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ECB-Global 2.0: a global macroeconomic model with dominant-currency pricing, tariffs and trade diversion

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Abstract

In a highly interlinked global economy a key question is how foreign shocks transmit to the domestic economy, how domestic shocks affect the rest of the world, and how policy actions mitigate or amplify spillovers. For policy analysis in such a context global multi-country macroeconomic models that allow a structural interpretation are needed. In this paper we present a revised version of ECB-Global, the European Central Bank's global macroeconomic model. ECB-Global 2.0 is a semi-structural, global multi-country model with rich channels of international shock propagation through trade, oil prices and global financial markets for the euro area, the US, Japan, the UK, China, oil-exporting economies, Emerging Asia, and a rest-of-the-world block. Relative to the original version of model, ECB-Global 2.0 features dominant-currency pricing, tariffs and trade diversion. We illustrate the usefulness of ECB-Global exploring scenarios motivated by recent trade tensions between China and the US.

Keywords: Macro-modelling, multi-country models, spillovers.

JEL-Classification: C51, E30, E50.

1 Non-technical summary

The rise of real and financial globalisation over the past decades has increased the importance of understanding the global transmission of local shocks and policy actions. Many recent events – certainly above all the COVID-19 pandemic – 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, as well as the role of policy in this context. In this paper, we present a substantially revised version of the ECB's global macroeconomic model: ECB-Global 2.0, a rich multi-country model for the euro area, the US, Japan, the UK, China, oil-producing economies, Emerging Asia and the rest of the world.

ECB-Global 2.0 continues to follow 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 the model is based on two considerations. First, the evolution of the economies in the model is determined by a set of core structural relationships, such as Phillips and IS curves. The advantage of the structural elements of the model is that shocks have an economic interpretation, which facilitates the design of scenario simulations. Second, reduced-form equations are added to enrich the core of the model. The advantage of the reduced-form elements of the model is that they facilitate modifying the model in a flexible manner, which allows us to address evolving issues in the policy discussion. Moreover, the reduced-form elements improve the empirical fit of the model.

The innovations relative to the original version of ECB-Global we describe in this paper are key in order to account for important aspects of the workings of the global economy and in order to make the model useful for policy analysis at the ECB. In particular, in ECB-Global 2.0 we depart from the traditional Mundellian assumption of producer-currency pricing (PCP). Instead, we allow for mixtures between PCP and dominant-currency pricing (DCP). Allowing for DCP is particularly important in a multi-country model that covers emerging market economies, as the dominance of US-$ invoicing is increasingly documented to be an important feature of trade data. Second, we allow for trade diversion, meaning that changes in the prices of imports from a specific source do not only induce expenditure switching towards domestic products, but also towards imports from other sources. This feature has been recognised to have been empirically relevant in particular in recent trade tensions between the US and China. Third, we allow for tariffs as a fiscal wedge between the price paid by the importer and the revenue received by the exporter. Hence, tariffs modelled in this manner induce adjustments not only on the side of the importer. We also introduce modifications to the original version of the model as regards GDP aggregation, the monetary policy reaction function, the presence of hand-to-mouth energy consumers, as well as the financial sector and associated spillovers.

Inspired by the recent trade disputes between the US and China right before the outbreak of the COVID pandemic, we use ECB-Global 2.0 to analyse a trade war scenario. In particular, we explore the global macroeconomic short-term implications of a scenario in which the US imposes persistent tariffs on imports from China, and in which China responds in kind. In the baseline, the effect of this trade war is contractionary for both the US and China, while other countries benefit mildly due to trade diversion. DCP modulates the transmission of the tariff shocks in important ways, as the US-$ depreciation that is caused by the contractionary impact on the US overall supports global trade and real activity.

2 Introduction

The rise of real and financial globalisation over the past decades has increased the importance of understanding the global transmission of local shocks and policy actions (for a discussion see Ca' Zorzi et al., 2020). Many recent events – certainly above all the COVID-19 pandemic – 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, as well as the role of policy in this context. In this paper, we present a substantially revised version of the ECB's global macroeconomic model: ECB-Global 2.0, a rich multi-country model for the euro area, the US, Japan, the UK, China, oil-producing economies, Emerging Asia and the rest of the world.

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[1] There is a growing literature on the advantages of semi-structural approaches see for example Hendry & Muellbauer (2017) and McKibbin & Stoeckel (2018).

induce adjustments not only on the side of the importer. We also introduce modifications to the original version of the model as regards GDP aggregation, the monetary policy reaction function, the presence of hand-to-mouth energy consumers, as well as the financial sector and associated spillovers.

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The rest of the paper is organised as follows. Section 3 provides a short summary of the essential features of ECB-Global. Section 4 lays out in detail the innovations we introduce in ECB-Global 2.0. Section 5 presents the innovations formally. Section 6 illustrates the workings of ECB-Global 2.0 exploring scenarios in the context of recent trade tensions between the US and China. Finally, Section 7 discusses possible ways for future model development.

3 A birds-eye view of ECB-Global

Before turning to the new elements in ECB-Global, we briefly sketch its overall structure.

Domestic output consists of consumption and investment, government spending and net exports. Domestic consumer-price inflation is a combination of producer-price inflation, non-oil import-price inflation and oil-price inflation. The equations describing the evolution of changes in various prices as well as consumption, investment and exports/imports closely resemble those in fully structural, open-economy New Keynesian DSGE models.

For example, consumption and investment decisions are governed by an augmented IS-curve, in which spending decisions are determined by the real interest rate as well as lagged and expected future consumption/investment, financial variables such as risk premia and equity prices. The relationship between output, marginal costs and domestic inflation is governed by an augmented Phillips-curve, in which marginal costs are determined by the current level of the output gap, as well as the price of oil and other imported intermediates aimed to reflect global value chains (GVCs).

Monetary policy is assumed to stabilise medium-term inflation and output by setting a riskless, short-term policy rate. The domestic financial sector determines equity prices, the private-sector credit spread, the tightness of bank-lending conditions and sovereign risk premia. The private-sector credit spread drives a wedge between the central bank's policy rate and the interest rate that governs consumption/saving decisions of private agents. These financial variables affect domestic output through financial accelerator mechanisms. Finally, the level of imports (exports) is determined by the relative price of domestic and foreign goods, and the composition of imports depends on the relative prices between all trading partners. The exchange rate is determined in an uncovered interest rate parity condition.

Oil is produced in the oil-exporting country block and imported by all other economies. The price of oil is determined by oil demand (endogenous to global output) and oil supply (endogenously chosen by the oil-exporting countries). The composition of imports, the endogenous reaction of relative prices and openness of a country-block jointly determine its susceptibility to real spillovers. In turn, financial spillovers occur through three channels: equity prices, bank lending conditions, and risk premia. Domestic financial variables are directly affected by their foreign analogues. The relative magnitude of trade and financial spillovers across country-blocks is calibrated based on data on trade and financial exposures measured by bilateral trade and financial shares.

4 Innovations in ECB-Global 2.0 relative to the original version

ECB-Global 2.0 incorporates numerous changes along several dimensions relative to the previous version laid out in Dieppe et al. (2018). In this section we briefly list the major innovations, grouping them in four main categories: (i) trade, (ii) domestic real economy, (iii) financial sector and (iv) monetary policy. The following sections provide a more detailed description of these changes.

4.1 Trade

ECB-Global 2.0 features an arguably more realistic representation of global trade. The new elements relate to the export pricing paradigm, trade diversion effects and tariffs.

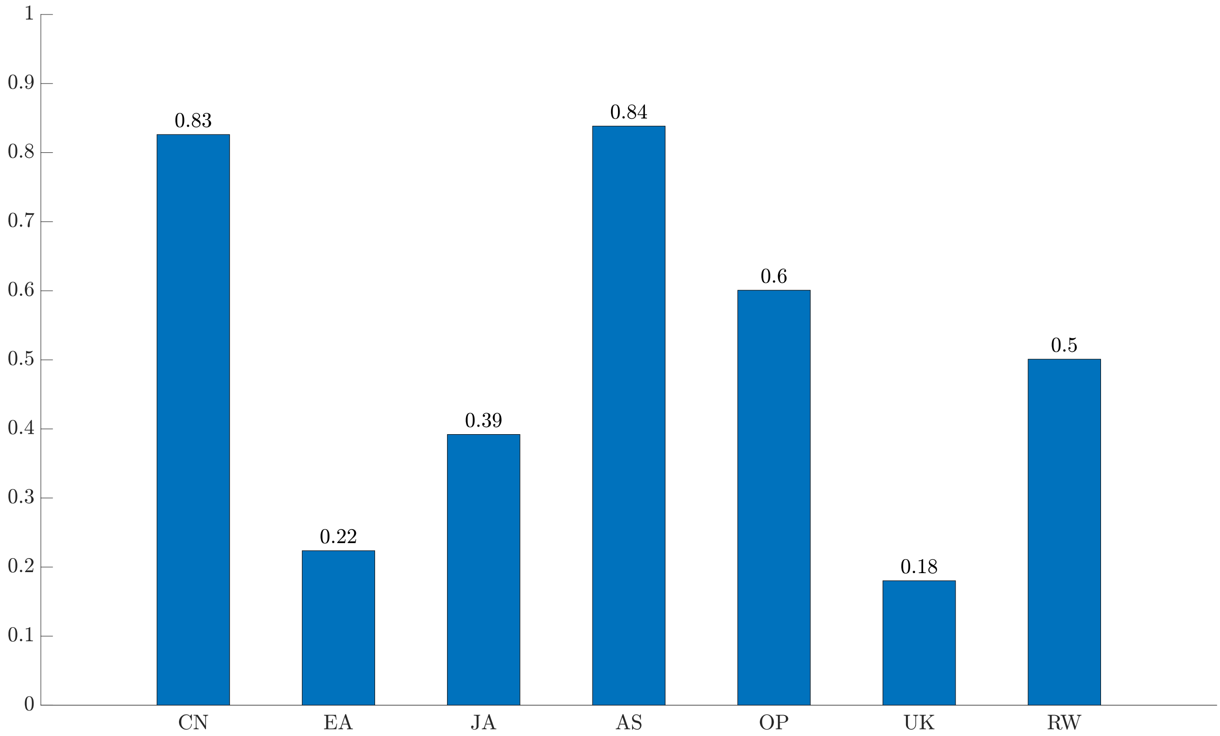
4.1.1 Dominant-currency pricing

ECB-Global 2.0 departs from the traditional Mundellian assumption of PCP according to which export prices are sticky in the currency of the producer. Following the rapidly growing literature on DCP, we move beyond PCP and consider a more general price setting paradigm. For instance, Boz et al. (2020) document that a large share of global trade that does not involve the US is in fact invoiced in US-\$.[2] ECB-Global 2.0 features a mixture of PCP and DCP, with their relative importance determined by the data on invoicing shares in Boz et al. (2020). In particular, we assume that exports of all countries are subject to *partial* DCP, meaning that a share of

[2] While invoicing and pricing do not need to coincide necessarily, in the literature it is typically assumed that they do. See Georgiadis & Schumann (2019) for tests of this assumption.

each country's exports is priced in US-\$ – independent of the destination market – while the remainder is priced in the producer's currency (see Figure 1).

Figure 1
Share of US-\$ exports in exports to non-US countries



Notes: The figure presents the shares of countries' non-US exports that are subject to DCP, that is priced in US-\$.

Note that for US exports DCP is equivalent to PCP. This assumption is labelled *US PCP assumption* in the remainder. For all other countries, we assume that the share of DCP exports is the same across all non-US trading partners. This assumption is labelled *proportional DCP assumption* in the remainder. For the trade of non-US countries with the US, we additionally assume that the US not only prices all exports in US-\$, but also that all imports by the US are priced in US-\$. As this pricing paradigm corresponds to local-currency pricing (LCP), the assumption is labelled *US LCP assumption* in the remainder.[3]

In the model, three parameters are connected to DCP and their values are either data-driven or follow directly from the above assumptions. Let Ξ_i represent the US-\$ share in total exports of country i. For oil-producing countries, this relates to non-oil exports as oil is traded in US-\$ by assumption. For the US, in line with the US PCP assumption, this parameter is equal to unity, i.e. $\Xi_{us} \equiv 1$. Let $\Xi_i^{\setminus us}$ represent the US-\$ share in exports of country i to non-US countries. This is obtained by subtracting country i's DCP exports to the US from country i's

[3] Boz et al. (2020) document that essentially all of US trade is invoiced in US-\$.

total DCP exports. Intuitively, for the US this equals total DCP exports, i.e. $\Xi_{us}^{\backslash us} = \Xi_{us} \equiv 1$. Finally, Ξ_i^{us} is the US-$ share in US imports from country i. Due to the US LCP assumption, this parameter is set to unity for all countries.

Consistent with the empirical findings in Gopinath et al. (2020), in ECB-Global 2.0 with DCP the US-$ exchange rate plays a much more consequential role in determining trade prices and quantities relative to the previous version. For example, and as illustrated in our simulation exercise, Gopinath et al. (2020) discuss that under DCP a multilateral appreciation of the US-$ causes prices of imports (in the currency of the importer) to rise *regardless of the source* and hence *global* rather than only US trade to weaken.[4]

4.1.2 Tariffs

In order to use ECB-Global to analyse recent trade tensions between the US and China we introduce tariffs. In particular, we model the tariffs in a similar way as Barbiero et al. (2019). Thus, throughout the model we distinguish between border prices, which is the effective price that the importers have to pay, and export prices, which correspond to the amount of money received by the exporting firm. The introduction of tariffs is modelled as an exogenous shock, which drives a wedge between the effective price and the export price. This is not to be interpreted as a shock to marginal costs of exporting firms or an export price shock, as the effects on countries' aggregate budget constraint are different. While the exporting country in the case of a tariff shock indeed faces lower demand for its goods, it is not compensated for the lack of demand by higher prices, which in part would offset the negative quantity effect on revenues. As a result, tariffs have a two-sided effect on the nominal trade balance as tariffs are fiscal revenues of the importing country instead of being paid to the exporter.

Also following Barbiero et al. (2019) the price setting of exporting firms is only indirectly affected by tariffs. In particular, while export prices do adjust in response to lower demand, firms are not willing to completely absorb the increase in tariffs into their margins so as to stabilise the border price (the effective price paid by the importer). Or, to put it differently: We assume that export prices rather than border prices are sticky, which corresponds to tariffs largely being passed on to consumers and firms in the importing country. As domestic firms use imported goods due to GVCs, tariffs also impact domestic production costs.

The implementation of tariffs is flexible in the sense that ECB-Global 2.0 allows for country-specific tariff rates (i.e. country i imposes tariffs on imports from j) or an average tariff rate on all imports. Finally, it is worth mentioning that oil imports are excluded from the imposition of tariffs.

[4] See Georgiadis & Mösle (2019) for a detailed discussion of DCP in ECB-Global.

4.1.3 Trade diversion

An additional novel element in ECB-Global 2.0 is trade diversion. For example, when China imposed tariffs on US soy beans in 2019 (thereby effectively making them more expensive), instead of growing soy beans in China (thereby reducing imports and improving net exports), importers switched to importing soy beans from Brazil. This phenomenon of 'trade diversion' implies that a country's total imports fluctuate less, while the distribution of bilateral imports across sources varies more. Obviously, trade diversion can only be meaningfully modelled in a multi-country context. In particular, we make the assumption that the prices of international competitors are disproportionately important (relative to their share in the domestic consumer price index) for the determination of imports. Thus, exports of country i to country j not only depend on the relative price of country i's exports to country j's overall consumer price level, but also relative to those of international competitors (the price of country j's imports from all other countries).

4.2 Domestic real economy

Differently from the previous version of the model, we assume that consumption and investment decisions are not solely determined by the short-term private-sector real interest rate (the sum of the central bank's safe rate and the private-sector risk premium adjusted for expected inflation). In ECB-Global 2.0 they also depend on a combination of short-term and expected long-term real private-sector interest rates. Furthermore, in order to capture the importance of energy prices for households that cannot perfectly smooth consumption (e.g. hand-to mouth-consumers), we assume that domestic-currency oil-price inflation has wealth effects by negatively impinging on current consumption expenditure.

4.3 Financial sector

In Dieppe et al. (2018) a strong emphasis was placed on the richness of the domestic financial sector in each country-block and large financial spillovers. In ECB-Global 2.0, we improve upon the empirical fit of spillovers, and we streamline the specification of some equations so as to make the model more stable in practical use and more easily adaptable to policy-request-driven modifications. In particular, in ECB-Global 2.0 government risk premia are assumed to be exogenous, and the bank-lending and equity price equation are modified to better fit large cross-country correlations. Moreover, in order to improve the usefulness of the model for policy requests, we introduce long-term rates and an exogenous term premium.

4.4 Monetary policy

The monetary policy rule in ECB-Global 2.0 exhibits several differences relative to the previous version of the model. In particular, the central bank sets the interest rate in order to stabilise medium-term, expected consumer-price inflation instead of reacting to current inflation. This reduces the sensitivity of monetary policy to short-term, transitory movements in energy and import prices. This change is motivated by the relatively large volatility of energy and import prices in the data, while at the same time monetary policy usually attempts to "see through" such movements.

