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Asymmetric Macroeconomic Effects of QE and Excess Reserves in a Monetary Union

Maximilian Horst* Ulrike Neyer† Daniel Stempel‡

Abstract

Large-scale asset purchases by a central bank (quantitative easing, QE) induce a strong and persistent increase in excess reserves in the banking sector. In the euro area, these excess reserves are heterogeneously distributed across the member states. This paper develops a two-country New Keynesian model – calibrated to represent a high- and a low-liquidity euro area country – to analyze the macroeconomic effects of QE, specifically considering strong and 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. Furthermore, we show that a shock in the form of a deposit shift of QE-created deposits 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

At times when short-term monetary policy rates approach their effective lower bound, central banks may engage in quantitative easing (QE). In doing so, they buy assets at a large scale to directly lower long-term interest rates to stimulate economic activities. The Eurosystem launched its first QE program in January 2015 to address the risks of too low inflation for a too prolonged period.¹ However, large-scale asset purchases do not only decrease long-term interest rates but also create large amounts of bank reserves, implying that excess reserves in the euro area banking sector increased to unprecedented levels.² Due to the specific QE implementation, these excess reserves are distributed heterogeneously across euro area countries.

Against this background, we analyze the macroeconomic effects of QE in a monetary union within a two-country New Keynesian model, considering explicitly how it is implemented. This includes the analysis of whether the QE-induced large increases in excess reserves and their heterogenous distribution across countries are just a technical feature or whether they have real effects. We find that, by lowering long-term interest rates, QE triggers economic activities, implying that aggregate consumption and investment increase (*interest rate channel of QE*). We distinguish between two different long-term interest rates: the bond rate and the bank loan rate. Crucially, the decrease of the latter is weakened by QE-induced increases in excess reserves and deposits. In particular, these increases imply higher bank balance sheet costs, e.g., in the form of agency or regulatory costs. Consequently, bank lending, and thus the stimulating effects of QE on economic

¹The 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. 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). For the respective announcement of the QE program, see European Central Bank (2015).

²Excess 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.

activities, are dampened (*reverse bank lending channel of QE*).³ Hence, we identify two channels of QE, an interest rate channel and a reverse bank lending channel, with the latter weakening the former. Therefore, the QE-induced increases in excess reserves and their heterogeneous distribution are not just a technical feature but indeed have real effects. Depending on the way QE is implemented, these channels may affect monetary union members asymmetrically.

In particular, we calibrate our model to represent a high- and a low-liquidity euro area country (Germany and Italy). Thus, in steady state, excess reserves and deposits are already asymmetrically distributed between the two countries. Considering the specific QE implementation in the euro area, that reinforces this heterogeneous liquidity distribution, we find that the two channels indeed have asymmetric macroeconomic effects in these countries. We analyze the model responses to two shocks: a preference shock and a deposit shift shock (sudden deposit shift between the two countries). After a symmetric, negative preference shock that implies a decrease in household consumption, for instance due to the COVID-19 pandemic, the central bank reacts to the shock-induced decreasing union-wide inflation with QE. The long-term interest rates decrease, triggering economic activity and thus an increase union-wide consumer price inflation. However, the QE-induced increase in excess reserves and deposits leads to higher bank balance sheet costs, implying a dampening effect on bank lending. The interest rate channel of QE is therefore 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, the deposit shift has a dampening effect on economic activities. Analogously, the low-liquidity country benefits from the deposit shift.

³This stands in contrast to Bernanke and Gertler (1995) who introduced a bank lending channel into the literature that *reinforces* the traditional interest rate channel. Therefore, we call it *reverse* bank lending channel.

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), Kumhof and Wang (2019), and Mendizábal (2020), 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 Keister and McAndrews (2009), Alvarez et al. (2017), and Baldo et al. (2017).

Our paper contributes to these strands by explicitly considering crucial technical particularities of the QE implementation in a realistically calibrated New Keynesian model of two representative euro area countries. QE is modelled more realistically compared to its presentation in other papers with respect to its aim (reducing long-term interest rates that are the relevant rates for households’ consumption and for firms’ investment decisions) and with respect to the technical particularities of its implementation (large increases in excess bank reserves that are heterogeneously distributed across monetary union countries). In particular, our approach to modelling QE differs from other New Keynesian models that include QE as the main monetary policy tool of central banks by considering a non-zero, positive bond rate. This depiction is more realistic with respect to the positive long-term (bond) interest rates in 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 two different shocks. Section 5 concludes.

2 A Note on the Implementation of QE 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 reserves⁵ in the euro area increased from 200 billion euros in March 2015 to a temporary record high of 1.9 trillion euros in December 2018.⁶ This value has increased significantly in the aftermath of the introduction of the Pandemic Emergency Purchase Programme (PEPP) that was launched by the ECB as a reaction to the COVID-19 pandemic.⁷ 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

⁴The 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).

⁵For the definition of excess reserves used in this paper see footnote 2.

⁶Note 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 COVID-19 pandemic (for more detailed information, see European Central Bank (2020a)).

⁷The PEPP is implemented in the same way as the PSPP and can thus technically be viewed as a further expansion of QE. For details with regard to its introduction, its objective and its volumes, see for example European Central Bank (2020c).

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 periods (Baldo et al., 2017).

