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Asymmetric Macroeconomic Effects of QE-Induced Increases in Excess Reserves in a Monetary Union

Maximilian Horst* Ulrike Neyer† Daniel Stempel‡

July 2020

Abstract

The Eurosystem's large-scale asset purchases (quantitative easing, QE) induce a strong and persistent increase in excess reserves in the euro area banking sector. These excess reserves are heterogeneously distributed across euro area countries. This paper develops a two-country New Keynesian model – calibrated to represent a high- and a low-liquidity euro area member – to analyze the macroeconomic effects of (QE-induced) heterogeneous increases in excess reserves and deposits in a monetary union. QE triggers economic activity and increases the union-wide consumer price level after a negative preference shock. However, its efficacy is dampened by a *reverse bank lending channel* that weakens the *interest rate channel* of QE. These dampening effects are higher in the high-liquidity country. We find similar results in response to a monetary policy shock. Furthermore, we show that a shock in the form of a deposit shift between the two countries, interpreted as capital flight, has negative (positive) effects for the economy of the country receiving (losing) the deposits.

JEL classification: E51, E52, E58, F41, F45.

Keywords: unconventional monetary policy, quantitative easing (QE), monetary policy transmission, excess liquidity, credit lending, heterogeneous monetary union, New Keynesian model.

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1 Introduction

In January 2015, the Eurosystem[1] launched its large-scale asset purchase program, often referred to as quantitative easing (QE), to address the risks of too low, temporarily even negative, inflation rates for a too prolonged period. The objective of this program is to directly lower long-term interest rates at times when (short-term) monetary policy interest rates are approaching the effective lower bound, so that it is no longer possible to realize expansionary monetary policy impulses by conventionally decreasing short-term interest rates.[2] When implementing QE in the euro area, the intent is for aggregate demand, and hence the price level, to increase until the target inflation rate of below, but close to, 2% over the medium-term is reached (European Central Bank, 2015). As a consequence of the Eurosystem's QE program, excess reserves in the euro area banking sector have increased to unprecedented levels.[3] However, the way QE is implemented in the euro area implies that these excess reserves are not homogeneously distributed across euro area countries.

Against this background, we develop a two-country New Keynesian model to analyze the macroeconomic effects of (QE-induced) heterogeneous increases in excess reserves and deposits in a monetary union (i.e., whether or not heterogeneously distributed excess reserves and deposits are just a technical feature without "real effects"). In our model, QE is the monetary policy tool. We conceptualize positive net asset purchases by the central bank to have two effects. First, they decrease the relevant interest rate for households' consumption and firms' investment decisions. Second, they imply an increase in the banking sector's excess reserve and deposit holdings, leading to increasing balance sheet costs for banks. We calibrate the model to represent a high- and a low-liquidity euro

[1]The term "Eurosystem" includes the institutions responsible for monetary policy in the euro area, i.e., the European Central Bank (ECB) and all euro area national central banks (NCBs). For simplicity, we use the terms ECB and Eurosystem synonymously in this paper.

[2]Note that in January 2015 the interest rate on the ECB's main refinancing operations (MROs) already amounted to .05%, the interest rate on its deposit facility was already negative at -.2%, and the interest rate on the marginal lending facility was at .3% (data source: ECB).

[3]Excess reserves are here defined as the sum of (i) commercial banks' current account balances at their national central bank in excess of those contributing to minimum reserve requirements, and (ii) deposits held at the ECB's overnight deposit facility. In ECB parlance this quantity is defined as "excess liquidity" since the ECB uses the term "excess reserves" to define the narrower concept of current account balances in excess of reserve requirements. We refer to excess reserves as all central bank overnight deposits beyond required reserves and hence do not distinguish between whether they are held on a current account or at the deposit facility. Since June 2014 excess reserves have been remunerated at a negative rate, currently (June 2020) at -.5%. Neglecting the recently (December 2019) introduced "two-tier system", this interest rate has to be paid independently of whether the liquidity is held in the ECB's overnight deposit facility or on current accounts with the Eurosystem (European Central Bank, 2019).

area country (Germany and Italy). Thus, in steady state, excess reserves and deposits are already asymmetrically distributed between the two countries. Considering the specific implementation of QE in the euro area that reinforces this heterogeneous liquidity distribution, allows us to identify two transmission channels of QE: an *interest rate channel* and a *reverse bank lending channel*.

We analyze the model responses to three shocks: a preference shock, a shock in the form of a deposit shift between the two countries (deposit shift shock), and a monetary policy shock. We find that after a symmetric, negative preference shock (implying a decrease in household consumption) in both countries, the stabilizing effects of expansionary monetary policy are weakened due to the implied increases in excess reserves and deposits. The central bank reacts to the shock-induced decreasing union-wide inflation with positive net asset purchases. This expansionary monetary policy measure leads to a decreasing interest rate and increasing excess reserves and deposits. The decreasing interest rate triggers economic activity and thus increases union-wide consumer price inflation. However, the increasing excess reserves and deposits weaken these effects (increasing balance sheet costs for banks due to increased deposits imply a dampening effect on lending), i.e., the interest rate channel of QE is dampened by a reverse bank lending channel. These weakening effects are more pronounced in the high-liquidity country.

The deposit shift shock implies that deposits and thus (excess) reserves are moved from the low-liquidity country to the high-liquidity country, which can be interpreted as capital flight ("safe-haven-flows" or "flight-to-quality" phenomena), for instance. This increase in deposits and excess reserves leads to higher balance sheet costs for banks in the high-liquidity country. Consequently, in that country, economic activity decreases. Analogously, the low-liquidity country benefits from the deposit shift.

The monetary policy shock in the form of an unexpected increase in the central bank's net asset purchases, implies an initial decrease in the real interest rate and an initial increase in excess reserves and deposits. Again, the stabilizing effects of the monetary policy reaction to this shock are dampened by the costs associated with excess reserves, i.e., the reverse bank lending channel weakens the interest rate channel of QE. These dampening effects are larger in the high-liquidity country.

Our paper primarily builds on three strands of literature. First, we contribute to the literature on DSGE models that include a banking sector to analyze the effects of unconventional monetary policy measures, such as QE. Respective examples are Gerali et al. (2010), Cúrdia and Woodford (2011), Gertler and Karadi (2011, 2013), Chen et al. (2012), Brunnermeier and Koby (2018), Kumhof and Wang (2019), and Wu and Zhang (2019a,b). Note that as in Jakab and Kumhof (2019) and Kumhof and Wang (2019), we assume that banks create deposits endogenously by granting loans (i.e., banks provide "financing through deposit creation"). Second, our work is related to several papers that develop DSGE models to analyze monetary policy effects in a monetary union such as in Benigno (2004), Beetsma and Jensen (2005), Galí and Monacelli (2005, 2008), Ferrero (2009), Bhattarai et al. (2015), and Saraceno and Tamborini (2020). Third, our work is based on literature investigating the relationship between the implementation of QE and the creation of excess reserves. Examples include Alvarez et al. (2017), Baldo et al. (2017) and Keister and McAndrews (2019).

Our paper contributes to these strands by combining empirical evidence on the technical particularities of the implementation of QE by the Eurosystem, including the effects on excess reserves, with a realistically calibrated New Keynesian model of the euro area. To the best of our knowledge, our paper is the first one to endogenously implement the development of excess reserves accompanying QE and to analyze the macroeconomic effects of this mechanical relationship in a monetary union model.

The remainder of this paper is organized as follows. Section 2 presents some notable fundamentals with regard to the implementation of QE in the euro area. In Section 3, we develop the model and derive the corresponding equilibrium. Section 4 describes the model calibration and derives and analyzes the results with regard to three different shocks. Section 5 concludes.

2 A Note on the Implementation of Quantitative Easing in the Euro Area

The ECB's large-scale asset purchase program (APP), commonly referred to as QE, involves four programs under which both private and public sector securities are purchased.[4] As a consequence of the implementation of QE, aggregate excess reserves[5] in the euro area increased from 200 billion euros in March 2015 to a record high of 1.9 trillion euros in December 2018.[6] The excess reserves are asymmetrically distributed across euro area countries. Since the beginning of QE, about 30% of overall excess reserves are, for example, held solely in Germany (see Figure 1). Alvarez et al. (2017) and Baldo et al. (2017) show that approximately 80-90% of total excess reserves predominantly accumulate in Germany, the Netherlands, France, Finland, and Luxembourg, whereas such holdings are much less pronounced in Italy, Portugal or Spain, for example.

Note that both an increase in excess reserves as well as a very similar heterogeneous distribution of this liquidity among euro area countries could already be observed during the financial and sovereign debt crisis (see Figure 1). However, compared to the QE period the reason for the heterogeneous distribution during these periods was different. In particular, capital flight (so-called "safe-haven-flows" and "flight-to-quality" phenomena) from lower-rated to higher-rated euro area countries was the main provoking factor at that time (Baldo et al., 2017).

By implementing QE, each euro area national central bank purchases assets according to its share in the ECB's capital key, inter alia, domestic government bonds. The asset purchases are funded through the creation of reserves by the Eurosystem, implying that total excess reserves in the banking sector mechanically increase. As a consequence of

[4]The APP consists of the Corporate Sector Purchase Programme (CSPP), the Public Sector Purchase Programme (PSPP), the Asset-Backed Securities Purchase Programme (ABSPP) and the Third Covered Bond Purchase Programme (CBPP3). Covering a share of more than 80% of all assets bought under the APP (until May 2020), the PSPP represents by far the largest component of the APP (European Central Bank, 2020a).

[5]For the definition of excess reserves used in this paper see footnote 3.

[6]Note that between March 2015 and December 2018, the average amount of monthly net asset purchases varied between 15 and 80 billion euros. Between January 2019 and October 2019, net asset purchases were for the time being stopped. In November 2019, the ECB restarted its net asset purchases at a monthly pace of 20 billion euros. In March 2020, the ECB announced additional net asset purchases of 120 billion euros in combination with the existing APP purchases until the end of 2020 as a reaction to the coronavirus pandemic (for more detailed information, see European Central Bank (2020a)).