4.5 China's exchange rate policy

In ECB-Gloal 2.0, China stabilises the exchange rate versus a basket of advanced economies' currencies (i.e. follows a managed float). However, this intervention is not carried out by constraining the central bank's policy rate to comply with exchange rate stabilisation, but rather by introducing a second policy instrument which only affects the foreign exchange market. Specifically, we allow for a wedge in China's UIP condition between the monetary policy rate and the rate that prevails on foreign exchange markets. This assumption implies that China effectively constrains access to the money market for foreign parties so that arbitrage opportunities cannot be exploited.

5 ECB-Global 2.0 in detail

This section describes the model equations of ECB-Global 2.0 in detail. While most countries are modelled symmetrically and differ only in the parameterisation, in some instances equations do differ. We document this heterogeneity in the respective instances.

Four economies stand out: the US, oil-producing countries, China, and Emerging Asia. First, the US differs from all other countries due to the introduction of DCP (see Section 4.1.1). Thus, wherever exchange rates are involved, the equations for the US are different from those for the other countries. Second, being the only global oil producer and exporter distinguishes oil-producing countries from the other countries (Section 5.4, 5.9, 5.10, and 5.12 below). Third, China differs from the other countries as it manages its exchange rate (Section 5.8) and as it is financially insulated from the rest of the world (Section 5.13). Finally, Emerging Asia's financial markets are more integrated with China's financial markets, and in contrast to the other countries its domestic financial conditions are affected by exchange rates (see Section 5.13).

The remainder of this section is organised as follows. Section 5.1 and 5.2 introduce notation and definitions. Then, Section 5.3 to 5.14 present the model equations.

5.1 Notation

Table 1 summarises the countries and regions in the model and the abbreviation that is used as an identifier in the equations in lower-cases.[5] Thus, the list of all countries included in ECB-Global 2.0 is defined by $K := \{\ us,\ cn,\ ea,\ ja,\ as,\ op,\ uk,\ rw\ \}$. We use the notation $\sum_{k\in K}$ to indicate summation over the variables of all countries. By writing $K\setminus\{i\}$ country i is excluded from the set. When needed, other sets of countries, e.g. advanced economies, are defined.

Table 1
Countries/regions in the model

Country/region	Abbreviation in model
United States	US
China	CN
Euro area	EA
Japan	JA
Emerging Asia, excl. China	AS
Oil-producing countries	OP
United Kingdom	UK
Rest of the world	RW

Note: A list of the countries considered for each block for calibration purposes can be found in the Appendix.

The notation x^{ss} indicates the steady-state value of variable x. Percentage deviations from steady state are denoted by hats

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

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

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

The subscripts in $\widehat{x}_{i,t}$ indicate that the variable relates to country i and period t.

Coefficients are generally denoted by $\alpha_i^{\ell,m}$, where i indicates the country to which this parameter relates, ℓ to the equation in which the parameter appears, and m to the variable it multiplies or – more generally – clarifies the role of the parameter. Bilateral weights/shares are denoted by ω_{ij}^x, where i is the domestic and j the partner country, and x indicates the type of the weight/share, for example representing a trade or financial exposure share. χ_i^x denotes steady-state GDP shares of variable x in country i. The DCP-related parameters are discussed in Section 4.1.1. Elasticities are denoted by θ_i^x, where x indicates the type of elasticity (see Section 4.1.3). φ_i^x denotes financial spillovers for variable x.

[5]Note that we are using the terms ‘country’ and ‘region’ as synonyms in the following.

5.2 Definition of exchange rates and relative prices

The real exchange rate of country i's currency vis-à-vis the US-\$ is defined as the ratio between the foreign consumer-price index (CPI) $P^{cpi}_{us,t}$ and the domestic CPI $P^{cpi}_{i,t}$ adjusted by the bilateral nominal exchange rate $S_{i,t}$

$$Q_{i,t} = \frac{S_{i,t}\, P^{cpi}_{us,t}}{P^{cpi}_{i,t}}.$$

An increase in $Q_{i,t}$ reflects a real depreciation of country i's currency against the US-\$. In linearised terms, we have

$$\widehat{Q}_{i,t} = \widehat{S}_{i,t} + \widehat{P}^{cpi}_{us,t} - \widehat{P}^{cpi}_{i,t}.$$

Moreover, we define $\widehat{Q}_{i,k,t}$ as the exchange rate of country i's currency vis-à-vis country k's currency. Non-US bilateral exchange rates can be obtained by combining exchange rates vis-à-vis the US-\$. For example, the exchange rate of the currency of country i vis-à-vis that of country k is given by $\widehat{Q}_{i,k,t} = \widehat{Q}_{i,t} - \widehat{Q}_{k,t}$, where an increase in $\widehat{Q}_{i,k,t}$ reflects a depreciation of country i's currency against that of country k. Finally, note that $\widehat{Q}_{us,k,t} = \widehat{Q}_{us,t} - \widehat{Q}_{k,t} = -\widehat{Q}_{k,t}$.

5.3 Consumer-price index and inflation

The CPI is a combination of domestic and foreign producer prices as well as oil prices, all expressed in domestic currency. As in ECB-Global 2.0 we continue to lump together private consumption and investment (see Section 5.4 below), CPI actually reflects the price levels of consumption and investment. Specifically, the CPI for all countries except the US is defined by

$$\begin{aligned} 0 = {} & \alpha^{cpi,oil}_i \left(\widehat{Q}_{i,t} + \widehat{p}^{oil}_t\right) \\ & + (1-\alpha^{cpi,oil}_i) \Bigg\{ \alpha^{cpi,H}_i\ \widehat{p}^{ry}_{i,t} + (1-\alpha^{cpi,H}_i) \Bigg[\omega^{M,\backslash oil}_{i,us} \left(\widehat{Q}_{i,t} + \widehat{p}^{ry}_{us,t} + \hat{\tau}^{T}_{i,us,t}\right) \\ & \quad + \sum_{k \in K \backslash \{us,i\}} \omega^{M,\backslash oil}_{i,k} \Bigg(\Xi^{\backslash us}_k \left(\widehat{Q}_{i,t} + \widehat{p}^{rx,us}_{k,t} + \hat{\tau}^{T}_{i,k,t}\right) \\ & \quad\quad + (1-\Xi^{\backslash us}_k) \left(\widehat{Q}_{i,k,t} + \widehat{p}^{ry}_{k,t} + \hat{\tau}^{T}_{i,k,t}\right) \Bigg) \Bigg] \Bigg\}, \end{aligned} \tag{1}$$

where $\alpha^{cpi,oil}_i$ represents the share of oil in the consumption basket, $\alpha^{cpi,H}_i$ is a measure of home-bias in consumption and thus $1-\alpha^{cpi,H}_i$ represents the share of imported consumption goods in total consumption; $\omega^{M,\backslash oil}_{i,k}$ represents the bilateral non-oil import share of country i from country k; $\widehat{Q}_{i,t}$ represents country i's exchange rate against the US-\$, $\widehat{p}^{oil}_t$ represents real oil prices denoted in terms of US-\$, $\widehat{p}_{i,t}^{ry}$ represents the price of output relative to consumption and investment, $\hat{\tau}_{i,k,t}^{T}$ represents bilateral and multilateral tariffs, and $\widehat{p}_{i,t}^{rx,us}$ represents the relative price of DCP exports in terms of US-\$. The US variables in (1) are not multiplied by any DCP share due to the US PCP assumption, i.e. all exports from the US have the relative price $\widehat{p}_{us,t}^{ry}$. For non-US imports, $\Xi_k^{\backslash us}$ measures the degree to which imports from country k are priced in US-\$ or in country k's currency.

Two assumptions distinguish the US from the other countries. First, as oil prices are denoted in US-\$ they do not need to be converted to local currency. Second, prices of DCP imports from country k, represented by $\widehat{p}_{k,t}^{rx,us}$, are denoted in US-\$, and do not need to be converted to local currency either. Therefore, for the US instead of (1) we have

$$0 = \alpha_{us}^{cpi,oil}\ \widehat{p}_t^{oil} + (1 - \alpha_{us}^{cpi,oil}) \Bigg\{ \alpha_{us}^{cpi,H}\ \widehat{p}_{us,t}^{ry} + (1 - \alpha_{us}^{cpi,H}) \sum_{k \in K \backslash \{us\}} \omega_{us,k}^{M,\backslash oil} \Bigg(\Xi_k^{us} \left(\widehat{p}_{k,t}^{rx,us} + \hat{\tau}_{us,k,t}^{T} \right) + (1 - \Xi_k^{us}) \left(-\widehat{Q}_{k,t} + \widehat{p}_{k,t}^{ry} + \hat{\tau}_{us,k,t}^{T} \right) \Bigg) \Bigg\}, \tag{2}$$

where $\widehat{p}_t^{ry}$ is the price of output relative to consumption and investment. Note that because of the US LCP assumption, Ξ_k^{us} equals unity for all countries.

CPI inflation $\widehat{\pi}_{i,t}^{cpi}$ is implicitly given by

$$\widehat{p}_{i,t}^{ry} - \widehat{p}_{i,t-1}^{ry} = \widehat{\pi}_{i,t}^{ppi} - \widehat{\pi}_{i,t}^{cpi}, \tag{3}$$

where $\widehat{\pi}_{i,t}^{ppi}$ represents producer-price index (PPI) inflation, which is determined by firms' price-setting in (6) below.

5.4 Consumption and investment

As in the previous version of ECB-Global we lump together private consumption and investment, and we denote them by $\widehat{ci}_{i,t}$. We assume that private consumption and investment are determined by a joint Euler equation. In particular, for all countries except OP we have

$$\widehat{ci}_{i,t} = \alpha_i^{ci,ci}\ E_t\widehat{ci}_{i,t+1} + \left(1 - \alpha_i^{ci,ci}\right) \widehat{ci}_{i,t-1} + \alpha_i^{ci,q}\ \widehat{q}_{i,t} - \alpha_i^{ci,p^{oil}} \left(\widehat{Q}_{i,t} + \widehat{p}_t^{oil}\right) - \alpha_i^{ci,r^3} \left((1 - \alpha_i^{ci,r^L})\ \widehat{r}_{i,t}^{3} + \alpha_i^{ci,r^L}\ \widehat{r}_{i,t}^{L} + \widehat{\varpi}_{i,t} \right) + \xi_{i,t}^{ci}, \tag{4}$$

where $\widehat{r}_{i,t}^{3}$ represents the real interbank rate, $\widehat{r}_{i,t}^{L}$ represents the long-term real rate, $\widehat{\varpi}_{i,t}$ represents the private-sector credit spread over the real interbank rate, $\widehat{q}_{i,t}$ represents equity prices, $\widehat{Q}_{i,t}+\widehat{p}_t^{oil}$ represents the oil price in local currency, and $\xi_{i,t}^{ci}$ a demand shock. We assume that private consumption and investment are (i) positively related to equity prices, (ii) negatively to the real rates faced by agents, i.e. a combination of the long-term rate, interbank rate, and private-sector credit-risk premium, and (iii) negatively to the price of oil, which captures the fact that oil cannot be substituted easily by other goods. The changes relative to the previous version of ECB-Global are discussed in Section 4.2.

For oil-exporting countries OP, oil revenues in terms of PPI prices $\widehat{x}_{op,t}^{oil,ppi}$ additionally enter the IS-curve such that

$$\begin{aligned}\widehat{ci}_{op,t} = \alpha_{op}^{ci,ci}\ E_t\widehat{ci}_{op,t+1} + \left(1-\alpha_{op}^{ci,ci}\right)\ \widehat{ci}_{op,t-1} + \alpha_{op}^{ci,q}\ \widehat{q}_{op,t} + \alpha_{op}^{ci,oil}\ \widehat{x}_{op,t}^{oil,ppi} \\ - \alpha_{op}^{ci,r^3}\left(\left(1-\alpha_{op}^{ci,r^L}\right)\widehat{r}_{op,t}^{3} + \alpha_{op}^{ci,r^L}\ \widehat{r}_{op,t}^{L} + \widehat{\varpi}_{op,t}\right) + \xi_{op,t}^{ci}.\end{aligned} \tag{5}$$

5.5 Domestic Phillips-curve and marginal costs

For all countries, PPI inflation $\widehat{\pi}_{i,t}^{ppi}$ is determined by the following Phillips-curve

$$\widehat{\pi}_{i,t}^{ppi} = \alpha_i^{\pi,\beta}\ \alpha_i^{\pi,\pi}\ E_t\widehat{\pi}_{i,t+1}^{ppi} + \frac{1-\alpha_i^{\pi,\pi}}{\alpha_i^{\pi,\beta}}\ \widehat{\pi}_{i,t-1}^{ppi} + \alpha_i^{\pi,mc}\ \widehat{mc}_{i,t} - \xi_{i,t}^{\pi}, \tag{6}$$

where $\widehat{mc}_{i,t}$ represents real marginal costs of production for the domestic market, and $\xi_{i,t}^{\pi}$ a productivity or cost-push shock.

For all countries except the US, real marginal costs of production for the domestic market $\widehat{mc}_{i,t}$ are determined by

$$\begin{aligned}\widehat{mc}_{i,t} = \alpha_i^{mc,y}\widehat{y}_{i,t} + \alpha_i^{mc,\pi}\Bigg\{\alpha_i^{mc,oil}\left(\widehat{Q}_{i,t} + \widehat{p}_t^{oil} - \widehat{p}_{i,t}^{ry}\right) \\ + \left(1-\alpha_i^{mc,oil}\right)\Bigg[\omega_{i,us}^{imp,int}\ \left(\widehat{Q}_{i,t} + \widehat{p}_{us,t}^{ry} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,us,t}^{T}\right) \\ + \sum_{k\in K\backslash\{us,i\}} \omega_{i,k}^{imp,int}\ \Bigg(\left(1-\Xi_k^{\backslash us}\right)\left(\widehat{Q}_{i,k,t} + \widehat{p}_{k,t}^{ry} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,k,t}^{T}\right) \\ + \Xi_k^{\backslash us}\left(\widehat{Q}_{i,t} + \widehat{p}_{k,t}^{rx,us} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,k,t}^{T}\right)\Bigg)\Bigg]\Bigg\} + \alpha_i^{mc,y^w}\sum_{k\in K\backslash\{i\}}\omega_{i,k}^{X}\ \hat{y}_{k,t},\end{aligned} \tag{7}$$

where $\widehat{y}_{i,t}$ represents output, $\widehat{Q}_{i,t}$ represents country i's real exchange rate against the US-\$, $\widehat{p}_t^{oil}$ represents the real oil price relative to the US CPI in US-\$, $\widehat{p}_{i,t}^{ry}$ represents the price of output relative to consumption and investment, $\widehat{p}_{i,t}^{rx,us}$ represents the relative price of DCP exports in US-\$, and $\hat{\tau}_{i,k,t}^{T}$ represents bilateral and multilateral tariffs. The weight $\omega_{i,k}^{imp,int}$ denotes the share of imported inputs from country k in country i's production, and $\omega_{i,k}^{X}$ represents the share of bilateral exports of country i to country k in country i's total exports. The US variables in (7) are not multiplied by any DCP share due to the US PCP assumption, that is all exports – also of intermediary goods – from the US have the relative price $\widehat{p}^{ry}_{us,t}$. The specification of marginal costs in (7) takes into account the use of oil as well as imported intermediates in production.

For the US, marginal costs are given by

$$\begin{aligned}\widehat{mc}_{us,t} = \alpha^{mc,y}_{us}\widehat{y}_{us,t} + \alpha^{mc,\pi}_{us}\Bigg\{ \alpha^{mc,oil}_{us}\left(\widehat{p}^{oil}_{t} - \widehat{p}^{ry}_{us,t}\right) + (1-\alpha^{mc,oil}_{us})\Bigg[\\ + \sum_{k\in K\setminus\{us\}} \omega^{imp,int}_{us,k}\Bigg((1-\Xi^{us}_{k})\left(-\widehat{Q}_{k,t} + \widehat{p}^{ry}_{k,t} - \widehat{p}^{ry}_{us,t} + \hat{\tau}^{T}_{us,k,t}\right) \\ + \Xi^{us}_{k}\left(\widehat{p}^{rx,us}_{k,t} - \widehat{p}^{ry}_{us,t} + \hat{\tau}^{T}_{us,k,t}\right)\Bigg)\Bigg]\Bigg\} + \alpha^{mc,y^{w}}_{us}\sum_{k\in K\setminus\{us\}} \omega^{X}_{us,k}\ \hat{y}_{k,t}, \qquad (8)\end{aligned}$$

where again the price of oil is already in US-\$ and therefore does not need to be adjusted for the exchange rate. Under the US LCP assumption, Ξ^{us}_{k} equals unity for all countries.