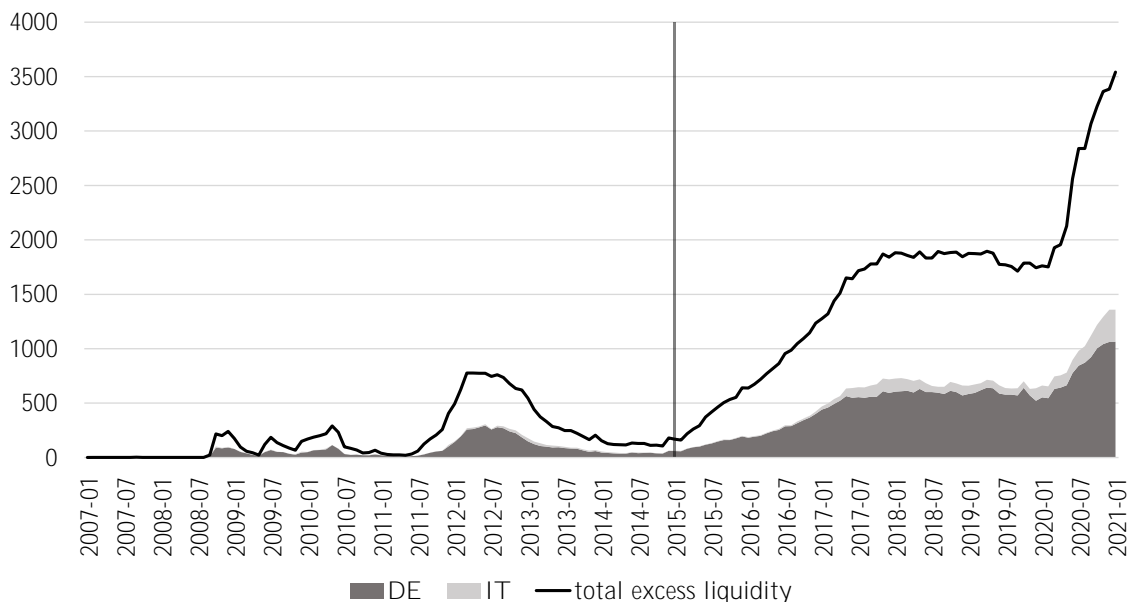


Figure 1: Excess reserve holdings of selected euro area national central banks in billion euros (maintenance period averages, vertical line indicates the launch of the QE program). Data Source: Eurosystem.

By implementing QE, each euro area national central bank purchases, inter alia, domestic government bonds according to its share in the ECB’s capital key. 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 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.⁸

There are different reasons for the observed heterogeneous distribution of QE-created bank reserves across euro area countries. By buying assets from the non-banking sector,

⁸For 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).

the Eurosystem does not only create bank reserves but also bank deposits.⁹ 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, 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), reserves and deposits in the domestic banking sector will increase. 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.¹⁰ 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

⁹For 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).

¹⁰TARGET2 (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, 2020f).

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 in each country by agent k . In addition, there is a union-wide central bank. Banks in each country face such large amounts of excess reserves that fulfilling reserve requirements is not a binding constraint.¹¹ 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

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

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 shock¹² 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

¹¹Other potential liquidity requirements, such as a liquidity coverage ratio for instance, play no role in our model. Banks face such a high liquidity surplus that those requirements are not a binding constraint when granting loans.

¹²Other works specifying preference shocks in this fashion include Ireland (2004), Dennis (2005), and Bekaert et al. (2010).

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

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

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

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

and

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

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

$$\begin{aligned} & \int_0^1 P_{k,t}(j) C_{k,t}^k(j) dj + \int_0^1 P_{-k,t}(j) C_{-k,t}^k(j) dj + B_t^k \\ & = (1 + i_{t-1}) B_{t-1}^k + W_{k,t} N_t^k + \Upsilon_t^k. \end{aligned} \quad (5)$$

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_t^k 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 long-term rate of interest, i.e., the bond rate 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_t^k from the ownership of firms and banks. The budget

constraint reveals that household k is connected with country $-k$ via the consumption of goods produced in country $-k$ and the 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 minimize its expenditures $\int_0^1 P_{k,t}(j)C_{k,t}^k(j)dj$ for any given level of the consumption index given by equation (3). Solving this optimization problem, the household's optimal consumption of the domestic good j becomes

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

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

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

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 minimize its expenditures $P_{k,t}C_{k,t}^k + P_{-k,t}C_{-k,t}^k$ for any given level of the consumption index given by equation (2). Solving this optimization problem, the optimal consumption of domestic and foreign goods are

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

and

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

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

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

and the budget constraint (5) becomes

$$P_{k,t}^C C_t^k + B_t^k = (1 + i_{t-1}) B_{t-1}^k + W_{k,t} N_t^k + \Upsilon_t^k. \quad (10)$$

In order to obtain the household's optimal labor supply and its optimal intertemporal consumption, we maximize equation (1) with respect to N_t^k , C_t^k , and B_t^k subject to equation (10). Denoting the marginal utility of consumption by

$$U_{c,t}^k \equiv \left(\frac{Z_t}{C_t^k - \Psi_k C_{t-1}^k} - \frac{\mathbb{E}_t [Z_{t+1}] \Psi_k \beta}{\mathbb{E}_t [C_{t+1}^k] - \Psi_k C_t^k} \right),$$