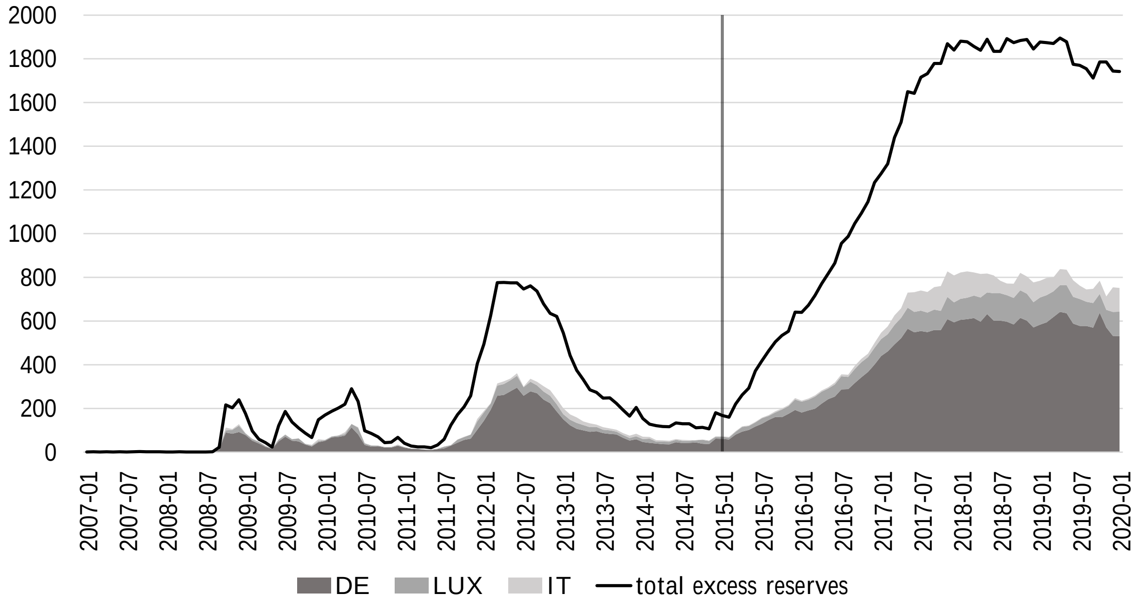

Figure 1: Excess reserve holdings of selected euro area national central banks in billion euros (maintenance period averages, vertical line indicates the launch of the QE program). Data Source: Eurosystem.

the QE-induced increases in reserves, the euro area banking sector has been subjected to a structural liquidity surplus since October 2015, i.e., since then the banking sector has held so much reserves that it can cover its structural liquidity needs occurring from minimum reserve requirements and autonomous factors, such as cash withdrawals, without borrowing from the central bank.[7]

There are different reasons for the observed heterogeneous distribution of bank reserves across euro area countries. By buying assets from the non-banking sector, the Eurosystem creates not only bank reserves but also bank deposits.[8] The individual creation of bank reserves and deposits in each country depends on the seller-type of the asset and its location. For example, if (i) a national central bank purchases assets from a domestic commercial bank, (excess) reserves in the domestic banking sector will increase. If (ii) a national central bank purchases assets from the domestic non-banking-sector (private households and private corporations), (excess) reserves and deposits in the domestic banking sector will increase: the central bank will finance the asset purchase by crediting the respective

[7]For detailed information with respect to the banking sector's liquidity needs and liquidity provision by the Eurosystem during different periods (*normal times, crisis times, times of too low inflation*), see e.g., Horst and Neyer (2019).

[8]For a more profound analysis of the creation and distribution of bank reserves and deposits within the implementation of QE in the euro area, see e.g., Baldo et al. (2017) and Horst and Neyer (2019).

amount in the form of newly created reserves to the commercial bank's current account. The commercial bank will then credit this amount in the form of deposits to its customer's current account. Lastly, if (iii) a national central bank purchases assets from a counterparty residing outside the respective country, reserves and bank deposits will increase in the banking sector of that euro area country in which the respective counterparty (or its bank) has its current account in order to get access to the TARGET2 system.[9] Case (iii) is the main reason for the QE-induced heterogeneous distribution of reserves and deposits between euro area countries. About 80% of overall central bank asset purchases are bought outside the respective country and about 50% of overall central bank asset purchases are conducted with counterparties residing outside the euro area (see also Baldo et al., 2017). As those counterparties have their current accounts predominantly with commercial banks in only a few selected countries, such as Germany, France, the Netherlands, Luxembourg, and Finland (which serve as so-called financial centers or gateways), the QE-induced creation of excess reserves and deposits takes place in these countries. Thus, the majority of the excess reserves and deposits created through the QE purchases accumulates in only a few countries. This consequence of the technical particularity of the implementation of QE plays an essential role in our model setup.

3 Model

We consider a monetary union consisting of two countries indexed by $k \in \{A, B\}$, where $-k$ denotes the respective other country. The core model framework of each country partly resembles the setup of the closed economy modeled by Gertler and Karadi (2011, 2013). In each country, there are five types of agents: households, intermediate goods firms, capital producing firms, retail firms, and banks. In both countries, each type forms a continuum of identical agents of measure unity, allowing us to consider representative agents. We denote the respective representative agent by agent k. In addition, there is a union-wide central bank. Banks in each country are operating in an environment characterized by a structural liquidity surplus. They face such large amounts of excess

[9] TARGET2 (Trans-European Automated Real-time Gross Settlement Express Transfer system) is the real-time gross settlement system owned and operated by the Eurosystem. It settles euro-denominated domestic and cross-border payments in central bank money continuously on an individual transaction-by-transaction basis without netting (European Central Bank, 2020e).

reserves that fulfilling reserve requirements is not a binding constraint. In order to capture the heterogeneous distribution of this liquidity in the euro area as outlined in Section 2, we specify country A as being a high-liquidity and country B as a low-liquidity country. The model contains a nominal rigidity in the form of price stickiness as well as real rigidities in the form of consumer habit formation and capital adjustment costs. In the following, we characterize the basic ingredients of the model.

3.1 Households

The infinitely lived household k consumes, saves, and supplies labor to intermediate goods firms. Household k seeks to maximize its expected discounted lifetime utility. Its objective function is

$$\max \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[Z_\tau ln \left(C_\tau^k - \Psi_k C_{\tau-1}^k \right) - \frac{\chi_k}{1+\varphi_k} (N_\tau^k)^{1+\varphi_k} \right] , \tag{1}$$

where the household draws period-t utility from consumption $C_t^k - \Psi_k C_{t-1}^k$ and period-t disutility from work N_t^k, where N_t^k denotes the number of hours worked. The variable Z_t is a preference shock[10] following an AR(1) process. The parameter Ψ_k is a habit parameter capturing consumption dynamics, χ_k determines the weight of labor disutility, and φ_k captures the inverse Frisch elasticity of labor supply.

Household k's total consumption C_t^k consists of the consumption of final goods produced in its home country $C_{k,t}^k$ and of those produced in the foreign country $C_{-k,t}^k$. Henceforth, we denote domestically produced goods as domestic goods and those produced abroad as foreign goods. The parameter σ_k can be interpreted as the share of foreign goods and $(1-\sigma_k)$ as the share of domestic goods in the household's total consumption. The respective consumption index is given by

$$C_t^k \equiv \frac{\left(C_{k,t}^k\right)^{1-\sigma_k} \left(C_{-k,t}^k\right)^{\sigma_k}}{(1-\sigma_k)^{1-\sigma_k} (\sigma_k)^{\sigma_k}} , \tag{2}$$

[10]Other works specifying preference shocks in this fashion include Ireland (2004), Dennis (2005), and Bekaert et al. (2010).

where $C^k_{k,t}$ and $C^k_{-k,t}$ are composite goods defined by the indices

$$C^k_{k,t} \equiv \left(\int_0^1 C^k_{k,t}(j)^{\frac{\epsilon_k - 1}{\epsilon_k}} dj \right)^{\frac{\epsilon_k}{\epsilon_k - 1}} \tag{3}$$

and

$$C^k_{-k,t} \equiv \left(\int_0^1 C^k_{-k,t}(j)^{\frac{\epsilon_k - 1}{\epsilon_k}} dj \right)^{\frac{\epsilon_k}{\epsilon_k - 1}} , \tag{4}$$

with $C^k_{k,t}(j)$ denoting the quantity of the domestic good j and $C^k_{-k,t}(j)$ denoting the quantity of the foreign good j consumed by household k in period t. ϵ_k represents the elasticity of substitution between differentiated goods (of the same origin). The household's budget constraint is given by

$$\begin{aligned} \int_0^1 P_{k,t}(j) C^k_{k,t}(j) dj + \int_0^1 P_{-k,t}(j) C^k_{-k,t}(j) dj + B^k_t \\ = (1 + i_{t-1}) B^k_{t-1} + W_{k,t} N^k_t + \Upsilon^k_t \ . \end{aligned} \tag{5}$$

The left-hand side (LHS) of equation (5) describes the household's nominal expenses. They include its consumption spending in countries k and $-k$ as well as its savings in nominally risk-free bonds. The price $P_{k,t}(j)$ is the price for product j produced in country k, and $P_{-k,t}(j)$ is the price for product j produced in country $-k$. B^k_t represents the quantity of one-period, nominally risk-free bonds purchased in period t and maturing in $t+1$. Bonds purchased in period $t-1$ pay a nominal rate of interest i_{t-1} in period t. The right-hand side (RHS) of equation (5) thus shows household k's nominal income. It includes its gross return on bonds, its wage earnings (with $W_{k,t}$ being the nominal wage), and exogenous (net) income Υ^k_t. The latter includes dividends from ownership of firms and banks and net income from exogenous savings.[11] The budget constraint reveals that household k is connected with country $-k$ via the consumption of goods produced in country $-k$ and the

[11]Net income from exogenous savings is a technical feature of our framework. Analogously to the net income from bond savings given by $(1 + i_{t-1})B^k_{t-1} - B^k_t$, the net income from exogenous savings in period t is the difference between the nominal gross return on one-period, nominally risk-free deposits (also remunerated at i_{t-1}) exogenously received in periods $t-1$ and t. Deposits are created by banks when granting loans to firms and therefore, have no influence on the household's optimal decision making. This allows us to treat deposits from the household' point of view as an exogenous variable and to capture the respective net income within Υ^k_t. The important role that these deposits play in our model becomes clear in sections 3.2, 3.3, and 3.5.

shared bond market. Labor markets and equity incomes are separated between the two countries.

