The Reverse Bank Lending Channel of QE and QT and its Heterogeneous Effects Across the Euro Area*

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Abstract

Large-scale asset purchases by a central bank (quantitative easing, QE) induce a strong and persistent increase in excess liquidity and deposits in the banking sector and, therefore, leads to an expansion of banks' balance sheets. In the euro area, excess liquidity and QE-created deposits are heterogeneously distributed across the member states. First, this paper uses local projection (LP) techniques to analyze the transmission of monetary policy to bank lending, conditional on a country's excess liquidity holdings. We find that in a high-liquidity country, such as Germany, an increase in the level of excess liquidity significantly dampens the effect of a monetary shock over time, while the transmission is amplified for a low-liquidity country, such as Italy. Second, we shed some light on these results in a two-country New Keynesian model. We show that QE has two opposing effects on banks' costs: (i) QE decreases long-term interest rates and, therefore, banks' refinancing costs; (ii) QE-created excess liquidity and deposits expand banks' balance sheets and increase balance sheet costs. Furthermore, QE-created deposits are not loanable funds but banks create deposits when granting loans, implying that bank lending does not increase in QE-created deposits. These model features imply a *reverse bank lending channel*, which dampens the expansionary effects of QE and the contractionary effects of quantitative tightening (QT). These dampening effects differ across euro area countries.

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

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

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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 in order to stimulate economic activities. The Eurosystem[1] launched its first QE-program, the Asset Purchase Programme (APP), in October 2014 to address the risks of too low inflation for a too prolonged period. In reaction to the outbreak of the COVID-19 pandemic, an additional asset purchase program, the Pandemic Emergency Purchase Programme (PEPP), was launched in March 2020.[2] However, large-scale asset purchases do not only decrease long-term interest rates but also create large amounts of bank reserves (i.e., commercial banks' current account balances at their national central bank), implying that excess liquidity[3] in the euro area banking sector increased to unprecedented levels. The specific QE-implementation implies that (i) excess liquidity is distributed heterogeneously across euro area countries, and (ii) bank deposits increase simultaneously, expanding banks' balance sheets (we comment on this in more detail in Section 2).

Against this background, this paper shows that the enormous increase in excess liquidity is not just a technical byproduct of QE but that it has real effects. The QE-induced increase in excess liquidity and bank deposits implies a negative impact on bank lending and, therefore, dampens the expansionary effect of QE. As the increase differs across euro area countries, this dampening effect is heterogeneous across the euro area. We refer to this dampening channel of monetary policy as the *reverse bank lending channel* due to the negative relationship between reserves/deposits and bank lending. We thereby invoke Bernanke and Blinder (1988) who introduced the bank lending channel into literature and Bernanke and Gertler (1995) expanding on this channel. Decisive for the existence of the bank lending channel is the positive relationship between reserves/deposits and bank lending. Bernanke and Gertler (1995, p. 40) point out that "the bank lending channel

[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]For details on the APP and the PEPP see European Central Bank (2020b, 2023) respectively.

[3]Excess liquidity, as defined by the ECB, is the sum of excess reserves (amount of reserves banks hold in excess of those contributing to minimum reserves requirements) and of overnight deposits banks make at the central bank (deposit facility) minus banks' overnight credits granted by the central bank (marginal lending facility).

suggested that open market sales by the Fed, which drain reserves and hence deposits from the banking system, would limit the supply of bank loans by reducing banks' access to loanable funds." Importantly, this bank lending channel only exists when banks operate under a scarce-reserves regime. In our model, however, we identify a reverse bank lending channel within an ample-reserves regime where bank reserves are not a binding constraint.[4]

Using local projections (LP), we derive our results by empirically investigating the transmission of monetary policy to loans in a "high excess liquidity country" (i.e., Germany) and a "low excess liquidity country" (i.e., Italy), both unconditionally and conditional on an increase in excess liquidity in the respective country. In contrast to what one might expect considering the bank lending channel, we find that loans in Germany react significantly negatively to a monetary policy shock conditional on a increase in excess liquidity, with a decline of up to 50 basis points. Conversely, bank lending in Italy increases (by up to 50 basis points). This implies that the creation of excess liquidity dampens the various other channels through which QE generally has expansionary effects (see, for instance, Schnabel (2024) and references therein), particularly in countries with large amounts of excess liquidity.

In order to shed some light on these empirical insights, we then set up a two-country New Keynesian model, considering explicitly how QE is implemented and how excess liquidity is distributed in the euro area. In particular, we calibrate our model to represent a high- and a low-liquidity euro area country (Germany and Italy). Following our empirical setup closely, we simulate a shock that increases excess liquidity and, thereby, QE-created deposits in both countries. The model replicates that the increase in excess liquidity leads to a decrease (increase) in bank lending in high-liquidity (low-liquidity) countries. There are three reasons for this outcome: (i) QE-induced increases in excess liquidity and bank deposits imply an expansion of banks' balance sheets. This expansion increases banks' balance sheet costs which has a negative impact on bank lending. This effect is stronger in high-liquidity countries. (ii) General equilibrium effects imply a decrease in the long-term interest rate, leading to lower interest costs for banks which has a positive impact

[4] A detailed discussion on the difference between the implementation/transmission of monetary policy in a scarce- and an ample-reserves environment can be found in Jefferson (2023).

on bank lending. (iii) Banks finance their lending through deposit creation, implying that they cannot use QE-created deposits as loanable funds. (i) and (ii) are the reasons for the diverging development of bank lending in high- and low-liquidity countries: in countries with high excess liquidity, balance sheet costs are high and outweigh the decrease in interest costs. An increase in excess liquidity, therefore, implies a net increase in costs. The opposite applies to low-liquidity countries.

Note that a similar argument holds for quantitative tightening (QT). Banks' balance sheets will shrink if the central bank does no longer reinvest maturing principal payments from earlier bought assets and/or if it starts to sell these assets. Consequently, balance sheet costs decrease and interest rates increase, implying that contractionary effects of QT are dampened by the reverse bank lending channel.