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

$$\chi_k (N_t^k)^{\varphi_k} = w_{k,t} U_{c,t}^k, \quad (11)$$

$$\beta(1 + i_t) \mathbb{E}_t \left[\frac{P_{k,t}^C}{P_{k,t+1}^C} \right] \Lambda_{t,t+1}^k = 1, \quad (12)$$

with

$$\Lambda_{t,t+1}^k \equiv \mathbb{E}_t \left[\frac{U_{c,t+1}^k}{U_{c,t}^k} \right]. \quad (13)$$

Equation (11) shows that optimal labor supply requires the marginal disutility of working (LHS) to be equal to the marginal utility of working (RHS). The latter results from

the additional possible consumption which is determined by the real wage $w_{k,t} \equiv W_{k,t}/P_{k,t}^C$. 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 $V_{-k,t}^k \equiv P_{-k,t}/P_{k,t}$, we get that

$$P_{k,t}^C = P_{k,t}^{1-\sigma_k} \left(V_{-k,t}^k P_{k,t} \right)^{\sigma_k} = P_{k,t} (V_{-k,t}^k)^{\sigma_k}, \quad (14)$$

and

$$\Pi_{k,t}^C = \Pi_{k,t} \left(\frac{V_{-k,t}^k}{V_{-k,t-1}^k} \right)^{\sigma_k}, \quad (15)$$

where $\Pi_{k,t}^C$ 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):

$$U_{c,t}^k = \vartheta_k (V_{-k,t}^k)^{(\sigma_k-1)} (V_{k,t}^{-k})^{(-\sigma_{-k})} U_{c,t}^{-k}, \quad (16)$$

where $\vartheta_k \equiv U_{c,ss}^k/U_{c,ss}^{-k}$ 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 $Y_{m,t}^k$ is produced with capital $K_{t-1,t}^k$ and labor N_t^k . The respective production function is given by

$$Y_{m,t}^k = \left(K_{t-1,t}^k \right)^{\alpha_k} \left(N_t^k \right)^{1-\alpha_k}. \quad (17)$$

Intermediate goods firm k buys the capital that is productive in t from the capital producing firm in $t-1$, i.e., $K_{t-1,t}^k$ is the capital stock chosen and bought at real price $Q_{k,t-1}$ in period $t-1$ and productive in t . At the end of period t , 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. The parameter δ_k is defined as the real depreciation rate.

So far, the setup closely resembles the modelling of intermediate goods firms by Gertler and Karadi (2011). However, with respect to the financing of their expenditures, we assume the following: at the end of period t , the intermediate goods firm borrows $L_{t,t+1}^k = Q_{k,t}K_{t,t+1}^k$ from bank k to buy the capital stock that is productive in $t + 1$. The bank credits the respective amount as deposits, $L_{t,t+1}^k = D_{t,t+1}^{L,k}$, on the intermediate goods firm's bank account, i.e., as in Kumhof and Wang (2019), loans create deposits.¹³ The corresponding objective function of intermediate goods firm k is given by

$$\max \Gamma_{m,t}^k = mc_{k,m,t}Y_{m,t}^k - w_{k,t}N_t^k - (1 + i_{k,t-1}^L)Q_{k,t-1}K_{t-1,t}^k + (Q_{k,t} - \delta_k)K_{t-1,t}^k. \quad (18)$$

Equation (18) reveals that in period t , the firm has to take into account four factors determining its real profits: (i) revenues defined as the product of real marginal costs and output,¹⁴ (ii) 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 $K_{t,t+1}^k$ and N_t^k gives the following FOCs:

$$(1 + i_{k,t}^L)Q_{k,t} = \alpha_k mc_{k,m,t+1} \frac{Y_{m,t+1}^k}{K_{t,t+1}^k} + (Q_{k,t+1} - \delta_k), \quad (19)$$

$$mc_{k,m,t} = \frac{w_{k,t}}{(1 - \alpha_k) \frac{Y_{m,t}^k}{N_t^k}}. \quad (20)$$

The LHS of equation (19) denotes the real marginal cost of capital in the form of credit and acquisition costs. The RHS describes the real marginal benefit of capital in the form of production 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.

¹³See Section 3.5 for details.

¹⁴Due to perfect competition, intermediate goods firms sell their products at nominal marginal costs.

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. Then, as in Gertler and Karadi (2011), it sells the refurbished capital and the newly produced capital, to the intermediate goods firm.¹⁵

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

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

The law of motion for capital is thus given by

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

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

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

with

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

where n_k captures the degree of capital adjustment costs and I_{ss} is steady state gross investment.¹⁶ Equation (23) shows that the real period profit is the result of: (i) the return from selling capital, (ii) the costs of buying the depreciated old capital, (iii) the

¹⁵The 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 invest. For the sake of simplicity, we neglect the general means of payment function of deposits (except for capital purchases) and focus on the bank deposit creation of bank loans (see Section 3.5).

