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ECB-Global:
introducing ECB's global
macroeconomic model for
spillover analysis

**Abstract**

In a highly interlinked global economy a key question for policy makers is how foreign shocks and policies transmit to the domestic economy. We develop a semi-structural multi-country model with rich real and financial channels of international shock propagation for the euro area, the US, Japan, the UK, China, oil-exporting economies and the rest of the world: ECB-Global. We illustrate the usefulness of ECB-Global for policy analysis by presenting its predictions regarding the global spillovers from a US monetary policy tightening, a drop in oil prices and a growth slowdown in China. The impulse responses implied by ECB-Global are well in line with those generated by other global models, with international spillovers in ECB-Global generally on the high side given its rich real and financial spillover structure.

*Keywords:* Macro-modelling, multi-country models, spillovers, monetary policy.
*JEL-Classification*: C51, E30, E50.

# 1 Non-Technical Summary

The rise of financial and real globalisation over the past decades has increased the importance of understanding the global transmission of shocks and policy actions. Consequently, there has been a growing interest in the use of global macroeconomic models for the assessment of the sign, the size and the transmission channels of cross-border spillovers. Therefore, we develop *ECB-Global*, a rich multi-country model for the euro area, the US, Japan, the UK, China, oil-producing economies and the rest-of-the-world featuring diverse cross-border spillover channels through real and financial interlinkages. The development of ECB-Global follows a semi-structural approach in order to combine the advantages of fully structural models and those composed of reduced-form equations. Specifically, the design of ECB-Global is based on two considerations. First, the evolution of the economies in the model is determined by a set of core structural relationships (e.g. Phillips and IS curves). The advantage of the structural elements of ECB-Global is that shocks have a clean economic interpretation, and that it facilitates tracking the domestic and international transmission of shocks. Second, reduced-form equations are added to enrich the core of the model. The advantage of the reduced-form aspect of ECB-Global is that it facilitates modifying the model in a flexible manner so that it can be adapted relatively straightforwardly, which allows us to address quickly-changing issues in the policy discussion. Moreover, the additional reduced-form elements improve the empirical fit of ECB-Global.

ECB-Global is similar in spirit to other semi-structural models, such as the IMF's Global Projection Model (GPM7; Blagrave et al., 2013), the IMF's Flexible System of Global Models (FSGM; Andrle et al., 2015) and the global DSGE model developed by Cova et al. (2015). ECB-Global has several features that set it apart. First, in order to be able to analyse a wider set of policy scenarios, ECB-Global features a more detailed financial and oil block. Second, in order to strengthen theoretical consistency, the equations in ECB-Global are more in line with those from fully micro-founded structural models such as the ECB's New Area Wide Model (NAWM; Christoffel et al., 2008) and the Euro Area and Global Economy model (EAGLE; Gomes et al., 2012). Compared to the FSGM, ECB-Global puts stronger emphasis on financial spillovers, and it is more useful for scenario analysis at the business cycle frequency given that it is a quarterly rather than an annual model.

We now discuss intuitively the structure of the model. Domestic output consists of consumption and investment, government spending and net exports, while domestic inflation is a combination of producer price inflation (determined by marginal costs) and imported oil price inflation. The central bank of each economy acts to stabilise inflation and output by setting its policy rate, which in turn affects the financial sector. The domestic financial sector determines equity prices, the short-term interbank credit spread, bank-lending tightness and sovereign risk premia. The interbank credit spread drives a wedge between the central bank's policy rate

and short-term interbank rate, and the private-sector risk premium is defined as the sum of bank-lending tightness and the sovereign risk premium. These financial variables are important determinants of domestic output as they act as financial accelerators and the sovereign risk premium interacts with government spending and government debt dynamics. Finally, net exports will respond to changes in the exchange rate, which is modelled via the uncovered interest rate parity condition. Real spillovers are based on countries being interlinked via global trade, which consists of oil and non-oil trade as two separate channels. All economies import and export non-oil goods, whereas only the oil-exporting country block produces and exports oil. The price of oil is determined by oil trade which equates oil demand (endogenous to global output) and oil supply (exogenously set by the oil-exporting countries). A key feature of the model is that we ensure consistency of global trade such that exports equal imports. Financial spillovers in ECB-Global occur through four channels: equity prices, the interbank rate spread, bank-lending tightness and sovereign risk premia. International financial spillovers arise endogenously in ECB-Global in the sense that changes in foreign financial variables transmit to domestic financial variables through contagion, with the relative magnitude of financial spillovers largely dependent on financial shares.

The dynamic properties of ECB-Global are illustrated by considering the domestic and international responses following a set of policy scenarios. First, a US monetary policy tightening not only causes domestic output and inflation to decline via a combination of trade, oil and financial channels, but also leads to a decline in output in other countries as tighter global financial conditions dominate favorable spillovers via trade. Second, a slowdown in Chinese demand only triggers limited international spillovers as negative domestic demand effects only transmit through lower oil prices and trade, given China's limited integration into the global financial system. Finally, a decline in oil prices driven by increased oil supply causes output in oil-importing countries to increase, whereas output in oil-exporting countries declines as government expenditures based on oil export revenues fall together with net exports. As ECB-Global is a calibrated model, a sensitivity analysis is added which demonstrates how spillovers depend on the values of key parameters. Comparing ECB-Global impacts on global output with other global models (Nigem and the FSGM) to a set of shocks, shows that the responses of ECB-Global are generally well in line with those generated by the other models, with international spillovers in ECB-Global generally on the high side given its rich real and financial spillover structure.

# 2   Introduction

The rise of financial and real globalisation over the past decades has increased the importance of understanding the global transmission of local shocks and policy actions. Recent events including the normalisation of monetary policy in the US, swings in commodity prices as well as concerns about China's growth prospects demonstrate the importance of understanding how shocks in one economy transmit to the rest of the world. Consequently, there has been a growing interest in the use of global macroeconomic models for the assessment of the sign, the size and the transmission channels of cross-border spillovers. In order to simulate the international transmission of local shocks and to examine the implications of alternative policy responses we develop *ECB-Global*, a rich multi-country model for the euro area, the US, Japan, the UK, China, oil-producing economies and the rest-of-the-world featuring diverse cross-border spillover channels through real and financial interlinkages.

The development of ECB-Global follows a semi-structural approach in order to combine the advantages of fully structural models and those composed of reduced-form equations. Specifically, the design of ECB-Global is based on two considerations. First, the evolution of the economies in the model is determined by a set of core structural relationships (e.g. Phillips and IS curves). The advantage of the structural elements of ECB-Global is that shocks have a clean economic interpretation, and that they facilitate tracking the domestic and international transmission of shocks. Second, reduced-form equations are added to enrich the core of the model. The advantage of the reduced-form aspect of ECB-Global is that it facilitates modifying the model in a flexible manner so that it can be adapted relatively straightforwardly, which allows us to address quickly-changing issues in the policy discussion. Moreover, the additional reduced-form elements improve the empirical fit of ECB-Global.

ECB-Global is similar in spirit to other semi-structural models, such as the IMF's Global Projection Model (GPM7; Blagrave et al., 2013), the IMF's Flexible System of Global Models (FSGM; Andrle et al., 2015) and the global DSGE model developed by Cova et al. (2015).[1] Compared to the GPM, ECB-Global has several features that set it apart. First, in order to be able to analyse a wider set of policy scenarios, ECB-Global features a more detailed financial and oil block. Second, in order to strengthen theoretical consistency, the equations in ECB-Global are more in line with those from fully micro-founded structural models such as the ECB's New Area Wide Model (NAWM; Christoffel et al., 2008) and the Euro Area and Global Economy model (EAGLE; Gomes et al., 2012). Compared to the FSGM, ECB-Global puts stronger

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[1]Other global models include the IMF's Global Economy Model (GEM; Laxton and Pesenti, 2003), the Global Integrated Monetary and Fiscal Model (GIMF; Laxton and Kumhof, 2007), NIGEM developed by the National Institute of Economic and Social Research as well as the global model of Oxford Economics. However, these models are more structural and therefore less flexible (GEM and GIMF), or mostly reduced form and therefore do not allow a meaningful economic interpretation of scenarios (NiGEM and the Oxford model).

emphasis on financial spillovers, and it is more useful for scenario analysis at the business cycle frequency given that it is a quarterly rather than an annual model. Compared to the model developed by Cova et al. (2015), ECB-Global is less structural but, in turn, more flexible.

The dynamic properties of ECB-Global are illustrated by considering the domestic and international responses following a set of policy scenarios: a US monetary policy shock, a China demand shock and an oil price shock. First, a US monetary policy tightening not only causes domestic output and inflation to decline through trade, oil and financial channels, but also leads to a decline in output in other countries as tighter global financial conditions dominate favorable spillovers through expenditure switching. In contrast, a slowdown in Chinese demand only triggers limited international spillovers as negative domestic demand effects only transmit through lower oil prices and trade, given China's limited integration into the global financial system. Finally, a decline in oil prices driven by increased oil supply raises output in oil-importing countries, while output in oil-exporting countries declines as government expenditures based on oil export revenues fall together with net exports. As ECB-Global is a calibrated model, we carry out a sensitivity analysis which demonstrates how the dynamics implied by ECB-Global depend on the values of key parameters. Finally, it is shown that the effects of several shocks on global output implied by ECB-Global are generally well in line with those implied by other global models (Nigem and the FSGM), with international spillovers in ECB-Global generally on the high side given its rich real and financial spillover structure.

The remainder of the paper is organised as follows. Section 3 provides an intuitive graphical description of the structure of ECB-Global before Section 4 presents the model equations in detail. Section 5 discusses the parametrisation of the model. Section 6 presents the predictions of ECB-Global regarding three scenarios: (i) a tightening of monetary policy in the US, (ii) a slowdown of economic growth in China and (iii) a negative oil price shock. Finally, Section 7 discusses current limitations of the model and possible future extensions and Section 8 concludes.

## 3  Intuitive Overview

Figure 1 highlights the main building blocks of ECB-Global and indicates the channels through which spillovers arise. Although the chart is set up from a US perspective, most other country blocks (the euro area, Japan, the UK and the rest-of-the-world) are modelled symmetrically. China and the oil-exporting countries feature some country-specific structures, which are explained in more detail in Section 4.13 and 4.14.

Concentrating first on the domestic economy, there are rich interactions between domestic output and inflation as well as the domestic financial sector. Domestic output consists of consumption and investment, government spending and net exports, while domestic inflation is a

combination of producer price inflation (determined by marginal costs) and imported oil price inflation. The central bank in each economy acts to stabilise inflation and output by setting its policy rate, which in turn affects the financial sector. The domestic financial sector determines equity prices, the short-term interbank credit spread, bank-lending tightness and sovereign risk premia. The interbank credit spread drives a wedge between the central bank's policy rate and short-term interbank rate, and the private-sector risk premium defined as the sum of bank-lending tightness and the sovereign risk premium drives a wedge between the interbank rate and the rate at which firms and households can borrow. The latter variables are important determinants of the dynamics of domestic output due to their role in financial accelerator feedback loops. Finally, net exports respond to changes in the exchange rate, which is determined in the uncovered interest rate parity condition.

Second, concentrating on the international dimension of ECB-Global, spillovers between countries occur via a multitude of real and financial channels. Real spillovers are based on countries being interlinked via global trade. Specifically, all economies import and export non-oil goods, whereas only the oil-exporting country block produces and exports oil. The price of oil is determined by oil demand (endogenous to global output) and oil supply (exogenously set by the oil-exporting countries), and affects the domestic economy through imported inflation. Finally, financial spillovers in ECB-Global occur through four channels: equity prices, the interbank rate spread, bank-lending tightness and sovereign risk premia.

# 4 The Model

This section describes the model equations of ECB-Global in detail. We only report the equations for the euro area as most other countries represented in ECB-Global are modelled symmetrically (i.e. the US, Japan, the UK and the rest-of-the-world). However, China and the oil-producing (OP) country-block differ in structure. The Chinese economy features a different monetary policy rule and UIP condition (as detailed in Section 4.13), and the OP differ in the sense that they receive oil export revenues which in turn determine government expenditures (as detailed in Section 4.14). For brevity, we only display the US and the OP as foreign economies in the equations with more countries. Moreover, we only show the log-linearised equations in this section and refer to the Model Appendix C.1 for more details on the derivations of the equations. The trend specifications, which are also part of the mod-files, are discussed in the Section C.3 of the appendix.

## 4.1 Notation

Uppercase (lowercase) letters represent aggregate (per capita) values; for example, while $Y_t$ is aggregate GDP, $y_t$ is per capita GDP. Variables with superscript $ss$ represent steady state values

and variables with bars represent trends. Percentage deviations from steady state or trend are denoted by hats, for example

$$\widehat{x}_t = log(x_t) - log(x^{ss}) = \frac{x_t - x^{ss}}{x^{ss}},$$

and absolute deviations from steady state or trend are denoted by tildes, for example

$$\widetilde{x}_t = x_t - x^{ss}.$$

Variables that are expressed relative to GDP are denoted by calligraphic letters; for example, with $Y_t$ denoting GDP, $N_t$ population and $B_t$ government debt, the government debt-to-GDP ratio is given by

$$\mathcal{b}_t = \frac{B_t/N_t}{Y_t/N_t} = \frac{b_t}{y_t}.$$

Coefficients are denoted by $\alpha_i^{\ell,m}$, where $\ell$ refers to the equation in which the parameter appears, $m$ to the variable it multiplies and $i$ to the economy in question. Autoregressive parameters in the process for shocks $\xi_{it}^{\ell}$ are denoted by $\rho_i^{\ell}$. Finally, bilateral weights and shares are denoted by $\omega_{ij}^x$, where $i$ is the domestic and $j$ the partner country and $x$ identifies the type of the weight/share. As mentioned above, when more countries are involved in an equation we only display the US and the OP as foreign economies (e.g. for the aggregation of an economy's total exports as the sum of other economies' bilateral imports). Finally, equations labeled in bold (**M.**) enter the log-linearised system of equations in the mod-files.

## 4.2 Definition of exchange rates and relative prices

The real exchange rate of the euro relative to the US dollar is defined as the ratio between the foreign consumer-price level $P_{us,t}^{cpi}$ and the domestic price level adjusted by the bilateral nominal exchange rate $S_{ea,t}$

$$Q_{ea,t} = \frac{S_{ea,t} P_{us,t}^{cpi}}{P_{ea,t}^{cpi}}.$$

An increase in $Q_{ea,t}$ therefore reflects a depreciation of the euro vis-à-vis the US dollar in real terms.

The price of output relative to consumption and investment, $\widehat{p}_t^{ry}$ is given by the ratio of the producer-price level and the consumer-price level, implying

$$\widehat{p}_{ea,t}^{ry} = \widehat{p}_{ea,t-1}^{ry} + \widehat{\pi}_{ea,t}^{ppi} - \widehat{\pi}_{ea,t}^{cpi}, \tag{M1}$$

where $\widehat{\pi}_{ea,t}^{cpi}$ and $\widehat{\pi}_{ea,t}^{ppi}$ are consumer-price and producer-price inflation, respectively.

## 4.3 IS Curve

We assume that private consumption and investment, $\widehat{ci}_{ea,t}$, follow Euler equations. In particular, we specify a combined IS-curve for private consumption and investment

$$
\begin{aligned}
\widehat{ci}_{ea,t} = {} & \alpha_{ea}^{ci,ci} E_t \widehat{ci}_{ea,t+1} + \left(1 - \alpha_{ea}^{ci,ci}\right) \widehat{ci}_{ea,t-1} - \alpha_{ea}^{ci,r^3} \left(\widehat{r}_{ea,t}^3 + \widehat{\varpi}_{ea,t}\right) + \alpha_{ea}^{ci,q} \widehat{q}_{ea,t} \\
& + \alpha_{ea}^{ci,ci} \left(E_t \Delta \overline{y}_{ea,t+1}^{cpi} - \Delta \overline{y}_{ea}^{cpi,ss}\right) - \left(1 - \alpha_{ea}^{ci,ci}\right) \left(\Delta \overline{y}_{ea,t}^{cpi} - \Delta \overline{y}_{ea}^{cpi,ss}\right) + \xi_{ea,t}^{ci}, \quad \textbf{(M2)}
\end{aligned}
$$

where $\widehat{\varpi}_{ea,t}$ represents the real private-sector credit spread over the real interbank rate $\widehat{r}_{ea,t}^3$, $\widehat{q}_{ea,t}$ equity prices, $\Delta \overline{y}_{ea,t}^{cpi}$ trend GDP growth and $\xi_{ea,t}^{ci}$ a demand shock.[2] For the coefficients on the expected and lagged output gap as well as trend output growth we follow the cross-parameter restrictions in the NAWM.

## 4.4 Phillips Curve

We specify a Phillips curve for domestic producer-price inflation

$$
\begin{aligned}
\widehat{\pi}_{ea,t}^{ppi} = {} & \widehat{\pi}_{ea,t}^T + \beta_{ea} \, \alpha_{ea}^{\pi,\pi} \left(E_t \widehat{\pi}_{ea,t+1}^{ppi} - E_t \widehat{\pi}_{ea,t+1}^T\right) + \frac{1 - \alpha_{ea}^{\pi,\pi}}{\beta_{ea}} \left(\widehat{\pi}_{ea,t-1}^{ppi} - \widehat{\pi}_{ea,t}^T\right) \\
& + \left(1 - \alpha_{ea}^{\pi,\pi}\right) \left(E_t \widehat{\pi}_{ea,t+1}^T - \widehat{\pi}_{ea,t}^T\right) + \alpha_{ea}^{\pi,mc} \, \widehat{mc}_{ea,t} - \xi_{ea,t}^{\pi} \quad \textbf{(M3)}
\end{aligned}
$$

where $\widehat{mc}_{ea,t}$ denotes real marginal costs defined in (**M4**) below, $\widehat{\pi}_{ea,t}^T$ the central bank's CPI inflation target and $\xi_{ea,t}^{\pi}$ is a productivity or cost shock.[3] We again adopt cross-parameter restrictions from the NAWM.

Marginal costs are defined to be a function of domestic real output, the real price of oil in domestic currency and the real price of imported intermediates in domestic currency

$$
\begin{aligned}
\widehat{mc}_{ea,t} = {} & \alpha_{ea}^{mc,y} \widehat{y}_{ea,t} + \alpha_{ea}^{mc,\pi^{ppi}} \Big\{ \alpha_{ea}^{mc,oil} \Big(\widehat{Q}_{ea,t} + \widehat{p}_t^{oil} - \widehat{p}_{ea,t}^{ry}\Big) \\
& + \left(1 - \alpha_{ea}^{mc,oil}\right) \Big[\omega_{ea,us}^M \Big(\widehat{Q}_{ea,t} \widehat{p}_{us,t}^{ry} - \widehat{p}_{ea,t}^{ry}\Big) + \omega_{ea,op}^M \Big(\widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{p}_{ea,t}^{ry}\Big)\Big]\Big\}.
\end{aligned} \quad \textbf{(M4)}
$$

with $\omega_{i,j}^M$ the bilateral import weights and $\widehat{p}_t^{oil}$ the real price of oil (relative to US CPI prices) in US dollars.

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[2] The inclusion of lags of consumption and investment can be motivated by the presence of habit formation in consumption and adjustment costs in investment.

[3] The central bank's inflation target $\widehat{\pi}_{ea,t}^T$ refers to CPI inflation. In turn, CPI inflation is determined by domestic and foreign PPI inflation given import weights and home-bias parameters, as well as changes in real exchange rates and oil-price inflation. In a future version of ECB-Global the implied PPI rather than the CPI inflation target will enter the Phillips curve.

## 4.5 Consumer price index

Consumer prices result from a combination of domestic and foreign producer prices as well as oil prices, all expressed in domestic currency. Specifically, consumer prices are defined by the following equation

$$0 = \bar{\omega}_{ea}^{oil} \cdot \left( \widehat{Q}_{ea,t} + \widehat{p}_t^{oil} \right) + (1 - \bar{\omega}_{ea}^{oil}) \alpha_{ea}^{H} \cdot \widehat{p}_{ea,t}^{ry} \tag{M5}$$
$$+ (1 - \bar{\omega}_{ea}^{oil})(1 - \alpha_{ea}^{H}) \left[ \omega_{ea,us}^{M^{nonoil}} \left( \widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry} \right) + \omega_{ea,op}^{M^{nonoil}} \left( \widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry} \right) \right].$$

with $\bar{\omega}_{ea}^{oil}$ denoting the share of oil in the consumption basket, $\alpha_{ea}^{H}$ a measure of home bias in consumption, $(1 - \alpha_{ea}^{H})$ the share of imported consumption goods in total consumption and $\omega_{ea,us}^{M^{nonoil}}$ the share of non-oil imports of the euro area that originates in the US.

## 4.6 Monetary Policy

The central bank sets the nominal policy rate, $\widehat{i}_t^s$, according to the following rule

$$\widehat{i}_{ea,t}^s = \alpha_{ea}^{i^s,i^s} \widehat{i}_{ea,t-1}^s + \left( 1 - \alpha_{ea}^{i^s,i^s} \right) \left[ \widehat{\pi}_{ea,t}^T + \alpha_{ea}^{i^s,\pi^T} \left( \widehat{\pi}_{ea,t}^{cpi} - \widehat{\pi}_{ea,t}^T \right) + \alpha_{ea}^{i^s,y} \widehat{y}_{ea,t} \right.$$
$$\left. + \alpha_{ea}^{i^s,\Delta y} \left( \widehat{y}_{ea,t} - \widehat{y}_{ea,t-1} \right) + \alpha_{ea}^{i^s,\pi} \left( \widehat{\pi}_{ea,t}^{cpi} - \widehat{\pi}_{ea,t-1}^{cpi} \right) \right] + \xi_{ea,t}^{i^s} \tag{M6}$$

where $\xi_{ea,t}^{i^s}$ is a monetary policy shock. We assume that the central bank's inflation target evolves according to

$$\widehat{\pi}_{ea,t}^T = \rho_{ea}^{\pi^T} \widehat{\pi}_{ea,t-1}^T + \xi_{ea,t}^{\pi^T}, \tag{M7}$$

and that the real policy rate is implied by the Fisher-equation

$$\widehat{r}_{ea,t}^s = \widehat{i}_{ea,t}^s - E_t \widehat{\pi}_{ea,t+1}^{cpi}. \tag{M8}$$

## 4.7 Fiscal Policy

### 4.7.1 Government debt

Real government debt, $\widetilde{b}_{ea,t}$, (relative to GDP in per capita terms) evolves according to

$$\widetilde{b}_{ea,t} = \widetilde{g}_{ea,t} - \widetilde{t}_{ea,t} \tag{M9}$$
$$+ (1 + r_{ea}^{g,ss} - \Delta y_{ea}^{ss}) \left[ \widetilde{b}_{ea,t-1} + b_{ea}^{ss} \left( \frac{\widehat{i}_{ea,t-1}^g}{1 + i_{ea}^{g,ss}} - \frac{\widehat{\pi}_{ea,t}}{1 + \pi_{ea}^{cpi,ss}} - \frac{\widehat{\Delta y}_{ea,t}}{1 + \Delta y_{ea}^{ss}} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry} \right) \right].$$

where $\widetilde{g}_{ea,t}$ and $\widetilde{t}_{ea,t}$ denote real per capita government expenditures and taxes respectively, and $\widehat{i}_{ea,t}^g$ is the nominal interest rate on government debt, and government expenditures are given by

$$\widetilde{g}_{ea,t} = g_{ea,t} - g_{ea}^{ss} = g_{ea}^{ss} \cdot \widehat{g}_{ea,t} = g_{ea}^{ss} \cdot (\widehat{g}_{ea,t} - \widehat{y}_{ea,t}^{ppi}). \tag{M10}$$

### 4.7.2 Fiscal rules for spending and revenues

We specify symmetric fiscal rules for government expenditures $\widehat{g}_{ea,t}$ and revenues $\widehat{\tau}_{ea,t}$ (see Leeper et al., 2010; Ratto et al., 2009; Ploedt and Reicher, 2014; Coenen et al., 2013)

$$\widehat{g}_{ea,t} = \alpha_{ea}^{g,g} \widehat{g}_{ea,t-1} - (1 - \alpha_{ea}^{g,g}) \alpha_{ea}^{g,\mathcal{B}} \widetilde{\mathcal{B}}_{ea,t-1} - (1 - \alpha_{ea}^{g,g}) \alpha_{ea}^{g,y} \widehat{y}_{ea,t} + \xi_{ea,t}^{g}, \tag{M11}$$

and

$$\widehat{\tau}_{ea,t} = \alpha_{ea}^{\tau,\tau} \widehat{\tau}_{ea,t-1} + (1 - \alpha_{ea}^{\tau,\tau}) \alpha_{ea}^{\tau,\mathcal{B}} \widetilde{\mathcal{B}}_{ea,t-1} + (1 - \alpha_{ea}^{\tau,\tau}) \alpha_{ea}^{\tau,y} \widehat{y}_{ea,t} + \xi_{ea,t}^{\tau}. \tag{M12}$$

where $\widetilde{\mathcal{B}}_{ea,t}$ is the absolute deviation of the debt-to-GDP ratio from its steady-state level.

## 4.8 Trade

All economies export and import non-oil goods. Also, all economies use oil in their production, and all except for the OP need to import oil to do so. Oil is produced and exported only by the OP. We model the determination of both oil and non-oil imports in behavioural equations. In turn, an economy's exports are given by the sum of all other economies' bilateral imports from the former. As a consequence, our setup for trade ensures that global exports equal global imports. In order to facilitate the exposition, we lay out the structure of the trade block focusing on the euro area as domestic economy and considering only the US and the OP as trading partners. More details on the derivations of all the trade equations below can be found in the Model Appendix C.1.

### 4.8.1 Oil and non-oil imports

We model the euro area's bilateral non-oil imports from the US as a function of the PPI price of US goods—assuming producer-currency pricing—in euro relative to euro area CPI prices and as a function of euro area domestic demand (given by the sum of private consumption, investment and government expenditures) $\widehat{m}_{ea,us,t}^{nonoil} = -\theta_{ea}^{nonoil} \cdot (\widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry}) + \widehat{da}_{ea,t}$, in which $\theta_{ea}^{nonoil}$ represents the price elasticity of euro area import demand and $\widehat{da}_{ea,t}$ domestic absorption. Oil imports, $\widehat{m}_{ea,t}^{oil}$, are modelled analogously, except that we assume that governments do not consume oil. Specifically, similarly to Medina and Soto (2005), we model the euro area's real oil import demand as

$$\widehat{m}_{ea,t}^{oil} = -\theta_{ea}^{oil} (\widehat{Q}_{ea,t} + \widehat{p}_{t}^{oil}) + \widehat{ci}_{ea,t}. \tag{M13}$$

where $\widehat{p}_t^{oil}$ is the real price of oil (relative to US CPI prices) in US dollars, $\theta_{ea}^{oil}$ is the price elasticity of oil demand.

### 4.8.2 Import aggregation

For the aggregation of non-oil and oil imports and of bilateral imports, denomination becomes important. Specifically, due to differences in the denomination of real import variables across economies we need to aggregate *nominal* quantities. To do so, we assume that real bilateral non-oil imports are denominated in source-economy output goods and real oil imports are denominated in barrels of oil.

**Total non-oil imports**    Based on these assumptions, the euro area's per capita total real non-oil imports is the sum of non-oil imports from the trading partner countries

$$\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t}^{nonoil} = \widehat{da}_{ea,t} + \omega_{ea,us}^{M^{nonoil}}\left[\widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry} - \theta_{ea}^{nonoil}\left(\widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry}\right)\right]$$
$$+ \omega_{ea,op}^{M^{nonoil}}\left[\widehat{Q}_{ea,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t} - \theta_{ea}^{nonoil}\left(\widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry}\right)\right] \quad \textbf{(M14)}$$

with $\widehat{m}_{ea,us,t}^{nonoil}$ non-oil imports discussed above.