Household k faces five optimization problems: (i) the optimal composition of its domestic composite consumption good, (ii) the optimal composition of its foreign composite consumption good, (iii) the optimal allocation of its overall consumption between domestic and foreign goods, (iv) its optimal labor supply, and (v) the optimal intertemporal allocation of consumption.

Starting with the optimal composition of the domestic consumption good, household k seeks to maximize the consumption index given by equation (3) for any given level of expenditures $\int_0^1 P_{k,t}(j)C_{k,t}^k(j)dj$. Solving this optimization problem, the household's optimal consumption of the domestic good j becomes

$$C_{k,t}^k(j) = \left(\frac{P_{k,t}(j)}{P_{k,t}}\right)^{-\epsilon_k} C_{k,t}^k\ , \tag{6}$$

where $P_{k,t} \equiv \left(\int_0^1 P_{k,t}(j)^{1-\epsilon_k}dj\right)^{\frac{1}{1-\epsilon_k}}$ is a price index of the goods produced in country k. Analogously, we obtain for its optimal consumption of the foreign good j

$$C_{-k,t}^k(j) = \left(\frac{P_{-k,t}(j)}{P_{-k,t}}\right)^{-\epsilon_k} C_{-k,t}^k\ , \tag{7}$$

where $P_{-k,t} \equiv \left(\int_0^1 P_{-k,t}(j)^{1-\epsilon_{-k}}dj\right)^{\frac{1}{1-\epsilon_{-k}}}$ is a price index for foreign goods.

In the same vein, we derive household k's optimal allocation of its overall consumption between domestic and foreign goods. The household seeks to maximize the consumption index given by equation (2) for any given level of expenditures $P_{k,t}C_{k,t}^k+P_{-k,t}C_{-k,t}^k$. Solving this optimization problem, the optimal consumption of domestic and foreign goods become

$$C_{k,t}^k = (1-\sigma_k)\left(\frac{P_{k,t}}{P_{k,t}^C}\right)^{-1} C_t^k \tag{8}$$

and

$$C_{-k,t}^k = \sigma_k\left(\frac{P_{-k,t}}{P_{k,t}^C}\right)^{-1} C_t^k\ , \tag{9}$$

where $P^C_{k,t} \equiv {P_{k,t}}^{1-\sigma_k} {P_{-k,t}}^{\sigma_k}$ is the consumer price index in country k. Thus,

$$P_{k,t}C^k_{k,t} + P_{-k,t}C^k_{-k,t} = (1-\sigma_k)P^C_{k,t}C^k_t + \sigma_k P^C_{k,t}C^k_t = P^C_{k,t}C^k_t$$

and the budget constraint (5) becomes

$$P^C_{k,t}C^k_t + B^k_t = (1+i_{t-1})B^k_{t-1} + W_{k,t}N^k_t + \Upsilon^k_t \,. \tag{10}$$

For obtaining the household's optimal labor supply and its optimal intertemporal consumption, we maximize equation (1) with respect to N^k_t and C^k_t subject to equation (10). Denoting the marginal utility of consumption by

$$U^k_{c,t} \equiv \left(\frac{Z_t}{C^k_t - \Psi_k C^k_{t-1}} - \frac{\mathbb{E}_t\left[Z_{t+1}\right]\Psi_k \beta}{\mathbb{E}_t\left[C^k_{t+1}\right] - \Psi_k C^k_t} \right) ,$$

solving the optimization problem yields the following standard first-order conditions (FOCs):

$$\chi_k (N^k_t)^{\varphi_k} = w_{k,t} U^k_{c,t} \,, \tag{11}$$

$$\beta(1+i_t)\,\mathbb{E}_t\left[\frac{P^C_{k,t}}{P^C_{k,t+1}}\right]\Lambda^k_{t,t+1} = 1 \,, \tag{12}$$

with

$$\Lambda^k_{t,t+1} \equiv \mathbb{E}_t\left[\frac{U^k_{c,t+1}}{U^k_{c,t}}\right] \,. \tag{13}$$

Equation (11) shows that optimal labor supply requires the marginal disutility of work (LHS) to be equal to the marginal utility of work (RHS). The latter results from the additional possible consumption which is determined by the real wage $w_{k,t} \equiv W_{k,t}/P^C_{k,t}$. Equation (12) represents the Euler equation governing optimal intertemporal consumption.

Finally, we rewrite some identities in terms of relative prices. Defining the terms of trade of country k with country $-k$ as $V^k_{-k,t} \equiv \frac{P_{-k,t}}{P_{k,t}}$, we get that

$$P^C_{k,t} = P^{1-\sigma_k}_{k,t} \left(V^k_{-k,t} P^k_{k,t}\right)^{\sigma_k} = P_{k,t} (V^k_{-k,t})^{\sigma_k} \tag{14}$$

and

$$\Pi^C_{k,t} = \Pi_{k,t} \left(\frac{V^k_{-k,t}}{V^k_{-k,t-1}}\right)^{\sigma_k} , \tag{15}$$

where $\Pi^C_{k,t}$ denotes consumer price inflation and $\Pi_{k,t}$ the inflation of domestic prices in country k. Due to our assumption of complete bond markets, we can obtain the following risk-sharing condition using equations (12) and (13):

$$U^k_{c,t} = \vartheta_k (V^k_{-k,t})^{(\sigma_k - 1)} (V^{-k}_{k,t})^{(-\sigma_{-k})} U^{-k}_{c,t} , \tag{16}$$

where $\vartheta_k \equiv U^k_{c,ss}/U^{-k}_{c,ss}$ with $U_{c,ss}$ being the zero inflation steady state value of marginal utility of consumption. This condition implies that, adjusted for relative prices, marginal utilities of consumption of the households k and $-k$ co-move proportionally over time.

3.2 Intermediate Goods Firms

Competitive intermediate goods firms produce goods that are solely sold to domestic retail firms. At time t, the output of a representative intermediate goods firm $Y^k_{m,t}$ is produced with capital $K^k_{t-1,t}$ and labor N^k_t. The respective production function is given by

$$Y^k_{m,t} = \left(K^k_{t-1,t}\right)^{\alpha_k} \left(N^k_t\right)^{1-\alpha_k} . \tag{17}$$

Intermediate goods firm k buys the capital that is productive in t from the capital producing firm in $t-1$, i.e., $K^k_{t-1,t}$ is the capital stock chosen and bought at real price $Q_{k,t-1}$ in period $t-1$ but productive in t. At the end of period t, as in Gertler and Karadi (2011), the intermediate goods firm sells the depreciated capital back to the capital producer at price $(Q_{k,t} - \delta_k)$, i.e., in $t-1$ they conclude a kind of repurchase agreement.

At the end of period t, additionally, the intermediate goods firm borrows $L^k_{t,t+1} = Q_{k,t}K^k_{t,t+1}$ from bank k to buy the capital stock that is productive in $t+1$. The bank credits the respective amount as deposits, $L^k_{t,t+1} = D^{L,k}_{t,t+1}$, directly on the capital producing firm's account, i.e., as in Kumhof and Wang (2019), loans create deposits. Note that loans and deposits that are created in period t will be paid off and extinguished in $t+1$. The corresponding objective function of intermediate goods firm k is given by

$$\max \Gamma^k_{m,t} = mc_{k,m,t}Y^k_{m,t} - w_{k,t}N^k_t - \left(1 + i^L_{k,t-1}\right) Q_{k,t-1}K^k_{t-1,t} + (Q_{k,t} - \delta_k)K^k_{t-1,t} \,. \tag{18}$$

Equation (18) reveals that in period t, the firm has to take into account four factors determining its profits: (i) revenues from selling their goods at real marginal costs due to perfect competition, (ii) real costs of labor, (iii) interest and principal payments on the loan agreed on in period $t-1$, and (iv) the payoff from reselling depreciated capital to the capital producer. Solving (18) with respect to $K^k_{t,t+1}$ and N^k_t gives the following FOCs:

$$\left(1 + i^L_{k,t}\right) Q_{k,t} = \alpha_k mc_{k,m,t+1}\frac{Y^k_{m,t+1}}{K^k_{t,t+1}} + Q_{k,t+1} - \delta_k \,, \tag{19}$$

$$mc_{k,m,t} = \frac{w_{k,t}}{(1-\alpha_k)\frac{Y^k_{m,t}}{N^k_t}} \,. \tag{20}$$

The LHS of equation (19) denotes the marginal cost of capital, i.e., its credit and acquisition costs. The RHS describes the marginal benefit of capital in the form of marginal revenues and the payoff from the repurchase agreement. Equation (20) shows that the real marginal costs of the intermediate goods firm in period t solely depend on the real costs of labor (i.e., the real wage), since any additional unit of output in t has to be produced using only labor input due to the lagged decision on capital input.

3.3 Capital Producing Firms

At the end of period t, the representative competitive capital producing firm k buys depreciated capital from intermediate goods firms and repairs it. It then sells both, the refurbished capital and the newly produced capital, to the intermediate goods firm (Gertler and Karadi, 2011).[12]

Gross capital produced in period t, $I_t^{gr,k}$, thus consists of newly created capital (net investment) I_t^k, and the refurbishment of the bought capital $\delta_k K_{t-1,t}^k$:

$$I_t^{gr,k} = I_t^k + \delta_k K_{t-1,t}^k \,. \tag{21}$$

The law of motion for capital is thus given by

$$K_{t,t+1}^k = K_{t-1,t}^k + I_t^k \,. \tag{22}$$

As in Gertler and Karadi (2011), we assume that production costs per unit capital are 1 and consider capital adjustment costs (CAC) for newly produced capital. Then, the real period profit of a capital producing firm is given by

$$\Gamma_{c,t}^k = Q_{k,t} K_{t,t+1}^k - (Q_{k,t} - \delta_k) K_{t-1,t}^k - \delta_k K_{t-1,t}^k - I_t^k - f\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}}\right)\left(I_t^k + I_{ss}\right) \,, \tag{23}$$

with

$$f\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}}\right) = \frac{n_k}{2}\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)^2 \,, \tag{24}$$

where n_k captures the degree of capital adjustment costs and I_{ss} is steady state gross investment.[13] Equation (23) shows that the real period profit consists of: (i) the return from selling capital, (ii) the costs of buying the depreciated old capital, (iii) the costs of repairing the old capital, (iv) the costs of producing the new capital, and (v) CAC (only

[12] The intermediate goods firm uses the loan-created deposits $D_{t,t+1}^{L,k}$ to pay for this capital. The capital producing firm sells these deposits at price 1 to the household in order to being able to buy its capital investment, since, for simplicity, we assume that deposits serve only as exogenous savings for household k (see footnote 11). For the sake of simplicity, we neglect the general means of payment function of deposits and focus on the bank deposit creation of bank loans (see Section 3.5).