¹⁶ 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. This would imply a division by zero if I_{ss} were excluded.

costs of repairing the old capital, (iv) the costs of producing the new capital, and (v) CAC (only for new capital). Considering equations (22), (23), and (24), the objective function of the capital producing firm becomes

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

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

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

The LHS shows real marginal revenues of net investment, the RHS the corresponding real marginal costs consisting 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. Retail firm k faces demand from households in both countries. 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

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

subject to

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

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, $Y_{\tau|t}^k(j)$ the

output in period τ for a firm that last reset its price in t , and $TC(\cdot)$ is the real total cost function. The respective demand function, 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 for goods produced in country k . The FOC of the maximization problem given by equation (27) is

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

where the real marginal cost function is given by $mc(Y_{\tau|t}^k(j)) = mc_{k,m,\tau}$, and $P_{k,t}^*(j)$ 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 , and get

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

where

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

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, i.e., $P_{k,t}^* = \epsilon_k / (\epsilon_k - 1) mc_{k,m,t} P_{k,t}^C$.

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 re-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 granted at the end of period $t - 1$, $L_{t-1,t}^k$, and real reserves R_t^k , its liabilities of real deposits D_t^k , so that its balance sheet constraint is given by

$$L_{t-1,t}^k + R_t^k = D_t^k . \quad (31)$$

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

$$R_t^k = R_t^{RR,k} + R_t^{ER,k} . \quad (32)$$

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

$$D_t^k = D_{t-1,t}^{L,k} + \underbrace{\tilde{D}_{k,t} \cdot D_{k,t}^{QE}}_{:=D_{k,t}^{ex}} , \quad (33)$$

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

With respect to $D_{t-1,t}^{L,k}$, 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 intermediate goods firm. One unit of granted loans creates one unit of deposits (*"financing through deposit creation"*),

i.e., $L_{t-1,t}^k = D_{t-1,t}^{L,k}$.¹⁷ We assume that loan-created deposits $D_{t-1,t}^{L,k}$ are credited on the intermediate goods firm k 's deposit account. The intermediate goods firm transfers the newly created deposits immediately to the capital producing firm to pay for the capital good. In period t , the intermediate goods firm repays its debt $(1 + i_{k,t-1}^L)L_{t-1,t}^k$, consisting of its loans remunerated at a long-term interest rate, i.e., the bank loan rate. The respective deposits, that are remunerated at i_{t-1} , mature. The loan $L_{t-1,t}^k$ and the deposits created through bank lending $D_{t-1,t}^{L,k}$ are extinguished.

As described in detail in Section 3.6, the bank is exposed to deposits created by the central bank's QE. Therefore, $D_{k,t}^{QE}$ evolves exogenously from *the point of view of the bank*. Besides the central bank's QE, a deposit shift shock $\tilde{D}_{k,t}$ may influence the bank's exogenous deposits $D_{k,t}^{ex}$. The deposit shift shock $\tilde{D}_{k,t}$ captures a shift of QE-created deposits from country k to $-k$ which can be the result of 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 of the central bank's monetary policy – given by

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

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

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 QE-created deposits from country B (low-liquidity country) to country A (high-liquidity country). Consider the case that, in steady state, the deposits are equally divided between both countries. In this case $\frac{D_{A,ss}^{QE}}{D_{B,ss}^{QE}} = 1$ and a 1% decrease of exogenous deposits in B leads to a 1% increase in A. However, if deposits are heterogeneously distributed between the countries, a $\frac{D_{A,ss}^{QE}}{D_{B,ss}^{QE}}\%$ decrease in $D_{B,t}^{ex}$ implies a 1% increase in $D_{A,t}^{ex}$.

¹⁷There exist two commonly known theories that describe the technical relationship between deposits and loans. In contrast to the theory of "financing through deposit creation", bank loans in the theory of "intermediation of loanable funds" reflect the intermediation of savings (or loanable funds) between non-bank savers and non-bank borrowers: banks collect deposits from one agent and lend those savings to another agent, i.e., deposits come before loans. However, our model builds on the theory of "financing through deposit creation". Banks' key function is the provision of financing through loans for a single agent that is both borrower and, at least temporarily, depositor. Banks create new deposits when granting loans. A survey of both theories can be found, for example, in Jakab and Kumhof (2019).

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

$$R_t^{ER,k} = D_{k,t}^{ex} - r \left(D_{k,t}^{ex} + D_{t-1,t}^{L,k} \right), \quad (34)$$

i.e., 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 $r \left(D_{k,t}^{ex} + D_{t-1,t}^{L,k} \right)$.¹⁸

Bank loans are remunerated at the rate $i_{k,t-1}^L$, required reserves at the rate i^{RR} , and excess reserves at the rate i^{ER} , with $i^{RR} > i^{ER}$.¹⁹ The rates i^{RR} and i^{ER} are determined by the central bank. Both bonds and bank deposits are assumed to be risk-free assets, so that they are remunerated at the same rate i_{t-1} . Thus, $i_{t-1} D_t^k$ constitutes the bank's interest costs on all deposits. 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 $\frac{1}{2} \nu_k \left(\mathbb{E}_t[D_{t+1}^k] \right)^2$. This captures the idea of existing agency and/or regulatory costs.²⁰

In period t , bank k seeks to maximize its real expected period- $(t+1)$ profit $\Gamma_{b,t,t+1}^k$. The bank's objective function is thus given by

$$\begin{aligned} \max \mathbb{E}_t[\Gamma_{b,t+1}^k] &= i_{k,t}^L I_{t,t+1}^k + i^{RR} r \mathbb{E}_t[D_{t+1}^k] + i^{ER} \mathbb{E}_t[R_{t+1}^{ER,k}] \\ &\quad - i_t \mathbb{E}_t[D_{t+1}^k] - \frac{1}{2} \nu_k \left(\mathbb{E}_t[D_{t+1}^k] \right)^2. \end{aligned} \quad (35)$$

¹⁸A detailed explanation of the one-to-one increase in QE-created deposits and reserves is given in Sections 2 and 3.6.