**Total imports**    For the euro area and all other non-OP economies, total per capita real imports are given by the sum of real non-oil and oil imports

$$\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t} = \left(1 - \zeta_{ea}^{M^{oil}}\right)\left(\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t}^{nonoil}\right) + \zeta_{ea}^{M^{oil}}\left(\widehat{Q}_{ea,t} + \widehat{p}_t^{oil} + \widehat{m}_{ea,t}^{oil}\right), \quad \textbf{(M15)}$$

where $\zeta_{ea}^{M^{oil}}$ is the share of oil imports in euro area total imports. Since the OP is importing only non-oil goods, its total imports equal non-oil imports

$$\widehat{m}_{op,t} = \widehat{m}_{op,t}^{nonoil}. \quad \textbf{(M16)}$$

### 4.8.3 Exports

In order to ensure global consistency of trade we specify the euro area's total nominal exports to the rest of the world as the sum of all other economies nominal bilateral imports from the euro area. For non-OP economies such as the euro area total real exports equal total real non-oil

exports, $\widehat{x}_{ea} = \widehat{x}_{ea}^{nonoil}$, with non-oil exports defined as

$$
\begin{aligned}
\widehat{x}_{ea,t} =& \omega_{ea,us}^{X^{nonoil}} \cdot \widehat{m}_{us,ea,t}^{nonoil} + \omega_{ea,op}^{X^{nonoil}} \cdot \widehat{m}_{op,ea,t}^{nonoil} \\
=& \omega_{ea,us}^{X^{nonoil}} \left[ \widehat{da}_{us,t} - \theta_{us}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{p}_{ea,t}^{ry}) \right] \\
& + \omega_{ea,op}^{X^{nonoil}} \left[ \widehat{da}_{op,t} - \theta_{op}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{Q}_{op,t} + \widehat{p}_{ea,t}^{ry}) \right].
\end{aligned}
\tag{M17}
$$

with $\omega_{ea,j}^{X^{nonoil}}$ the share of euro area exports that is sent to economy $j$ in total euro area exports.

For the OP which export oil and non-oil goods we have (recall that oil imports are denominated in barrels of oil)

$$
\widehat{p}_{op,t}^{ry} + \widehat{x}_{op,t} = (1 - \zeta_{op}^{X^{oil}}) \cdot \left( \widehat{p}_{op,t}^{ry} + \widehat{x}_{op,t}^{nonoil} \right) + \zeta_{op}^{X^{oil}} \cdot \left( \widehat{Q}_{op,t} + \widehat{p}_{t}^{oil} + \widehat{x}_{op,t}^{oil} \right),
\tag{M18}
$$

where $\zeta_{op}^{X^{oil}}$ is the share of oil exports in the OP's total exports, and the OP's total real oil exports are given by the weighted sum of country-specific oil imports.

### 4.8.4 Global imports and exports

**Global imports**   Due to differences in the denomination of economies' imports, we consider nominal imports in US dollars for the aggregation of global imports and denominate real global imports in US output goods. Global real per capita imports $\widehat{m}_t$ are then defined as

$$
\begin{aligned}
\widehat{p}_{us,t}^{ry} + \widehat{m}_t =& \chi_{ea}^{M} \cdot (\widehat{m}_{ea,t} + \qquad\qquad\qquad\qquad\qquad \widehat{p}_{ea,t}^{ry} - \widehat{Q}_{ea,t}) \\
& + \chi_{op}^{M} \cdot (\widehat{m}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t}) + \chi_{us}^{M} \cdot (\widehat{m}_{us,t} + \widehat{p}_{us,t}^{ry}),
\end{aligned}
\tag{M19}
$$

where $\chi_i^M$ denotes the share of country $i$'s imports in global imports.

**Global exports**   Similar to global imports, we denominate global total (oil and non-oil) exports in US output goods, so that global exports in per capita terms $\widehat{x}_t$ read as

$$
\begin{aligned}
\widehat{p}_{us,t}^{ry} + \widehat{x}_t = \chi_{ea}^{X} \cdot (\widehat{x}_{ea,t} + \widehat{p}_{ea,t}^{ry} - \widehat{Q}_{ea,t}) \\
+ \chi_{op}^{X} \cdot (\widehat{x}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t}) + \chi_{us}^{X} \cdot (\widehat{x}_{us,t} + \widehat{p}_{us,t}^{ry}).
\end{aligned}
\tag{M20}
$$

As we assume balanced trade for each economy in the steady state, each economies' share in global exports equals the corresponding share in global imports, i.e. $\chi_i^X = \chi_i^M$.

### 4.8.5 Real effective exchange rates

We define the euro area's real effective exchange rate as

$$\widehat{Q}_{ea,t}^{eff} = \omega_{ea,us}^{X^{nonoil}} \cdot \widehat{Q}_{ea,t} + \omega_{ea,op}^{X^{nonoil}} \cdot \left( \widehat{Q}_{ea,t} - \widehat{Q}_{op,t} \right), \tag{M21}$$

where $\omega_{ea,j}^{X^{nonoil}}$ is the share of euro area exports that is sent to economy $j$ in total euro area exports.

## 4.9 Oil market

ECB-Global features two types of oil shocks: (i) oil demand shocks endogenous to global growth and (ii) exogenous oil supply shocks.[4] More specifically, we assume oil is used in all economies so that global oil demand $\widehat{oil}_t^d$ is given by the sum of oil imports of oil-importing countries and OP oil demand

$$\widehat{oil}_t^d = \varpi_{us}^{C^{oil}} \widehat{m}_{us,t}^{oil} + \varpi_{ea}^{C^{oil}} \cdot \widehat{m}_{ea,t}^{oil} + \varpi_{op}^{C^{oil}} \cdot \widehat{oil}_{op,t}^d, \tag{M22}$$

where $\varpi_i^{C^{oil}}$ represents economy $i$'s share in global oil consumption, and OP oil demand is given by

$$\widehat{oil}_{op,t}^d = -\theta_{op}^{oil}(\widehat{Q}_{op,t} + \widehat{p}_t^{oil}) + \widehat{ci}_{op,t}. \tag{M23}$$

In equilibrium, oil demand equals oil supply so that

$$\widehat{oil}_t^d = \widehat{oil}_t^s = \theta^{oil,s}\widehat{p}_t^{oil} + \xi_t^{oil}, \tag{M24}$$

where $\theta^{oil,s}$ reflects the price elasticity of oil supply and $\xi_t^{oil}$ is an oil supply shock.

We assume there is a positive trend in oil prices reflecting that demand is growing faster than supply, specifying

$$\widehat{\pi}_t^{oil} = \pi_t^{oil} - \pi^{oil,ss} = \pi_t^{oil} - \Delta\overline{oil}, \tag{M25}$$

where $\pi^{oil,ss}$ represents steady-state oil-price inflation that is given by the difference between

---

[4]In the current version of ECB-Global we abstain from modelling "oil-specific" demand shocks. Such oil-specific demand shocks change the demand for oil for a given level of economic activity. Examples for oil-specific demand shocks are precautionary shocks to the demand for oil inventories in the face of geopolitical tensions. These oil-specific demand shocks have the same qualitative effects on output and inflation as oil supply shocks, namely dampening economic activity and increasing inflation, albeit being more short-lived. This taxonomy of oil supply, activity-driven oil demand, and oil-specific demand shocks is consistent with a large literature (see Kilian, 2009; Peersman and Van Robays, 2009, 2012; Kilian and Murphy, 2012).

the growth rate of trend oil consumption and production, $\Delta \overline{oil}$. Furthermore, we have that

$$\widehat{\pi}_t^{oil} = \widehat{p}_t^{oil} - \widehat{p}_{t-1}^{oil} + \widehat{\pi}_{us,t}^{cpi}. \tag{M26}$$

Noting that oil supply necessarily equals oil demand in equilibrium, we also have

$$\Delta \widehat{oil}_t^s - \Delta \overline{oil}^s = \widehat{oil}_t^s - \widehat{oil}_{t-1}^s = \widehat{oil}_t^d - \widehat{oil}_{t-1}^d. \tag{M27}$$

## 4.10   Financial sector

Macro-financial linkages in ECB-Global arise through changes in (i) the interbank interest rate spread, (ii) credit supply constraints reflected in bank-lending tightness, (iii) the sovereign credit risk premium, and (iv) equity prices. Each of these variables is subject to cross-country spillovers in the sense that domestic financial variables directly depend on their foreign analogues.

### 4.10.1   Interbank interest rate spread

The real interbank interest rate spread $\widehat{\varsigma}_{i,t}^b$ is a wedge between the real policy rate $\widehat{r}_{i,t}^s$ and the real short-term interbank rate $\widehat{r}_{i,t}^3$

$$\widehat{r}_{ea,t}^3 = \widehat{r}_{ea,t}^s + \widehat{\varsigma}_{ea,t}^b. \tag{M28}$$

The interbank rate spread evolves according to

$$\begin{aligned}
\widehat{\varsigma}_{ea,t}^b = {} & \alpha_{ea}^{\varsigma^b,\varsigma^b} \cdot \left[ \varphi_{ea}^{\varsigma^b} \left( \omega_{ea,us}^F \widehat{\varsigma^b}_{us,t} + \omega_{ea,op}^F \widehat{\varsigma}_{op,t}^b \right) \right] \\
& + \left( 1 - \alpha_{ea}^{\varsigma^b,\varsigma^b} \right) \cdot \left( \alpha_{ea}^{\varsigma^b,lag} \widehat{\varsigma}_{ea,t-1}^b - \alpha_{ea}^{\varsigma^b,\widehat{y}} \widehat{y}_{ea,t} \right) + \xi_{ea,t}^b,
\end{aligned} \tag{M29}$$

where $\omega_{ij}^F$ reflects the weight of country $j$ in country $i$'s overall financial integration with the rest of the world. The parameter $\alpha_i^{\varsigma^b,\varsigma^b}$ can be interpreted as the degree of economy $i$'s financial market integration and its overall susceptibility to financial spillovers from the rest of the world. In the polar case of $\alpha_i^{\varsigma^b,\varsigma^b} = 1$, economy $i$'s financial markets are perfectly integrated with those in the rest of the world, and the domestic spread equals the global spread. The dependence of the interbank interest rate spread on the output gap is in line with the recent literature on financial frictions (see, for example, Gertler and Karadi, 2011). The mechanism underlying this feedback loop is motivated by the procyclical variation in banks' balance sheets which follow fluctuations in output.

### 4.10.2 Bank-lending tightness

In order to incorporate the effects of variations in private-sector credit risk on the macroeconomy, we consider bank-lending tightness, $\widehat{blt}_{ea,t}$, as a measure of credit supply constraints. Specifically,

$$
\begin{aligned}
\widehat{blt}_{ea,t} = \alpha_{ea}^{blt,blt} \cdot \widehat{blt}_{ea,t-1} + \left( 1 - \alpha_{ea}^{blt,blt} \right) \cdot \Big[ & \alpha_{ea}^{blt,y4} \left( E_t \widehat{y}_{ea,t+4} - \widehat{y}_{ea,t} \right) - \alpha_{ea}^{blt,y} \left( \widehat{y}_{ea,t} - \widehat{y}_{ea,t-4} \right) \\
& - \alpha_{ea}^{blt,rs} \left( \widehat{r}_{ea,t}^s - \widehat{r}_{ea,t-1}^s \right) + \varphi_{ea}^{blt} \left( \omega_{ea,us}^F \widehat{blt}_{us,t} + \omega_{ea,op}^F \widehat{blt}_{op,t} \right) \Big] + \xi_{ea,t}^{blt}.
\end{aligned}
\tag{M30}
$$

Consistent with the findings in Bassett et al. (2014), bank-lending tightness is specified to be determined by its own one-quarter lag, the expected one-year ahead year-on-year growth rate of real GDP, the change in the real policy rate and a cross-country spillover term.

### 4.10.3 Sovereign credit risk

We also consider a sovereign credit-risk premium $\widehat{\varsigma}_{ea,t}^g$ that depends on the debt-to-GDP ratio and foreign sovereign credit-risk premia

$$
\widehat{\varsigma}_{ea,t}^g = \alpha_{ea}^{\varsigma^g,\varsigma^g} \cdot \widehat{\varsigma}_{ea,t-1}^g + (1 - \alpha_{ea}^{\varsigma^g,\varsigma^g}) \cdot \alpha_{ea}^{\varsigma^g,\mathcal{B}} \cdot \widetilde{\mathcal{B}}_{ea,t} + \varphi_{ea}^{\varsigma^g} \cdot \left( \omega_{ea,us}^F \widehat{\varsigma}_{us,t}^g + \omega_{ea,op}^F \widehat{\varsigma}_{op,t}^g \right) + \xi_{ea,t}^{\varsigma^g}
\tag{M31}
$$

where $\widetilde{\mathcal{B}}_{i,t}$ denotes the absolute deviation of the debt-to-GDP ratio from its steady-state level. The sovereign credit risk premium is a wedge between the real policy rate $\widehat{r}_{i,t}^s$ and the real short-term sovereign bond yield $\widehat{r}_{i,t}^g$

$$
\widehat{r}_{ea,t}^g = \widehat{r}_{ea,t}^s + \widehat{\varsigma}_{ea,t}^g.
\tag{M32}
$$

Term premia in long-term sovereign bond yields are specified as

$$
\widehat{r}_{ea,t}^l = \alpha^{r^s,r^s} \cdot \widehat{r}_{ea,t}^s + \widehat{\varsigma}_{ea,t}^g + \alpha^{r^l,r^l} \cdot E_t \widehat{r}_{ea,t+1}^l + \xi_{ea,t}^{r^l}.
\tag{M33}
$$

### 4.10.4 Private-sector credit risk premium

The private-sector credit risk premium is the sum of bank-lending tightness and the sovereign credit-risk premium

$$
\widehat{\varpi}_{ea,t} = \alpha_{ea}^{\varpi,blt} \cdot \widehat{blt}_{ea,t} + \alpha_{ea}^{\varpi,\varsigma^g} \cdot \widehat{\varsigma}_{ea,t}^g + \varphi_{ea}^{\varpi} \cdot \left( \omega_{ea,us}^F \widehat{\varpi}_{us,t} + \omega_{ea,op}^F \widehat{\varpi}_{op,t} \right)
\tag{M34}
$$

and is also subject to cross-country spillovers.

### 4.10.5 Equity prices

We assume equity prices are determined according to a Tobin's Q relationship (see Christiano et al., 2005; Gilchrist and Zakrajsek, 2012)

$$\widehat{q}_{ea,t} = \alpha_{ea}^{q,q} E_t \widehat{q}_{ea,t+1} - \alpha_{ea}^{q,r^3} \cdot \left(\widehat{r}_{ea,t}^3 + \widehat{\varpi}_{ea,t}\right) + \alpha_{ea}^{q,y} E_t \widehat{y}_{ea,t+1} \tag{M35}$$
$$+ \alpha_{ea}^{q,q} \cdot \left(E_t \Delta \overline{q}_{ea,t+1} - \Delta \overline{q}^{ss}\right) + \varphi_{ea}^q \cdot \left(\omega_{ea,us}^F \widehat{q}_{us,t} + \omega_{ea,op}^F \widehat{q}_{op,t}\right) + \xi_{ea,t}^q.$$

The arbitrage condition for the value of installed capital states that the value of capital today depends positively on the expected future marginal product of capital and the expected future value of capital, and negatively on the rate of return required by households—that is, the real interest rate relative to the inter-temporal shock to preferences. We consider the output gap as a proxy for the future marginal product of capital. Similar to the other financial variables, equity prices are subject to spillovers from foreign equity prices.

## 4.11 Net foreign asset position

An economy's aggregate net foreign asset position $\widetilde{nfa}_{ea,t}$ (in per capita terms and relative to GDP) evolves according to

$$\widetilde{nfa}_{ea,t} = \left(1 + r_{ea}^{l,ss} - \Delta y_{ea}^{ss}\right) \cdot \widetilde{nfa}_{ea,t-1} + \widetilde{x}_{ea,t} - \widetilde{m}_{ea,t} \tag{M36}$$

where $\widetilde{x}_{ea,t}$ and $\widetilde{m}_{ea,t}$ are per capita exports and imports relative to GDP respectively.

## 4.12 Uncovered interest rate parity

The uncovered interest rate parity condition is given by

$$\widehat{r}_{ea,t}^3 + \widehat{\varpi}_{ea,t} - \left(\widehat{r}_{us,t}^3 + \widehat{\varpi}_{us,t} - \alpha_{ea}^{nfa} \cdot \widetilde{nfa}_{ea,t}\right) = E_t \widehat{Q}_{ea,t+1} - \widehat{Q}_{ea,t}. \tag{M37}$$

The home economy's net foreign asset position relative to GDP enters as a premium on holdings of foreign debt. The premium on foreign debt captures the costs for domestic agents of engaging in transactions in the international asset market and ensures the stationarity of the net foreign asset position (Benigno, 2009; Schmitt-Grohe and Uribe, 2003).

## 4.13 China

As outlined below, China features a different monetary policy rule and UIP condition. The rest of China's economy is modelled symmetrically to that of the other countries in ECB-Global.

### 4.13.1 Monetary policy

China's monetary policy includes a response to changes in the nominal exchange rate in order to ensure limited variations in the external value of its currency. Specifically,

$$
\begin{aligned}
\widehat{i}^s_{ch,t} =& \alpha^{i^s,i^s}_{ch} \widehat{i}^s_{ch,t-1} + \left(1 - \alpha^{i^s,i^s}_{ch}\right) \left[\widehat{\pi}^T_{ch,t} + \alpha^{i^s,\pi^T}_{ch} \left(\widehat{\pi}^{cpi}_{ch,t} - \widehat{\pi}^T_{ch,t}\right) + \alpha^{i^s,y}_{ch} \widehat{y}_{ch,t}\right] \\
& + \alpha^{i^s,\Delta S}_{ch} \left(\Delta S_{ch,t} - \Delta \overline{S}_{ch}\right) + \xi^\varrho_{ch,t} + \xi^{i^s}_{ch,t},
\end{aligned} \tag{M38}
$$

where $\Delta S_{ch,t}$ is the change in the nominal exchange rate vis-à-vis a basket of advanced economies' currencies (consisting of the US dollar, the euro, the Japanese yen and the pound sterling) and $\varepsilon^\varrho_{ch,t}$ is a shock to the reserve requirement ratio.

Borrowing from the GPM, the reserve requirement ratio $\widehat{\varrho}_{ch,t}$ is set according to a Taylor-rule type relationship

$$
\widehat{\varrho}_{ch,t} = \rho^\varrho_{ch} \widehat{\varrho}_{ch,t-1} + \left(1 - \rho^\varrho_{ch}\right) \left[\alpha^{\varrho,y}_{ch} \widehat{y}_{ch,t} + \alpha^{\varrho,\pi}_{ch}(E_t \widehat{\pi}^{cpi}_{ea,t+3} - \widehat{\pi}^T_{ch,t})\right] + \varepsilon^{\varrho,}_{ch,t} + \alpha^{\varrho,\varepsilon^{i^s}}_{ch} \varepsilon^{i^s}_{ch,t}.
$$

The trend reserve requirement evolves as

$$
\Delta \overline{\varrho}_{ch,t} = \alpha^{\overline{\varrho}}_{ch} \Delta \overline{\varrho}_{ch,t-1} + \overline{\varrho}^{ss}_{ch} \left(1 - \alpha^{\overline{\varrho}}_{ch}\right) + \varepsilon^{\Delta \overline{\varrho}}_{ch,t}. \tag{M39}
$$

In order to impact aggregate demand, we enter the reserve requirement in China's IS-curve

$$
\begin{aligned}
\widehat{ci}_{ch,t} =& \alpha^{ci,ci}_{ch} \widehat{ci}_{ch,t+1} + \widehat{ci}_{ch,t-1} \left(1 - \alpha^{ci,ci}_{ch}\right) - \left(\widehat{r^3}_{ch,t} + \widehat{\varpi}_{ch,t}\right) \alpha^{ci,r^3}_{ch} + \alpha^{ci,q}_{ch} \widehat{q}_{ch,t} \\
& + \alpha^{ci,ci}_{ch} \left(\Delta \overline{y}^{cpi}_{ch,t+1} - \Delta \overline{y}^{cpi,ss}_{ch}\right) - \left(1 - \alpha^{ci,ci}_{ch}\right) \left(\Delta \overline{y}^{cpi}_{ch,t} - \Delta \overline{y}^{cpi,ss}_{ch}\right) - \alpha^{ci,\varrho}_{ch} \widehat{\varrho}_{ch,t} + \xi^{ci}_{ch,t}.
\end{aligned} \tag{M40}
$$

### 4.13.2 Exchange rate regime, net foreign assets and UIP

For the evolution of China's exchange rate we assume a friction in the uncovered interest rate parity

$$
\begin{aligned}
& \theta^{uip}_{ch} \left[\widehat{r^3}_{ch,t} + \widehat{\varpi}_{ch,t} + E_t \widehat{\pi}^{cpi}_{ch,t+1} - \left(\widehat{r^3}_{us,t} + \widehat{\varpi}_{us,t} + E_t \widehat{\pi}^{cpi}_{us,t+1} - \widetilde{nfa}_{ch,t} \alpha^{nfa}_{ch}\right)\right] \\
& + \left(1 - \theta^{uip}_{ch}\right) \left(\Delta \overline{Q}_{ch,t} - \Delta \overline{Q}^{ss}_{ch}\right) = E_t \widehat{Q}_{ch,t+1} - \widehat{Q}_{ch} + E_t \widehat{\pi}^{cpi}_{ch,t+1} - \widehat{\pi}^{cpi}_{us,t+1} + \xi^{uip}_{ch,t},
\end{aligned} \tag{M41}
$$

where $0 \leq \theta^{uip}_{ch} \leq 1$. In particular, if $\theta^{uip}_{ch} = 1$ the dynamics of China's nominal exchange rate are pinned down by the usual uncovered interest rate parity logic. In contrast, if $\theta^{uip}_{ch} = 0$ the change in China's nominal exchange rate is given by the deviation of the trend real exchange rate from its steady state value.

## 4.14 Oil producers

Besides the fact that they export oil, the OP differ from the other economies in ECB-Global as oil export revenues affect consumption and investment through the IS curve and also determine government spending.

### 4.14.1 IS Curve

We introduce oil export revenues (in OP PPI) in the IS curve of the OP in order to reflect that private investment and consumption in oil-producing economies typically depend on oil export revenues $\widehat{x}_{op,t}^{oil}$ through transfers, tax rates and subsidies

$$\widehat{ci}_{op,t} = \alpha_{op}^{ci,ci} E_t \widehat{ci}_{op,t+1} + \left(1 - \alpha_{op}^{ci,ci}\right) \widehat{ci}_{op,t-1} - \alpha_{op}^{ci,r^3} \left(\widehat{r^3}_{op,t} + \widehat{\varpi}_{op,t}\right) + \alpha_{op}^{ci,q} \widehat{q}_{op,t} \qquad \text{(M42)}$$
$$+ \alpha_{op}^{ci,ci} \left(E_t \Delta \overline{y}_{op,t+1} - \Delta \overline{y}^{ss}\right) - \left(1 - \alpha_{op}^{ci,ci}\right)\left(\Delta \overline{y}_{op,t} - \Delta \overline{y}^{ss}\right) + \alpha_{op}^{ci,oil} \widehat{x}_{op,t}^{oil} + \xi_{op,t}^{ci},$$

where oil export revenues are given by

$$\widehat{x}_{op,t}^{oil} = \widehat{Q}_{op,t} + \widehat{p}_t^{oil} + \widehat{x}_{op,t}^{oil} - \widehat{p}_{op,t}^{ry}. \qquad \text{(M43)}$$

### 4.14.2 Fiscal rule for government expenditure

A reduction in export revenues also typically impinges on public finances of oil-producing economies, as the oil sector generates a large part of fiscal revenues.[5] We therefore assume that a decline in oil export revenues imposes a fiscal retrenchment and introduce them in the fiscal rule for government expenditure

$$\widehat{g}_{op,t} = \alpha_{op}^{g,g} \widehat{g}_{op,t-1} - (1 - \alpha_{op}^{g,g}) \cdot \alpha_{op}^{g,\mathcal{B}} \widetilde{\mathcal{B}}_{op,t-1} - (1 - \alpha_{op}^{g,g}) \cdot \alpha_{op}^{g,y} \widehat{y}_{op,t} + \alpha_{op}^{g,xoil} \widehat{x}_{op,t}^{oil,ppi} + \xi_{op,t}^{g}, \text{(M44)}$$

## 4.15 Resource constraint

Finally, for all economies the market clearing condition for real aggregate demand in per capita terms is given by

$$\widehat{p}_{ea,t}^{ry} + \widehat{y}_{ea,t} = \chi_i^{ci} \widehat{ci}_{ea,t} + \chi_i^{g} (\widehat{g}_{ea,t} + \widehat{p}_{ea,t}^{g}+) + \chi_i^{X} (\widehat{x}_{ea,t} - \widehat{m}_{ea,t}). \qquad \text{(M45)}$$

We assume that the price of government expenditures relative to CPI follows

$$\widehat{p}_{ea,t}^{rg} = \rho_{ea}^{\widehat{p}^{rg}} \widehat{p}_{ea,t-1}^{rg} + \xi_t^{\widehat{p}^{rg}}. \qquad \text{(M46)}$$

---

[5] According to Villafuerte and Lopez-Murphy (2010), for at least 31 of the oil producing countries examined in the study, oil revenues account for more than 25% of total fiscal revenue in the time period from 2005 to 2008.

### 4.16 List of shocks included in the model

The model features several exogenous shocks $\xi_{it}^\ell$, which are listed in Table 1. Shocks are all modelled as first-order autoregressive processes with autoregressive coefficient $\rho_i^\ell$ and i.i.d. innovations $\varepsilon_{it}^\ell$ with mean zero and standard deviation $\sigma_i^\ell$. In the table below we also list the i.i.d. innovations which enter some of the equations in ECB-Global.

Table 1
List of the exogenous shocks in ECB-Global

| Shock | Equation |
|---|---|
| $\xi^{ci}$ | IS curve |
| $\xi_t^{\Delta\overline{y}}$ | GDP growth rate |
| $\xi_t^{\pi}$ | Phillips curve |
| $\xi_t^{i^s}$ | Monetary policy rule |
| $\xi_t^{g}$ | Government expenditure |
| $\xi_t^{\tau}$ | Government revenues |
| $\xi_t^{oil}$ | Oil supply and demand |
| $\xi_t^{b}$ | Interbank rate spread |
| $\xi_t^{blt}$ | Bank lending tightness |
| $\xi_t^{\varsigma^g}$ | Sovereign credit risk premium |
| $\xi_t^{r^l}$ | Long-term premium |
| $\xi_t^{q}$ | Equity prices |
| $\varepsilon_{ea,t}^{\Delta\overline{q}}$ | Innovation to equity prices trend |
| $\xi_{ch,t}^{\varrho}$ | China's reserve requirement ratio |
| $\varepsilon_{ch,t}^{\Delta\overline{\varrho}}$ | Innovation to China's reserve requirement ratio trend |
| $\xi_{ch,t}^{uip}$ | China's uncovered interest parity |
| $\xi_t^{p^{r^g}}$ | Price of government expenditure relative to CPI |

## 5 Parameterisations

### 5.1 Calibration

Parameters in ECB-Global can be divided in three groups: (i) those that affect the deterministic steady state of the model, (ii) (bilateral) weights and (iii) those that have a structural interpretation. The first two groups of parameters include the contribution of each country block to global GDP, its share in global trade and financial exposure to other countries, which we calibrate using actual data. Sections 5.2 to 5.5 provide more details. The parameters that have a structural interpretation are parameterised through an informal "limited information" impulse response matching approach which ensures that ECB-Global exhibits dynamics that are consistent with the findings in the literature. Section 5.8 provides more details on this.

## 5.2 Steady-state values

These parameters pertain to the trend of the nominal exchange rate and of equity prices, the steady-state level of the inflation target, government bond yields, nominal rates, the measure of bank-lending tightness, the debt-to-GDP ratio and government spending (Table 3). The parameters are set equal to the averages of the corresponding data over 1990 to 2013. Given that in ECB-Global the rest of the world is defined as a residual, the steady-state values for its variables are defined as averages across the values of the economies which are included explicitly in ECB-Global. For the growth rate of GDP we assume instead that there is a common global trend, which is defined as the average of the growth rate of the other country blocks (excluding the rest of the world). Finally, the discount factor $\beta$ is calibrated on the basis of real long-term interest rates for all countries. For example, for the US its value is consistent with a real interest rate of 2.5%.

## 5.3 Parameterising shares and weights in the trade block

For the trade block we need to parameterise the share of oil imports in total imports for non-OP economies $\zeta_i^{M^{oil}}$ in Equation (M15), the share of oil exports in the OP's total exports $\zeta_{op}^{X^{oil}}$ in Equation (M18), bilateral shares of non-oil imports $\omega_{ij}^{M^{nonoil}}$ in Equation (M14), and bilateral shares of non-oil exports $\omega_{ij}^{X^{nonoil}}$ in (M19).