5.6 Export-price Phillips-curve and marginal costs

As introduced in Section 4.1.1, exports are partly priced in US-\$, so that an additional pricing equation is needed. For all countries except the US, DCP export-price inflation $\widehat{\pi}^{x^{dcp}}_{i,t}$ is determined by

$$\widehat{\pi}^{x}_{i,t} = \alpha^{\pi^{x},\beta^{x}}_{i}\ \alpha^{\pi^{x},\pi^{x}}_{i}\ E_{t}\widehat{\pi}^{x}_{i,t+1} + \frac{1-\alpha^{\pi^{x},\pi^{x}}_{i}}{\alpha^{\pi^{x},\beta^{x}}_{i}}\ \widehat{\pi}^{x}_{i,t-1} + \alpha^{\pi^{x},mc^{x}}_{i}\ \left(-\widehat{Q}_{i,t} + \widehat{mc}^{x}_{i,t}\right) - \xi^{\pi^{x}}_{i,t}, \qquad (9)$$

where $\widehat{mc}^{x}_{i,t}$ represents real marginal costs of DCP export production, $\widehat{Q}_{i,t}$ represents country i's real exchange rate against the US-\$, and $\xi^{\pi^{x}}_{i,t}$ a productivity or cost-push shock. Given the US PCP assumption, the US does not have an export-price Phillips-curve. PPI and export prices are instead both determined by (6).

For all countries except the US, real marginal costs for DCP exports $\widehat{mc}^{x}_{i,t}$ are given by

$$\begin{aligned}\widehat{mc}^{x}_{i,t} = \alpha^{mc^{x},x}_{i}\ \widehat{x}_{i,t} + \alpha^{mc^{x},\pi^{x}}_{i}\Bigg\{ \alpha^{mc^{x},oil}_{i}\left(\widehat{Q}_{i,t} + \widehat{p}^{oil}_{t} - \widehat{p}^{ry}_{i,t}\right) \\ + (1-\alpha^{mc^{x},oil}_{i})\Bigg[\ \omega^{imp,int}_{i,us}\left(\widehat{Q}_{i,t} + \widehat{p}^{ry}_{us,t} - \widehat{p}^{ry}_{i,t} + \hat{\tau}^{T}_{i,us,t}\right) \\ + \sum_{k\in K\setminus\{us,i\}} \omega^{imp,int}_{i,k}\Bigg((1-\Xi^{\setminus us}_{k})\left(\widehat{Q}_{i,k,t} + \widehat{p}^{ry}_{k,t} - \widehat{p}^{ry}_{i,t} + \hat{\tau}^{T}_{i,k,t}\right) \\ + \Xi^{\setminus us}_{k}\left(\widehat{Q}_{i,t} + \widehat{p}^{rx,us}_{k,t} - \widehat{p}^{ry}_{i,t} + \hat{\tau}^{T}_{i,k,t}\right)\Bigg)\Bigg]\Bigg\}, \qquad (10)\end{aligned}$$

where $\widehat{x}_{i,t}$ represents country i's total exports, $\widehat{Q}_{i,t}$ represents country i's real exchange rate against the US-\$, $\widehat{p}_t^{oil}$ represents the real oil price relative to the US CPI in US-\$, $\widehat{p}_{i,t}^{ry}$ represents the price of output relative to consumption and investment, $\widehat{p}_{i,t}^{rx,us}$ represents the relative price of DCP exports in US-\$, and $\hat{\tau}_{i,k,t}^{T}$ bilateral and multilateral tariffs. The weight $\omega_{i,k}^{imp,int}$ denotes the share of imported inputs from country k in country i's production. DCP is thus also assumed for intermediate goods. The US variables in (10) are not multiplied by any DCP share due to the US PCP assumption, i.e. all exports – also those of intermediate goods – from the US have the relative price $\widehat{p}_{us,t}^{ry}$.

For the US, it is assumed that all export prices are sticky in US-\$, that is in the domestic currency. For all other countries, DCP export prices are given by

$$\widehat{p}_{i,t}^{rx,us} = \widehat{p}_{i,t-1}^{rx,us} + \widehat{\pi}_{i,t}^{x} - \widehat{\pi}_{us,t}. \tag{11}$$

PPI and export-price inflation are determined by (6) and (9), respectively.

5.7 Monetary policy

Central banks in all countries set the nominal policy rate $\widehat{i}_{i,t}^{s}$ according to

$$\widehat{i}_{i,t}^{s} = \alpha_i^{i^s,i^s}\,\widehat{i}_{i,t-1}^{s} + \left(1-\alpha_i^{i^s,i^s}\right)\left[\alpha_i^{i^s,\pi}\,\frac{E_t\widehat{\pi}_{i,t+4}^{cpi,y}}{4} + \alpha_i^{i^s,y}\,\widehat{y}_{i,t}\right] + \xi_{i,t}^{i^s}, \tag{12}$$

where $\widehat{\pi}_{i,t+4}^{cpi,y}$ represents annualised future CPI inflation given by $\widehat{\pi}_{i,t+4}^{cpi,y} = \widehat{\pi}_{i,t+4}^{cpi} + \widehat{\pi}_{i,t+3}^{cpi} + \widehat{\pi}_{i,t+2}^{cpi} + \widehat{\pi}_{i,t+1}^{cpi}$, $\widehat{y}_{i,t}$ represents the output gap, and $\xi_{i,t}^{i^s}$ a monetary policy shock.

The short-term real rate is defined according to the Fisher-equation

$$\widehat{r}_{i,t}^{s} = \widehat{i}_{i,t}^{s} - E_t\widehat{\pi}_{i,t+1}^{cpi}. \tag{13}$$

5.8 Exchange rates and China's exchange rate policy

For all countries except CN, real exchange rates vis-à-vis the US-\$ are determined by the UIP condition

$$E_t\widehat{Q}_{i,t+1} - \widehat{Q}_{i,t} + \xi_{i,t}^{Q} = \widehat{r}_{i,t}^{3} + \widehat{\varpi}_{i,t} - \left(\widehat{r}_{us,t}^{3} + \widehat{\varpi}_{us,t} - \alpha_i^{uip,nfa}\,\widetilde{nfa}_{i,t}\right), \tag{14}$$

where $\widehat{r}_{i,t}^{3} + \widehat{\varpi}_{i,t}$ represents the real interbank rate plus the private-sector credit-risk premium (the real short-term rate faced by households in country i), $\widetilde{nfa}_{i,t}$ is the aggregate net foreign asset position relative to GDP of country i as given by (18) below, and $\xi_{i,t}^{Q}$ is an exchange rate shock. The relevant interest rate is determined in the financial sector as outlined in Section 5.13. Country i's net foreign asset position $\widetilde{nfa}_{i,t}$ enters as a premium on holdings of foreign debt, which 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 & Uribe, 2003).

As introduced in Section 4.5, in ECB-Global 2.0, the exchange rate of CN is assumed to be a managed float. Thus, for the evolution of its exchange rate a friction in the UIP is added so that

$$E_t\widehat{Q}_{cn,t+1} - \widehat{Q}_{cn,t} + \xi^{Q}_{cn,t} = \widehat{i}^{uip}_{cn,t} + \widehat{\varpi}_{cn,t} - \left(\widehat{r}^{3}_{us,t} + \widehat{\varpi}_{us,t} - \alpha^{uip,nfa}_{cn}\ \widetilde{nfa}_{cn,t}\right). \tag{15}$$

In particular, CN stabilises its real exchange rate vis-à-vis a basket of advanced economy countries by setting a distinct UIP interest rate $\widehat{i}^{uip}_{cn,t}$ determined by

$$\widehat{i}^{uip}_{cn,t} = \widehat{r}^{3}_{cn,t} + \alpha^{iuip,reer}_{cn}\ \widehat{REER}_{cn,ae,t}, \tag{16}$$

where $\widehat{REER}_{cn,ae,t}$ is the real effective exchange rate against the advanced economy country basket (see (17) below). We introduce $\widehat{i}^{uip}_{cn,t}$ to mimic foreign exchange interventions by CN. It does not enter any other equations.

Finally, real effective exchange rates $\widehat{REER}_{i,t}$ are defined as

$$\widehat{REER}_{i,t} = \sum_{k\in K\setminus\{i\}} \omega^{X}_{i,k}\ \widehat{Q}_{i,k,t}. \tag{17}$$

$\widehat{REER}_{cn,ae,t}$ is defined analogously, except that it only considers exchange rates against advanced economy currencies.

Economy i's aggregate net foreign asset position $\widetilde{nfa}_{i,t}$ evolves according to

$$\widetilde{nfa}_{i,t} = \alpha^{nfa,nfa}\ \widetilde{nfa}_{i,t-1} + \chi^{X}_{i}\widehat{tot}_{i,t} + \chi^{X}_{i}\left(\widehat{x}_{i,t} - \widehat{y}_{i,t}\right) - \chi^{M}_{i}\left(\widehat{m}_{i,t} - \widehat{y}_{i,t}\right), \tag{18}$$

where $\widehat{tot}_{i,t}$ represents the terms-of-trade as defined in (42). $\widetilde{nfa}_{i,t}$ is denoted in per capita terms relative to GDP.

5.9 Fiscal policy

Government revenues $\widehat{t}_{i,t}$ and spending $\widehat{g}_{i,t}$ follow fiscal rules defined as

$$\widehat{t}_{i,t} = \alpha^{t,t}_{i}\ \widehat{t}_{i,t-1} + (1-\alpha^{t,t}_{i})\left(\alpha^{t,\mathcal{B}}_{i}\ \widetilde{\mathcal{B}}_{i,t-1} + \alpha^{t,y}_{i}\widehat{y}_{i,t}\right) + \xi^{t}_{i,t}, \tag{19}$$

$$\widehat{g}_{i,t} = \alpha^{g,g}_{i}\ \widehat{g}_{i,t-1} - (1-\alpha^{g,g}_{i})\left(\alpha^{g,\mathcal{B}}_{i}\ \widetilde{\mathcal{B}}_{i,t-1} + \alpha^{g,y}_{i}\widehat{y}_{i,t}\right) + \xi^{g}_{i,t}, \tag{20}$$

where $\widetilde{\mathcal{B}}_{i,t}$ denotes the real debt-to-GDP ratio in terms of absolute deviations from steady state, and $\xi^{t}_{i,t}$ and $\xi^{g}_{i,t}$ are shocks to government revenues and spending, respectively (see Leeper et al., 2010; Ratto et al., 2009; Ploedt & Reicher, 2014; Coenen et al., 2013). As for private consumption and investment in Section 5.4, government spending in OP depends additionally on oil revenues $\widehat{x}_{op,t}^{oil,ppi}$

$$\widehat{g}_{op,t} = \alpha_{op}^{g,g}\ \widehat{g}_{op,t-1} - (1-\alpha_{op}^{g,g}) \left(\alpha_{op}^{g,\mathcal{B}}\ \widetilde{\mathcal{B}}_{op,t-1} + \alpha_{op}^{g,y}\widehat{y}_{op,t}\right) + \alpha_{op}^{g,oil}\ \widehat{x}_{op,t}^{oil,ppi} + \xi_{op,t}^{g}. \tag{21}$$

Real government spending in terms of absolute deviations from steady state $\widetilde{\mathcal{G}}_{i,t}$ and real government revenues in terms of absolute deviations from steady state $\widetilde{\mathcal{T}}_{i,t}$ evolve according to

$$\widetilde{\mathcal{G}}_{i,t} = \chi_i^g \left(\widehat{g}_{i,t} - \widehat{y}_{i,t}\right), \tag{22}$$

$$\widetilde{\mathcal{T}}_{i,t} = \chi_i^g \left(\widehat{t}_{i,t} - \widehat{y}_{i,t}\right). \tag{23}$$

The real debt-to-GDP ratio as deviation from the steady-state level $\widetilde{\mathcal{B}}_{i,t}$ evolves according to

$$\widetilde{\mathcal{B}}_{i,t} = \widetilde{\mathcal{G}}_{i,t} - \widetilde{\mathcal{T}}_{i,t} + (1 + r_i^{g,ss} - \Delta\overline{y}^{ss}) \Bigg[\widetilde{\mathcal{B}}_{i,t-1} + \mathcal{B}_i^{ss}\times \left(\frac{\widehat{i}_{i,t-1}^{g}}{1+i_i^{g,ss}} - \frac{\widehat{\pi}_{i,t}}{1+\pi_i^{ss}} - \frac{\Delta\widehat{y}_{i,t}}{1+\Delta\overline{y}^{ss}} + \widehat{p}_{i,t-1}^{ry} - \widehat{p}_{i,t}^{ry}\right)\Bigg]. \tag{24}$$

5.10 Trade

All countries export and import non-oil goods. Also, all countries use oil in their production, and all except OP need to import oil. Oil is produced and exported only by OP. In this section, we discuss non-oil trade and total trade, while oil trade is discussed in Section 5.12. Export and import prices are discussed in Section 5.11.

5.10.1 Imports

For all countries except the US, non-oil imports $\widehat{m}_{i,t}^{\backslash oil}$ are determined by

$$
\begin{aligned}
\widehat{m}_{i,t}^{\backslash oil} = \theta_i^{da}\, \widehat{da}_{i,t} - \theta_i^{Q} \times \Bigg(\\
& \omega_{i,us}^{M,\backslash oil} \Bigg\{ \left(\widehat{Q}_{i,t} + \widehat{p}_{us,t}^{ry} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,us,t}^{T}\right) \\
& \quad + \theta^{div} \left(\widehat{Q}_{i,t} + \widehat{p}_{us,t}^{ry} - \widehat{p}_{i,t}^{rm,\backslash us} + \hat{\tau}_{i,us,t}^{T}\right) + \xi_{i,us,t}^{m} \Bigg\} \\
& + \sum_{k \in K \backslash \{us,i\}} \omega_{i,k}^{M,\backslash oil} \Bigg\{ \Xi_k^{\backslash us} \Bigg[\left(\widehat{Q}_{i,t} + \widehat{p}_{k,t}^{rx,us} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,k,t}^{T}\right) \\
& \quad + \theta^{div} \left(\widehat{Q}_{i,t} + \widehat{p}_{k,t}^{rx,us} - \widehat{p}_{i,t}^{rm,\backslash k} + \hat{\tau}_{i,k,t}^{T}\right) \Bigg] \\
& \quad + (1 - \Xi_k^{\backslash us}) \Bigg[\left(\widehat{Q}_{i,k,t} + \widehat{p}_{k,t}^{ry} - \widehat{p}_{i,t}^{ry} + \hat{\tau}_{i,k,t}^{T}\right) \\
& \quad + \theta^{div} \left(\widehat{Q}_{i,k,t} + \widehat{p}_{k,t}^{ry} - \widehat{p}_{i,t}^{rm,\backslash k} + \hat{\tau}_{i,k,t}^{T}\right) \Bigg] \\
& \quad + \xi_{i,k,t}^{m} \Bigg\} \Bigg),
\end{aligned}
\tag{25}
$$

where $\widehat{da}_{i,t}$ represents domestic absorption (the sum of private consumption, investment, and government spending), $\widehat{Q}_{i,t}$ and $\widehat{Q}_{i,k,t}$ are the real exchange rates of country i's currency against the US-\$ and country k's currency, respectively, $\widehat{p}_{i,t}^{rx,us}$ is the relative price of DCP exports from country i, $\widehat{p}_{i,t}^{ry}$ is the domestic price of output relative to private consumption and investment (PCP), $\widehat{p}_{i,t}^{rm,\backslash j}$ represents the import-price index of country i excluding country j, $\widehat{\tau}_{i,k,t}^{T}$ represents bilateral and multilateral tariffs, and $\xi_{i,k,t}^{m}$ represents a trade shock; $\omega_{i,k}^{M,\backslash oil}$ is the share of bilateral non-oil imports of country i from country k in country i's total non-oil imports, θ_i^{da} and θ_i^{Q} represent the import demand elasticity to domestic absorption and relative prices, and θ^{div} measures the degree of trade diversion. The US variables in (25) are not multiplied by any DCP share due to the US PCP assumption, i.e. all exports – also of intermediary goods – from the US have the relative price $\widehat{p}_{us,t}^{ry}$.

Intuitively, imports of country i increase if domestic demand $\widehat{da}_{i,t}$ increases, they decrease if the price of i's imports increases relative to the domestic price level ($\widehat{p}_{k,t}^{rx,us} - \widehat{p}_{i,t}^{ry}$ for DCP imports and $\widehat{p}_{k,t}^{ry} - \widehat{p}_{i,t}^{ry}$ for PCP imports), and they decrease due to trade diversion if the price of i's imports increases relative to competitors' export prices ($\widehat{p}_{k,t}^{rx,us} - \widehat{p}_{i,t}^{rm,\backslash k}$ for DCP exports and $\widehat{p}_{k,t}^{ry} - \widehat{p}_{i,t}^{rm,\backslash k}$ for PCP exports). Finally, tariffs of country i on country k's exports lower country

i's imports as the effective price increases.