¹⁹Note that with regard to the euro area, i^{RR} corresponds to the ECB's main refinancing rate and i^{ER} to the rate on the ECB's overnight deposit facility.

²⁰Models explicitly considering balance sheet costs can, for example, also be found in Martin et al. (2013, 2016), Ennis (2018), Kumhof and Wang (2019), and Williamson (2019).

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

$$i_{k,t}^L + r(i^{RR} - i^{ER}) = i_t + v_k \left(\mathbb{E}_t[D_{k,t+1}^{ex}] + L_{t,t+1}^k \right) . \quad (36)$$

The LHS of (36) 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 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.²¹ Crucially, bank costs are affected by the central bank’s net asset purchases in two (opposing) ways: through interest costs i_t and through balance sheet costs $v_k \mathbb{E}_t[D_{k,t+1}^{ex}]$.

3.6 Central Bank

Monetary policy is conducted at the union level. We conceptualize the conduct of monetary policy by the central bank to closely follow the monetary policy operations of the ECB. Conventionally, the ECB implements monetary policy by setting its short-term interest rates.²² However, when these short-term interest rates reach their effective lower bound, the ECB switches to unconventional monetary policy instruments, such as QE, to directly lower long-term interest rates (resulting in a flattening yield curve), i.e., the interest rates that are relevant for households’ consumption and firms’ investment decisions (European Central Bank, 2015). However, QE does not only decrease long-term interest rates, but parallelly also increases bank reserves. Furthermore, a large part of the Eurosystem’s asset purchases are conducted with counterparties residing outside the euro area, which leads to

²¹With regard to the euro area, since June 2014 excess reserves have been remunerated at a negative rate, currently (February 2021) at -5%. Neglecting the “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).

²²The ECB’s short-term interest rates consist of (i) the rate on its one-week main refinancing operations with commercial banks, (ii) the rate on its overnight deposit facility, and (iii) the rate on its overnight marginal lending facility.

a one-to-one increase in bank deposits and reserves of the banking sector in that country, where the respective counterparties have their deposit accounts with.²³

In our model, the central bank has already encountered the lower bound on short-term monetary policy rates, so that QE has become its main monetary policy tool. We do not explicitly model the asset purchases but consider the resulting increase in bank reserves. Furthermore, we consider that an increase in reserves implies a one-to-one increase in bank deposits:

$$dR_t^k = dD_{k,t}^{QE} . \quad (37)$$

This allows us to depict the monetary policy instrument QE by an increase in bank deposits $D_{k,t}^{QE}$, and to model a central bank reaction function, a kind of Taylor rule, given by

$$D_{k,t}^{QE} = \Omega_k - \iota_k \left(1 + \ln \left(\frac{1}{\beta} \right) \right) - \iota_k \phi_\pi (\gamma_{k,t} \pi_{k,t}^C + \gamma_{-k,t} \pi_{-k,t}^C) . \quad (38)$$

Equation (38) reveals that the central bank reacts to the weighted average of country-specific consumer price inflation rates, given by $(\gamma_{k,t} \pi_{k,t}^C + \gamma_{-k,t} \pi_{-k,t}^C)$, where $\pi_{k,t}^C \equiv \ln(\Pi_{k,t}^C)$ and $\gamma_{k,t} = (C_t^k) / (C_t^k + C_t^{-k})$. The weights on the country-specific rates express the overall consumption level of the respective country in relation to the aggregate union consumption level. This reflects how consumer price inflation, which is relevant for the ECB's inflation target, is measured in the euro area.²⁴ Equation (38) shows that if the central bank observes a decrease in the average of consumer price inflation, it conducts QE, i.e., bank deposits $D_{k,t}^{QE}$ increase. How strongly these deposits increase in country k is determined by the parameters ι_k and ϕ_π . The latter represents the standard reaction coefficient of the central bank to inflation in Taylor rules. The former, a country-specific parameter, allows us to depict the country-specific QE-induced increases in bank deposits, and thus to account for the heterogeneous distribution of QE-induced increases in bank deposits and excess liquidity (reserves) across euro area countries. The parameter Ω_k is

²³See Section 2 for the institutional details.

²⁴See European Central Bank (2020b) for detailed information.

a country-specific calibrated parameter to match the share of QE-created deposits in the length of the bank's balance sheet.²⁵

A central bank's large asset purchases lower the longer-term interest rate. We account for this effect by modeling a negative relationship between i_t and $D_{k,t}^{QE}$:

$$1 + i_t = \frac{\Omega_k - D_{k,t}^{QE}}{\iota_k}. \quad (39)$$

Therefore, our model considers the simultaneous QE-induced decrease in long-term interest rates and the increase in bank reserves, and bank deposits respectively. Note that the negative relationship between i_t and $D_{k,t}^{QE}$ is a technical depiction to simplify matters. The increase in $D_{k,t}^{QE}$ and the decrease in i_t are both consequences of the implementation of QE. In reality, they occur independently of each other. New Keynesian models using QE as the central bank's monetary policy tool usually set $i_t = 0$ to illustrate that the central bank has reached the lower bound on short-term interest rates. However, since i_t is the relevant interest rate for households' consumption and firms' investment decisions, it has rather a long-term characteristic, and we assume that this rate is still above the lower bound, as it has actually been the case in the euro area.

