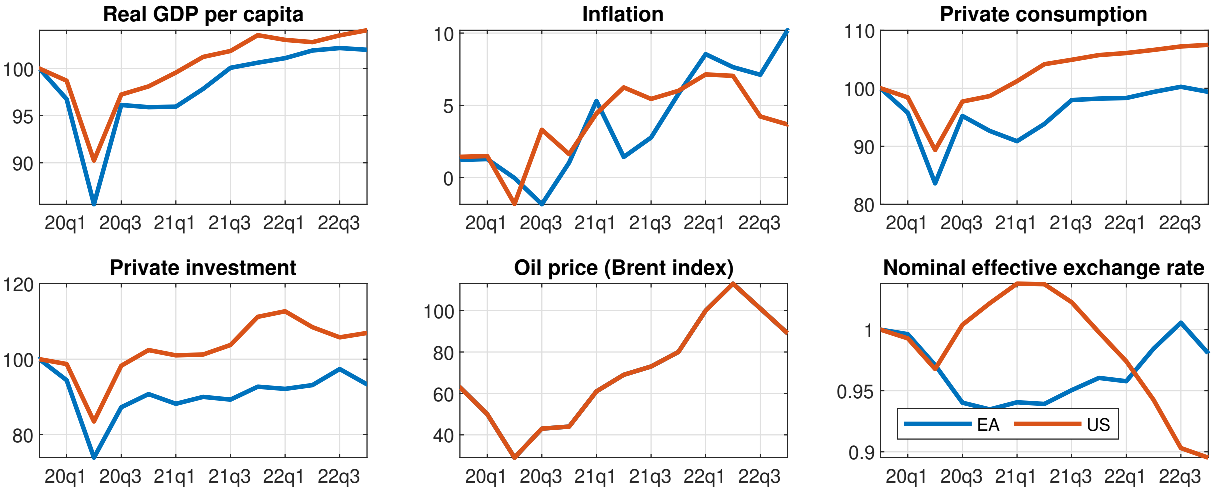

Figure 2: Quarterly macro time series for EA and US (2019q4-2022q4)

Notes: Quarterly GDP, private investment, and private consumption are levels at constant prices (real terms), normalised to 100 in 2019q4. Consumption inflation is the annualised y-o-y growth (%) of the HICP for the EA and the PCE price index for the US. The Brent price is measured in USD per barrel. The nominal effective exchange rate (NEER) is normalised to 1 in 2019q4, and an increase indicates NEER depreciation of the domestic currency. *Sources:* BEA and Eurostat.

US depends less on commodity imports than the EA, commodity price shocks had milder adverse terms-of-trade effects on the US economy.

Third, US fiscal policy has been more expansionary than its EA counterpart, as indicated by the substantial deterioration of the US (primary) government balance in 2020-21. In addition, the COVID-19 shock hit the EA economy at the ELB. Short-term interest rates in the US were above the ELB in 2019, to the contrary, providing space for some conventional monetary stimulus, followed by tightening in light of rising inflation.

Fourth, EA and US real wages grew in 2020 as nominal wages outpaced price inflation. This pattern reversed in 2021-22. Part of the real wage growth in 2020 can be ascribed to composition effects. Less-skilled, younger and temporary-contract workers with less-paid jobs face a higher risk of unemployment during recessions, which increases the average hourly wage in the economy of the workers remaining employed without a rise in individual wages.[1]

Fifth, employment patterns during the pandemic differed markedly between the two regions. Employment in persons and hours co-moved closely in the US but decoupled in the EA in 2020-21. In the EA, hours worked declined, whereas employment in persons remained relatively stable (even in the most affected sectors), which indicates quantitatively important labour hoarding ('short-time work') to preserve existing matches.[2]

Finally, prices of fossil fuels (oil in Figure 2) declined at the start of the pandemic and recovered in the second half of 2020. Oil prices and prices for gas and electricity rose steeply in 2021-22, notably in the EA, in reaction to the pandemic recovery, geopolitical tensions, and Russia's war of aggression against Ukraine. In the EA, the price increase has also been amplified by NEER depreciation between mid-2020 and 2022, whereas the USD gained value in 2021-22 in nominal effective terms.

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[1] See, e.g., Anderton et al. (2021), Bodnár et al. (2023), Christodoulopoulou and Kouvavas (2022) and Howard et al. (2022) on the role of composition effects for aggregate wage dynamics.

[2] For a detailed discussion of EA-US differences in employment dynamics, notably a more detailed breakdown of adjustment at the intensive and extensive margins, see Bodnár et al. (2023). Kiss et al. (2022) gives a broad account of EA labour market developments during and after the pandemic. 15-34% of employees in Germany, France, Italy, and Spain were on job retention schemes in April 2020 compared to 1-3% on average during the financial crisis in 2009. In most large EA countries, benefits paid under these schemes go directly to employees and are recorded as social transfers, whereas, e.g., the Netherlands pays them as wage subsidies to employers, leading to increasing compensations per hour worked in the data (Anderton et al. (2021)). Giupponi et al. (2022) provides a theory-based comparison between short-time work schemes and unemployment insurance in positive and normative (welfare) terms, as well as a wider cross-country comparison.

3 Related literature

This paper offers a comparative perspective on the macroeconomic impact of the COVID-19 pandemic. It connects to three strands of the literature. The first relates to the class of estimated multi-country structural models for cross-country comparison. Christiano et al. (2008), as an early example, investigates the role of shocks, structure (such as wage and price stickiness) and monetary policy in accounting for differences in EA and US business cycles after 2001. Smets and Wouters (2003) and Smets and Wouters (2007) estimate their (single-country) model on EA and US data alike and compare outcomes in terms of structural parameters and exogenous shock. Kollmann et al. (2016) and Giovannini et al. (2019) have estimated EA-US-RoW models similar to the present one to compare the EA and US economies during and after the Global Financial Crisis (GFC) and the impact of commodity price and emerging market shocks on the EA and the US, respectively.

The second strand of the literature focuses on modelling the economic impact of COVID-19. By now, there is extensive literature on the micro and macro implications of the pandemic, including goods, labour and financial markets. 'Non-standard' structural models have been developed to capture elements of the pandemic. This strand includes papers that merge epidemiological and economic dynamics to understand the interplay between the pandemic, containment policies, and economic activity (Eichenbaum et al. (2021, 2022); Jones et al. (2021)), and multi-sector models that show the importance of cross-sector linkages and (demand) externalities (Guerrieri et al. (2022), Corrado et al. (2021)). Concerning price dynamics, Benigno and Eggertsson (2023), Hall (2023) and Harding et al. (2023) argue that models with non-linear Phillips curves can explain the acceleration of post-pandemic inflation through a steepening of the slope of the Phillips curve, where the motivation (micro foundation) for the steepening varies across the three contributions.[3]

Other authors have adapted established macro models used in policy institutions ('workhorse models') to allow estimation based on data including the period of the pandemic (Chen et al., 2020; Cardani et al., 2022). We follow the pragmatic approach in Cardani et al. (2022) to augment the European Commission's GM model with short-lived ('forced') savings shocks and labour hoarding (short-time work) to map important char-

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[3] In particular, Hall (2023) stresses that the Phillips curve can become much steeper in times of highly volatile price determinants (costs, productivity) in models with constant costs of price adjustment, i.e. the sensitivity of inflation to demand and supply shocks may depend on the shock size. Benigno and Eggertsson (2023) develop a non-linear NK Phillips curve in which inflation reacts to labour market tightness (vacancies relative to the number of unemployed) and argue that recent high inflation was compatible with an exceptionally tight labour market (labour shortage). Harding et al. (2023), instead, derive non-linearity in the Phillips curve from non-linearity in the demand for goods.

acteristics of data from the COVID-19 period. We extend our earlier work by explicitly modelling labour hoarding that distinguishes between hours worked per employee (intensive margin) and the numbers of employees (extensive margin) broadly along the lines of Merz and Yashiv (2007) to account for total hours worked. The model in this paper also accounts for commodity extraction in the US. The US block becomes a commodity supplier, implying a wedge between the demand for commodities in the US and US net commodity imports. The role of commodities in the economy as input to production and part (energy) of final consumption demand is modelled along the lines of Blanchard and Gali (2007), Blanchard and Riggi (2013), Bodenstein et al. (2012), and Gagliardone and Gertler (2023).

Third, a rich empirical literature on economic developments during the pandemic and in the post-pandemic environment developed in recent years and months, drawing on different approaches. Inflation dynamics on both sides of the Atlantic have attracted particular attention as EA and US price levels have grown at a pace not seen for decades. The general tendency in the debate is to assign a more prominent role to demand versus supply factors in the US compared to the EA. Pasimeni (2022) observes that energy and food prices account for almost 3/4 of EA post-COVID headline inflation, which started rising in early 2021, and that price pressure stems mainly from sectors with high import content and concerns goods more than services. He also suggests a dominance (4/5) of supply factors in producer price inflation at the sector level. Similarly, Hansen et al. (2023) emphasise the importance of import prices for EA post-pandemic inflation. For the US, di Giovanni (2022) attributes 60% of consumer price inflation in 2019-21 to increased goods demand and 40% to supply-side constraints. di Giovanni et al. (2023) find 2/3 of the increase in US inflation between December 2019 and June 2022 to be demand-driven.[4]

Ball et al. (2022) emphasise the importance of labour market tightness (defined as vacancies over unemployment) for US (core) inflation in 2021-22, part of which (1.0 pp y-o-y in July 2022) is attributed to demand deriving from US fiscal stimulus, in addition to pass-through from headline to core.[5] Bernanke and Blanchard (2023), by contrast, attribute most of US inflation since 2021 to price shocks (commodity prices, sectoral demand shifts, supply constraints) for given wages. Ferrante et al. (2023) estimate a multi-sector New Keynesian (NK) model on US data and find an important role of cross-sector demand reallocation (from services to goods) for inflation in the presence of (labour) adjustment frictions that constrain a shift in supply, suggesting that reallocation could

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[4] Similar (institutional) perspectives on EA versus US inflation are provided by Boone (2022) and Lane (2023).

[5] Related to that, Blanchard et al. (2022) emphasise the role of dampening labour market tightness for controlling inflation.

explain up to 4 pp of the increase in US inflation in recent years.

Cavallo and Kryvtsov (2023) use detailed micro data on product availability from seven countries to document a substantial increase in product shortages (supply disruptions) during the pandemic, with significant inflationary effects within a quarter. Comin et al. (2023) build a multi-sector open-economy model with temporarily binding domestic and foreign supply chain constraints, which bind in case of positive demand or negative supply shocks. The impact of binding constraints on activity and inflation is similar to the effect of price markup shocks, i.e. it could provide a structural interpretation of the latter. Comparing the model with binding constraints to a counterfactual in which the constraints are slack at any time, the authors attribute around half of the increase in US consumer price inflation in 2021-22 to binding supply chain constraints.[6]

Reis (2022) lists supply disruptions, less well-anchored inflation expectations, and expansionary monetary and fiscal policies as possible inflation drivers. Jorda and Nechio (2023) underline the role of fiscal stimulus and inflation expectations for wage and price setting during the pandemic in a sample of 18 OECD countries. Hale et al. (2023) find inflationary effects of fiscal support to households, but not to firms, in a sample of ten large countries, notably in an environment of improving economic conditions. Bayer et al. (2023) use a heterogeneous-agent New Keynesian (HANK) model and find an important role of fiscal transfers to explain the stronger post-pandemic recovery and higher inflation in the US compared to the EA.[7] di Giovanni et al. (2023) attribute as much as 1/3 of the US inflation increase between end-2019 and mid-2022 to fiscal stimulus. Gagliardone and Gertler (2023) develop a simple New Keynesian (NK) model with oil as complementary consumption good and production input and find an important role for oil price shocks combined with ‘easy’ monetary policy to explain recent US inflation, notably its persistence in 2022.

From a different perspective, Cavallo (2020) and Diewert and Fox (2022) emphasise measurement problems, notably the underestimation (overestimation) of inflation in 2020 (2021) due to the use of a CPI with a fixed basket of goods and services which contrast with strong shifts in relative demand at sector and goods level during the pandemic.

The present paper adds to the literature by providing a comparative perspective on EA versus US macroeconomic dynamics during and after the COVID-19 pandemic, using an

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[6] More than inflation through labour market tightness, the Comin et al. (2023) channel would be consistent with rising profit margins in the post-COVID recovery (Arce et al. (2023); Glover et al. (2023)), although some of the work on profit dynamics also attributes a significant role to expected future increases in production costs in an environment of infrequent price adjustment (Glover et al. (2023)).

[7] Some countries, such as Germany, have also implemented less conventional fiscal policy measures during the pandemic, such as temporary VAT cuts that mimic the effect of interest rate reduction (Bachmann et al. (2021); Baudisch and Neuenkirch (2023); Clemens and Röger (2021)).

estimated workhorse DSGE model with three regions and ex-ante largely identical model blocks for the EA and the US.[8] The rich structure of the model with many observable variables implies that a plausible narrative of recent macroeconomic developments has to account for a large number of observations at the same time, including the macro facts summarised in Figures 1 and 2 above. The model captures a large number of possible demand-side and supply-side drivers of GDP growth and inflation, including private domestic demand, monetary and fiscal policy, foreign activity and trade, wage and price setting, productivity, and commodity prices, and jointly assesses their quantitative importance in the estimation.

4 The multi-region model

The analysis builds on an estimated three-region DSGE model consisting of the EA, the US, and the RoW.[9] The model needs to be rather elaborate in terms of economic structure and shocks to allow for a quantitative account of the macroeconomic dynamics in the three regions, notably in light of the large number of observable time series in the estimation.

In light of the salient differences between the EA and the US economies during the COVID-19 recession, discussed in Section 2, we extend the model in Cardani et al. (2022) in two directions. First, we improve the modelling of commodities (energy and non-energy commodities) by including the US as a supplier of commodities along the RoW block. In line with the data, this modification distinguishes between US domestic demand for commodities and US net commodity imports. Second, we differentiate between the extensive (workers) and intensive (hours per worker) margin of employment adjustment in light of the discrepancy between the US (co-movement between total hours and employment in persons) and the EA (short-time work) during the pandemic. Finally, the present analysis will also draw on a longer sample, extending the coverage of the post-pandemic period, which now covers the energy crisis in 2021-22.

Each model region features households, non-financial firms operating in the domestic market or the import-export sector, and a central bank. Short-lived savings and labour hoarding shocks are introduced as in Cardani et al. (2022) to replicate distinctive features of the pandemic recession, i.e. strong and short-lived volatility in quarterly consumption

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[8] The main structural difference imposed by facts is the modelling of the US economy as a commodity supplier.

[9] The model builds on and extends the European Commission's Global Multi-country (GM) model (Albonico et al., 2019; Giovannini et al., 2019; Kollmann et al., 2016). The description in this section introduces only the key elements. It abstracts from linear taxes and contains only the main exogenous shocks. Readers can find a comprehensive model description in Appendix A.

and the wedge, especially in the EA, between employment and hours worked. Separating the extensive versus intensive margins of adjusting total hours worked broadly follows Merz and Yashiv (2007). Monopolistic trade unions set EA and US wages. Intermediate goods prices and nominal wages are sticky. Each region has a central bank conducting monetary policy following a Taylor-type rule. The EA and US central banks face an occasionally binding effective lower bound (ELB) on nominal short-term policy rates. The EA and US blocks also include a government sector with taxation and public spending. The three regions are linked through trade in goods (final goods and industrial supplies) and an internationally traded financial asset (bond).

The US and the RoW supply commodities, which enter as industrial supplies in the production process for manufactured output and as energy directly in the households' consumption basket. This two-stage use of commodities corresponds to the modelling of oil demand in Blanchard and Gali (2007), Blanchard and Riggi (2013), Bodenstein et al. (2012) and Gagliardone and Gertler (2023).

Due to limited data availability, the RoW block (which comprises a group of 56 countries) is more stylised. Another difference between the regions and with respect to previous versions of the GM model (e.g., Giovannini et al. (2019)) is that the US and RoW both supply commodities. The model includes nominal and real rigidities to provide an empirically plausible account of macroeconomic dynamics and persistence at a quarterly frequency. Unless stated otherwise, the exogenous random variables follow autoregressive processes of order 1. Time is discrete and indexed by t.

The following subsections present the key elements of the EA model block. The US block has the same structure, except that the US economy also supplies and exports commodities.[10] While the EA and US block are ex-ante identical (except for commodity supply), model estimation and the calibration of selected parameters imply that parameter values can differ between the EA and the US.

4.1 Multi-stage production

Final goods. The EA final good is produced from the domestic output and imported outputs of the US and RoW economies. Let $Z_t \in \{C_t^{FG}, G_t, I_t, IG_t, X_t\}$ be the demand for final goods by households and the government, private and government investors, and exporters of final goods, respectively. Perfectly competitive firms assemble Z_t, using

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[10] To ease notation, we omit country-specific indices when not explicitly needed (e.g., for the common parts of the EA and US block).

domestic output (O_t^Z) and imported output (M_t^Z) into a CES production function:

$$Z_t = A_t^Z \left[\left(1 - s_t^{M,Z}\right)^{\frac{1}{\sigma^z}} \left(O_t^Z\right)^{\frac{\sigma^z - 1}{\sigma^z}} + \left(s_t^{M,Z}\right)^{\frac{1}{\sigma^z}} \left(M_t^Z\right)^{\frac{\sigma^z - 1}{\sigma^z}} \right]^{\frac{\sigma^z}{\sigma^z - 1}}, \tag{1}$$

where A_t^Z denotes a productivity shock in sector Z, and $0 < s_t^{M,Z} < 1$ is the stochastic import share associated with the different components of final demand.[11] The parameter $\sigma^z > 0$ is the elasticity of substitution between domestic output and imports in the assembly of the final good. This elasticity is assumed to be the same across all final demand components.

Output. Perfectly competitive firms produce output (O_t) by combining domestic value added (Y_t) and imported industrial supplies (IS_t) in a CES production function:

$$O_t = \left[\left(1 - s_t^{IS}\right)^{\frac{1}{\sigma^o}} \left(Y_t\right)^{\frac{\sigma^o - 1}{\sigma^o}} + \left(s_t^{IS}\right)^{\frac{1}{\sigma^o}} \left(IS_t\right)^{\frac{\sigma^o - 1}{\sigma^o}} \right]^{\frac{\sigma^o}{\sigma^o - 1}}, \tag{2}$$

where s_t^{IS} is the input share of commodities (industrial supplies) used in production. This share is stochastic and captures fluctuations in the CO intensity of production.The parameter $\sigma^o > 0$ is the elasticity of substitution between the two components. Industrial supplies in the EA are imported from the RoW and the US subject to an excise duty τ^{CO}, so that: $P_t^{CO} = P_t^{CO,M} + \tau^{CO} P_t$, where $P_t^{CO,M}$ denotes the import price in terms of domestic currency.[12]

Value added. Value added Y_t aggregates the EA intermediate goods:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\sigma^y - 1}{\sigma^y}} di \right]^{\frac{\sigma^y}{\sigma^y - 1}}, \tag{3}$$

where $Y_{i,t}$ denotes intermediate good $i \in [0,1]$. The parameter $\sigma^y > 0$ is the elasticity of substitution between the varieties $Y_{i,t}$. The production function for good i is:

$$Y_{i,t} = \left(A_t^Y (N_{i,t} - FN)\right)^{\alpha} \left(cu_{i,t} K_{i,t-1}\right)^{1-\alpha} \left(K_{t-1}^G\right)^{1-\alpha_G} - \Phi_t, \tag{4}$$

where A_t^Y is exogenous stochastic total factor productivity (TFP), subject to trend and level shocks. $N_{i,t}$, $K_{i,t-1}$, and $cu_{i,t}$ are firm i's labour input (minus overhead labour

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[11] $s_t^{M,Z} = s^{M,Z} \exp(\varepsilon_t^{M,Z})$, where $s^{M,Z}$ denotes the steady-state import share of the demand component Z and $\varepsilon_t^{M,Z}$ is a shock to the import demand (preference).

[12] The excise duty is also levied on domestically supplied commodities in the US block.

FN), capital stock, and endogenous capacity utilisation, respectively, and Φ_t are fixed costs (indexed to trend).[13] Gross investment $I_{i,t}$ drives the law of motion for capital $K_{i,t} = K_{i,t-1}(1-\delta) + I_{i,t}$, with the depreciation rate $0 < \delta < 1$. Public capital (K^G_{t-1}) follows an analogous accumulation equation and features an output elasticity α_G.

Labour input and labour hoarding. The EA and the US differ in the relative importance of the extensive and intensive margins for labour adjustment. To account for this disparity, we distinguish between persons employed ($Empl_{i,t}$) and hours worked per employee ($Hpere_{i,t}$). Overall hours paid are $N^{paid}_{i,t} = Empl_{i,t} Hpere_{i,t}$, and firms can adjust at both margins subject to specific adjustment costs.

In light of the restrictions on work during the COVID-19 pandemic, we introduce a transitory labour hoarding shock (ε^{LU}_t), which creates a discrepancy between hours paid (wage income) and actual hours worked (production function):

$$\frac{N_{i,t}}{N^{paid}_{i,t}} = (1 - \varepsilon^{LU}_t). \tag{5}$$

A positive innovation to ε^{LU}_t implies that employees work fewer hours compared to their wage income.[14] Incorporating the shock into firm dividends and the government budget allows for the inclusion of subsidies related to short-time work schemes. Firm nominal dividends in period t are then given by:

$$div_{i,t} = P_{i,t}Y_{i,t} - \underbrace{W_t N^{paid}_{i,t}}_{\text{Wage bill}} + \tau^{LU} \underbrace{W_t \left(N^{paid}_{i,t} - N_{i,t}\right)}_{\text{Hoarding}} - P^I_t I_{i,t} - \Gamma_{i,t}, \tag{6}$$

where W_t and P^I_t are the nominal wage rate and the price of investment goods, respectively. τ^{LU} is the share of publicly financed labour hoarding. $\Gamma_{i,t}$ collects quadratic price and factor adjustment costs. Each intermediate goods firm i sets the good's price $P_{i,t}$ in a monopolistically competitive market, subject to Rotemberg (1982) price adjustment costs and the demand function $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\sigma^y} Y_t$. Appendix A provides additional details and the equilibrium conditions for the production sector.

4.2 Households

Two groups of households consume and provide labour to intermediate goods producers.

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[13] On a balanced growth path, $\Phi_t = \Phi \times \left(A^Y_t\right)^{\frac{\alpha}{\alpha+\alpha_G-1}}$.

[14] Put differently, actual hours are given $N_{i,t} = Empl_{i,t} Hpere_{i,t}(1 - \varepsilon^{LU}_t)$.

Savers. A share ω^s of households are savers (s), who own domestic firms and participate in financial markets by saving and borrowing. Savers choose consumption $C_{j,t}^s$ (which includes energy as explained below) and financial assets $B_{j,t}^{\mathcal{Q}}$ to maximise welfare:

$$E_0 \sum_{t=0}^{\infty} \beta^t \xi_t \left\{ \frac{\left(C_{j,t}^s - \varepsilon_t^{tC} - h(C_{t-1}^s - \varepsilon_{t-1}^{tC})\right)^{1-\theta}}{1-\theta} - \omega_t^N \frac{\left(N_{j,t}^{s,paid}\right)^{1+\theta^N}}{1+\theta^N} \right\}, \tag{7}$$

where E_0 denotes the expectations operator and $0 < \theta$ and $0 < \theta^N$. The parameter h governs the importance of external consumption habits. The shock ξ_t captures stochastic disturbances to the discount factor β.[15] The term ω_t^N is a stochastic labour disutility factor.[16]

Utility maximisation is subject to the budget constraint:

$$P_t^C C_{j,t}^s + \sum_{\mathcal{Q}} B_{j,t+1}^{\mathcal{Q}} = W_t N_{j,t}^{s,paid} + div_t^{TOT} + \sum_{\mathcal{Q}} R_t^{\mathcal{Q}} B_{j,t}^{\mathcal{Q}} + T_{j,t}^s, \tag{8}$$

div_t^{TOT} and $T_{j,t}^s$ summarises the taxes and transfers, which are detailed in Appendix A.