For the US, non-oil imports are defined analogously by

$$\widehat{m}_{us,t}^{\backslash oil} = \theta_{us}^{da}\ \widehat{da}_{us,t} - \theta_{us}^{Q} \times \Bigg(+ \sum_{k \in K \backslash \{us\}} \omega_{us,k}^{M,\backslash oil} \Bigg\{ \Xi_k^{us} \Bigg[\left(\widehat{p}_{k,t}^{rx,us} - \widehat{p}_{us,t}^{ry} + \hat{\tau}_{us,k,t}^{T} \right) + \theta^{div} \left(\widehat{p}_{k,t}^{rx,us} - \widehat{p}_{us,t}^{rm,\backslash k} + \hat{\tau}_{us,k,t}^{T} \right) \Bigg] + (1 - \Xi_k^{us}) \Bigg[\left(-\widehat{Q}_{k,t} + \widehat{p}_{k,t}^{ry} - \widehat{p}_{us,t}^{ry} + \hat{\tau}_{us,k,t}^{T} \right) + \theta^{div} \left(-\widehat{Q}_{k,t} + \widehat{p}_{k,t}^{ry} - \widehat{p}_{us,t}^{rm,\backslash k} + \hat{\tau}_{us,k,t}^{T} \right) \Bigg] + \xi_{i,k,t}^{m} \Bigg\} \Bigg). \tag{26}$$

Due to the US LCP assumption Ξ_k^{us} is equal to unity for all countries.

Total imports $\widehat{m}_{i,t}$ are the sum of non-oil and oil imports

$$\widehat{m}_{i,t} = \frac{\chi_i^{M,\backslash oil}}{\chi_i^{M}}\ \widehat{m}_{i,t}^{\backslash oil} + \frac{\chi_i^{M,oil}}{\chi_i^{M}}\ \widehat{m}_{i,t}^{oil}, \tag{27}$$

$$\widehat{m}_{i,t} = \widehat{m}_{i,t}^{\backslash oil}, \tag{28}$$

where $\chi_i^{M,\backslash oil}$ and $\chi_i^{M,oil}$ represent the share of non-oil and oil imports relative to GDP, respectively, and χ_i^{M} represents the share of total imports relative to GDP. For OP, total imports equal non-oil imports. Oil imports are defined in Section 5.12 by (43) below.

5.10.2 Exports

For all countries except the US and OP, total exports $\widehat{x}_{i,t}$ are determined by

$$\begin{aligned}
\widehat{x}_{i,t} = \omega^X_{i,us} \Bigg\{ & \theta^{da}_{us} \, \widehat{da}_{us,t} - \Xi^{us}_i \Bigg[\theta^Q_{us} \left(\widehat{p}^{rx,us}_{i,t} - \widehat{p}^{ry}_{us,t} + \widehat{\tau}^T_{us,i,t} \right) \\
& \qquad + \theta^Q_i \, \theta^{div} \left(\widehat{p}^{rx,us}_{i,t} - \widehat{p}^{rm,\backslash i}_{us,t} + \widehat{\tau}^T_{us,i,t} \right) \Bigg] \\
& - (1 - \Xi^{us}_i) \Bigg[\theta^Q_{us} \left(-\widehat{Q}_{i,t} + \widehat{p}^{ry}_{i,t} - \widehat{p}^{ry}_{us,t} + \widehat{\tau}^T_{us,i,t} \right) \\
& \qquad + \theta^Q_i \, \theta^{div} \left(-\widehat{Q}_{i,t} + \widehat{p}^{ry}_{i,t} - \widehat{p}^{rm,\backslash i}_{us,t} + \widehat{\tau}^T_{us,i,t} \right) \Bigg] \\
& + \xi^m_{us,i,t} \Bigg\} \\
+ \sum_{k \in K \backslash \{us,i\}} \omega^X_{i,k} \Bigg\{ & \theta^{da}_k \, \widehat{da}_{k,t} - \Xi^{\backslash us}_i \Bigg[\theta^Q_k \left(\widehat{Q}_{k,t} + \widehat{p}^{rx,us}_{i,t} - \widehat{p}^{ry}_{k,t} + \widehat{\tau}^T_{k,i,t} \right) \\
& \qquad + \theta^Q_i \, \theta^{div} \left(\widehat{Q}_{k,t} + \widehat{p}^{rx,us}_{i,t} - \widehat{p}^{rm,\backslash i}_{k,t} + \widehat{\tau}^T_{k,i,t} \right) \Bigg] \\
& - (1 - \Xi^{\backslash us}_i) \Bigg[\theta^Q_k \left(\widehat{Q}_{k,i,t} + \widehat{p}^{ry}_{i,t} - \widehat{p}^{ry}_{k,t} + \widehat{\tau}^T_{k,i,t} \right) \\
& \qquad + \theta^Q_i \, \theta^{div} \left(\widehat{Q}_{k,i,t} + \widehat{p}^{ry}_{i,t} - \widehat{p}^{rm,\backslash i}_{k,t} + \widehat{\tau}^T_{k,i,t} \right) \Bigg] \\
& + \xi^m_{k,i,t} \Bigg\}, \qquad (29)
\end{aligned}$$

where $\widehat{da}_{i,t}$ is domestic absorption (the sum of private consumption, investment, and government spending), $\widehat{Q}_{i,t}$ and $\widehat{Q}_{i,k,t}$ are the real exchange rates of country i's currency against the US-$ and country k's currency, respectively, $\widehat{p}^{rx,us}_{i,t}$ is the relative price of DCP exports from country i, $\widehat{p}^{ry}_{i,t}$ represents the domestic price of output relative to consumption and investment (PCP), $\widehat{p}^{rm,\backslash j}_{i,t}$ represents the import-price index of country i excluding country j, $\widehat{\tau}^T_{i,k,t}$ represents bilateral and multilateral tariffs, and $\xi^m_{i,k,t}$ represents a trade shock. $\omega^X_{i,k}$ is the share of bilateral exports from country i to country k in country i's total exports, θ^{da}_i and θ^Q_i represent the import demand elasticity to domestic absorption and relative prices, and θ^{div} measures the degree of trade diversion.

Intuitively, exports of country i increase if foreign demand given by foreign domestic absorption $\widehat{da}_{k,t}$ increases, they decrease if the price of i's exports increases relative to the importers' price level ($\widehat{p}^{rx,us}_{i,t} - \widehat{p}^{ry}_{k,t}$ for DCP exports and $\widehat{p}^{ry}_{i,t} - \widehat{p}^{ry}_{k,t}$ for PCP exports), and they decrease due to trade diversion if the price of i's exports increases relative to competitors' export prices ($\widehat{p}^{rx,us}_{i,t} - \widehat{p}^{rm,\backslash i}_{k,t}$ for DCP exports and $\widehat{p}^{ry}_{i,t} - \widehat{p}^{rm,\backslash i}_{k,t}$ for PCP exports). Finally, tariffs of country k on country i's exports lower country i's exports as the effective price increases. Due to the US LCP assumption Ξ^{us}_i equals unity for all countries.

For the US, total exports simplify substantially due to the US PCP assumption. US total exports are given by

$$\widehat{x}_{us,t} = \sum_{k\in K\backslash\{us\}} \omega^X_{us,k} \Big\{ \theta^{da}_k \ \widehat{da}_{k,t} - \theta^Q_k \left(\widehat{Q}_{k,t} + \widehat{p}^{ry}_{us,t} - \widehat{p}^{ry}_{k,t} + \widehat{\tau}^T_{k,us,t} \right) - \theta^Q_{us} \ \theta^{div} \left(\widehat{Q}_{k,t} + \widehat{p}^{ry}_{us,t} - \widehat{p}^{rm,\backslash us}_{k,t} + \widehat{\tau}^T_{k,us,t} \right) + \xi^m_{k,us,t} \Big\}. \tag{30}$$

For OP, total OP exports are the sum of non-oil and oil exports

$$\widehat{x}_{op,t} = \frac{\chi^{X,\backslash oil}_{op}}{\chi^X_{op}} \ \widehat{x}^{\backslash oil}_{op,t} + \frac{\chi^{X,oil}_{op}}{\chi^X_{op}} \ \widehat{x}^{oil}_{op,t}. \tag{31}$$

Oil exports $\widehat{x}^{oil}_{op,t}$ are defined in (46) in Section 5.12 below, and non-oil exports $\widehat{x}^{\backslash oil}_{op,t}$ are defined by the same logic as total exports for all other countries substituting $\omega^X_{i,k}$ from (33) by $\omega^{X,\backslash oil}_{op,k}$, the non-oil export share for OP. $\chi^{X,\backslash oil}_{op}$ and $\chi^{X,oil}_{op}$ represent the ratio of non-oil and oil exports to GDP, respectively, and χ^X_{op} represents the ratio of total exports to GDP.

5.11 Export and import prices

5.11.1 Export prices

Non-oil export prices in domestic currency – taking into account DCP and PCP exports – are determined by

$$\widehat{p}^{rx,\backslash oil}_{i,t} = (1 - \Xi_i) \ \widehat{p}^{ry}_{i,t} + \Xi_i \left(\widehat{Q}_{i,t} + \widehat{p}^{rx,us}_{i,t} \right), \tag{32}$$

where Ξ_i is the total US-\$ DCP export share of country i, i.e. the share of US-\$ exports in i's total (non-oil) exports. Thus, non-oil export prices in domestic currency are the weighted sum of producer prices $\widehat{p}^{ry}_{i,t}$ and DCP export prices in domestic currency $\widehat{Q}_{i,t} + \widehat{p}^{rx,us}_{i,t}$. Notice that for the US, due to the US PCP assumption non-oil export prices equal producer prices ($\widehat{p}^{rx,\backslash oil}_{us,t} = \widehat{p}^{ry}_{us,t}$). $\widehat{p}^{rx,\backslash oil}_{i,t}$ is used for the calculation of total export prices $\widehat{p}^{rx}_{i,t}$.

For all countries except OP, total export prices in domestic currency $\widehat{p}^{rx}_{i,t}$ are identical to non-oil export prices in domestic currency $\widehat{p}^{rx,\backslash oil}_{i,t}$

$$\widehat{p}^{rx}_{i,t} = \widehat{p}^{rx,\backslash oil}_{i,t}. \tag{33}$$

For OP, total export prices are given by the weighted sum of non-oil export prices and oil export prices in domestic currency

$$\widehat{p}^{rx}_{op,t} = \frac{\chi^{X,\backslash oil}_{op}}{\chi^{X}_{op}}\,\widehat{p}^{rx,\backslash oil}_{op,t} + \frac{\chi^{X,oil}_{op}}{\chi^{X}_{op}}\,\left(\widehat{Q}_{op,t} + \widehat{p}^{oil}_{t}\right). \tag{34}$$

$\widehat{p}^{rx}_{i,t}$ is used to calculate the global export price used for the calculation of the global trade balance and for countries' terms-of-trade.

5.11.2 Import prices

We also obtain import prices excluding tariffs for countries' terms-of-trade and import prices including tariffs as a benchmark. For all countries except the US, non-oil import prices including tariffs $\widehat{p}^{rm,\backslash oil}_{i,t}$ are given by

$$\begin{aligned}\widehat{p}^{rm,\backslash oil}_{i,t} &= \omega^{M,\backslash oil}_{i,us}\left(\widehat{Q}_{i,t} + \widehat{p}^{ry}_{us,t} + \widehat{\tau}^{T}_{i,us,t}\right)\\ &+ \sum_{k\in K\backslash\{us,i\}} \omega^{M,\backslash oil}_{i,k}\left(\Xi^{\backslash us}_{k}\left[\widehat{Q}_{i,k,t} + \widehat{p}^{rx,us}_{k,t} + \widehat{\tau}^{T}_{i,k,t}\right]\right.\\ &\left. + (1-\Xi^{\backslash us}_{k})\left[\widehat{Q}_{i,k,t} + \widehat{p}^{ry}_{k,t} + \widehat{\tau}^{T}_{i,k,t}\right]\right),\end{aligned} \tag{35}$$

where $\widehat{Q}_{i,t}$ and $\widehat{Q}_{i,k,t}$ are the real exchange rates of country i's currency against the US-$ and country k's currency, respectively, $\widehat{p}^{rx,us}_{i,t}$ is the relative price of DCP exports from country i, $\widehat{p}^{ry}_{i,t}$ represents the domestic price of output relative to consumption and investment (PCP), and $\widehat{\tau}^{T}_{i,k,t}$ represents bilateral and multilateral tariffs. $\omega^{M,\backslash oil}_{i,k}$ is the share of bilateral non-oil imports of country i from country k in country i's total non-oil imports.

For the US, non-oil import prices including tariffs are given

$$\begin{aligned}\widehat{p}^{rm,\backslash oil}_{us,t} &= \sum_{k\in K\backslash\{us\}} \omega^{M,\backslash oil}_{us,k}\left(\Xi^{us}_{k}\left[\widehat{p}^{rx,us}_{k,t} + \widehat{\tau}^{T}_{us,k,t}\right]\right.\\ &\left. + (1-\Xi^{us}_{k})\left[-\widehat{Q}_{k,t} + \widehat{p}^{ry}_{k,t} + \widehat{\tau}^{T}_{us,k,t}\right]\right).\end{aligned} \tag{36}$$

Due to the US LCP assumption, Ξ^{us}_{k} equals unity for all countries.

For all countries except OP – assuming that no tariffs apply to oil trade – the total import-price index including tariffs is the weighted sum of non-oil import prices including tariffs and oil import prices and is given by

$$\widehat{p}^{rm}_{i,t} = \frac{\chi^{M,\backslash oil}_i}{\chi^M_i}\,\widehat{p}^{rm,\backslash oil}_{i,t} + \frac{\chi^{M,oil}_i}{\chi^M_i}\,\left(\widehat{Q}_{i,t} + \widehat{p}^{oil}_t\right), \tag{37}$$

$$\widehat{p}^{rm}_{op,t} = \widehat{p}^{rm,\backslash oil}_{op,t}, \tag{38}$$

where $\chi^{M,\backslash oil}_i$ and $\chi^{M,oil}_i$ represent the ratio of non-oil and oil imports to GDP, respectively, and χ^M_i represents the ratio of total imports to GDP. For OP, total import prices are given by non-oil import prices due to the fact that OP do not import any oil.

Import prices excluding tariffs $\widehat{p}^{rm,\backslash\tau}_{i,t}$ are obtained by excluding tariffs from non-oil import prices. Obtaining total import prices excluding tariffs follows the same logic as for import prices including tariffs.

5.11.3 Competitor prices

Introducing trade diversion in ECB-Global 2.0 requires defining competitor-price indices that exclude a specific country. For instance, a competitor price would measure the price of country i's imports from all countries except country j. The import price index for country i – i being any country except the US – excluding country j – j not being equal to i and not being the US – is defined by

$$\begin{aligned}\widehat{p}^{rm,\backslash j}_{i,t} &= \omega^{M,\backslash j}_{i,us}\left(\widehat{Q}_{i,t} + \widehat{p}^{ry}_{us,t} + \widehat{\tau}^{T}_{i,us,t}\right)\\ &\quad + \sum_{k\in K\backslash\{us,i,j\}} \omega^{M,\backslash j}_{i,k}\left\{\Xi^{\backslash us}_k\left(\widehat{Q}_{i,t} + \widehat{p}^{rx,us}_{k,t} + \widehat{\tau}^{T}_{i,k,t}\right)\right.\\ &\qquad\left. + \left(1-\Xi^{\backslash us}_k\right)\left(\widehat{Q}_{i,k,t} + \widehat{p}^{ry}_{k,t} + \widehat{\tau}^{T}_{i,k,t}\right)\right\},\end{aligned} \tag{39}$$

where $\omega^{M,\backslash j}_{i,k}$ represents the bilateral import share of country i from country k excluding the trade related to country j and $i \in K \setminus \{us\}$ and $j \in K \setminus \{i, us\}$.

For the US, the import price index excluding country j – j not being the US – is defined by

$$\begin{aligned}\widehat{p}^{rm,\backslash j}_{us,t} &= \sum_{k\in K\backslash\{us,j\}} \omega^{M,\backslash j}_{us,k}\left\{\Xi^{us}_k\left(\widehat{p}^{rx,us}_{k,t} + \widehat{\tau}^{T}_{us,k,t}\right)\right.\\ &\qquad\left. + \left(1-\Xi^{us}_k\right)\left(-\widehat{Q}_{k,t} + \widehat{p}^{ry}_{k,t} + \widehat{\tau}^{T}_{us,k,t}\right)\right\},\end{aligned} \tag{40}$$

where $j \in K \setminus \{us\}$.

Finally, the import price index for country i – i not being the US – excluding the US is given by

$$\widehat{p}_{i,t}^{rm,\backslash us} = \sum_{k \in K \backslash \{us,i\}} \omega_{i,k}^{M,\backslash us} \Bigg\{ \Xi_k^{\backslash us} \left(\widehat{Q}_{i,t} + \widehat{p}_{k,t}^{rx,us} + \widehat{\tau}_{i,k,t}^{T} \right) + (1 - \Xi_k^{\backslash us}) \left(\widehat{Q}_{i,k,t} + \widehat{p}_{k,t}^{ry} + \widehat{\tau}_{i,k,t}^{T} \right) \Bigg\}, \tag{41}$$

where $i \in K \setminus \{us\}$.