The values for the share of oil imports in total imports for non-OP economies $\zeta_i^{M^{oil}}$ and the share of oil exports in the OP's total exports $\zeta_{op}^{X^{oil}}$ can be determined easily based on IMF data according to

$$
\begin{aligned}
\zeta_i^{M^{oil}} &= s_i^{M^{oil}}/s_i^M, \quad i \neq op, \\
\zeta_{op}^{X^{oil}} &= s_{op}^{X^{oil}}/s_{op}^X,
\end{aligned}
$$

where $s_i^X$ and $s_i^M$ are the GDP shares of economies' total (non-oil and oil) exports and imports and $s_i^{M^{oil}}$ and $s_i^{X^{oil}}$ are the shares of oil imports and exports in GDP.[6]

We determine bilateral non-oil import shares according to

$$
\begin{aligned}
\omega_{ij}^{M^{nonoil}} &= \frac{\omega_{ij}^M \cdot s_i^M}{s_i^M - s_i^{M^{oil}}}, \qquad j \neq op,\ i \neq op \\
\omega_{i,op}^{M^{nonoil}} &= \frac{\omega_{i,op}^M \cdot s_i^M - s_i^{M^{oil}}}{s_i^M - s_i^{M^{oil}}}, \qquad i \neq op.
\end{aligned}
$$

---

[6]We assume $s_i^M = s_i^X$, consistent with the assumption of balanced steady state trade for individual economies.

The bilateral non-oil export shares of the OP are obtained from

$$
\begin{aligned}
X_{op,i}^{nonoil} &= \left( \omega_{i,op}^{M} \cdot s_i^{M} - s_i^{M^{oil}} \right) \cdot Y_i, \\
\omega_{op,i}^{X^{nonoil}} &= \frac{X_{op,i}^{nonoil}}{\sum_i X_{op,i}^{nonoil}},
\end{aligned}
$$

where $X_{op,i}^{nonoil}$ is nominal total non-oil exports of the OP. For the non-OP economies we have

$$
\omega_{ij}^{X^{nonoil}} = \omega_{ij}^{X}, \qquad i \neq op,
$$

as these do not export oil.

## 5.4 Adjusting the data underlying the parameterisations in order to ensure consistency of global trade

While it appears straightforward to ensure consistency of trade based on Section 5.3, three features in the data complicate the derivation of the implied values of the bilateral shares of non-oil imports $\omega_{ij}^{M^{nonoil}}$ and the bilateral shares of non-oil exports $\omega_{ij}^{X^{nonoil}}$. First, combining the bilateral total (oil and non-oil) export and import *shares* $\omega_{ij}^{X}$ and $\omega_{ij}^{M}$ from the IMF Direction of Trade Statistics with data for nominal GDP and export and import shares in GDP $s_i^{X}$ and $s_i^{M}$ does not imply consistent bilateral export and import flows. That is, in the data it is generally not the case that the exports of economy $i$ to economy $j$, $X_{ij}$, are equal to the imports of economy $j$ from economy $i$, $M_{ji}$, inconsistent with the corresponding assumption in ECB-Global. Second, summing up economies' trade balances in the data does not produce balanced global trade, inconsistent with the assumption in ECB-Global. Third, in the data economies do not have balanced trade, which is inconsistent with the steady state in ECB-Global. These three features of the data are important, as we can only expect the global trade balance in ECB-Global to close both in the steady state and in response to shocks as well as that the individual economies' trade balances close in the steady state when the data we use for the parametrisation of the trade shares in combination with GDP shares imply balanced global and country-specific trade. Therefore, prior to carrying out the calculations laid out in Section 5.3 we have to adjust the data in a way such that they are consistent with balanced global and country-specific trade. We explain in detail in Section C.5 how we do this.

## 5.5 Shares in global oil consumption

In order to determine the shares in global oil consumption we first obtain non-OP economies' oil imports and the associated shares in global oil imports according to

$$
\begin{aligned}
M_i^{oil} &= s_i^{M^{oil}} \cdot Y_i, \\
\varpi_i^{M^{oil}} &= \frac{M_i^{oil}}{\sum_j M_j^{oil}}.
\end{aligned}
$$

Then, we obtain the shares in global oil consumption as (given the share of global oil consumption of the OP)

$$
\varpi_i^{C^{oil}} = (1 - \varpi_{op}^{C^{oil}}) \cdot \varpi_i^{M^{oil}}, \qquad i \neq op.
$$

## 5.6 Share of oil and intermediate inputs in production

We calibrate $\alpha_{ea}^{mc,oil}$ in Equation (**M4**) for marginal costs using data from the World Input-Output Tables (WIOD; Dietzenbacher et al., 2013) based on the share of imported intermediates from other economies' "Coke, Refined Petroleum and Nuclear Fuel" sectors in the euro area's total imported intermediates. Similarly, we calibrate $\omega_{ea,i}^M$ based on WIOD data pertaining to the share of intermediate inputs that stem from economy $i$ in the euro area's total imported intermediates.

## 5.7 Share of imported consumption goods in total consumption

We calibrate the share of imported consumption goods in total consumption $(1-\alpha_{ea}^H)$ in Equation (**M6**) based on the WIOD database.

## 5.8 "Limited information" impulse response function matching

The calibration of the parameters in the model that have a structural interpretation are carried out balancing, on the one hand, having parameter values that are consistent with estimates in the literature and, on the other hand, implying dynamics which are in line with the empirical evidence. To this end, we carry out a systematic grid search for the main parameters, and thereby the implied impulse response functions. This approach—which could be dubbed a "limited information" impulse response function matching approach—draws extensively from the empirical and theoretical literature in order to find a configuration of parameter values that implies empirically plausible impulse response functions for standard shocks.

We implement this approach in two steps. In the first step, we set an initial value for the structural parameters by drawing on the literature, both on other semi-structural models such as the Andrle et al. (2015) and Carabenciov et al. (2013) as well as fully-structural models such

as Christiano et al. (2005), Altig et al. (2011), Smets and Wouters (2007), Christoffel et al. (2008), Gomes et al. (2012) and De Graeve (2008). The first step allows us to specify the value of the structural parameters in a way similar to that of other estimated models, but it does not necessarily imply empirically plausible dynamics in ECB-Global. We therefore fine tune the parameter values in a second step. In particular, we systematically vary the values of the key parameters and assess the plausibility of the implied impulse response functions. The parameter values are eventually chosen so as to minimise—informally—the distance between the impulse response functions implied by ECB-Global and those found in the literature.

# 6 Model properties

This section presents the dynamic properties of ECB-Global by considering the effects of three shocks: (i) a US monetary policy shock, (ii) a demand shock in China and (iii) an oil price (supply) shock. This set of shocks allows us to illustrate the main channels of propagation in ECB-Global and its possible policy applications. Specifically, the US monetary policy shock informs about the domestic and international transmission of financial shocks. The demand shock in China illustrates how shocks originating in the real economy transmit to the rest of the world. Finally, the oil price shock shows how developments in commodity markets impinge on the global economy.

## 6.1 US monetary policy shock

**Domestic effects** The predictions regarding the domestic effects of a monetary policy shock in ECB-Global are in line with existing studies (see, for example, Christiano et al., 2005; Smets and Wouters, 2007; Coibion, 2012). Specifically, in ECB-Global a 100 basis points annualised contractionary monetary policy shock lowers the output gap by about 0.6 percent after 2 quarters and annualised CPI (PPI) inflation by about 0.2% (0.15%) after four quarters (see Figure 2). The monetary policy shock transmits to output and inflation through financial, trade and oil channels. First, the monetary policy tightening dampens consumption and investment due to a rise of real interest rates. The slowdown of economic activity is amplified through financial accelerator mechanisms, which are reflected in the rise of the interbank interest rate spread as well as the private sector risk premium (composed of bank lending tightness and the sovereign risk premium). Equity prices also drop in response to the monetary policy tightening, further amplifying the deceleration of real activity through financial feedback loops. Second, the tightening of monetary policy also transmits through trade. On the one hand, the fall in domestic private demand lowers US imports and thereby supports GDP through an increase in net exports (income absorption effect). On the other hand, the appreciation of the US dollar resulting from the tightening of monetary policy stimulates imports and reduces exports, thereby low-

ering net exports and eventually GDP (expenditure switching effect). Finally, the decline in the US output gap as well as the negative spillovers to the rest of the world (see below) reduce oil prices, which supports the US economy through two channels. First, the fall in oil prices puts further downward pressure on US inflation, allowing US monetary policy to loosen which supports output and inflation. Second, the fall in oil prices dampens the fall in GDP through a rise in net exports, as the value of oil imports for a given amount of imported barrels of oil falls. Overall, the contractionary effects of a US monetary policy tightening dominate.

**Spillovers** The tightening of US monetary policy depresses output and inflation in the rest of the world (see Figure 3). The spillovers materialise through financial markets, trade and oil channels. First, the tightening of US financial conditions spills over to foreign financial markets and causes a global tightening of financial conditions, reflected in significant co-movements in interbank rate spreads, private-sector risk premia and equity prices. Second, as is the case for the US, several effects operate through trade. On the one hand, the fall in US import demand negatively weighs on the rest of the world's exports. On the other hand, the depreciations vis-à-vis the US dollar support the rest of the world's net exports through expenditure switching. Finally, as in the US, the decline in oil prices represents a positive spillover as it dampens inflation and thereby allows central banks to loosen monetary policy. At the same time, the fall in oil prices supports net exports as the value of a given amount of imported oil barrels falls. Overall, however, the contractionary spillovers dominate. As regards cross-country heterogeneities, China experiences larger GDP spillovers than other oil-importing countries because its central bank stabilises the exchange rate so that it does not benefit as much from a depreciation vis-à-vis the US dollar. Spillovers to oil-producing countries are also larger as they additionally experience a fall in oil export revenues as oil prices decline, which impacts negatively on their domestic demand by dampening consumption, investment and government expenditures. Overall, the magnitude of the spillovers implied by ECB-Global are consistent with those estimated in the literature (see Kim, 2001; Dedola et al., 2015; Feldkircher and Huber, 2015; Georgiadis, 2016). Also consistent with the findings in this empirical literature, financial markets seem to be the dominant transmission channel of US monetary policy spillovers in ECB-Global.

**Sensitivity analysis** In order to illustrate the relative importance of the spillover channels, we perform a sensitivity analysis by varying the value of two important spillover channels in ECB-Global; the interbank rate spillover parameter and the price elasticity of oil supply. First, changing the values for the parameters governing the magnitude of spillovers in interbank interest rate spreads $\varphi^{\varsigma^b}$ in Equation (**M29**) illustrates that financial markets are an important transmission channel for US monetary policy shocks. Specifically, increasing the value of this parameter magnifies the spillovers from US monetary policy to euro area output predicted by

ECB-Global (see Figure 4). Second, making oil prices less sensitive to a US monetary policy shock by increasing the price elasticity of oil supply $\theta^{oil,s}$ in Equation (**M24**) illustrates that the oil price decline usually triggered by a hike in US interest rates is an important offsetting spillover channel. Specifically, Figure 5 shows that in the absence of an oil price response, the output spillovers from a US monetary policy shock are considerably larger for oil-importing and smaller for oil-exporting countries.

## 6.2 Demand shock in China

**Domestic effects**   In ECB-Global a shock that lowers domestic private demand in China by 0.4% on impact is followed by a fall in the output gap by about 0.4% after two quarters, see Figure 6. Beyond the direct effect on output (due to domestic private demand being a component of GDP), the shock transmits through financial accelerator mechanisms reflected in a rise in the interbank interest rate spread and the private sector risk premium, as well as a fall in equity prices which all amplify the direct effects. Several channels dampen the contractionary impact of the negative demand shock. First, due to the decline in private domestic demand, China's import demand falls which supports GDP through a rise in net exports. Second, the drop in output loosens price pressures so that CPI inflation falls. In the face of lower inflation the central bank eases monetary policy by lowering the policy rate as well as the reserve requirement ratio, which stimulates domestic private demand. Moreover, the easing of monetary policy leads to a depreciation of the Chinese renminbi in real effective terms, which discourages imports, raises net exports and thereby supports GDP. Finally, the reduction in China's oil imports driven by the deceleration of real activity and the depreciation of the renminbi causes a fall in oil prices, which also supports net exports. The fall in oil prices also contributes to a further decline in inflation, which allows the central bank to ease monetary policy further. Moreover, it supports net exports as the value of a given amount of imported barrels of oil falls.

**Spillovers**   The spillovers of a demand slowdown in China to real activity in the rest of the world implied by ECB-Global are relatively moderate (see Figure 7). The transmission of the demand shock in China to the rest of the world occurs in particular through trade and oil prices. Specifically, first, the weakening in China's domestic demand reduces its imports, implying a decline in the rest of the world's exports. As financial exposures of the rest of the world to China are limited, financial spillovers from China to the rest of the world are rather small; this is reflected in muted responses of the financial market variables such as the interbank interest rate spread in the rest of the world (except for the OP countries, see below). Finally, the drop in oil prices dampens the negative spillovers from the demand slowdown in China to the other oil-importing countries. First, it eases price pressures, allowing central banks to loosen monetary policy. Second, it supports net exports as the value of a given amount of imported barrels of oil

falls. The spillovers to oil-exporting countries are markedly larger than those to oil-importing countries, due to the decline in oil export revenues, which dampens private and public demand. The magnitude of the spillovers implied by ECB-Global is well in line with the findings in the literature (see, for example, Cesa-Bianchi et al., 2011; Ahuja and Myrvoda, 2012; Duval et al., 2014; Feldkircher and Korhonen, 2014; IMF, 2014a,b; Andrle et al., 2015; Dizioli et al., 2016a).

## 6.3 Oil price shock

As a third example, we consider an exogenous oil supply shock and its effects on the global economy. We discuss how oil-exporting countries, oil-importing countries and the global economy are affected. The effects of a drop in oil prices in ECB-Global are quantitatively consistent with estimates in the literature (see Peersman and Van Robays, 2009, 2012; Kilian, 2009; Cashin et al., 2014)

**Oil-producing countries**   A relatively persistent drop in oil prices of around 4% caused by an exogenous increase in oil supply has a rather large contractionary effect on the OP, lowering their output gap by about 0.5% on impact (see Figure 8). The slowdown in real activity in the OP occurs through three channels. First, GDP is lower due to the decline in oil export revenues and government expenditures as well as consumption and investment. Second, private consumption and investment are further dampened due to financial accelerator mechanisms materialising in rising interbank interest rate spreads and risk premia. Third, the decline in the value of oil exports in terms of OP output goods for a given value of oil exports in barrels worsens net exports. Nevertheless, several effects alleviate the contractionary effects of the oil price fall. First, the depreciation of the OP's exchange rate stimulates non-oil exports. Second, the slowdown in real activity and lower inflation allows the central bank to ease monetary policy, which in turn stimulates domestic private demand.

**Oil-importing countries**   We illustrate the effects of the supply-driven oil price decline on oil-importing countries by focussing on the euro area. After the drop of oil prices, euro area output gap rises by about 0.08% after four quarters and CPI (annualised) inflation falls by 0.4% on impact (see Figure 9). The expansionary effects from a decline in oil prices arise through domestic demand and trade. First, the decline in CPI inflation allows central banks to ease monetary policy, which stimulates domestic private demand and is accelerated through looser financial conditions as illustrated by a decline in the interbank rate spread. Second, the fall in oil prices improves net exports as the value of the same amount of imported barrels of oil falls. Cross-country differences in the spillovers are mainly due to differences in economies' shares of oil imports in GDP (see Figure 10). For example, in the US the share of oil imports in

GDP is lower than in the euro area, which experiences larger spillovers.[7] Finally, world output increases following an exogenously supply-driven decline in oil prices, reaching a peak response of about 0.05% after three quarters (see Figure 11). The initial negative response is due to the immediate drop in output in oil-exporting countries that offsets the positive response in oil-importing countries which takes more time to unfold.

## 6.4 Global GDP elasticities comparison

In this section ECB-Global is compared with two other global models. This comparison provides a benchmark and a measure of uncertainty around the estimates, as well as enables a reflection on possible implications of different model specifications and philosophies. The two other models used are also semi-structural: (1) the IMF's annual Flexible System of Global models (FSGM Andrle et al., 2015)[8] and (2) a traditional large-scale semi-structural model with very limited forward-looking aspects from the National Institute for Social and Economic Research (NiGEM). Of these 3 global models, only ECB-Global has direct cross-country financial inter-linkages. We compare the impacts following four shocks; (i) a US monetary policy tightening, (ii) an oil supply shock increasing oil prices, (iii) a Chinese demand slowdown, and (iv) a US demand slowdown. In order to directly compare the impacts across models, we impose in each model the same magnitude of the shock in the first year.[9] Figure 12 shows the comparison of the global GDP responses for all four shocks while Figure 13 displays the cross-country effects of each shock scenario in detail. Following all the shocks considered, the impact on global GDP simulated by ECB-Global is close to those of the other models (see Figure 12).

First, a 25 basis point monetary policy shock leads to negative effects across all models. Spillovers from a rise in US interest rates tend to be larger for countries with stronger trade linkages with the US (see Figure 13). In ECB-Global, various macro-financial linkages, such as frictions in the banking sector as well as in equity markets and bond markets lead to stronger adverse effects on economic activity (via the financial accelerator mechanism). In addition, financial integration with the US leads to higher interest rate spreads and tighter bank lending

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[7]China does not benefit as strongly from the oil price decline as the other oil-importing countries as an increase in the reserve requirement ratio (due to the rise in the output gap) offsets somewhat the positive response of GDP. The parameterisations of the reserve requirement ratio and monetary policy rule for China are taken directly from the GPM.

[8]Some key elements of the model, like private consumption and investment, are fully micro-founded, while others, such as trade, labour supply, and inflation have reduced-form representations. This flexibility allows it to model a larger number of regions. In addition to trade linkages the model has TFP spillovers and also incorporates an international commodity market.

[9]For the US monetary policy shock we deviate from this approach, by considering a one-off unanticipated shock, with interest rates endogenously reacting to the initial shock. The reason for taking the ex-ante shock size is that we do not want to make the results too much dependent on the specification of the policy rule as well as being able to compare it with other DSGE and VAR models in the literature. The size of other shocks has been set to approximate ex-post a 1% of GDP for the demand shocks and 10% of oil prices for the oil supply shock. Afterwards the models endogenously determine the impulse response path, without any additional shocks. Therefore, only the first year real GDP responses are reported.

standards in trading partner countries which further depress global growth (beyond the trade channel), which in turn spillback to the US. For these reasons, ECB-Global has larger global output effects than NiGEM or the FSGM which do not have these channels to this extent. Moreover, the result of ECB-Global is consistent with Wieland et al. (2016) who find that models with financial linkages have larger GDP effects.

Second, a 1% domestic private demand driven decrease in US GDP lowers real global GDP by between 0.3-0.4%. This reflects the direct impact of lower real GDP in the US as well as spillover and spillback effects. In ECB-Global, weakening US private demand lowers exports in non-US economies, which leads to a decrease in equity prices and an increase in interest rate spreads. Weak demand leads to lower policy rates which together with lower oil prices provide an automatic stabilizer to growth. In ECB-Global, limited financial market integration imply spillovers from a US demand shock to China to be weaker compared to advanced economies.

Third, a temporary 10% increase in oil prices driven by a decline in oil supply reduces world real GDP in a range between 0.05% in the first year in ECB-Global and NiGEM and the -0.15% in the FSGM. For all countries the FSGM shows stronger effects than NiGEM and ECB-Global. However, the relative effects on the countries are broadly comparable (Japan is mostly affected, while the effects on the United States and China are smaller than for the euro area).

Fourth, a 1% demand driven slowdown in China's GDP leads to a 0.1-0.3% slowdown in world GDP, see Figure 12. [10].In this scenario all models imply relatively modest spillovers with the economies most affected are those with strong trade linkages to China. As is the case for the US demand shock, the range around the global output responses for the different models is relatively tight, with the US demand shock however causing larger global spillovers. The spillovers of a China demand shock are mitigated by a loosening of monetary policy and a fall in oil prices which is a particularly strong channel in ECB-Global. However, it should be noted that the size of the spillovers from a China slowdown is very sensitive to the source of the shock, in particular a productivity or credit-driven slowdown scenario could have larger spillovers, see Dizioli et al. (2016b).

# 7 Future Extensions

ECB-Global is an on-going modelling project and this paper is intended to lay out the structure of the first version of the model. Although the current version of ECB-Global is already useful for cross-country spillover analysis, it is subject to several limitations that should be kept in mind. First, the current version of ECB-Global is calibrated. The calibration is based on institutional knowledge about the sign and magnitude of impulse responses, as well as on an

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[10]A combined steeper slowdown in investment along with weaker consumption growth was implemented in the other models

informal matching of the impulse responses with those from a wide range of existing studies in the literature. Second, the current parametrisation features only limited cross-country heterogeneity. Specifically, heterogeneities are introduced essentially only in the parameters reflecting bilateral trade and financial exposures to spillovers from abroad, as well as a few key structural parameters. Third, albeit the country coverage is relatively large compared to most structural macro-models used in the profession, there remain limitations in terms of cross-sectional granularity. For example, all emerging market economies (except for the oil-producing economies) as well as small advanced economies are lumped together in the rest-of-the-world block. Finally, the structural detail and complexity in ECB-Global is limited in several dimensions, for example by the pooling of private consumption and investment, by the rather stylised fiscal block, and the lack of incomplete exchange-rate pass-through or local-currency pricing. Additionally, several important determinants of macroeconomic dynamics in emerging market economies are not accounted for such as currency mismatches and their heightened susceptibility to abrupt changes in investors risk appetite. The possibility that monetary policy is constrained by a zero lower bound on nominal interest rates is also not yet addressed. These limitations will be dealt with in future versions of ECB-Global.

## 8 Conclusion

As globalisation deepens, the importance of developing global macroeconomic models to rationalise the nature and transmission of shocks is growing. In this paper we introduced ECB-Global; a semi-structural, multi-country model with rich cross-country interactions that arise through trade, oil and financial linkages. We illustrated the potential use of ECB-Global by discussing its domestic and global responses to a US monetary policy shock, a demand shock in China and an oil price shock. Obviously, numerous other cross-country spillover scenarios can be analysed within the model. This paper documents the first version of ECB-Global. Future versions of ECB-Global will sequentially address its limitations, among which the limited country coverage, granularity and degree of cross-country heterogeneity.

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# A Tables

## A.1 Bilateral weights

The shares are defined as follows:

Table 2
Bilateral weights

| Variable | | US | EA | CH | UK | JA | OP | RoW |
|---|---|---|---|---|---|---|---|---|
| Total Bilateral Import Weights: | $\omega_{us,i}^{M}$ | - | 0.147 | 0.130 | 0.030 | 0.094 | 0.247 | 0.353 |
| | $\omega_{ea,i}^{M}$ | 0.122 | - | 0.048 | 0.146 | 0.024 | 0.162 | 0.500 |
| | $\omega_{ch,i}^{M}$ | 0.214 | 0.152 | - | 0.030 | 0.099 | 0.107 | 0.398 |
| | $\omega_{uk,i}^{M}$ | 0.088 | 0.486 | 0.057 | - | 0.030 | 0.111 | 0.228 |
| | $\omega_{ja,i}^{M}$ | 0.141 | 0.087 | 0.157 | 0.013 | - | 0.226 | 0.375 |
| | $\omega_{op,i}^{M}$ | 0.216 | 0.257 | 0.071 | 0.037 | 0.083 | - | 0.335 |
| | $\omega_{rw,i}^{M}$ | 0.221 | 0.304 | 0.184 | 0.042 | 0.072 | 0.176 | - |
| GDP Ex-/Import share: | $\frac{M_{SS}}{Y_{SS}}$ | 0.161 | 0.238 | 0.276 | 0.307 | 0.162 | 0.365 | 0.148 |
| Total Bilateral Export Weights: | $\omega_{us,i}^{X}$ | - | 0.134 | 0.097 | 0.036 | 0.044 | 0.250 | 0.438 |
| | $\omega_{ea,i}^{X}$ | 0.124 | - | 0.077 | 0.130 | 0.023 | 0.139 | 0.507 |
| | $\omega_{ch,i}^{X}$ | 0.207 | 0.147 | - | 0.030 | 0.083 | 0.103 | 0.431 |
| | $\omega_{uk,i}^{X}$ | 0.129 | 0.436 | 0.058 | - | 0.015 | 0.092 | 0.271 |
| | $\omega_{ja,i}^{X}$ | 0.176 | 0.081 | 0.240 | 0.018 | - | 0.063 | 0.422 |
| | $\omega_{op,i}^{X}$ | 0.226 | 0.211 | 0.104 | 0.040 | 0.076 | - | 0.343 |
| | $\omega_{rw,i}^{X}$ | 0.193 | 0.325 | 0.186 | 0.039 | 0.070 | 0.188 | - |
| Bilateral Financial Weights: | $\omega_{us,i}^{F}$ | - | 0.210 | 0.033 | 0.152 | 0.071 | 0.124 | 0.409 |
| | $\omega_{ea,i}^{F}$ | 0.346 | - | 0.023 | 0.232 | 0.046 | 0.053 | 0.301 |
| | $\omega_{uk,i}^{F}$ | 0.284 | 0.384 | 0.023 | - | 0.055 | 0.031 | 0.222 |
| | $\omega_{ja,i}^{F}$ | 0.355 | 0.243 | 0.009 | 0.067 | - | 0.035 | 0.290 |
| | $\omega_{op,i}^{F}$ | 0.407 | 0.227 | 0.015 | 0.105 | 0.045 | - | 0.200 |
| | $\omega_{rw,i}^{F}$ | 0.368 | 0.347 | 0.090 | 0.125 | 0.026 | 0.044 | - |

*Sources: IMF Direction of Trade Staitstics (Dots) for the trade weights; IMF Coordinated Portfolio Investment Survey (CPIS) for the financial weights. Weights are averaged over the $2009 - 2014/15$ period.*

*Notes: $\omega_{j,i}^{M}$ and $\omega_{j,i}^{X}$ represent respectively the share of imports of country $j$ from country $i$ and the share of exports of country $j$ from country $i$. China weights includes Hong Kong.*