The theoretical part of our paper primarily builds on three strands of literature. First, we contribute to the literature on DSGE models that 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), Wu and Zhang (2019a,b), and Alpanda and Kabaca (2020). 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), Saraceno and Tamborini (2020), and Kabaca et al. (2023). Third, our work is based on literature investigating the relationship between the implementation of QE and the creation of excess liquidity. Examples include Keister and McAndrews (2009), Alvarez et al. (2017), Armenter and Lester (2017), Baldo et al. (2017), Afonso et al. (2019). The importance of QE-induced increases in bank reserves and deposits is also the key issue in Acharya and Rajan (2024). They argue that these increases may create and exacerbate situations of liquidity stress in the banking sector, implying that QE-intended effects on the real economy may be weaker than expected. Our results complement theirs as we argue that the effects of QE are weaker due to additional costs of the banking sector, independently of situations of liquidity stress. Overall, our paper contributes to the three strands by explicitly considering crucial technical particularities of the QE implementation. QE is modeled 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 consequences of its implementation (large increases in excess bank liquidity that is heterogeneously distributed across monetary union countries). We further contribute to this literature by implementing the development of excess liquidity accompanying QE and analyzing the effects of this mechanical relationship on macroeconomic outcomes, particularly on bank lending, in a monetary union model. Furthermore, the analysis in this paper is expanded past the QE-period, giving first insights on how excess liquidity affects the efficacy of QT.

The empirical contribution of this paper relates to the literature on how excess liquidity impacts bank lending, such as Altavilla et al. (2024) or Diamond et al. (2024). In particular, Diamond et al. (2024) show that reserves injected by QE reduce bank lending in the US (deeming it the reserve supply channel of unconventional monetary policy) by estimating a structural model. While our paper was developed independently from theirs, it addresses a similar question with regards to the euro area and our results complement the ones brought forward by Diamond et al. (2024). In addition, this paper adds to the literature on the transmission of monetary policy shocks (see, e.g., Altavilla et al., 2019; Miranda-Agrippino and Nenova, 2022) conditional on the state of a country's economy (see, among many others, Caramp and Feilich, 2024; Ferreira et al., 2024), using LP techniques (Jordà, 2005).

The remainder of this paper is organized as follows. Section 2 presents some notable fundamentals with regard to the implementation of QE and QT in the euro area. Section 3 presents the empirical methodology and the impulse responses of bank lending of selected euro area countries to an increase in excess liquidity. In Section 4, we state the model. Section 5 describes the model calibration and presents some intuition for the reverse bank lending channel. Section 6 concludes.

2 The Implementation of QE and QT in the Euro Area

The Eurosystem's asset purchases implied large increases in bank reserves to unprecedented levels. However, these reserves are distributed unevenly across euro area countries. This section comments on these two observations in more detail. Under its asset purchase programs APP and PEPP, the Eurosystem bought private and public assets at a large scale. However, the purchases of public assets accounted by far for the largest share. In the APP, nearly 80% of all asset purchases were public ones, in the PEPP 97%. The respective (sub-)program of the APP under which the public assets were bought is the Public Sector Purchase Programme (PSPP).[5] The Eurosystem's asset purchases are funded through the creation of bank reserves. This implies that the liquidity of the banking sector mechanically increases one-to-one in these asset purchases. Figure 1a shows the immense increases in excess liquidity from March 2015 and March 2020 onwards, when the PSPP and PEPP were introduced. Positive *net* asset purchases[6] under the PEPP ended in March 2022, those under the APP in June 2022. This explains the flattening of the excess liquidity curve. Under the APP, the Eurosystem reduced the reinvestments of redemptions from March 2023 onwards, and fully stopped these reinvestments from July 2023 onwards. This implied reductions in both bond holdings on the asset side and bank reserves on the liability side of the Eurosystem's balance sheet. Therefore, the Eurosystem's balance sheet started to shrink (QT). Thus, QT partly explains the decrease in excess liquidity since then.[7] An increase in excess liquidity can also be observed during and after the financial crisis (2008) and sovereign debt crisis (2011). However, the causes for the accumulation of excess liquidity during these crises and under the asset purchase programs are different. The creation of excess liquidity under asset purchase programs are *supply-driven*. The ECB conducts the asset purchases to reduce the long-term interest rates directly in order to boost aggregate demand and thus prices (and output). These asset purchases automatically imply a one-to-one increase in bank reserves. The banking sector is forced to absorb this liquidity. The creation of excess liquidity during the financial and sovereign debt crises, in contrast, was *demand-driven*. Banks increased their demand for liquidity

[5] For details on the asset purchase programs see European Central Bank (2023).

[6] Net asset purchases are total asset purchases minus those purchases that reinvest redemptions.

[7] The main reason for the decrease results from a reduction in the Eurosystem's open market operations.

via their credit operations with the ECB due to increased levels of distrust and risk perception as well as increased informational asymmetries. Banks with a liquidity surplus did not want to place this liquidity on the interbank market. In general, banks wanted to hold precautionary liquidity (see Bucher et al. (2020) for details). The resulting increase in demand for liquidity was fully satisfied by the Eurosystem via its credit operations with the banks and, therefore, excess liquidity emerged.

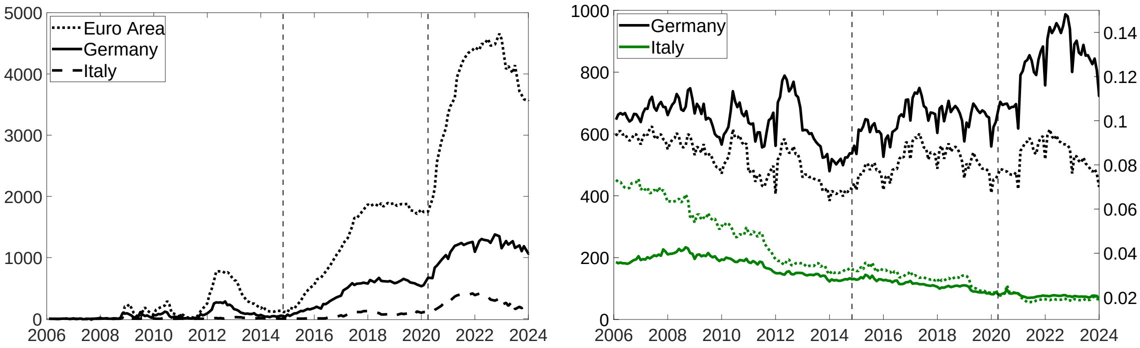
Furthermore, Figure 1a indicates the enormously heterogeneous distribution of excess liquidity across euro area countries. Between June 2016 and January 2024, on average, 33% of overall excess liquidity in the euro area was held solely in Germany, whereas only 6% was held in Italy.[8] According to Alvarez et al. (2017) and Baldo et al. (2017) approximately 80% to 90% of total excess liquidity in the euro area predominantly accumulate in Germany, the Netherlands, France, Finland, and Luxembourg, whereas such holdings are much less pronounced in Italy, Portugal, or Spain, for example. This heterogeneous distribution has been mainly the result of the specific implementation and settlement of the Eurosystem's asset purchases. Under the PSPP and the PEPP, i.e., under the two programs which contribute by far the largest share to the Eurosystem's liquidity creation, each national central bank purchases domestic public assets according to its share in the Eurosystem capital key.[9] The capital key reflects the respective country's share in the population and the GDP of the EU. The Italian capital key is 17%, the German capital key 26%. However, the observed difference in liquidity creation cannot only be explained by the different capital keys.