5.11.4 Terms-of-trade

The terms-of-trade $\widehat{tot}_{i,t}$ follow from the difference between export and import prices excluding tariffs, both denoted in domestic currency

$$\widehat{tot}_{i,t} = \widehat{p}_{i,t}^{rx} - \widehat{p}_{i,t}^{rm,\backslash \tau}. \tag{42}$$

5.12 Oil market

Oil imports $\widehat{m}_{i,t}^{oil}$ are modelled analogously to non-oil imports. However, governments consume no oil and OP do not import oil. Specifically, similarly to Medina & Soto (2005), country i's real oil import demand is given by

$$\widehat{m}_{i,t}^{oil} = \theta_i^{da}\ \widehat{ci}_{i,t} - \theta_i^{oil} \left(\widehat{Q}_{i,t} + \widehat{p}_t^{oil} \right), \tag{43}$$

where θ_i^{da} represents the elasticity of imports to changes in domestic absorption and θ_i^{oil} represents the price elasticity of oil imports and demand.

Oil demand of OP $\widehat{oil}_{op,t}^{d}$ is modelled analogously as

$$\widehat{oil}_{op,t}^{d} = \widehat{ci}_{op,t} - \theta_{op}^{oil} \left(\widehat{Q}_{op,t} + \widehat{p}_t^{oil} \right). \tag{44}$$

Global oil demand $\widehat{oil}_t^{d}$ is given by the sum of oil imports of oil-importing countries $\widehat{m}_{i,t}^{oil}$ and OP's oil demand $\widehat{oil}_{op,t}^{d}$

$$\widehat{oil}_t^{d} = \omega_{op}^{oil}\ \widehat{oil}_{op,t}^{d} + \sum_{k \in K \backslash \{op\}} \omega_k^{oil}\ \widehat{m}_{k,t}^{oil}, \tag{45}$$

where ω_i^{oil} represents economy i's share in global oil consumption.

OP oil exports, and thus global oil exports, are given by

$$\widehat{x}^{oil}_{op,t} = \sum_{k \in K \setminus \{op\}} \frac{\omega^{oil}_k}{(1-\omega^{oil}_{op})} \, \widehat{m}^{oil}_{k,t}. \tag{46}$$

While $\widehat{x}^{oil}_{op,t}$ is denoted in real terms, oil revenues affect private consumption, investment, and government spending in (5) and (21) in terms of OP PPI $\widehat{x}^{oil,ppi}_{op,t}$ defined as

$$\widehat{x}^{oil,ppi}_{op,t} = \widehat{Q}_{op,t} + \widehat{p}^{oil}_t + \widehat{x}^{oil}_{op,t} - \widehat{p}^{ry}_{op,t}. \tag{47}$$

In equilibrium, oil demand equals oil supply

$$\widehat{oil}^d_t = \widehat{oil}^s_t = \theta^{oil,s} \, \widehat{p}^{oil}_t + \xi^{oil}_t, \tag{48}$$

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

5.13 Financial sector

Macro-financial linkages in ECB-Global arise through (i) the interbank interest rate spread, (ii) credit supply constraints reflected in bank-lending tightness, (iii) the private-sector and sovereign credit risk premia, (iv) equity prices, and (v) long-term rates. Some of these variables are subject to cross-country spillovers in the sense that domestic financial variables directly depend on their foreign counterparts. China is not integrated into global financial markets and therefore does not face inward financial spillovers. The parameters φ_i determine the strength of inward financial spillovers from other countries. Thus, $\varphi_{cn} = 0$ for all cases. $\omega^b_{i,k}$ represents the bilateral share of country i's country-k assets in country i's total assets in the data, and is used to calibrate the relative importance of other countries' financial variables for country i's inward financial spillovers.

5.13.1 Interbank interest rate spread

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

$$\widehat{r}^3_{i,t} = \widehat{r}^s_{i,t} + \widehat{\varsigma}^b_{i,t}, \tag{49}$$

where the real interbank interest rate spread evolves according to

$$\widehat{\varsigma}^b_{i,t} = \alpha^{\varsigma^b,\varsigma^b}_i \, \widehat{\varsigma}^b_{i,t-1} + \varphi^{\varsigma^b}_i \sum_{k \in K \setminus \{i\}} \omega^b_{i,k} \, \widehat{\varsigma}^b_{k,t} + \xi^{\varsigma}_{i,t}, \tag{50}$$

as a combination of an idiosyncratic interbank rate shock $\xi^{\varsigma}_{i,t}$ and cross-country spillovers. Intuitively, the specification of the spillovers in interbank markets reflects contagion between countries' banking systems.

5.13.2 Bank-lending tightness

In order to incorporate the effects of variations in private-sector credit risk on the economy, we consider bank-lending tightness $\widehat{blt}_{i,t}$ as a measure of credit supply constraints. Bank-lending tightness for all countries except AS is given by

$$\widehat{blt}_{i,t} = \alpha_i^{blt,blt}\ \widehat{blt}_{i,t-1} - \alpha_i^{blt,y}\ \widehat{y}_{i,t} + \alpha_i^{blt,r^3}\ \widehat{r}^s_{i,t} + \varphi_i^{blt} \sum_{k \in AE \setminus \{i\}} \frac{\omega^b_{i,k}}{\omega^b_{i,AE}}\ \widehat{blt}_{k,t} + \xi^{blt}_{i,t}, \tag{51}$$

where $AE := \{us,\ ea,\ uk,\ ja\}$. Thus, only advanced economies' lending conditions enter country i's bank-lending tightness. We thereby reflect that cross-border bank lending is dominated by advanced economies' banks (Bank for International Settlements, 2020), and furthermore prevent spillbacks from emerging markets to advanced economies through bank-lending channels. Bank-lending tightness is determined by changes to domestic economic conditions as measured by the output gap $\widehat{y}_t$, refinancing costs determined by the real policy rate $\widehat{r}^s_t$, and bank-lending conditions in advanced economies. Again, there are no inward financial spillovers in China ($\varphi^{blt}_{cn} = 0$). In ECB-Global 2.0 we incorporate the interplay between the effects of pro-cyclical variation in banks' balance sheets and the anti-cyclical impact of monetary policy on bank lending. Since the latter is in most cases not sufficient to entirely offset the impact of the former, bank-lending tightness acts as an additional financial accelerator mechanism in the model. $\xi^{blt}_{i,t}$ represents an exogenous shock to lending conditions.

Due to the greater financial integration of financial markets of emerging economies in Asia with China (Asian Development Bank, 2017), AS bank-lending tightness is additionally affected by lending conditions in China and is given by

$$\begin{aligned} \widehat{blt}_{as,t} = {} & \alpha_{as}^{blt,blt}\ \widehat{blt}_{as,t-1} - \alpha_{as}^{blt,y}\ \widehat{y}_{as,t} + \alpha_{as}^{blt,r^3}\ \widehat{r}^s_{as,t} + \alpha_{as}^{blt,Q}\ \widehat{Q}_{as,t} \\ & + \varphi_{as}^{blt} \sum_{k \in \{AE,cn\}} \frac{\omega^b_{as,k}}{\left(\omega^b_{as,AE} + \omega^b_{as,cn}\right)}\ \widehat{blt}_{k,t} + \xi^{blt}_{as,t}. \end{aligned} \tag{52}$$

Furthermore, we incorporate a financial channel of the exchange rate, meaning that Emerging Asia's bank-lending conditions are affected by the exchange rate against the US-\$ $\widehat{Q}_{as,t}$. Because of the dominant role of the US-\$ in debt contracts and cross-border bank loans, a US-\$ appreciation (increase in $\widehat{Q}_{as,t}$) leads to a weakening of borrowers' balance sheets, effective credit risk faced by banks increases and thus lending conditions in Emerging Asia tighten, see Bruno

& Shin (2015) and the empirical evidence in Kearns & Patel (2016) as well as Avdjiev et al. (2019).[6]

5.13.3 Private-sector and sovereign credit risk premia

The private-sector credit risk premium $\widehat{\varpi}_{i,t}$ is the sum of bank-lending tightness $\widehat{blt}_{i,t}$ and the sovereign credit-risk premium $\widehat{\varsigma}^{g}_{i,t}$ for all countries

$$\widehat{\varpi}_{i,t} = \alpha_i^{\varpi,blt}\ \widehat{blt}_{i,t} + \alpha_i^{\varpi,\varsigma^g}\ \widehat{\varsigma}^{g}_{i,t} + \xi^{\varpi}_{i,t}. \tag{53}$$

Cross-country spillovers in the private-sector credit risk premium materialise via bank-lending tightness. The private-sector credit risk premium enters private consumption and investment in (4) and (5). $\xi^{\varpi}_{i,t}$ is a risk premium shock.

The sovereign credit risk premium $\widehat{\varsigma}^{g}_{i,t}$ is a wedge between the real policy rate $\widehat{r}^{s}_{i,t}$ and the real short-term sovereign bond yield $\widehat{r}^{g}_{i,t}$ and is given by

$$\widehat{r}^{g}_{i,t} = \widehat{r}^{s}_{i,t} + \widehat{\varsigma}^{g}_{i,t}, \tag{54}$$

where the sovereign credit risk premium evolves according to

$$\widehat{\varsigma}^{g}_{i,t} = \alpha_i^{\varsigma^g,\varsigma^g}\ \widehat{\varsigma}^{g}_{i,t-1} + \alpha_i^{\varsigma^g,\mathscr{B}}\ \widetilde{\mathscr{B}}_{i,t} + \xi^{\varsigma^g}_{i,t}, \tag{55}$$

where $\widetilde{\mathscr{B}}_{i,t}$ denotes the absolute deviation of the debt-to-GDP ratio from its steady-state level given in (24). $\xi^{\varsigma^g}_{i,t}$ represents a sovereign credit risk premium shock.

In the data, sovereign credit risk premium spillovers are highly shock dependent. For example, while a flight-to-safety typically implies negatively correlated sovereign bond yield spreads, global improvement of trust in governments induce a positive correlation. Additionally, whether a country is considered as a safe heaven may change over time. Given the limitations of a linear model in this context, we do not include cross-country spillovers in the sovereign credit risk premium.

[6] Bruno & Shin (2019) discuss and provide empirical evidence for a related financial channel of the exchange rate: When production of exports requires working capital or trade financing – for example due to a stretching of the point in time in which production is initiated and in which revenues accrue to to integration in cross-border value chains – extended in US-$ from globally active banks, dollar appreciation tightens financing conditions and thereby reduces exports.

5.13.4 Equity prices

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

$$\widehat{q}_{i,t} = \alpha_i^{q,q}\ E_t\widehat{q}_{i,t+1} - \alpha_i^{q,r^3}\ \left(\widehat{r}^3_{i,t} + \widehat{\varpi}_{i,t}\right) + \alpha_i^{q,y}\ E_t\widehat{y}_{i,t+1}$$
$$+ \varphi_i^q \sum_{k\in K\setminus\{i\}} \omega^b_{i,k}\ \widehat{q}_{k,t} + \xi^q_{i,t}. \tag{56}$$

The no-arbitrage condition for the value of installed capital states that the value of capital today $\widehat{q}_{i,t}$ 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 $(\widehat{r}^3_{i,t} + \widehat{\varpi}_{i,t})$. We consider the future output gap $\widehat{y}_{i,t+1}$ 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. For China, inward financial spillovers are again precluded. $\xi^q_{i,t}$ denotes an equity price shock.

5.13.5 Long-term interest rates

Long-term interest rates $\widehat{r}^L_{i,t}$, which enter the IS-curves (4) and (5), are determined by

$$\widehat{r}^L_{i,t} = \alpha_i^{r^L,r^s}\ \widehat{r}^s_{i,t} + \alpha_i^{r^L,r^l_{t1}}\ E_t\widehat{r}^l_{i,t} + \alpha_i^{r^L,r^l_{t2}}\ 1/3\cdot\left[E_t\widehat{r}^l_{i,t} + E_t\widehat{r}^l_{i,t+4} + E_t\widehat{r}^l_{i,t+8}\right]$$
$$+ \alpha_i^{r^L,r^l_{t4}}\ 1/5\cdot\left[E_t\widehat{r}^l_{i,t} + E_t\widehat{r}^l_{i,t+4} + E_t\widehat{r}^l_{i,t+8} + E_t\widehat{r}^l_{i,t+12} + E_t\widehat{r}^l_{i,t+16}\right]$$
$$+ \widehat{\varsigma}^g_{i,t} + \xi^{r^l}_{i,t}, \tag{57}$$

where the weights $\alpha_i^{r^L,r^s}$ and all $\alpha_i^{r^L,r^l_t}$ are chosen such that they reflect the average maturity of private sector credit (World Bank, 2015). The expected average short-term rate over the next four quarters is given by

$$E_t\widehat{r}^l_{i,t} = \frac{1}{4}E_t\sum_{j=1}^{4}\widehat{r}^s_{i,t+j}. \tag{58}$$

Thus – as introduced in Section 4.3 – the long-term interest rate is determined by the expected path of future short-term interest rates, the sovereign credit risk premium $\widehat{\varsigma}^g_{i,t}$, and an exogenous term premium $\xi^{r^l}_{i,t}$.

5.14 Market clearing

Domestic absorption $\widehat{da}_{i,t}$ is the weighted sum of private consumption, investment, and government spending

$$\widehat{da}_{i,t} = \frac{\chi_i^{ci}}{(\chi_i^{ci} + \chi_i^g)} \, \widehat{ci}_{i,t} + \frac{\chi_i^g}{(\chi_i^{ci} + \chi_i^g)} \, \widehat{g}_{i,t}, \tag{59}$$

where the weights are given by the steady-state shares of the respective variables in GDP.

Real GDP $\widehat{y}_{i,t}$ is determined by the market clearing condition as the weighted sum of private consumption, investment, government spending, and net exports

$$\widehat{y}_{i,t} = \frac{\chi_i^{ci}}{(\chi_i^{ci} + \chi_i^g)} \, \widehat{ci}_{i,t} + \frac{\chi_i^g}{(\chi_i^{ci} + \chi_i^g)} \, \widehat{g}_{i,t} + \frac{\chi_i^X}{(\chi_i^{ci} + \chi_i^g)} \, \left(\widehat{x}_{i,t} - \widehat{m}_{i,t}\right), \tag{60}$$

where the weights are again the steady-state shares of the respective variables in GDP. Due to the assumption of balanced trade, the steady-state share of exports equals that of imports.

6 Tariffs and trade wars through the lens of ECB-Global

Inspired by the recent trade disputes between the US and China right before the outbreak of the COVID pandemic, in this section we explore the short-term macroeconomic implications of a trade war. The goal of our analysis is not to provide a precise quantitatively assessment of the implications of the imposition of tariffs by the US and China. Instead, the purpose of the analysis of this scenario is to illustrate the workings and the role of the new features of ECB-Global 2.0. To do so, we discuss below in some detail several sensitivity analyses in which we turn on and off some features of ECB-Global 2.0.

6.1 Scenario specification and assumptions

We consider a scenario in which the US imposes a 10% tariff on its bilateral imports from China in the first period, and China retaliates contemporaneously in kind. The size of the tariff shock is calibrated such that the *effective* tariff rate – computed as the share of total imports affected times the tariff rate applied – is the same for the US and China. Because the share of bilateral imports of the US from China in total US imports is larger than the share of China's imports from the US in China's total imports, China is assumed to respond with a 18.3% tariff rate.

We shock tariffs in the first period only and simulate the model in a deterministic setup.[7] The tariff shock $\eta^{\tau}_{i,j,t}$ imposed by country i on imports from country j is temporary, i.e. we shock the model in the first quarter and allow the autoregressive component of the shock (ρ^{τ}_t)

[7] This is akin to shocking the tariff process in a stochastic setup for the first period only.

to take its course according to

$$\tau_{i,j,t} = \rho^{\tau} \tau_{i,j,t-1} + \eta^{\tau}_{i,j,t}. \tag{61}$$

However, the shock is assumed to be quite persistent with $\rho^{\tau}_{t} = 0.975$, which implies a half-life of around 15 quarters. This specification of the shock process implies that agents do not anticipate the imposition of tariffs but, given their forward-looking behaviour, once the shock has materialised, they anticipate how tariffs will evolve.

Several points should be borne in mind when interpreting the results from the trade war scenario. First, envisaging a shock which is not permanent limits our focus to short-term dynamics and reflects the implicit assumption that agents expect, at the time of the imposition of tariffs, a future reversion of policymakers' preferences back towards a more liberal trade policy stance. This assumption is partly justified by the already observed permanent suspension of some of the tariffs imposed by the US on China in late 2019.[8] Although it is not obvious that the US trade policy stance will change in the near term, an irreversible increase in tariffs would reflect a potentially even less plausible assumption.

Second, note that ECB-Global 2.0 implicitly features an exogenous output trend. To the extent we think that permanent tariffs might have long-run effects – impinging on the reallocation of capital and labour across sectors – the model would fail to capture these unless further shocks are imposed *ad hoc* on trend dynamics. Because we are ignoring an important transmission channel for the medium and long-term effects, the results of our analysis of the trade war scenario with ECB-Global 2.0 should be interpreted as reflecting short-term dynamics.

Third, due to its linear nature the model does not take into account the uncertainty surrounding the imposition of tariffs.