As in Cardani et al. (2022), the households face non-persistent 'forced' savings shocks, ε_t^{tC}, that constrain consumption outside of habit persistence and are zero before 2020 in the benchmark version of the model.[17]

The portfolio $\sum_{\mathcal{Q}} B_{j,t+1}^{\mathcal{Q}}$ with gross nominal returns $R_t^{\mathcal{Q}}$ includes risk-free private domestic bonds (rf), government bonds (g), an internationally traded bond (bw), and domestic corporate shares (S).[18] The model allows for asset-specific risk premia shocks $\varepsilon_t^{\mathcal{Q}}$ with $\mathcal{Q} \in \{bw, g, S\}$.[19]

'Hand-to-mouth'. The remaining households $(1 - \omega^s)$ with the label (c) are 'hand-to-mouth'. They face a liquidity constraint (or zero-borrowing constraint) and consume their net disposable period income (wages and transfers minus taxes paid). The financing constraint binds every period, except during COVID-19 when even 'hand-to-mouth'

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[15] $\xi_{t+1}/\xi_t = \exp\left(\varepsilon_t^C\right)$ implies that the Euler equation features the time t shock ε_t^C.

[16] To ensure a balanced growth path, labour disutility includes a multiplicative term $C_t^{1-\theta}$, such that $\omega_t^N = \omega^N \exp(\varepsilon_t^U) C_t^{1-\theta}$, where ε_t^U is exogenous.

[17] Given its large estimated contribution to the pandemic recession, we discuss the 'forced' savings shock and its macroeconomic transmission compared to standard persistent savings shocks in more detail below.

[18] Like in, e.g., Benigno (2009) and Ratto et al. (2009), only the RoW bond is traded internationally.

[19] Appendix A provides a microfoundation of these shocks by incorporating assets in the utility function, as proposed by Fisher (2015). The term ε_t^S is an investment-specific risk premium shock; ε_t^g is a risk premium on government debt; ε_t^{bw} distorts the first-order condition for foreign bond demand and amounts to a disturbance to the uncovered interest parity (UIP) condition.

consumers accumulate ‘forced’ savings that they spend gradually upon exit from the pandemic.[20] Therefore, the budget constraint of ‘hand-to-mouth’ households is:

$$P_t^C C_{j,t}^c = W_t N_{j,t}^{c,paid} + T_{j,t}^c + P_t^C \left(\varepsilon_t^{tC} - \frac{1}{6} \sum_{i=8}^{13} \varepsilon_{t-i}^{tC} \right). \tag{9}$$

Aggregation across households. Per-capita consumption and hours worked by EA households are $C_t = (1 - \omega^s)\, C_t^c + \omega^s C_t^s$ and $N_t = (1 - \omega^s)\, N_t^c + \omega^s N_t^s$, respectively.

4.3 Wage setting

A monopolistic trade union differentiates homogeneous labour hours provided by the two households into imperfectly substitutable labour services. The union then offers these services to local intermediate goods firms. The labour input $(N_{i,t})$ in the production function is a CES aggregate of the differentiated labour services. The union sets wage rates at a markup over the marginal rate of substitution between leisure and consumption. The wage markup is inversely related to the substitutability among labour varieties in intermediate goods production.

We introduce nominal wage rigidity through quadratic wage adjustment costs (γ^w). In addition, the parameter γ^{wr} adds real wage rigidity in the spirit of Blanchard and Galí (2007) and Coenen and Straub (2005). A share $(1 - sfw)$ of unions indexes wages to past inflation. Per-capita employment is the same across both household types.

4.4 Monetary and fiscal policy

Monetary policy. Monetary policy follows a Taylor (1993)-type rule subject to an occasionally binding ELB constraint. The target interest rate i_t^{not} responds sluggishly to (quarterly annualised) deviations of inflation and the output gap $(Y_t^{gap,QA})$ from their respective target levels:

$$i_t^{not} - \bar{i} = \rho^i (i_{t-1} - \bar{i}) + (1 - \rho^i) \left[\frac{\eta^{i\pi}}{4} \left(\pi_t^{C,QA} - \bar{\pi}^{C,QA} \right) + \eta^{iy} Y_t^{gap,QA} \right], \tag{10}$$

---

[20] Evidence that also liquidity-constrained households saved the largest part of transfer income during the pandemic is provided by Parker et al. (2022).

where $\bar{i}$ is the steady-state nominal interest rate, $\pi_t^{C,QA}$ is quarterly annualised CPI inflation, and $\bar{\pi}^{C,QA}$ is the latter's steady-state value.[21] The variable i_t in the persistence term is the actual or effective short-term interest rate. The parameters ρ^i, $\eta^{i\pi}$ and η^{iy} govern interest rate inertia and the response to annualised inflation and output gap, respectively. The output gap is the (log) difference between actual and potential output. Potential output at date t is the output level that would prevail if the labour input equalled the amount of hours worked in the absence of nominal wage rigidity, as in Galí (2011), the capital stock was utilised at full capacity, and the TFP equalled its trend value.

The effective policy rate i_t corresponds to the target nominal short-term rate only when the latter is above the ELB (i^{lb}). The effective policy rate hence satisfies:

$$i_t = \max\{i_t^{not}, i^{lb}\} + \varepsilon_t^i, \tag{11}$$

where ε_t^i is a monetary policy shock following an ARMA(1,1) structure.[22]

Fiscal policy. The fiscal authority collects constant linear taxes on consumption, wage income, and corporate profits, a commodity import duty, and a lump-sum tax (introduced to close the government budget) to finance consumptive purchases, public investment, and transfers.[23] The individual government expenditure components follow feedback rules. Appendix C.3 provides impulse response functions (IRFs) illustrating the transmission of the main fiscal shocks.

4.5 Commodities: energy and industrial supplies

Commodities trade at flexible, destination-specific prices, driven by exogenous supply (price) shocks.[24] The total demand for commodities, CO_t, is the sum of household energy consumption, C_t^E, and demand for industrial supplies in final goods production, IS_t.

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[21] Quarterly annualised inflation is defined as $\pi_t^{C,QA} = \log\left(\sum_{r=0}^{3} P_{t-r}^C\right) - \log\left(\sum_{r=4}^{7} P_{t-r}^C\right)$. We have also tested specifications with separate targets on core versus headline inflation. Estimation results suggest that US monetary policy compared to EA targets more core inflation. Since overall results are similar, we limit the discussion of results to the simpler formulation.

[22] Compared to a white noise process, the predictable MA-component helps capture forward guidance policies at the ELB.

[23] For simplicity, the different taxes are omitted from equations in the overview in Section 4 and instead included in the detailed model description in Appendix A.

[24] We also tested model versions in which commodity demand affects global commodity prices. In light of the additional complexity, we have kept the more stylised assumption of exogenous supply shocks as drivers of commodity prices, leaving a more detailed treatment of demand versus supply factors in commodity markets in recent years for future work. For a distinction between the two in earlier work, see Giovannini et al. (2019).

Energy goods. Final household consumption is a CES aggregate of commodities used for consumption ('energy', denoted C_t^E) and final manufactured goods C^{FG}:

$$C_t = \left[(1 - s_t^E)^{\frac{1}{\sigma^E}} \left(C_t^{FG} \right)^{\frac{\sigma^E - 1}{\sigma^E}} + (s_t^E)^{\frac{1}{\sigma^E}} (C_t^E)^{\frac{\sigma^E - 1}{\sigma^E}} \right]^{\frac{\sigma^E}{\sigma^E - 1}}, \tag{12}$$

with energy share s_t^E and the elasticity of substitution $\sigma^E > 0$.

US commodity supply. While all commodities used in the EA are imported, the US not only uses commodities but also supplies them (while remaining a net importer). A share of value-added is used for commodity extraction ($Y_t^{CO,US}$).[25] Commodity producers maximise dividends, $div_{i,t}^{US,CO} = CO_t^{US} P_t^{CO} - Y_t^{CO,US} P_t^{US}$, using a decreasing return to scale technology, $CO_t^{US} = A^{CO} \left(Y^{CO,US} t \right)^{\alpha CO}$, where A^{CO} is a scaling parameter. With $\alpha_{CO} < 1$, US production is an increasing function in the (relative) price of commodities.

4.6 Resource constraint

The resource constraint of the EA economy is:

$$P_t Y_t + \tau^{CO} P_t CO_t = P_t^C C_t + P_t^I I_t + P_t^{IG} IG_t + P_t^G G_t + TB_t, \tag{13}$$

where P_t^{IG} and P_t^G are the prices of investment and consumption goods purchased by the government, respectively, and:

$$TB_t = P_t^X X_t - P_t^{CO,M} CO_t - \sum_z P_t^M M_t^Z \tag{14}$$

defines the EA trade balance as the difference between exports and imports in value terms. The US trade balance, in addition, includes US commodity exports to the RoW and the EA.

4.7 Rest of the world

The RoW block adopts a simplified structure, excluding 'hand-to-mouth' households and fiscal policy. Perfectly competitive final goods firms bundle the final consumption good C_t^*, the investment good I_t^*, and the RoW (non-commodity) export good X_t^* following a structure analogous to the production of aggregate demand components in the EA

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[25] Thus, output production (eq. 2) in the US uses $Y_{i,t}^{int} = Y_{i,t} - Y_{i.t}^{CO}$.

outlined in Subsection 4.1 (bundling of domestic and imported output).

Monopolistically competitive intermediates goods firms in the RoW use a Cobb-Douglas technology as in equation (4) to produce domestic (non-commodity) output. The price setting for non-commodity output follows a New Keynesian Phillips curve with cost-push shock.

In addition to final goods, RoW is a commodity exporter. Compared to the US, the supply of commodities by RoW is residual, satisfying global demand. A competitive sector supplies commodities CO, namely Brent oil and other commodities materials, to foreign firms.[26] Both supply schedules follow exogenous stochastic processes (see Appendix A.7).

Preferences of RoW households include consumption with external consumption habits and endogenous labour supply. RoW output combines industrial supplies and final goods. The latter are also required for commodity extraction. However, for simplicity, consumption in the RoW does not feature an energy component. Monetary policy in RoW follows a Taylor-type interest rate rule targeting inflation and GDP growth.

5 Econometric approach

This section describes the econometric approach to estimating the three-region model and retrieving the exogenous shocks. Subsection 5.1 describes the data for estimation, and Subsection 5.2 the model solution and the filtering. Subsection 5.3 summarises important calibrated and estimated parameters.

5.1 Data

The data set covers 1998q4-2022q4.[27] EA and US data (quarterly national accounts, fiscal aggregates, quarterly interest and exchange rates) are taken from Eurostat and the BEA. Annual RoW series are compiled from the IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases.[28] The data for RoW short-term nominal interest rates are available only until 2021 (included). The observed data also include commodity prices (Brent oil and other commodities, including natural gas) from the Eurostat Comext database, allowing us to observe import prices (total and commodities)

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[26] We do not specify separate demand functions for the different commodity types but allow for different prices (and, hence, supply schedules).

[27] In estimations, we include a pre-sample of five quarters.

[28] RoW series include GDP, prices, investment, and the short-term nominal interest rate with some gaps for 2022. Annual data points are treated as last quarter observations (as quarterly annualised variables) to ensure model-consistent interpolation.

for each region.[29] Appendix B provides additional details on the data sources and the RoW aggregation.

5.2 Model solution and filtering

State-space representation. We construct a linear solution of the economy's dynamic equilibrium. The model also includes a stochastic productivity trend (as a component of A_t^Y), which affects all real variables. Let Θ denote the parameters of the DSGE model. Using the de-trended model solution, we can specify the following system of observation and state equations:

$$\mathcal{Y}_t^{data} = \Psi_1(\Theta)S_t, \tag{15}$$

$$S_t = \Phi_1(\Theta)S_{t-1} + \Phi_\varepsilon(\Theta)\varepsilon_t \qquad \varepsilon_t \sim N(0, Q_t I). \tag{16}$$

The observation equation (15) links the vector of observed variables $\mathcal{Y}_t^{data}$ at time t to the model variables S_t through the coefficient matrix $\Psi_1(\Theta)$. The state equation (16) describes the transition of the system's state variables S_t using the coefficient matrices $\Phi_1(\Theta)$ and $\Phi_\varepsilon(\Theta)$. The model shocks ε_t follow a normal distribution with time-varying covariance matrix $Q_t I$. With this formulation, we incorporate deterministic heteroskedasticity in the subset of COVID-related shocks, following the approach of Lenza and Primiceri (2022), previously used in Cardani et al. (2022). Specifically, for the COVID-19 period $t \in$ 2020q1:2022q4, $Q_t = Q^{COVID}$ includes temporary shocks specific to the pandemic. Prior to the pandemic, i.e. for $t <$ 2020q1, $Q_t = Q$ assumes zero standard deviations for these shocks. This approach implies that expectations regarding COVID-19 were zero before its occurrence.

Two-step estimation. The estimation proceeds in two steps. First, we estimate the model parameters (Θ) using data until 2019q4. Then, in the second step, we estimate the variances of heteroskedastic, COVID-specific shocks using data for 2020q1-2022q4 while keeping all other parameters unchanged and initialising the system's state (16) and covariance matrix at their estimates from the first step (i.e., at the pre-COVID Kalman filter recursions). This approach is equivalent to using the full dataset starting from 1998q4, but it is more efficient given the large model size. Both estimation steps employ a linear Kalman filter and a parallelised slice sampling algorithm (Neal, 2003) to draw parameters from their posterior distribution using Markov Chain Monte Carlo methods. The simulations and estimations are performed using DYNARE (Adjemian et al., 2022).

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[29] Due to data limitations, we do not observe the prices of bilateral imports and exports.

Nonlinear smoothing. Based on the estimated parameter values, we run a piecewise linear Kalman filter, as in Giovannini et al. (2021), to identify the structural shocks, where we account for endogenous ELB periods using the OccBin approach (Guerrieri and Iacoviello, 2015). The smoothing algorithm covers observations until 2022q4, given the parameter estimates. Appendix D provides additional methodological details. In particular, counterfactual simulations suggest that the ELB played a substantial role in constricting monetary policy, which intensified the recessionary shocks and deflationary dynamics.

5.3 Model parameters

Calibration. We calibrate a subset of model parameters to match long-run data averages and targets. The values are summarised in table B.2. All real variables grow at the average annual growth rate of EA GDP (1.3%). The trend growth of the price level corresponds to the targeted annual inflation rate (2%). The time preference rate, together with trend output growth and trend inflation, determines the steady-state nominal interest rate (4% p.a.). The steady-state shares of main economic aggregates in GDP match historical averages over the estimation period. Furthermore, the share of saver households is set to 0.67 in the EA and 0.73 in the US, in line with the evidence in Dolls et al. (2012). The Cobb-Douglas labour share, α, is 0.65 in both regions. We calibrate the import content in aggregate demand components, $s^{M,Z}$, to Bussiere et al. (2013). The steady-state share of industrial supplies in output, s^{CO}, matches the average of imported commodities to GDP for the EA (0.04). For the US, this includes domestically produced commodities and the US (0.05).

Posterior estimates. We estimate the remaining parameters using Bayesian full information methods applied to the linearised model. Table 1 reports estimates for key parameters of the three model regions. Appendix B collects the estimates for the remaining parameters and processes. Overall, the parameter estimates are similar to the ones in Kollmann et al. (2016) and Giovannini et al. (2019). On the household side, EA and US display consumption habits of similar size (0.87 and 0.92) and similar risk aversion (1.57 and 1.49). Labour supply is estimated to be more elastic in the US. The demand for imports and energy commodities (oil) is (somewhat) more price elastic in the EA (2.55 and 0.44) compared to the US (1.67 and 0.38).

On the production side, estimated investment adjustment costs are higher in the EA. In line with the stylised facts presented above, employment adjustment costs are substantially lower in the US, while hours are more flexible in the EA. The degree of

		Prior distribution		Posterior mode distribution	
		Distr.	Mode	EA	US
			Std.	(10%-90%)	(10%-90%)
Preferences and technology					
Habit persistence	h	Beta	0.50	0.87	0.92
			0.10	(0.83-0.93)	(0.89-0.95)
Risk aversion	θ	Gamma	1.50	1.57	1.49
			0.20	(1.29-2.01)	(1.20-1.75)
Inverse Frisch elasticity of labour supply	θ^N	Gamma	2.50	2.48	1.68
			0.50	(2.08-3.77)	(1.37-2.23)
Import price elasticity	σ^z	Gamma	2.00	2.55	1.67
			0.40	(1.47-2.75)	(1.41-2.08)
Commodity price elasticity	σ^o	Beta	0.50	0.44	0.38
			0.08	(0.35-0.60)	(0.31-0.50)
Energy consumption elasticity	σ^E	Beta	0.50	0.43	0.38
			0.08	(0.36-0.57)	(0.32-0.52)
Commodity extraction elasticity	α^{CO}				0.13
					(0.07-0.20)
Nominal and real frictions					
Price adj. cost	γ^P	Gamma	20.00	55.48	72.06
			12.00	(40.26-79.77)	(55.26-106.15)
Capacity utilisation adj. cost	$\gamma^{U,2}$	Gamma	0.03	0.02	0.03
			0.01	(0.01-0.02)	(0.02-0.04)
Investment adj. cost 1	$\gamma^{I,1}$	Gamma	60.00	122.72	92.28
			20.00	(79.44-166.03)	(40.18-120.01)
Investment adj. cost 2	$\gamma^{I,2}$	Gamma	60.00	63.62	47.16
			40.00	(25.39-168.10)	(9.57-122.46)
Employment adj. cost (pers.)	$\gamma^{E,2}$	Gamma	20.00	27.23	10.38
			12.00	(20.45-36.93)	(6.92-14.06)
Hours adj. cost	$\gamma^{H,2}$	Gamma	20.00	11.95	28.74
			12.00	(8.67-16.08)	(19.47-47.89)
Nominal wage adj. cost	γ^w	Gamma	20.00	14.28	18.62
			12.00	(1.08-22.56)	(12.32-27.84)
Real wage rigidity	γ^{wr}	Beta	0.85	0.95	0.82
			0.06	(0.94-0.98)	(0.80-0.94)
Policy					
Interest rate persistence	ρ^i	Beta	0.85	0.83	0.90
			0.08	(0.75-0.87)	(0.82-0.93)
Response to inflation	$\eta^{i,\phi}$	Inv.Gamma	1.70	1.55	1.71
			0.15	(1.42-1.68)	(1.53-1.92)
Response to output gap	$\eta^{i,y}$	Beta	0.20	0.06	0.02
			0.08	(0.04-0.11)	(0.01-0.04)
Tax rule persistence	ρ^τ	Beta	0.85	0.91	0.95
			0.06	(0.85-0.95)	(0.92-0.98)
Tax rule deficit response	η^{DEF}	Beta	0.03	0.03	0.02
			0.01	(0.02-0.04)	(0.01-0.04)
RoW region					
Habit persistence	h^*	Beta	0.70	0.92	
			0.10	(0.91-0.95)	
Risk aversion	θ^*	Gamma	1.50	1.31	
			0.20	(1.18-1.52)	
Commodity price elasticity	$\sigma^{C,*}$	Gamma	2.00	2.05	
			0.40	(1.52-2.30)	
Price adj. cost	$\gamma^{P,*}$	Gamma	20.00	18.08	
			6.00	(12.72-27.85)	
Response to inflation	$\eta^{i,\phi,*}$	Inv.Gamma	1.70	1.55	
			0.15	(1.42-1.68)	
Response to GDP growth	$\eta^{i,y,*}$	Beta	0.20	0.06	
			0.08	(0.04-0.11)	

Table 1: Prior and posterior distribution of key estimated model parameters.

Notes: This table reports the mode and the standard deviation (std) of the posterior distributions of EA and US parameters, respectively. RoW parameters are reported below. Identical priors are assumed for EA and US parameters.

		Prior distribution		Posterior mode distribution	
		Distr.	Mode Std.	EA (10%-90%)	US (10%-90%)
Shock processes (domestic) COVID-19					
Forced savings - std	ε^{tC}	Gamma	0.01	0.04	0.03
			0.00	(0.03-0.05)	(0.02-0.04)
Labour hoarding - std	ε^{LU}	Gamma	0.01	0.02	0.01
			0.00	(0.02-0.03)	(0.01-0.01)
Temporary employment - std	$\varepsilon^{ND,covid}$	Gamma	0.05	0.19	0.28
			0.02	(0.16-0.23)	(0.23-0.29)
Shock processes (rest of the world) COVID-19				RoW	
Forced savings - std	$\varepsilon^{tC,*}$	Gamma	0.05	0.27	
			0.02	(0.22-0.29)	
Temporary productivity - std	$\varepsilon^{AY,*}$	Gamma	0.05	0.30	
			0.02	(0.24-0.30)	

Table 2: Selected estimated COVID-specific shock variances

Notes: This table reports the mode and the standard deviation (std) of the posterior distributions of EA and US COVID-specific shock parameters, respectively. RoW parameters are reported below. Identical priors are assumed for EA and US parameters.

nominal price and wage rigidity is similar for the EA and the US, but EA estimates point to stronger real wage persistence.[30]

Concerning monetary policy, estimates of the Taylor rule parameters indicate somewhat less interest inertia (0.83 and 0.90) and a weaker response to inflation (1.55 and 1.71) in the EA compared to the US. The Taylor rule response to the output gap is modest (0.06 versus 0.02) in both regions, according to the estimates.

Table 2 reports second-step estimation results, specifically focused on the period influenced by COVID-19. Compared to the US, the model estimation indicates a more pronounced incidence of ‘forced savings’. It also suggests more substantial labour hoarding shocks in the EA, in line with the economic measures and labour market policies adopted by many European countries. Conversely, the estimation finds stronger US employment shocks (in addition to lower structural employment adjustment costs).

6 Impulse response functions

This section discusses impulse response functions (IRFs) for selected shocks that are characteristic of the pandemic and recovery period according to the estimated model to understand the dynamics of the model given the parameter estimates. In particular, we display

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[30] The price adjustment cost estimate here is difficult to compare to evidence from the literature about the stickiness of retail prices (e.g., Karadi et al. (2023)) because price rigidity in our model occurs at the level of intermediate goods production, i.e. before the levels of output assembly (adding industrial supplies) and final demand (adding household energy consumption and imports). Moreover, inflation inertia interacts with real rigidities, which are higher in the EA (Christiano et al., 2005).

IRFs for the transitory 'forced' savings shock compared to the standard persistent savings (time preference) shock, the COVID-specific labour demand shock, a shock to commodity (oil) prices, a persistent government transfer shock, and a consumption-specific retail price shock. The IRFs in this section consider an economy away from the ELB in which monetary policy can adjust short-term interest rates up and down.[31]

Savings shocks. Figure 3 displays IRFs for the temporary ('forced') savings shock (blue solid lines) that accounts for most of the contraction of private consumption demand in 2020 at quarterly frequency, in comparison to a persistent 'forced' savings (time preference) shock (red dashed lines). This section shows the IRFs for the EA. Appendix C.4 compares EA and US responses. The shock is a temporary increase in private savings, i.e. a temporary contraction in consumption demand. Private consumption and real GDP decline (and, by consequence, hours worked, mitigated by labour adjustment costs), as does the government's primary balance due to the working of automatic stabilisers (government expenditure relative to GDP increases, whereas tax revenue declines).

Monetary policy reacts by lowering the short-term nominal interest rate, which stimulates investment demand and depreciates the exchange rate. Together with the decline in total domestic demand, the depreciation contributes to an increase in the trade balance. The real wage increases temporarily given downward price adjustment (in reaction to lower demand) combined with nominal wage stickiness, whereas, in the case of the persistent savings shock, the decline in hours worked also weighs negatively on real wage growth.

IRFs for the persistent savings shock (positive shock to the rate of time preference, depicted as red dashed in Figure 3) are more persistent but qualitatively similar otherwise. A notable difference is the similar initial inflation response despite the much bigger initial GDP contraction associated with the 'forced' savings shock. Compared to the demand and output contraction, the inflation response to transitory higher savings is modest. As the 'forced' savings shock is short-lived, it has little impact on expectations about future inflation, which dampens its impact on inflation compared to the persistent demand shock in an environment with price stickiness described by the New Keynesian Phillips curve (NKPC). In the case of the persistent shock, the lasting contraction of economic activity also lowers expectations of future inflation, which feeds into lower current inflation through the NKPC.

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[31] Appendix C.5, in addition, provides IRFs for the temporary labour demand shock, which is a transitory shock to the firm's first-order condition for employment during the pandemic and recovery period. A negative labour demand shock implies lower employment for given real wages. It can be understood as a shock to labour costs other than wages. It may equally proxy a mark-down of wages associated with the increased market power of employers in labour markets.