The decisive reason for that difference is that the national central banks buy assets from counterparties not residing in the national central bank's home country. 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). Those counterparties have their current accounts predominantly with commercial banks in only a few selected countries, such as Germany, France, and the Netherlands. They serve as so-called financial centers

[8] This heterogeneous distribution of excess liquidity could also be observed in 2008 and 2011. However, this was mainly the result of capital flight (so-called "safe-haven-flows" and "flight-to-quality" phenomena) from lower-rated to higher-rated euro area countries (Baldo et al., 2017).

[9] The PEPP allows for some flexibility, see European Central Bank (2020b). For more information and the country specific capital keys see European Central Bank (2019).

or gateways. Consequently, the QE-induced creation of excess liquidity as well as the QE-induced creation of bank deposits takes place in these countries.



(a) Excess Liquidity

(b) Non-EMU Deposits

Figure 1: Panel (a): Excess liquidity of credit institutions in the euro area, Germany, and Italy in billion euros, monthly data. The vertical lines indicate the launch of the APP and the PEPP, respectively. Data: Euro area: ECB; Germany: until June 2016 Deutsche Bundesbank, thereafter ECB; Italy: until June 2016 Banca d'Italia, thereafter ECB. Panel (b): Liabilities of Monetary Financial Institutions (MFI), excluding the Eurosystem, towards non-euro area residents in Germany and Italy in billion euros (solid lines) and the share of these liabilities in banks' total liabilities (dotted lines). Data: Banca d'Italia, Deutsche Bundesbank.

If, for example, the Italian central bank buys Italian government bonds from a UK pension fund, reserves and bank customer deposits will increase in the banking sector of that euro area country in which the respective counterparty (the UK pension fund) or its bank has its current account with the Eurosystem in order to get access to the TARGET2 (now T2) system,[10] for example in Germany. The size of the bank balance sheets in that euro area country (Germany) increases, whereas there are no effects on the banking sector in the country whose central bank actually bought the assets (Italy).[11]

[10]TARGET2 (Trans-European Automated Real-time Gross Settlement Express Transfer system) was replaced by T2 in March 2023. Both are real-time gross settlement payment systems owned and operated by the Eurosystem, settling euro-denominated domestic and cross-border payments in central bank money (European Central Bank, 2020c).

[11]One can distinguish between three cases regarding the impact of the type and the location of the counterparty of the Eurosystem's asset purchases on country-specific creation of reserves and deposits. (i) If the national central bank purchases assets from counterparties residing outside the euro area, reserves and deposits will increase in the banking sector of that euro area country in which the respective counterparty (or its bank) has its deposit account. This case is described above and is considered in this paper. (ii) If the national central bank purchases assets from the domestic banking sector (or from the banking sector in another euro area country), reserves only will increase. They increase in the domestic banking sector (in the banking sector of the respective euro area country). Note that bank deposits do not increase, there is only an asset swap on banks' balance sheets (government bonds for reserves, for example). (iii) If the national central bank purchases assets from the domestic non-banking sector (from the non-banking sector in another euro area country), reserves and deposits will increase in the domestic banking sector (in the banking sector of the respective euro area country). For more details see Horst and Neyer (2019).

The development of non-euro area residents' deposits in the German and the Italian banking sector shown in Figure 1b indicates the importance of the German banking sector as a financial gateway with respect to the QE-induced asset purchases by the Eurosystem. These deposits do not only accumulate at a much higher rate in Germany compared to Italy (in absolute values and in shares in banks' total liabilities) but also experienced significantly higher increases with the beginning of QE in 2015, and especially with the introduction of the PEPP in 2020.

3 Empirical Insights

In this section, we provide empirical insights into how the level of excess liquidity in the euro area affects the transmission of monetary policy. In particular, we estimate the impact of monetary policy using LP, finding loan responses to differ across countries depending on their levels of excess liquidity.

3.1 Data and Methodology

We estimate the transmission of monetary policy to loans in Germany and Italy, both unconditionally and conditional on an increase in the amount of excess liquidity held in the respective country. The baseline sample runs from 2003m1 to 2019m12, with a robustness check extending the data to 2021m6 to include the COVID-19 period.[12] To derive country-specific impulse response functions (IRFs), the following LPs (Jordà, 2005) are estimated at a monthly frequency for a series of horizons h:

$$x_{t+h} = \alpha^h + \beta_1^h MP_t + \beta_2^h EL_t \times MP_t + \beta_3^h EL_t + \gamma w_t + \varepsilon_{t+h}, \tag{1}$$

where x_t represents the variable of interest, being MFI loans to non-financial corporations (NFCs), at horizon $t+h$. MP_t is an exogenous euro-area monetary policy shock derived by Miranda-Agrippino and Nenova (2022).[13] This surprise series captures the high-frequency

[12]Data on country-specific loans are available from 2003 onwards. The decision to restrict the baseline sample to 2019m12 is motivated by the fact that the large shock volatilities observed in the COVID-19 period could bias the IRFs, as argued by Lenza and Primiceri (2022).

[13]Using alternative monetary policy shocks as identified by Altavilla et al. (2019) or by a straightforward sign-restriction approach, we report qualitatively similar results (see, Appendix A).

movements in long-term rates around monetary policy announcements.[14] We normalize the shock to reflect a monetary loosening, i.e., a decrease in long-term interest rates. The variable EL_t represents the measure of excess liquidity in Germany and Italy, as defined in Section 1 (Footnote 3).[15] We standardize this variable to have a mean of zero and a standard deviation of one. The vector w_t captures country-specific controls, including the industrial production index, the harmonized consumer price index, and the unemployment rate.[16] Additionally, we add the euro area shadow rate to the set of control variables, indicating the accommodative policy of the Eurosystem at the zero lower bound.[17]

Since the excess liquidity measure is standardized, the impulse response for the average level of excess liquidity is obtained by setting $EL_t = 0$. The corresponding IRF is then the sequence of all estimated β_1^h. In the case where the standardized excess liquidity measure is one standard deviation above its sample mean (i.e., when setting $EL_t = 1$), the IRF is the sequence of all estimated $\{\beta_1^h + \beta_2^h\}$. We are particularly interested in the coefficient β_2^h as it captures the effect of monetary policy conditional on an increase in excess liquidity relative to its sample mean.[18] We calculate impulse responses for Germany, representing a "high excess liquidity country" and Italy representing a "low excess liquidity country".