Finally, the results presented in the next subsection are furthermore based on the following assumptions. First, tariffs are not rebated to consumers by fiscal authorities; they are instead assumed to be used to consolidate public finances. Second, tariffs do not affect the price-setting behaviour of foreign firms over and above the observed fall in sales. Thus, while exporting firms endogenously react by lowering prices in response to the observed fall in foreign demand, they cannot entirely squeeze their margins in order to absorb the loss in competitiveness as prices are sticky. This implies that there is an almost perfect initial pass-through of tariffs into import prices. Third, we explicitly model trade diversion as explained in Section 4.1.3 and 5. Namely, each country's import demand also depends on a country-specific export-competitor price index. Fourth, the analysis abstracts from the explicit modelling of GVCs and their potential disruption caused by the imposition of tariffs.[9] Fifth, tariffs are usually assumed to introduce a distortion in

[8] Moreover, it could be additionally justified by a change in the administration, which in the US can potentially occur every four years.

[9] GVCs are only partially accounted for in ECB-Global 2.0 as trade in intermediate goods enters countries' marginal costs.

investment. Given that we bundle consumption and investment in (4), ECB-Global 2.0 cannot capture this channel. Finally, ECB-Global 2.0 considers only trade in a single composite good apart from oil. Therefore, it is not possible to design a scenario which takes into account the imposition of tariffs at a sectoral level.

6.2 Baseline results

The baseline version of ECB-Global 2.0 includes some traditional spillover channels such as trade and those discussed in the model description in Section 5. Table 2 provides a summary of the baseline model specification, listing the main transmission channels by country groups. Specifically, in our baseline model both trade and financial spillover channels are active; a block of oil producers exports oil and all other countries import it. Trade diversion is allowed for. Emerging Asia, oil producers and China differ from the other countries due to some idiosyncratic characteristics. In particular, the Emerging Asia's block incorporates the financial channel of the exchange rate (see Section 4.3 and 5.13).[10] In addition, as specified in Section 5.13, bank-lending tightness in Emerging Asia is also affected by financial conditions in China, in contrast to other countries, for which only advanced economies' financial conditions matter. Furthermore, as discussed in Section 4.5, 5.13 and 5.8 China is modelled differently from the other countries as regards the exchange rate regime, which is not entirely flexible, and the absence of inward financial spillovers. Additionally, in the baseline we allow oil revenues to affect oil producers' domestic demand (see Section 5.4 and 5.9).

Table 2
Baseline model specification

Transmission channels	Specification	Region
Global transmission channels		
Trade linkages	active	World
Financial linkages	active	World ex China
Oil prices	active	World
Trade diversion	active	World
Oil in consumption	active	World
Local transmission channels		
Risk taking channel of FX appreciation	active	EMEs Asia
Larger weight of CN in EMEs Asia fin. cond.	active	EMEs Asia
FX intervention	active/mild	China
Oil revenues in DA	active	oil producers
Pricing regime	DCP	World

Notes: The table lists the main transmission channels and idiosyncratic characteristic and if they are considered in the Baseline version of the model.

Figure 2 shows the results from this exercise for both the US and China. The results suggests

[10] For a detailed description and sensitivity analysis on this channel see Dieppe et al. (2018).

that the bilateral trade war is contractionary for both the US and China. Specifically, output drops by around 0.1% in the US on impact, while it contracts by 0.25% in China. The difference in the output responses across the two countries reflects (i) net trade and (ii) domestic demand dynamics. Specifically, net trade is affected by relative prices, for which tariffs, exchange rate movements and the export-pricing paradigm all play a role. Domestic demand dynamics, on the other hand, are mainly determined by changes in short and long-term rates, which ultimately move in response to changes in output and CPI inflation as central banks react to changing domestic conditions. Of course, the parametrisation of the price rigidities and elasticities of substitution for trade are the deeper determinants of country dynamics. For both countries, the contribution of net trade is negative as imports contract less than exports. For China this is due to both the presence of trade diversion and the export-pricing paradigm. In particular, given that a large share of China's imports is priced in US-$ and given that the renminbi appreciates against the US-$ as the former is not modelled as free floating, a rise in demand for imports dampens the negative impact of falling domestic demand on China's imports. For the US, the negative contribution of net trade, on the one hand, follows the increase in consumption,[11] which is due to the decline in interest rates as the central bank loosens in response to the fall in output. On the other hand, it is also resulting from the US LCP assumption that all US imports are priced in US-$, which causes the depreciation of the US-$ to only marginally translate into higher import prices.

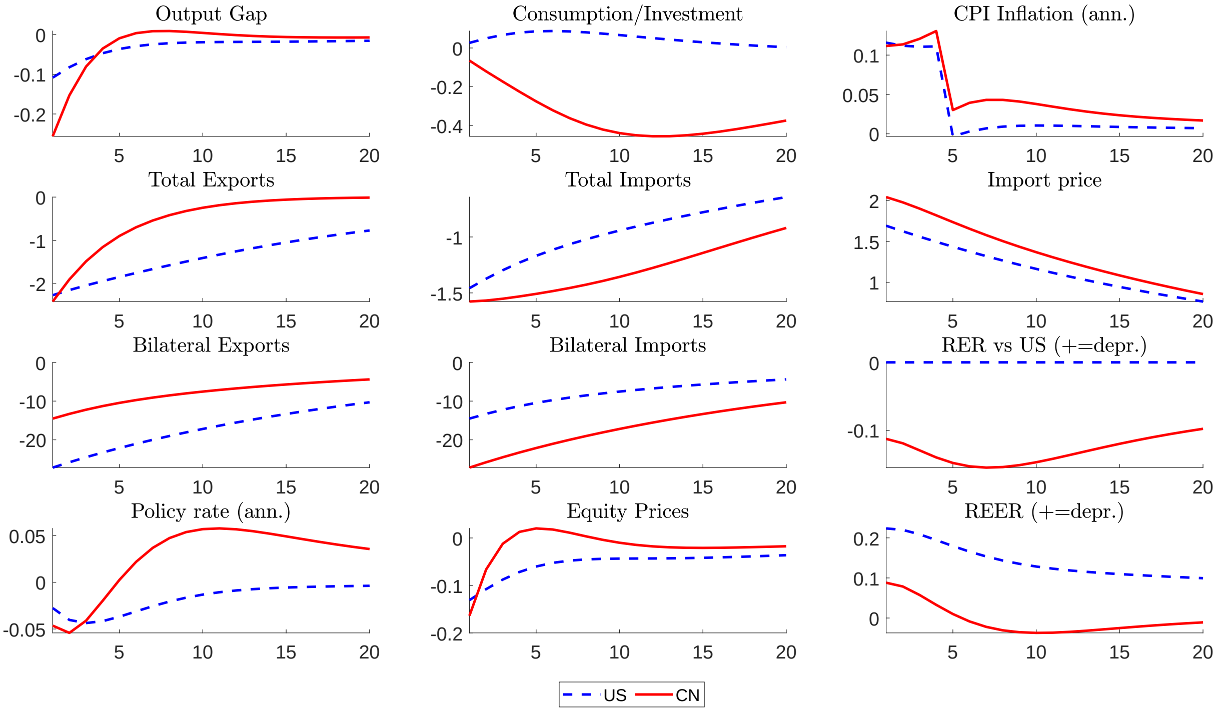
Figure 3 shows the response of selected variables for the trading partners of the US and China. Spillovers are limited in the baseline specification, as the output response of the countries not directly involved in the trade war is slightly positive due to trade diversion. The reason for muted and even positive spillovers relates to counteracting forces. On the one hand, net trade for the trading partners of the US and China is positive, while on the other hand, financial spillovers, arising from the fact that a contraction in US output tightens financial conditions worldwide, impinge negatively on their aggregate demand. Finally, an important role is also played by exchange rate movements and their interaction with the export-pricing paradigm. We elaborate on this in more detail in the next subsection.

6.3 Exploring the role of individual model features

This subsection discusses the role played by specific transmission channels in ECB-Global 2.0 for the outcomes of the trade war scenario analysis.

[11] The difference in the responses of consumption in the US and China is analysed in detail in the next subsection.

Figure 2
Responses of US and China to a bilateral trade war



Notes: All variables are expressed in percentage point changes from steady state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

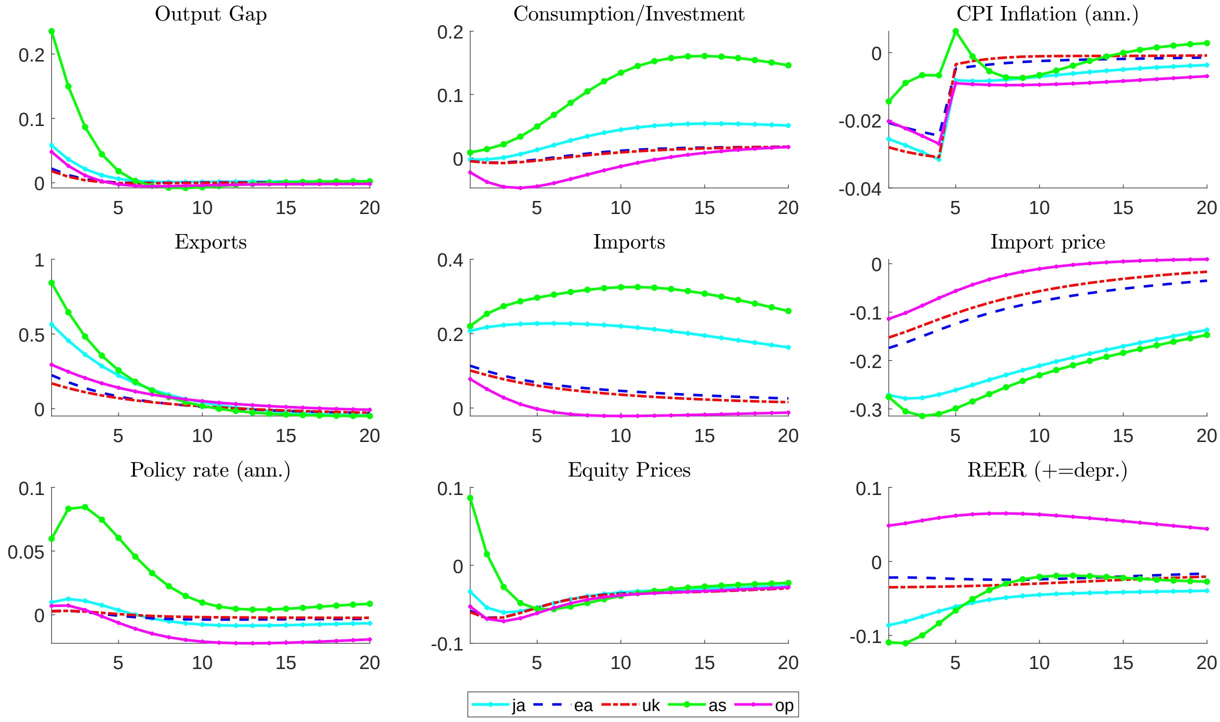
6.3.1 The role of DCP for trade tariff scenarios

DCP influences the dynamics mainly through two channels: (i) a competitiveness channel and (ii) an inflation channel. In sum, we find that under DCP the impact of the trade war on global real economic activity is slightly positive, while under PCP it is slightly negative, even if the difference is rather small. The global output effects are positive under DCP, because in this case the depreciation of the US-$ induced by the trade war causes global – in particular non-US – trade to benefit.

To analyse the role of DCP, it is useful to analyse separately, on the one hand, (i) the response in the US and in China (Figure 4) and, on the other hand, (ii) exchange rate movements and the implied role of trade across trading partners (Figure 5). Looking at China, we see that under DCP exports recover more quickly, amidst a depreciation of the US-$ exchange rate and its impact on exports, as a large share of China's exports is priced in US-$ and therefore becomes cheaper from the perspective of importers. In contrast, in the PCP case what matters for China's trade is its real effective exchange rate rather than changes in other countries' bilateral exchange rates vis-à-vis the US-$. Under PCP, China's exports take longer to recover as China's real effective exchange rate depreciation is rather contained, partly due to the fact

Figure 3

Responses of trading partners to bilateral trade war between China and the US



Notes: All variables are expressed in percentage point changes from steady-state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

that the renminbi is not modelled as a freely-floating currency. This implies that after the initial contraction in output, activity recovers faster under DCP as net trade effects are positive.

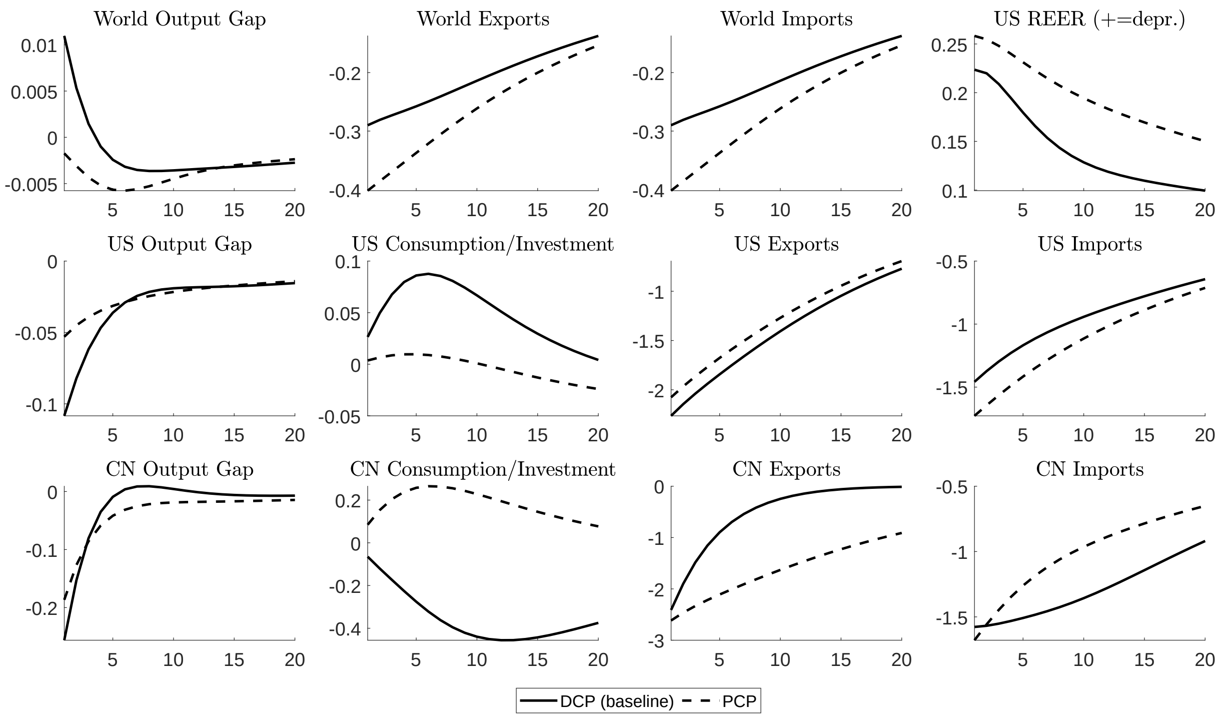
At the same time, the central bank, which initially reacts by lowering rates in response to the drop in output, tightens monetary policy to curb the inflationary pressures that result from the rise in tariffs. Ultimately, the response of short and long-term rates determine the responses of consumption and investment, which have a significant forward-looking component.

For the US, the impact of the US-$ depreciation on exports plays a similar role under both export-pricing paradigms, as they coincide for the country issuing the dominant currency (i.e. DCP *is* PCP in the case of US exports). As for US imports, DCP coincides with LCP (see Section 4.1.1). This explains why imports fall by more under PCP and why the negative net trade effect on output is dampened. This also relates to the different responses of consumption. As the central bank under DCP observes the increased negative impact of trade on domestic activity, it reacts by cutting interest rates more aggressively, and thereby consumption spending increases by more relative to the PCP case.

Notice that DCP has a strong effect on trade dynamics, depending on the share of exports which are priced in US-$. As stated above, countries' currencies appreciate vis-à-vis the US-$.

This means that imports become cheaper for these countries. Figure 5 shows how exports behave for all trading partners of the US and China and their dependence on the share of trade priced in US-$. In particular, Emerging Asia and oil producers, countries which have the largest share of trade invoiced in US-$, benefit from the bilateral trade war the most. In addition, Emerging Asia also positively benefits from the appreciation of their currency due to the financial channel of the exchange rate. These results point to some important conclusions in terms of global trade and output: Global models which do not include DCP might misrepresent trade dynamics and therefore the overall direct impact of bilateral trade wars. On a global scale, the effects are dependent not only on DCP but also on the degree of trade diversion, which is discussed in the following subsection.