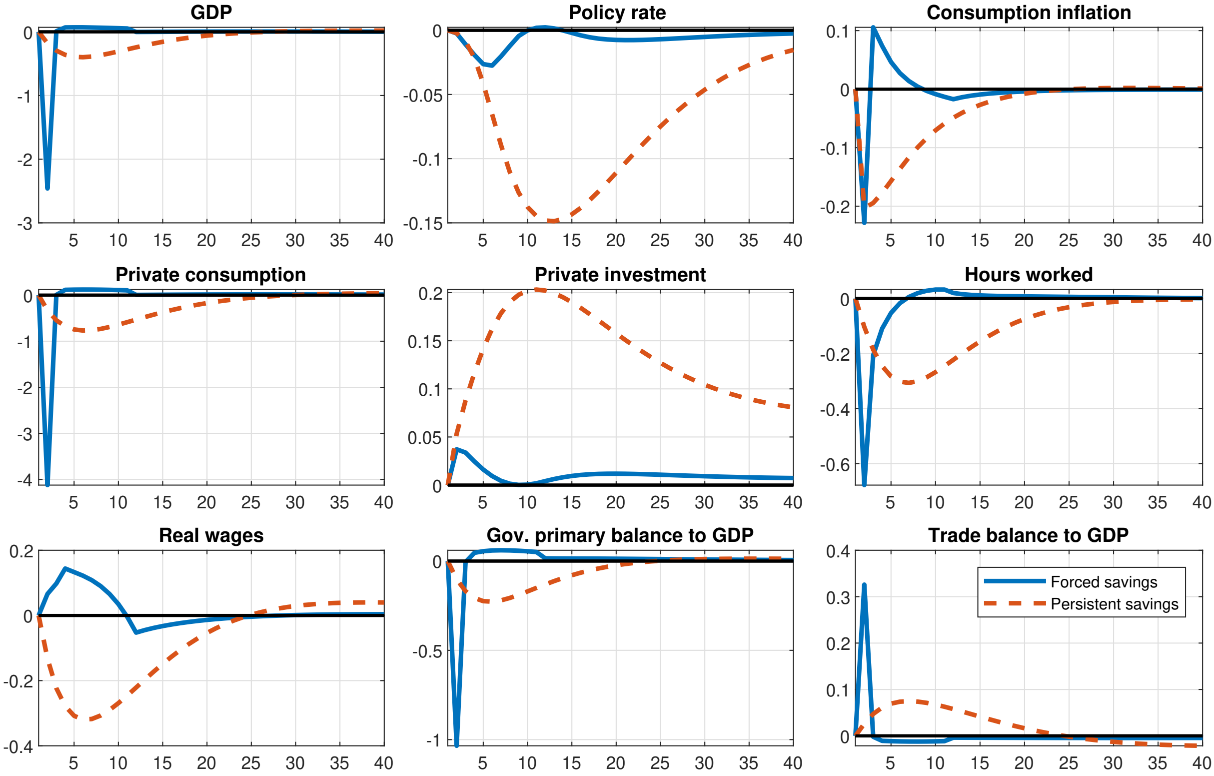

Figure 3: Response to different savings shocks in EA

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters. The shock sizes correspond to one estimated standard deviation.

Oil price shock. Figure 4 shows the macroeconomic response to an increase in the price of energy commodities ('oil price' for short). The higher oil price, which affects consumers indirectly through higher costs for industrial supplies that feed into higher prices of domestic manufactured products and directly through the energy component in the final demand bundle, increases headline inflation. Monetary policy tightens, which leads to higher real rates in the medium term and further dampens domestic demand and output. The EA (blue solid lines) trade balance deteriorates due to the higher commodity import bill. The US (red dashed lines) trade balance is rather stable (small surplus) instead. Given that the US is a commodity supplier in our model, an oil price increase has less of a negative wealth effect (resource transfer to RoW), which contributes to the resilience of domestic consumption and activity in the US.

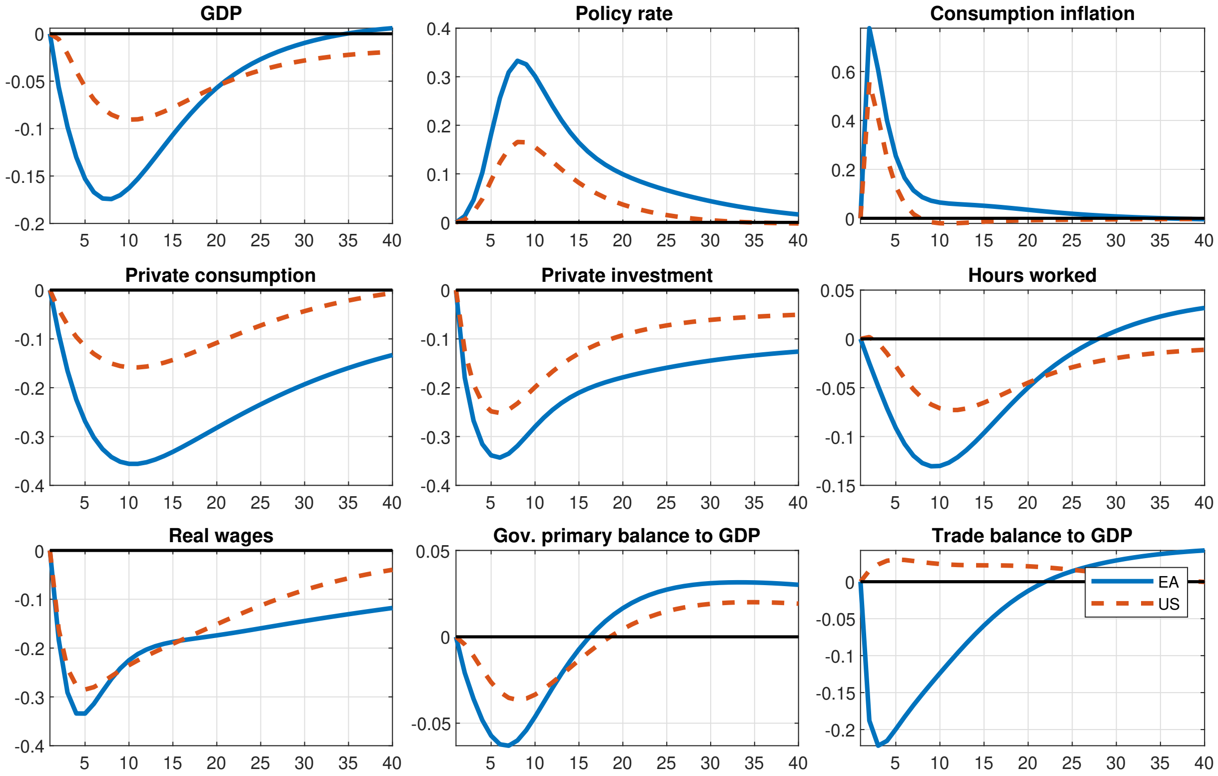

Figure 4: Response to oil price shock in EA and US

Notes: See Figure 3 for additional details on the variable units and the simulation setup. The shock size corresponds to an approximately 10 USD increase in global oil prices.

Government transfer shock. An important part of the fiscal response to the COVID-19 pandemic has been government transfers rather than purchases. The literature has argued that the appropriate fiscal response to lockdowns consists of household income insurance rather than additional demand (Guerrieri et al. (2022)).

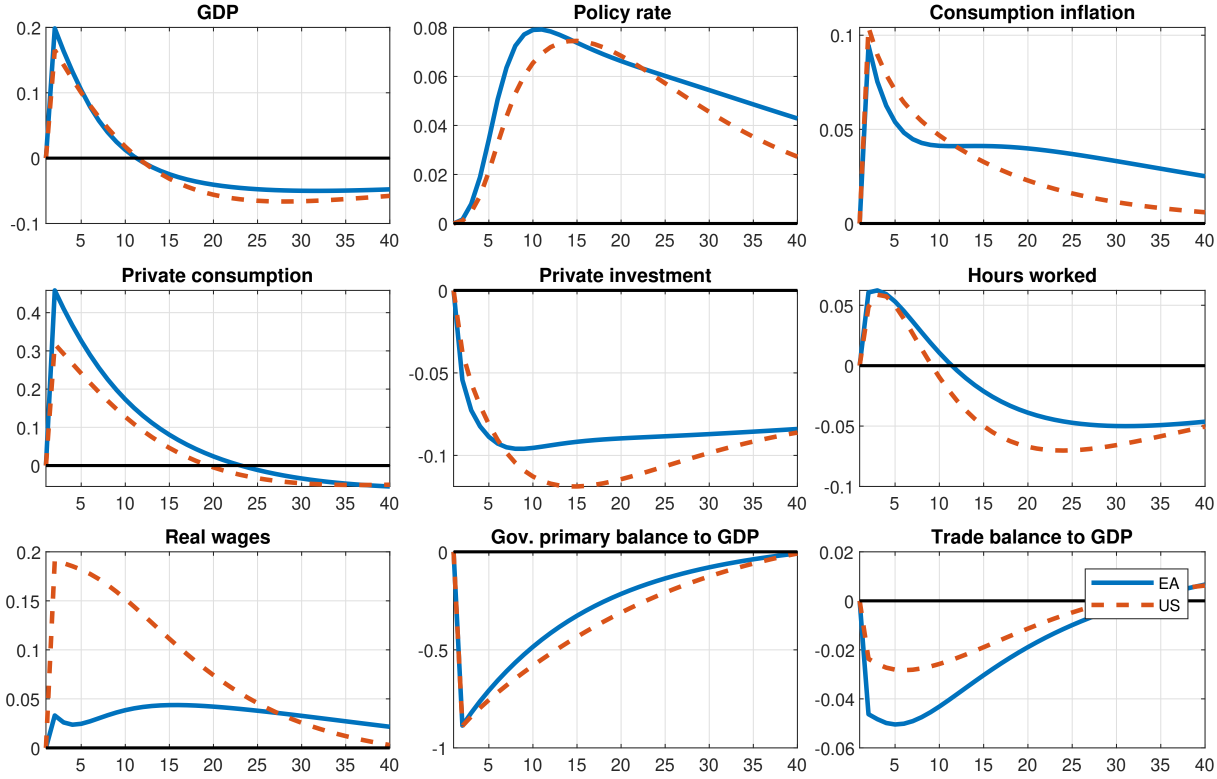

Figure 5: Response to persistent government transfer shock in EA and US

Notes: The shock size corresponds 1% of GDP on impact. See Figure 3 for additional details on the variable units and the simulation setup.

Figure 5 plots the IRFs for a persistent increase in government transfers (1% of GDP on impact). Private consumption increases in the presence of 'hand-to-mouth' consumers and triggers a monetary tightening away from the ELB, with an increase in the real interest rate that partly crowds out private investment. The private consumption response is stronger in the EA (blue solid lines), owing to a higher share of 'hand-to-mouth' consumers than in the US (red dashed lines). The trade balance declines in response to higher domestic demand and declining price competitiveness (appreciation of the real effective exchange rate (REER)) of domestic output. Domestic inflation increases in response to stronger activity. In light of the persistence of the shock and the output response, the inflation effect is relatively strong in relation to the initial GDP increase, given the impact of shock persistence on inflation expectations and current inflation in the NKPC.

Retail price shock. Figure 6 plots IRFs for a positive retail price shock. This shock is a wedge between the costs of output (aggregation of the final good and energy consumption) and the consumer price. Technically, the shock is a negative shock to productivity in the provision of the final consumption good (A_t^{CFG} in eq. (1)). It can also be interpreted as a proxy for a consumption-specific price markup collected by retailers.

The shock increases consumer prices and lowers consumption demand, which, in turn, dampens economic activity. The central bank raises interest rates in response to inflation. Investment falls in response and contributes to the decline in GDP. Net exports (the trade balance) weaken in response to the REER appreciation, following monetary tightening, despite the converse effect of lower domestic demand on imports.

The response of consumption and activity to the shock is stronger in the EA (blue solid lines) than in the US (red dashed lines), which reflects the different shock persistence (substantially higher in EA). By contrast, the estimated shock size is larger in the US block, implying a stronger initial price impact in the US. Together with smaller rigidities, this difference explains the larger US inflation response despite a smaller initial GDP response to the shock. Higher estimated real wage rigidity explains the stronger negative response of employment to the shock in the EA.

7 Shock decompositions

Shock decompositions (SDs) split the dynamics of endogenous model variables into their main exogenous drivers (shocks), thereby providing information about the relative importance of individual factors. This section compares quarterly SDs for GDP growth and headline CPI inflation in the EA and the US, focusing on the COVID-19 period and recov-

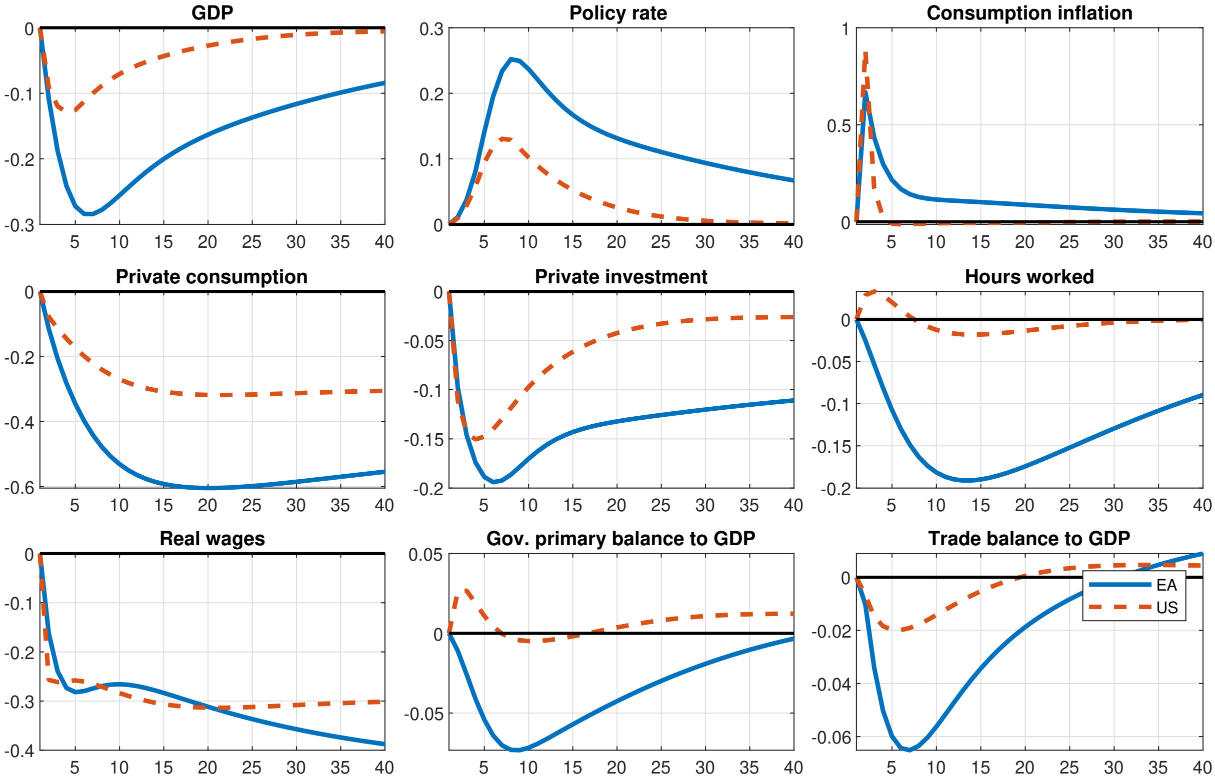

Figure 6: Response to a retail price shock

Notes: The shock size corresponds one estimated standard deviation. See Figure 3 for additional details on the variable units.

ery (2019-22). SDs for GDP growth and inflation starting in 2000q1-2022q4 are presented in Appendix C (Figures C.1-C.2) for completeness.

Real GDP growth. Figure 7 shows the decompositions of year-on-year real GDP growth in the US (left) and the EA (right) for 2019q1-2022q4. It illustrates the dominant role that the model ascribes to the transitory ('forced') savings shock to explain the contraction of economic activity in 2020 and the recovery in 2021 and early 2022.[32] The dominant role of 'forced' savings also echoes the important role of declining consumption demand in the pandemic recession, contrary to the average recessions with a stronger role for investment demand.

Additional downside factors in 2020 are other private domestic demand shocks, including the standard persistent savings (time preference) shock and a shock to private investment demand, as well as negative shocks to foreign activity and international trade,

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[32] The transitory 'forced' savings shock is the one that dominates the contribution of the group of 'lockdown' shocks in the EA and US SDs for real GDP growth. Other elements of this group are the labour hoarding shock and a COVID-specific labour demand shock.

which dampen net export demand.[33] Fiscal shocks (discretionary fiscal policy) play a stabilising role in 2020, especially in the US, whereas they dampen the 2021 recovery, i.e. the phasing out of fiscal support becoming a drag on US growth.

Falling commodity prices supported growth in 2020 (though moderate in their quantitative contribution). In contrast, the rise of commodity prices in 2021-22 was a downside factor in more recent quarters. Domestic supply shocks play little role in explaining the EA and US fluctuation in activity in 2020-21. They are a downside factor more in 2021-22, notably positive shocks to retail prices; the latter are negative retail-specific productivity shocks but can also be understood as positive price markup shocks on the domestic component of final aggregate demand.

Overall, the SDs explain the milder US recession (trough at around 10% yoy contraction in 2020q1 compared to circa 15% in the EA) through less pronounced 'forced' savings, stronger fiscal expansion, less shocks to export demand and more favourable supply conditions compared to the EA.

Consumer price inflation. Figure 8 provides the decompositions for US (left) and EA (right) consumer price inflation (yoy). Strikingly, the main driver of activity at quarterly frequency in 2020, 'forced' savings (as part of the lockdown shocks), has only a minor effect on inflation during the pandemic and in the recovery. This result is linked to the transitory nature of the shock, which excludes a relevant impact on expected future inflation that would feed back into current inflation in the NKPC.

According to the SDs, the rise in inflation in both regions in 2021-22 was, instead, driven by rising commodity prices, the recovery of foreign demand and domestic consumption and investment (reversal of the negative persistent demand shocks), and an increase in price markups.[34] Supply shocks had a sizable impact on EA inflation already during the pandemic in 2020-21, also reflecting the absence of deflation despite the strength of downside factors. For the US, there was a role for the pandemic-specific labour cost shock (i.e., an increase in labour costs other than wages) as a contributor to rising inflation since 2020.[35]

Fiscal expansion had a persistent and positive impact on inflation in the US and EA,

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[33] The negative shock to foreign activity implies a contraction of foreign activity but no change in trade openness. On the contrary, the shock to international trade is a negative shock to trade, which accounts for the fact that world trade contracted more strongly than world output, implying a decline in trade openness.

[34] The commodity price effect on inflation is stronger in the EA given the larger commodity price increase in the region in 2021-22 that has to do with the previous sourcing of EA commodity imports and the need to find short-term replacements at elevated world market prices.

[35] The stronger role of the labour demand shock for US inflation reflects the fact that this shock applies to the external margin of employment, where changes were more pronounced in the US.

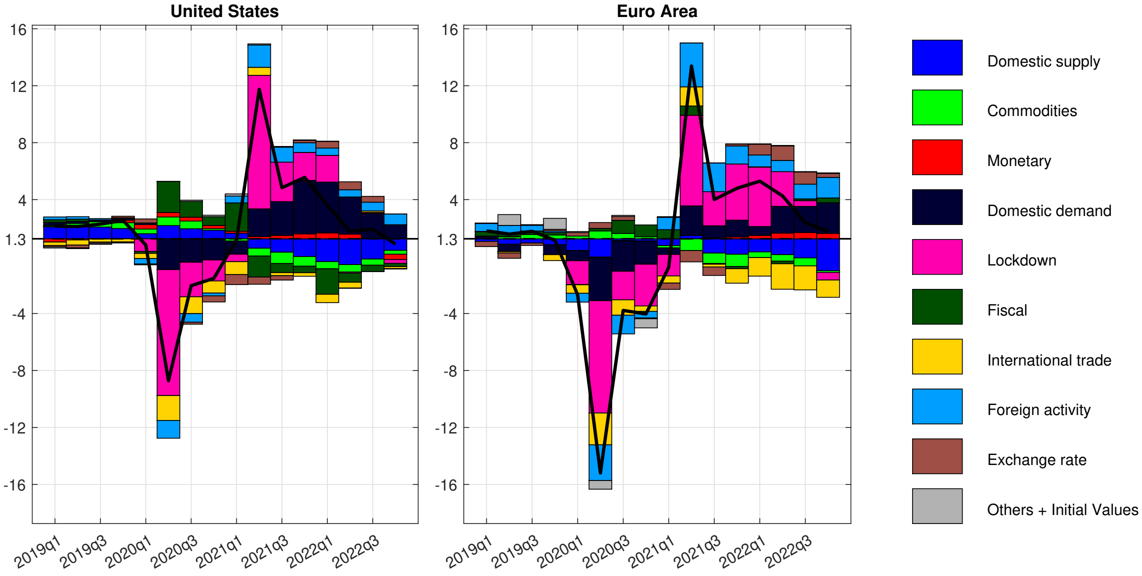

Figure 7: Real GDP growth (yoy) decomposition (2019q1-22q4)

Notes: The panels show shock decompositions of quarterly real GDP growth (year-on-year). All structural shocks together recover the observed time series of GDP growth (continuous black line). Units on the y-axis are in % (1=1%). We have grouped the estimated shocks into the following categories: (1) domestic supply shocks, including TFP, price and wage markup shocks (blue); (2) commodity price shocks (light green); (3) monetary policy, i.e. innovations to the estimated Taylor rule (red); (4) shocks to private domestic demand (excluding COVID-specific transitory shocks), such as persistent saving and investment risk premium shocks (black); (5) lockdown shocks since 2020, i.e. transitory ('forced') saving and temporary labour hoarding shocks (pink); (6) discretionary fiscal policy shocks, which capture deviations from estimated fiscal policy rules (dark green); (7) shocks to international trade, which include deviations of trade volumes and prices from the estimated export and import demand and pricing equations (yellow); (8) shocks to foreign activity, which include shocks to demand and supply in the respective foreign regions (light blue); (9) exchange rate shocks, which are shocks to the UIP that affect the exchange rate for given 'fundamentals' (brown); (10) any remaining factors (grey).

especially in the US during 2020-21, when the stimulus was largest.[36] The persistence of fiscal stimulus effects on inflation is linked to the persistence of the stimulus effect on output levels as well as the presence of strong real wage rigidity in the model that leads to delayed inflation effects through nominal wage growth. The (small) positive contribution of monetary shocks in 2021-22 reflects the cautious reaction of monetary policy to rising inflation, i.e. more gradual tightening than suggested by the model's estimated Taylor rules.

A notable difference between the two regions regarding inflation concerns the role of exchange rate shocks. Appreciation pressure on the USD during the pandemic and since

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[36] The observation that a substantial part of transfers to households has been saved rather than spent by the latter would be interpreted by the model as a positive contribution from fiscal stimulus combined with a positive household savings (i.e., negative household consumption) shock.

('flight to safety') has partly offset push factors through a dampening effect on import and commodity prices in USD terms. In EA, to the contrary, depreciation pressure added to consumer price inflation via the impact on commodity and manufactured import prices and second-round effects associated with high real wage rigidity.

Overall, the shock decompositions for CPI inflation are in line with the result from previous literature (di Giovanni (2022); Pasimeni (2022); di Giovanni et al. (2023)) that inflation in 2021-22 had a stronger supply-side component in the EA and a more substantial demand-side component in the US.