3.2 Impulse responses

We find that the transmission of monetary policy shocks in the euro area is dampened when the level of excess liquidity is high.

Figure 2a plots the effects of monetary policy shocks on loans in Germany and Italy, respectively, when the measure of excess liquidity is at its sample mean. In the base-

[14] If multiple announcements occur in the same month, the surprises are added up to convert them to a monthly data series. If there were no announcements in a given month, the surprises are set to 0.

[15] Instead of using the standardized measure of excess liquidity as defined by the ECB, one can replace this variable by the excess liquidity to GDP ratio or the excess liquidity as defined by Acharya et al. (2020). The latter is calculated as the sum of banks' current account and deposit facility holdings divided by the minimum reserve requirement imposed by the ECB for the specific reserve maintenance period, minus one. Both alternative measures of the level of excess liquidity produce qualitatively similar results.

[16] More precisely, w_t summarizes p lagged values of a vector of control variables, and q lagged values of the dependent variable. A lag length of two is chosen according to information criteria. The results are robust to altering the number of lags.

[17] All variables except the shadow rate and the unemployment rate are introduced as logs in the model. Modifying the panel of controls has no significant effect on the estimated impulse response functions.

[18] A similar approach using LP methods to analyze the asymmetries in the transmission of monetary policy can be found in Caramp and Feilich (2024) and Ferreira et al. (2024). To overcome the issue of autocorrelated residuals, we apply a Newey-West correction, using heteroscedasticity and autocorrelation consistent/robust estimators (HAC/HAR), as suggested by Jordà (2005).

line model, both German and Italian loans increase over time, peaking after 25 and 20 months, with a maximum increase of about 18 and 36 basis points, respectively. However, only Italian loans show a significant response at the 90 percent confidence interval (CI). Qualitatively similar responses are obtained when the sample is extended to 2021m6.

(a) Average Effect **(b) Conditional Effect**

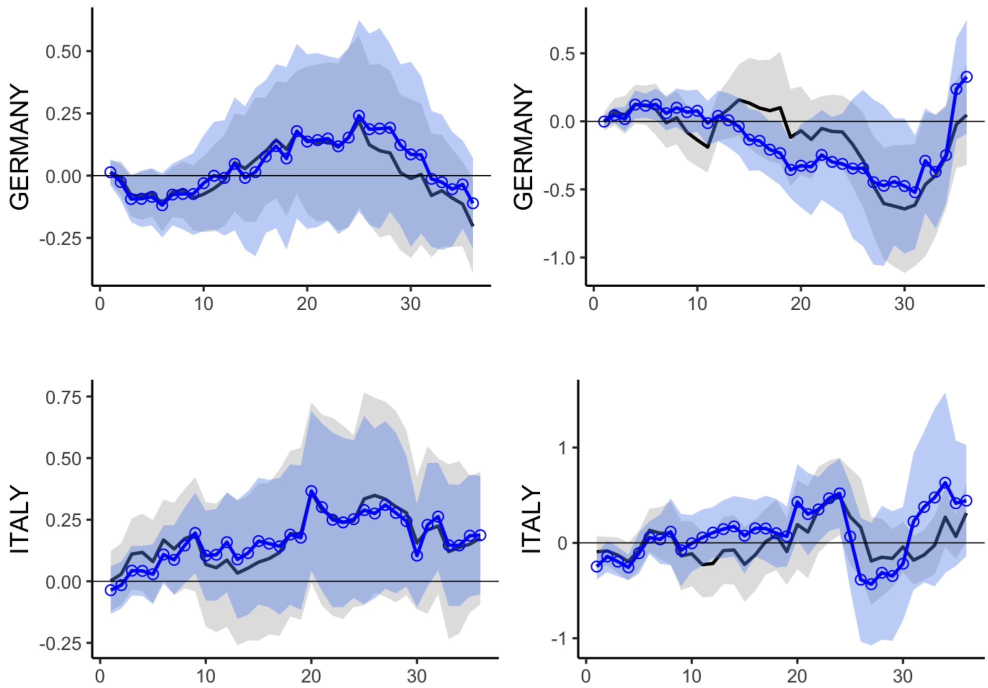


Figure 2: Response of loans to a monetary policy shock, normalized to represent monetary easing. Panel (a) shows the average effect, β_1^h, from the LP in equation 3.1, while panel (b) shows the effect conditional on a 1SD increase in excess liquidity, β_2^h. Y-axis is expressed in %. The blue circled lines and the blue shaded areas represent the IRFs and the 90 percent CI for the baseline sample, respectively. The black solid lines and gray shaded areas represent the IRFs and the 90 percent CI for the sample extended to 2021m6, respectively.

Figure 2b plots the estimate of β_2^h, which captures the interaction between the monetary easing shock and the level of excess liquidity.[19] We find that when the measure of excess liquidity in Germany is one standard deviation above its sample mean, the effect of a monetary shock on lending is dampened by up to 50 basis points relative to the mean case. In contrast, when excess liquidity increases in Italy, loans also increase in response to a monetary easing. The effects have a significant maximum peak of around 50 basis points.

[19]More precisely, Figure 2 plots the difference between the impulse responses to a monetary shock when our measure of excess liquidity is at its sample mean and when it is one standard deviation above the sample mean.

To further investigate this divergent empirical result, we build a model that incorporates important elements of the implementation of QE in the euro area.

4 Model

We consider a monetary union consisting of two countries indexed by $k \in \{A, B\}$, where $-k$ denotes the respective other country.[20] 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. 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 liquidity that fulfilling reserve requirements is not a binding constraint.[21] In order to capture the heterogeneous distribution of this excess 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.

4.1 Households

The infinitely lived household k consumes, saves, and supplies labor to intermediate goods firms.[22] Household k seeks to maximize its expected discounted lifetime utility. Its objective function is

$$\max \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[ln \left(C_\tau^k - \Psi_k C_{\tau-1}^k \right) - \frac{\chi_k}{1+\varphi_k} (N_\tau^k)^{1+\varphi_k} \right] \right] , \tag{2}$$

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 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.

[20] Note that all variable definitions from the previous section do not apply to the model section.