Figure 4
DCP (baseline) vs. PCP



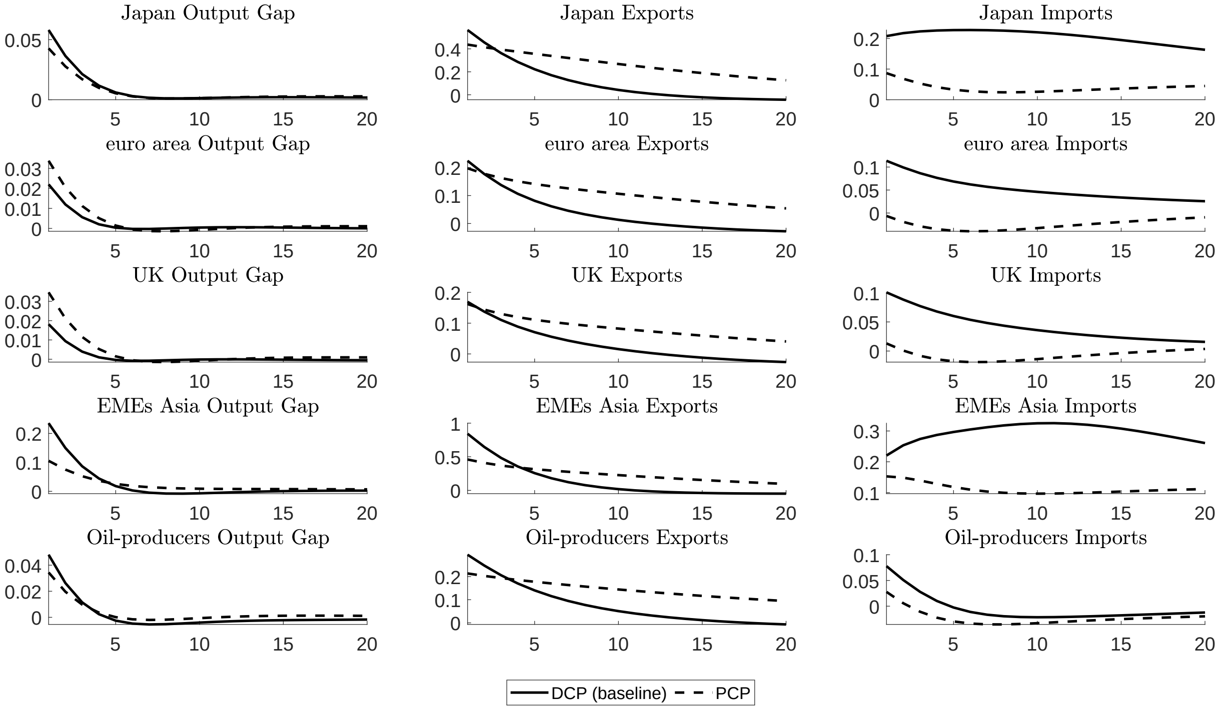
Notes: All variables are expressed in percentage point changes from steady-state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

6.3.2 The effect of trade diversion

As explained in Section 4.1.3 and 5, in ECB-Global 2.0 we introduce an additional element in the import equation to account for trade diversion. Figure 6 shows that switching off trade diversion reduces exports of all trading partners, which now no longer benefit as much from the trade war between the US and China. As a result, output falls on impact in the countries not

Figure 5

DCP (baseline) vs. PCP: Response of trading partners



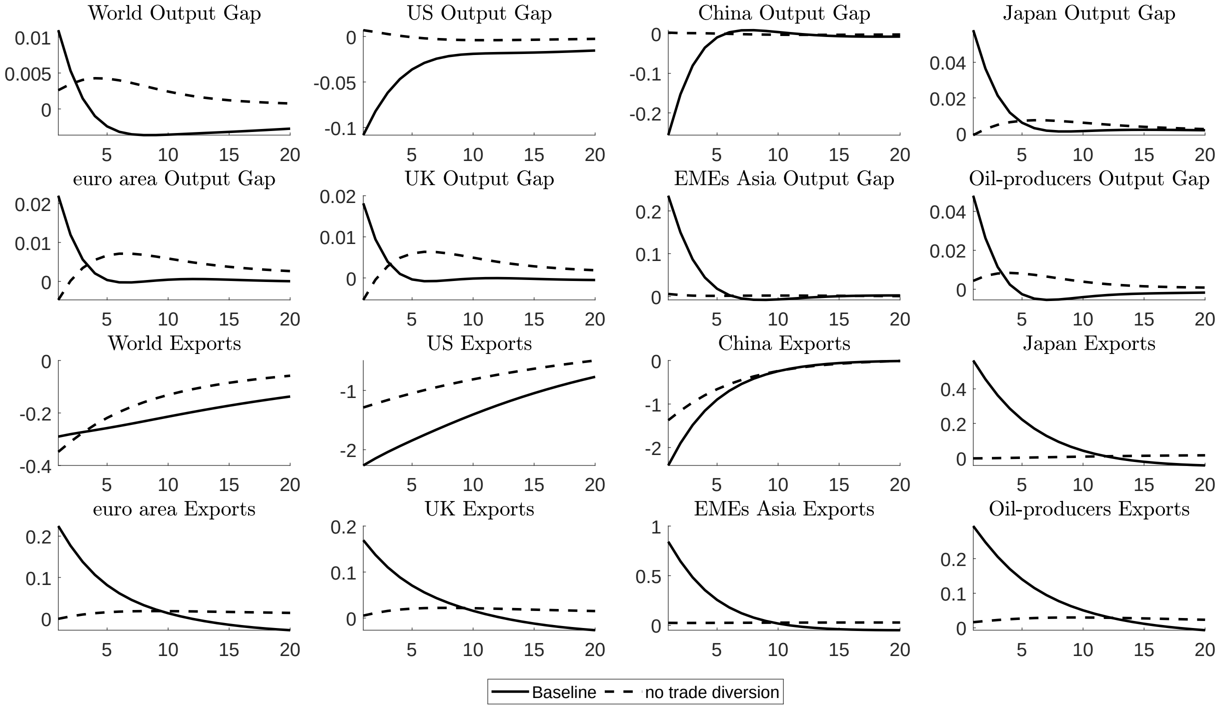
Notes: All variables are expressed in percentage point changes from steady state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

involved in the trade war as the negative financial spillovers are no longer offset by positive net trade spillovers. Switching off trade diversion also impacts the dynamics in the US and China. In particular, under the baseline specification, importers can more easily substitute between imports from different sources. Therefore, an increase in tariffs impinges more strongly on the exports of a country subject to tariffs. Furthermore, without trade diversion imports are more easily substituted by domestic production as importers do not immediately substitute imports across source countries. For these reasons, when trade diversion is switched off the output responses in the US and China are muted relative to the baseline.

6.3.3 China-specific model elements

In this section, we investigate the role of the managed exchange rate of the renminbi and the idiosyncrasies within China's economic structure. In particular, we relax some of the assumptions maintained in the baseline specification which set China apart from the other countries (see Section 4.5 and 5). In particular, Figure 7 reports the responses of output, trade and financial variables in China under four different specifications: (i) the baseline (in which the exchange rate is *mildly* managed), (ii) a specification with tight exchange rate management, (iii) a flexible

Figure 6
Switching off trade diversion

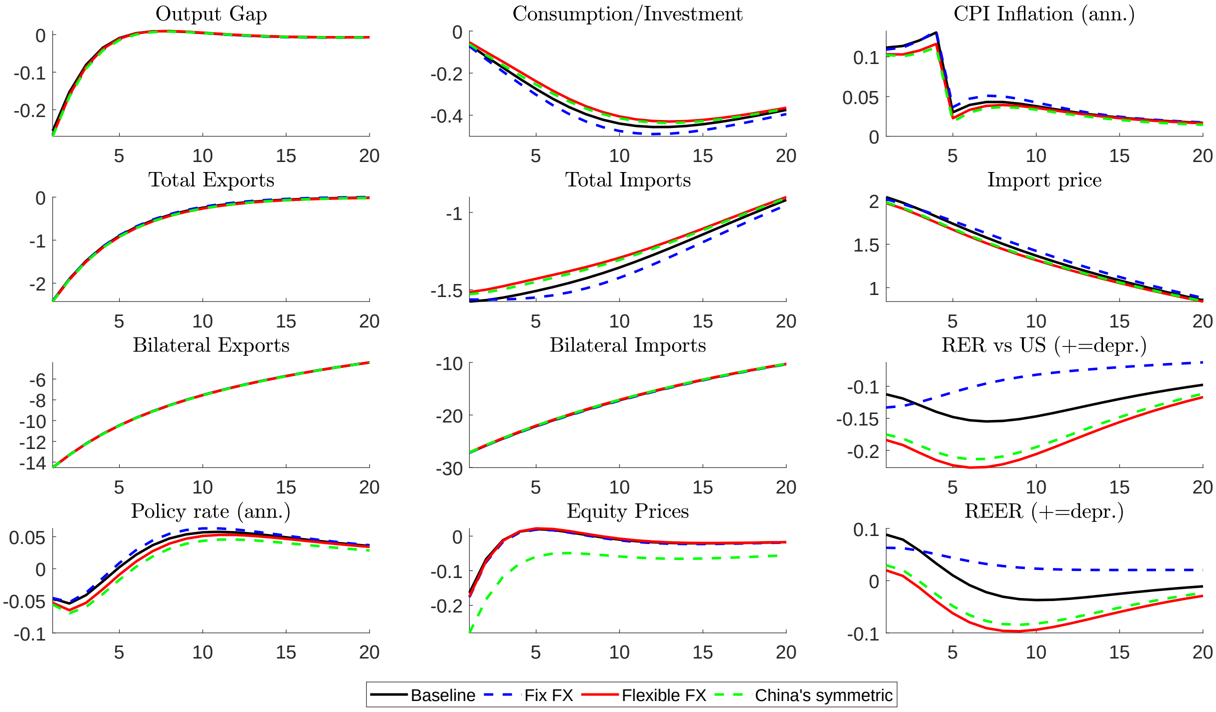


Notes: All variables are expressed in percentage point changes from steady state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

exchange rate regime specification and (iv) a specification in which China's monetary policy reaction and other model equations are symmetric to those of other advanced economies (this mostly means harmonising the policy rules with those of the other countries and allowing for inward financial spillovers).

The main conclusion of this exercise is that China's exchange rate regime only mildly affects the dynamics in response to a trade war. This result is in line with what we report in the previous subsections, and in particular with the fact that under DCP, the competitiveness of China's exports depends only to a very small extent on the exchange rate of the renmimbi vis-à-vis that of the importing country. It is also interesting to notice that – given the relatively mild tightening of financial conditions in response to the tariff shock – harmonising China with the other countries results only in a marginal increase in spillovers. Overall, the results suggest that our findings presented above are not driven by the idiosyncratic structure of China in the baseline specification.

Figure 7
Changing the specification for China



Notes: All variables are expressed in percentage point changes from steady state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

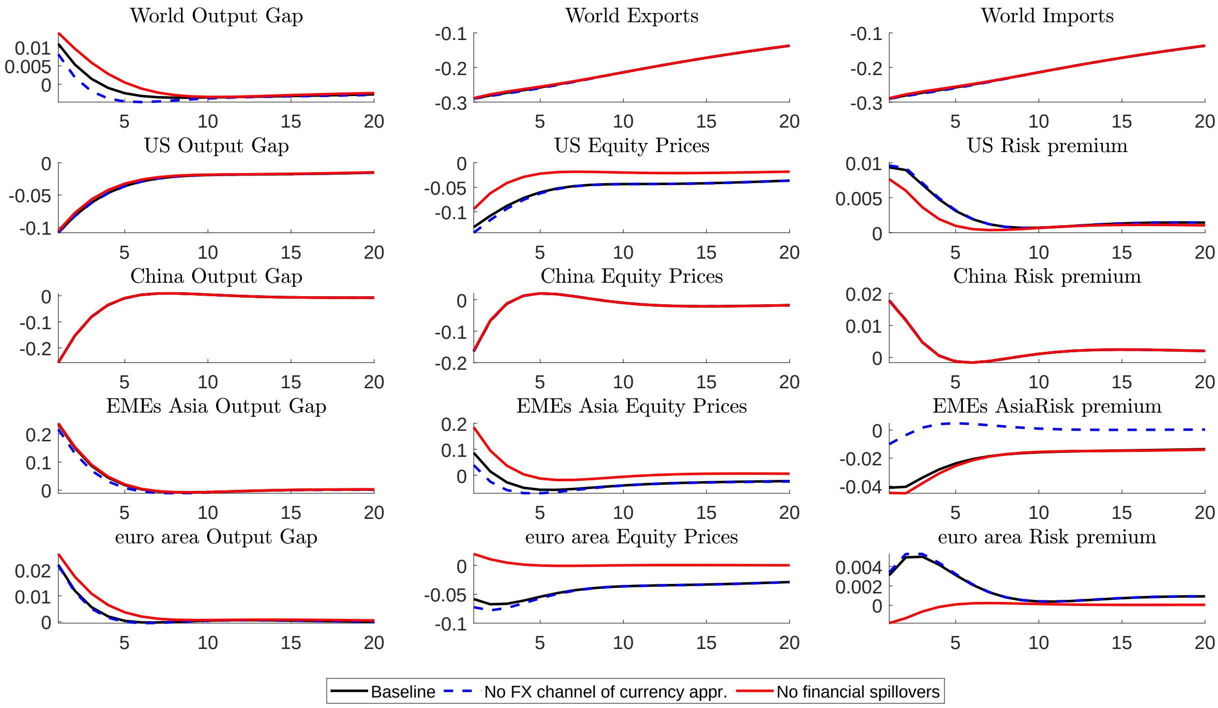
6.3.4 Additional channels

This final subsection seeks to illustrate how some additional model features affect the transmission of tariff shocks in the model. We focus on the role of financial frictions on a global scale and for Emerging Asia. Figure 8 shows the comparison between (i) the baseline, (ii) a specification without financial spillovers, and (iii) a specification in which the financial channel of the exchange rate for Emerging Asia is switched off.[12]

Looking at the responses of output in the euro area as an example for the advanced economies, it can be seen that the absence of financial spillover channels entails a larger positive response of output to the trade war. At the same time, the positive impact on Emerging Asia stemming from the US-$ depreciation is slightly smaller when the financial channel of the exchange rate is switched off. Overall, financial spillover channels do not play a prominent role in the dynamics that unfold in response to a trade war between China and the US, as the largest part of the adjustments are due to trade and price dynamics.

[12]Note that switching off financial spillovers does not mean that financial conditions do not correlate across economies. Rather, it means that the economies are only interconnected via trade linkages, and financial conditions affect trading partners to the extent that they first impinge on domestic variables and then transmit via trade.

Figure 8
The role of financial spillover channels



Notes: All variables are expressed in percentage point changes from steady state levels and are in quarterly terms except for interest rates and inflation rates, which are quarterly annualised figures.

7 Summary and way forward

This paper lays out ECB-Global 2.0, an updated version of the ECB's semi-structural multi-country model for the global economy. Besides a general overhaul of the first version of ECB-Global, the innovations we describe include dominant-currency pricing replacing producer-currency pricing, trade diversion and the inclusion of tariffs. We illustrate the role of these and some other model features in ECB-Global 2.0 for the dynamic adjustments of the global economy to shocks, focusing on a scenario of a trade war between the US and China.

While ECB-Global 2.0 is a significant improvement in terms of reflecting and incorporating empirically relevant transmission mechanisms, further improvements are warranted. For example, first, lumping together private consumption and investment is based on an implausibly strong assumption of them being determined by the same mechanisms; moreover, it also constrains the set of policy scenarios that can be explored. Second, especially in light of the policy responses to the COVID pandemic, ECB-Global would benefit from a more detailed fiscal block. Third, while ECB-Global 2.0 allows for separate dynamics of non-oil and oil trade, the specification of the oil sector is rather stylised. Improving the mechanisms that determine oil prices and production seems to be worthwhile in particular in view of the changing nature of the global oil market. Relatedly, while there are similarities between the dynamics and the properties of oil and non-oil commodities, it may broaden the applicability of ECB-Global in terms of policy scenarios to separate oil and non-oil commodities. Fourth, while it has to be recognised that parameterisation through (Bayesian) estimation is challenging given the size of ECB-Global 2.0, it may be possible to use more information from data to improve the model's quantitative properties. This list of possible improvements is of course not exhaustive.

References

Asian Development Bank. (2017). *2017 Asian Economic Integration Report.* Manila: Asian Development Bank.

Avdjiev, S., Bruno, V., Koch, C., & Shin, H. S. (2019). The Dollar Exchange Rate as a Global Risk Factor: Evidence from Investment. *IMF Economic Review*, *67*(1), 151-173.

Bank for International Settlements. (2020, June). International Banking and Financial Market Developments. *BIS Quarterly Review*.

Barbiero, O., Farhi, E., Gopinath, G., & Itskhoki, O. (2019). The macroeconomics of border taxes. *NBER Macroeconomics Annual*, *33*(1), 395–457.

Benigno, P. (2009). Price Stability with Imperfect Financial Integration. *Journal of Money, Credit and Banking*, *41*(s1), 121-149.

Boz, E., Casas, C., Georgiadis, G., Gopinath, G., Le Mezo, H., Mehl, A., & Nguyen, T. (2020). Patterns in Invoicing Currency in Global Trade. *IMF Working Paper*, *20/126*.

Bruno, V., & Shin, H. S. (2015). Cross-Border Banking and Global Liquidity. *Review of Economic Studies*, *82*(2), 535-564.