[13] I_{ss} is included because in the zero inflation steady state net investment has to be zero since the capital stock is constant over time, implying a division by zero when I_{ss} is excluded.

for new capital). Considering equations (22), (23), and (24), the objective function of the capital producing firm becomes

$$\max \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \Lambda_{t,\tau}^k \left((Q_{k,\tau} - 1) I_\tau^k - \frac{n_k}{2} \left(\frac{I_\tau^k + I_{ss}}{I_{\tau-1}^k + I_{ss}} - 1 \right)^2 \left(I_\tau^k + I_{ss} \right) \right) . \tag{25}$$

The capital producer chooses net investment I_t^k to solve (25). The respective FOC is

$$\begin{aligned} Q_{k,t} = 1 + \frac{n_k}{2} \left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1 \right)^2 + \frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} n_k \left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1 \right) \\ - \mathbb{E}_t \, \beta \Lambda_{t,t+1}^k \left(\frac{I_{t+1}^k + I_{ss}}{I_t^k + I_{ss}} \right)^2 n_k \left(\frac{I_{t+1}^k + I_{ss}}{I_t^k + I_{ss}} - 1 \right) . \end{aligned} \tag{26}$$

The LHS shows real marginal revenues of net investment, the RHS the corresponding real marginal costs which consist of production costs as well as current and expected CAC.

3.4 Retail Firms

The representative retail firm k produces differentiated final output by aggregating intermediate goods. One unit of intermediate output is needed to produce one unit of final output. Consequently, the marginal costs of final goods firms correspond to the price of the intermediate good. Furthermore, retail firm k faces demand from households in both countries, k and $-k$. Price setting is assumed to be staggered, following Calvo (1983). Firm j chooses its price $P_{k,t}(j)$ to maximize discounted expected real profits given by

$$\max \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} {\theta_k}^{\tau-t} \beta^{\tau-t} \Lambda_{t,\tau}^k \left(\frac{P_{k,t}(j)}{P_{k,\tau}^C} Y_{k,\tau|t}(j) - TC(Y_{k,\tau|t}(j)) \right) \right] , \tag{27}$$

subject to

$$Y_{k,\tau|t}(j) = \left(\frac{P_{k,t}(j)}{P_{k,\tau}} \right)^{-\epsilon_k} Y_{k,\tau} , \tag{28}$$

where θ_k is the probability of a single producer being unable to adjust the price in a certain period. Furthermore, $\beta^{\tau-t}\Lambda_{t,\tau}^k$ denotes the stochastic discount factor and $TC(\cdot)$ is the real total cost function. Demand for the retail good j, given by equation (28), depends on the relative price of the good, the heterogeneity of the goods (captured by the elasticity of substitution ϵ_k), and total aggregate demand. The FOC of the maximization problem given by (27) is

$$0 = \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} {\theta_k}^{\tau-t} \beta^{\tau-t} \Lambda_{t,\tau}^k Y_{k,\tau|t}(j) \left(\frac{P_{k,t}^*(j)}{P_{k,\tau}^C} - \frac{\epsilon_k}{\epsilon_k - 1} mc(Y_{k,\tau|t}(j)) \right) \right] , \tag{29}$$

where the real marginal costs of the retail firm equal the price they are paying for each unit of intermediate goods given by equation (20), i.e., the real marginal cost function is given by

$$mc(Y_{k,\tau|t}(j)) = mc_{k,m,\tau}$$

since the retail firm re-packages goods from the perfectly competitive intermediate goods firm. $P_{k,t}^*(j)$ is the optimal price of firm j. Since all firms that are able to reset their price choose the same one, we can drop the index j. The optimal price is thus:

$$\frac{P_{k,t}^*}{P_{k,t}} = \frac{\epsilon_k}{\epsilon_k - 1} \frac{x_{k,1,t}}{x_{k,2,t}} , \tag{30}$$

where

$$x_{k,1,t} \equiv U_{c,t}^k Y_{k,t} mc_{k,m,t} + \beta\theta_k \, \mathbb{E}_t \left[\Pi_{k,t,t+1}^{\epsilon_k} x_{k,1,t+1} \right] ,$$

$$x_{k,2,t} \equiv U_{c,t}^k Y_{k,t} \left(V_{-k,t}^k \right)^{-\sigma_k} + \beta\theta_k \, \mathbb{E}_t \left[\Pi_{k,t,t+1}^{\epsilon_k - 1} x_{k,2,t+1} \right] .$$

Obviously, if all retail firms were able to reset their price in every period ($\theta_k = 0$), they would set their optimal price as a markup over nominal marginal costs.

The overall domestic price level in country k at time t is given by

$$P_{k,t}^{1-\epsilon_k} = (1 - \theta_k)(P_{k,t}^*)^{1-\epsilon_k} + \theta_k (P_{k,t-1})^{1-\epsilon_k} ,$$

i.e., a weighted average of the optimal price of the firms that can optimize in period t and the price level of period $t-1$.

3.5 Banks

Competitive bank k's assets in period t consist of one-period real loans $L^k_{t-1,t}$ and real reserves R^k_t, its liabilities of real deposits D^k_t, so that the bank's balance sheet constraint is given by

$$L^k_{t-1,t} + R^k_t = D^k_t \,. \tag{31}$$

The total amount of reserves R^k_t is splitted into required reserves $R^{RR,k}_t$ and excess reserves $R^{ER,k}_t$, i.e.,

$$R^k_t = R^{RR,k}_t + R^{ER,k}_t \,. \tag{32}$$

Required reserves are computed as a certain proportion r of the bank's deposits D^k_t. The required reserve ratio r is determined by the central bank. The total amount of bank k's deposits is given by

$$D^k_t = D^{L,k}_{t-1,t} + D^{ex}_{k,t} \,, \tag{33}$$

where $D^{L,k}_{t-1,t}$ represents the amount of deposits created through credit lending and $D^{ex}_{k,t} > 0 \; \forall \, t$ denotes the amount of deposits created exogenously (from the bank's point of view) through the central bank's asset purchases (QE) and a potential shock. Note that therefore, we refer to the deposits $D^{ex}_{k,t}$ simply as exogenous deposits. In the following, we will comment on $D^{L,k}_{t-1,t}$ and $D^{ex}_{k,t}$ in more detail.

With respect to $D^{L,k}_{t-1,t}$, we assume that bank k funds only one type of activity, namely the capital goods purchases of the intermediate goods firm k. As in Kumhof and Wang (2019), the intermediate goods firm relies on bank loans to finance its capital purchases. In period $t-1$, bank k grants the respective loan to the indermediate goods firm. One unit of granted loans creates one unit of deposits *("financing through deposit creation")*, i.e., $L^k_{t-1,t} = D^{L,k}_{t-1,t}$. We assume that loan-created deposits $D^{L,k}_{t-1,t}$ are directly credited on the capital producing firm k's deposit account. The capital producing firm sells these deposits immediately at price 1 to household k, i.e., the household k holds these deposits as net exogenous savings, captured by Υ_t^k (see Section 3.1 for details). In period t, the intermediate goods firm repays its debt $(1 + i^L_{k,t-1})$ and the respective deposits, that are remunerated at i_{t-1}, mature. Consequently, the loan $L^k_{t-1,t}$ and the deposits created through bank lending $D^{L,k}_{t-1,t}$ are extinguished.

With respect to $D^{ex}_{k,t}$, we assume that it evolves exogenously from the point of view of the bank:

$$D^{ex}_{k,t} = \tilde{D}_{k,t}\left[\Omega_k - \iota_k(1+i_t)\right] . \tag{34}$$

Note that Ω_k is simply a country-specific calibrated parameter to match the share of exogenous deposits on the length of the bank's balance sheet.[14] Equation (34) reveals that there are two factors influencing $D^{ex}_{k,t}$: a shock (deposit shift shock in the following) and QE. The former is captured by $\tilde{D}_{k,t}$, the latter by $\iota_k(1+i_t)$.

The deposit shift shock $\tilde{D}_{k,t}$ captures a shift of exogenous deposits from country k to $-k$ which can be interpreted as capital flight ("safe-haven-flows" or "flight-to-quality" phenomena), for instance. In particular, $\tilde{D}_{k,t}$ depicts an AR(1) shock process – which is independent from the monetary policy of the central bank – given by

$$ln\left(\tilde{D}_{A,t}\right) = \rho_{\tilde{d},A} ln\left(\tilde{D}_{A,t-1}\right) + \epsilon_{\tilde{d},t} ,$$

$$ln\left(\tilde{D}_{B,t}\right) = \rho_{\tilde{d},B} ln\left(\tilde{D}_{B,t-1}\right) - \frac{D^{ex}_{A,ss}}{D^{ex}_{B,ss}}\epsilon_{\tilde{d},t} ,$$

where $\rho_{\tilde{d},k}$ depicts the shock persistence and $\epsilon_{\tilde{d},k}$ denotes a standard normally-distributed shock. This specification ensures a one-to-one shift of exogenous deposits from country B (low-liquidity country) to country A (high-liquidity country). Consider the case that the exogenous deposits in the economy in steady state are equally divided between both countries. In this case $\frac{D^{ex}_{A,ss}}{D^{ex}_{B,ss}} = 1$ and a 1% decrease of exogenous deposits in B leads to a 1% increase in A. However, if exogenous deposits are heterogeneously distributed between the countries, a $\frac{D^{ex}_{A,ss}}{D^{ex}_{B,ss}}$% decrease in $D^{ex}_{B,t}$ implies a 1% increase in $D^{ex}_{A,t}$.