[21] Other 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.

[22] We use the superscript k for variables the households chooses, while the subscript k denotes variables and parameters exogenous to household k.

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 consumption index is given by

$$C_t^k \equiv \frac{\left(C_{k,t}^k\right)^{1-\sigma_k}\left(C_{-k,t}^k\right)^{\sigma_k}}{(1-\sigma_k)^{1-\sigma_k}(\sigma_k)^{\sigma_k}} \,, \tag{3}$$

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

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

with $C_{k,t}^k(j)$ denoting consumption of the domestic good j and $C_{-k,t}^k(j)$ denoting consumption of the foreign good j. 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

$$\int_0^1 P_{k,t}(j)C_{k,t}^k(j)dj + \int_0^1 P_{-k,t}(j)C_{-k,t}^k(j)dj + B_t^k = (1+i_{t-1})B_{t-1}^k + W_{k,t}N_t^k + \Upsilon_{k,t} \,. \tag{5}$$

The left-hand side (LHS) of equation (5) describes the household's nominal expenses. 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 $\Upsilon_{k,t}$ from the ownership of firms and banks.

Expenditure minimization implies that the household's optimal consumption of the domestic and the foreign good j is given by

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

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. Optimal consumption of domestic and foreign goods is

$$C_{k,t}^{k} = (1-\sigma_k)\left(\frac{P_{k,t}}{P_{k,t}^{C}}\right)^{-1} C_t^k, \qquad C_{-k,t}^{k} = \sigma_k \left(\frac{P_{-k,t}}{P_{k,t}^{C}}\right)^{-1} C_t^k, \tag{7}$$

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

$$P_{k,t}^{C}C_t^k + B_t^k = (1+i_{t-1})B_{t-1}^k + W_{k,t}N_t^k + \Upsilon_t^k \,. \tag{8}$$

In order to obtain the household's optimal labor supply and its optimal intertemporal consumption, we maximize equation (2) with respect to N_t^k, C_t^k, and B_t^k subject to equation (8). Denoting the marginal utility of consumption by

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

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

$$\chi_k (N_t^k)^{\varphi_k} = w_{k,t} U_{c,t}^k \,, \tag{9}$$

$$\beta(1+i_t)\,\mathbb{E}_t\left[\frac{P_{k,t}^{C}}{P_{k,t+1}^{C}}\right]\Lambda_{t,t+1}^{k} = 1 \,, \tag{10}$$

with

$$\Lambda^k_{t,t+1} \equiv \mathbb{E}_t \left[\frac{U^k_{c,t+1}}{U^k_{c,t}} \right] . \tag{11}$$

Equation (9) shows optimal labor supply with the real wage being defined as $w_{k,t} \equiv W_{k,t}/P^C_{k,t}$. Equation (10) 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 $V^k_{-k,t} \equiv P_{-k,t}/P_{k,t}$, we get that

$$P^C_{k,t} = P^{1-\sigma_k}_{k,t} \left(V^k_{-k,t} P_{k,t} \right)^{\sigma_k} = P_{k,t} (V^k_{-k,t})^{\sigma_k} , \tag{12}$$

and

$$\Pi^C_{k,t} = \Pi_{k,t} \left(\frac{V^k_{-k,t}}{V^k_{-k,t-1}} \right)^{\sigma_k} , \tag{13}$$

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 (10) and (11):

$$U^k_{c,t} = \vartheta_k (V^k_{-k,t})^{(\sigma_k - 1)} (V^{-k}_{k,t})^{(-\sigma_{-k})} U^{-k}_{c,t} , \tag{14}$$

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.

4.2 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

$$Y^k_{m,t} = \left(K^k_{t-1,t} \right)^{\alpha_k} \left(N^k_t \right)^{1-\alpha_k} . \tag{15}$$

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 $t-1$ 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 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 $L^k_{t,t+1} = Q_{k,t}K^k_{t,t+1}$ at the bank loan rate $i^L_{k,t}$ from bank k to buy the capital stock that is productive in $t+1$. The bank credits the respective amount as deposits, $L^k_{t,t+1} = D^{L,k}_{t,t+1}$, on the intermediate goods firm‘s bank account, i.e., as in Kumhof and Wang (2019), loans create deposits.[23] The corresponding objective function of intermediate goods firm k is given by

$$\max \Gamma^k_{m,t} = mc_{k,m,t}Y^k_{m,t} - w_{k,t}N^k_t - \left(1 + i^L_{k,t-1}\right) Q_{k,t-1}K^k_{t-1,t} + (Q_{k,t} - \delta_k)K^k_{t-1,t} \, . \quad (16)$$

Real profits are therefore determined by real revenues (due to perfect competition, intermediate goods firms sell their products at marginal costs. Real marginal costs are denoted by $mc_{k,m,t}$), real costs of labor and of loans for capital, and the payoff from the repurchase agreement. Solving (16) with respect to $K^k_{t,t+1}$ and N^k_t gives the following FOCs:

$$\left(1 + i^L_{k,t}\right) Q_{k,t} = \alpha_k mc_{k,m,t+1}\frac{Y^k_{m,t+1}}{K^k_{t,t+1}} + (Q_{k,t+1} - \delta_k) \, , \quad (17)$$

$$w_{k,t} = (1 - \alpha_k)mc_{k,m,t}\frac{Y^k_{m,t}}{N^k_t} \, , \quad (18)$$

equating the marginal costs of capital (equation (17)) and labor (equation (18)) to their respective marginal revenues.

4.3 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

[23] See Section 4.5 for details.

and Karadi (2011), it sells the refurbished capital and the newly produced capital, to the intermediate goods firm.[24]

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 $\delta_k K_{t-1,t}^k$:

$$I_t^{gr,k} = I_t^k + \delta_k K_{t-1,t}^k \, . \tag{19}$$

The law of motion for capital is thus given by

$$K_{t,t+1}^k = K_{t-1,t}^k + I_t^k \, . \tag{20}$$

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

$$\Gamma_{c,t}^k = Q_{k,t} K_{t,t+1}^k - (Q_{k,t} - \delta_k) K_{t-1,t}^k - \delta_k K_{t-1,t}^k - I_t^k - f\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}}\right)\left(I_t^k + I_{ss}\right) \, , \tag{21}$$

with

$$f\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}}\right) = \frac{n_k}{2}\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)^2 \, , \tag{22}$$

where n_k captures the degree of capital adjustment costs and I_{ss} is steady state gross investment. Equation (21) shows that the real period profit is given by the return from selling capital, the costs of buying and repairing the depreciated old capital as well as producing the new capital, and CAC. Considering equations (20), (21), and (22), the objective function of the capital producing firm becomes

$$\max \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} \beta^{\tau-t} \Lambda_{t,\tau}^k \left((Q_{k,\tau} - 1) I_\tau^k - \frac{n_k}{2}\left(\frac{I_\tau^k + I_{ss}}{I_{\tau-1}^k + I_{ss}} - 1\right)^2 \left(I_\tau^k + I_{ss}\right)\right)\right] \, . \tag{23}$$

[24]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 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 4.5).