## A.2   Parameter Values

Table 3
Parameter values

| | | | | | |
|---|---|---|---|---|---|
| $\alpha_{ea}^{ci,ci}$ | 0.55 | $\alpha_{rw}^{ci,ci}$ | 0.55 | $\alpha_{ja}^{ci,ci}$ | 0.55 |
| $\alpha_{us}^{ci,ci}$ | 0.55 | $\alpha_{uk}^{ci,ci}$ | 0.55 | $\alpha_{ch}^{ci,ci}$ | 0.55 |
| $\alpha_{op}^{ci,ci}$ | 0.55 | $\alpha_{ea}^{ci,r3}$ | 0.18 | $\alpha_{rw}^{ci,r3}$ | 0.18 |
| $\alpha_{ja}^{ci,r3}$ | 0.18 | $\alpha_{us}^{ci,r3}$ | 0.18 | $\alpha_{uk}^{ci,r3}$ | 0.18 |
| $\alpha_{ch}^{ci,r3}$ | 0.10 | $\alpha_{op}^{ci,r3}$ | 0.18 | $\alpha_{ch}^{ci,rrr}$ | 0.11 |
| $\alpha_{ea}^{ci,q}$ | 0.09 | $\alpha_{rw}^{ci,q}$ | 0.09 | $\alpha_{ja}^{ci,q}$ | 0.09 |
| $\alpha_{us}^{ci,q}$ | 0.09 | $\alpha_{uk}^{ci,q}$ | 0.09 | $\alpha_{ch}^{ci,q}$ | 0.09 |
| $\alpha_{op}^{ci,q}$ | 0.09 | $\alpha_{op}^{ci,oil}$ | 0.01 | $\rho_{ea}^{ci}$ | 0.75 |
| $\rho_{ja}^{ci}$ | 0.75 | $\rho_{us}^{ci}$ | 0.75 | $\rho_{uk}^{ci}$ | 0.75 |
| $\rho_{ch}^{ci}$ | 0.75 | $\rho_{op}^{ci}$ | 0.75 | $\rho_{rw}^{ci}$ | 0.75 |
| $\alpha_{ea}^{\pi,\pi}$ | 0.80 | $\alpha_{rw}^{\pi,\pi}$ | 0.80 | $\alpha_{ja}^{\pi,\pi}$ | 0.80 |
| $\alpha_{us}^{\pi,\pi}$ | 0.80 | $\alpha_{uk}^{\pi,\pi}$ | 0.80 | $\alpha_{ch}^{\pi,\pi}$ | 0.80 |
| $\alpha_{op}^{\pi,\pi}$ | 0.80 | $\alpha_{ea}^{\pi,mc}$ | 0.00 | $\alpha_{rw}^{\pi,mc}$ | 0.00 |
| $\alpha_{ja}^{\pi,mc}$ | 0.00 | $\alpha_{us}^{\pi,mc}$ | 0.00 | $\alpha_{uk}^{\pi,mc}$ | 0.00 |
| $\alpha_{ch}^{\pi,mc}$ | 0.00 | $\alpha_{op}^{\pi,mc}$ | 0.00 | $\rho_{ea}^{\pi}$ | 0.80 |
| $\rho_{ja}^{\pi}$ | 0.80 | $\rho_{us}^{\pi}$ | 0.80 | $\rho_{uk}^{\pi}$ | 0.80 |
| $\rho_{ch}^{\pi}$ | 0.80 | $\rho_{op}^{\pi}$ | 0.80 | $\alpha_{ea}^{mc,oil}$ | 0.05 |
| $\alpha_{rw}^{mc,oil}$ | 0.04 | $\alpha_{ja}^{mc,oil}$ | 0.05 | $\alpha_{us}^{mc,oil}$ | 0.05 |
| $\alpha_{uk}^{mc,oil}$ | 0.03 | $\alpha_{ch}^{mc,oil}$ | 0.03 | $\alpha_{op}^{mc,oil}$ | 0.06 |
| $\alpha_{ea}^{mc,y}$ | 2.50 | $\alpha_{rw}^{mc,y}$ | 2.50 | $\alpha_{ja}^{mc,y}$ | 2.50 |
| $\alpha_{us}^{mc,y}$ | 2.50 | $\alpha_{uk}^{mc,y}$ | 2.50 | $\alpha_{ch}^{mc,y}$ | 2.50 |
| $\alpha_{op}^{mc,y}$ | 2.50 | $\alpha_{ea}^{mc,\pi^{ppi}}$ | 0.10 | $\alpha_{rw}^{mc,\pi^{ppi}}$ | 0.10 |
| $\alpha_{ja}^{mc,\pi^{ppi}}$ | 0.10 | $\alpha_{ch}^{mc,\pi^{ppi}}$ | 0.10 | $\alpha_{uk}^{mc,\pi^{ppi}}$ | 0.10 |
| $\alpha_{op}^{mc,\pi^{ppi}}$ | 0.10 | $\alpha_{us}^{mc,\pi^{ppi}}$ | 0.10 | $\omega_{ea,ja}^{M}$ | 0.02 |
| $\omega_{ea,us}^{M}$ | 0.13 | $\omega_{ea,uk}^{M}$ | 0.12 | $\omega_{ea,rw}^{M}$ | 0.53 |
| $\omega_{ea,ch}^{M}$ | 0.10 | $\omega_{ea,op}^{M}$ | 0.11 | $\omega_{ja,ea}^{M}$ | 0.04 |
| $\omega_{ja,us}^{M}$ | 0.08 | $\omega_{ja,uk}^{M}$ | 0.01 | $\omega_{ja,rw}^{M}$ | 0.62 |
| $\omega_{ja,ch}^{M}$ | 0.14 | $\omega_{ja,op}^{M}$ | 0.10 | $\omega_{us,ea}^{M}$ | 0.13 |
| $\omega_{us,ja}^{M}$ | 0.03 | $\omega_{us,uk}^{M}$ | 0.03 | $\omega_{us,rw}^{M}$ | 0.54 |
| $\omega_{us,ch}^{M}$ | 0.12 | $\omega_{us,op}^{M}$ | 0.15 | $\omega_{uk,ea}^{M}$ | 0.37 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\omega_{uk,ja}^{M}$ | 0.02 | $\omega_{uk,us}^{M}$ | 0.14 | $\omega_{uk,rw}^{M}$ | 0.35 |
| $\omega_{uk,ch}^{M}$ | 0.06 | $\omega_{uk,op}^{M}$ | 0.06 | $\omega_{rw,ea}^{M}$ | 0.26 |
| $\omega_{rw,ja}^{M}$ | 0.07 | $\omega_{rw,us}^{M}$ | 0.16 | $\omega_{rw,uk}^{M}$ | 0.04 |
| $\omega_{rw,ch}^{M}$ | 0.13 | $\omega_{rw,op}^{M}$ | 0.34 | $\omega_{ch,ea}^{M}$ | 0.12 |
| $\omega_{ch,ja}^{M}$ | 0.09 | $\omega_{ch,us}^{M}$ | 0.09 | $\omega_{ch,uk}^{M}$ | 0.01 |
| $\omega_{ch,rw}^{M}$ | 0.62 | $\omega_{ch,op}^{M}$ | 0.07 | $\omega_{op,ea}^{M}$ | 0.05 |
| $\omega_{op,ja}^{M}$ | 0.02 | $\omega_{op,us}^{M}$ | 0.09 | $\omega_{op,uk}^{M}$ | 0.01 |
| $\omega_{op,rw}^{M}$ | 0.80 | $\omega_{op,ch}^{M}$ | 0.04 | $\bar{\omega}_{ea}$ | 0.02 |
| $\bar{\omega}_{rw}$ | 0.02 | $\bar{\omega}_{ja}$ | 0.02 | $\bar{\omega}_{us}$ | 0.02 |
| $\bar{\omega}_{uk}$ | 0.02 | $\bar{\omega}_{ch}$ | 0.02 | $\bar{\omega}_{op}$ | 0.02 |
| $\phi_{ea}$ | 1.00 | $\phi_{us}$ | 1.00 | $\phi_{uk}$ | 1.00 |
| $\phi_{ja}$ | 1.00 | $\phi_{ch}$ | 1.00 | $\phi_{rw}$ | 1.00 |
| $\phi_{op}$ | 1.00 | $\phi_{ea}^{oil}$ | 1.00 | $\phi_{ja}^{oil}$ | 1.00 |
| $\phi_{uk}^{oil}$ | 1.00 | $\phi_{us}^{oil}$ | 1.00 | $\phi_{ch}^{oil}$ | 1.00 |
| $\phi_{rw}^{oil}$ | 1.00 | $\phi_{op}^{oil}$ | 1.00 | $a_{ea}^{H}$ | 0.93 |
| $a_{us}^{H}$ | 0.94 | $a_{uk}^{H}$ | 0.87 | $a_{ja}^{H}$ | 0.95 |
| $a_{ch}^{H}$ | 0.96 | $a_{rw}^{H}$ | 0.93 | $a_{op}^{H}$ | 0.88 |
| $\alpha_{ea}^{i^s,i^s}$ | 0.80 | $\alpha_{rw}^{i^s,i^s}$ | 0.80 | $\alpha_{ja}^{i^s,i^s}$ | 0.80 |
| $\alpha_{us}^{i^s,i^s}$ | 0.80 | $\alpha_{uk}^{i^s,i^s}$ | 0.80 | $\alpha_{ch}^{i^s,i^s}$ | 0.80 |
| $\alpha_{op}^{i^s,i^s}$ | 0.80 | $\alpha_{ea}^{i^s,\pi^T}$ | 2.50 | $\alpha_{rw}^{i^s,\pi^T}$ | 2.50 |
| $\alpha_{ja}^{i^s,\pi^T}$ | 2.50 | $\alpha_{us}^{i^s,\pi^T}$ | 2.50 | $\alpha_{uk}^{i^s,\pi^T}$ | 2.50 |
| $\alpha_{ch}^{i^s,\pi^T}$ | 2.50 | $\alpha_{op}^{i^s,\pi^T}$ | 2.50 | $\alpha_{ea}^{i^s,\pi}$ | 0.00 |
| $\alpha_{rw}^{i^s,\pi}$ | 0.00 | $\alpha_{ja}^{i^s,\pi}$ | 0.00 | $\alpha_{us}^{i^s,\pi}$ | 0.00 |
| $\alpha_{uk}^{i^s,\pi}$ | 0.00 | $\alpha_{ch}^{i^s,\pi}$ | 0.00 | $\alpha_{op}^{i^s,\pi}$ | 0.00 |
| $\alpha_{ea}^{i^s,y}$ | 0.30 | $\alpha_{rw}^{i^s,y}$ | 0.30 | $\alpha_{ja}^{i^s,y}$ | 0.30 |
| $\alpha_{us}^{i^s,y}$ | 0.30 | $\alpha_{uk}^{i^s,y}$ | 0.30 | $\alpha_{ch}^{i^s,y}$ | 0.30 |
| $\alpha_{op}^{i^s,y}$ | 0.30 | $\alpha_{ea}^{i^s,\Delta y}$ | 0.00 | $\alpha_{rw}^{i^s,\Delta y}$ | 0.00 |
| $\alpha_{ja}^{i^s,\Delta y}$ | 0.00 | $\alpha_{us}^{i^s,\Delta y}$ | 0.00 | $\alpha_{uk}^{i^s,\Delta y}$ | 0.00 |
| $\alpha_{ch}^{i^s,\Delta y}$ | 0.00 | $\alpha_{op}^{i^s,\Delta y}$ | 0.00 | $\rho_{ea}^{i^s}$ | 0.00 |
| $\rho_{us}^{i^s}$ | 0.00 | $\rho_{ja}^{i^s}$ | 0.00 | $\rho_{uk}^{i^s}$ | 0.00 |
| $\rho_{ch}^{i^s}$ | 0.00 | $\rho_{op}^{i^s}$ | 0.00 | $\rho_{ea}^{\pi^T}$ | 0.50 |
| $\rho_{rw}^{\pi^T}$ | 0.50 | $\rho_{ja}^{\pi^T}$ | 0.50 | $\rho_{us}^{\pi^T}$ | 0.50 |
| $\rho_{uk}^{\pi^T}$ | 0.50 | $\rho_{ch}^{\pi^T}$ | 0.50 | $\rho_{op}^{\pi^T}$ | 0.50 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\alpha_{ch}^{i^s,\Delta S}$ | 0.50 | $\theta_{ch}^{uip}$ | 0.10 | $\rho_{ch}^{uip}$ | 0.30 |
| $\rho_{ch}^{\varrho}$ | 0.40 | $\alpha_{ch}^{\varrho,\pi}$ | 0.50 | $\alpha_{ch}^{\varrho,y}$ | 0.50 |
| $\alpha_{ch}^{\varrho,\varepsilon_{i^s}}$ | 1.00 | $\overline{\varrho}_{ch}^{ss}$ | 8.00 | $\alpha_{ch}^{\overline{\varrho}}$ | 0.80 |
| $\alpha_{ea}^{\tau,t}$ | 0.75 | $\alpha_{rw}^{\tau,t}$ | 0.75 | $\alpha_{ja}^{\tau,t}$ | 0.75 |
| $\alpha_{us}^{\tau,t}$ | 0.75 | $\alpha_{uk}^{\tau,t}$ | 0.75 | $\alpha_{ch}^{\tau,t}$ | 0.75 |
| $\alpha_{op}^{\tau,t}$ | 0.75 | $\alpha_{ea}^{\tau,\mathcal{B}}$ | 0.01 | $\alpha_{rw}^{\tau,\mathcal{B}}$ | 0.01 |
| $\alpha_{ja}^{\tau,\mathcal{B}}$ | 0.01 | $\alpha_{us}^{\tau,\mathcal{B}}$ | 0.01 | $\alpha_{uk}^{\tau,\mathcal{B}}$ | 0.01 |
| $\alpha_{ch}^{\tau,\mathcal{B}}$ | 0.01 | $\alpha_{op}^{\tau,\mathcal{B}}$ | 0.01 | $\alpha_{ea}^{\tau,y}$ | 0.70 |
| $\alpha_{rw}^{\tau,y}$ | 0.70 | $\alpha_{ja}^{\tau,y}$ | 0.70 | $\alpha_{us}^{\tau,y}$ | 0.70 |
| $\alpha_{uk}^{\tau,y}$ | 0.70 | $\alpha_{ch}^{\tau,y}$ | 0.70 | $\alpha_{op}^{\tau,y}$ | 0.70 |
| $\rho_{ea}^{\tau}$ | 0.50 | $\rho_{rw}^{\tau}$ | 0.50 | $\rho_{ja}^{\tau}$ | 0.50 |
| $\rho_{us}^{\tau}$ | 0.50 | $\rho_{uk}^{\tau}$ | 0.50 | $\rho_{ch}^{\tau}$ | 0.50 |
| $\rho_{op}^{\tau}$ | 0.50 | $\alpha_{ea}^{g,\mathcal{B}}$ | 0.01 | $\alpha_{rw}^{g,\mathcal{B}}$ | 0.01 |
| $\alpha_{ja}^{g,\mathcal{B}}$ | 0.01 | $\alpha_{us}^{g,\mathcal{B}}$ | 0.01 | $\alpha_{uk}^{g,\mathcal{B}}$ | 0.01 |
| $\alpha_{ch}^{g,\mathcal{B}}$ | 0.01 | $\alpha_{op}^{g,\mathcal{B}}$ | 0.01 | $\alpha_{ea}^{g,g}$ | 0.75 |
| $\alpha_{ch}^{g,g}$ | 0.75 | $\alpha_{ja}^{g,g}$ | 0.75 | $\alpha_{us}^{g,g}$ | 0.75 |
| $\alpha_{uk}^{g,g}$ | 0.75 | $\alpha_{ch}^{g,g}$ | 0.75 | $\alpha_{op}^{g,g}$ | 0.75 |
| $\alpha_{ea}^{g,y}$ | 0.70 | $\alpha_{rw}^{g,y}$ | 0.70 | $\alpha_{ja}^{g,y}$ | 0.70 |
| $\alpha_{us}^{g,y}$ | 0.70 | $\alpha_{uk}^{g,y}$ | 0.70 | $\alpha_{ch}^{g,y}$ | 0.70 |
| $\alpha_{op}^{g,y}$ | 0.70 | $\rho_{ea}^{g}$ | 0.50 | $\rho_{rw}^{g}$ | 0.50 |
| $\rho_{ja}^{g}$ | 0.50 | $\rho_{us}^{g}$ | 0.50 | $\rho_{uk}^{g}$ | 0.50 |
| $\rho_{ch}^{g}$ | 0.50 | $\rho_{op}^{g}$ | 0.50 | $\alpha_{op}^{g,xoil}$ | 0.20 |
| $\rho_{ea}^{\widehat{p}^{rg}}$ | 0.95 | $\rho_{rw}^{\widehat{p}^{rg}}$ | 0.95 | $\rho_{ja}^{\widehat{p}^{rg}}$ | 0.95 |
| $\rho_{us}^{\widehat{p}^{rg}}$ | 0.95 | $\rho_{ch}^{\widehat{p}^{rg}}$ | 0.95 | $\rho_{uk}^{\widehat{p}^{rg}}$ | 0.95 |
| $\rho_{op}^{\widehat{p}^{rg}}$ | 0.95 | $\chi_{ea}^{gdp}$ | 0.15 | $\chi_{uk}^{gdp}$ | 0.03 |
| $\chi_{ja}^{gdp}$ | 0.06 | $\chi_{ch}^{gdp}$ | 0.10 | $\chi_{us}^{gdp}$ | 0.19 |
| $\chi_{op}^{gdp}$ | 0.09 | $\chi_{rw}^{gdp}$ | 0.38 | $\chi_{ea}^{gdp,no-op}$ | 0.17 |
| $\chi_{us}^{gdp,no-op}$ | 0.21 | $\chi_{uk}^{gdp,no-op}$ | 0.03 | $\chi_{ja}^{gdp,no-op}$ | 0.07 |
| $\chi_{ch}^{gdp,no-op}$ | 0.10 | $\chi_{rw}^{gdp,no-op}$ | 0.41 | $\chi_{ea}^{M,oil}$ | 0.02 |
| $\chi_{rw}^{M,oil}$ | 0.02 | $\chi_{ja}^{M,oil}$ | 0.03 | $\chi_{us}^{M,oil}$ | 0.01 |
| $\chi_{uk}^{M,oil}$ | 0.01 | $\chi_{ch}^{M,oil}$ | 0.02 | $\chi_{ea}^{M,nonoil}$ | 0.23 |
| $\chi_{ja}^{M,nonoil}$ | 0.14 | $\chi_{us}^{M,nonoil}$ | 0.15 | $\chi_{uk}^{M,nonoil}$ | 0.33 |
| $\chi_{ch}^{M,nonoil}$ | 0.22 | $\chi_{rw}^{M,nonoil}$ | 0.13 | $\chi_{ea}^{X}$ | 0.25 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\chi^X_{rw}$ | 0.16 | $\chi^X_{ja}$ | 0.17 | $\chi^X_{ua}$ | 0.16 |
| $\chi^X_{uk}$ | 0.34 | $\chi^X_{ch}$ | 0.24 | $\chi^M_{ea}$ | 0.25 |
| $\chi^M_{rw}$ | 0.16 | $\chi^M_{ja}$ | 0.17 | $\chi^M_{us}$ | 0.16 |
| $\chi^M_{uk}$ | 0.34 | $\chi^M_{ch}$ | 0.24 | $\chi^{X,oil}_{op}$ | 0.22 |
| $\chi^{X,nonoil}_{op}$ | 0.10 | $\chi^X_{op}$ | 0.33 | $\chi^M_{op}$ | 0.33 |
| $\omega^X_{ea,ja}$ | 0.02 | $\omega^X_{ea,us}$ | 0.12 | $\omega^X_{ea,uk}$ | 0.13 |
| $\omega^X_{ea,rw}$ | 0.51 | $\omega^X_{ea,ch}$ | 0.08 | $\omega^X_{ea,op}$ | 0.14 |
| $\omega^X_{ja,ea}$ | 0.08 | $\omega^X_{ja,us}$ | 0.18 | $\omega^X_{ja,uk}$ | 0.02 |
| $\omega^X_{ja,rw}$ | 0.42 | $\omega^X_{ja,ch}$ | 0.24 | $\omega^X_{ja,op}$ | 0.06 |
| $\omega^X_{us,ea}$ | 0.13 | $\omega^X_{us,ja}$ | 0.04 | $\omega^X_{us,uk}$ | 0.04 |
| $\omega^X_{us,rw}$ | 0.44 | $\omega^X_{us,ch}$ | 0.10 | $\omega^X_{us,op}$ | 0.25 |
| $\omega^X_{uk,ea}$ | 0.44 | $\omega^X_{uk,ja}$ | 0.01 | $\omega^X_{uk,us}$ | 0.13 |
| $\omega^X_{uk,rw}$ | 0.27 | $\omega^X_{uk,ch}$ | 0.06 | $\omega^X_{uk,op}$ | 0.09 |
| $\omega^X_{rw,ea}$ | 0.33 | $\omega^X_{rw,ja}$ | 0.07 | $\omega^X_{rw,us}$ | 0.19 |
| $\omega^X_{rw,uk}$ | 0.04 | $\omega^X_{rw,ch}$ | 0.19 | $\omega^X_{rw,op}$ | 0.19 |
| $\omega^X_{ch,ea}$ | 0.15 | $\omega^X_{ch,ja}$ | 0.08 | $\omega^X_{ch,us}$ | 0.21 |
| $\omega^X_{ch,uk}$ | 0.03 | $\omega^X_{ch,rw}$ | 0.43 | $\omega^X_{ch,op}$ | 0.10 |
| $\omega^X_{op,ea}$ | 0.21 | $\omega^X_{op,ja}$ | 0.08 | $\omega^X_{op,us}$ | 0.23 |
| $\omega^X_{op,uk}$ | 0.04 | $\omega^X_{op,rw}$ | 0.34 | $\omega^X_{op,ch}$ | 0.10 |
| $\omega^{M,nonoil}_{ea,ja}$ | 0.02 | $\omega^{M,nonoil}_{ea,us}$ | 0.12 | $\omega^{M,nonoil}_{ea,uk}$ | 0.13 |
| $\omega^{M,nonoil}_{ea,rw}$ | 0.56 | $\omega^{M,nonoil}_{ea,ch}$ | 0.10 | $\omega^{M,nonoil}_{ea,op}$ | 0.07 |
| $\omega^{M,nonoil}_{ja,ea}$ | 0.10 | $\omega^{M,nonoil}_{ja,us}$ | 0.16 | $\omega^{M,nonoil}_{ja,uk}$ | 0.02 |
| $\omega^{M,nonoil}_{ja,rw}$ | 0.48 | $\omega^{M,nonoil}_{ja,ch}$ | 0.22 | $\omega^{M,nonoil}_{ja,op}$ | 0.02 |
| $\omega^{M,nonoil}_{us,ea}$ | 0.17 | $\omega^{M,nonoil}_{us,ja}$ | 0.07 | $\omega^{M,nonoil}_{us,uk}$ | 0.05 |
| $\omega^{M,nonoil}_{us,rw}$ | 0.41 | $\omega^{M,nonoil}_{us,ch}$ | 0.17 | $\omega^{M,nonoil}_{us,op}$ | 0.14 |
| $\omega^{M,nonoil}_{uk,ea}$ | 0.49 | $\omega^{M,nonoil}_{uk,ja}$ | 0.02 | $\omega^{M,nonoil}_{uk,us}$ | 0.11 |
| $\omega^{M,nonoil}_{uk,rw}$ | 0.23 | $\omega^{M,nonoil}_{uk,ch}$ | 0.07 | $\omega^{M,nonoil}_{uk,op}$ | 0.09 |
| $\omega^{M,nonoil}_{rw,ea}$ | 0.38 | $\omega^{M,nonoil}_{rw,ja}$ | 0.09 | $\omega^{M,nonoil}_{rw,us}$ | 0.26 |
| $\omega^{M,nonoil}_{rw,uk}$ | 0.06 | $\omega^{M,nonoil}_{rw,ch}$ | 0.20 | $\omega^{M,nonoil}_{rw,op}$ | 0.01 |
| $\omega^{M,nonoil}_{ch,ea}$ | 0.14 | $\omega^{M,nonoil}_{ch,ja}$ | 0.12 | $\omega^{M,nonoil}_{ch,us}$ | 0.14 |
| $\omega^{M,nonoil}_{ch,uk}$ | 0.03 | $\omega^{M,nonoil}_{ch,rw}$ | 0.53 | $\omega^{M,nonoil}_{ch,op}$ | 0.04 |
| $\omega^{M,nonoil}_{op,ea}$ | 0.19 | $\omega^{M,nonoil}_{op,ja}$ | 0.02 | $\omega^{M,nonoil}_{op,us}$ | 0.27 |
| $\omega^{M,nonoil}_{op,uk}$ | 0.03 | $\omega^{M,nonoil}_{op,rw}$ | 0.40 | $\omega^{M,nonoil}_{op,ch}$ | 0.08 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\omega_{op,ea}^{X,nonoil}$ | 0.25 | $\omega_{op,ja}^{X,nonoil}$ | 0.02 | $\omega_{op,us}^{X,nonoil}$ | 0.46 |
| $\omega_{op,uk}^{X,nonoil}$ | 0.10 | $\omega_{op,rw}^{X,nonoil}$ | 0.08 | $\omega_{op,ch}^{X,nonoil}$ | 0.08 |
| $\chi_{ea}^{X,tot.share}$ | 0.19 | $\chi_{us}^{X,tot.share}$ | 0.15 | $\chi_{uk}^{X,tot.share}$ | 0.05 |
| $\chi_{ja}^{X,tot.share}$ | 0.05 | $\chi_{ch}^{X,tot.share}$ | 0.11 | $\chi_{op}^{X,tot.share}$ | 0.14 |
| $\chi_{rw}^{X,tot.share}$ | 0.30 | $\theta_{ea}^{nonoil}$ | 1.50 | $\theta_{rw}^{nonoil}$ | 1.50 |
| $\theta_{ja}^{nonoil}$ | 1.50 | $\theta_{us}^{nonoil}$ | 1.50 | $\theta_{uk}^{nonoil}$ | 1.50 |
| $\theta_{ch}^{nonoil}$ | 1.50 | $\theta_{op}^{nonoil}$ | 1.50 | $\omega_{op}^{X,oil}$ | 0.68 |
| $\omega_{us}^{oil}$ | 0.11 | $\omega_{ea}^{oil}$ | 0.17 | $\omega_{ja}^{oil}$ | 0.09 |
| $\omega_{uk}^{oil}$ | 0.01 | $\omega_{ch}^{oil}$ | 0.10 | $\omega_{rw}^{oil}$ | 0.42 |
| $\omega_{op}^{oil}$ | 0.10 | $\theta_{us}^{oil}$ | 0.15 | $\theta_{ea}^{oil}$ | 0.15 |
| $\theta_{ja}^{oil}$ | 0.15 | $\theta_{uk}^{oil}$ | 0.15 | $\theta_{ch}^{oil}$ | 0.15 |
| $\theta_{rw}^{oil}$ | 0.15 | $\theta_{op}^{oil}$ | 0.03 | $\theta^{oil,s}$ | 0.05 |
| $\rho^{oil}$ | 0.95 | $\alpha_{ea}^{\varsigma^b,lag}$ | 0.40 | $\alpha_{rw}^{\varsigma^b,lag}$ | 0.40 |
| $\alpha_{ja}^{\varsigma^b,lag}$ | 0.40 | $\alpha_{ch}^{\varsigma^b,lag}$ | 0.40 | $\alpha_{uk}^{\varsigma^b,lag}$ | 0.40 |
| $\alpha_{op}^{\varsigma^b,lag}$ | 0.40 | $\alpha_{us}^{\varsigma^b,lag}$ | 0.40 | $\varphi_{ea}^{b}$ | 1.00 |
| $\varphi_{uk}^{b}$ | 1.00 | $\varphi_{ja}^{b}$ | 1.00 | $\varphi_{us}^{b}$ | 1.00 |
| $\varphi_{rw}^{b}$ | 1.00 | $\varphi_{op}^{b}$ | 1.00 | $\varphi_{ch}^{b}$ | 1.00 |
| $\alpha_{ea}^{\varsigma^b,\varsigma^b}$ | 0.50 | $\alpha_{rw}^{\varsigma^b,\varsigma^b}$ | 0.50 | $\alpha_{ja}^{\varsigma^b,\varsigma^b}$ | 0.50 |
| $\alpha_{us}^{\varsigma^b,\varsigma^b}$ | 0.50 | $\alpha_{uk}^{\varsigma^b,\varsigma^b}$ | 0.50 | $\alpha_{ch}^{\varsigma^b,\varsigma^b}$ | 0.00 |
| $\alpha_{op}^{\varsigma^b,\varsigma^b}$ | 0.50 | $\alpha_{ea}^{\varsigma^b,\widehat{y}}$ | 0.07 | $\alpha_{rw}^{\varsigma^b,\widehat{y}}$ | 0.07 |
| $\alpha_{ja}^{\varsigma^b,\widehat{y}}$ | 0.07 | $\alpha_{ch}^{\varsigma^b,\widehat{y}}$ | 0.07 | $\alpha_{uk}^{\varsigma^b,\widehat{y}}$ | 0.07 |
| $\alpha_{op}^{\varsigma^b,\widehat{y}}$ | 0.07 | $\alpha_{us}^{\varsigma^b,\widehat{y}}$ | 0.07 | $\rho_{ea}^{b}$ | 0.80 |
| $\rho_{rw}^{b}$ | 0.80 | $\rho_{ja}^{b}$ | 0.80 | $\rho_{uk}^{b}$ | 0.80 |
| $\rho_{us}^{b}$ | 0.80 | $\rho_{ch}^{b}$ | 0.80 | $\rho_{op}^{b}$ | 0.80 |
| $\alpha_{ea}^{blt,rs}$ | 1.50 | $\alpha_{rw}^{blt,rs}$ | 1.50 | $\alpha_{ja}^{blt,rs}$ | 1.50 |
| $\alpha_{us}^{blt,rs}$ | 1.50 | $\alpha_{uk}^{blt,rs}$ | 1.50 | $\alpha_{ch}^{blt,rs}$ | 1.50 |
| $\alpha_{op}^{blt,rs}$ | 1.50 | $\alpha_{ea}^{blt,y}$ | 1.25 | $\alpha_{rw}^{blt,y}$ | 1.25 |
| $\alpha_{ja}^{blt,y}$ | 1.25 | $\alpha_{us}^{blt,y}$ | 1.25 | $\alpha_{uk}^{blt,y}$ | 1.25 |
| $\alpha_{ch}^{blt,y}$ | 1.25 | $\alpha_{op}^{blt,y}$ | 1.25 | $\rho_{ea}^{blt}$ | 0.85 |
| $\rho_{rw}^{blt}$ | 0.85 | $\rho_{ja}^{blt}$ | 0.85 | $\rho_{us}^{blt}$ | 0.85 |
| $\rho_{uk}^{blt}$ | 0.85 | $\rho_{ch}^{blt}$ | 0.85 | $\rho_{op}^{blt}$ | 0.85 |
| $\alpha_{ea}^{blt,blt}$ | 0.75 | $\alpha_{rw}^{blt,blt}$ | 0.75 | $\alpha_{ja}^{blt,blt}$ | 0.75 |
| $\alpha_{us}^{blt,blt}$ | 0.75 | $\alpha_{uk}^{blt,blt}$ | 0.75 | $\alpha_{ch}^{blt,blt}$ | 0.75 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\alpha_{op}^{blt,blt}$ | 0.75 | $\alpha_{ea}^{blt,y4}$ | 3.34 | $\alpha_{us}^{blt,y4}$ | 3.34 |
| $\alpha_{ja}^{blt,y4}$ | 3.34 | $\alpha_{uk}^{blt,y4}$ | 3.34 | $\alpha_{rw}^{blt,y4}$ | 3.34 |
| $\alpha_{ch}^{blt,y4}$ | 3.34 | $\alpha_{op}^{blt,y4}$ | 3.34 | $\alpha_{ea}^{blt,Q}$ | 0.00 |
| $\alpha_{us}^{blt,Q}$ | 0.00 | $\alpha_{ja}^{blt,Q}$ | 0.00 | $\alpha_{uk}^{blt,Q}$ | 0.00 |
| $\alpha_{rw}^{blt,Q}$ | 0.00 | $\alpha_{ch}^{blt,Q}$ | 0.00 | $\alpha_{op}^{blt,Q}$ | 0.00 |
| $\varphi_{ea}^{blt}$ | 0.50 | $\varphi_{uk}^{blt}$ | 0.50 | $\varphi_{ja}^{blt}$ | 0.50 |
| $\varphi_{us}^{blt}$ | 0.50 | $\varphi_{rw}^{blt}$ | 0.50 | $\varphi_{ch}^{blt}$ | 0.00 |
| $\varphi_{op}^{blt}$ | 0.50 | $\alpha_{ea}^{\varsigma^g,\mathcal{B}}$ | 0.00 | $\alpha_{rw}^{\varsigma^g,\mathcal{B}}$ | 0.00 |
| $\alpha_{ja}^{\varsigma^g,\mathcal{B}}$ | 0.00 | $\alpha_{us}^{\varsigma^g,\mathcal{B}}$ | 0.00 | $\alpha_{uk}^{\varsigma^g,\mathcal{B}}$ | 0.00 |
| $\alpha_{ch}^{\varsigma^g,\mathcal{B}}$ | 0.00 | $\alpha_{op}^{\varsigma^g,\mathcal{B}}$ | 0.00 | $\alpha_{ea}^{\varsigma^g,\varsigma^g}$ | 0.80 |
| $\alpha rw^{\varsigma^g,\varsigma^g}$ | 0.80 | $\alpha_{ja}^{\varsigma^g,\varsigma^g}$ | 0.80 | $\alpha_{us}^{\varsigma^g,\varsigma^g}$ | 0.80 |
| $\alpha_{uk}^{\varsigma^g,\varsigma^g}$ | 0.80 | $\alpha_{ch}^{\varsigma^g,\varsigma^g}$ | 0.80 | $\alpha_{op}^{\varsigma^g,\varsigma^g}$ | 0.80 |
| $\rho_{ea}^{\varsigma^g}$ | 0.75 | $\rho_{ja}^{\varsigma^g}$ | 0.75 | $\rho_{us}^{\varsigma^g}$ | 0.75 |
| $\rho_{rw}^{\varsigma^g}$ | 0.75 | $\rho_{uk}^{\varsigma^g}$ | 0.75 | $\rho_{ch}^{\varsigma^g}$ | 0.75 |
| $\rho_{op}^{\varsigma^g}$ | 0.75 | $\rho_{ea}^{rl}$ | 0.75 | $\rho_{rw}^{rl}$ | 0.75 |
| $\rho_{ja}^{rl}$ | 0.75 | $\rho_{us}^{rl}$ | 0.75 | $\rho_{uk}^{rl}$ | 0.75 |
| $\rho_{ch}^{rl}$ | 0.75 | $\rho_{op}^{rl}$ | 0.75 | $\varphi_{ea}^{\varsigma^g}$ | 0.00 |
| $\varphi_{uk}^{\varsigma^g}$ | 0.00 | $\varphi_{ja}^{\varsigma^g}$ | 0.00 | $\varphi_{us}^{\varsigma^g}$ | 0.00 |
| $\varphi_{rw}^{\varsigma^g}$ | 0.00 | $\varphi_{ch}^{\varsigma^g}$ | 0.00 | $\varphi_{op}^{\varsigma^g}$ | 0.00 |
| $\alpha_{ea}^{rl,rl}$ | 0.97 | $\alpha_{us}^{rl,rl}$ | 0.97 | $\alpha_{uk}^{rl,rl}$ | 0.97 |
| $\alpha_{ja}^{rl,rl}$ | 0.97 | $\alpha_{op}^{rl,rl}$ | 0.97 | $\alpha_{ch}^{rl,rl}$ | 0.97 |
| $\alpha_{rw}^{rl,rl}$ | 0.97 | $\alpha_{ea}^{rl,rs}$ | 0.63 | $\alpha_{us}^{rl,rs}$ | 0.63 |
| $\alpha_{uk}^{rl,rs}$ | 0.63 | $\alpha_{ja}^{rl,rs}$ | 0.63 | $\alpha_{op}^{rl,rs}$ | 0.63 |
| $\alpha_{ch}^{rl,rs}$ | 0.63 | $\alpha_{rw}^{rl,rs}$ | 0.63 | $\alpha_{ea}^{\varphi,\varsigma^g}$ | 1.00 |
| $\alpha_{rw}^{\varphi,\varsigma^g}$ | 1.00 | $\alpha_{ja}^{\varphi,\varsigma^g}$ | 1.00 | $\alpha_{us}^{\varphi,\varsigma^g}$ | 1.00 |
| $\alpha_{uk}^{\varphi,\varsigma^g}$ | 1.00 | $\alpha_{ch}^{\varphi,\varsigma^g}$ | 1.00 | $\alpha_{op}^{\varphi,\varsigma^g}$ | 1.00 |
| $\alpha_{ea}^{\varphi,blt}$ | 0.05 | $\alpha_{rw}^{\varphi,blt}$ | 0.05 | $\alpha_{ja}^{\varphi,blt}$ | 0.05 |
| $\alpha_{us}^{\varphi,blt}$ | 0.05 | $\alpha_{uk}^{\varphi,blt}$ | 0.05 | $\alpha_{ch}^{\varphi,blt}$ | 0.05 |
| $\alpha_{op}^{\varphi,blt}$ | 0.05 | $\phi_{ea}^{\varphi}$ | 0.00 | $\phi_{uk}^{\varphi}$ | 0.00 |
| $\phi_{ja}^{\varphi}$ | 0.00 | $\phi_{us}^{\varphi}$ | 0.00 | $\phi_{rw}^{\varphi}$ | 0.00 |
| $\phi_{op}^{\varphi}$ | 0.00 | $\phi_{ch}^{\varphi}$ | 0.00 | $\alpha_{ea}^{q,y}$ | 0.25 |
| $\alpha_{rw}^{q,y}$ | 0.25 | $\alpha_{ja}^{q,y}$ | 0.25 | $\alpha_{us}^{q,y}$ | 0.25 |
| $\alpha_{uk}^{q,y}$ | 0.25 | $\alpha_{ch}^{q,y}$ | 0.25 | $\alpha_{op}^{q,y}$ | 0.25 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\alpha_{ea}^{q,q}$ | 0.30 | $\alpha_{rw}^{q,q}$ | 0.30 | $\alpha_{ja}^{q,q}$ | 0.30 |
| $\alpha_{us}^{q,q}$ | 0.30 | $\alpha_{uk}^{q,q}$ | 0.30 | $\alpha_{ch}^{q,q}$ | 0.30 |
| $\alpha_{op}^{q,q}$ | 0.30 | $\rho_{ea}^{q}$ | 0.75 | $\rho_{rw}^{q}$ | 0.75 |
| $\rho_{ja}^{q}$ | 0.75 | $\rho_{us}^{q}$ | 0.75 | $\rho_{uk}^{q}$ | 0.75 |
| $\rho_{ch}^{q}$ | 0.75 | $\rho_{op}^{q}$ | 0.75 | $\alpha_{ea}^{q,r^3}$ | 1.00 |
| $\alpha_{rw}^{q,r^3}$ | 1.00 | $\alpha_{ja}^{q,r^3}$ | 1.00 | $\alpha_{us}^{q,r^3}$ | 1.00 |
| $\alpha_{uk}^{q,r^3}$ | 1.00 | $\alpha_{ch}^{q,r^3}$ | 1.00 | $\alpha_{op}^{q,r^3}$ | 1.00 |
| $\varphi_{ea}^{q}$ | 0.15 | $\varphi_{uk}^{q}$ | 0.15 | $\varphi_{ja}^{q}$ | 0.15 |
| $\varphi_{us}^{q}$ | 0.15 | $\varphi_{rw}^{q}$ | 0.15 | $\varphi_{ch}^{q}$ | 0.00 |
| $\varphi_{op}^{q}$ | 0.15 | $\alpha_{ea}^{nfa}$ | 0.00 | $\alpha_{uk}^{nfa}$ | 0.00 |
| $\alpha_{ja}^{nfa}$ | 0.00 | $\alpha_{ch}^{nfa}$ | 0.00 | $\alpha_{rw}^{nfa}$ | 0.00 |
| $\alpha_{op}^{nfa}$ | 0.00 | $\alpha^{nfa,nfa}$ | 1.00 | $\omega_{ea,ja}^{F}$ | 0.05 |
| $\omega_{ea,us}^{F}$ | 0.37 | $\omega_{ea,uk}^{F}$ | 0.24 | $\omega_{ea,ch}^{F}$ | 0.03 |
| $\omega_{ea,rw}^{F}$ | 0.26 | $\omega_{ea,op}^{F}$ | 0.05 | $\omega_{ja,ea}^{F}$ | 0.30 |
| $\omega_{ja,us}^{F}$ | 0.43 | $\omega_{ja,uk}^{F}$ | 0.08 | $\omega_{ja,rw}^{F}$ | 0.13 |
| $\omega_{ja,ch}^{F}$ | 0.01 | $\omega_{ja,op}^{F}$ | 0.04 | $\omega_{us,ea}^{F}$ | 0.25 |
| $\omega_{us,ja}^{F}$ | 0.08 | $\omega_{us,uk}^{F}$ | 0.18 | $\omega_{us,rw}^{F}$ | 0.32 |
| $\omega_{us,ch}^{F}$ | 0.04 | $\omega_{us,op}^{F}$ | 0.14 | $\omega_{uk,ea}^{F}$ | 0.41 |
| $\omega_{uk,ja}^{F}$ | 0.06 | $\omega_{uk,us}^{F}$ | 0.29 | $\omega_{uk,rw}^{F}$ | 0.19 |
| $\omega_{uk,ch}^{F}$ | 0.02 | $\omega_{uk,op}^{F}$ | 0.03 | $\omega_{rw,ea}^{F}$ | 0.37 |
| $\omega_{rw,ja}^{F}$ | 0.03 | $\omega_{rw,us}^{F}$ | 0.32 | $\omega_{rw,uk}^{F}$ | 0.13 |
| $\omega_{rw,ch}^{F}$ | 0.10 | $\omega_{rw,op}^{F}$ | 0.04 | $\omega_{ch,ea}^{F}$ | 0.02 |
| $\omega_{ch,ja}^{F}$ | 0.02 | $\omega_{ch,us}^{F}$ | 0.02 | $\omega_{ch,uk}^{F}$ | 0.02 |
| $\omega_{ch,rw}^{F}$ | 0.90 | $\omega_{ch,op}^{F}$ | 0.02 | $\omega_{op,ea}^{F}$ | 0.23 |
| $\omega_{op,ja}^{F}$ | 0.05 | $\omega_{op,us}^{F}$ | 0.43 | $\omega_{op,uk}^{F}$ | 0.11 |
| $\omega_{op,rw}^{F}$ | 0.17 | $\omega_{op,ch}^{F}$ | 0.02 | $\chi_{ea}^{ci}$ | 0.75 |
| $\chi_{rw}^{ci}$ | 0.80 | $\chi_{ja}^{ci}$ | 0.75 | $\chi_{us}^{ci}$ | 0.85 |
| $\chi_{uk}^{ci}$ | 0.80 | $\chi_{ch}^{ci}$ | 0.96 | $\chi_{op}^{ci}$ | 0.80 |
| $\chi_{ea}^{g}$ | 0.25 | $\chi_{rw}^{g}$ | 0.20 | $\chi_{ja}^{g}$ | 0.25 |
| $\chi_{us}^{g}$ | 0.15 | $\chi_{uk}^{g}$ | 0.20 | $\chi_{ch}^{g}$ | 0.04 |
| $\chi_{op}^{g}$ | 0.20 | $\eta^{\Delta\bar{y}}$ | 0.75 | $\eta_{ea}^{\Delta\bar{y}}$ | 0.15 |
| $\eta_{rw}^{\Delta\bar{y}}$ | 0.15 | $\eta_{ja}^{\Delta\bar{y}}$ | 0.15 | $\eta_{uk}^{\Delta\bar{y}}$ | 0.15 |
| $\eta_{us}^{\Delta\bar{y}}$ | 0.15 | $\eta_{ch}^{\Delta\bar{y}}$ | 0.15 | $\eta_{op}^{\Delta\bar{y}}$ | 0.15 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\rho_{ea}^{\Delta\overline{y}}$ | 0.75 | $\rho_{ja}^{\Delta\overline{y}}$ | 0.75 | $\rho_{uk}^{\Delta\overline{y}}$ | 0.75 |
| $\rho_{us}^{\Delta\overline{y}}$ | 0.75 | $\rho_{ch}^{\Delta\overline{y}}$ | 0.75 | $\rho_{op}^{\Delta\overline{y}}$ | 0.75 |
| $\alpha_{ea}^{\Delta\overline{ci}}$ | 0.15 | $\alpha_{ja}^{\Delta\overline{ci}}$ | 0.15 | $\alpha_{rw}^{\Delta\overline{ci}}$ | 0.15 |
| $\alpha_{uk}^{\Delta\overline{ci}}$ | 0.15 | $\alpha_{us}^{\Delta\overline{ci}}$ | 0.15 | $\alpha_{ch}^{\Delta\overline{ci}}$ | 0.15 |
| $\alpha_{op}^{\Delta\overline{ci}}$ | 0.15 | $\alpha^{\Delta\overline{q}}$ | 0.75 | $\alpha_{ea}^{\Delta\overline{q}}$ | 0.15 |
| $\alpha_{rw}^{\Delta\overline{q}}$ | 0.15 | $\alpha_{ja}^{\Delta\overline{q}}$ | 0.15 | $\alpha_{us}^{\Delta\overline{q}}$ | 0.15 |
| $\alpha_{uk}^{\Delta\overline{q}}$ | 0.15 | $\alpha_{ch}^{\Delta\overline{q}}$ | 0.15 | $\alpha_{op}^{\Delta\overline{q}}$ | 0.15 |
| $\eta_{ea}^{\Delta\overline{m}}$ | 0.15 | $\eta_{rw}^{\Delta\overline{m}}$ | 0.15 | $\eta_{ja}^{\Delta\overline{m}}$ | 0.15 |
| $\eta_{us}^{\Delta\overline{m}}$ | 0.15 | $\eta_{uk}^{\Delta\overline{m}}$ | 0.15 | $\eta_{ch}^{\Delta\overline{m}}$ | 0.15 |
| $\eta_{op}^{\Delta\overline{m}}$ | 0.15 | $\eta_{ea}^{\Delta\overline{x}}$ | 0.15 | $\eta_{rw}^{\Delta\overline{x}}$ | 0.15 |
| $\eta_{ja}^{\Delta\overline{x}}$ | 0.15 | $\eta_{us}^{\Delta\overline{x}}$ | 0.15 | $\eta_{uk}^{\Delta\overline{x}}$ | 0.15 |
| $\eta_{ch}^{\Delta\overline{x}}$ | 0.15 | $\eta_{op}^{\Delta\overline{x}}$ | 0.15 | $\Delta\overline{oil}$ | 1.53 |
| $\overline{oil}^{s}$ | 0.16 | $\Delta\overline{y}^{ppi,ss}$ | 0.67 | $\Delta\overline{y}^{cpi,ss}$ | 0.67 |
| $\Delta\overline{q}^{ss}$ | 1.14 | $\Delta\overline{q}^{idio,ss}$ | 0.47 | $\Delta\overline{S}_{ch}$ | $-0.57$ |
| $\Delta\overline{S}_{ea}$ | $-0.13$ | $\Delta\overline{S}_{rw}$ | $-0.21$ | $\Delta\overline{S}_{ja}$ | $-0.42$ |
| $\Delta\overline{S}_{uk}$ | 0.02 | $\Delta\overline{S}_{op}$ | 0.02 | $\pi_{ea}^{T,ss}$ | 0.55 |
| $\pi_{rw}^{T,ss}$ | 0.42 | $\pi_{ja}^{T,ss}$ | 0.08 | $\pi_{us}^{T,ss}$ | 0.64 |
| $\pi_{uk}^{T,ss}$ | 0.64 | $\pi_{ch}^{T,ss}$ | $-0.02$ | $\pi_{op}^{T,ss}$ | 0.64 |
| $\overline{\pi}_{ea}^{ppi}$ | 0.55 | $\overline{\pi}_{rw}^{ppi}$ | 0.42 | $\overline{\pi}_{ja}^{ppi}$ | 0.08 |
| $\overline{\pi}_{us}^{ppi}$ | 0.64 | $\overline{\pi}_{uk}^{ppi}$ | 0.64 | $\overline{\pi}_{ch}^{ppi}$ | $-0.02$ |
| $\overline{\pi}_{op}^{ppi}$ | 0.64 | $i_{ea}^{sss}$ | 0.59 | $i_{rw}^{sss}$ | 0.92 |
| $i_{ja}^{sss}$ | 0.27 | $i_{us}^{sss}$ | 0.85 | $i_{uk}^{sss}$ | 1.29 |
| $i_{ch}^{sss}$ | 1.22 | $i_{op}^{sss}$ | 1.29 | $i_{ea}^{gss}$ | 1.19 |
| $i_{rw}^{gss}$ | 0.95 | $i_{ja}^{gss}$ | 0.33 | $i_{us}^{gss}$ | 0.96 |
| $i_{uk}^{gss}$ | 1.27 | $i_{ch}^{gss}$ | 0.67 | $i_{op}^{gss}$ | 1.27 |
| $i_{ea}^{lss}$ | 1.42 | $i_{rw}^{lss}$ | 1.18 | $i_{ja}^{lss}$ | 0.60 |
| $i_{us}^{lss}$ | 1.26 | $i_{uk}^{lss}$ | 1.44 | $i_{ch}^{lss}$ | 0.91 |
| $i_{op}^{lss}$ | 1.44 | $i_{ea}^{3ss}$ | 0.81 | $i_{rw}^{3ss}$ | 0.90 |
| $i_{ja}^{3ss}$ | 0.05 | $i_{us}^{3ss}$ | 0.92 | $i_{uk}^{3ss}$ | 1.35 |
| $i_{ch}^{3ss}$ | 0.90 | $i_{op}^{3ss}$ | 1.35 | $\mathcal{G}_{ea}^{ss}$ | 48.14 |
| $\mathcal{G}_{ja}^{ss}$ | 26.89 | $\mathcal{G}_{us}^{ss}$ | 32.19 | $\mathcal{G}_{uk}^{ss}$ | 36.12 |
| $\mathcal{G}_{rw}^{ss}$ | 32.83 | $\mathcal{G}_{ch}^{ss}$ | 17.51 | $\mathcal{G}_{op}^{ss}$ | 36.12 |
| $\mathcal{T}_{ea}^{ss}$ | 45.29 | $\mathcal{T}_{ja}^{ss}$ | 25.77 | $\mathcal{T}_{us}^{ss}$ | 28.20 |