The impact of QE on $D^{ex}_{k,t}$ is captured by the term $\iota_k(1+i_t)$. Considering a main institutional feature described in Section 2, the central bank's asset purchases are con-

[14] For more detailed information with regard to the calibrated parameter Ω_k, see Section 4.1.

ducted with counterparties residing outside the monetary union that have their deposit account with a bank inside the monetary union. This implies that the asset puchases lead to a one-to-one increase in deposits and reserves of the bank in that country, where the respective counterparties have their deposit accounts with, i.e.,

$$\mathrm{d}R_t^k = \mathrm{d}D_{k,t}^{ex} \,. \tag{35}$$

To capture this QE-induced increase in bank deposits $D_{k,t}^{ex}$ in our model, we consider that the central bank's large-scale asset purchases induce decreasing yields of the respective assets: the asset purchases imply a rising demand for assets, leading to increasing asset prices and decreasing yields. The latter is represented by a decrease in the nominal interest rate in the model. Therefore, we model a negative relationship between i_t and $D_{k,t}^{ex}$ (see equation (34)). However, note that this relationship is a technical depiction to simplify matters. The increase in $D_{k,t}^{ex}$ and the decrease in i_t are both consequences of the implementation of QE, but they occur independently of each other. The strength of the negative relationship between i_t and $D_{k,t}^{ex}$ is determined by the country-specific calibrated parameter ι_k.

Moreover, we assume that in each period, each bank faces such a high liquidity surplus that fulfilling minimum reserve requirements is not a binding constraint when granting loans. Thus, the one-to-one increase in deposits and reserves implies that bank k's excess reserves are given by

$$R_t^{ER,k} = D_{k,t}^{ex} - r\left(D_{k,t}^{ex} + D_{t-1,t}^{L,k}\right) \,, \tag{36}$$

i.e., in period t they correspond to the net amount of cumulated reserves created through central bank's asset purchases, and/or a deposit shift shock, $D_{k,t}^{ex}$, and required minimum reserve holdings.

Bank loans are remunerated at the rate $i_{k,t-1}^{L}$, required reserves at the central bank's main refinancing rate i^{RR}, and excess reserves at the rate on the central bank's deposit facility i^{ER}, with $i^{RR} > i^{ER}$. Bank deposits are remunerated at the same rate as bonds, i.e., at the nominal interest rate i_{t-1}, since both bonds and deposits are assumed to be risk-free assets. A key feature of our model is that the bank faces increasing marginal balance sheet costs, i.e., costs increasing disproportionately in the size of its balance sheet, given in real terms by $\frac{1}{2}\upsilon_k \left(D_t^k\right)^2$. This captures the idea of existing agency and/or regulatory costs.[15] Furthermore, managing loans is costly. The respective real costs are expressed by $\frac{1}{2}\omega_k \left(D_{t-1,t}^{L,k}\right)^2$.[16] For simplicity, as in Kumhof and Wang (2019), we assume that management and balance sheet costs represent lump-sum transfers to the household instead of resource costs. Note that, although interpreted as interest rate payments from the bank to agents residing outside the union, the interest costs of exogenous bank deposits also represent lump-sum transfers. Since we do not consider any agents outside the union, interest costs on exogenous deposits do not differ from balance sheet or management costs within our framework. Thus, for simplicity, we treat them equally in this aspect. However, our results are not affected by these assumptions.

In period t, bank k seeks to maximize its real period profit $\Gamma_{b,t,t+1}^k$ for period $t+1$, which will be transferred to domestic households as the owners of the bank. Therefore, dividend payments from the bank to households include profits and the three cost factors mentioned above. The bank's objective function is thus given by

$$\begin{aligned} \max \mathbb{E}_t[\Gamma_{b,t+1}^k] = i_{k,t}^L L_{t,t+1}^k + i^{RR} r\, \mathbb{E}_t[D_{t+1}^k] + i^{ER}\, \mathbb{E}_t[R_{t+1}^{ER,k}] \\ -i_t\, \mathbb{E}_t[D_{t+1}^k] - \frac{1}{2}\upsilon_k \left(\mathbb{E}_t[D_{t+1}^k]\right)^2 - \frac{1}{2}\omega_k \left(L_{t,t+1}^k\right)^2 . \end{aligned} \tag{37}$$

Taking all rates as given, the bank decides on its optimal loan supply to maximize this profit. Solving this optimization problem with respect to $L_{t,t+1}^k$ yields the first order condition

$$i_{k,t}^L + r(i^{RR} - i^{ER}) = i_t + \upsilon_k \left(\mathbb{E}_t[D_{k,t+1}^{ex}] + L_{t,t+1}^k\right) + \omega_k L_{t,t+1}^k . \tag{38}$$

The LHS of (38) represents the bank's real marginal revenues and the RHS its real marginal costs of granting loans. Note that granting more loans does not only imply more direct interest revenues (first term) but also more indirect interest revenues (second term). The

[15] Other examples of models with balance sheet costs include Martin et al. (2013, 2016), Ennis (2018), Kumhof and Wang (2019), and Williamson (2019).

[16] With respect to the convex bank management cost function, see also Freixas and Rochet (2008, ch. 2), Ennis (2018), Bucher et al. (2020) and Kumhof and Wang (2019).

latter is the consequence of a beneficial reserve shifting: Granting loans implies the creation of deposits. These deposits are subject to reserve requirements so that part of a bank's (costly) excess reserve holdings are shifted to the higher remunerated required reserve holdings.

3.6 Central Bank

Monetary policy is conducted at the union level. We assume that the common central bank has encountered the effective lower bound on conventional instruments, so that QE has become its main monetary policy tool. By buying assets, the central bank influences the nominal interest rate i_t, i.e., the interest rate which is relevant for the firms' investment and the households' consumption decisions. However, the central bank's asset purchases have an impact not only on i_t but, parallely, also on bank deposits (see Section 2 for institutional details). This impact of QE is captured by equation (34) in our model.

Note that we assume that, in each country, the banking sector faces a structural liquidity surplus. In steady state, all banks have a high stock of excess reserves and thus of exogenous deposits (see equation (35)) as a result, for example, of past central bank asset purchases. This allows us to motivate the central bank's influence on i_t via its *net* asset purchases. If the central bank buys more assets than mature, i.e., if its net asset purchases are positive, it will conduct expansionary monetary policy. As a consequence, the interest rate i_t will decrease and exogenous bank deposits will increase. If the central bank's net asset purchases are negative, monetary policy will be contractionary with an increasing i_t and decreasing exogenous bank deposits.[17] Note that positive or negative net asset purchases by the central bank imply independently of each other a *simultaneous* change in i_t and exogenous bank deposits (see Section 3.5). If the central bank realizes positive or negative net asset purchases, exogenous bank deposits will change by the same amount.

[17] Note that, therefore, negative net asset purchases may also be interpreted as *quantitative tightening.*

The central bank reacts (i.e., realizes positive or negative net asset purchases) to variations in the consumer price inflation rates of both countries A, B with a (log-linearized) Taylor rule given by

$$i_t = ln\left(\frac{1}{\beta}\right) + \phi_\pi[\gamma_{A,t}\pi^C_{A,t} + \gamma_{B,t}\pi^C_{B,t}] + \tilde{q}_t \ , \tag{39}$$

where $\pi^C_{k,t} \equiv ln(\Pi^C_{k,t})$. The country-specific levels of consumer price inflation rates are weighted by $\gamma_{k,t}$, which expresses the overall consumption level in period t of the respective country in relation to the aggregate union consumption level:

$$\gamma_{A,t} = \frac{C^A_t}{C^A_t + C^B_t} \ ,$$

$$\gamma_{B,t} = \frac{C^B_t}{C^A_t + C^B_t} \ .$$

Note that this reflects how consumer price inflation, which is relevant for the ECB's inflation target, is measured in the euro area.[18] The variable $\tilde{q}_t$ represents an AR(1) monetary policy shock, i.e., an unexpected change in the central bank's net asset purchases and thus an unexpected change in the risk-free interest rate i_t. Besides influencing i_t via its net asset purchases, the central bank sets the nominal interest rates on the commercial banks' required and excess reserves holdings r^{RR} and r^{ER}, respectively, and determines the ratio for banks' required reserve holdings r.

3.7 Equilibrium

In order to close the model, we continue by stating the market clearing conditions. Bond market clearing implies

$$B^k_t = -B^{-k}_t \ , \tag{40}$$

[18] See European Central Bank (2020d) for detailed information.

i.e., bonds are in zero net supply. Final goods are consumed by households in the union and used to adjust capital:

$$Y_t^k = C_{k,t}^k + C_{k,t}^{-k} + I_t^{gr,k} + \frac{n_k}{2}\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)^2 \left(I_t^k + I_{ss}\right) . \tag{41}$$

Furthermore, all goods sold by retail firms have to be produced by intermediate goods firms, i.e.,

$$Y_{m,t}^k = Y_t^k . \tag{42}$$

Note that the standard condition for labor market clearing with sticky prices given by

$$\left(\frac{Y_t^k}{K_{t-1,t}^{k\ \ \alpha_k}}\right)^{\frac{1}{1-\alpha_k}} \Delta_t^k = N_t^k , \tag{43}$$

where $\Delta_t^k \equiv \int_0^1 \left(\frac{P_{k,t}(j)}{P_{k,t}}\right)^{-\frac{\epsilon_k}{1-\alpha_k}} dj$, holds. Moreover, the market for loans clears

$$L_{t,t+1}^k = Q_{k,t} K_{t,t+1}^k . \tag{44}$$

Lastly, note that we can define the real interest rate in terms of the (log-linearized) risk-free, union-wide nominal interest rate and consumer price inflation of country k as

$$i_{k,t}^{real} = i_t - \mathbb{E}_t\left[\pi_{k,t+1}^C\right] , \tag{45}$$

i.e., the Fisher equation. Note that $i_{k,t}^{real}$ is the relevant interest rate for the optimal intertemporal consumption decision of household k given by (12).

4 Model Analysis

In this section, we discuss the macroeconomic consequences of a preference shock at the household level, a deposit shift shock at the bank level, and a monetary policy shock to the Taylor rule of the common central bank. Before analyzing the model responses to these shocks, we state the calibration strategy.