The capital producer chooses net investment I_t^k to solve equation (23). The respective FOC is

$$Q_{k,t} = 1 + \frac{n_k}{2}\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)^2 + \frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} n_k \left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)$$
$$- \mathbb{E}_t\, \beta \Lambda_{t,t+1}^k \left(\frac{I_{t+1}^k + I_{ss}}{I_t^k + I_{ss}}\right)^2 n_k \left(\frac{I_{t+1}^k + I_{ss}}{I_t^k + I_{ss}} - 1\right) . \tag{24}$$

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.

4.4 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

$$\max \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} {\theta_k}^{\tau-t} \beta^{\tau-t} \Lambda_{t,\tau}^k \left(\frac{P_{k,t}(j)}{P_{k,\tau}^C} Y_{\tau|t}^k(j) - TC(Y_{\tau|t}^k(j))\right)\right] , \tag{25}$$

subject to the demand function

$$Y_{\tau|t}^k(j) = \left(\frac{P_{k,t}(j)}{P_{k,\tau}}\right)^{-\epsilon_k} Y_\tau^k , \tag{26}$$

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 FOC of the maximization problem given by equation (25) is

$$0 = \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} {\theta_k}^{\tau-t} \beta^{\tau-t} \Lambda_{t,\tau}^k Y_{\tau|t}^k(j) \left(\frac{P_{k,t}^*(j)}{P_{k,\tau}^C} - \frac{\epsilon_k}{\epsilon_k - 1} mc(Y_{\tau|t}^k(j))\right)\right] , \tag{27}$$

where the real marginal cost function is given by $mc(Y^k_{\tau|t}(j)) = mc_{k,m,\tau}$, 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

$$\frac{P^*_{k,t}}{P_{k,t}} = \frac{\epsilon_k}{\epsilon_k - 1} \frac{x_{k,1,t}}{x_{k,2,t}} , \tag{28}$$

where

$$x_{k,1,t} \equiv U^k_{c,t} Y^k_t mc_{k,m,t} + \beta\theta_k \, \mathbb{E}_t \left[\Pi^{\epsilon_k}_{k,t,t+1} x_{k,1,t+1} \right] ,$$

$$x_{k,2,t} \equiv U^k_{c,t} Y^k_t \left(V^k_{-k,t} \right)^{-\sigma_k} + \beta\theta_k \, \mathbb{E}_t \left[\Pi^{\epsilon_k - 1}_{k,t,t+1} x_{k,2,t+1} \right] .$$

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

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

4.5 Banks

Competitive bank k's assets in period t consist of one-period real loans granted at the end of period $t-1$, $L^k_{t-1,t}$, and real liquidity R^k_t, its liabilities of real deposits D^k_t. We assume that bank k grants loans solely to domestic firms, an assumption that is consistent with the high level of fragmentation of the euro area banking sector (Enria, 2023). Its balance sheet constraint is given by

$$L^k_{t-1,t} + R^k_t = D^k_t . \tag{29}$$

The total amount of liquidity R^k_t is splitted into required reserves $R^{RR,k}_t$ and excess liquidity $R^{EL,k}_t$, i.e.,[25]

$$R^k_t = R^{RR,k}_t + R^{EL,k}_t . \tag{30}$$

[25] We do not distinguish between excess reserves and excess liquidity (for the difference between excess reserves and excess liquidity see Section 1) as the distinction will only be relevant (i) if banks hold excess reserves and use the deposit facility simultaneously, and (ii) if excess reserves and funds held in the deposit facility are remunerated at different interest rates. However, this has generally not been the case in the euro area. At times when the DFR was positive, the rate on excess reserves was zero. Thus, banks did not hold significant amounts of excess reserves but used the deposit facility instead. At times when the DFR was negative, the rate on excess reserves equalled the DFR, and banks were indifferent whether to hold excess reserves or funds in the deposit facility.

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

$$D_t^k = D_{t-1,t}^{L,k} + \tilde{D}_{k,t} \cdot D_{k,t}^{QE} \ , \tag{31}$$

where $D_{t-1,t}^{L,k}$ represents the amount of deposits created through credit lending, $D_{k,t}^{QE} > 0 \ \forall \ t$ denotes the amount of deposits created through the central bank's large scale asset purchases and $\tilde{D}_{k,t}$ a potential excess liquidity shock following an AR(1) process.[26] The shock is modeled with the excess liquidity shock identified in Section 3 in mind. We will further comment on the properties of the shock and its relationship to excess liquidity and interest rates in Section 4.6.

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., $L_{t-1,t}^k = D_{t-1,t}^{L,k}$.[27] 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 pays principal and interest $(1+i_{k,t-1}^L)L_{t-1,t}^k$, and the respective deposits, that are remunerated at i_{t-1}, mature. Consequently, the loan $L_{t-1,t}^k$ and the deposits created through bank lending $D_{t-1,t}^{L,k}$ are extinguished.

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-

[26]Note that in our model an increase in reserves/liquidity results in a one-to-one increase in deposits. Refer to Section 4.6 for details.