Table 3
Parameter values (continued)

| | | | | | |
|---|---|---|---|---|---|
| $\mathcal{T}^{ss}_{uk}$ | 36.12 | $\mathcal{T}^{ss}_{rw}$ | 31.69 | $\mathcal{T}^{ss}_{ch}$ | 18.66 |
| $\mathcal{T}^{ss}_{op}$ | 36.12 | $\beta_{ea}$ | 0.99 | $\beta_{rw}$ | 0.99 |
| $\beta_{ja}$ | 0.99 | $\beta_{us}$ | 0.99 | $\beta_{uk}$ | 0.99 |
| $\beta_{ch}$ | 0.99 | $\beta_{op}$ | 0.99 | $\overline{blt}_{ea}$ | 11.45 |
| $\overline{blt}_{rw}$ | 0.00 | $\overline{blt}_{ja}$ | $-18.17$ | $\overline{blt}_{us}$ | 8.34 |
| $\overline{blt}_{uk}$ | 4.00 | $\overline{blt}_{ch}$ | 34.46 | $\overline{blt}_{op}$ | 4.00 |
| $\mathcal{B}^{ss}_{ea}$ | 84.77 | $\mathcal{B}^{ss}_{rw}$ | 75.14 | $\mathcal{B}^{ss}_{ja}$ | 170.06 |
| $\mathcal{B}^{ss}_{us}$ | 60.49 | $\mathcal{B}^{ss}_{uk}$ | 50.19 | $\mathcal{B}^{ss}_{ch}$ | 35.13 |
| $\mathcal{B}^{ss}_{op}$ | 50.19 | $\Delta\overline{\mathcal{B}}_{ea}$ | 1.86 | $\Delta\overline{\mathcal{B}}_{ja}$ | 8.41 |
| $\Delta\overline{\mathcal{B}}_{us}$ | 1.43 | $\Delta\overline{\mathcal{B}}_{uk}$ | 2.51 | $\Delta\overline{\mathcal{B}}_{ch}$ | 4.81 |
| $\Delta\overline{\mathcal{B}}_{op}$ | 2.51 | $\Delta\overline{\mathcal{T}}_{ea}$ | 0.01 | $\Delta\overline{\mathcal{T}}_{ja}$ | $-0.07$ |
| $\Delta\overline{\mathcal{T}}_{us}$ | 0.00 | $\Delta\overline{\mathcal{T}}_{uk}$ | 0.08 | $\Delta\overline{\mathcal{T}}_{ch}$ | 0.38 |
| $\Delta\overline{\mathcal{T}}_{op}$ | 0.08 | $\Delta\overline{\mathcal{G}}_{ea}$ | 0.01 | $\Delta\overline{\mathcal{G}}_{ja}$ | 0.09 |
| $\Delta\overline{\mathcal{G}}_{us}$ | 0.01 | $\Delta\overline{\mathcal{G}}_{uk}$ | 0.08 | $\Delta\overline{\mathcal{G}}_{ch}$ | 0.15 |
| $\Delta\overline{\mathcal{G}}_{op}$ | 0.08 | $\Delta\overline{Q}^{ss}_{ea}$ | $-0.13$ | $\Delta\overline{Q}^{ss}_{rw}$ | $-0.21$ |
| $\Delta\overline{Q}^{ss}_{ja}$ | $-0.42$ | $\Delta\overline{Q}^{ss}_{uk}$ | 0.02 | $\Delta\overline{Q}^{ss}_{ch}$ | $-0.57$ |
| $\Delta\overline{Q}^{ss}_{op}$ | 0.02 | | | | |

*Notes: In another version of the model we introduced incomplete pass-through in import prices and oil prices. The parameters that measure the extent of the pass-through are $\phi_{i,t}$ and $\phi^{oil}_{i,t}$ respectively. In this version of ECB-G, both parameters are set to one so that the pass-through is complete.*

## A.3   List of variables

Table 4
List of variables and parameters

| Symbol | Name | Symbol | Name |
|--------|------|--------|------|
| $\omega^F$ | Financial Weights | $\omega^M$ | Import Weights |
| $\omega^X$ | Export Weights | $\omega^{oil}$ | Oil Demand Weights |
| $\omega^{oil,M}$ | Oil Import Weights | $\chi$ | Shares |
| $\alpha$ | Coefficients | $\eta$ | Trend coefficients |
| $\theta$ | Elasticities | $\beta$ | Discount factor |
| $\rho$ | AR coefficients for shocks | $\xi$ | Exogenous shocks |
| $\varepsilon$ | Innovation | $ci_t$ | IS curve (c+i) |
| $y_t$ | Output | $p_t^{ry}$ | Relative price of y and c |
| $\pi_t^{ppi}$ | Producer-price inflation | $\pi_t^{cpi}$ | Consumer-price inflation |
| $mc_t$ | Marginal costs | $S_t$ | Nominal exchange rate |
| $Q_t$ | Real exchange rate | $i_t^s$ | Nominal policy rate |
| $\pi_t^T$ | Inflation target | $r_t^s$ | Risk-free real rate |
| $b_t$ | Real government debt | $g_t$ | Real government expenditure |
| $\tau_t$ | Real government taxes | $q_t$ | Equity prices |
| $m_t^{nonoil}$ | Non-oil imports | $m_t^{oil}$ | Oil imports |
| $m_t$ | Total imports | $x_t^{nonoil}$ | Non-oil exports |
| $x_{op,t}^{oil}$ | Oil exports | $x_t$ | Total exports |
| $oil_t^d$ | Global oil demand | $\pi_t^{oil}$ | Oil inflation |
| $r^3$ | Real Interbank rate | $\varsigma_t^b$ | Interbank rate spread |
| $blt_t$ | Bank lending tightness | $\varsigma_t^g$ | Sovereign credit-risk premium |
| $r_t^g$ | Real Short term government yield | $r_t^l$ | Real Long term government yield |
| $\varphi_t$ | Private sector credit-risk premium | $nfa_t$ | Net foreign asset position |
| $\varrho_{ch,t}$ | Reserve requirement ratio | $p_t^{rg}$ | Price of gov. exp. relative to cpi |