4.1 Calibration

As discussed in Section 2, QE asset purchases are to a large extent conducted with counterparties residing outside the euro area, implying a heterogeneous increase in excess reserves and deposits across euro area countries. Accordingly, we calibrate the model to represent Germany (as the high-liquidity country) and Italy (as the low-liquidity country) in steady state. The euro area bank balance sheet statistics refer to these deposits of non-euro area residents held on accounts with euro area commercial banks officially as "liabilities of euro area monetary financial institutions (excluding the Eurosystem) towards non-euro area residents." In our model, these deposits are captured by the variable D_k^{ex}. In relation to the length of banks' balance sheets in the respective banking sector, D_k^{ex} adds up to 9% in Germany (data source: Deutsche Bundesbank, 2020) and 2% in Italy (data source: Banca d'Italia, 2020). We calibrate the parameter Ω_k accordingly.

In order to realistically capture the (mechanical) relationship between exogenous deposits and the risk-free interest rate (ι_k in our model), we draw from the work of Urbschat and Watzka (2019), who use an event study approach to estimate the effect of QE-related press releases on bond yields. On average, German bond yields fell by 5.91 basis points (bp), while Italian bond yields dropped by 69.67 bp after APP press releases between 2014 and 2016. Naturally, these decreases can only serve as an approximation of yield changes since they only capture the impact of press releases while leaving out the actual purchases. However, this approach ensures that we capture the isolated effect of QE on bond yields. Alternatives, for example using actual drops in bond yields, are more likely to be prone to influences independent of the asset purchases of the ECB.

Regarding the structural parameters of the household and the firm sector, we draw from the work by Albonico et al. (2019), who build a multi-country model including Germany and Italy. They estimate certain structural parameters based on the respective economies, some of which are also used in our model specification.

With respect to bank costs, we calibrate management and balance sheet costs in a way that, given ECB policy and interest rates, the loan interest rate matches data for average (yearly) interest rates of newly granted loans to non-financial corporations in Germany and Italy provided by the European Central Bank (2020c,b). Obviously, there exist more potential cost factors to a firm's credit than the loan interest rate, e.g., additional fees. Therefore, the calibrated management and balance sheet costs serve as a lower bound, implying that all effects resulting from either cost factor also constitute a lower bound.

Lastly, the interest rates as well as the required reserve ratio set by the central bank are chosen to represent the respective values of the ECB. Note that the yearly rates of the ECB have to be converted into quarterly rates due to the timing of the model. Table 1 depicts the corresponding calibration.

	Description	Value A Germany	Value B Italy	Target/Source
		Households		
β	Time Preference	0.9983	0.9983	Albonico et al. (2019)
Ψ_k	Habit Parameter	0.73	0.81	Albonico et al. (2019)
χ_k	Labor Disutility Parameter	2.62	5.98	Internally Calibrated
φ_k	Inverse Frisch Elasticity of Labor Supply	2.98	2.07	Albonico et al. (2019)
σ_k	Share of Foreign Goods in Consumption	0.2612	0.205	Albonico et al. (2019)
ϵ_k	Price Elasticity of Demand	9	9	Galí (2015)
$\rho_{z,k}$	Preference Shock Persistence	0.9	0.9	
		Firms		
δ_K	Capital Depreciation Rate	0.0143	0.0136	Albonico et al. (2019)
n_k	Capital Adjustment Cost Parameter	31	19	Albonico et al. (2019)
α_k	Partial Factor Elasticity of Capital	0.35	0.35	Albonico et al. (2019)
θ_k	Price Stickiness Parameter	0.75	0.75	Galí (2015)
		Banks and Central Bank		
Ω_k	Exogenously Created Deposits on Bank Balance Sheet	106.51	2.41	Share Germany: 9%, Share Italy: 2%, Internally Calibrated
ι_k	Interdependence Parameter of QE and Risk-Free Interest Rate	100.41	1.42	Drop German Bond Yields: 5.91 bp, Drop Italian Bond Yields: 69.67 bp, Internally Calibrated
$\rho_{\tilde{d},k}$	Excess Reserve Shift Shock Persistence	0.9	0.9	
r	Required Reserve Ratio	0.01	0.01	ECB Rate
i^{RR}	Required Reserve Interest Rate	0	0	ECB Policy Rate
i^{ER}	Excess Reserve Interest Rate	$-\frac{0.005}{4}$	$-\frac{0.005}{4}$	ECB Policy Rate
υ_k	Balance Sheet Costs	0.00001085	0.00001855	Interest Rate Germany: $\frac{0.0122}{4}$, Interest Rate Italy: $\frac{0.0140}{4}$, Internally Calibrated
ω_k	Management Costs	0.00001085	0.00001855	Interest Rate Germany: $\frac{0.0122}{4}$, Interest Rate Italy: $\frac{0.0140}{4}$, Internally Calibrated
ϕ_π	Inflation Response Taylor Rule	1.5	1.5	Galí (2015)
$\rho_{\tilde{q}}$	Monetary Policy Shock Persistence	0.9	0.9	

Table 1: Calibration.

We now turn to a comparison of the steady state, generated by this particular calibration, with data. Table 2 shows several data points and the corresponding steady state values of our model. The steady state replicates the relative capital stock of Germany to Italy (1.24 in the data, 1.24 in the model). Furthermore, in steady state, the model fits the data for average (yearly) interest rates of newly granted loans to non-financial corporations in Germany (1.22% to 1.22%) and Italy (1.40% to 1.40%). This implies that the choice of the level of balance sheet and management costs is reasonable. Note that, considering that our model does not capture government spending, the share of investment and consumption in GDP is slightly higher in the model than in the data, as expected.

Description	Value Data	Data Source	Value Model
Relative GDP/Capita: Germany (A) to Italy (B)	1.27	OECD (2019)	1.26
Relative Average (Yearly) Salary: Germany (A) to Italy (B)	1.32	OECD (2018)	1.26
Consumption Share Germany (A) in Overall Consumption (Germany (A) + Italy (B)), Taylor Rule Parameter	0.63	The World Bank (2018)	0.65
Relative Capital Stock: Germany (A) to Italy (B)	1.24	University of Groningen and University of California (2017a,b)	1.24
Investment Share in GDP: Germany (A)	0.225	CEIC (2020a)	0.256
Investment Share in GDP: Italy (B)	0.194	CEIC (2019a)	0.247
Consumption Share in GDP: Germany (A)	0.506	CEIC (2020b)	0.744
Consumption Share in GDP: Italy (B)	0.569	CEIC (2019b)	0.753
Average (Yearly) Interest Rate of New Loans to Corporations: Germany (A) 2017 − 2020	1.22%	European Central Bank (2020c)	1.22%
Average (Yearly) Interest Rate of New Loans to Corporations: Italy (B) 2017 − 2020	1.40%	European Central Bank (2020b)	1.40%
Share of Liabilities of Euro Area Monetary Financial Institutions (Excluding the Eurosystem) Towards Non-Euro Area Residents on Banks' Balance Sheets: Germany (A)	9%	Deutsche Bundesbank (2020)	9%
Share of Liabilities of Euro Area Monetary Financial Institutions (Excluding the Eurosystem) Towards Non-Euro Area Residents on Banks' Balance Sheets: Italy (B)	2%	Banca d'Italia (2020)	2%

Table 2: Steady State in Comparison to Data.

Moreover, while the model slightly understates labor income inequality between Germany and Italy (1.32 to 1.26), it closely replicates relative GDP per capita of Germany to Italy (1.27 to 1.26). In addition, the parameter relevant for weighting consumer price inflation in country A and B in the Taylor rule, $\gamma_{k,t}$, is very close to the data-equivalent in steady state (0.63 to 0.65). Lastly, as already mentioned, we calibrate the model to exactly replicate the share of liabilities of euro area monetary financial institutions (excluding the Eurosystem) towards non-euro area residents on banks' balance sheets in Germany (9%) and Italy (2%).

4.2 Dynamic Analysis

We continue by examining the model responses to a preference shock, a deposit shift shock, and a monetary policy shock. All results are deviations from the zero inflation steady state.

4.2.1 Preference Shock

Figure 2 depicts the impulse responses of the monetary union to a symmetric negative 1% preference shock in countries A and B. Hence, the responses are qualitatively similar in both countries. The preference shock implies a decrease in the households' appreciation of consumption, i.e., there is a decrease in their marginal utility. Thus, consumption decreases, proportionally in domestic and foreign terms. Note that the low-liquidity country B reaches its lowest consumption slightly later due to its higher habit parameter. Furthermore, the households' marginal benefit from labor, and thus their labor supply, decreases and real wages go up initially. The demand for goods decreases, implying falling output and prices. The latter implies an expansionary monetary policy reaction. The central bank increases its net asset purchases (QE), leading to a decrease in the nominal interest rate and an increase in exogenous bank deposits (equation (34)). Note that, motivated by the mechanical peculiarities of QE in the euro area presented in Section 2, exogenous bank deposits increase more in the high-liquidity country A than in the low-liquidity country B.

As a consequence of this expansionary monetary policy action, there are two effects on bank costs. On the one hand, banks face lower interest costs (interest rate channel of QE), on the other hand, they have to cope with higher balance sheet costs due to the increase in deposits (reverse bank lending channel of QE). As we calibrate balance sheet costs to be rather low (see Section 4.1), ensuring that our results with respect to the negative impact of balance sheet costs on the efficacy of QE constitute a lower bound, the decrease in costs due to the lower interest rate outweighs the increase implied by higher balance sheet costs.

Consequently, bank loan supply increases, implying a decrease in the bank loan rate and higher bank lending (interest rate channel but weakened by the reverse bank lending channel). Investments and thus (one period lagged) capital increase. The increasing capital stock implies higher labor productivity. Real wages rise, leading to increasing labor and consumption. Inflation starts to increase but rather slowly, due to the price rigidities, implying that monetary policy remains expansionary, leading to further increases in the capital stock. Therefore, there are two positive effects on consumption over time: first, the shock reduction, and second, the rise in real wages due to the increase in the capital stock and thus higher labor productivity. The price rigidities imply a still expansionary monetary policy and, therefore, a further buildup of the capital stock, even when the shock itself is already completely reduced. This leads to a temporary "overshooting" (levels temporarily exceed their steady state) of real wages, consumption, and output.[19]

[19]This overshooting is slightly reinforced by the one-period lag between the firm's investment decision and the use of the capital in the production process.