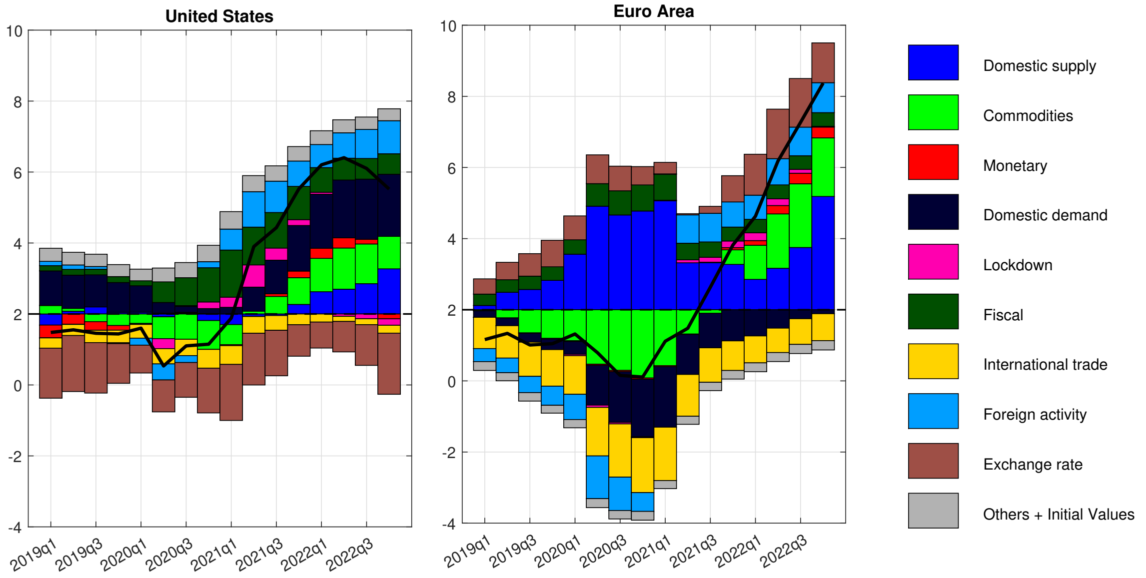

Figure 8: Consumer price inflation (yoy) decomposition (2019q1-22q4)

Notes: Inflation rates are year-on-year, i.e. they measure consumer price deflator growth relative to the same period of the previous year. Units on the y-axis are in % (1=1%). The solid black line represents the data. Bars below (above) the dashed line (trend inflation) indicate negative (positive) contributions to consumer price inflation. All structural shocks together recover the observed time series of GDP growth (continuous black line). We have grouped the estimated shocks into the following categories: (1) domestic supply shocks, including TFP, price and wage markup shocks (blue); (2) commodity price shocks (light green); (3) monetary policy, i.e. innovations to the estimated Taylor rule (red); (4) shocks to private domestic demand (excluding COVID-specific transitory shocks), such as persistent saving and investment risk premium shocks (black); (5) lockdown shocks since 2020, i.e. transitory 'forced saving' and temporary labour hoarding shocks (pink); (6) discretionary fiscal policy shocks, which capture deviations from estimated fiscal policy rules (dark green); (7) shocks to international trade, which include deviations of trade volumes and prices from the estimated export and import demand and pricing equations (yellow); (8) shocks to foreign activity, which include shocks to demand and supply in the respective foreign regions (light blue); (9) exchange rate shocks, which are shocks to the UIP that affect the exchange rate for given 'fundamentals' (brown); (10) any remaining factors (grey).

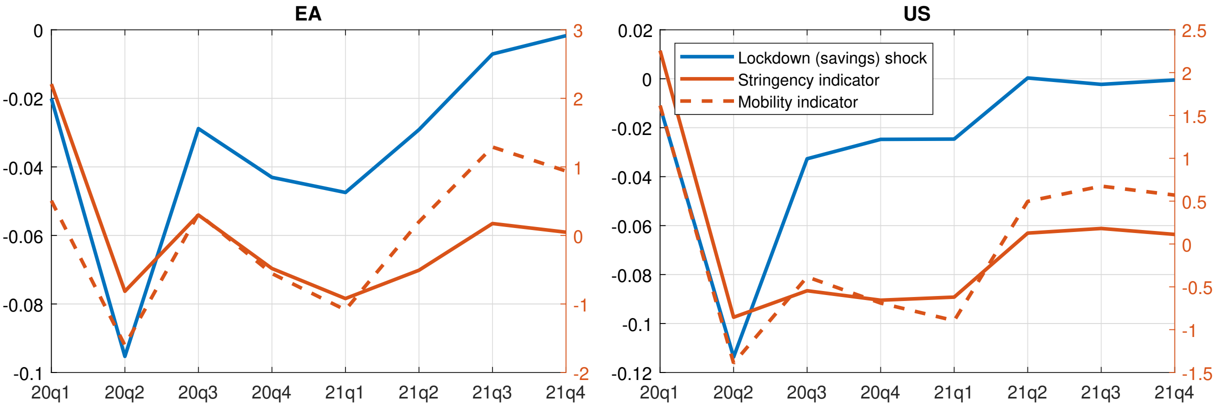

Figure 9: Lockdown shocks and indicators

Notes: The model shock (blue solid line) corresponds to the estimated 'forced savings' shock as described in equation (7). The data are time series of the Oxford stringency index (Hale et al., 2020) (red solid line) and Google's mobility indicator (red dashed line). All series are standardised. For the EA, we aggregate indicators across countries using GDP weights.

8 Comparison to off-model evidence

The decomposition above of GDP growth dynamics in the EA and the US assigns an important role to lockdown shocks, notably 'forced' savings. This section provides additional support for this channel by comparing the estimated shock profile with off-model evidence. In particular, Figure 9 compares the shape of the transitory savings shock to available indicators of pandemic-related restrictions that are not part of the data set used for model estimation. More precisely, the smoothed estimates of the transitory 'forced' savings shocks are displayed together with empirical measures of lockdown stringency and mobility restrictions for the EA and the US.

The time profiles of these series are similar across the EA and the US blocks throughout the year 2020, with close co-movement between the estimated 'forced' savings shocks and the mobility indicators, especially in 2020q1-3. There is some decoupling after the first wave of the pandemic. Notably, private consumption recovers faster than restriction ease, reflecting possible adjustments in the retail and service sectors (more online retail, sanitary measures, and less compliance with legal restrictions).

The positive co-movement of the estimated shock with the off-model indicators of lockdown stringency in both regions suggests that 'forced' savings in the model relate to contact and mobility restrictions. We interpret the evidence in Figure 9 as supporting the modelling of the COVID-related contraction of economic activity in this paper.

9 Robustness checks

This section explores two model modifications to explore the robustness of our results around the baseline specification. The first exercise considers a model with government debt in utility that can generate larger fiscal multipliers, notably for government transfers. The second extension uses shadow estimated rates to proxy for the effect of unconventional monetary policy.

9.1 Size of fiscal multipliers

Non-targeted government transfer shocks have small output and inflation effects in the standard New Keynesian model, where optimising households would balance the income gain with the expectation of higher future tax liabilities. This channel is relevant in particular for the US block, where government transfers to households accounted for a large part of fiscal stimulus during COVID-19 and are more important in the SD of real GDP growth than for the EA, where government purchases dominate the impact of the fiscal shock. Targeted transfers to 'hand-to-mouth' consumers have a larger multiplier, but the share of these households in the population is modest (33% in the EA and 27% in the US), which dampens the overall effect.

A model mechanism that increases the transfer multiplier with intertemporally maximising consumers is to introduce government bonds as a safe asset with a concave functional form in household utility, as proposed by Rannenberg (2021). Debt-financed fiscal expansions increase the households' stock of safe assets, which implies a decreasing marginal utility of government debt. Households react by reducing their savings by means of higher consumption spending (and lower labour supply).[37]

The approach by Rannenberg (2021) with preferences over safe assets (POSA) has the advantage of being easy to implement in a standard NK DSGE framework. We augment our baseline model structure accordingly to assess the implications for the size of the transfer multiplier and the associated inflation effects.

Figure 10 shows IRFs for a standard US transfer shock, comparing the benchmark version of the model with the POSA extension away from as well as at the ELB. The

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[37] Alternative approaches would be available in heterogeneous-agent NK (HANK) models (e.g., Bayer et al. (2023)). Agents in HANK models face non-insurable income risk, and income risk raises private precautionary savings. Targeted transfers reduce individual income risk, which, by implication, lowers precautionary savings, strengthens private consumption, and increases the fiscal multiplier. Analysis with a HANK model by Bayer et al. (2023) introduced a liquidity channel of fiscal policy. In this framework, debt-financed fiscal expansions lower the liquidity premium (government debt being a liquid asset) and increase liquid asset holdings, which act as insurance against individual income risk.

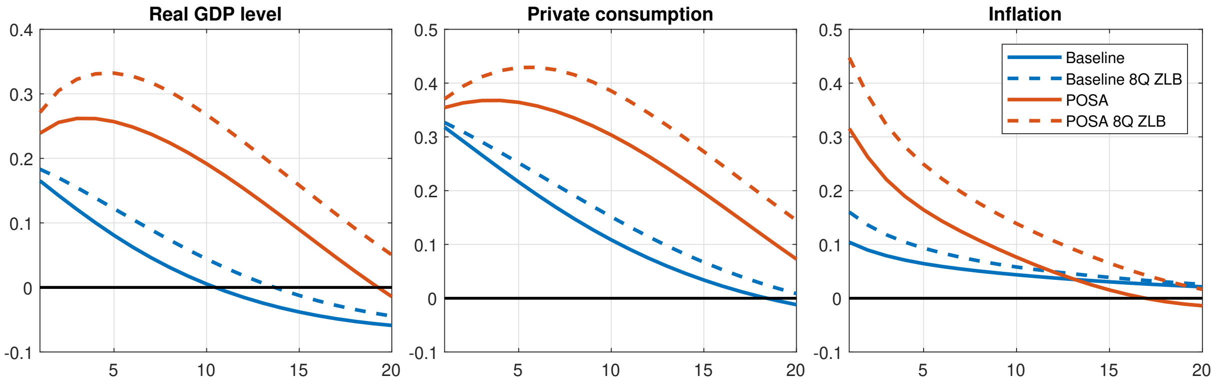

Figure 10: Transfer shock with preferences over safe assets

Notes: This graph reports results for the US. All variables are displayed in % deviations from the steady state, except for consumer price inflation (annualised), which is expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters. The label '8Q ZLB' indicates a duration of the (exogenous) ELB of eight quarters. Appendix C.6 reports additional details on this illustrative application.

model with preferences over safe assets (POSA) implies a stronger consumption and GDP response to a given transfer shock, i.e. a stronger fiscal multiplier. It also affects the initial ratio of inflation over output impacts, which one could frame as the slope of the Phillips curve. In particular, the inflation response becomes stronger for a given size of the output response. This is even more the case with the economy at the ELB or with partial monetary accommodation.[38]

In sum, the POSA extension increases the transfer multiplier and (especially at the ELB) the inflation response for given GDP effects. It could therefore strengthen the contribution of fiscal shocks to 2021-22 inflation, notably in the US. It would also imply larger inflation effects of fiscal stimulus at times when observed inflation was more moderate.

9.2 Unconventional monetary policy

Central banks have increasingly applied unconventional monetary policy (UMP) at the ELB in recent years. The benchmark model with endogenous ELB on the short-term nominal policy rate does not account directly for the impact of UMP, however. Without explicit modelling, the effects of UMP are hidden in other estimated shocks instead. Priftis and Vogel (2016), e.g., illustrate that quantitative easing (QE) corresponds to

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[38] The hump-shape pattern of the POSA consumption and output response follows the path of government debt. Private consumption increases when debt increases and declines when outstanding debt is reduced. The POSA version of the model requires a more aggressive fiscal debt stabilisation rule. Imposing the more aggressive fiscal closure rule in a no-POSA setting with Ricardian households would not affect the dynamics when the fiscal closure rule operates through lump-sum taxes.

a combination of foreign-bond preference, investment risk premium and private savings shocks in standard open-economy NK models. Accounting for UMP, by implication, should affect the quantitative importance of exogenous financial market shocks as drivers of economic activity.

Similarly, a decomposition of exchange rate dynamics in our benchmark model suggests that exchange rates are driven mainly by preference shocks for foreign versus domestic-currency bonds in the short term. This result is in line with the finding in Eichenbaum et al. (2021) of the US dollar exchange rate being driven mainly by disturbances in the foreign demand for dollar-denominated bonds. Similarly, Itskhoki and Mukhin (2021) emphasise the importance of financial market shocks to account for the disconnect between nominal exchange rate dynamics and macroeconomic fundamentals in the data.

In this subsection, we use estimated shadow rates by Wu and Xia (2016, 2020) as a measure for UMP in an ELB environment.[39] In particular, we replace the constrained short-term rate with the shadow rate when the economy operates at the ELB.[40] For simplicity, the estimated shadow rates are plugged into the estimated Taylor rule of the baseline model, i.e., the coefficients of the policy rule are not re-estimated.

Figure 11 provides a comparison of the decomposition of annual EA real GDP growth (2004-22) in the baseline model with occasionally binding ELB and the shadow-rate version that replaces the actual short-term policy rate with the shadow-rate equivalent of UMP measures when the economy reaches the ELB.

The decomposition in Figure 11 focuses on the monetary, private savings, investment and exchange rate shocks. It shows that when UMP took off in the EA in 2015, it positively contributed to GDP growth, implying that UMP measures in their shadow-rate equivalent provided stronger stimulus than would have been foreseen by the estimated Taylor rule, given inflation and output. Interestingly, the contribution of UMP shifts the sign in 2021-22, indicating a change towards monetary tightening and leaving the ELB environment. This tightening step has been larger compared to the shadow rate metric than compared to an interest rate at the ELB in 2020 so that the negative contribution of monetary shocks to GDP growth in 2021-22 becomes more pronounced. Finally, accounting for UMP shocks affects the growth contribution of private savings, investment and exchange rate shocks in Figure 11, which would otherwise absorb the omitted UMP effect in a model with occasionally binding ELB. However, the quantitative discrepancies in the SDs between both model variants remain moderate.

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[39] The data is available at `https://sites.google.com/view/jingcynthiawu/shadow-rates.`

[40] Away from the ELB, the short-term policy rate and shadow rate are (almost) identical. The shadow-rate approach translates the impact of UMP on the yield curve into a sequence of short-term rates with the equivalent effect.

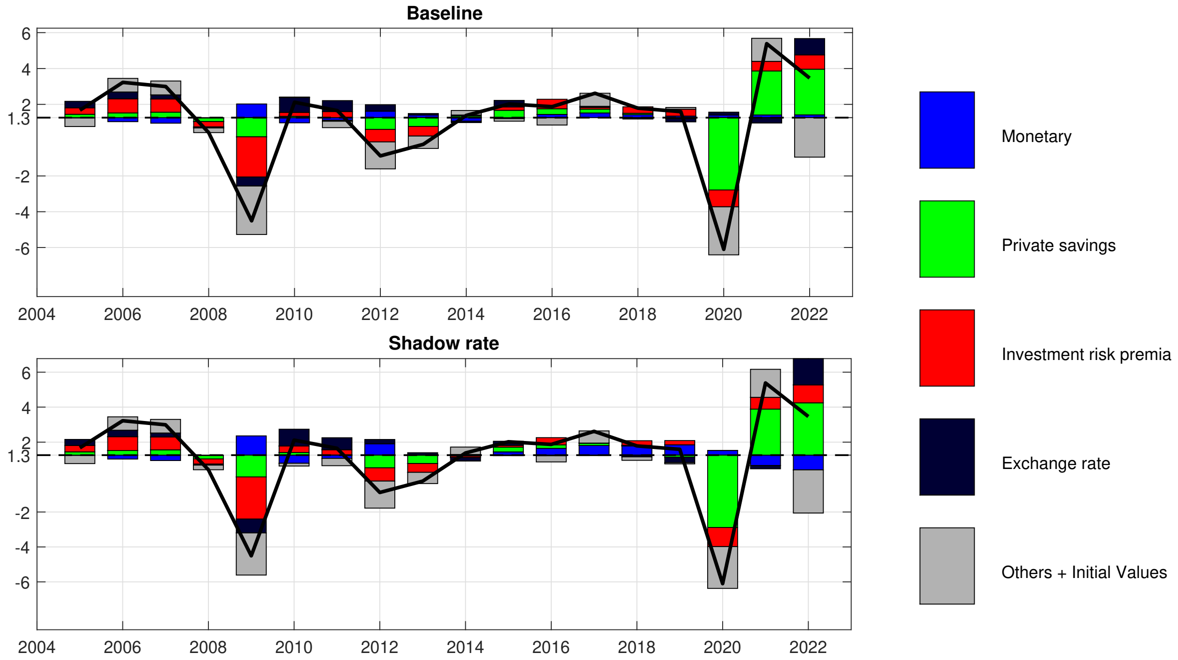

Figure 11: EA annual real GDP growth decomposition (2004-22) in different model versions

10 Conclusion

This paper has estimated a three-region (EA, US, and RoW) DSGE model to compare drivers of the COVID-19 recession and recovery in the EA and the US. We have augmented the European Commission's Global Multi-country (GM) model (Albonico et al. (2019); Giovannini et al. (2019)) with shocks and channels that have been specific to, or particularly relevant during, the pandemic. These elements include transitory 'forced' savings shocks, an explicit distinction between the extensive and intensive margins of employment, and a richer structure of commodity trade and use.

Overall, the paper adopts a parsimonious approach to adapt a workhorse policy model to salient features of the COVID-19 recession. The model extensions allow the inclusion of the pandemic period in the data set while preserving plausible model dynamics prior to COVID-19.

The analysis attributes an important role to transitory consumption ('forced' savings) to explain the quarterly profile of EA and US economic activity in 2020-21. More persistent consumption and investment shocks and shocks to foreign activity and trade also played a role. Fiscal policy stabilised aggregate activity during the pandemic. Rising inflation in 2021-22 was driven by recovering domestic and foreign demand and rising commodity prices. Fiscal policy added to price pressure. Appreciation (depreciation) pressure on the USD (euro) dampened (added to) inflation in the US (EA). Particularly for the EA, the estimation also points to inflation from retail price shocks. Overall, the shock decompositions align with the result from existing literature that inflation in 2021-22 had a stronger supply-side component in the EA and a more substantial demand-side component in the US.

The robustness checks on fiscal multipliers show that a model with government debt (safe bonds) in household utility increases the multiplier of debt-financed fiscal expansion. Especially at the ELB, it also leads to a steepening of the Phillips curve, i.e. more inflation for a given output response. Accounting for unconventional measures as a substitute for lower short-term policy rates at the ELB implies a more stabilising impact of monetary policy during ELB episodes, which affects the contribution of domestic savings and investment as well as exchange rate shocks in the shock decompositions.

In sum, our enhanced multi-region model can provide interesting insights into output and inflation dynamics during and after the pandemic. In particular, it allows for joint testing of the quantitative relevance of different drivers on the demand and the supply side rather than focusing the discussion on one or a few elements.

References

Adjemian, S., H. Bastani, M. Juillard, F. Karamé, F. Mihoubi, W. Mutschler, J. Pfeifer, M. Ratto, N. Rion, S. Villemot, et al. (2022). Dynare: Reference manual version 5. Technical report, CEPREMAP.

Albonico, A., L. Calais, R. Cardani, O. Croitorov, F. Ferroni, M. Giovannini, S. Hohberger, B. Pataracchia, F. Pericoli, P. Pfeiffer, R. Raciborski, M. Ratto, W. Roeger, and L. Vogel (2019). The Global Multi-Country Model (GM): An estimated DSGE model for euro area countries. Working Papers 102, European Economy Discussion Papers.

Anderton, R., V. Botelho, A. Consolo, A. D. Da Silva, C. Foroni, M. Mohr, and L. Vivian (2021). The impact of the COVID-19 pandemic on the euro area labour market. *ECB Economic Bulletin 8/2020*.

Arce, O., E. Hahn, and G. Koester (2023). How tit-for-tat inflation can make everyone poorer. *The ECB Blog March 30, 2023*.

Bachmann, R., B. Born, O. Goldfayn-Frank, G. Kocharkov, R. Luetticke, and M. Weber (2021). A temporary VAT cut as unconventional fiscal policy. NBER Working Papers 29442, National Bureau of Economic Research.

Ball, L., D. Leigh, and P. Mishra (2022). Understanding US inflation during the COVID era. In *Brookings Papers on Economic Activity conference, September*, pp. 8–9.

Baudisch, V. and M. Neuenkirch (2023). Costly, but (relatively) ineffective? An assessment of Germany's temporary VAT rate reduction during the COVID-19 pandemic. CESifo Working Papers 10417.

Bayer, C., B. Born, and R. Luetticke (2023). The liquidity channel of fiscal policy. *Journal of Monetary Economics 134*, 86–117.

Bayer, C., B. Born, R. Luetticke, and G. J. Müller (2023). The coronavirus stimulus package: How large is the transfer multiplier. *The Economic Journal 133*(652), 1318–1347.

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

Benigno, P. and G. B. Eggertsson (2023). It's baaack: The surge in inflation in the 2020s and the return of the non-linear Phillips curve. NBER Working Papers 31197, National Bureau of Economic Research.

Bernanke, B. and O. Blanchard (2023). What caused the US pandemic-era inflation? PIIE Working Papers 23-4, Peterson Institute for International Economics.

Blanchard, O., A. Domash, and L. Summers (2022). Bad news for the Fed from the Beveridge space. PIIE Policy Brief 22–7, Peterson Institute for International Economics.

Blanchard, O. and J. Gali (2007). The macroeconomic effects of oil shocks: Why are the 2000s so different from the 1970s? NBER Working Papers 13368, National Bureau of Economic Research.

Blanchard, O. and J. Galí (2007). Real wage rigidities and the New Keynesian model. *Journal of Money, Credit and Banking 39*, 35–65.

Blanchard, O. J. and M. Riggi (2013). Why are the 2000s so different from the 1970s? A structural interpretation of changes in the macroeconomic effects of oil prices. *Journal of the European Economic Association 11*(5), 1032–1052.

Bodenstein, M., L. Guerrieri, and L. Kilian (2012). Monetary policy responses to oil price fluctuations. *IMF Economic Review 60*(4), 470–504.

Bodnár, K., E. Gonçalves, L. Górnicka, and G. Koester (2023). Wage developments and their determinants since the start of the pandemic. *ECB Economic Bulletin 8/2022*.

Boone, L. (2022). The EA and the US in the COVID-19 crisis: Implications for the 2022-2023 policy stance. OECD Ecoscope, January 18, 2022.

Bussiere, M., G. Callegari, F. Ghironi, G. Sestieri, and N. Yamano (2013). Estimating trade elasticities: Demand composition and the trade collapse of 2008-2009. *American Economic Journal: Macroeconomics 5*(3), 118–151.

Cardani, R., O. Croitorov, M. Giovannini, P. Pfeiffer, M. Ratto, and L. Vogel (2022). The euro area's pandemic recession: A DSGE-based interpretation. *Journal of Economic Dynamics and Control*, 104512.

Cavallo, A. (2020). Inflation with Covid consumption baskets. NBER Working Paper 27352, National Bureau of Economic Research.

Cavallo, A. and O. Kryvtsov (2023). What can stockouts tell us about inflation? Evidence from online micro data. *Journal of International Economics*, 103769.

Chen, W., M. D. Negro, S. Goyal, and A. Johnson (2020). The New York Fed DSGE Model Forecast—December 2020. Liberty Street Economics December 23, Federal Reserve Bank of New York.

Christiano, L., R. Motto, and M. Rostagno (2008). Shocks, structures or monetary policies? The euro area and US after 2001. *Journal of Economic Dynamics and Control 32*(8), 2476–2506.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Christodoulopoulou, S. and O. Kouvavas (2022). Wages, compositional effects and the business cycle. ECB Working Paper 2653, European Central Bank.

Clemens, M. and W. Röger (2021). Temporary VAT reduction during the lockdown. DIW Discussion Paper 1944.

Coenen, G. and R. Straub (2005). Does government spending crowd in private consumption? Theory and empirical evidence for the euro area. *International Finance 8*(3), 435–470.

Comin, D. A., R. C. Johnson, and C. J. Jones (2023). Supply chain constraints and inflation. NBER Working Papers 31179, National Bureau of Economic Research.

Corrado, L., S. Grassi, and A. Paolillo (2021). Modelling and estimating large macroeconomic shocks during the pandemic. NIESR Discussion Paper 530, National Institute of Economic and Social Research.

di Giovanni, J. (2022). How much did supply constraints boost US inflation? Federal Reserve Bank of New York Liberty Street Economics, August 24, 2022, Federal Reserve Bank of New York.

di Giovanni, J., S. Kalemli-Özcan, A. Silva, and M. A. Yildirim (2023). Quantifying the inflationary impact of fiscal stimulus under supply constraints. *AEA Papers and Proceedings 113*, 76–80.

Diewert, W. E. and K. J. Fox (2022). Measuring real consumption and consumer price index bias under lockdown conditions. *Canadian Journal of Economics/Revue canadienne d'économique 55*, 480–502.

Dolls, M., C. Fuest, and A. Peichl (2012). Automatic stabilizers and economic crisis: US vs. Europe. *Journal of Public Economics 96*(3), 279–294.