Figure 1
ECB-GLOBAL SCHEME
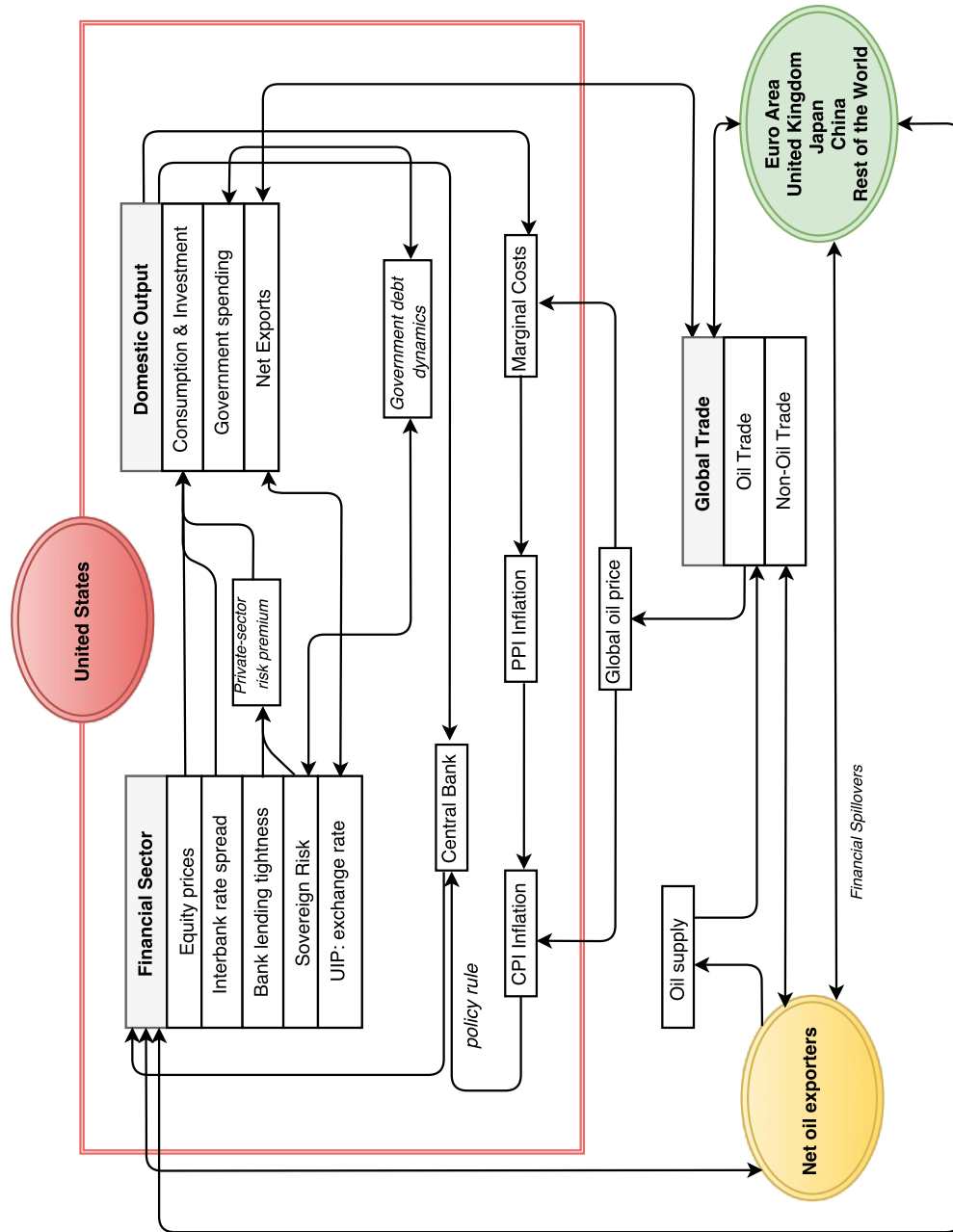
Figure 2
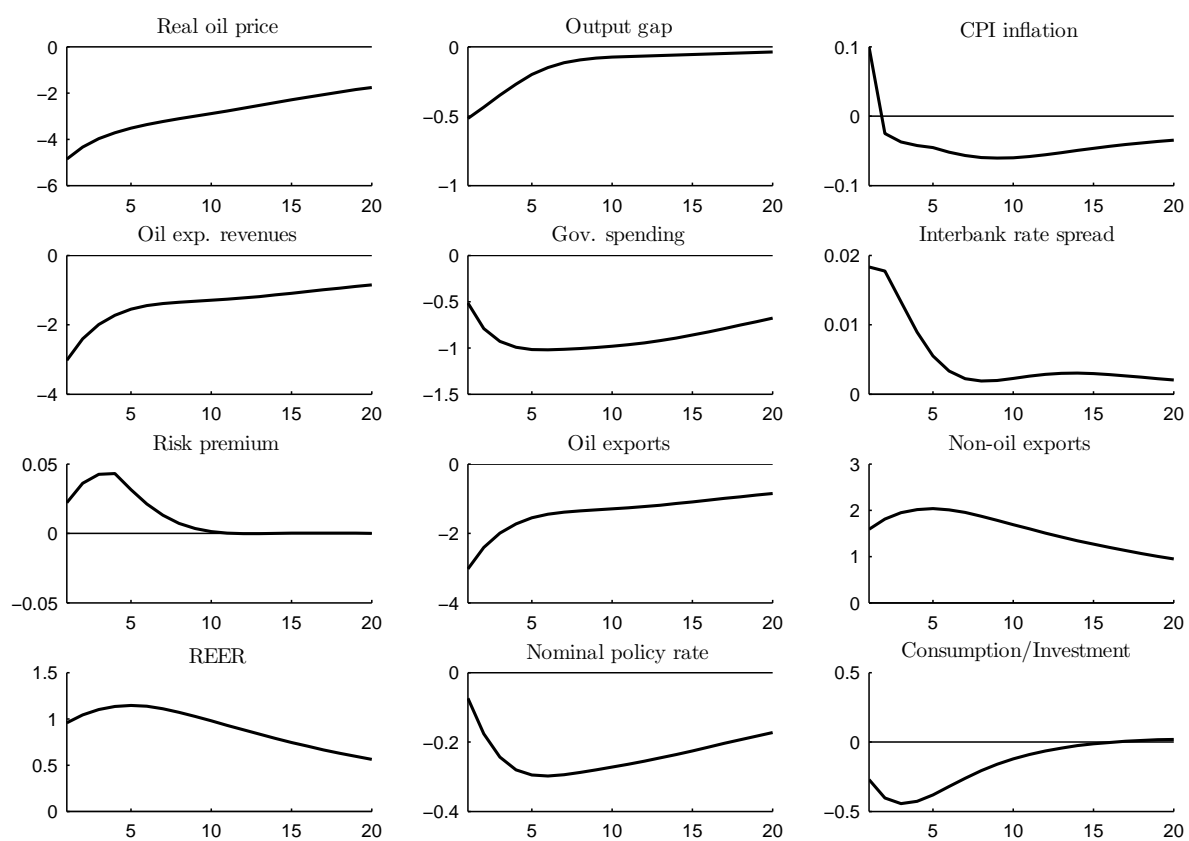US MONETARY POLICY SHOCK: IMPULSE RESPONSES OF DOMESTIC VARIABLES
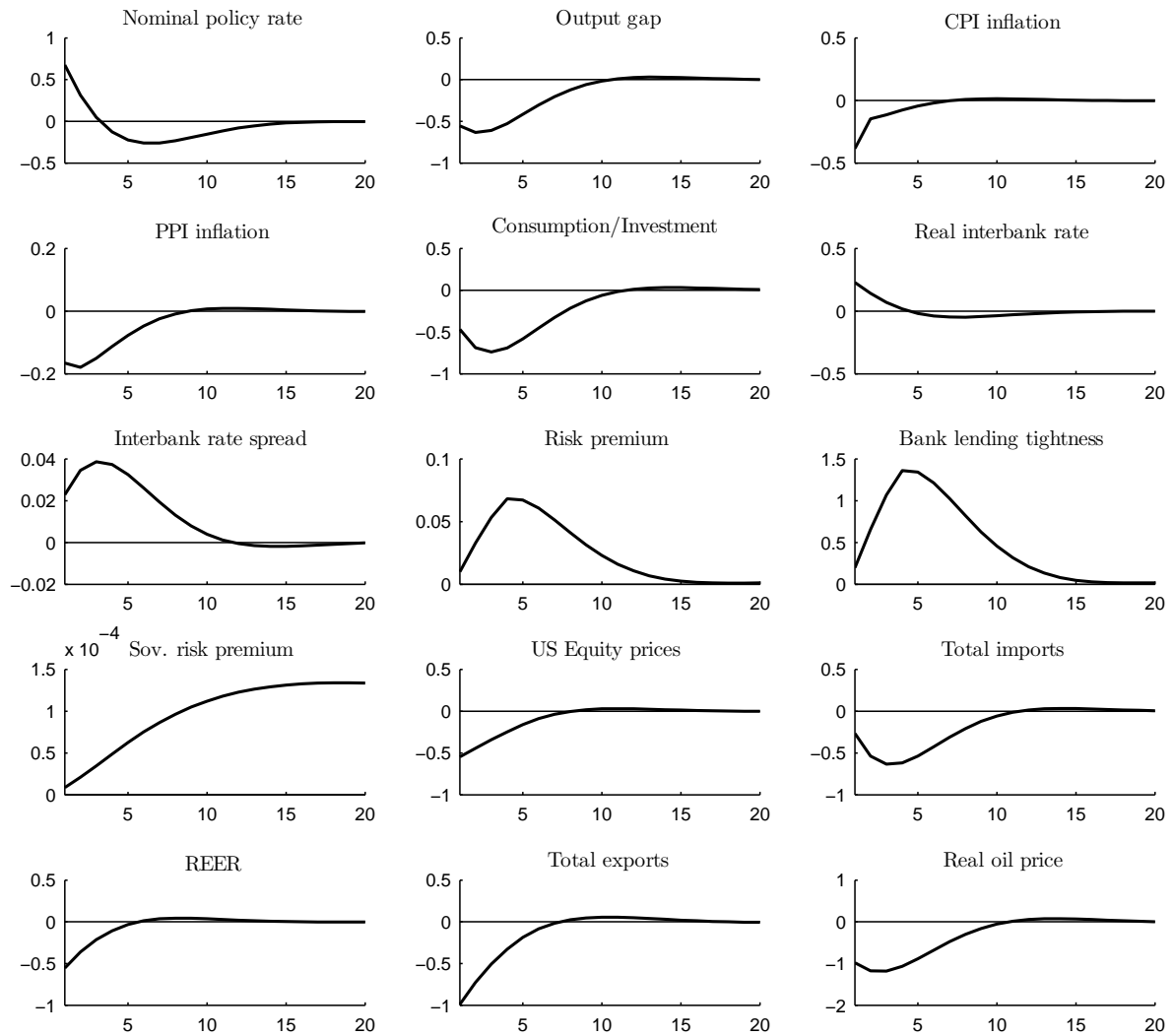


Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate, CPI and PPI 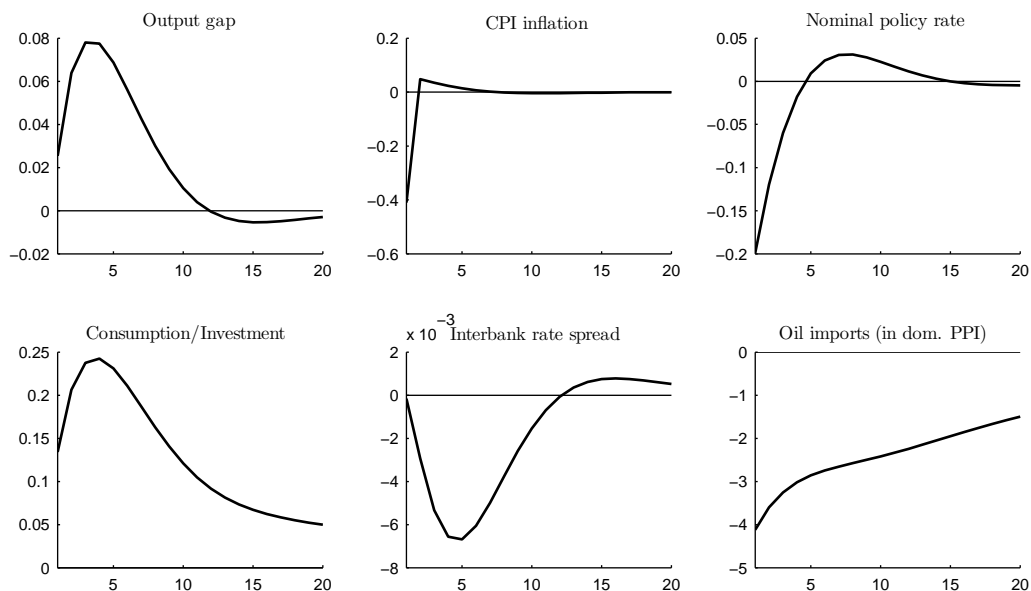inflation which are annualised. The exchange rate refers to the US dollar real effective exchange rate with an increase being a depreciation of US dollar.

Figure 3

US MONETARY POLICY SHOCK: IMPULSE RESPONSES OF FOREIGN VARIABLES
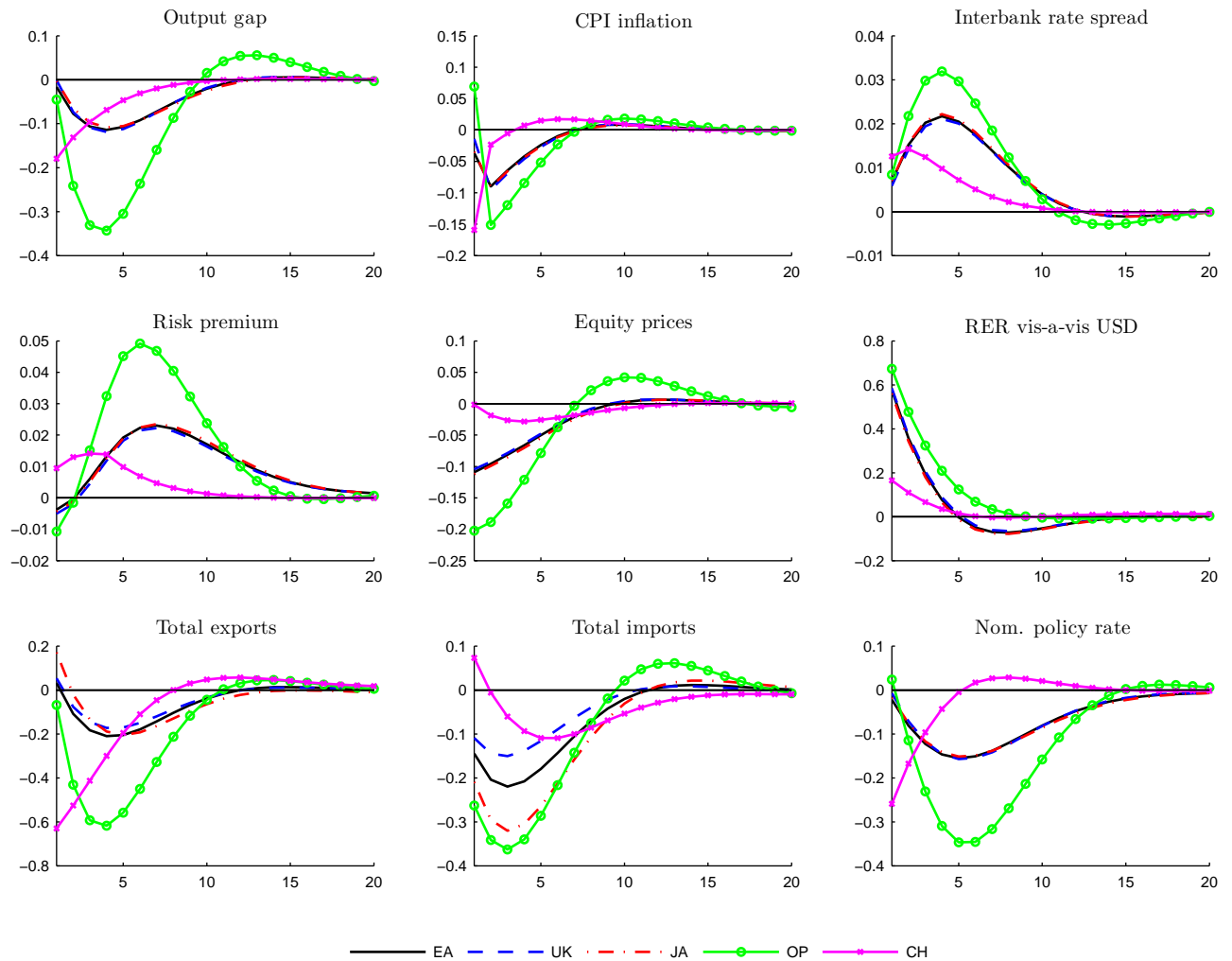


Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate and CPI inflation which are annualised. The exchange rate refers to the bilateral exchange rate vis-à-vis the US dollar real with an increase being a depreciation of the foreign economy exchange rate vis-à-vis the US dollar.

Figure 4
US MONETARY POLICY SHOCK: DIFFERENT MAGNITUDES OF FINANCIAL SPILLOVERS



Output gap US                    Output gap EA
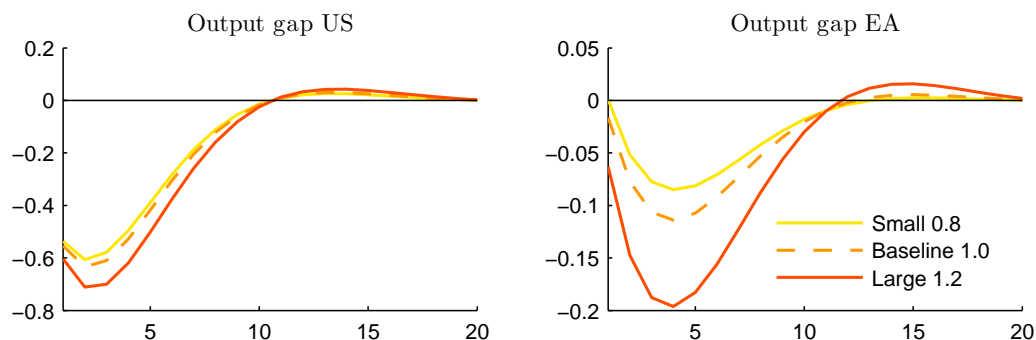
Notes: This figure shows the sensitivity of the output gap when varying the value of the interbank interest rate spillover parameter; a higher value denotes higher financial spillovers through interbank rates. The baseline value for the parameter is 1, in the low sensitivity calibration the parameter is 0.8 and in the high sensitivity its value is set to 1.2. All variables are expressed in percentage point changes from the steady state and are in quarterly terms.

Figure 5
US MONETARY POLICY SHOCK: DIFFERENT MAGNITUDES OF OIL SPILLOVERS



Real oil price              Output gap EA              Output gap OP
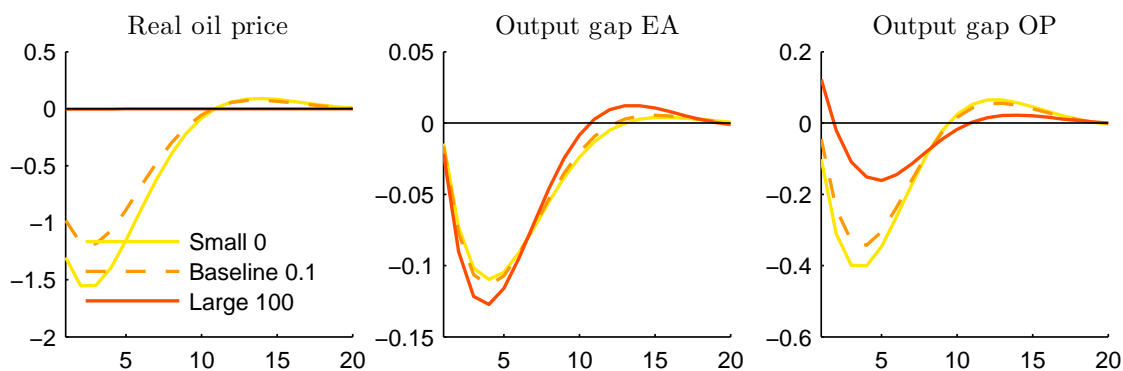
Notes: This figure shows the sensitivity of the output gap when varying the price elasticity of oil supply; a higher value denotes a higher response of oil supply to an oil price change (and therefore a smaller reaction of oil prices to a monetary policy shock). The baseline value for the parameter is 0.05, in the low sensitivity calibration the parameter is 0 and in the high sensitivity its hypothetical value is set to 100. All variables are expressed in percentage point changes from the steady state and are in quarterly terms.

Figure 6
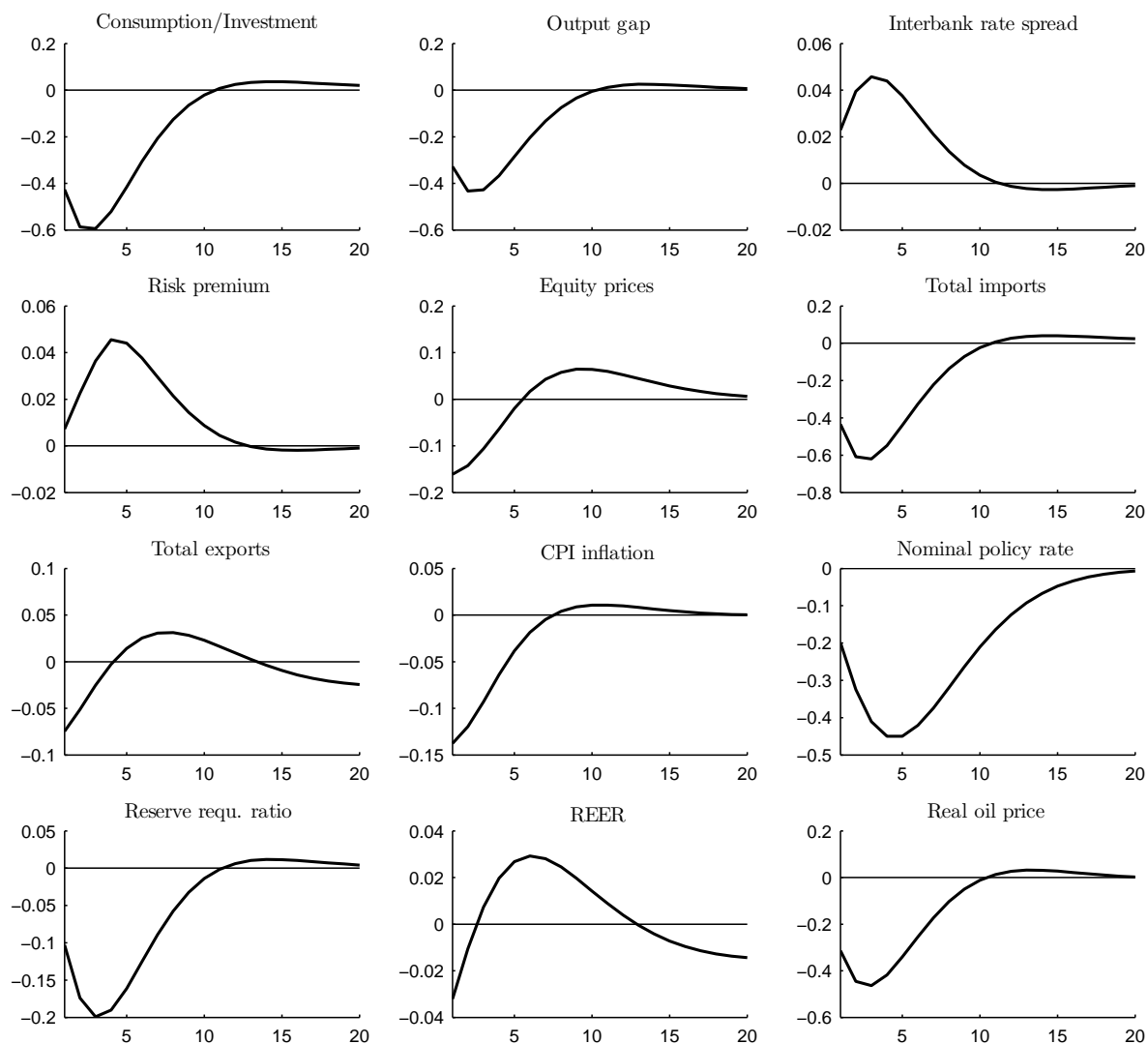
DEMAND SHOCK IN CHINA: IMPULSE RESPONSES OF DOMESTIC VARIABLES



Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate and CPI inflation which are annualised. The exchange rate refers to the real effective exchange rate of the Chinese renminbi with an increase being a depreciation of renminbi.

Figure 7

DEMAND SHOCK IN CHINA: IMPULSE RESPONSES OF FOREIGN VARIABLES
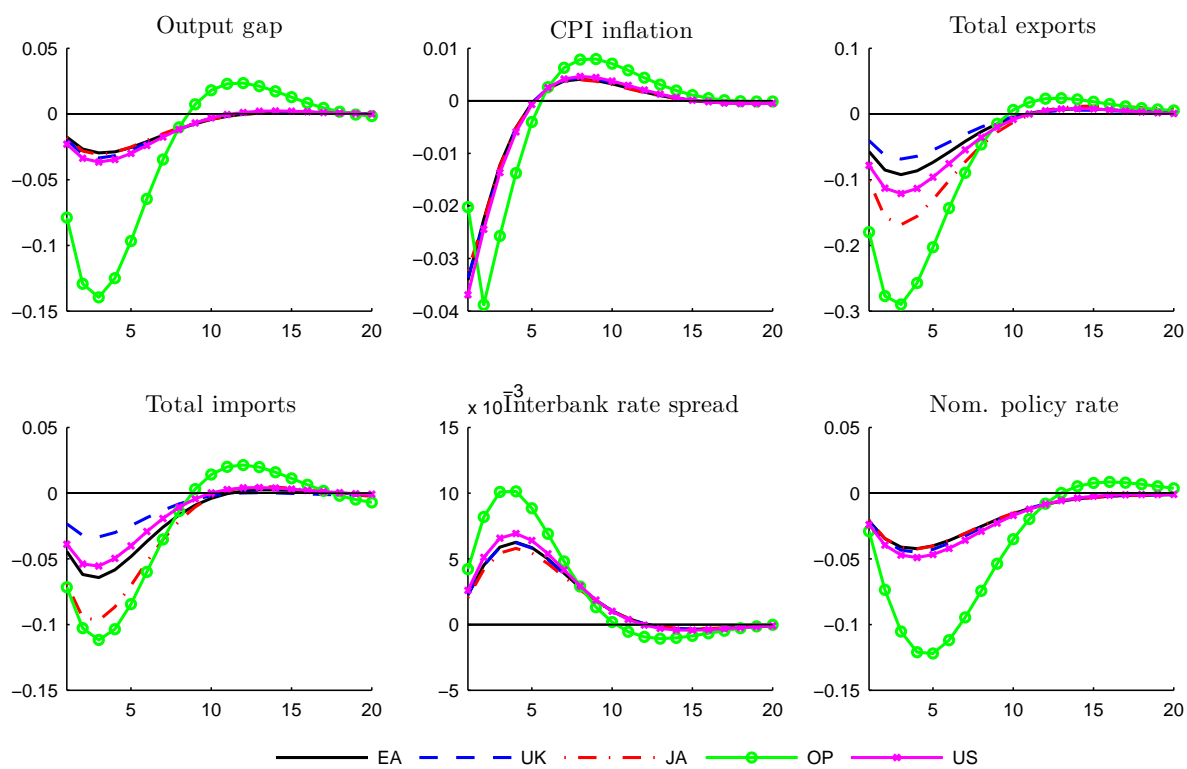


Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate and CPI inflation which are annualised.

Figure 8

Oil supply shock: Impulse responses of oil-exporting country variables



Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate and CPI inflation which are annualised. The exchange rate refers to the real effective exchange rate of the oil-exporting country with an increase being a depreciation of the oil-exporting country's currency.

Figure 9

OIL SUPPLY SHOCK: IMPULSE RESPONSES OF EURO AREA VARIABLES (AS EXAMPLE OIL-IMPORTING COUNTRY)



Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms except for the nominal policy rate and CPI inflation which are annualised.

Figure 10

OIL PRICE SHOCK: HETEROGENEITIES IN OUTPUT GAP SPILLOVERS
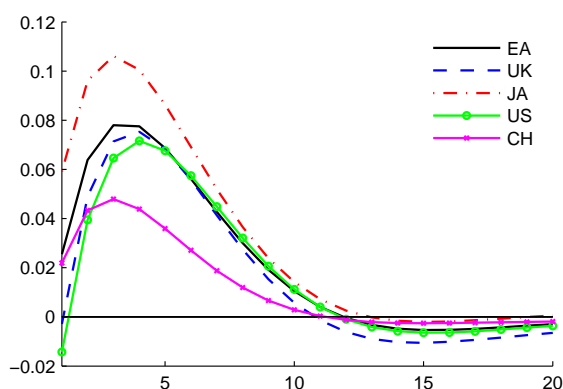


Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms.

Figure 11
OIL PRICE SHOCK: IMPULSE RESPONSES OF GLOBAL OUTPUT GAP
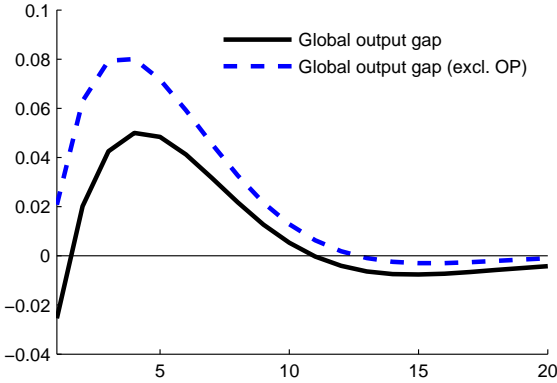


Notes: All variables are expressed in percentage point changes from the steady state and are in quarterly terms.

Figure 12
GLOBAL GDP ELASTICITIES COMPARISON
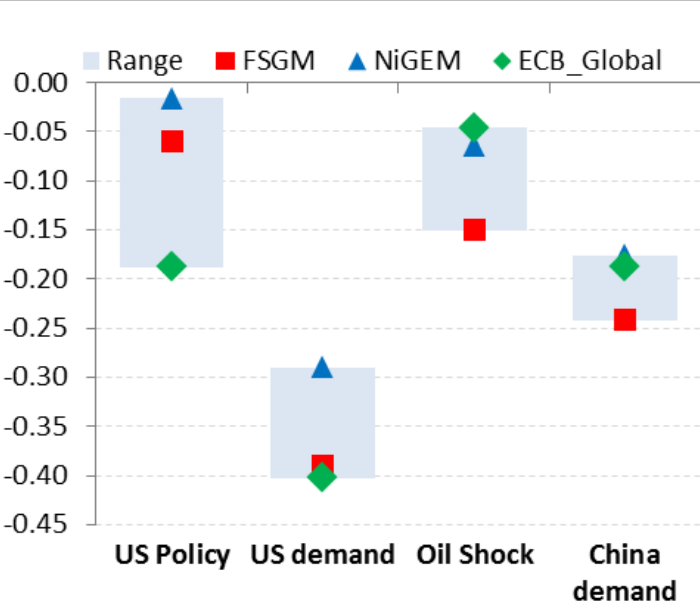


Notes: All variables are expressed in average percentage deviations over the first year after the shock. Shocks are: i) 25 bps monetary policy shock, ii) a 1% domestic demand driven decrease in US GDP, iii) a 10% supply driven increase in oil prices, iv) a 1% domestic demand driven decrease in China GDP.