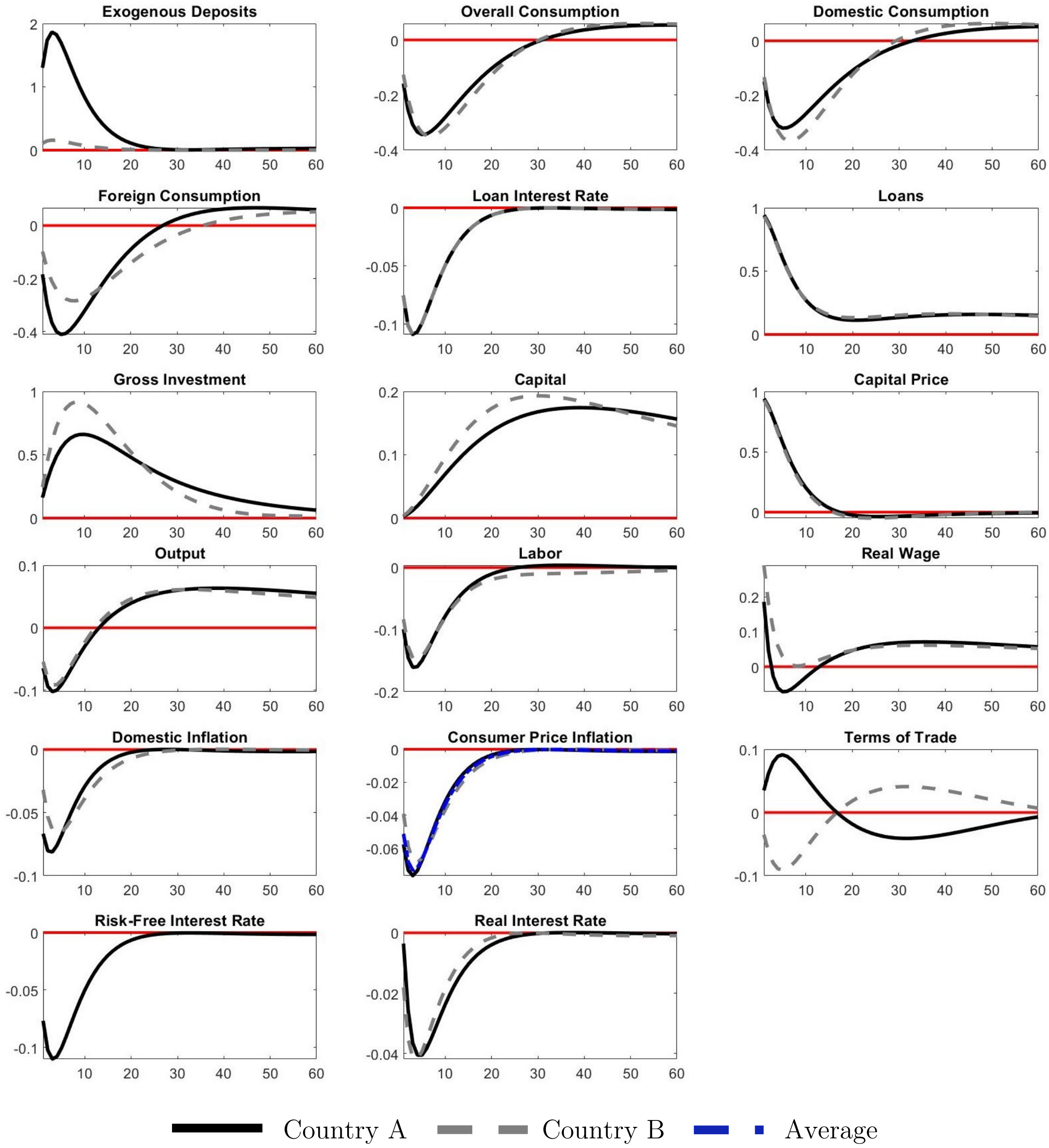

Figure 2: Impulse Responses to a Symmetric, Negative 1% Preference Shock.

The rigidities in the form of the CAC imply, on the one hand, that the buildup of the capital stock is impeded. Consequently, coming from negative consumption deviations, the steady state of consumption is reached later and the overshooting is dampened. However, on the other hand, the CAC also imply that the overshooting lasts longer as the reduction of the capital stock is also impeded. Note that higher CAC in the high-liquidity country A imply a lower increase in investment and capital in A than in B as well as a longer lasting overshooting.

Consequently, QE in our model works as expected of an expansionary monetary policy impulse: it triggers investment and therefore increases the capital stock, supporting output, consumption, and ultimately the consumer price level to reach steady state levels. However, the effect would be stronger if it were not for the QE-induced increase in balance sheet costs resulting from higher exogenous bank deposits. Balance sheet costs imply a reverse bank lending channel. The traditional bank lending channel describes a positive relationship between bank deposits and credit lending. For instance, a contractionary monetary policy impulse leads to decreasing deposits and hence to a decline in lending (Bernanke and Gertler, 1995; Kashyap and Stein, 1995). Accordingly, expansionary monetary policy, for instance QE, should increase bank deposits and credit lending. However, in our model, increasing deposits imply larger (balance sheet) costs for banks. Therefore, there is a reverse bank lending channel weakening the interest rate channel of QE. The specific implementation of QE implies a higher increase in excess reserves and exogenous deposits, and thereby also in bank balance sheet costs, in country A than in country B. Thus, the dampening effects are stronger in the high-liquidity country A, i.e., in our model, monetary policy is less effective in that country.

4.2.2 Deposit Shift Shock

Figure 3 depicts the impulse responses of the monetary union to a deposit shift shock. We simulate an approximately 12% withdrawal of exogenous deposits from low-liquidity country B. These deposits are then moved to the high-liquidity country A, increasing deposits by 2%. Note that this shock can be interpreted as capital flight ("safe-haven-flows" or "flight-to-quality" phenomena). As described in Section 2, such a shift in deposits could be primarily observed during the financial and sovereign debt crisis. In current times, an additional deposit shift would strengthen the already existing asymmetric distribution of deposits.

The consequences of such a deposit shift shock in country A are as follows. Bank A's deposits, and thus its balance sheet costs, increase which leads to a decrease in its loan supply. The bank loan rate increases and bank lending in country A decreases. Consequently, investment and thus the capital stock decrease, implying a lower output.

The influence of the CAC are analogous to the described effects in Section (4.2.1). Labor productivity, and therefore labor demand, decrease. Real wages and labor input fall. First, the resulting lower labor costs imply decreasing prices. However, over time higher loan and capital costs dominate and firms adjust prices upwards.

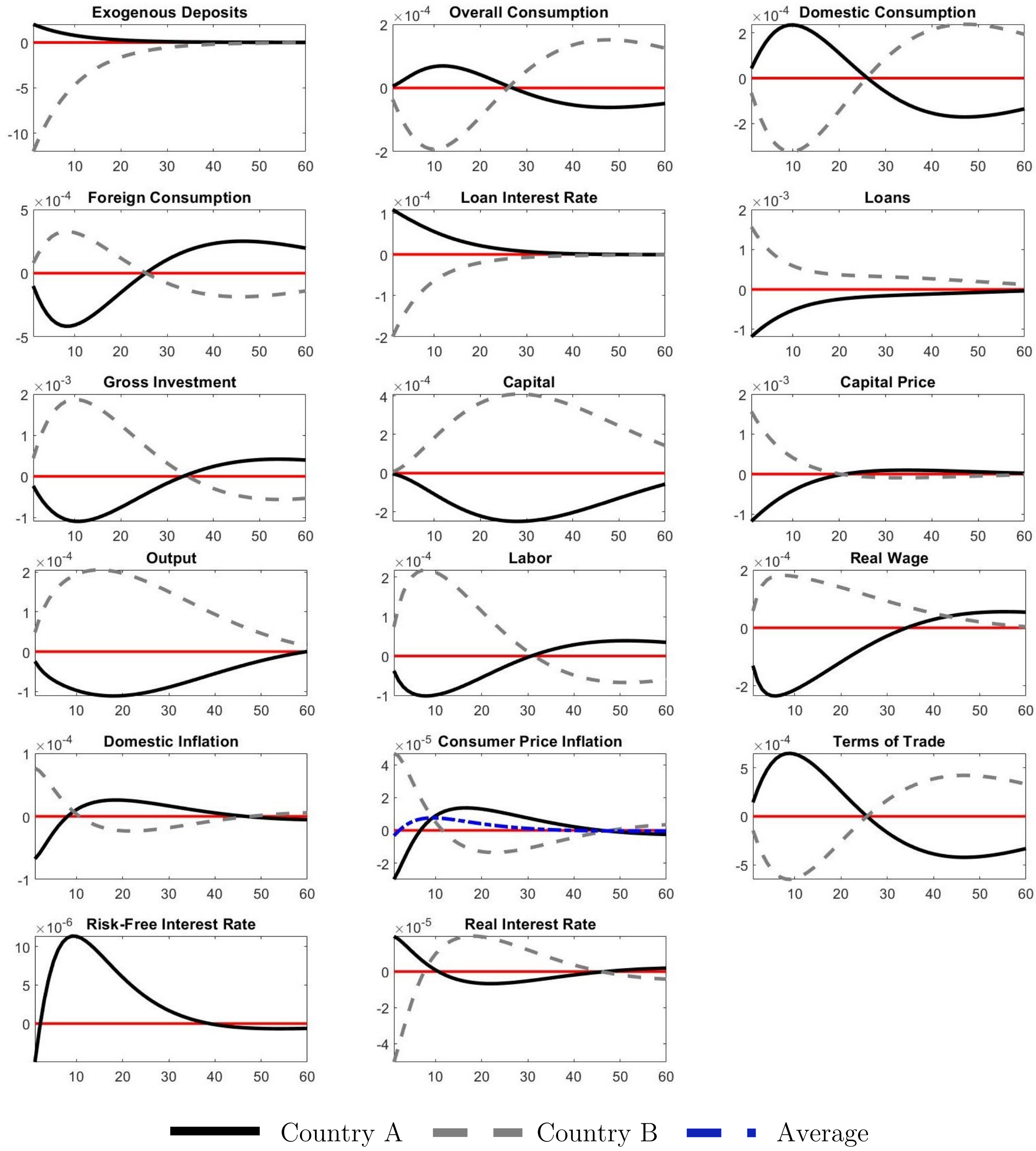

Figure 3: Impulse Responses to a Deposit Shift Shock from Country B to A.