In our model, all banks have a high stock of excess reserves and thus of QE-created deposits in steady state. They can be interpreted as a result of past central bank asset purchases. This allows us to also consider contractionary monetary policy. The central bank conducts monetary policy 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. If the central bank's net asset purchases are negative, monetary policy will be contractionary (quantitative tightening). Besides conducting QE, the central bank sets the nominal interest rates on commercial banks' required and excess reserves holdings r^{RR} and r^{ER} , respectively, and determines the ratio for banks' required reserve holdings r .

²⁵For more detailed information with regard to the calibrated parameters ι_k and Ω_k , see Section 4.1.

3.7 Equilibrium

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

$$B_t^k = -B_t^{-k}, \quad (40)$$

i.e., bonds are in zero net supply. Final goods are consumed by households in the union and used to adjust capital.²⁶

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

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

$$Y_{m,t}^k = Y_t^k. \quad (42)$$

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

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

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

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

Lastly, the real interest rate is defined in terms of the (log-linearized) union-wide bond rate and consumer price inflation of country k (Fisher equation):

$$i_{k,t}^{real} = i_t - \mathbb{E}_t [\pi_{k,t+1}^C]. \quad (45)$$

²⁶Note that for simplicity, as in Kumhof and Wang (2019), we assume that balance sheet costs as well as interest costs for QE-created deposits represent lump-sum transfers to the household instead of resource costs. However, our results are not affected by these assumptions.

4 Model Analysis

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

4.1 Calibration

The calibration of our model is depicted in Table 1. 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^{QE} . In relation to the length of banks’ balance sheets in the respective banking sector, D_k^{QE} adds up to 9% in Germany and 2% in Italy.²⁷ We calibrate the parameter Ω_k accordingly.

In order to realistically capture the (mechanical) relationship between QE-created deposits and the bond rate i_t (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 the announcement of QE measures 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

²⁷The respective data can be found at Deutsche Bundesbank (2020) and Banca d’Italia (2020).

Germany and Italy. They estimate certain structural parameters based on the respective economies, some of which are also used in our model specification.

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	QE-Created Deposits in Bank Balance Sheet	106.51	2.41	Share Germany: 9%, Share Italy: 2%, Internally Calibrated
ι_k	Interdependence Parameter of QE and Bond Rate	100.41	1.42	Drop German Bond Yields: 5.91 bp, Drop Italian Bond Yields: 69.67 bp, Internally Calibrated
$\rho_{d,k}$	Deposit Shift Shock Persistence	0.9	0.9	
r	Required Reserve Ratio	0.01	0.01	ECB: Minimum Reserve Ratio
i^{RR}	Required Reserve Interest Rate	0	0	ECB: Main Refinancing Rate
i^{ER}	Excess Reserve Interest Rate	$-\frac{0.005}{4}$	$-\frac{0.005}{4}$	ECB: Deposit Rate
v_k	Balance Sheet Costs	0.000021	0.000037	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)

Table 1: Calibration.

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 annual rates of the ECB have to be converted into quarterly rates due to the timing of the model.

With respect to bank costs, we calibrate balance sheet costs in a way that, given the respective ECB interest rates and the required reserve ratio, the loan interest rate matches data for average (annual) interest rates of newly granted loans to non-financial corporations in Germany and Italy between August 2017 and February 2020, provided by the European Central Bank (2020d,e). Obviously, when firms take out a loan from a bank, they do not only have to pay interest, but often additional fees. Consequently, the banks' marginal revenues (LHS of (36)) consist of more than interest payments which in turn implies higher marginal costs due to perfect competition of banks. However, as we consider only interest payments when calibrating the banks' balance sheet costs (second

on the RHS of (36)), the corresponding calibrated value of this cost factor serve as a lower bound, implying that all effects resulting from balance sheet costs also constitute a lower bound.

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 (annual) 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 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 (Annual) 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)	0.170	CEIC (2020c)	0.247
Consumption Share in GDP: Germany (A)	0.506	CEIC (2020b)	0.744
Consumption Share in GDP: Italy (B)	0.608	CEIC (2020d)	0.753
Average (Annual) Interest Rate of New Loans to Corporations: Germany (A) 2017 – 2020	1.22%	European Central Bank (2020d)	1.22%
Average (Annual) Interest Rate of New Loans to Corporations: Italy (B) 2017 – 2020	1.40%	European Central Bank (2020e)	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 and a deposit shift 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. An example for this shock could be the COVID-19 pandemic. The responses are qualitatively similar in both countries but differ quantitatively. The preference shock implies a decrease in the households' appreciation of consumption, formally captured by a decrease in their marginal utility for each level of consumption. 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 long-term interest rate i_t , i.e., the bond rate, and an increase in QE-created bank deposits (equation (38)). Note that, motivated by the mechanical peculiarities of QE in the euro area presented in Section 2, QE-created 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). Investment and thus (one period lagged) capital increase. The increasing capital

stock implies higher labor productivity. Real wages rise, leading to increasing labor and consumption.