Figure 13
GDP ELASTICITIES: COUNTRY COMPARISON
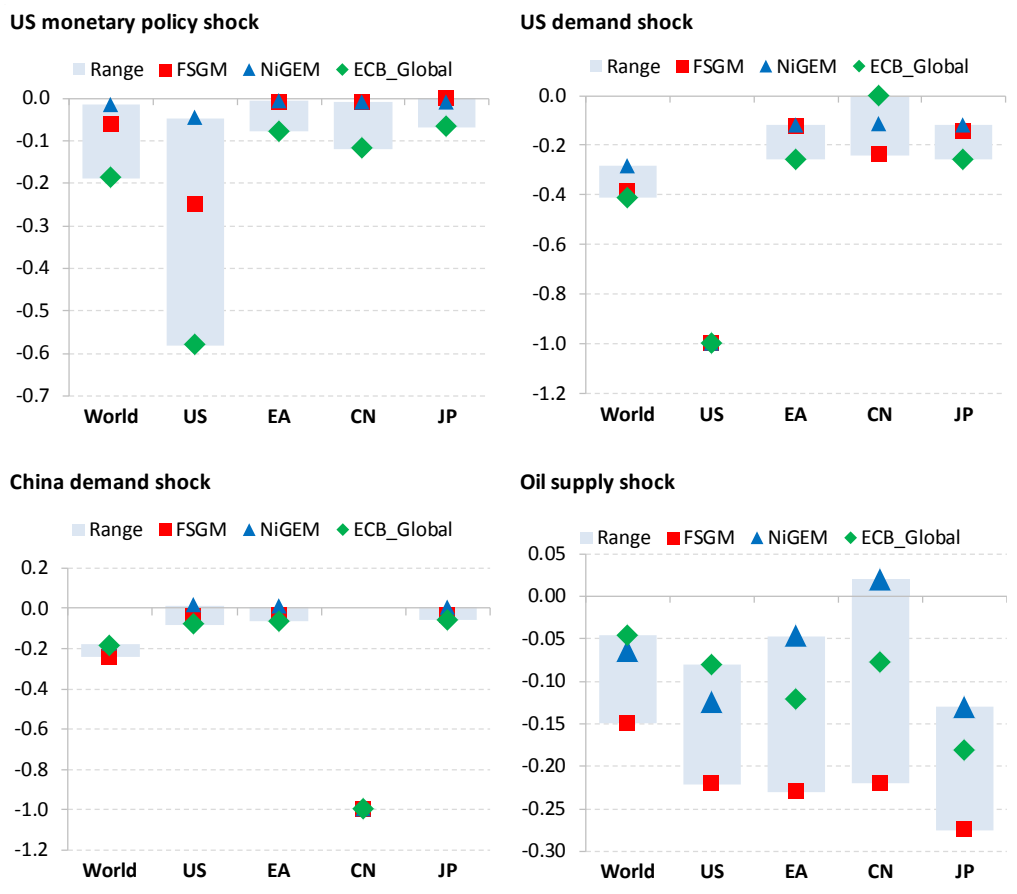


**US monetary policy shock**

**US demand shock**

**China demand shock**

**Oil supply shock**

Notes: All variables are expressed in average percentage deviations over the first year after the shock. Shocks are: i) 25 bps monetary policy shock, ii) a 1% domestic demand driven decrease in US GDP, iii) a 10% supply driven increase in oil prices, iv) a 1% domestic demand driven decrease in China GDP.

# C Model appendix

This appendix provides details on the derivation of the log-linearised equations of ECB-Global. Equations labeled with (**M.**) correspond to the equations described in the main text that enter the log-linearised system of equations in the mod-files.

## C.1 Model equations

### C.1.1 Definition of relative prices

The relative price of output and consumption is given by the ratio of the producer-price level and the consumer-price level

$$p_{ea,t}^{ry} = \frac{P_{ea,t}^{ppi}}{P_{ea,t}^{cpi}}. \tag{C.1}$$

Log-linearised this is

$$\widehat{p}_{ea,t}^{ry} = \widehat{p}_{ea,t}^{ppi} - \widehat{p}_{ea,t}^{cpi}, \tag{C.2}$$

which implies

$$\widehat{p}_{ea,t}^{ry} = \widehat{p}_{ea,t-1}^{ry} + \widehat{\pi}_{ea,t}^{ppi} - \widehat{\pi}_{ea,t}^{cpi} \tag{M1}$$

where $\widehat{\pi}_{ea,t}^{cpi}$ and $\widehat{\pi}_{ea,t}^{ppi}$ are consumer-price and producer-price inflation, respectively.

### C.1.2 Marginal Costs

Denoting by $Y_t$ nominal GDP, by $P_t^{oil}$ the oil price in US dollars, and $p_t^{oil}$ the oil price relative to US consumer prices, we specify real marginal costs to be a function of domestic real output, the real price of oil, and the real price of imported intermediates as[11]

$$
\begin{aligned}
mc_{ea,t} =& A_{ea} \cdot \left( \frac{Y_{ea,t}}{P_{ea,t}^{ppi}} \right)^{\alpha_{ea}^{mc,y}} \\
& \cdot \left\{ \left( \frac{S_{ea,t} P_t^{oil}}{P_{ea,t}^{ppi}} \right)^{\alpha_{ea}^{mc,oil}} \left[ \left( \frac{S_{ea,t} P_{us,t}^{ppi}}{P_{ea,t}^{ppi}} \right)^{\omega_{ea,us}^{M}} \left( \frac{S_{ea,t}}{S_{op,t}} \cdot \frac{P_{op,t}^{ppi}}{P_{ea,t}^{ppi}} \right)^{\omega_{ea,op}^{M}} \right]^{(1-\alpha_{ea}^{mc,oil})} \right\}^{\alpha_{ea}^{mc,\pi^{ppi}}} \\
=& A_{ea} \cdot \left( y_{ea,t} \right)^{\alpha_{ea}^{mc,y}} \\
& \cdot \left\{ \left( \frac{Q_{ea,t} p_t^{oil}}{p_{ea,t}^{ry}} \right)^{\alpha_{ea}^{mc,oil}} \left[ \left( Q_{ea,t} \frac{p_{us,t}^{ry}}{p_{ea,t}^{ry}} \right)^{\omega_{ea,us}^{M}} \left( \frac{Q_{ea,t}}{Q_{op,t}} \frac{p_{op,t}^{ry}}{p_{ea,t}^{ry}} \right)^{\omega_{ea,op}^{M}} \right]^{(1-\alpha_{ea}^{mc,oil})} \right\}^{\alpha_{ea}^{mc,\pi^{ppi}}}.
\end{aligned}
\tag{C.3}
$$

---

[11]For a derivation of the oil price entering the Phillips curve see Pickering and Valle (2008).

Log-linearising yields

$$\widehat{mc}_{ea,t} = \alpha_{ea}^{mc,y}\widehat{y}_{ea,t} + \alpha_{ea}^{mc,\pi^{ppi}}\left\{\alpha_{ea}^{mc,oil}\left(\widehat{Q}_{ea,t} + \widehat{p}_t^{oil} - \widehat{p}_{ea,t}^{ry}\right)\right.$$
$$\left. + (1 - \alpha_{ea}^{mc,oil})\left[\omega_{ea,us}^M\left(\widehat{Q}_{ea,t}\widehat{p}_{us,t}^{ry} - \widehat{p}_{ea,t}^{ry}\right) + \omega_{ea,op}^M\left(\widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{p}_{ea,t}^{ry}\right)\right]\right\}. \quad \textbf{(M4)}$$

### C.1.3 Consumer Prices

Consumer prices result from a combination of domestic and foreign producer prices as well as oil prices. Specifically, we define the CPI as

$$P_{ea,t}^{cpi} = \left(S_{ea,t}P_t^{oil}\right)^{\varpi_{ea}^{oil}} \cdot \left(P_{ea,t}^{ppi}\right)^{(1-\varpi_{ea}^{oil})\alpha_{ea}^H} \cdot$$
$$\left[\left(S_{ea,t}P_{ea,t}^{ppi}\right)^{\omega_{ea,us}^{M^{nonoil}}} \cdot \left(S_{ea,t}/S_{op,t} \cdot P_{op,t}^{ppi}\right)^{\omega_{ea,op}^{M^{nonoil}}}\right]^{(1-\varpi_{ea}^{oil})(1-\alpha_{ea}^H)}, \quad \text{(C.4)}$$

where $\omega_{ea,us}^{M^{nonoil}}$ is the share of non-oil imports of the euro area that originates in the US[12], $\varpi_{ea}^{oil}$ the share of oil in the consumption basket and $(1 - \alpha_{ea}^H)$ is the share of imported consumption goods in total consumption, which we calibrate based on the WIOD database; $\alpha_{ea}^H$ can be read as a measure of home bias. Then,

$$1 = \left(\frac{S_{ea,t}P_t^{oil}}{P_{ea,t}^{cpi}}\right)^{\varpi_{ea}^{oil}} \cdot \left(\frac{P_{ea,t}^{ppi}}{P_{ea,t}^{cpi}}\right)^{(1-\varpi_{ea}^{oil})\alpha_{ea}^H} \cdot$$
$$\left[\left(\frac{S_{ea,t}P_{us,t}^{ppi}}{P_{ea,t}^{cpi}}\right)^{\omega_{ea,us}^M}\left(\frac{S_{ea,t}P_{op,t}^{ppi}}{S_{op,t}P_{ea,t}^{cpi}}\right)^{\omega_{ea,op}^M}\right]^{(1-\varpi_{ea}^{oil})(1-\alpha_{ea}^H)}$$
$$= \left(Q_{ea,t}p_t^{oil}\right)^{\varpi_{ea}^{oil}} \cdot \left(p_{ea,t}^{ry}\right)^{(1-\varpi_{ea}^{oil})\alpha_{ea}^H} \cdot$$
$$\left[\left(p_{us,t}^{ry}Q_{ea,t}\right)^{\omega_{ea,us}^M}\left(p_{op,t}^{ry}Q_{ea,t}/Q_{op,t}\right)^{\omega_{ea,op}^M}\right]^{(1-\varpi_{ea}^{oil})(1-\alpha_{ea}^H)}. \quad \text{(C.5)}$$

Log-linearising Equation (C.5) results in

$$0 = \varpi_{ea}^{oil} \cdot \left(\widehat{Q}_{ea,t} + \widehat{p}_t^{oil}\right) + (1 - \varpi_{ea}^{oil})\alpha_{ea}^H \cdot \widehat{p}_{ea,t}^{ry} \quad \textbf{(M5)}$$
$$+ (1 - \varpi_{ea}^{oil})(1 - \alpha_{ea}^H)\left[\omega_{ea,us}^M\left(\widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry}\right) + \omega_{ea,op}^M\left(\widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry}\right)\right].$$

### C.1.4 Government debt

Denote real government debt by $B_{ea,t}$ and real government expenditures and taxes denominated in euro area output goods by $G_{ea,t}$ and $T_{ea,t}$, respectively. Denoting by $I_{ea,t}^g$ the gross nominal

---

[12]In fact, it should be the share of imported goods in the consumption basket of the euro area that is imported from the US. These data are not available.

interest rate on government debt, the latter evolves according to

$$P_{ea,t}^{ppi}B_{ea,t} \;=\; P_{ea,t}^{ppi}G_{ea,t} - P_{ea,t}^{ppi}T_{ea,t} + I_{ea,t-1}^{g}\cdot P_{ea,t-1}^{ppi}B_{ea,t-1},$$

$$B_{ea,t} \;=\; G_{ea,t} - T_{ea,t} + I_{ea,t-1}^{g}\frac{p_{ea,t-1}^{ry}}{p_{ea,t}^{ry}\Pi_{ea,t}^{cpi}}\cdot B_{ea,t-1}, \tag{C.6}$$

where $\Pi_{ea,t}^{cpi}$ is the gross CPI inflation rate. In per capita terms we have

$$\frac{B_t}{N_{ea,t}} \;=\; \frac{G_{ea,t}}{N_{ea,t}} - \frac{T_{ea,t}}{N_{ea,t}} + \frac{p_{ea,t-1}^{ry}I_{ea,t-1}^{g}}{p_{ea,t}^{ry}\Pi_{ea,t}^{cpi}}\frac{N_{ea,t-1}}{N_{ea,t}}\frac{B_{ea,t-1}}{N_{ea,t-1}},$$

$$b_{ea,t} \;=\; g_{ea,t} - t_{ea,t} + \frac{p_{ea,t-1}^{ry}I_{ea,t-1}^{g}}{p_{ea,t}^{ry}\Pi_{ea,t}^{cpi}G_{ea,t}^{n}}\cdot b_{ea,t-1}, \tag{C.7}$$

where $G_{ea,t}^{n}$ is the gross population growth rate. Then, relative to GDP per capita we have

$$\frac{b_{ea,t}}{y_{ea,t}} \;=\; \frac{g_{ea,t}}{y_{ea,t}} - \frac{t_{ea,t}}{y_{ea,t}} + \frac{p_{ea,t-1}^{ry}I_{ea,t-1}^{g}}{p_{ea,t}^{ry}\Pi_{ea,t}^{cpi}G_{ea,t}^{n}}\frac{y_{ea,t-1}}{y_{ea,t}}\frac{b_{ea,t-1}}{y_{ea,t-1}}$$

$$\mathfrak{b}_{ea,t} \;=\; g_{ea,t} - t_{ea,t} + \frac{p_{ea,t-1}^{ry}I_{ea,t-1}^{g}}{p_{ea,t}^{ry}\Pi_{ea,t}^{cpi}G_{ea,t}^{n}G_{ea,t}^{y}}\cdot \mathfrak{b}_{ea,t-1}, \tag{C.8}$$

where $G_{ea,t}^{y}$ is the gross growth rate of real GDP per capita. In log-linear deviations from steady state we have

$$\mathfrak{b}_{ea}^{ss}\widehat{\mathfrak{b}}_{ea,t} \;=\; g_{ea}^{ss}\widehat{g}_{ea,t} - t_{ea}^{ss}\widehat{t}_{ea,t}$$
$$+ \left(\frac{I_{ea}^{g,ss}\mathfrak{b}_{ea}^{ss}}{\Pi_{ea}^{cpi,ss}G_{ea}^{n,ss}G_{ea}^{y,ss}}\right)\left(\widehat{\mathfrak{b}}_{ea,t-1} + \widehat{I}_{ea,t-1}^{g} - \widehat{\Pi}_{ea,t}^{cpi} - \widehat{G}_{ea,t}^{n} - \widehat{G}_{ea,t}^{y} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry}\right),$$

$$\widetilde{\mathfrak{b}}_{ea,t} \;=\; \widetilde{g}_{ea,t} - \widetilde{t}_{ea,t}$$
$$+ \left(\frac{R_{ea}^{g,ss}}{G_{ea}^{n,ss}G_{ea}^{y,ss}}\right)\left[\widetilde{\mathfrak{b}}_{ea,t-1} + \mathfrak{b}_{ea}^{ss}\left(\widehat{I}_{ea,t-1}^{g} - \widehat{\Pi}_{ea,t}^{cpi} - \widehat{G}_{ea,t}^{n} - \widehat{G}_{ea,t}^{y} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry}\right)\right]$$

$$=\; +\widetilde{g}_{ea,t} - \widetilde{t}_{ea,t} + \left[\frac{(1+r_{ea}^{g,ss})}{(1+n_{ea}^{ss})(1+\Delta y_{ea}^{ss})}\right]\left[\widetilde{\mathfrak{b}}_{ea,t-1}\right.$$
$$\left. +\mathfrak{b}_{ea}^{ss}\left(\frac{ig_{ea,t-1} - i_{ea}^{g,ss}}{1+i_{ea}^{g,ss}} - \frac{\pi_{ea,t}^{cpi} - \pi^{cpi,ss}}{1+\pi^{cpi,ss}} - \frac{n_{ea,t} - n_{ea}^{ss}}{1+n_{ea}^{ss}} - \frac{\Delta y_{ea,t} - \Delta y_{ea}^{ss}}{1+\Delta y_{ea}^{ss}} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry}\right)\right]$$

$$=\; \widetilde{g}_{ea,t} - \widetilde{t}_{ea,t} + \left[\frac{(1+r_{ea}^{g,ss})}{(1+n_{ea}^{ss})(1+\Delta y_{ea}^{ss})}\right]\left[\widetilde{\mathfrak{b}}_{ea,t-1}\right.$$
$$\left. +\mathfrak{b}_{ea}^{ss}\left(\frac{\widehat{i}_{ea,t-1}^{g}}{1+i_{ea}^{g,ss}} - \frac{\widehat{\pi}_{ea,t}}{1+\pi_{ea}^{cpi,ss}} - \frac{\widehat{n}_{ea,t}}{1+n_{ea}^{ss}} - \frac{\widehat{\Delta y}_{ea,t}}{1+\Delta y_{ea}^{ss}} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry}\right)\right]. \tag{C.9}$$

We can approximate to simplify further

$$
\begin{aligned}
\widetilde{\ell}_{ea,t} \;=\; & \widetilde{g}_{ea,t} - \widetilde{t}_{ea,t} + (1 + r_{ea}^{g,ss} - n_{ea}^{ss} - \Delta y_{ea}^{ss}) \Bigg[ \widetilde{\ell}_{ea,t-1} \\
& + \ell_{ea}^{ss} \left( \frac{\widehat{i}_{ea,t-1}^{g}}{1 + i_{ea}^{g,ss}} - \frac{\widehat{\pi}_{ea,t}}{1 + \pi_{ea}^{cpi,ss}} - \frac{\widehat{n}_{ea,t}}{1 + n_{ea}^{ss}} - \frac{\widehat{\Delta y}_{ea,t}}{1 + \Delta y_{ea}^{ss}} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry} \right) \Bigg]. \; \text{(C.10)}
\end{aligned}
$$

If we assume population to be constant we obtain

$$
\begin{aligned}
\widetilde{\ell}_{ea,t} =& \widetilde{g}_{ea,t} - \widetilde{t}_{ea,t} \hspace{9cm} \text{(M9)} \\
& + (1 + r_{ea}^{g,ss} - \Delta y_{ea}^{ss}) \Bigg[ \widetilde{\ell}_{ea,t-1} + \ell_{ea}^{ss} \left( \frac{\widehat{i}_{ea,t-1}^{g}}{1 + i_{ea}^{g,ss}} - \frac{\widehat{\pi}_{ea,t}}{1 + \pi_{ea}^{cpi,ss}} - \frac{\widehat{\Delta y}_{ea,t}}{1 + \Delta y_{ea}^{ss}} + \widehat{p}_{ea,t-1}^{ry} - \widehat{p}_{ea,t}^{ry} \right) \Bigg].
\end{aligned}
$$

As we use variables in per capita terms in the GDP aggregation in (**M46**) below, we need to map absolute deviations of government expenditures relative to GDP from the steady state, $\widetilde{g}_{ea,t}$, to percentage deviations of per capita government expenditures from steady state, $\widehat{g}_{ea,t}$,

$$
\mathcal{G}_{ea,t} \equiv \frac{G_{ea,t}}{Y_{ea,t}^{ppi}} = \frac{G_{ea,t}/N_{ea,t}}{Y_{ea,t}^{ppi}/N_{ea,t}} = \frac{g_{ea,t}}{y_{ea,t}^{ppi}} = g_{ea,t}, \tag{C.11}
$$

which implies

$$
\widehat{g}_{ea,t} = \frac{g_{ea,t} - g_{ea}^{ss}}{g_{ea}^{ss}} = \widehat{g}_{ea,t} - \widehat{y}_{ea,t}^{ppi}, \tag{C.12}
$$

and finally

$$
\widetilde{g}_{ea,t} = g_{ea,t} - g_{ea}^{ss} = g_{ea}^{ss} \cdot \widehat{g}_{ea,t} = g_{ea}^{ss} \cdot (\widehat{g}_{ea,t} - \widehat{y}_{ea,t}^{ppi}). \tag{\textbf{M10}}
$$

### C.1.5   Trade

**Non-oil imports**   We model the euro area's bilateral (non-oil) imports from the US as a function of the PPI price of US goods—assuming producer-currency pricing—in euro relative to euro area CPI prices and as a function of euro area domestic demand. In particular, we specify real (non-oil) bilateral imports of the euro area from the US as

$$
M_{ea,us,t}^{nonoil} = \left( \frac{S_{ea,t} P_{us,t}^{ppi}}{P_{ea,t}^{cpi}} \right)^{-\theta_{ea}^{nonoil}} DA_{ea,t}, \tag{C.13}
$$

where $\theta_{ea}^{nonoil}$ represents the price elasticity of euro area import demand, and $DA_{ea,t}$ domestic absorption given by the sum of private consumption, investment and government expenditures

$$
DA_{ea,t} = CI_{ea,t} + G_{ea,t}. \tag{C.14}
$$

Re-writing Equation (C.13) yields

$$
\begin{aligned}
M_{ea,us,t}^{nonoil} &= \left( \frac{S_{ea,t} P_{us,t}^{cpi}}{P_{ea,t}^{cpi}} \cdot \frac{P_{us,t}^{ppi}}{P_{us,t}^{cpi}} \right)^{-\theta_{ea}^{nonoil}} DA_{ea,t} \\[2mm]
&= \left( Q_{ea,t} \cdot p_{us,t}^{ry} \right)^{-\theta_{ea}^{nonoil}} DA_{ea,t}.
\end{aligned}
\tag{C.15}
$$

Euro area per capita demand for imports from the US is then given by

$$
m_{ea,us,t}^{nonoil} = \left( Q_{ea,t} \cdot p_{us,t}^{ry} \right)^{-\theta_{ea}^{nonoil}} da_{ea,t}.
\tag{C.16}
$$

In log-linear deviations from steady state we have

$$
\widehat{m}_{ea,us,t}^{nonoil} = -\theta_{ea}^{nonoil} \cdot (\widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry}) + \widehat{da}_{ea,t}.
\tag{C.17}
$$

**Oil imports**  We specify oil imports analogously to non-oil imports, except that we assume that governments do not consume oil. Specifically, similarly to Medina and Soto (2005), we model the euro area's real oil import demand as

$$
M_{ea,t}^{oil} = \left( \frac{S_{ea,t} P_t^{oil}}{P_{ea,t}^{cpi}} \right)^{-\theta_{ea}^{oil}} CI_{ea,t},
\tag{C.18}
$$

where $P_t^{oil}$ is the nominal price of oil in US dollars and $\theta_{ea}^{oil}$ is the price elasticity of oil demand. Given the real price of oil relative to US CPI prices $p_t^{oil}$, the real price of oil relative to euro area CPI prices in Equation (C.18) can be written as

$$
\begin{aligned}
\frac{S_{ea,t} P_t^{oil}}{P_{ea,t}^{cpi}} &= \frac{S_{ea,t} P_{us,t}^{cpi}}{P_{ea,t}^{cpi}} \cdot \frac{P_t^{oil}}{P_{us,t}^{cpi}} \\[2mm]
&= Q_{ea,t} \cdot p_t^{oil},
\end{aligned}
\tag{C.19}
$$

and hence real oil import demand is given by

$$
M_{ea,t}^{oil} = (Q_{ea,t} p_t^{oil})^{-\theta_{ea}^{oil}} CI_{ea,t}.
\tag{C.20}
$$

In per capita terms the log-linearised real oil import demand equation reads as

$$
\widehat{m}_{ea,t}^{oil} = -\theta_{ea}^{oil} (\widehat{Q}_{ea,t} + \widehat{p}_t^{oil}) + \widehat{ci}_{ea,t}.
\tag{M13}
$$

**Import aggregation**  In the previous subsections we have specified behavioural equations that determine the volume of imports. For this purpose, the denomination of imports is not relevant. However, denomination is relevant for the aggregation of non-oil and oil imports and that of bilateral imports from economy $i$ across economies in the rest of the world that make up economy $i$'s total exports. Specifically, due to differences in the denomination of real import variables across economies for the purpose of aggregation of imports and exports in a multi-country context we need to aggregate *nominal* quantities. To do so, we assume that real bilateral non-oil imports $m_{ijt}^{nonoil}$ are denominated in source-economy output goods. Moreover, we assume that real oil imports $m_{it}^{oil}$ are denominated in barrels of oil. As a result, for example, nominal non-oil imports of the euro area from economy $j$ in euro are given by $S_{ea,t} P_{jt}^{ppi} m_{ea,j,t}^{nonoil} / S_{jt}$, and nominal oil imports in euro are given by $S_{ea,t} P_t^{oil} m_{ea,t}^{oil}$.

**Total non-oil imports**  Based on these assumptions, the euro area's per capita total nominal non-oil imports are given by

$$P_{ea,t}^{ppi} \cdot m_{ea,t}^{nonoil} = S_{ea,t} P_{us,t}^{ppi} \cdot m_{ea,us,t}^{nonoil} + \left( \frac{S_{ea,t} P_{op,t}^{ppi}}{S_{op,t}} \right) \cdot m_{ea,op,t}^{nonoil}. \tag{C.21}$$

Dividing by euro area CPI prices, Equation (C.21) can be re-written as

$$p_{ea,t}^{ry} \cdot m_{ea,t}^{nonoil} = Q_{ea,t} p_{us,t}^{ry} \cdot m_{ea,us,t}^{nonoil} + \left( \frac{Q_{ea,t} p_{op,t}^{ry}}{Q_{op,t}} \right) \cdot m_{ea,op,t}^{nonoil}, \tag{C.22}$$

implying the log-linearised equation

$$\begin{aligned}
\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t}^{nonoil} &= \omega_{ea,us}^{M^{nonoil}} \cdot \left( \widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry} + \widehat{m}_{ea,us,t}^{nonoil} \right) \\
&\quad + \omega_{ea,op}^{M^{nonoil}} \cdot \left( \widehat{Q}_{ea,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t} + \widehat{m}_{ea,op,t}^{nonoil} \right). \tag{C.23}
\end{aligned}$$

Avoiding the use of bilateral import variables we have

$$\begin{aligned}
\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t}^{nonoil} &= \widehat{da}_{ea,t} + \omega_{ea,us}^{M^{nonoil}} \left[ \widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry} - \theta_{ea}^{nonoil} \left( \widehat{Q}_{ea,t} + \widehat{p}_{us,t}^{ry} \right) \right] \\
&\quad + \omega_{ea,op}^{M^{nonoil}} \left[ \widehat{Q}_{ea,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t} - \theta_{ea}^{nonoil} \left( \widehat{Q}_{ea,t} - \widehat{Q}_{op,t} + \widehat{p}_{op,t}^{ry} \right) \right]. \tag{M14}
\end{aligned}$$

**Total imports**  Recall that we assume that the euro area's total real non-oil imports $m_{ea,t}^{nonoil}$ are denominated in euro area output goods in Equation (C.21), and that we assume that oil imports $m_{ea,t}^{oil}$ are denominated in oil barrels. For the euro area and all other non-OP economies,

total per capita nominal imports are then given by the sum of nominal non-oil and oil imports

$$P_{ea,t}^{ppi} \cdot m_{ea,t} = P_{ea,t}^{ppi} \cdot m_{ea,t}^{nonoil} + S_{ea,t} P_t^{oil} \cdot m_{ea,t}^{oil}. \tag{C.24}$$

Dividing by euro area CPI prices, Equation (C.24) can be re-written as

$$p_{ea,t}^{ry} \cdot m_{ea,t} = p_{ea,t}^{ry} \cdot m_{ea,t}^{nonoil} + Q_{ea,t} p_t^{oil} \cdot m_{ea,t}^{oil}, \tag{C.25}$$

implying the log-linearised equation

$$\widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t} = (1 - \zeta_{ea}^{M^{oil}}) \left( \widehat{p}_{ea,t}^{ry} + \widehat{m}_{ea,t}^{nonoil} \right) + \zeta_{ea}^{M^{oil}} \left( \widehat{Q}_{ea,t} + \widehat{p}_t^{oil} + \widehat{m}_{ea,t}^{oil} \right), \tag{M15}$$

where $\zeta_{ea}^{M^{oil}}$ is the share of oil imports in euro area total imports. Since the OP is importing only non-oil goods, its total imports equal non-oil imports

$$\widehat{m}_{op,t} = \widehat{m}_{op,t}^{nonoil}. \tag{M16}$$

**Exports**   In order to ensure global consistency of trade we specify the euro area's total nominal exports to the rest of the world as the sum of all other economies nominal bilateral imports from the euro area. In this aggregation it is important to recall that we assume that real bilateral non-oil imports are denominated in source-economy output goods. Moreover, we cannot aggregate per capita quantities as these have different denominators. The euro area's total aggregate nominal exports are given by

$$X_{ea,t}^{nonoil} = M_{us,ea,t}^{nonoil} + M_{op,ea,t}^{nonoil}. \tag{C.26}$$

In per capita terms this reads as

$$\frac{X_{ea,t}^{nonoil}}{N_{ea,t}} = \frac{M_{us,ea,t}^{nonoil}}{N_{us,t}} \cdot \frac{N_{us,t}}{N_{ea,t}} + \frac{M_{op,ea,t}^{nonoil}}{N_{op,t}} \cdot \frac{N_{op,t}}{N_{ea,t}},$$

$$x_{ea,t}^{nonoil} = \gamma_{us,ea} \cdot m_{us,ea,t}^{nonoil} + \gamma_{op,ea} \cdot m_{op,ea,t}^{nonoil}, \tag{C.27}$$

where $\gamma_{ij}$ denotes the ratio of economy $i$'s population relative to that of economy $j$. Log-linearising yields

$$
\begin{aligned}
\widehat{x}_{ea,t}^{nonoil} &= \left( \frac{\gamma_{us,ea} m_{us,ea}^{nonoil,ss}}{x_{ea}^{nonoil,ss}} \right) \cdot \widehat{m}_{us,ea,t}^{nonoil} + \left( \frac{\gamma_{op,ea} m_{op,ea}^{nonoil,ss}}{x_{ea}^{nonoil,ss}} \right) \cdot \widehat{m}_{op,ea,t}^{nonoil} \\
&= \left( \frac{x_{ea,us}^{nonoil,ss}}{x_{ea}^{nonoil,ss}} \right) \cdot \widehat{m}_{us,ea,t}^{nonoil} + \left( \frac{x_{ea,op}^{nonoil,ss}}{x_{ea}^{nonoil,ss}} \right) \cdot \widehat{m}_{op,ea,t}^{nonoil} \\
&= \omega_{ea,us}^{X^{nonoil}} \cdot \widehat{m}_{us,ea,t}^{nonoil} + \omega_{ea,op}^{X^{nonoil}} \cdot \widehat{m}_{op,ea,t}^{nonoil},
\end{aligned}
\tag{C.28}
$$

where $\omega_{ea,j}^{X^{nonoil}}$ is the share of euro area exports that is sent to economy $j$ in total euro area exports. Notice that in general $\omega_{ea,j}^{X^{nonoil}} \neq \omega_{ea,j}^{M^{nonoil}}$ and $\omega_{ea,j}^{X^{nonoil}} \neq \omega_{j,ea}^{M^{nonoil}}$.