Eichenbaum, M. S., B. K. Johannsen, and S. T. Rebelo (2021). Monetary policy and the predictability of nominal exchange rates. *The Review of Economic Studies 88*(1), 192–228.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt (2021). The macroeconomics of epidemics. *The Review of Financial Studies 34*(11), 5149–5187.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt (2022). Epidemics in the New Keynesian model. *Journal of Economic Dynamics and Control* (140), 104334.

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

Fiorentini, G., C. Planas, and A. Rossi (2012). A Fortran program for dynamic mixture models. Working Papers 11, Universitá degli Studi di Firenze Working Paper Series.

Fisher, J. D. (2015). On the structural interpretation of the Smets-Wouters "risk premium" shock. *Journal of Money, Credit and Banking 47*(2-3), 511–516.

Gagliardone, L. and M. Gertler (2023). Oil prices, monetary policy and inflation surges. NBER Working Papers 31263, National Bureau of Economic Research.

Galí, J. (2011). The return of the wage Phillips curve. *Journal of the European Economic Association 9*(3), 436–461.

Giovannini, M., S. Hohberger, R. Kollmann, M. Ratto, W. Roeger, and L. Vogel (2019). Euro area and US external adjustment: The role of commodity prices and emerging market shocks. *Journal of International Money and Finance 94*, 183–205.

Giovannini, M., P. Pfeiffer, and M. Ratto (2021). Efficient and robust inference of models with occasionally binding constraints. Working Papers 2021-03, Joint Research Centre, European Commission (Ispra site).

Giupponi, G., C. Landais, and A. Lapeyre (2022). Should we insure workers or jobs during recessions? *Journal of Economic Perspectives 36*(2), 29–54.

Glover, A., J. Mustre-del Rio, and A. von Ende-Becker (2023). How much have record corporate profits contributed to recent inflation? *Federal Reserve Bank of Kansas City Economic Review 108*(1), 1–13.

Glover, A., J. Mustre-del Río, and J. Nichols (2023). Corporate profits contributed a lot to inflation in 2021 but little in 2022—a pattern seen in past economic recoveries. *kcFED Economic Bulletin May 12, 2023*.

Guerrieri, L. and M. Iacoviello (2015). OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics 70*, 22–38.

Guerrieri, V., G. Lorenzoni, L. Straub, and I. Werning (2022). Macroeconomic implications of COVID-19: Can negative supply shocks cause demand shortages? *American Economic Review 112*(5), 1437–74.

Hale, G., J. C. Leer, and F. Nechio (2023). Inflationary effects of fiscal support to households and firms. NBER Working Paper 30906, National Bureau of Economic Research.

Hale, T., A. Petherick, T. Phillips, and S. Webster (2020). Variation in government responses to COVID-19. Blavatnik School of Government Working Paper 2020-32, University of Oxford.

Hall, R. E. (2023). A major shock makes prices more flexible and may result in a burst of inflation or deflation. NBER Working Paper 31025, National Bureau of Economic Research.

Hansen, N.-J., F. Toscani, and J. Zhou (2023). Euro area inflation after the pandemic and energy shock: Import prices, profits and wages. IMF Working Paper 2023/131, International Monetary Fund.

Harding, M., J. Lindé, and M. Trabandt (2023). Understanding Post-COVID inflation dynamics. *Journal of Monetary Economics* (https://doi.org/10.1016/j.jmoneco.2023.05.012).

Howard, S., R. Rich, and J. Tracy (2022). Real wages grew during two years of COVID-19 after controlling for workforce composition. Dallas Fed Economics February 15, 2022, Federal Reserve Bank of Dallas.

Itskhoki, O. and D. Mukhin (2021). Exchange rate disconnect in general equilibrium. *Journal of Political Economy 129*(8), 2183–2232.

Jones, C., T. Philippon, and V. Venkateswaran (2021). Optimal mitigation policies in a pandemic: Social distancing and working from home. *Review of Financial Studies 34*(11), 5188–5223.

Jorda, O. and F. Nechio (2023). Inflation and wage growth since the pandemic. *European Economic Review 156*, 104474.

Karadi, P., J. Amann, J. S. Bachiller, P. Seiler, and J. Wursten (2023). Price setting on the two sides of the Atlantic - Evidence from supermarket scanner data. *Journal of Monetary Economics.*

Kiss, Á., M. C. Morandini, A. Turrini, and A. Vandeplas (2022). Slack and tightness: Making sense of post COVID-19 labour market developments in the EU. European Economy Discussion Papers 178, DG ECFIN, European Commission.

Kollmann, R., B. Pataracchia, R. Raciborski, M. Ratto, W. Roeger, and L. Vogel (2016). The post-crisis slump in the euro area and the US: Evidence from an estimated three-region DSGE model. *European Economic Review 88*(C), 21–41.

Lane, P. (2023). Interview with Financial Times. Financial Times, January 12, 2023.

Lenza, M. and G. E. Primiceri (2022). How to estimate a vector autoregression after March 2020. *Journal of Applied Econometrics 37*(4), 688–699.

Merz, M. and E. Yashiv (2007). Labor and the market value of the firm. *American Economic Review 97*(4), 1419–1431.

Neal, R. M. (2003). Slice sampling. *The Annals of Statitics 31*(3), 705–767.

Parker, J. A., J. Schild, L. Erhard, and D. Johnson (2022). Household spending responses to the Economic Impact Payments of 2020: Evidence from the consumer expenditure survey. NBER Working Papers 29648, National Bureau of Economic Research.

Pasimeni, P. (2022). Supply, or demand, that is the question: Decomposing euro area inflation. Single Market Economics Papers 02/2022, DG Internal Market, Industry, Entrepreneurship and SMEs, European Commission.

Priftis, R. and L. Vogel (2016). The portfolio balance mechanism and QE in the euro area. *The Manchester School 84*(S1), 84–105.

Rannenberg, A. (2021). State-dependent fiscal multipliers with preferences over safe assets. *Journal of Monetary Economics 117*, 1023–1040.

Ratto, M., W. Roeger, and J. in't Veld (2009). QUEST III: An estimated open-economy DSGE model of the euro area with fiscal and monetary policy. *Economic Modelling 26*(1), 222–233.

Reis, R. (2022). The burst of high inflation in 2021-22: How and why did we get here? CEPR Discussion Paper 17514, Centre for Economic Policy Research.

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

Smets, F. and R. Wouters (2003). An estimated dynamic stochastic general equilibrium model of the euro area. *Journal of the European Economic Association 1*(5), 1123–1175.

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review 97*(3), 586–606.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy 39*(1), 195–214.

Wu, J. C. and F. D. Xia (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit, and Banking 48*(2-3), 253–291.

Wu, J. C. and F. D. Xia (2020). Negative interest rate policy and the yield curve. *Journal of Applied Econometrics 35*(6), 653–672.

Appendices

Appendix A Model details

This appendix provides additional model details omitted in the main text. The model shares many standard elements with Albonico et al. (2019), and we also refer to the model description contained therein. The US and EA regions are isomorphic, and we omit explicit country indices unless required for understanding.

A.1 Households

Two groups of representative households consume and provide labour to intermediate goods producers. A share ω^s of households are savers (s), who own domestic firms and participate in financial markets (saving and borrowing).

A.1.1 Savers

Savers maximise lifetime utility over consumption and leisure:

$$\max_{C_{j,t},B^{\mathcal{Q}}_{j,t}} E_0 \sum_{t=0}^{\infty} (\beta)^t \xi_t \left\{ \frac{(C^s_{j,t} - \varepsilon^{tC}_{t-1} - h(C^s_{t-1} - \varepsilon^{tC}_t))^{1-\theta}}{1-\theta} - \omega^N_t \frac{(N^{s,,paid}_{j,t})^{1+\theta^N}}{1+\theta^N} - \frac{\overline{\lambda}^s_t}{P^C_t} \sum_{\mathcal{Q}} B^{\mathcal{Q}}_{j,t}(\alpha^{\mathcal{Q}} - \varepsilon^{\mathcal{Q}}_t) \right\}, \tag{A.1}$$

where $0 < \theta, \theta^N$. h governs the importance of external consumption habits. ξ_t captures stochastic disturbances to the discount factor β, where $\xi_{t+1}/\xi_t = \exp\left(\varepsilon^C_t\right)$ implies that the Euler equations are affected by the time t cyclical saving shock process ε^C_t; while the forced saving shock, ε^{tC}_t, is a transitory shock outside the habit persistence. ω^N_t represents a stochastic labour disutility term.[41]

We allow for asset-specific risk premia shocks $\varepsilon^{\mathcal{Q}}_t$ with $\mathcal{Q} \in \{bw, g, S\}$, which we incorporate in the utility function, as proposed by Fisher (2015). ε^S_t is an investment-specific risk premium shock. ε^{bw}_t distorts the first-order condition for the foreign bond and amounts to a disturbance to the uncovered interest parity (UIP) condition. Asset-specific intercepts, $\alpha^{\mathcal{Q}}$, capture the steady-state risk premia, except for risk-free bonds.

Savers maximise utility subject to a sequence of budget constraints:

$$P^C_t C^s_{j,t} + \sum_{\mathcal{Q}} B^{\mathcal{Q}}_{j,t+1} = W_t N^{s,paid}_{j,t} + div^{TOT}_t + \sum_{\mathcal{Q}} R^Q_t B^{\mathcal{Q}}_{j,t} + T^s_{j,t}, \tag{A.2}$$

where $N^{s,paid}_{j,t} = N^s_{j,t}/(1 - \varepsilon^{TLU}_t)$ indicates total hours paid by the intermediary firms and div^{TOT}_t redistributed by (all domestic) firms to households. The portfolio consists of risk-free domestic bonds (rf), one internationally traded asset (bw), denoted in euro currency, and domestic firm shares (S). We also include government bonds (G) in the portfolio. Each asset has gross nominal return R^Q_t (returns to bonds are pre-determined, whereas the return on firm shares is unknown

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[41] To ensure a balanced growth path, labour disutility includes a multiplicative term $C^{1-\theta}_t$, such that $\omega^N_t = \omega^N \exp(\varepsilon^U_t) C^{1-\theta}_t$ where ε^U_t is exogenous. Similarly, we scale asset utility by marginal utility $\overline{\lambda}^s_t$.

at time t). The net of transfers and taxes is:

$$T^s_{j,t} = TR^s_{j,t} - tax^s_{j,t} - \tau^N W_t N^{s,paid}_{j,t} - \tau^C P^C_t C^s_{j,t}, \tag{A.3}$$

where $TR^s_{j,t}, tax^s_{j,t}$, τ^C and τ^N denote transfers, lump-sum taxes, the consumption (sales) tax and the labour tax rate, respectively.

Optimality. Saver households are identical and make identical choices. The first-order necessary conditions in a symmetric equilibrium are for $\mathcal{Q} \in \{rf, bw, S, G\}$:

$$1 = E_t \left[\Lambda^s_{t,t+1} \frac{R^{\mathcal{Q}}_t + \varepsilon^{\mathcal{Q}}_t - \alpha^{\mathcal{Q}}}{1 + \pi^{C,vat}_{t+1}} \right], \tag{A.4}$$

where $\alpha^{rf} = 0$, $\lambda^s_t = (C^s_t - \varepsilon^{tC}_t - h^s(C^s_{t-1} - \varepsilon^{tC}_t))^{-\theta}$, and $\Lambda^s_{t,t+1} = \beta \exp(\varepsilon^C_t) \frac{\lambda^s_{t+1}}{\lambda^s_t}$.

Approximating the first-order condition for investment in foreign bonds gives a standard uncovered interest parity (UIP) condition:

$$E_t \left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] i^W_t = i^{rf}_t + rprem^W_t, \tag{A.5}$$

where i^W_t and $rprem^W_t$ are the return and risk premium on the foreign bond, respectively.

A.1.2 'Hand-to-mouth'

The remaining households with a population share $1 - \omega^s$ are 'hand-to-mouth' consumers (c) who face a zero-borrowing constraint. In each period, they consume their current disposable wage and transfer income:

$$P^C_t C^c_{j,t} = W_t N^{c,paid}_{j,t} + T^c_{j,t} - P^C_t \left(\varepsilon^{tC}_t - \frac{1}{6} \sum_{i=8}^{13} \varepsilon^{tc}_{t-i} \right). \tag{A.6}$$

During COVID-19, these households accumulate forced savings that will be spent gradually upon exit from the pandemic.

A.1.3 Aggregation

Total consumption by households (in per-capita terms) is:

$$C_t = (1 - \omega^s)\, C^c_t + \omega^s C^s_t \tag{A.7}$$

and total labour supply:

$$N_t = (1 - \omega^s)\, N^c_t + \omega^s N^s_t. \tag{A.8}$$

A.2 Wage setting

The labour market structure follows Albonico et al. (2019). Households are providing differentiated labour services in a monopolistically competitive market. A labour union bundles hours worked provided by both types of domestic households into a homogeneous labour service and resells it to intermediate goods-producing firms. We assume that Ricardian (saver) and liquidity-constrained (hand-to-mouth) households' hours are distributed proportionally to their respective population shares. Since both households face the same labour demand schedule, each household works the same number of hours as the average of the economy. It follows that the individual union's choice variable is a common nominal wage rate for both types of households.

The union maximises the discounted future stream of the weighted average of lifetime utility of its members with respect to the wage and subject to the weighted sum of their budget constraints, $C_{j,t}$. Unions bargain over contractual hours, i.e. $N_t^{paid} = \frac{N_t}{1-\varepsilon_t^{LU}}$:

$$\max_{W_{j,t}} U_{j,t} = \sum_{t=0}^{\infty} (\beta_t)^t U(C_{j,t}, N_{j,t}^{paid}, \cdot) \tag{A.9}$$

subject to:

$$P_t^C C_{j,t}^s + \omega^s B_{j,t+1} + \Gamma_{jt}^W = W_{j,t} N_{j,t}^{paid} + \omega^s (R_t^r B_{j,t} + div_t^{TOT}) + T_{j,t} \tag{A.10}$$

$$N_{j,t}^{paid} = \left(\frac{W_{j,t}}{W_t}\right)^{-\sigma^n} N_t^{paid}, \tag{A.11}$$

where $\Gamma_{j,t}^W = \frac{\gamma^w(\sigma^n-1)}{2} W_t N_t^{paid} \left(\pi_t^w - \pi^w - (1-sfw)(\pi_{t-1}^{C,vat} - \bar{\pi})\right)^2$ is a quadratic wage adjustment cost that is borne by the households, and 1-sfw is the share of wage setters that index the growth rate of wages to the previous period inflation. σ^n is the inverse of the steady-state gross wage markup. Additionally, we allow for a slow adjustment of real wages in the spirit of Blanchard and Galí (2007). Specifically, $P_t^{C,vat,lag}$ in equation A.12 implies a gradual adjustment of the past real wages to changes in the price level, i.e. $P_t^{C,vat,lag} = \rho^{pcvat} P_{t-1}^{C,vat,lag} + (1-\rho^{pcvat}) P_t^{C,vat,QA}$, where $P_t^{C,vat,QA}$ denotes quarterly annualised consumption prices including taxes.

The resulting wage equation is:

$$\left(\frac{U_{N,t}}{\lambda_t}\frac{P_t^{C,vat}}{P_t^{C,vat,lag}}\right)^{1-\gamma^{wr}} \left[\frac{(1-\tau^N)W_{t-1}}{P_{t-1}^{C,vat,lag}}\right]^{\gamma^{wr}} = \frac{W_t}{P_t^{C,vat,lag}}(1-\tau^N)\mu_t^w, \tag{A.12}$$

where μ_t^w is the fluctuating gross wage markup:

$$\mu_t^w = \mu^w + \frac{\mu^w \gamma^w}{1-\tau^N}\left[\frac{\partial \Gamma_t^w}{\partial W_t} - \beta_t E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}^{C,vat}+1} \frac{\partial \Gamma_{t+1}^w}{\partial W_t} + \frac{1}{\gamma^w}\varepsilon_t^U\right].$$

$\mu^w = (\frac{\sigma^n}{1-\sigma^n})$ is the steady state markup, γ^{wr} and γ^w govern real and nominal rigidity, respectively. ε_t^U is a labour supply shock. $U_{N,t}$ is the derivative of the utility function with respect to labour. $P_t^{C,vat}$ is the price of consumption goods adjusted for the sales tax ($P_t^{C,vat} = (1+\tau^C)P_t^C$).

A.3 Intermediate goods

Each firm $i \in [0,1]$ produces a variety of the domestic good, which is an imperfect substitute for varieties produced by other firms. Firms are monopolistically competitive and face a downward-sloping demand function for goods.

Differentiated goods are produced using capital, $K_{i,t-1}$, and labour, $N_{i,t}$, which are combined in a Cobb-Douglas production function:

$$Y_{i,t} = \left(A_t^Y (N_{i,t} - FN)\right)^{\alpha} \left(cu_{i,t} K_{i,t-1}\right)^{1-\alpha} \left(K_{i,t-1}^G\right)^{1-\alpha_G} - \left(A_t^Y\right)^{\frac{\alpha}{\alpha+\alpha_G-1}} \Phi, \tag{A.13}$$

where α is the steady-state labour share, A_t^Y represents the labour-augmenting productivity common to all firms in the differentiated goods sector, $cu_{i,t}$ denotes firm-specific capital utilisation. Φ captures fixed costs in production. α_G denotes the output elasticity of public capital. A_t^Y is a non-stationary process, and we allow for two types of technology shocks, ε_t^{GA} and ε_t^A. They are related to a non-stationary process and its autoregressive component ρ^A:

$$\log(A_t^Y) - \log(A_{t-1}^Y) = g_t^A + \varepsilon_t^A, \tag{A.14}$$

$$g_t^A = \rho^A g_{t-1}^A + (1 - \rho^A) g^A + \varepsilon_t^{GA}, \tag{A.15}$$

where g_t^A and g^A are the time-varying growth and the long-run growth of technology, respectively.

Total hours paid are $N_{i,t}^{paid} = Empl_{i,t} Hpere_{i,t}$, and firms can adjust at both margins (employment in persons and hours per worker) subject to specific adjustment costs. In light of the restrictions on work during the COVID-19 pandemic, we introduce a transitory labour hoarding shock (ε_t^{LU}), which creates a discrepancy between hours paid (wage income) and actual hours worked (production function):

$$\frac{N_{i,t}}{N_{i,t}^{paid}} = (1 - \varepsilon_t^{LU}). \tag{A.16}$$

Monopolistically competitive firms maximise the real value of the firm $\frac{P_t^S}{P_t} S_t^{tot}$, that is the discounted stream of expected future profits, subject to the output demand $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\sigma^y} Y_t$, the technology constraint (A.13), and the capital accumulation equation $K_{i,t} = I_{i,t} + (1 - \delta) K_{i,t-1}$.[42] Their optimisation problem can be written as:

$$\max_{P_{i,t}, N_{i,t}, I_{i,t}, cu_{i,t}, K_{i,t}} \sum_{s=t}^{\infty} D_t^S div_{i,t}, \tag{A.17}$$

where the stochastic discount factor, D_t^S, is:

$$D_t^S = \frac{1 + r_t^S}{\Pi_{r=t}^S (1 + r_r^S)} \tag{A.18}$$

with $1 + r_t^S = \frac{1+i_{t+1}^S}{1+\pi_{t+1}^I}$ being the real stock return and π_t^I the change in the investment price deflator. $P_{i,t}$ is the price of intermediate inputs, and the corresponding price index is:

$$P_t = \left(\int_0^1 (P_{i,t})^{1-\sigma^y} di\right)^{\frac{1}{1-\sigma^y}}. \tag{A.19}$$

The period t dividend of an intermediate goods firm i in real terms is given by:

$$\frac{div_{i,t}}{P_t} = (1 - \tau^K)\Big(\frac{P_{i,t}}{P_t} Y_{i,t} - \frac{W_t}{P_t} N_{i,t}^{paid}\Big) + \tau^K \delta \frac{P_t^I}{P_t} K_{i,t-1} - \frac{P_t^I}{P_t} I_{i,t} - \Gamma_{i,t}, \tag{A.20}$$

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[42] We assume that the total number of shares $S_t^{tot} = 1$.

where $I_{i,t}$ is the physical investment at price $P^I_{i,t}$, τ^K is the corporate tax, and δ is the capital depreciation rate.

Firms face quadratic factor adjustment costs, $\Gamma_{i,t}$, measured in terms of production input factors:

$$\Gamma_{i,t} = \Gamma^P_{i,t} + \Gamma^E_{i,t} + \Gamma^H_{i,t} + \Gamma^I_{i,t} + \Gamma^{cu}_{i,t}. \tag{A.21}$$

Specifically, the adjustment costs are associated with the output price $P_{i,t}$, employment ($Empl_{i,t}$, extensive margin), hours per employee ($Hpere_{i,t}$, intensive margin), investment $I_{i,t}$, as well as capacity utilisation variation $cu_{i,t}$:

$$\Gamma^P_{i,t} = \sigma^y \frac{\gamma^P}{2} Y_t \left[\frac{P_{i,t}}{P_{i,t-1}} - \exp(\bar{\pi})\right]^2, \tag{A.22}$$

$$\Gamma^E_{i,t} = \frac{\gamma^E}{2} \left[\frac{Empl_{i,t}}{Empl_{i,t-1}} - \exp(g^{pop})\right]^2, \tag{A.23}$$

$$\Gamma^H_{i,t} = \frac{W_t}{P_t} Empl_{i,t} Hpere^{trend}_t \left[\gamma^{H,1}(Hpere_{i,t} - 1) + \frac{\gamma^{H,2}}{2}(Hpere_{i,t} - 1)^2\right], \tag{A.24}$$

$$\Gamma^I_{i,t} = \frac{P^I_t}{P_t} \left[\frac{\gamma^{I,1}}{2} K_{t-1}\Big(\frac{I_{i,t}}{K_{t-1}} - \delta^K_t\Big)^2 + \frac{\gamma^{I,2}}{2} \frac{(I_{i,t} - I_{i,t-1}\exp(g^Y + g^{PI}))^2}{K_{t-1}}\right], \tag{A.25}$$

$$\Gamma^{cu}_{i,t} = \frac{P^I_t}{P_t} K_{i,t-1} \left[\gamma^{cu,1}(cu_{i,t} - 1) + \frac{\gamma^{cu,2}}{2}(cu_{i,t} - 1)^2\right], \tag{A.26}$$

where γ-parameters capture the degree of adjustment costs. $\bar{\pi}$ denotes steady-state inflation. g^{pop}, g^Y, and g^{PI} are trend factors of population, GDP and prices for investment goods, respectively. $Hpere^{trend}_t$ is an exogenous trend in hours per employee. $\delta^K_t \neq \delta$ is a function of the depreciation rate adjusted for the capital trend to have zero adjustment costs on the trend path.[43] Given the Lagrange multiplier associated with the technology constraint, μ^y, the FOCs with respect to employment, hours, capital, investments and capital utilisation are given by:

$$\alpha \frac{\mu^y_t P_t Y_t}{W_t Empl_t Hpere^{trend}_t} = Hpere_t \left[\gamma^{H1} + \gamma^{H2}\left(Hpere_t - 1 + \varepsilon^{Hpere}_t\right)\right] \tag{A.27}$$

$$(1 - \tau^K)\frac{W_t}{P_t} = \alpha\left(\mu^y_t - \varepsilon^{ND}_t\right)\frac{Y_t}{Empl_t - FN} - \frac{\partial \Gamma^E_t}{\partial Empl_t} + E_t\left[\frac{1 + \pi_{t+1}}{1 + i^s_{t+1}} \frac{\partial \Gamma^E_{t+1}}{\partial Empl_t}\right], \tag{A.28}$$

$$Q_t = E_t\left[\frac{1 + \pi_{t+1}}{1 + i^s_{t+1}} \frac{P^I_{t+1}}{P_{t+1}} \frac{P_t}{P^I_t}\left(\tau^K \delta^K - \frac{\partial \Gamma^{cu}_t}{\partial K_{t-1}} + Q_{t+1}(1 - \delta) + (1 - \alpha)\mu^y_{t+1}\frac{P_{t+1}}{P^I_{t+1}}\frac{Y_{kt+1}}{K_t}\right)\right], \tag{A.29}$$

$$\begin{aligned} \frac{I_t}{K_{t-1}} - \delta^K_t &= \frac{1}{\gamma^{I,1}} Q_t - 1 - \gamma^{I,2}\frac{(I_t - I_{t-1}\exp(g^Y + g^{PI}))}{K_{t-1}} \\ &+ E_t\left[\frac{1 + \pi_{t+1}}{1 + i^s_{t+1}} \frac{P^I_{t+1}}{P_{t+1}} \frac{P_t}{P^I_t}\exp(g^Y + g^{PI})\gamma^{I,2}\frac{(I_{t+1} - I_t\exp(g^Y + g^{PI}))}{K_t}\right], \end{aligned} \tag{A.30}$$

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[43] We specify $\delta^K_t = exp(g^Y + g^{PI}) - (1 - \delta)$, so that $\frac{I}{K} - \delta^k \neq 0$ along the trend path.

$$\mu_t^y (1-\alpha) \frac{Y_t}{cu_t} \frac{P_t}{P_t^I} = K_{t-1} \Big[\gamma^{u,1} + \gamma^{u,2} (cu_t - 1) \Big], \tag{A.31}$$

where $Q_t = \mu_t^y / \frac{P_t^I}{P_t}$. In equations (A.27) and (A.28), ε_t^{Hpere} and ε_t^{ND} are shocks to labour demand on the intensive and extensive margin, respectively. We also allow for temporary one-off shocks during the COVID period.