[27]There exist two commonly known theories that describe the technical relationship between deposits and loans: "financing through deposit creation" and "intermediation of loanable funds". In the latter banks collect deposits (loanable funds) and lend those savings. Our model refers to the former theory. Banks create new deposits when granting loans. A survey of both theories can be found, for example, in Jakab and Kumhof (2019).

to-one increase in QE-created deposits and reserves (see also Acharya and Rajan, 2024), bank k's excess liquidity is given by

$$R_t^{EL,k} = \tilde{D}_{k,t} \cdot D_{k,t}^{QE} - r\left(\tilde{D}_{k,t} \cdot D_{k,t}^{QE} + D_{t-1,t}^{L,k}\right) , \tag{32}$$

i.e., it corresponds to the cumulated reserves created through central bank's asset purchases minus required minimum reserve holdings $r\left(\tilde{D}_{k,t} \cdot D_{k,t}^{QE} + D_{t-1,t}^{L,k}\right)$.[28]

Bank loans are remunerated at the rate $i_{k,t-1}^{L}$, required reserves at the rate i^{RR}, and excess liquidity at the rate i^{DF}.[29] The rates i^{RR} and i^{DF} 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}. 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 $\frac{1}{2}\upsilon_k\left(\mathbb{E}_t[D_{t+1}^k]\right)^2$. This captures the idea of existing agency and/or regulatory costs.[30]

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

$$\begin{aligned}\max \mathbb{E}_t[\Gamma_{b,t+1}^k] = i_{k,t}^L L_{t,t+1}^k + i^{RR} r\, \mathbb{E}_t[D_{t+1}^k] + i^{DF}\, \mathbb{E}_t[R_{t+1}^{EL,k}] \\ -i_t\, \mathbb{E}_t[D_{t+1}^k] - \frac{1}{2}\upsilon_k\left(\mathbb{E}_t[D_{t+1}^k]\right)^2 .\end{aligned} \tag{33}$$

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

$$i_{k,t}^L + r(i^{RR} - i^{DF}) = i_t + \upsilon_k\left(\mathbb{E}_t[\tilde{D}_{k,t+1} \cdot D_{k,t+1}^{QE}] + L_{t,t+1}^k\right) . \tag{34}$$

[28] A detailed explanation of the one-to-one increase in QE-created deposits and reserves is given in Sections 2 and 4.6.

[29] In the euro area, required reserves were remunerated at the MRO rate until December 2022, i.e., during the entire QE-period. From December 2022 until September 2023, they were remunerated at the DFR; since September 2023 they are no longer remunerated. Excess liquidity has always been remunerated at the DFR, except from the period between Octorber 2019 and September 2022, when a two-tier system applied.

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

If $i^{RR} > i^{DF}$, as it was the case in the euro area during the QE-period, the LHS of (34) will represent 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 liquidity holdings are shifted to the higher remunerated required reserve holdings. Crucially, a bank's marginal costs of granting loans are affected by the central bank's net asset purchases in two (opposing) ways: Positive net asset purchases (QE) decrease the bank's interest costs (i_t decreases), but increase its balance sheet costs ($\upsilon_k \tilde{D}_{k,t} \cdot D^{QE}_{k,t}$ increases). Conversely, if $i^{RR} < i^{DF}$ (QT-period),[31] the expression $r(i^{RR} - i^{DF})$ denotes additional marginal costs of granting loans and negative net asset purchases increase interest but decrease balance sheet costs.

4.6 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 during the QE-period. The central bank operates in a supply-driven excess liquidity environment. Therefore, the relevant short-term monetary policy rate (the DFR in the euro area) has already reached its effective lower bound. Consequently, QE is the central bank's main instrument to conduct expansionary monetary policy. By buying assets at a large scale, the central bank aims to directly lower the long-term interest rate relevant for consumption and investment (European Central Bank, 2015), which is i_t in our model. However, we do not explicitly model the asset purchases, but the corresponding increases in bank reserves instead. As the focus of this paper is the QE-induced heterogeneous distribution of liquidity in the euro area, which has mainly been the result of the fact that a large part of the Eurosystem's asset purchases were conducted with counterparties residing outside the euro area, we consider that each asset purchase always implies a

[31] During the QT-period, which started in the euro area in March 2023, i^{rr} either equalled i^{DF} or zero (see footnote 29). In both cases, there are no indirect interest revenues. If $i^{rr} = 0$, there will even be additional marginal costs of granting loans as the resulting reserve shifting is no longer beneficial but costly.

one-to-one increase in bank reserves.[32] Consequently, we model QE as an equally strong increase in bank reserves and deposits:

$$\mathrm{d}R_t^k = \mathrm{d}\left(\tilde{D}_{k,t} \cdot D_{k,t}^{QE}\right) . \tag{35}$$

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

$$D_{k,t}^{QE} = \Omega_k - \iota_k \left(1 + ln\left(\frac{1}{\beta}\right)\right) - \iota_k \phi_\pi \left(\gamma_k \pi_{k,t}^C + \gamma_{-k} \pi_{-k,t}^C\right) . \tag{36}$$

Equation (36) reveals that the central bank reacts to the weighted average of country-specific consumer price inflation rates, given by $(\gamma_k \pi_{k,t}^C + \gamma_{-k} \pi_{-k,t}^C)$, where $\pi_{k,t}^C \equiv ln(\Pi_{k,t}^C)$ and $\gamma_k = C_{SS}^k / \left(C_{SS}^k + C_{SS}^{-k}\right)$. 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.[33] Equation (36) shows that if the central bank observes a decrease in the average of consumer price inflation, it conducts QE, thereby increasing reserves and deposits in the monetary union. This implies that country-specific bank deposits $D_{k,t}^{QE}$ increase. How strongly these deposits increase 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 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 a country-specific calibrated parameter to match the share of QE-created deposits in the length of the bank's balance sheet.[34]

[32] See Section 2 for the institutional details.

[33] See European Central Bank (2020a) for detailed information.

[34] For more detailed information with regard to the calibrated parameters ι_k and Ω_k, see Section 5.1.

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

$$1 + i_t = \frac{\Omega_k - D_{k,t}^{QE}}{\iota_k} \,. \tag{37}$$

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. 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 long-term characteristics, and we assume that this rate is still above the lower bound, as it has actually been the case in the euro area. We thereby also capture the ECB's objective to decrease the long-term interest rate through QE. A further important property is the fact that the excess liquidity shock does not decrease the long-term interest rate. In reality, an increase in excess liquidity coincides with a decrease in the long-term interest rate. However, this specification of the shock allows us to identify the effect of an increase in excess liquidity on bank lending, which corresponds to the excess liquidity shock considered in Section 3.

We assume that all banks have a high stock of excess liquidity and thus of QE-created deposits in steady state. They can be interpreted as a result of past central bank asset purchases. The central bank therefore 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 buys less assets than mature or sells bonds, i.e., if its net asset purchases are negative (QT), monetary policy is contractionary. Besides conducting QE or QT, the central bank sets the nominal interest rates on commercial banks' required and excess liquidity holdings i^{RR} and i^{EL}, respectively, and determines the ratio for banks' required reserve holdings r.