Bruno, V., & Shin, H. S. (2019). Dollar and Exports. *BIS Working Paper*, *819*.

Ca' Zorzi, M., Dedola, L., Georgiadis, G., Jarocinski, M., Stracca, L., & Strasser, G. (2020). Monetary Policy and its Transmission in a Globalised World. *ECB Working Paper*, *2407*.

Christiano, L. J., Eichenbaum, M., & Evans, C. L. (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, *113*(1), 1-45.

Coenen, G., Straub, R., & Trabandt, M. (2013). Gauging the Effects of Fiscal Spackages in the Euro Area. *Journal of Economic Dynamics and Control*, *37*(2), 367-386.

Dieppe, A., Georgiadis, G., Ricci, M., Van Robays, I., & Van Roye, B. (2018). ECB-Global: Introducing the ECB's global macroeconomic model for spillover analysis. *Economic Modelling*, *72*, 78–98.

Georgiadis, G., & Mösle, S. (2019). Introducing Dominant Currency Pricing in the ECB's Global Macroeconomic Model. *International Finance*, *23*(2), 234-256.

Georgiadis, G., & Schumann, B. (2019). Dominant-currency Pricing and the Global Output Spillovers from US Dollar Appreciation. *ECB Working Paper*, *2308*.

Gilchrist, S., & Zakrajsek, E. (2012). Credit Spreads and Business Cycle Fluctuations. *American Economic Review*, *102*(4), 1692-1720.

Gopinath, G. (2015). The International Price System. *NBER Working Paper*, *21646*.

Gopinath, G., Boz, E., Casas, C., Diez, F., Gourinchas, P.-O., & Plagborg-Moller, M. (2020). Dominant Currency Paradigm. *American Economic Review*, *110*(3), 677-719.

Hendry, D., & Muellbauer, J. (2017). The Future of Macroeconomics: Macro Theory and Models at the Bank of England. *University of Oxford Economics Series Working Papers*, *832*.

Kearns, J., & Patel, N. (2016). Does the Financial Channel of Exchange Rates Offset the Trade Channel? *BIS Quarterly Review*.

Leeper, E. M., Plante, M., & Traum, N. (2010). Dynamics of Fiscal Financing in the United States. *Journal of Econometrics*, *156*(2), 304 - 321.

McKibbin, W., & Stoeckel, A. (2018). Modelling a Complex World: Improving Macro-models. *Oxford Review of Economic Policy*, *34*(1-2), 329-347.

Medina, J., & Soto, C. (2005). Oil Shocks and Monetary Policy in an Estimated DSGE Model for a Small Open Economy. *Central Bank of Chile Working Paper*, *353*.

Ploedt, M., & Reicher, C. (2014). Estimating Simple Fiscal Policy Reaction Functions for the Euro Area Countries. *Kiel Institute for the World Economy Working Paper*, *1899*.

Ratto, M., Roeger, W., & in 't Veld, J. (2009). QUEST III: An Estimated Open-economy DSGE Model of the Euro Area with Fiscal and Monetary Policy. *Economic Modelling*, *26*(1), 222 - 233.

Schmitt-Grohe, S., & Uribe, M. (2003). Closing Small Open Economy Models. *Journal of International Economics*, *61*(1), 163-185.

World Bank. (2015). *Global Financial Development Report 2015/2016* (No. 22543). The World Bank.

8 Appendix

8.1 List of parameters and Dynare counterparts

Table 3
Model parameters in LaTeX, Dynare, and their meaning

LaTeX	Dynare	Description
		DCP parameters
Ξ_i	dcp_usd_@{co}	Total DCP share in exports of i
$\Xi_i^{\backslash us}$	dcp_usd_nous_@{co}	DCP share in exports of i to non-US countries
Ξ_i^{us}	dcp_usd_us_@{co}	DCP share in US imports from i
		Bilateral trade and financial shares
$\omega_{i,k}^{M,\backslash oil}$	imp_@{co}_@{mo}_NO	Non-oil import share of i from k
$\omega_{i,k}^{M,\backslash j}$	imp_@{co}_@{mo}_no@{no}_T	Import share of i from k without j
$\omega_{i,k}^{X}$	exp_@{co}_@{mo}_T	Export share from i to k
$\omega_{op,k}^{X,\backslash oil}$	exp_op_@{mo}_NO	Non-oil export share from OP to k
$\omega_{i,k}^{imp,int}$	impintinp_@{co}_@{mo}	Imported inputs from k in i's production
ω_i^{oil}	oilweight_@{co}	Share of i's oil imports in global oil imports
$\omega_{i,k}^{b}$	fin_@{co}_@{mo}	Share of k's assets in i's total assets
		Steady state GDP shares of trade and GDP components
χ_i^M	yshare_imp_@{co}	GDP share of imports
$\chi_i^{M,\backslash oil}$	yshare_imp_nonoil_@{co}	GDP share of non-oil imports
$\chi_i^{M,oil}$	yshare_imp_oil_@{co}	GDP share of oil imports
χ_i^X	yshare_exp_@{co}	GDP share of exports
$\chi_{op}^{X,\backslash oil}$	yshare_exp_nonoil_op	GDP share of non-oil exports of OP
$\chi_{op}^{X,oil}$	yshare_exp_oil_op	GDP share of oil exports of OP
χ_i^{ci}	yshare_ci_@{co}	GDP share of consumption and investment
χ_i^{g}	yshare_gspend_@{co}	GDP share of government spending
		Consumer-price index (Section 5.3)
$\alpha_i^{cpi,oil}$	coeff_cpi_oil_@{co}	Share of oil in CPI
$\alpha_i^{cpi,H}$	coeff_cpi_H_@{co}	Home bias in CPI
		Consumption and investment (Section 5.4)
$\alpha_i^{ci,ci}$	coeff_ci_ci_@{co}	Response to expected CI
α_i^{ci,r^3}	coeff_ci_r3_@{co}	Response to real interbank rate
α_i^{ci,r^L}	coeff_ci_rL_@{co}	Response to real long-term rate
$\alpha_i^{ci,q}$	coeff_ci_q_@{co}	Response to equity prices
$\alpha_i^{ci,p^{oil}}$	coeff_ci_poil_@{co}	Response to oil prices

Table 3
Model parameters in LaTeX, Dynare, and their meaning

LaTeX	Dynare	Description
$\alpha_{op}^{ci,oil}$	coeff_ci_oil_op	Response to oil revenues
	Phillips curves and marginal costs (Section 5.5 and 5.6)	
$\alpha_i^{\pi,\beta}$	coeff_pi_discount_@{co}	Households' discount factor
$\alpha_i^{\pi,\pi}$	coeff_pi_pi_@{co}	Forward- & backward lookingness of PC
$\alpha_i^{\pi,mc}$	coeff_pi_mc_@{co}	Response to marginal costs of PC
$\alpha_i^{mc,y}$	coeff_mc_y_@{co}	Response of MC to output
$\alpha_i^{mc,\pi}$	coeff_mc_pi_@{co}	Response to relative input prices
$\alpha_i^{mc,oil}$	coeff_mc_oil_@{co}	Response to oil price
α_i^{π,β^x}	coeff_pix_discount_@{co}	Households' discount factor
$\alpha_i^{\pi^x,\pi^x}$	coeff_pix_pix_@{co}	Forward- & backward lookingness of PC
$\alpha_i^{\pi^x,mc^x}$	coeff_pix_mcx_@{co}	Response to marginal costs of PC
$\alpha_i^{mc^x,x}$	coeff_mcx_x_@{co}	Response of MC to exports
$\alpha_i^{mc^x,\pi^x}$	coeff_mcx_pix_@{co}	Response to relative input prices
$\alpha_i^{mc^x,oil}$	coeff_mcx_oil_@{co}	Response to oil price
	Monetary policy and exchange rates (Section 5.7 and 5.8)	
$\alpha_i^{i^s,i^s}$	coeff_is_is_@{co}	Policy rate smoothing
$\alpha_i^{i^s,\pi}$	coeff_is_pi_@{co}	Policy response to inflation
$\alpha_i^{i^s,y}$	coeff_is_y_@{co}	Policy response to output
$\alpha_i^{uip,nfa}$	coeff_uip_nfa_@{co}	UIP response to net foreign assets
$\alpha_{cn}^{i^{uip},reer}$	coeff_is_uip_reer_cn	CN exchange rate stabilisation parameter
$\alpha^{nfa,nfa}$	coeff_nfa_nfa	Autocorrelation of net foreign assets
	Fiscal policy (Section 5.9)	
$\alpha_i^{t,t}$	coeff_grev_grev_@{co}	Revenue smoothing
$\alpha_i^{t,\mathcal{B}}$	coeff_grev_debt_@{co}	Response to government debt
$\alpha_i^{t,y}$	coeff_grev_y_@{co}	Response to output
$\alpha_i^{g,g}$	coeff_gspend_gspend_@{co}	Spending smoothing
$\alpha_i^{g,\mathcal{B}}$	coeff_gspend_debt_@{co}	Response to government debt
$\alpha_i^{g,y}$	coeff_gspend_y_@{co}	Response to output
$\alpha_{op}^{g,oil}$	coeff_gspend_oil_op	Response to oil revenues
	Trade and oil (Section 5.10 and 5.12)	
θ_i^{da}	coeff_trade_da_@{co}	Import demand elasticity to income
θ_i^{Q}	coeff_trade_Q_@{co}	Import demand elasticity to relative prices
θ^{div}	coeff_trade_div	Degree of trade diversion

Table 3
Model parameters in LaTeX, Dynare, and their meaning

LaTeX	Dynare	Description
θ_i^{oil}	coeff_el_d_@{co}	Oil import demand elasticity to income
$\theta^{oil,s}$	coeff_el_s	Price elasticity of oil supply
	Financial block (Section 5.13)	
$\alpha_i^{\varsigma^b,\varsigma^b}$	coeff_spread_spread_@{co}	Autocorrelation of interbank spread
$\varphi_i^{\varsigma^b}$	coeff_spread_spillover_@{co}	Spillovers in interbank spread
$\alpha_i^{blt,blt}$	coeff_blt_blt_@{co}	Autocorrelation of lending tightness
$\alpha_i^{blt,y}$	coeff_blt_y_@{co}	Response of lending tightness to output
α_i^{blt,r^3}	coeff_blt_r3_@{co}	Response of lending tightness to interest rates
φ_i^{blt}	coeff_blt_spillover_@{co}	Spillovers in lending tightness
$\alpha_{as}^{blt,Q}$	coeff_blt_Q_as	Exchange rate channel on lending tightness
$\alpha_i^{\varpi,blt}$	coeff_rp_blt_@{co}	Response of risk to lending tightness
$\alpha_i^{\varpi,\varsigma^g}$	coeff_rp_govspread_@{co}	Response of risk to government spread
$\alpha_i^{\varsigma^g,\varsigma^g}$	coeff_govspread_govspread_@{co}	Autocorrelation of government spread
$\alpha_i^{\varsigma^g,\mathscr{B}}$	coeff_govspread_debt_@{co}	Response of government spread to debt
$\alpha_i^{q,q}$	coeff_q_q_@{co}	Response to expected equity price
α_i^{q,r^3}	coeff_q_r3_@{co}	Response of equity price to short rates
$\alpha_i^{q,y}$	coeff_q_y_@{co}	Response of equity price to output
φ_i^{q}	coeff_q_spillover_@{co}	Spillovers in equity price

Notes: Only non-zero parameters are reported here.

8.2 List of variables and Dynare counterparts

Table 4
Model variables in LaTeX, Dynare, and their meaning

LaTeX	Dynare	Description
	Consumption and investment and market clearing	
$\widehat{ci}_i$	CI_HAT_@{co}	Consumption and investment
$\widehat{da}_i$	DA_HAT_@{co}	Domestic absorption
$\widehat{y}_i$	Y_HAT_@{co}	Output
	Phillips curves and marginal costs	
$\widehat{\pi}_i$	PI_HAT_@{co}	CPI inflation
$\widehat{mc}_i$	MC_HAT_@{co}	Marginal costs - domestic
$\widehat{\pi}_i^{ppi}$	PIPP_HAT_@{co}	Producer price inflation
$\widehat{p}_i^{ry}$	PRY_HAT_@{co}	Relative price index (CPI/PPI)

Table 4
Model variables in LaTeX, Dynare, and their meaning

LaTeX	Dynare	Description
$\widehat{mc}_i^x$	MCX_HAT_@{co}	Marginal costs - exports
$\widehat{\pi}_i^x$	PIX_HAT_@{co}	Import price index (relative to CPI)
$\widehat{p}_i^{rx,us}$	PRX_US_HAT_@{co}	Export price index (relative to CPI)
	Monetary and fiscal policy	
$\widehat{i}_i^s$	IS_HAT_@{co}	Nominal policy rate
$\widehat{r}_i^s$	RS_HAT_@{co}	Real policy rate
$\widehat{t}_i$	GREV_HAT_@{co}	Government revenues
$\widehat{g}_i$	GSPEND_HAT_@{co}	Government spending
$\widetilde{\mathcal{T}}_i$	GREV_TILDE_@{co}	Government revenues as abs. dev. from SS
$\widetilde{\mathcal{G}}_i$	GSPEND_TILDE_@{co}	Government spending as abs. dev. from SS
$\widetilde{\mathcal{B}}_i$	DEBT_TILDE_@{co}	Government debt as abs. dev. from SS
	Exchange rates	
$\widehat{Q}_i$	LQ_HAT_@{co}	Real exchange rate of i vs US-$
$\widehat{Q}_{i,k}$	LQ_HAT_@{co}_@{mo}	Real exchange rate of i vs k
$\widehat{REER}_i$	REER_HAT_@{co}	Real effective exchange rate
$\widehat{i}_{cn}^{uip}$	IS_UIP_HAT_cn	Chinese UIP interest rate
$\widetilde{nfa}_i$	NFA_TILDE_@{co}	Net foreign assets as abs. dev. from SS
	Trade and trade prices	
$\widehat{m}_i^{\backslash oil}$	M_NO_HAT_@{co}	Non-oil imports
$\widehat{m}_i$	M_TOT_HAT_@{co}	Total imports
$\widehat{x}_i$	X_TOT_HAT_@{co}	Total exports
$\widehat{x}_{op}^{\backslash oil}$	X_NO_HAT_op	Non-oil exports of OP
$\widehat{p}_i^{rx,\backslash oil}$	PRX_NO_HAT_@{co}	Non-oil export prices in domestic currency
$\widehat{p}_i^{rx}$	PRX_HAT_@{co}	Total export prices in domestic currency
$\widehat{p}_i^{rm,\backslash oil}$	PRM_NO_HAT_@{co}	Non-oil import prices including tariffs
$\widehat{p}_i^{rm}$	PRM_HAT_@{co}	Total import prices including tariffs
$\widehat{p}_i^{rm,\backslash j}$	PRM_HAT_no_@{co}_@{mo}	Competitors' export prices
$\widehat{tot}_i$	TOT_HAT_@{co}	Terms-of-trade
	Oil market	
$\widehat{m}_i^{oil}$	M_OIL_HAT_@{co}	Oil imports
$\widehat{oil}_{op}^d$	OILD_HAT_op	Oil demand of OP
$\widehat{oil}^d$	OILD_HAT	Global oil demand
$\widehat{x}_{op}^{oil}$	X_OIL_HAT_op	Oil exports of OP

Table 4
Model variables in LaTeX, Dynare, and their meaning

LaTeX	**Dynare**	**Description**
$\widehat{x}_{op}^{oil,ppi}$	X_OIL_REV_HAT_op	Oil revenues of OP
$\widehat{p}^{oil}$	POIL_HAT	Relative oil price
	Financial markets	
$\widehat{r}_i^3$	R3_HAT_@{co}	Real short-term interbank rate
$\widehat{\varsigma}_i^b$	SPREAD_HAT_@{co}	Interbank interest rate spread
$\widehat{blt}_i$	BLT_HAT_@{co}	Bank lending tightness
$\widehat{\varpi}_i$	RP_HAT_@{co}	Private credit risk premium
$\widehat{r}_i^g$	RG_HAT_@{co}	Real short-term sovereign bond yield
$\widehat{\varsigma}_i^g$	GOVSPREAD_HAT_@{co}	Government spread
$\widehat{q}_i$	EQUITY_HAT_@{co}	Equity prices
$\widehat{r}_i^L$	RL_HAT_@{co}	Long-term interest rate

Notes: Variables denoted by a hat represent percentage point deviations from steady state.

8.3 List of countries included in the regional blocks

This section lists the countries included in the regional blocks.

Oil-exporting countries: Saudi Arabia, Venezuela, Oman, Qatar, United Arab Emirates, Norway, Ecuador, Nigeria, Angola, Russia, Iran, Kuwait, Canada, Gabon, Equatorial Guinea, Bahrain, Kazakhstan.

Emerging Asia: Pakistan, India, Sri Lanka, Nepal, Bhutan, Bangladesh, Myanmar, Laos, Thailand, Cambodia, Vietnam, Malaysia, Singapore, Indonesia, Phillipines, South Korea.

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