In a symmetric equilibrium ($P_{i,t} = P_t$), the FOC with respect to $P_{i,t}$ yields the New Keynesian Phillips curve:

$$\begin{aligned} \mu_t^y \sigma^y = {} & (1-\tau^K)(\sigma^y - 1) + \sigma^y \gamma^P \frac{P_t}{P_{t-1}} \Big(\pi_t - \bar{\pi} \Big) \\ & - \sigma^y \gamma^P \left[\frac{1+\pi_{t+1}}{1+i_{t+1}^s} \frac{P_{t+1}}{P_t} \frac{Y_{t+1}}{Y_t} \Big(\pi_{t+1} - \bar{\pi} \Big) \right] + \sigma^y \varepsilon_t^{\mu}, \end{aligned} \tag{A.32}$$

where ε_t^{μ} is a white noise markup shock.

A.4 Fiscal policy

The government collects taxes on labour, τ^N, corporate profits, τ^K, consumption, τ^C, and lump-sum taxes, tax_t, and issues one-period bonds, B_t^G, to finance government consumption, G_t, public investment, I_t^G, transfers, T_t, and the servicing of the outstanding government debt. The tax on commodity imports from RoW, τ^{CO}, is fixed. τ^{LU} denotes a labour hoarding subsidy. The government budget constraint is:

$$B_t^G = (1 + i_{t-1}^G) B_{t-1}^G - R_t^G + P_t^G G_t + P_t^{IG} I_t^G + T_t P_t, \tag{A.33}$$

where nominal government revenues, R^G, are defined as:

$$\begin{aligned} R_t^G = {} & \tau^K (P_t Y_t - W_t N_t^{paid} - P_t^I \delta K_{t-1}) + \tau^N W_t N_t^{paid} + \tau^C P_t^C C_t \\ & + \tau^{CO} P_t CO_t + tax_t P_t Y_t + \tau^{LU} W_t \Big(N_t^{paid} - N_t \Big). \end{aligned} \tag{A.34}$$

The government closes its budget via lump-sum taxes:

$$tax_t = \rho^{\tau} tax_{t-1} + \eta^d \left(\frac{\Delta B_{t-1}^G}{Y_{t-1} P_{t-1}} - \bar{def} \right) + \eta^B \left(\frac{B_{t-1}^G}{Y_{t-1} P_{t-1}} - \bar{BG} \right) + \varepsilon_t^{tax}, \tag{A.35}$$

where $\bar{def}$ and $\bar{BG}$ are the targets for the government deficit and the government debt level, with debt rule coefficients η^d and η^B, respectively. ε_t^{tax} is a white noise shock. ρ^{τ} governs the debt rule persistence. The accumulation equation for government capital is:

$$K_t^G = (1-\delta) K_{t-1}^G + I_t^G, \tag{A.36}$$

where δ is the depreciation rate.

We use the following fiscal rules for government consumption, G_t, investment, I_t^G, and transfers, T_t:

$$\frac{G_t P_t^G}{P_t Y_t^{pot}} = \varepsilon_t^G, \tag{A.37}$$

$$\frac{I_t^G P_t^{IG}}{P_t Y_t^{pot}} = \varepsilon_t^{IG}, \tag{A.38}$$

$$\frac{T_t}{Y_t} = \varepsilon_t^T, \tag{A.39}$$

where ε_t^G, ε_t^{IG}, ε_t^T represent shocks to government consumption, investment and transfers, respectively.

COVID-specific features. To account for the substantial fiscal packages in the EA and US, we introduce two COVID-specific features. Firstly, considering the large-scale US transfer packages, we re-estimate the variance of US transfer shocks (see eq. A.39) during the COVID period.[44] Secondly, in the EA, we incorporate COVID-specific lump-sum taxes (distributed to households based on population shares), broadly capturing tax reductions and similar policies. These two features, while having comparable macroeconomic effects, are identified based on distinct data series (transfers for the US and revenue data for the EA), reflecting the varying compositions of fiscal support in these two regions.

A.5 Commodity importers

Commodity importers seek to maximise the dividends subject to the inverse-sloping demand equation for each variety with respect to $P_{i,t}^{CO}$:

$$\max_{P_{i,t}^{CO}} E_0 \sum_{t=0}^{\infty} \beta^t D_t^S \left[\left(\frac{P_{i,t}^{CO}}{P_t} - \frac{P_t^{CO,M}}{P_t} - \tau^{CO} \right) CO_{i,t} - \frac{\gamma^{P,CO}(\sigma^{COMM}-1)}{2} CO_t \frac{P_t^{CO}}{P_t} \left(\frac{P_{i,t}^{CO}}{P_{i,t-1}^{CO}} - 1 \right)^2 \right]$$

$$s.t. \quad CO_{i,t} = \left(\frac{P_{i,t}^{CO}}{P_t^{CO}} \right)^{-\sigma^{COMM}} CO_t, \tag{A.40}$$

where D_t^S is the stochastic discount factor, and $P_t^{CO,M}$ is the import price of energy commodities. $\gamma^{P,CO}$ is the adjustment cost parameter for the energy commodity price, and σ^{COMM} is the elasticity of substitution between different energy commodity varieties. Rearranging the first-order condition with respect to $P_{i,t}^{CO}$ gives[45]:

$$\begin{aligned} P_t^{CO} = {} & P_t^{CO,M} + \tau^{CO} P_t - \gamma^{P,CO} \frac{P_t^{CO^2}}{P_{t-1}^{CO}} \left(\frac{P_t^{CO}}{P_{t-1}^{CO}} - 1 \right) \\ & + \beta \frac{D_{t+1}^S}{D_t^S} \gamma^{P,CO} \frac{CO_{t+1}}{CO_t} \frac{P_t}{P_{t+1}} \frac{P_{t+1}^{CO^2}}{P_t^{CO}} \left(\frac{P_{t+1}^{CO}}{P_t^{CO}} - 1 \right). \end{aligned} \tag{A.41}$$

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[44] Additionally, we allow for a portion of targeted transfers to 'hand-to-mouth' households. The estimated parameter value suggests that approximately 55% of transfers were targeted.

[45] We also impose symmetry across importer and assume that σ^{COMM} is sufficiently large so that in the limit $\frac{\sigma^{COMM}}{\sigma^{COMM}-1} = \frac{1}{1-\frac{1}{\sigma^{COMM}}} \approx 1$, allowing to eliminate the steady-state markup.

A.6 Exporters

The exporters in each region use a mix of domestic-cost pricing and destination-market pricing. The mix of pricing strategies is specific for each destination l, including also a destination-specific shock term $\varepsilon_{l,t}^{PX,*}$:

$$P_{l,t}^{X} = \exp(\varepsilon_{klt}^{PX,*}) \left(P_t^O\right)^{1-\alpha_l^{PX}} \left(\mathcal{E}_{l,t} P_{l,t}^O\right)^{\alpha_{l,k}^{PX}} . \tag{A.42}$$

Total nominal exports of final goods (excluding commodities) are defined as:

$$P_t^X X_t = \sum_l P_{l,t}^X M_{l,t}. \tag{A.43}$$

A.7 RoW details

The RoW final good. As for the EA and the US, final goods producers combine domestic output, $Y_t^{int,*}$, and imported goods, M_t^*, in a CES production function:

$$Z_t^* = A_t^{Z,*} \left[\left(1 - s_t^{M,Z,*}\right)^{\frac{1}{\sigma^{z,*}}} \left(O_t^{Z,*}\right)^{\frac{\sigma^{z,*}-1}{\sigma^{z,*}}} + \left(s_t^{M,Z,*}\right)^{\frac{1}{\sigma^{z,*}}} \left(M_t^{Z,*}\right)^{\frac{\sigma^{z,*}-1}{\sigma^{z,*}}} \right]^{\frac{\sigma^{z,*}}{\sigma^{z,*}-1}}, \tag{A.44}$$

where $Z_t^* \in \{C^*t, I_t^*, X_t^*\}$ denotes the demand for final goods by households, private investors, and exporters of final goods, respectively. $A_t^{Z,*}$ denotes a productivity shock in sector Z, and $0 < s_t^{M,Z,*} < 1$ is the stochastic import share associated with the different components of final demand. This is given by $s_t^{M,Z,*} = s^{M,Z,*} \exp(\varepsilon_t^{M,*})$, where $s^{M,Z,*}$ denotes the steady-state import share of the demand component Z, and $\varepsilon_t^{M,*}$ is an import demand (preference) shock. The parameter $\sigma^{z,*} > 0$ is the elasticity of substitution between domestic output and imports in the assembly of the final good. This elasticity is assumed to be common across all final demand components.

Output. Perfectly competitive firms produce output (O_t) by combining domestic value added (Y_t) and imported industrial supplies (IS_t) in a CES production function:

$$O_t^* = \left[\left(1 - s_t^{IS,*}\right)^{\frac{1}{\sigma^{o,*}}} \left(Y_t^*\right)^{\frac{\sigma^{o,*}-1}{\sigma^{o,*}}} + \left(s_t^{IS,*}\right)^{\frac{1}{\sigma^{o,*}}} \left(IS_t^*\right)^{\frac{\sigma^{o,*}-1}{\sigma^{o,*}}} \right]^{\frac{\sigma^{o,*}}{\sigma^{o,*}-1}}, \tag{A.45}$$

where $s_t^{IS,*}$ is the RoW share of commodities use.[46] The specification in eq. (A.45) leads to optimality conditions for the demand for commodities as in the detailed regions of the model.

Intermediate goods. The intermediate good producers use labour and capital to manufacture domestic goods (non-commodity output) according to a Cobb-Douglas production function and are subject to a standard CES demand function of RoW output packers (analogously to the EA and US blocks):

$$Y_{i,t}^* = A_t^{Y,*} \left(cu_{i,t}^* K_{i,t-1}^*\right)^{1-\alpha} \left(N_t^*\right)^{\alpha}, \tag{A.46}$$

---

[46] Unlike the EA and US, the RoW block does not feature energy commodities as an additional (direct) element in the households' consumption good.

where $A_t^{Y,*}$ captures a trend in the productivity, and $N_t^* = Actr_t^* Pop_t^*$ is the active population in the economy. $K_{i,t-1}^*$ denotes capital. It is utilised at rate $cu_{i,t}^*$ and follows a law of motion analogous to the detailed regions in the model. RoW adjustment costs are given by:

$$\Gamma_{i,t}^{P,*} = \frac{\sigma^{Y,*}\gamma^{P,*}}{2} Y_t^* \left(\frac{P_{i,t}^*}{P_{i,t-1}^*} - 1 - \pi^* \right)^2 \tag{A.47}$$

$$\Gamma_{i,t}^{cu,*} = \frac{P_t^{I,*}}{P_t^*} K_{i,t-1}^* \left(\gamma_0^{u,*} \left(cu_{i,t}^* - 1 \right) + \frac{\gamma_1^{u,*}}{2} \left(cu_{i,t}^* - 1 \right)^2 \right) \tag{A.48}$$

$$\Gamma_{i,t}^{I,*} = \frac{\gamma_0^{I,*}}{2} \frac{P_t^{I,*}}{P_t^*} K_{t-1}^* \left(\frac{I_{i,t}^*}{K_{t-1}^*} - \delta_t \right)^2 + \frac{\gamma_1^{I,*}}{2} \frac{P_t^{I,*}}{P_t^*} \frac{\left(I_{i,t}^* - I_{i,t-1}^* \exp\left(g^Y + g^{P^I,*} \right) \right)^2}{K_{t-1}^*} \tag{A.49}$$

The first-order condition with respect to $I_{i,t}^*$ reads:

$$\begin{aligned} Q_t^* = & \left(1 + \gamma_0^{I,*} \left(\frac{I_t^*}{K_{t-1}^*} - \delta_t \right) + \gamma_1^{I,*} \frac{\left(I_t^* - I_{t-1}^* \exp\left(g^Y + g^{P^I} \right) \right)}{K_{t-1}^*} \right) \\ & - E_t \left[\frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{P_{t+1}^{I,*}}{P_t^{I,*}} \frac{P_t^*}{P_{t+1}^*} \gamma_1^{I,*} \frac{\left(I_{t+1}^* - I_t^* \exp\left(g^Y + g^{P^I} \right) \right)}{K_t^*} \exp\left(g^Y + g^{P^I} \right) \right], \end{aligned} \tag{A.50}$$

where $Q_t^* \equiv \frac{\mu_{i,t}^*}{\frac{P_t^{I,*}}{P_t^*}}$ is Tobin's marginal Q. The first-order condition with respect to $K_{i,t}^*$ solves:

$$\begin{aligned} Q_t^* = & E_t \left[\frac{\lambda_{i,t+1}^*}{\lambda_{i,t}^*} \frac{P_{t+1}^{I,*}}{P_{t+1}^*} \frac{P_t^*}{P_t^{I,*}} \left(\left(-\gamma_0^{u,*} \left(cu_{i,t+1}^* - 1 \right) - \frac{\gamma_1^{u,*}}{2} \left(cu_{i,t+1}^* - 1 \right)^2 \right) \right. \right. \\ & \left. \left. + \left(1 - \delta^* \right) Q_{t+1}^* + \left(1 - \alpha^* \right) \mu_{t+1}^{Y,*} \frac{P_{t+1}^*}{P_{t+1}^{I,*}} \frac{Y_{i,t+1}^*}{K_{i,t}^*} \right) \right]. \end{aligned} \tag{A.51}$$

The first-order condition with respect to $cu_{i,t}^*$ yields:

$$\frac{P_t^{I,*}}{P_t^*} K_{i,t-1}^* \left(\gamma_0^{u,*} + \gamma_1^{u,*} \left(cu_{i,t}^* - 1 \right) \right) = \mu_t^{Y,*} \left(1 - \alpha^* \right) \frac{Y_{i,t}^*}{cu_{i,t}^*}. \tag{A.52}$$

Price setting for non-oil output follows a New Keynesian Phillips curve:

$$\pi_t^{Y,*} - \bar{\pi}^{Y,*} = \beta_t^* \frac{\lambda_{t+1}^*}{\lambda_t^*} \left[\left(\pi_{t+1}^{Y,*} - \bar{\pi}^{Y,*} \right) \right] + \phi^{y,*} \log \frac{Y_t^*}{\bar{Y}^*} + \varepsilon_t^{Y,*}, \tag{A.53}$$

where $\lambda_t^* = \left(C_t^* - h^* C_{t-1}^* \right)^{-\theta^*}$ is the marginal utility of consumption, and $\varepsilon_t^{Y,*}$ is a cost push shock.

RoW commodity supply. In the RoW, a competitive sector supplies two distinct commodities, namely oil (o, Brent) and non-oil commodities (no, e.g. natural gas and materials) to domestic and foreign firms. There is a supply disturbance $\varepsilon^{CO,*}$ that captures exogenous commodity supply shocks, such as the discovery of new raw material deposits. EA, US and local demand for commodities is determined by final good producers in these regions (see above). The producer combines oil (o^*) and non-oil (no^*) commodities into bundles of CO^* that are exported to EA and US or used locally. The price of the CO^* bundle is destination-specific. The prices of CO^* exports to EA and US contain shock terms $\varepsilon^{P,CO,*}_{l,t}$ where $l = (EA, US)$. This specification accounts for price differences due, e.g., to different commodity baskets. Thus:

$$P^{CO,*}_{l,t} = \epsilon^{P,CO,*}_{l,t} \left[s^{o,*}_l (P^{o,*}_t)^{1-\sigma^{COMM,*}} + (1 - s^{o,*}_l)(P^{no,*}_t)^{1-\sigma^{COMM,*}} \right]^{1/(1-\sigma^{COMM,*})}, \tag{A.54}$$

$$P^{CO,*}_t = \left[s^* (P^{o,*}_t)^{1-\sigma^{COMM,*}} + (1 - s^*)(P^{no,*}_t)^{1-\sigma^{COMM,*}} \right]^{1/(1-\sigma^{COMM,*})}. \tag{A.55}$$

Commodity prices are exogenous in this model specification, i.e.:

$$P^{o,*}_t = \frac{P^*_t}{A^{o,*}_t}, \tag{A.56}$$

where $A^{o,*}_t$ is the exogenous oil-specific productivity technology (analogously for prices of non-oil commodities).

The total supply of commodities by RoW is residual, i.e. it satisfies global demand given US production (see below).

Non-commodity exporters. The exporters of final goods follow a mix of domestic-cost pricing and destination-market pricing, which is specific for each destination $l = \{\text{EA, US}\}$, including also a destination-specific shock term $\varepsilon^{PX,*}_{l,t}$:

$$P^{X,*}_{l,t} = e^{\varepsilon^{PX,*}_{l,t}} \left(P^{O,*}_t \right)^{1-\alpha^{PX,*}_l} \left(\mathcal{E}^*_{l,t} P^*_{l,t} \right)^{\alpha^{PX,*}_l}. \tag{A.57}$$

Euler equation. RoW households maximise utility subject to the aggregate budget constraint:

$$P^*_t Y^*_t + div^*_t = P^{C,*}_t C^*_t + P^{C,*}_t I^*_t + TB^*_t, \tag{A.58}$$

where div^*_t are dividends from intermediate good producers, and TB^*_t are net exports. I^*_t denotes investment. The consumption Euler equation is:

$$1 = E_t \left[\Lambda^*_{t,t+1} \frac{R^*_t}{1 + \pi^{C,*}_{t+1}} \right], \tag{A.59}$$

where $\Lambda^*_{t,t+1} = \beta^* \exp(\varepsilon^{C,*}_t + \varepsilon^{tC,*}_t) \frac{\left(C^*_{t+1} - h^* C^*_t\right)^{-\theta^*}}{\left(C^*_t - h^* C^*_{t-1}\right)^{-\theta^*}}$. $\varepsilon^{C,*}_t$ and $\varepsilon^{tC,*}_t$ denote persistent and COVID-specific temporary discount factor shocks, respectively.

A.8 US commodity supply

While all commodities used in the EA are imported, the US not only uses commodities but also supplies them. The supply of intermediate goods comprises commodity extraction, i.e. $Y_{i,t} = Y^{int}_{i,t} + Y^{co}_{i.t}$. Thus, commodities are produced with the same production function, capital and labour input as other intermediate goods. US commodity producers maximise dividends:

$$div^{US,CO}_{i,t} = CO^{US}_t P^{CO}_t - Y^{CO,US}_t P^{US}_t, \tag{A.60}$$

$$CO_t^{US} = A_t^{CO} \left(Y_t^{CO,US} \right)^{\alpha_{CO}} , \tag{A.61}$$

using a decreasing return to scale technology, where A_t^{CO} is a scaling parameter. With $\alpha_{CO} < 1$, US commodity extraction is an increasing function in the (relative) price of commodities:

$$Y_t^{CO,US} = \left(\frac{\alpha_{CO} A_t^{CO} P_t^{CO}}{P_t^{US}} \right)^{1-\alpha_{CO}} . \tag{A.62}$$

Appendix B Data, calibration, and posterior estimates

B.1 Data sources

The analysis uses quarterly and annual data for the period 1998q4 to 2022q4 based on the data set of the European Commission's Global Multi-country Model (Albonico et al., 2019). This appendix repeats the description contained therein for convenience. Data for EMU countries and the Euro Area aggregate (EA20) are taken from Eurostat (in particular, from the European System of National Accounts). US data come the BEA. Bilateral trade flows are based on trade shares from the GTAP trade matrices for trade in goods and services. The Rest of the World (RoW) data are annual data and are constructed using IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases.

Series for GDP and prices in the RoW start in 1999 and are constructed on the basis of data for the following 56 countries: Albania, Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Brazil, Bulgaria, Canada, Chile, China, Colombia, Czech Republic, Denmark, Egypt, Georgia, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Israel, Japan, Jordan, Korea, Lebanon, Libya, FYR Macedonia, Malaysia, Mexico, Moldova, Montenegro, Morocco, New Zealand, Nigeria, Norway, Philippines, Poland, Romania, Russia, Saudi Arabia, Serbia, Singapore, South Africa, Sweden, Switzerland, Syria, Taiwan, Thailand, Tunisia, Turkey, Ukraine, United Arab Emirates, United Kingdom, and Venezuela.

When quarterly-frequency data is not available, mixed frequency data estimation is used. In this case, we observe annual RoW data in the last quarters of each year (as quarterly annualised variables) and allow the Kalman smoother to interpolate the annual data in the other three quarters in a model-consistent manner.

Table B.1 lists the observed time series. GDP deflators and relative prices of aggregates are computed as the ratios of current price value to chained indexed volume. The trend component of total factor productivity is computed using the DMM package developed by Fiorentini et al. (2012). The obtained series at quarterly frequency is then used to estimate potential output.

We make a few transformations to the raw investment series. In particular, we compute the deflator of public investments based on annual data and then obtain its quarterly frequency counterpart through interpolation. This series together with nominal public investments is then used to compute real quarterly public investments. In order to assure consistency between nominal GDP and the sum of the nominal components of aggregate demand, we impute change in inventories to the series of investments.

Euro Area and US	
i	Nominal short term interest rate
$\log(actr_k)$	Log of active rate population
$\log(\frac{B^g}{Y})$	Log of nominal gov. bonds share
$\log(\frac{C^g}{Y})$	Log of nominal gov. consumption share
$\log(\frac{C}{Y})$	Log of nominal consumption share
$\log(e)$	Log effective nominal exchange rate
$\log(\frac{i^g}{Y})$	Log of nominal gov. interest payments share
$\log(\frac{I^g}{Y})$	Log of nominal gov. investment share
$\log(\frac{I}{Y})$	Log of nominal investment share
$\log(\frac{M}{Y})$	Log of nominal total import share
$\log(Empl)$	Log of employment
$\log(N)$	Log of hours
$\log(Hpere^T)$	Log of hours per employee trend
g^{N^T}	Potential hour growth
$\log(\frac{P^{c,vat}}{P})$	Log of consumption price final to observed GDP price
$\log(\frac{P^g}{P})$	Log of gov. observed price to observed GDP price
$\log(\frac{P^{IG}}{P})$	Log of govt. investment price to observed GDP price
$\log(\frac{P^I}{P})$	Log of observed total investment price to observed GDP price
$\log(\frac{P^M}{P})$	Log of import price to observed GDP price
$\log(Pop)$	Log of population
$\log(\frac{P^X}{P})$	Log of export price to GDP price
$\log(P)$	Log of observed GDP price
$\log(t\bar{f}p)$	Log of TFP trend
$\log(\frac{T}{Y})$	Log of nominal gov transfers share
$\log(\frac{W}{Y})$	Nominal wage share
$\log(\frac{X}{Y})$	Log of nominal export share
$\log(Y)$	Log of observed GDP
$\frac{CO}{Y}$	Nominal industrial supply import share
P^{CO}	Price of industrial supply
$\log\frac{TB}{Y}$	Nominal trade balance share
$P^{CO,O}$	Oil price in US dollars
Rest of the World	
i^*	RoW nominal Interest rate
$\log(Pop^*)$	Log of population
$\log(P^*)$	Log of observed GDP price
$\log(Y^*)$	Log of observed GDP
$\log(\frac{I^*}{Y^*})$	Log of nominal investment share
$\log(\bar{Y}^*)$	Log of GDP trend

Table B.1: List of observables.

B.2 Calibration and posterior estimates

Table B.2 reports the calibrated parameter values. Table B.3 collects main estimated parameter values.