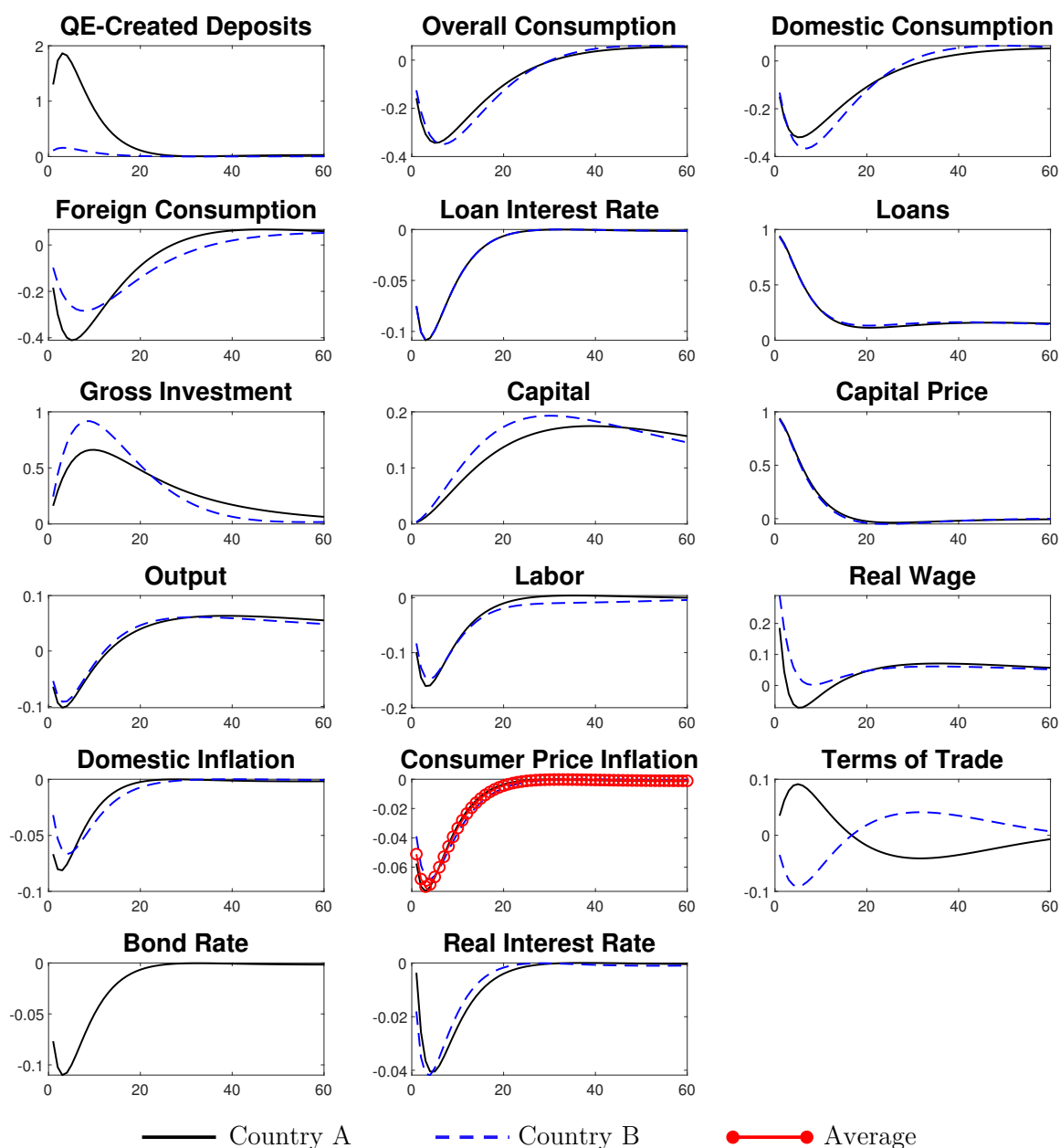


Figure 2: Impulse Responses to a Symmetric, Negative 1% Preference Shock.

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 reduc-

tion, 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.²⁸

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 QE-created 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 QE-created 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.

²⁸This overshooting is slightly reinforced by the one-period lag between the firms’ investment decision and the use of the capital in the production process.

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 QE-created deposits from low-liquidity country B. These deposits are then moved to the high-liquidity country A, increasing deposits by 2%. 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.

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.