While for non-OP economies total real exports equal total real non-oil exports

$$
\widehat{x}_{it} = \widehat{x}_{it}^{nonoil}, \quad i \neq op,
\tag{M17}
$$

for the OP we have (recall that oil imports are denominated in barrels of oil)

$$
\widehat{p}_{op,t}^{ry} + \widehat{x}_{op,t} = (1 - \zeta_{op}^{X^{oil}}) \cdot \left( \widehat{p}_{op,t}^{ry} + \widehat{x}_{op,t}^{nonoil} \right) + \zeta_{op}^{X^{oil}} \cdot \left( \widehat{Q}_{op,t} + \widehat{p}_t^{oil} + \widehat{x}_{op,t}^{oil} \right),
\tag{M18}
$$

where $\zeta_{op}^{X^{oil}}$ is the share of oil exports in the OP's total exports. The OP's total real oil exports $\widehat{x}_{op,t}^{oil}$ are given by

$$
\widehat{x}_{op,t}^{oil} = \tau_{ea}^{oil} \cdot \widehat{m}_{ea,t}^{oil} + \tau_{us}^{oil} \cdot \widehat{m}_{us,t}^{oil},
\tag{C.29}
$$

where $\tau_j^{oil}$ denotes economy $j$'s share in global oil imports.

In order to reduce the number of equations, we avoid the use of bilateral non-oil imports $\widehat{m}_{ijt}^{nonoil}$. Specifically, using the equations for real per capita bilateral non-oil imports of the OP and the US from the euro area

$$
\begin{aligned}
\widehat{m}_{us,ea,t}^{nonoil} &= -\theta_{us}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{p}_{ea,t}^{ry}) + \widehat{da}_{us,t}, \\
\widehat{m}_{op,ea,t}^{nonoil} &= -\theta_{op}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{Q}_{op,t} + \widehat{p}_{ea,t}^{ry}) + \widehat{da}_{op,t},
\end{aligned}
\tag{C.30}
\tag{C.31}
$$

in Equation (C.28), we obtain for the euro area's total real per capita (non-oil) exports

$$
\begin{aligned}
\widehat{x}_{ea,t} = &\omega_{ea,us}^{X^{nonoil}} \left[ \widehat{da}_{us,t} - \theta_{us}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{p}_{ea,t}^{ry}) \right] \\
&+ \omega_{ea,op}^{X^{nonoil}} \left[ \widehat{da}_{op,t} - \theta_{op}^{nonoil}(-\widehat{Q}_{ea,t} + \widehat{Q}_{op,t} + \widehat{p}_{ea,t}^{ry}) \right].
\end{aligned}
\tag{M19}
$$

**Global imports and exports**

**Global imports**  Recall that we denominated economies' total (oil and non-oil) imports in source-economy output goods. Due to differences in the real denomination of economies' imports, we consider nominal imports in US dollars for the aggregation of global imports $M_t$. In doing so, we denominate real global imports in US output goods

$$P_{us,t}^{ppi} \cdot M_t = M_{ea,t} \cdot \frac{P_{ea,t}^{ppi}}{S_{ea,t}} + M_{op,t} \cdot \frac{P_{op,t}^{ppi}}{S_{op,t}} + M_{us,t} \cdot P_{us,t}^{ppi}. \tag{C.32}$$

We can then re-write Equation (C.32) as

$$p_{us,t}^{ry} \cdot M_t = M_{ea,t} \cdot \frac{p_{ea,t}^{ry}}{Q_{ea,t}} + M_{op,t} \cdot \frac{p_{op,t}^{ry}}{Q_{op,t}} + M_{us,t} \cdot p_{us,t}^{ry}. \tag{C.33}$$

In per capita terms we have

$$
\begin{aligned}
p_{us,t}^{ry} \cdot \frac{M_t}{N_t} &= \frac{M_{ea,t}}{N_{ea,t}} \cdot \frac{N_{ea,t}}{N_t} \cdot \frac{p_{ea,t}^{ry}}{Q_{ea,t}} + \frac{M_{op,t}}{N_{op,t}} \cdot \frac{N_{op,t}}{N_t} \cdot \frac{p_{op,t}^{ry}}{Q_{op,t}} + \frac{M_{us,t}}{N_{us,t}} \cdot \frac{N_{us,t}}{N_t} \cdot p_{us,t}^{ry} \\
p_{us,t}^{ry} \cdot m_t &= \gamma_{ea}^N \cdot m_{ea,t} \cdot \frac{p_{ea,t}^{ry}}{Q_{ea,t}} + \gamma_{op}^N \cdot m_{op,t} \cdot \frac{p_{op,t}^{ry}}{Q_{op,t}} + \gamma_{us}^N \cdot m_{us,t} \cdot p_{us,t}^{ry},
\end{aligned} \tag{C.34}
$$

where $\gamma_i^N$ is economy $i$'s share in world population. After log-linearising, we obtain

$$
\begin{aligned}
\widehat{p}_{us,t}^{ry} + \widehat{m}_t &= \frac{\gamma_{ea}^N m_{ea}^{ss} \frac{p_{ea}^{ry,ss}}{Q_{ea}^{ss}}}{p_{us}^{ry,ss} m^{ss}} \cdot \left( \widehat{m}_{ea,t} + \widehat{p}_{ea,t}^{ry} - \widehat{Q}_{ea,t} \right) \\
&\quad + \frac{\gamma_{op}^N m_{op}^{ss} \frac{p_{op}^{ry,ss}}{Q_{op}^{ss}}}{p_{us}^{ry,ss} m^{ss}} \cdot \left( \widehat{m}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t} \right) + \frac{\gamma_{us}^N m_{us}^{ss} p_{us}^{ry,ss}}{p_{us}^{ry,ss} m^{ss}} \cdot \left( \widehat{m}_{us,t} + \widehat{p}_{us,t}^{ry} \right),
\end{aligned} \tag{C.35}
$$

which gives

$$
\begin{aligned}
\widehat{p}_{us,t}^{ry} + \widehat{m}_t &= \chi_{ea}^M \cdot ( \widehat{m}_{ea,t} + \widehat{p}_{ea,t}^{ry} - \widehat{Q}_{ea,t}) \\
&\quad + \chi_{op}^M \cdot ( \widehat{m}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t}) + \chi_{us}^M \cdot ( \widehat{m}_{us,t} + \widehat{p}_{us,t}^{ry}),
\end{aligned} \tag{M20}
$$

where $\chi_i^M$ defines the share of country $i$'s imports in global imports.

**Global exports**  We denominate global total (oil and non-oil) exports in US output goods, so that

$$P_{us,t}^{ppi} \cdot X_t = X_{ea,t} \cdot \frac{P_{ea,t}^{ppi}}{S_{ea,t}} + X_{op,t} \cdot \frac{P_{op,t}^{ppi}}{S_{op,t}} + X_{us,t} \cdot P_{us,t}^{ppi}. \tag{C.36}$$

As for imports, we can re-write Equation (C.36) as

$$p_{us,t}^{ry} \cdot X_t = X_{ea,t} \cdot \frac{p_{ea,t}^{ry}}{Q_{ea,t}} + X_{op,t} \cdot \frac{p_{op,t}^{ry}}{Q_{op,t}} + X_{us,t} \cdot p_{us,t}^{ry}. \tag{C.37}$$

Log-linearised, global exports in per capita terms then read as

$$\widehat{p}_{us,t}^{ry} + \widehat{x}_t = \chi_{ea}^{X} \cdot (\widehat{x}_{ea,t} + \widehat{p}_{ea,t}^{ry} - \widehat{Q}_{ea,t}) + \chi_{op}^{X} \cdot (\widehat{x}_{op,t} + \widehat{p}_{op,t}^{ry} - \widehat{Q}_{op,t}) + \chi_{us}^{X} \cdot (\widehat{x}_{us,t} + \widehat{p}_{us,t}^{ry}),$$
(M21)

As we assume balanced trade for each economy in the steady state, each economies' share in global exports equals the corresponding share in global imports, i.e. $\chi_i^{X} = \chi_i^{M}$.

**Real effective exchange rates**   We define the euro area's real effective exchange rate as

$$Q_{ea,t}^{eff} = (Q_{ea,t})^{\omega_{ea,us}^{X^{nonoil}}} \cdot \left(\frac{Q_{ea,t}}{Q_{op,t}}\right)^{\omega_{ea,op}^{X^{nonoil}}},$$
(C.38)

which yields in log-linearised form

$$\widehat{Q}_{ea,t}^{eff} = \omega_{ea,us}^{X^{nonoil}} \cdot \widehat{Q}_{ea,t} + \omega_{ea,op}^{X^{nonoil}} \cdot \left(\widehat{Q}_{ea,t} - \widehat{Q}_{op,t}\right).$$
(M22)

where $\omega_{ea,j}^{X^{nonoil}}$ is the share of euro area exports that is sent to economy $j$ in total euro area exports.

### C.1.6   Oil market

We assume oil is used in all economies so that global oil demand $\widehat{oil}_t^{d}$ is given by the sum of oil imports of oil-importing countries and OP oil demand

$$\widehat{oil}_t^{d} = \varpi_{us}^{C^{oil}} \widehat{m}_{us,t}^{oil} + \varpi_{ea}^{C^{oil}} \cdot \widehat{m}_{ea,t}^{oil} + \varpi_{op}^{C^{oil}} \cdot \widehat{oil}_{op,t}^{d},$$
(M23)

where $\varpi_i^{C^{oil}}$ represents economy $i$'s share in global oil consumption, and OP oil demand is given by

$$\widehat{oil}_{op,t}^{d} = -\theta_{op}^{oil}(\widehat{Q}_{op,t} + \widehat{p}_t^{oil}) + \widehat{ci}_{op,t}.$$
(M24)

In equilibrium, oil demand equals oil supply so that

$$\widehat{oil}_t^{d} = \widehat{oil}_t^{s} = \theta^{oil,s}\widehat{p}_t^{oil} + \xi_t^{oil}.$$
(M25)

where $\theta^{oil,s}$ reflects the price elasticity of oil supply and $\xi_t^{oil}$ is an oil supply shock.

We assume there is a positive trend in oil prices reflecting that demand is growing faster than supply, specifying

$$\widehat{\pi}_t^{oil} = \pi_t^{oil} - \pi^{oil,ss} = \pi_t^{oil} - \Delta\overline{oil},$$
(M26)

where $\pi^{oil,ss}$ represents steady-state oil-price inflation that is given by the difference between the growth rate of trend oil consumption and production, $\Delta \overline{oil}$. Notice that

$$
\begin{aligned}
1 + \pi_t^{oil} &= \frac{P_t^{oil}}{P_{t-1}^{oil}} = \frac{P_t^{oil} P_{us,t}^{cpi} P_{us,t-1}^{cpi}}{P_{t-1}^{oil} P_{us,t}^{cpi} P_{us,t-1}^{cpi}} = \frac{p_t^{oil} P_{us,t}^{cpi}}{p_{t-1}^{oil} P_{us,t-1}^{cpi}} \\
&= \frac{p_t^{oil}}{p_{t-1}^{oil}} \left( 1 + \pi_{us,t}^{cpi} \right),
\end{aligned} \tag{C.39}
$$

so that

$$
\widehat{\pi}_t^{oil} = \widehat{p}_t^{oil} - \widehat{p}_{t-1}^{oil} + \widehat{\pi}_{us,t}^{cpi}. \tag{M27}
$$

Noting that oil supply necessarily equals oil demand in equilibrium, we also have

$$
\Delta \widehat{\overline{oil}}_t^s - \Delta \overline{\overline{oil}}^s = \widehat{\overline{oil}}_t^s - \widehat{\overline{oil}}_{t-1}^s = \widehat{\overline{oil}}_t^d - \widehat{\overline{oil}}_{t-1}^d. \tag{M28}
$$

### C.1.7 Net foreign asset position

Denote by $NFA_{i,t}$ an economy's aggregate net foreign asset position. Then,

$$
\begin{aligned}
P_{ea,t}^{ppi} \cdot NFA_{ea,t} &= I_{ea,t-1}^l \cdot P_{ea,t-1}^{ppi} \cdot NFA_{ea,t-1} + P_{ea,t}^{ppi} \cdot X_{ea,t} - P_{ea,t}^{ppi} \cdot M_{ea,t} \\
NFA_{ea,t} &= I_{ea,t-1}^l \cdot \frac{P_{ea,t-1}^{ppi}}{P_{ea,t}^{ppi}} \cdot NFA_{ea,t-1} + X_{ea,t} - M_{ea,t} \\
&= \frac{p_{ea,t}^{ry} I_{ea,t-1}^l}{p_{ea,t-1}^{ry} \Pi_{ea,t}^{cpi}} \cdot NFA_{ea,t-1} + X_{ea,t} - M_{ea,t}.
\end{aligned} \tag{C.40}
$$

In per capita terms we have

$$
\begin{aligned}
\frac{NFA_{ea,t}}{N_{ea,t}} &= \frac{p_{ea,t}^{ry} I_{ea,t-1}^l}{p_{ea,t-1}^{ry} \Pi_{ea,t}^{cpi} G_{ea,t}^n} \cdot \frac{NFA_{ea,t-1}}{N_{ea,t-1}} + \frac{X_{ea,t}}{N_{ea,t}} - \frac{M_{ea,t}}{N_{ea,t}} \\
nfa_{ea,t} &= \frac{p_{ea,t}^{ry} I_{ea,t-1}^l}{p_{ea,t-1}^{ry} \Pi_{ea,t}^{cpi} G_{ea,t}^n} \cdot nfa_{ea,t-1} + x_{ea,t} - m_{ea,t}.
\end{aligned} \tag{C.41}
$$

Relative to GDP per capita we have

$$
\begin{aligned}
\frac{nfa_{ea,t}}{y_{ea,t}} &= \frac{p_{ea,t}^{ry} I_{ea,t-1}^l}{p_{ea,t-1}^{ry} \Pi_{ea,t}^{cpi} G_{ea,t}^n G_{ea,t}^y} \cdot \frac{nfa_{ea,t-1}}{y_{ea,t-1}} + \frac{x_{ea,t}}{y_{ea,t}} - \frac{m_{ea,t}}{y_{ea,t}} \\
\widetilde{nfa}_{ea,t} &= \frac{p_{ea,t}^{ry} I_{ea,t-1}^l}{p_{ea,t-1}^{ry} \Pi_{ea,t}^{cpi} G_{ea,t}^n G_{ea,t}^y} \cdot \widetilde{nfa}_{ea,t-1} + x_{ea,t} - m_{ea,t}.
\end{aligned} \tag{C.42}
$$

In log-linear deviations from steady state we have

$$
nfa_{ea}^{ss} \cdot \widehat{nfa}_{ea,t} = \left( \frac{I_{ea}^{l,ss} nfa_{ea}^{ss}}{\Pi_{ea}^{cpi,ss} G_{ea}^{n,ss} G_{ea}^{y,ss}} \right) \cdot \left( \widehat{nfa}_{ea,t-1} + \widehat{I}_{ea,t-1}^{l} - \widehat{\Pi}_{ea,t}^{cpi} \right.
$$
$$
\left. - \widehat{G}_{ea,t}^{n} - \widehat{G}_{ea,t}^{y} + p_{ea,t}^{ry} - p_{ea,t-1}^{ry} \right) + x_{ea}^{ss} \cdot \widehat{x}_{ea,t} - m_{ea}^{ss} \cdot \widehat{m}_{ea,t}
$$

$$
\widetilde{nfa}_{ea,t} = \left( \frac{R_{ea}^{l,ss}}{G_{ea}^{n,ss} G_{ea}^{y,ss}} \right) \left[ \widetilde{nfa}_{ea,t-1} + nfa_{ea}^{ss} \cdot \left( \widehat{I}_{ea,t-1}^{l} - \widehat{\Pi}_{ea,t}^{cpi} \right. \right.
$$
$$
\left. \left. - \widehat{G}_{ea,t}^{n} - \widehat{G}_{ea,t}^{y} + p_{ea,t}^{ry} - p_{ea,t-1}^{ry} \right) \right] + \widetilde{x}_{ea,t} - \widetilde{m}_{ea,t}. \tag{C.43}
$$

Assuming a balanced net foreign asset position in the steady state and constant population we obtain

$$
\widetilde{nfa}_{ea,t} = \left( \frac{R_{ea}^{l,ss}}{G_{ea}^{n,ss} G_{ea}^{y,ss}} \right) \cdot \widetilde{nfa}_{ea,t-1} + \widetilde{x}_{ea,t} - \widetilde{m}_{ea,t}
$$
$$
= \left( \frac{1 + r_{ea}^{l,ss}}{1 + \Delta y_{ea}^{ss}} \right) \cdot \widetilde{nfa}_{ea,t-1} + \widetilde{x}_{ea,t} - \widetilde{m}_{ea,t}
$$
$$
= \left( 1 + r_{ea}^{l,ss} - \Delta y_{ea}^{ss} \right) \cdot \widetilde{nfa}_{ea,t-1} + \widetilde{x}_{ea,t} - \widetilde{m}_{ea,t} \tag{M37}
$$

## C.2 Resource constraint

The market clearing condition for aggregate demand in per capita terms is

$$
P_{ea,t}^{ppi} y_{ea,t} = P_{ea,t}^{cpi} ci_t + P_{ea,t}^{g} g_{ea,t} + P_{ea,t}^{ppi} x_{ea,t} - P_{ea,t}^{ppi} m_{ea,t}, \tag{C.44}
$$

which implies that $y_{ea,t}$ is real per capita output in domestic output goods. Consumption and investment are denominated in CPI terms, total exports and imports are denominated in domestic output goods; $P_{ea,t}^{g}$ is the price deflator for government expenditure. By dividing equation (C.44) by CPI prices we get

$$
p_{ea,t}^{ry} y_{ea,t} = ci_{ea,t} + p_{ea,t}^{rg} g_{ea,t} + p_{ea,t}^{ry} x_{ea,t} - p_{ea,t}^{ry} m_{ea,t}. \tag{C.45}
$$

In log-linear deviations from steady state we have

$$
\widehat{p}_{ea,t}^{ry} + \widehat{y}_{ea,t} = \chi_i^{ci} \widehat{ci}_{ea,t} + \chi_i^{g} (\widehat{g}_{ea,t} + \widehat{p}_{ea,t}^{g}+) + \chi_i^{X} (\widehat{x}_{ea,t} + \widehat{p}_{ea,t}^{ry}) - \chi_i^{M} (\widehat{m}_{ea,t} + \widehat{p}_{ea,t}^{ry})
$$
$$
= \chi_i^{ci} \widehat{ci}_{ea,t} + \chi_i^{g} (\widehat{g}_{ea,t} + \widehat{p}_{ea,t}^{g}+) + \chi_i^{X} (\widehat{x}_{ea,t} - \widehat{m}_{ea,t}), \tag{M46}
$$

where the second equality follows from the assumption of balanced trade in the steady state, $\chi_i^X = \chi_i^M$. We assume the price of government expenditure relative to CPI follows

$$\widehat{p}_{ea,t}^{rg} = \rho_{ea}^{\widehat{p}^{rg}} \widehat{p}_{ea,t-1}^{rg} + \xi_t^{\widehat{p}^{rg}}. \tag{M47}$$

## C.3 Specification of trends

The trend specifications are also part of the log-linearised system of equations in the mod-files. Global trend output follows

$$\Delta \overline{y}_t = \eta^{\Delta \overline{y}} \Delta \overline{y}_{t-1} + \left(1 - \eta^{\Delta \overline{y}}\right) \Delta \overline{y}^{ss}, \tag{M47}$$

to which economies' trend GDP growth rates adjust sluggishly according to an error-correction mechanism given by

$$\Delta \overline{y}_{ea,t} = \Delta \overline{y}_{ea,t-1} - \eta^{\Delta \overline{y},ea} \left(\Delta \overline{y}_{ea,t-1} - \Delta \overline{y}_t\right) + \xi_{ea,t}^{\Delta \overline{y}}. \tag{M48}$$

The global trend in equity prices $\Delta \overline{q}_t$ is composed of the global trend in output $\Delta \overline{y}_t$ and an idiosyncratic equity price component $\Delta \overline{q}_t^{idio}$. In particular,

$$\Delta \overline{q}_t = \Delta \overline{y}_t + \Delta \overline{q}_t^{idio}. \tag{M49}$$

The idiosyncratic equity price trend component evolves according to

$$\Delta \overline{q}_t^{idio} = \alpha^{\Delta \overline{q}^{idio}} \Delta \overline{q}_{t-1}^{idio} + \left(1 - \alpha^{\Delta \overline{q}^{idio}}\right) \Delta \overline{q}^{idio,ss}. \tag{M50}$$

The country-specific equity price trend may deviate temporarily from the global trend in equity prices

$$\Delta \overline{q}_{ea,t} = \Delta \overline{q}_{ea,t-1} - \alpha_{ea}^{\Delta \overline{q}} \left(\Delta \overline{q}_{ea,t-1} - \Delta \overline{q}_t\right) + \varepsilon_{ea,t}^{\Delta \overline{q}}. \tag{M51}$$

## C.4 Oil-producing economies

We include in the group of OP economies for which the net oil trade balance represents a significant contribution to their GDP and which have contributed quantitatively to the global oil supply. Specifically, we label as OP economies: Saudi Arabia, Venezuela, Oman, Qatar, United Arab Emirates, Norway, Ecuador, Nigeria, Angola, Russia, Iran, Kuwait, Libya, Gabon, Equatorial Guinea, Bahrain, Kazakhstan, Turkmenistan, Brunei, Azerbaijan and Algeria. To form the aggregate we take a GDP-weighted average.

## C.5 Algorithm to adjust the data underlying the parameterisations in order to ensure consistency of global trade

**Ensuring consistency of bilateral export and import flows.** In order to ensure consistency of bilateral export and import flows we start our parameterisations with export data, and then determine the bilateral import flow figures as mirror images of the corresponding trade partners' bilateral exports. More specifically, we first determine for all economies except for the RW their total (oil and non-oil) nominal bilateral exports in current US dollars according to

$$X_{ij} = Y_i \cdot s_i^X \cdot \omega_{ij}^X, \qquad i \neq rw. \tag{C.46}$$

For the RW, given that we do not have data on the share of exports in GDP, $s_{rw}^X$, we determine RW exports as the mirror image of the other economies' bilateral imports, that is

$$X_{rw,i} = Y_i \cdot s_i^M \cdot \omega_{i,rw}^M. \tag{C.47}$$

Given the data on nominal GDP, this implies the RW's share of exports in GDP

$$s_{rw}^X = \left( \sum_i X_{rw,i} \right) / Y_{rw}. \tag{C.48}$$

Finally, for all economies we set bilateral imports equal to the mirror image of their trading partners' bilateral exports

$$M_{ij} = X_{ji}. \tag{C.49}$$

These steps ensure consistency of bilateral export and import flows. However, they do not ensure balanced trade for each economy or the world as a whole.

**Ensuring balanced trade for individual economies and the world as a whole.** We adopt an iterative algorithm in which the value of an economy's total (non-oil and oil) exports is modified in each iteration $r$ until balanced trade for individual economies and the world as a whole are achieved. Denoting by $X_{ij}^{(0)}$ the value of bilateral total (non-oil and oil) exports determined in equations (C.46) and (C.47), we consider

$$X_{ij}^{(r+1)} = \left( 1 + \delta_i^{(r)} \right) \cdot X_{ij}^{(r)}, \tag{C.50}$$

$$M_{ji}^{(r+1)} = X_{ij}^{(r+1)}, \tag{C.51}$$

with

$$\delta_i^{(r)} = \left( \sum_{j=1} M_{ij}^{(r)} - \sum_{j=1} X_{ij}^{(r)} \right) / D, \tag{C.52}$$

and where we set $D = 10^4$. If an economy runs a trade deficit, $\delta_i^{(r)}$ is larger than zero and we increase that economy's exports. We iterate over Equations (C.50) to (C.52) until the sum of individual economies' squared trade balances

$$\Delta^{(r)} \equiv \sum_i \left[ \sum_{j=1} \left( M_{ij}^{(r+1)} - X_{ij}^{(r+1)} \right) \right]^2, \tag{C.53}$$

is smaller than $10^{-6}$. Based on the resulting export and import flows $X_{ij}^{(R+1)}$ and $M_{ij}^{(R+1)}$ we determine new bilateral total (non-oil and oil) import shares $\omega_{ij}^M$.[13] The left-hand side panel in Figure 14 shows scatterplots of the original and the new bilateral total import shares, suggesting that the adjustments we carry out in order to ensure individual economies' and global trade is balanced is quantitatively small.

As the magnitudes of exports (and imports) have been modified during this algorithm, we need to update the shares of total (non-oil and oil) exports and imports in GDP according to

$$s_i^X = \left( \sum_{j=1} X_{ij}^{(r+1)} \right) / Y_i, \tag{C.54}$$

$$s_i^M = s_i^X. \tag{C.55}$$

The middle panel in Figure 14 displays scatterplots of the original and the new shares of total (non-oil and oil) exports and imports in GDP, suggesting that the adjustments are again quantitatively small.

Finally, in order to preserve the shares of oil imports (exports) in total imports (exports) for non-OP (OP) economies from the original data we also update the shares of oil imports (exports) in GDP for non-OP (OP) economies according to

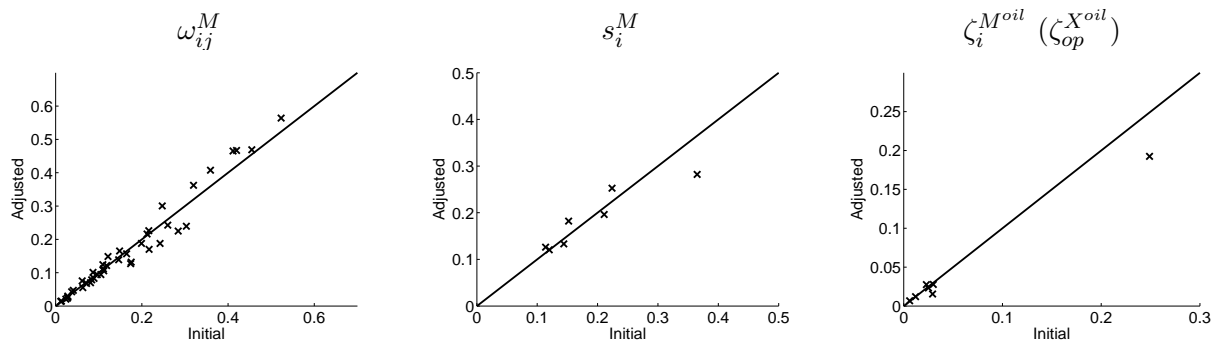$$s_{op}^{Xoil} = s_{op}^X \cdot \zeta_{op}^{Xoil}, \tag{C.56}$$

$$s_i^{Moil} = s_i^M \cdot \zeta_i^{Moil}, \quad i \neq op, rw, \tag{C.57}$$

$$s_{rw}^{Moil} = \left[ s_{op}^{Xoil} \cdot Y_{op} - \left( \sum_i s_i^{Moil} \cdot Y_i \right) \right] / Y_{rw}, \tag{C.58}$$

where $\zeta_i^{Moil}$ ($\zeta_{op}^{Xoil}$) is the share of oil imports (exports) in total imports (exports) in non-OP (OP) economies in the original IMF data. Again, Figure The right-hand side panel in Figure 14 suggests that the necessary adjustments are once again quantitatively small.

---

[13] The bilateral export shares $\omega_{ij}^X$ are not affected by the algorithm as we adjust all of an economy's bilateral exports by the same factor in Equation (C.50) in every iteration of the algorithm.

Figure 14
Comparing initial and adjusted shares

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