		EA	US
Households			
Preference for government bonds	α^B	-0.001	0.002
Preference for stocks	α^S	0.005	0.011
Preference for foreign bonds	α^{BW}	0.010	0.010
Intertemporal discount factor	β	0.998	0.998
Savers share	ω^S	0.670	0.730
Import share in consumption	$s^{M,C}$	0.099	0.053
Import share in investment (private and gov)	$s^{M,I}$	0.150	0.125
Import share in exports	$s^{M,X}$	0.140	0.058
Weight of disutility of labor	ω^N	3.342	18.319
Production			
Cobb-Douglas labor share	α	0.650	0.650
Depreciation of private capital stock	δ	0.014	0.017
Share of oil in total output	s^{Oil}	0.037	0.048
Linear capacity utilisation adj. costs	$\gamma^{u,1}$	0.028	0.040
Value-added demand elasticity	σ^y	6.085	11.543
Monetary and fiscal policy			
Nominal interest rate in SS	$\bar{i}$	0.004	0.005
Nominal interest rate in SS	$\bar{i}$	0.004	0.005
CPI inflation in SS	$\bar{\pi}^{c,vat}$	0.005	0.005
Interest rate persistence	ρ^i	0.807	0.852
Consumption tax	τ^C	0.200	0.100
Corporate profit tax	τ^k	0.300	0.300
Labour tax	τ^N	0.436	0.348
Deficit target	def^T	0.024	0.028
Debt target	$\bar{BG}$	3.025	3.416
Long-run growth and ratios			
Private consumption share in SS	C/Y	0.559	0.700
Private investment share in SS	I/Y	0.176	0.148
Govt consumption share in SS	C^G/Y	0.204	0.150
Govt investment share in SS	I^G/Y	0.031	0.036
Transfers share in SS	T/Y	0.163	0.131

Table B.2: Selected calibrated parameters.

		Prior distribution		Posterior mode distribution	
		Distr.	Mode Std.	EA (10%-90%)	US (10%-90%)
Shock processes (domestic)					
Price markup - std	ε^{μ}	Gamma	0.02	0.02	0.02
			0.01	(0.01-0.03)	(0.01-0.04)
Labour supply - std	ε^{U}	Gamma	0.01	0.00	0.02
			0.00	(0.00-0.00)	(0.01-0.03)
Temporary TFP level - std	ε^{LAY}	Gamma	0.00	0.00	0.00
			0.00	(0.00-0.00)	(0.00-0.00)
Labour demand - AR(1) coeff.	ρ^{ND}	Beta	0.50	0.70	0.77
			0.20	(0.63-0.83)	(0.72-0.86)
Labour demand -std	ε^{ND}	Gamma	0.01	0.01	0.02
			0.00	(0.01-0.02)	(0.02-0.02)
Government consumption - AR(1) coeff.	ρ^{G}	Beta	0.70	0.94	0.93
			0.10	(0.90-0.97)	(0.89-0.96)
Government consumption - std	ε^{G}	Gamma	0.01	0.00	0.00
			0.00	(0.00-0.00)	(0.00-0.00)
Government investment - AR(1) coeff.	ρ^{IG}	Beta	0.70	0.92	0.93
			0.10	(0.88-0.97)	(0.90-0.95)
Government investment - std	ε^{IG}	Gamma	0.01	0.00	0.00
			0.00	(0.00-0.00)	(0.00-0.00)
Transfers - AR(1) coeff.	ρ^{T}	Beta	0.70	0.95	0.97
			0.10	(0.91-0.97)	(0.94-0.98)
Transfers - std	ε^{T}	Gamma	0.01	0.00	0.00
			0.00	(0.00-0.00)	(0.00-0.00)
Tax - AR(1) coeff.	ρ^{TAX}	Beta	0.85	0.91	0.95
			0.06	(0.85-0.95)	(0.92-0.98)
Tax - std	ε^{TAX}	Gamma	0.01	0.01	0.01
			0.00	(0.01-0.01)	(0.01-0.01)
Import - AR(1) coeff.	$\rho^{M,Z}$	Beta	0.50	0.96	0.90
			0.20	(0.93-0.98)	(0.84-0.94)
Import - std	$\varepsilon^{M,Z}$	Gamma	0.01	0.02	0.02
			0.00	(0.02-0.03)	(0.01-0.02)
Bilateral export price - AR(1) coeff.	ρ^{X}	Beta	0.30	0.17	0.17
			0.10	(0.09-0.26)	(0.09-0.26)
Bilateral export price - std	ε^{X}	Gamma	0.00	0.01	0.01
			0.00	(0.01-0.01)	(0.01-0.01)
International bond preference - AR(1) coeff.	ρ^{BW}	Beta	0.50	0.83	0.95
			0.20	(0.84-0.93)	(0.94-0.98)
International bond preference - std	ε^{BW}	Gamma	0.01	0.01	0.00
			0.00	(0.00-0.01)	(0.00-0.00)
Monetary policy - std	ε^{I}	Gamma	0.00	0.00	0.00
			0.00	(0.00-0.00)	(0.00-0.00)
Shock processes (rest of the world)					
Time preference - AR(1) coeff.	ρ^{C}	Gamma	0.01	0.01	
			0.00	(0.01-0.02)	
Time preference - std	ε^{C}	Beta	0.50	0.73	
			0.20	(0.62-0.81)	
Investment risk prem. - AR(1) coeff.	ρ^{S}	Beta	0.01	0.01	
			0.00	(0.01-0.02)	
Investment risk prem. - std	ε^{S}	Beta	0.50	0.68	
			0.20	(0.62-0.82)	
Price markup	ε^{μ}	Gamma	0.01	0.01	
			0.00	(0.00-0.02)	
Import - AR(1) coeff.	$\rho^{M,Z}$	Beta	0.50	0.97	
			0.20	(0.95-0.98)	
Import - std	$\varepsilon^{M,Z}$	Gamma	0.01	0.02	
			0.00	(0.02-0.02)	
Monetary policy - std	ε^{I}	Gamma	0.01	0.00	
			0.00	(0.00-0.00)	

Table B.3: Selected estimated shock processes.

Appendix C Additional results

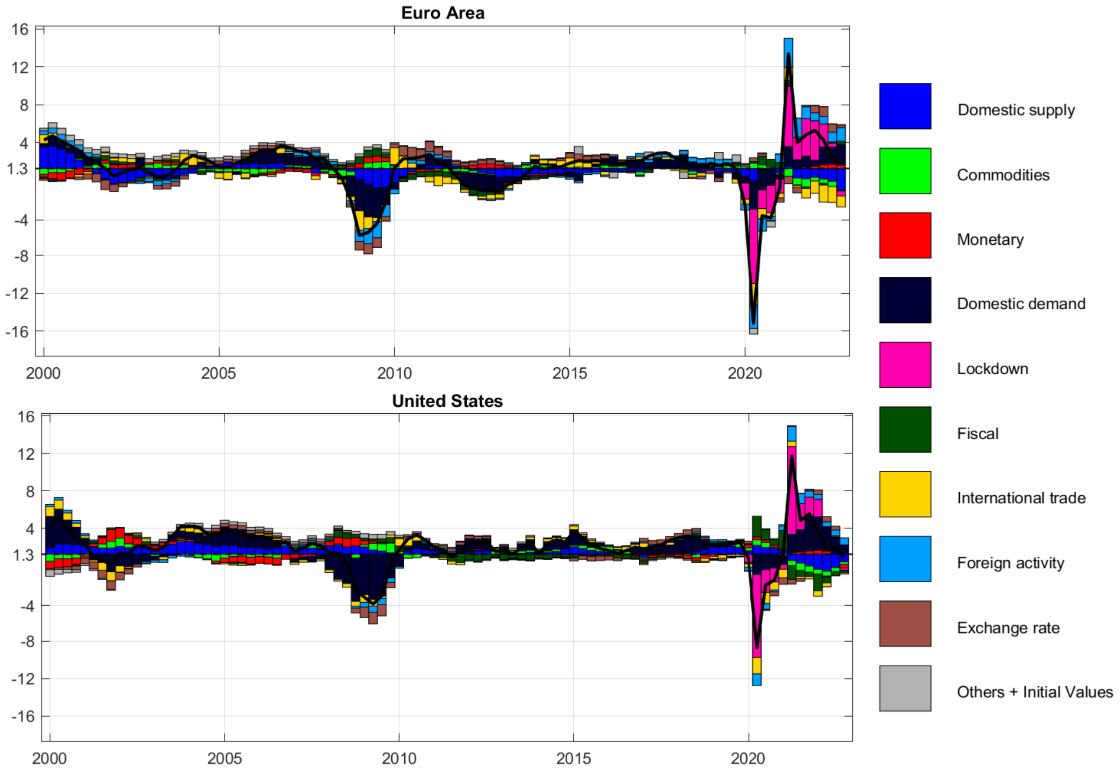

Figure C.1: Real GDP growth shock decomposition (yoy)

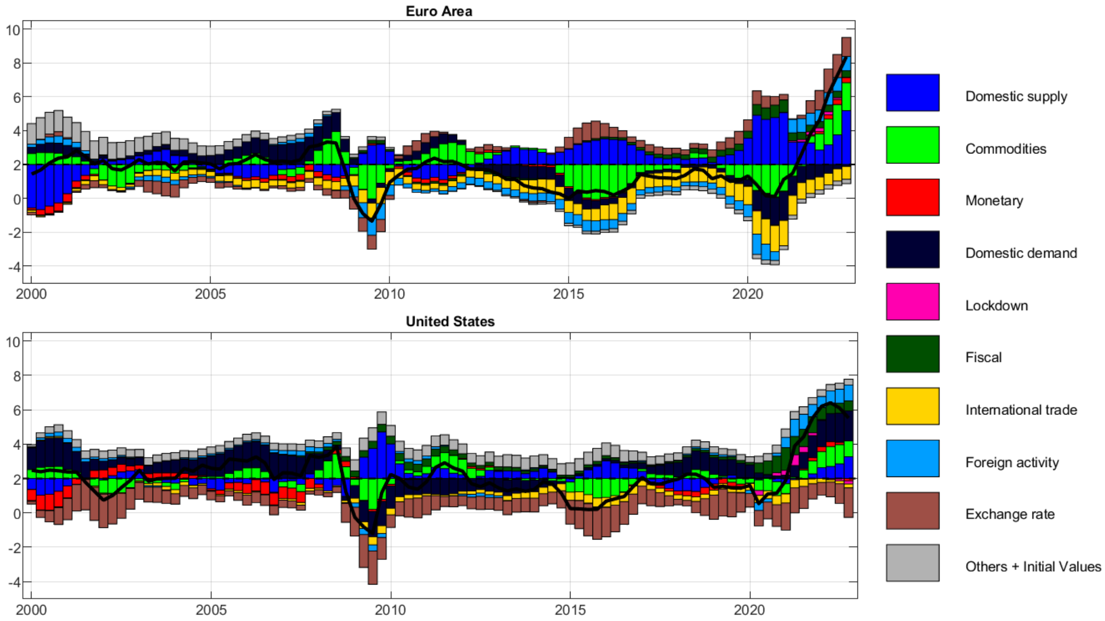

Figure C.2: Inflation shock decomposition (yoy)

C.2 Shadow rates

Shadow rates represent hypothetical short-term interest rates determined through the application of term structure models. These models provide a basis to derive the trajectory of short-term interest rates in line with shifts in long-term rates, particularly in reaction to the impact of unconventional monetary policy (UMP) on long-term yields.

In standard economic circumstances (i.e., away from the ELB), or 'normal times', shadow rates align with short-term policy rates. However, when the effective lower bound (ELB) comes into play—when the short-term policy rate touches the ELB and long-term rates are lowered by UMP—shadow rates go into negative territory.

For our research, we utilise shadow rate estimates provided by Wu and Xia (2016, 2020). In Figure C.3, we graphically represent these rates for both the Euro Area (EA) and the United States (US), alongside the actual short-term policy rates (bold blue). This illustration effectively highlights the disparity between shadow rates and short-term policy rates when the latter hit the ELB, and central banks implement UMP measures.

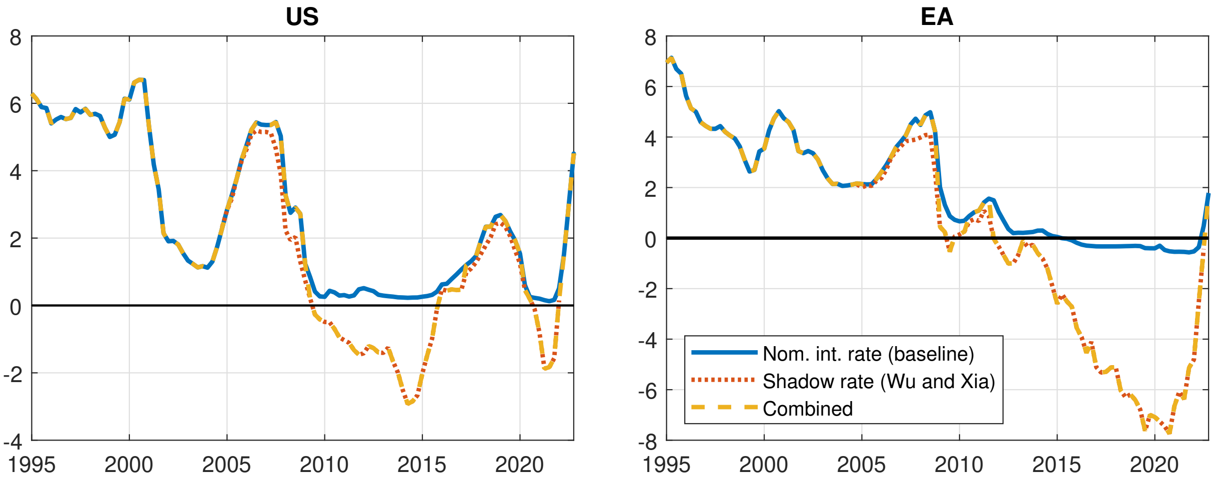

Figure C.3: Shadow rates and nominal short-term interest rates

Notes: This graph depicts the interest rate measures used in the baseline (bold blue) and shadow-rate (dashed yellow) versions of the model.

C.3 Fiscal policy: dynamic effects of fiscal shocks

Figure C.4 shows the macroeconomic response to a persistent increase in government purchases. Domestic output increases, and the government's primary balance deteriorates as the purchases are only partly offset by higher tax revenue. Monetary policy tightens away from the ELB, which raises real interest rates and reduces private consumption and investment demand. The exchange rate appreciates in reaction to monetary tightening, which reinforces the initial negative trade balance effect from higher import demand. The inflation response is similar in strength to the persistent private savings shock in the main text. The shock transmission in the EA versus the US is similar in quantitative terms, except for stronger crowding out of investment and a weaker trade balance response in the US.

Compared to the shock to government purchases, government investment shocks lead to a more persistent increase in GDP and generate less crowding out of private investment (Figure C.5). Finally, for comparison, Figure C.6 shows the effect of an untargeted transfer shock, which we discuss in the main text.

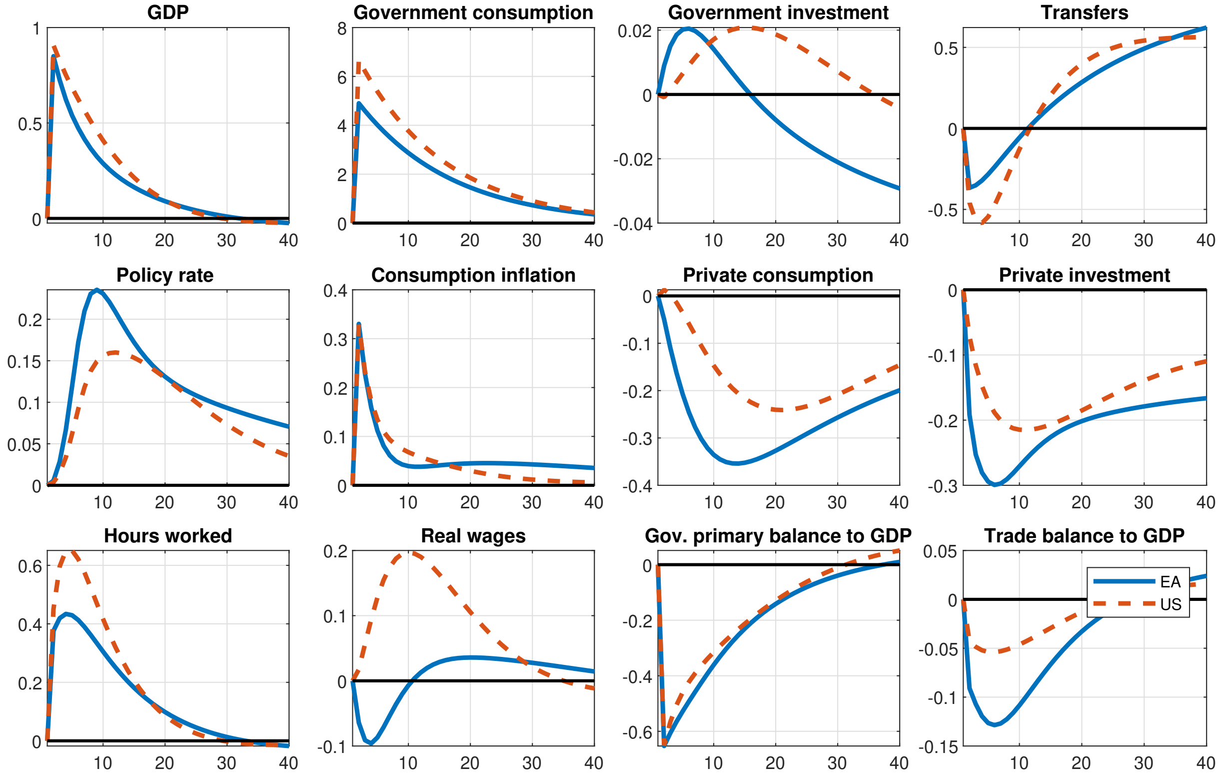

Figure C.4: Response to a government consumption shock

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

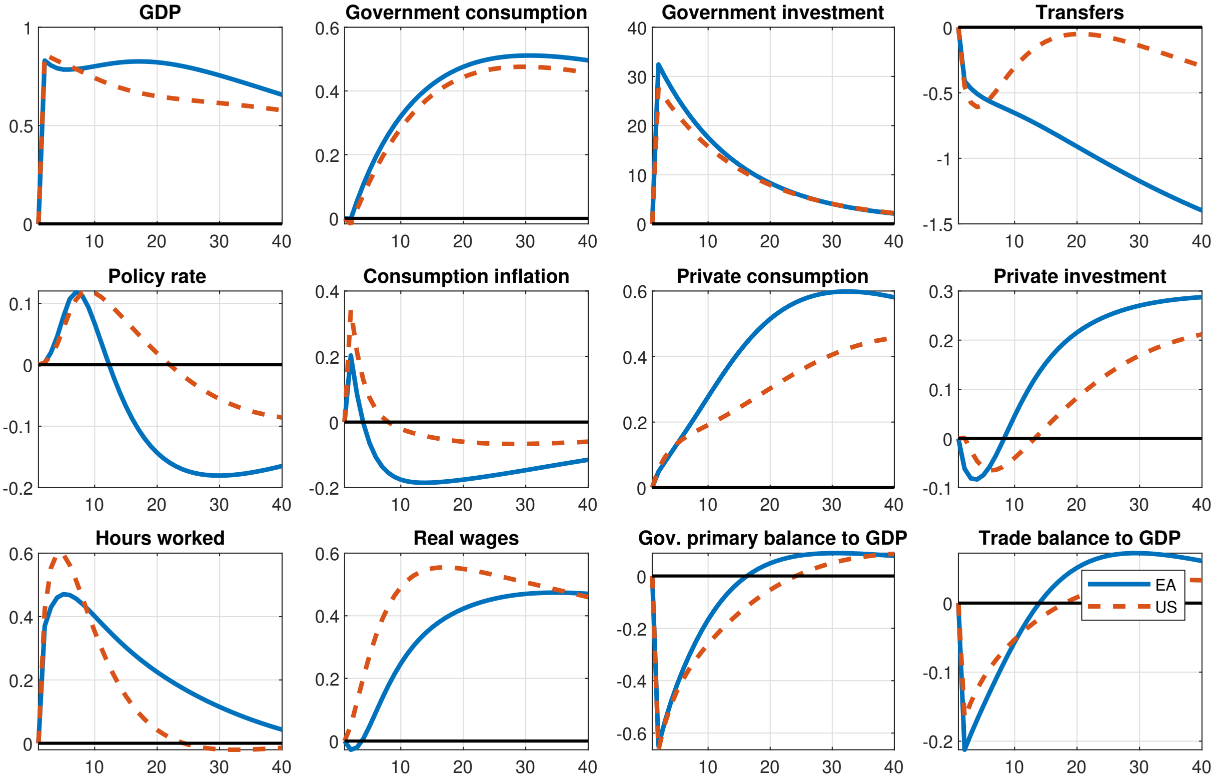

Figure C.5: Response to a government investment shock

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

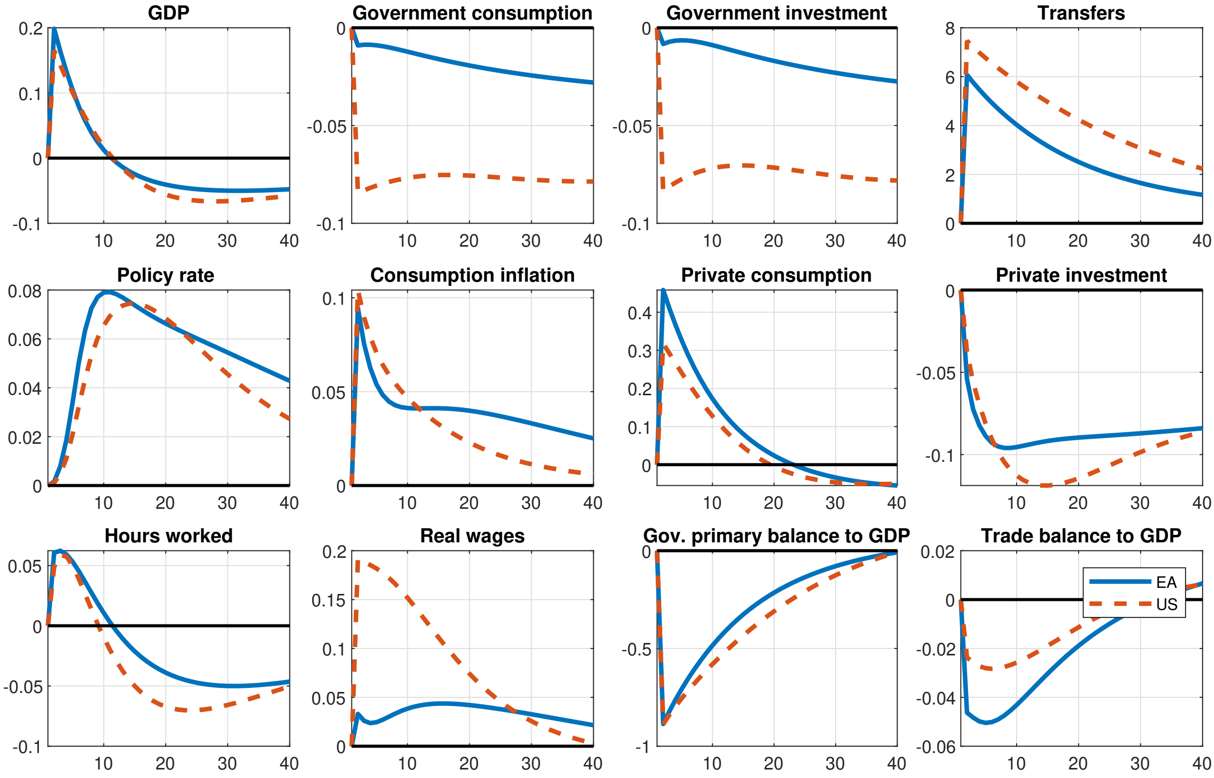

Figure C.6: Response to an untargeted government transfer shock

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

C.4 Savings shocks

This section presents additional details on the IRFs of the two types of savings shocks.