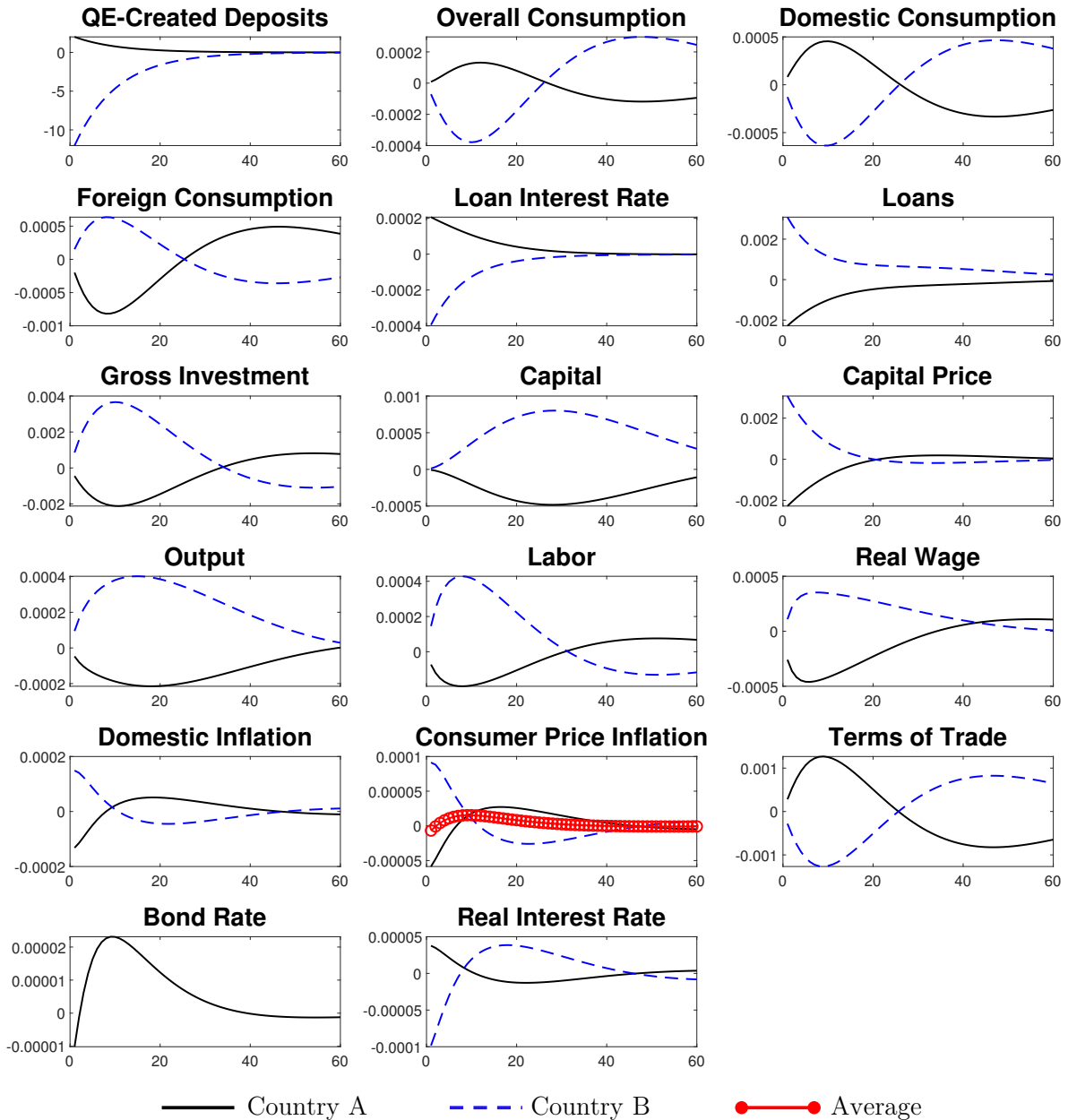


Figure 3: Impulse Responses to a Deposit Shift Shock from Country B to A.

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.

5 Conclusion

Since the start 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 resulting from 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 New Keynesian model to analyze the macroeconomic effects of QE, explicitly considering the 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, i.e., the resulting large amount of excess reserves in the banking sector, as well as its heterogeneous distribution across euro area countries. These consequences have important implications for our model as banks are exposed to balance sheet costs, i.e., costs related to the size of their balance sheet (for instance, in the form of agency or regulatory costs). We introduce QE as the central bank's monetary policy tool. Applying QE decreases long-term interest rates, but, in addition, also implies an increase in banks' excess reserve and deposit holdings.

Analyzing the model responses to a negative preference shock in both countries (due to the COVID-19 pandemic, for instance), we find that QE, as an expansionary monetary policy tool, works as expected: the QE-induced decrease in long-term interest rates implies an increase in consumption and bank loan-financed investment. As a consequence, output, employment, and prices rise (*interest rate channel* of QE). However, the effects of this expansionary monetary policy reaction to the shock are weakened by QE-induced increases in excess reserves and deposits, implying increasing (balance sheet) costs for banks and, therefore, a smaller decrease in the bank loan rate and thus a lower increase in bank loan-

financed investment. Consequently, the interest rate channel is dampened by a *reverse bank lending channel*. The dampening effects are more pronounced in the high-liquidity country.

With respect to the ECB's reaction to the COVID-19 pandemic, one can conclude the following from our model. One measure of the ECB in response to the pandemic was the introduction of the Pandemic Emergency Purchase Programme (PEPP). While the PEPP has a dual objective, i.e., creating financial conditions (low interest rates) to stabilize the economy and mitigating the pandemic-induced malfunctioning of financial markets (Schnabel, 2020), its implementation is similar to the implementation of the APP introduced in 2015. Therefore, the stabilizing effects on the economy of the PEPP through an interest rate channel are also weakened by a reverse bank lending channel.

Our model suggests that central banks should consider that QE-induced increases in excess reserves and deposits may dampen the stimulating and stabilizing effects of this monetary policy measure on the economy. In particular, it should be taken into consideration that these dampening effects may 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 may differ when these effects are taken into account.

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