In country B, the consequences of the deposit shift are reversed. Lower bank costs imply more investment, and thus a higher capital stock and labor input, which leads to more output and initially increasing prices. As a consequence of higher prices, domestic consumption initially decreases in country B. Nevertheless, output increases due to higher investment, causing higher labor demand and wages. Over time, lower capital costs lead to a decrease in the price level, implying higher consumption of domestic goods, lower consumption of foreign goods, and an increase in the terms of trade between country B and country A over time.

Note that the monetary policy reaction is rather weak as it reacts to the average consumer price inflation rate in the monetary union. As the shock becomes less relevant, so too does the decrease (increase) in country A's (B's) capital stock, until the process returns and the capital stock converges to its steady state. Thus, in our model that focusses on excess reserves and does not consider potential underlying reasons for this shift, the deposit shift from country B to A negatively affects the economy of country A due to higher bank costs, implying lower investment and thus a lower capital stock, and therefore a decrease in output and consumption. Analogously, the country B economy benefits from this shock.

4.2.3 Monetary Policy Shock

Figure 4 depicts the impulse responses of the monetary union to an expansionary (annualized) 1% monetary policy shock that decreases the real interest rate. The responses of both countries are qualitatively the same.

As expected, the expansionary monetary policy shock increases consumption, wages, and inflation. This implies a contractionary monetary policy reaction, i.e., the central bank decreases its net asset purchases in comparison to steady state. This leads to an increase in the risk-free interest rate accompanied by a decrease in exogenous deposits. While the shock decreases the risk-free interest rate, the central bank's reaction to increases in union-wide inflation leads to an immediate overall increase of the risk-free rate in the initial period.

Note that the contractionary monetary policy reaction induces the reverse effects of the expansionary monetary policy response described in Section (4.2.1). Consequently, the afore analyzed mechanisms can be interpreted reversely. This implies that the reverse bank lending channel again weakens the interest rate channel of QE by decreasing the effects of the contractionary monetary policy response.

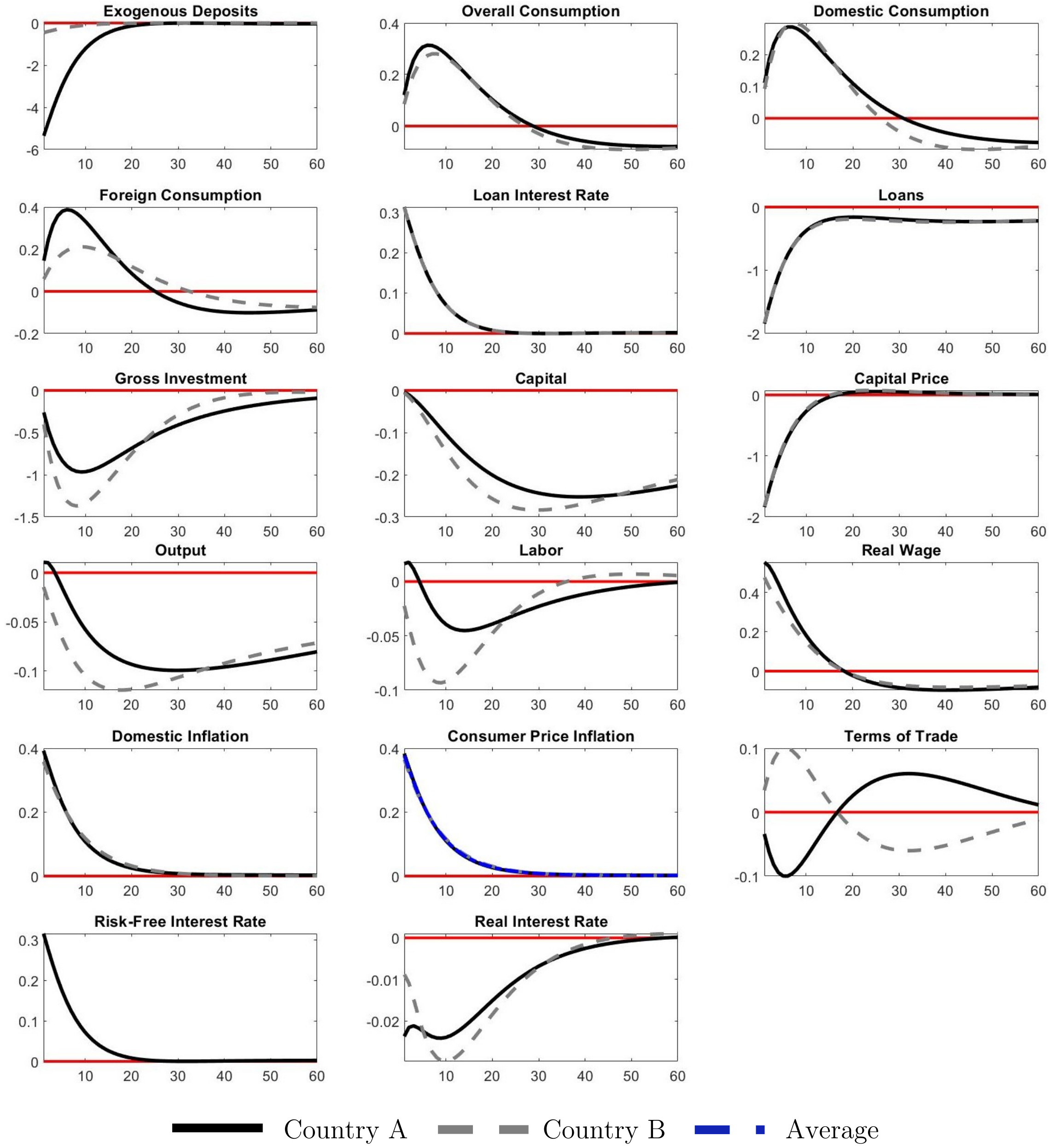

Figure 4: Impulse Responses to an Expansionary (Annualized) 1% Monetary Policy Shock.

The decrease in investment and capital leads to lower labor productivity. Therefore, firms demand less labor, leading to lower wages. Thus, output decreases over time. Accordingly, consumption decreases. Again, this decrease proportionally splits into domestic and foreign consumption. Consequently, firms decrease their prices, implying that the goal of the central bank (stabilizing increased inflation due to the expansionary shock) has been reached. However, the effects of the contractionary monetary policy reaction are dampened by the decrease in deposits. Moreover, the dampening effects are heterogeneously distributed, with the high-liquidity country being affected more.

5 Conclusion

Since the start of the implementation of the Eurosystem's QE program in March 2015, excess reserves in the euro area banking sector have persistently increased. The large quantity of excess reserves as well as its asymmetric distribution across euro area countries as a consequence of the specific implementation of QE has triggered a great amount of concern and debate. However, there is little analysis of whether and to what extent large quantities of excess reserves affect macroeconomic variables in different countries of a monetary union. For instance, with regard to the impact on bank lending, only little research has been conducted on whether there is a *bank lending channel* in the sense that QE-induced increases in bank reserves and deposits have a positive impact on bank lending.

Against this background, our paper develops a two-country DSGE model to analyze the macroeconomic effects of QE-induced heterogeneous increases in excess reserves and deposits in a monetary union. The model is calibrated for Germany and Italy to represent a high- and a low-liquidity euro area country. Hereby, we capture the consequences of the specific implementation of QE in the euro area dealt with in Section 2, i.e., the large amount of excess reserves in the banking sector as well as its heterogeneous distribution across euro area countries. In our model, banks in each country face such large amounts of excess reserves that fulfilling reserve requirements is not a binding constraint. They operate in an environment characterized by a structural liquidity surplus. Moreover, banks are exposed to balance sheet costs, i.e., costs related to the size of their balance sheet. We introduce QE as the central bank's monetary policy tool. The central bank influences the risk-free interest rate through its net asset purchases. However, these asset purchases do not imply only a decrease (increase) in the interest rate, but also an increase (decrease) in banks' excess reserve and deposit holdings. Furthermore, we introduce a preference shock, a deposit shift shock, and a monetary policy shock into the model.

With regard to the negative preference shock in both countries, we find that QE, as an expansionary monetary policy tool, works as expected: the QE-induced decreased interest rate implies an increase in bank lending and hence investment, output, employment, and prices (*interest rate channel of QE*). However, this expansionary monetary policy reaction to the shock is weakened by increases in excess reserves and deposits since buying assets not only decreases the interest rate but also increases (costly) excess reserves and deposits implying increasing (balance sheet) costs for banks. Thus, the *interest rate channel* is dampened by a *reverse bank lending channel.* These effects are more pronounced in the high-liquidity country.

After a deposit shift shock – which can be interpreted as sudden capital flight ("safe-haven-flows" or "flight-to-quality" phenomena) from the low- to the high-liquidity country – the increase in deposits in the high-liquidity country has negative effects on economic activity in that country. Analogously, the low-liquidity country benefits from the deposit shift to the high-liquidity country in an environment with large excess reserves, i.e., a decrease in deposits stimulates economic activity.

In response to a monetary policy shock, the effects of the central bank's reaction through the interest rate channel to this shock are again dampened by the reverse bank lending channel. Naturally, these weakening effects are larger in the high-liquidity country.

Our results raise questions for future research. Our model suggests that central banks should consider potential dampening effects arising through the reverse bank lending channel when implementing unconventional monetary policy. In particular, it should be taken into consideration that the dampening effects might differ across countries due to the asymmetric distribution of excess reserves and bank deposits as a consequence of the specific technical implementation of QE in the euro area. Moreover, optimal monetary policy within the given institutional framework might differ when these effects are taken into account, raising the question of whether there is an optimal level of QE.

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