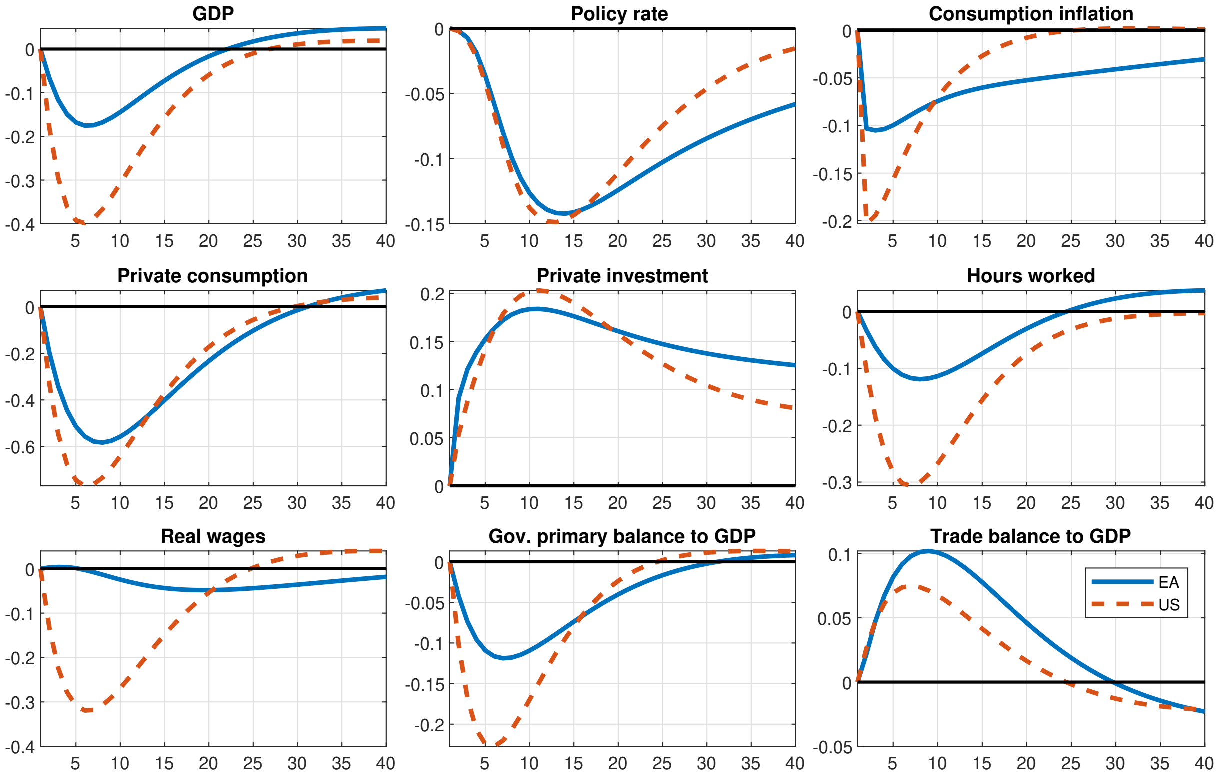

Figure C.7: Response to a persistent savings shock

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

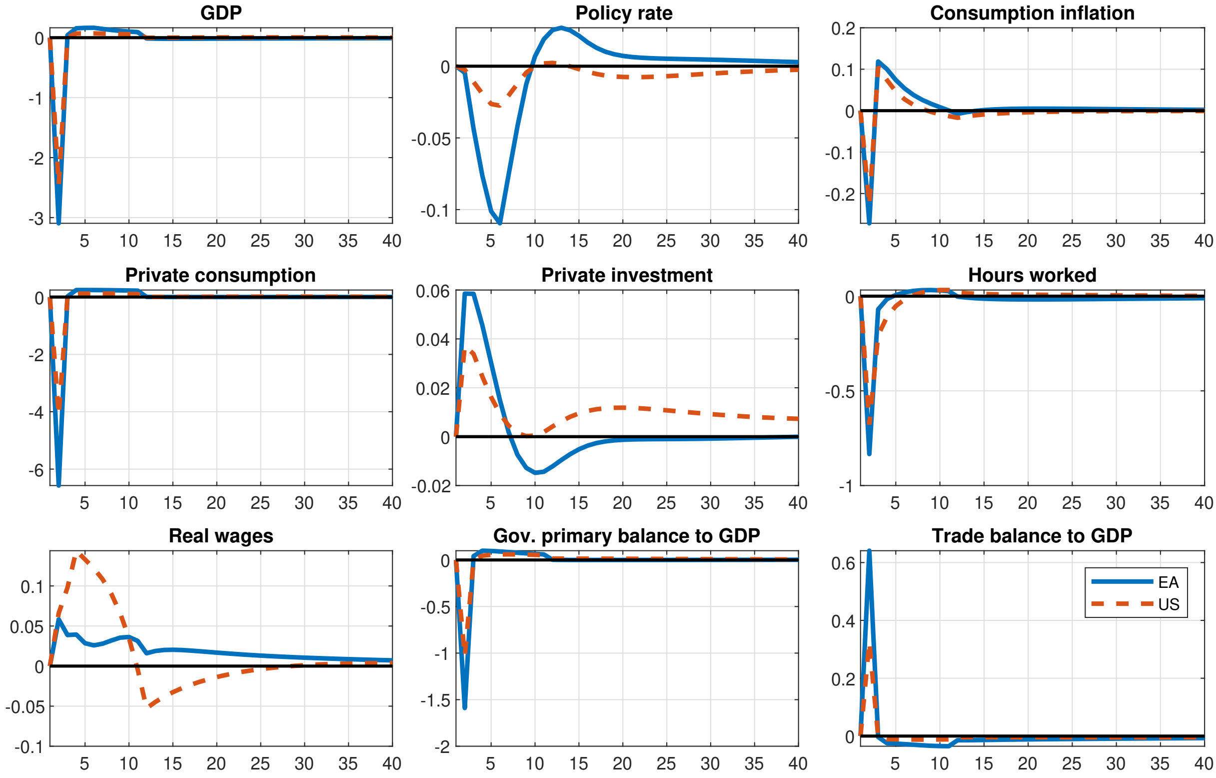

Figure C.8: Response to a temporary savings (lockdown) shock

Notes: All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

C.5 COVID-specific labour demand shock

Figure C.9 shows the effects of a temporary labour demand shock. This disturbance is active only during the COVID period to help fit the employment dynamics, notably in the US. The estimated contribution of this shock to GDP growth and inflation in the pandemic period is relatively minor with the exception of a small inflationary effect in the US in 2021 (included in the contribution of 'lockdown shocks').

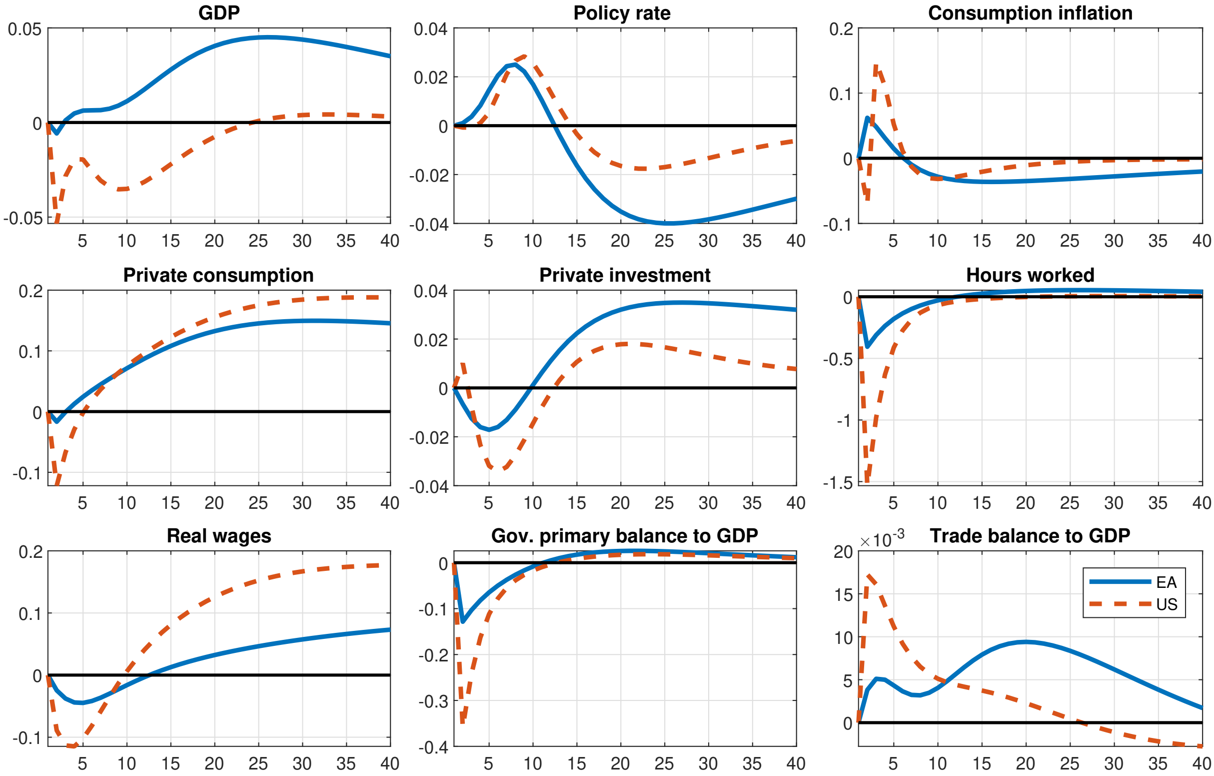

Figure C.9: Response to a COVID-specific labour demand shock

Notes: The shock size corresponds to one estimated standard deviation. All variables are displayed in % deviations from the steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP, the policy rate (annualised), and consumption inflation (annualised), which are expressed in percentage-point deviations from the steady state instead. Periods correspond to quarters.

C.6 Preferences over safe assets

We incorporate preferences over safe assets (POSA), as proposed in Rannenberg (2021), by extending the utility function outlined in equation (7) to include preferences towards government debt. The modified utility function is presented in equation (C.1):

$$E_0 \sum_{t=0}^{\infty} \beta^t \xi_t \left(\frac{\left(C^s_{j,t} - \varepsilon^{tC}_t - h(C^s_{t-1} - \varepsilon^{tC}_{t-1})\right)^{1-\theta}}{1-\theta} - \omega^N_t \frac{\left(N^{s,paid}_{j,t}\right)^{1+\theta^N}}{1+\theta^N} \right.$$
$$\left. + \chi_b \frac{(b_{G,t})^{1-\sigma_b}}{1-\sigma_b} - \frac{\overline{\lambda}^s_t}{P^C_t} \sum_{\mathcal{Q}} B^{\mathcal{Q}}_{j,t}(\alpha^{\mathcal{Q}} - \varepsilon^{\mathcal{Q}}_t), \right), \tag{C.1}$$

where $\chi_b > 0$ introduces POSA and σ_b governs the curvature of the safe asset preferences. $b_{G,t} \equiv \frac{B^G_t}{Y_t P_t} - \bar{BG}$ denotes deviations of the government debt-to-GDP ratio from the steady-state government debt-to-GDP ratio. We assume government debt to be (almost) risk-free and explicitly associate the interest rate of risk-free assets with government bonds, such that $i^G_t = i_t + \alpha^G$, with α^G being very small.

The first-order condition for government bond holdings is provided by equation (C.2):

$$1 = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{1}{1 + \alpha^G + \varepsilon^B_t} \left((1 + i^G_t) \right) \right] + \chi_b \left(b_{G,t} \right). \tag{C.2}$$

As clarified in Rannenberg (2021) (p.1026), POSA results in a discount wedge, θ^{POSA}, which is the net value that the household savers assign to the marginal utility of consumption in the following period.[47] Emulating his paper, our illustrative application sets $(\sigma_b, \theta^{POSA}) = (0.15, 0.96)$. All other parameters persist at their estimated values.

The introduction of an extra benefit from saving in government bonds, beyond the utility associated with future consumption, reduces consumption smoothing over time. This is because the current period's consumption does not only depend on the benefit of future consumption but also on the benefit of holding government bonds. Moreover, the additional utility value implies that the interest rate offered may be lower than households would naturally discount their future earnings. We refer to Rannenberg (2021) for additional discussion of the effects of POSA.

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[47] In the steady state, $\theta^{POSA} = \beta \bar{i} / \bar{\pi}^{C,vat}$.

Appendix D Effective lower bound: simulation and smoothing algorithm

D.1 Overview

We build on the OccBin toolkit (Guerrieri and Iacoviello 2015) to account for the occasionally binding constraint on nominal interest rates. This method handles the constraints as different regimes of the same model in which the constraints are either slack or binding. Consequently, our model consists of the following four regimes: an unconstrained baseline; two variations, which include either an ELB constraint in the EA or the US leaving the other constraint slack; and a regime in which both constraints are active. Importantly, the dynamics in all regimes depend on the endogenous length of that regime. The expected duration, in turn, depends on the state variables and exogenous disturbances. As emphasised in Guerrieri and Iacoviello (2015), this interaction can result in highly nonlinear dynamics. We lay out the details below in Section D.2.

Following Giovannini et al. (2021), we integrate the nonlinear solution into a specially adapted Kalman filter to estimate shocks in the model with the two occasionally binding constraints. We summarise the algorithm for the shock decompositions in Section D.3.

D.2 Details on the OccBin algorithm

For ease of exposition, this Appendix assumes a single occasionally binding constraint. The reference regime (e.g., ELB constraint is slack) can be expressed as a linearised system (M1):

$$A_1 E_t[X_{t+1}] + A_0 X_t + A_{-1} X_{t-1} + \mathcal{E} u_t = 0$$

Here, X_t denotes the model variables in deviation from the steady state.

The alternative regime (e.g., ELB constraint is binding) features a constant D^* (M2):

$$A_1^* E_t[X_{t+1}] + A_0^* X_t + A_{-1}^* X_{t-1} + D^* + \mathcal{E}^* u_t$$

M1 and M2 are linearised around the same point.

Regimes The solution for M1 (reference regime) can be written as:

$$X_t = T X_{t-1} + C u_t$$

In this case, the transition matrices T and C are constant. The Blanchard-Kahn conditions hold for M1.

The solution for the alternative regime (M2) can be written as:

$$X_t = \begin{cases} T_t X_{t-1} + R_t + C_t u_t & \text{for } t = 1 \\ T_t X_{t-1} + R_t & \text{for } t \geq 2 \end{cases}$$

Here, the time-varying matrices depend on the expected regime length. The system's behaviour, exhibiting certainty equivalence, does not depend on shocks u_{t+j} for $j \geq 1$.

Guess and verify The guess and verify approach begins by guessing regime 1 (M1): If $u_t = 0$ for all future periods, the system returns to M1. We then check whether we are indeed in M1 (e.g., the constraint is slack), and if regime M2 is in period t given state X_{t-1} and shocks u_t. This approach involves guessing T such that for $\tau \geq T$, we are in M1, then verifying whether the guess is correct, following the process outlined in Guerrieri and Iacoviello (2015). If not, an update is required.

D.3 Nonlinear smoothing

D.3.1 Additive representation of shock decompositions

This section provides additional details on obtaining an additive shock decomposition for the nonlinear model. To fix ideas, consider a piecewise-linear Kalman smoother, which estimates the sequence of regimes in the historical time interval. The sequence of regimes triggers a sequence of state-space matrices:

$$x_t = \mathbf{T}(x_{t-1}, \varepsilon_t; \theta)x_{t-1} + \mathbf{C}(x_{t-1}, \varepsilon_t; \theta) + \mathbf{R}(x_{t-1}, \varepsilon_t; \theta)\varepsilon_t, \tag{D.1}$$

where x_t stacks all endogenous variables in deviation from steady state, u_t are the smoothed shocks, and $\mathbf{C}_t$ is a constant, which is triggered by the regime, i.e. $\mathbf{C}(\cdot) = 0$ in the unconstrained regime.[48]

The algorithm estimates the additive shock decompositions in two steps. The first step exploits the piecewise-linear Kalman smoother that provides the smoothed estimate of the sequence of regimes together with the historical series of exogenous shocks. Given the sequence of regimes, the shocks are propagated individually through the sequence of state-space matrices $\mathbf{T}(\cdot)$ and $\mathbf{R}(\cdot)$. The array $\mathbf{C}(\cdot)$ is treated as an additional exogenous process, labelled "regime effect".

A second step extends this procedure to obtain an additive shock decomposition. Note that the regime effect results from the interaction of all shocks simultaneously hitting the system $\forall \tau \leq t$. Hence, the regime effect is a function of exogenous shocks. For each t and variable j, we compute the absolute value of the contribution of each shock $u_{i,t}$ onto a variable x^R_j:

$$w_{j,i,t} = |x^R_t(u_{i,t})|, \tag{D.2}$$

where $w_{j,i,t}$ is a set of weights which apportion the regime effect to all shocks, and x^R_j is a variable determining the regime sequence.

D.3.2 Implied regime sequences

Figure D.1 reports the identified regime sequences for the US and EA.

D.4 Counterfactual: no effective lower bound

Figure D.2 reports the counterfactual simulations on the role of the ELB. The baseline simulation, depicted in solid blue, introduces the estimated shocks into the *baseline* model, incorporating the occasionally binding ELB constraints. By design, these shocks, in the baseline

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[48] Note that at the ELB, the Taylor rule $i_t = i^{lb}$ violates the steady-state condition ($i^{lb} < \bar{i}$).

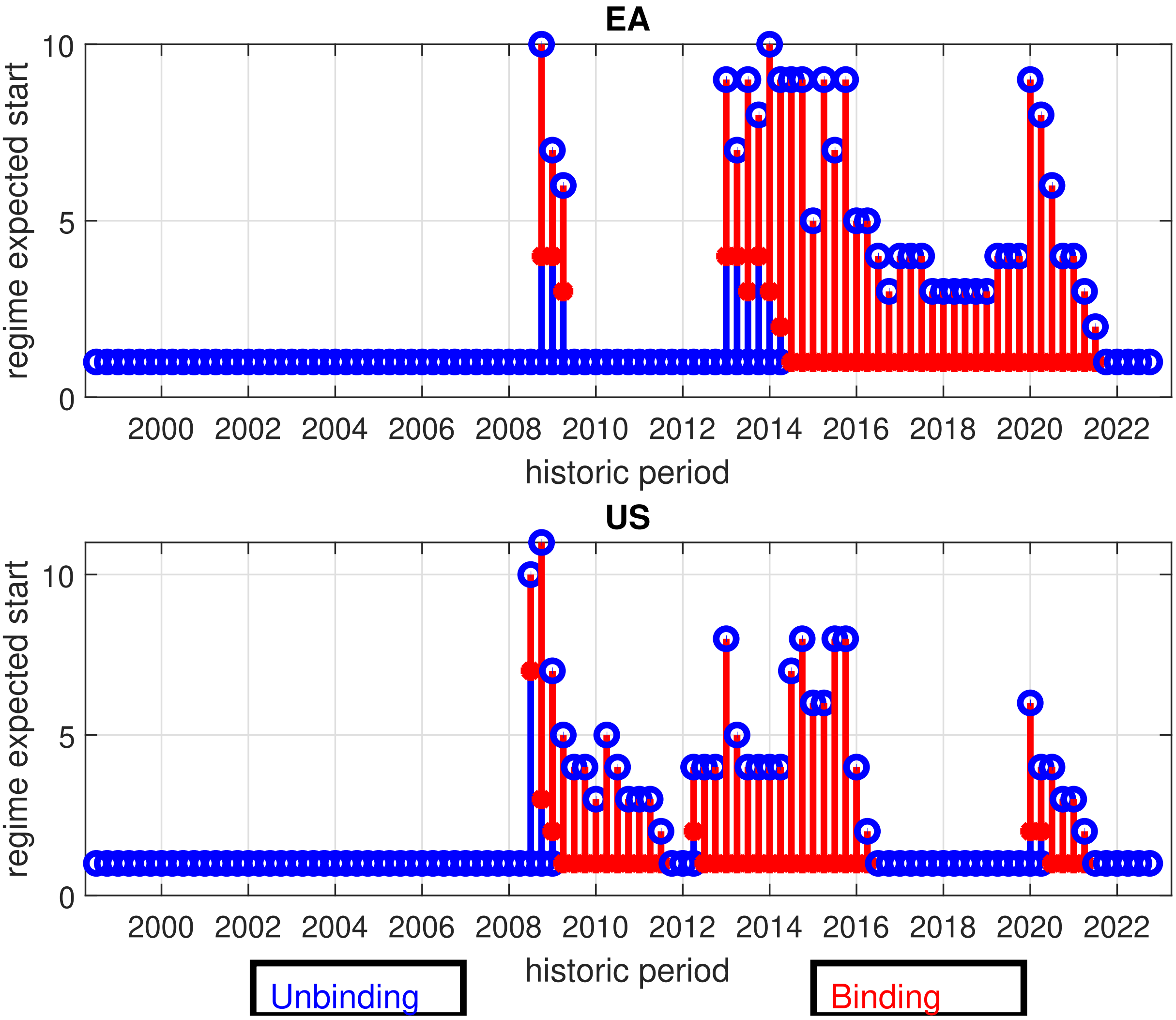

Figure D.1: Model-identified ELB periods

Notes: This graph reports the ELB regime sequences. The vertical axes show the expected length in each period as simulated using the piecewise-linear model.

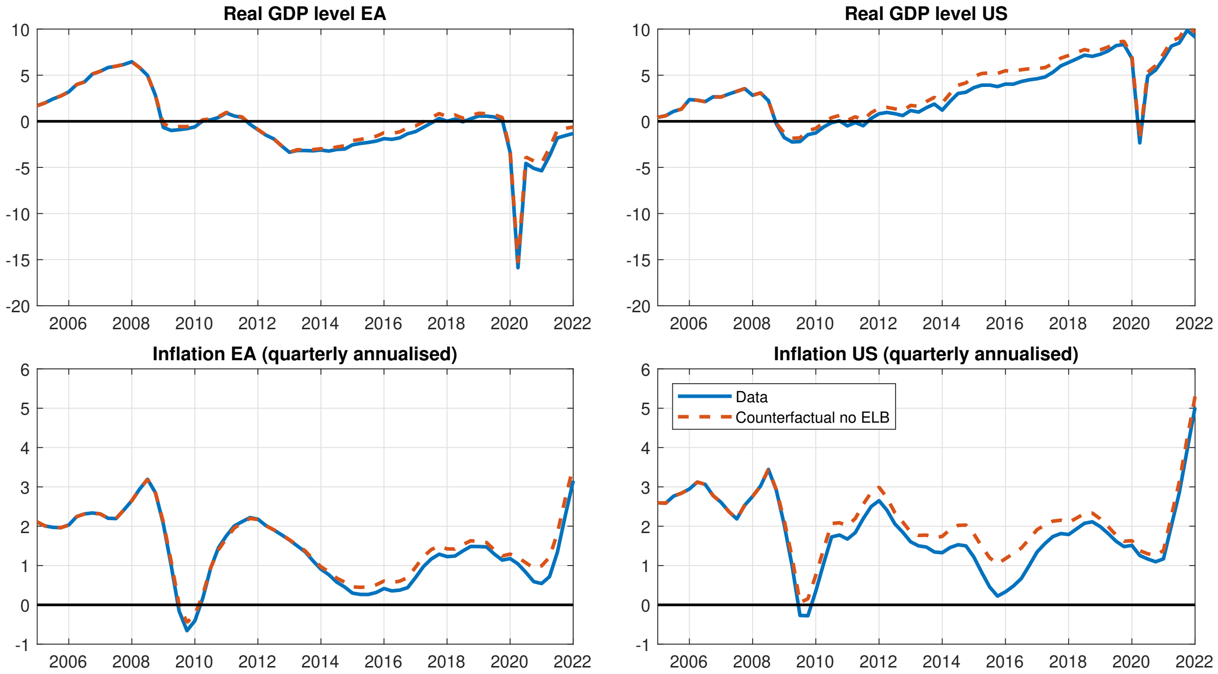

Figure D.2: No-ELB Counterfactual

Notes: This graph reports the level of real GDP (de-trended) and inflation (annualised) in the data (baseline, blue) and the counterfactual simulations (red, dashed), where the latter feeds the estimated shocks into a linear model version.

model, replicate the observed time series of real GDP and inflation (and the other endogenous variables not shown here). According to our model, the second simulation (depicted in dashed red lines) measures the macroeconomic effects attributable to the ELB. For this purpose, the simulation introduces the identical set of estimated shocks into a linear model variant *without the ELB constraints*. This generates a counterfactual trajectory of endogenous variables and shows the output losses and deflationary effects associated with the ELB in the two regions (neglecting the potential offsetting effects of unconventional monetary policy implemented during ELB episodes).

INSTITUT DE RECHERCHE
ÉCONOMIQUES ET SOCIALES

Place Montesquieu 3
1348 Louvain-la-Neuve

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