4.7 Equilibrium

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

$$B_t^k = -B_t^{-k} \, , \tag{38}$$

i.e., bonds are in zero net supply. Final goods are consumed by households in the union and used to adjust capital:[35]

$$Y_t^k = C_{k,t}^k + C_{k,t}^{-k} + I_t^{gr,k} + \frac{n_k}{2}\left(\frac{I_t^k + I_{ss}}{I_{t-1}^k + I_{ss}} - 1\right)^2 \left(I_t^k + I_{ss}\right) \, . \tag{39}$$

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

$$Y_{m,t}^k = Y_t^k \, . \tag{40}$$

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

$$\left(\frac{Y_t^k}{{K_{t-1,t}^k}^{\alpha_k}}\right)^{\frac{1}{1-\alpha_k}} \Delta_t^k = N_t^k \, , \tag{41}$$

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

$$L_{t,t+1}^k = Q_{k,t} K_{t,t+1}^k \, . \tag{42}$$

Lastly, the real interest rate is determined by the Fisher equation:

$$i_{k,t}^{real} = i_t - \mathbb{E}_t \left[\pi_{k,t+1}^C\right] \, . \tag{43}$$

[35] Note 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.

5 Model Analysis

In this section, we discuss the macroeconomic consequences of an excess liquidity shock and derive the reverse bank lending channel. Before analyzing the model responses, we state the calibration strategy.

5.1 Calibration

The calibration of our model for the QE-period is depicted in Table 1. We comment on the calibration for the QT-period in Appendix B. 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 liquidity 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 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.[36] 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, see equation (37)), we draw from the work of Urbschat and Watzka (2020), 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

[36] The respective data can be found at Deutsche Bundesbank (2024) and Banca d'Italia (2024). While these deposits cannot solely be attributed to asset purchases under QE, we calibrate our model under this assumption. This assures that the calibrated balance sheet costs per unit of deposits constitute a lower bound.

bond yields, are more likely to be prone to influences independent of the asset purchases of the ECB.

	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)
		Firms		
δ_K	Capital Depreciation Rate	0.0143	0.0136	Albonico et al. (2019)
n_k	Capital Adjustment Cost Parameter	0.31	0.19	Relation of CAC: 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
$\rho_{\tilde{d},k}$	Excess Liquidity 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: Rate on Main Refinancing Operations
i^{DF}	Excess Liquidity Interest Rate	$-\frac{0.005}{4}$	$-\frac{0.005}{4}$	ECB: Rate on Deposit Facility
υ_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.

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.

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 until June 2022. Note that we use these values as our analysis primarily focuses on the QE-period with positive net asset purchases. 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 (2024a,b).[37]

We now turn to a comparison of the steady state with data. Table 2 shows several data points and the corresponding steady state values of our model. The steady state closely replicates the relative capital stock of Germany to Italy (1.14 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%). 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)	1.31	OECD (2024b)	1.26
Relative Average (Annual) Salary: Germany (A) to Italy (B)	1.36	OECD (2024a)	1.26
Consumption Share Germany (A) in Overall Consumption (Germany (A) + Italy (B)), Taylor Rule Parameter	0.66	The World Bank (2024)	0.65
Relative Capital Stock: Germany (A) to Italy (B)	1.14	University of Groningen and University of California (2024a,b)	1.24
Investment Share in GDP: Germany (A)	0.225	CEIC (2024a)	0.256
Investment Share in GDP: Italy (B)	0.170	CEIC (2024c)	0.247
Consumption Share in GDP: Germany (A)	0.506	CEIC (2024b)	0.744
Consumption Share in GDP: Italy (B)	0.608	CEIC (2024d)	0.753
Average (Annual) Interest Rate of New Loans to Corporations: Germany (A) 2017 − 2020	1.22%	European Central Bank (2024a)	1.22%
Average (Annual) Interest Rate of New Loans to Corporations: Italy (B) 2017 − 2020	1.40%	European Central Bank (2024b)	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 (2024)	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 (2024)	2%

Table 2: Steady State in Comparison to Data.

Moreover, the model slightly understates labor income inequality between Germany and Italy (1.36 to 1.26), and closely replicates relative GDP per capita of Germany to Italy (1.31 to 1.26). In addition, the parameter relevant for weighting consumer price inflation in country A and B in the Taylor rule, γ_k, is very close to the data-equivalent in steady state (0.66 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%).

[37] Equation (34) implies that the steady state loan rate of competitive banks can solely be determined by the level of balance sheet costs for given policy rates.

5.2 The Reverse Bank Lending Channel

We continue by examining the model responses to a positive one percent shock to excess liquidity in both countries.[38] All results are deviations from the zero inflation steady state. The shock leads to an increase in excess liquidity, deposits, and balance sheet costs in both countries. This increase in costs translates into a decrease of loan supply and an increase in the loan interest rate. Investment and capital decrease, as do aggregate demand and, thereby, output and inflation. In order to mitigate the effects of the shock, the central bank conducts QE, thereby simultaneously decreasing the bond rate and further increasing QE-created deposits. The decrease in the bond rate decreases banks' costs. Thus, banks' costs are affected in two opposing ways: (i) the increase in QE-created deposits increases balance sheet costs, particularly due to the excess liquidity shock, and (ii) the decrease in the bond rate decreases interest rate costs due to general equilibrium effects.

The high excess liquidity in country A implies that (marginal) balance sheet costs are particularly high, leading the increasing effect on costs to outweigh the decreasing effect. Therefore, a reverse bank lending channel emerges, which leads to a decrease in bank loans after an increase in QE-created deposits in the high-liquidity country, as shown in Figure 3. In the low-liquidity country B, the decrease in the bond rate outweighs the increase in balance sheet costs. Thus, the effect of the shock is not only mitigated but the reaction in B's economy is reversed and loans increase after the shock. However, the reverse bank lending channel also has a negative impact on bank lending in country B, i.e., loans would increase more if deposits did not increase in B. Overall, output and inflation increase in the low-liquidity country, while decreasing in the high-liquidity country due to the stronger dampening effects of the reverse bank lending channel. The reverse bank lending channel, therefore, weakens expansionary effects of QE more strongly in country A than in B.

The model therefore replicates the empirical results discussed in Section 3. It further allows us to shed light on the effects of the reverse bank lending channel not only on loans but also on other macroeconomic outcomes. Furthermore, it provides two necessary conditions for the existence of the reverse bank lending channel: (i) balance sheet costs, implying that excess liquidity is costly, and (ii) financing through deposit creation, i.e.,

[38] Note that, technically, QE-created deposits increase by 1%, implying an increase of excess liquidity by $(1-r)\%$.

banks cannot use additional deposits and excess liquidity to grant more loans (except from the small incentive due to beneficial reserve shifting).

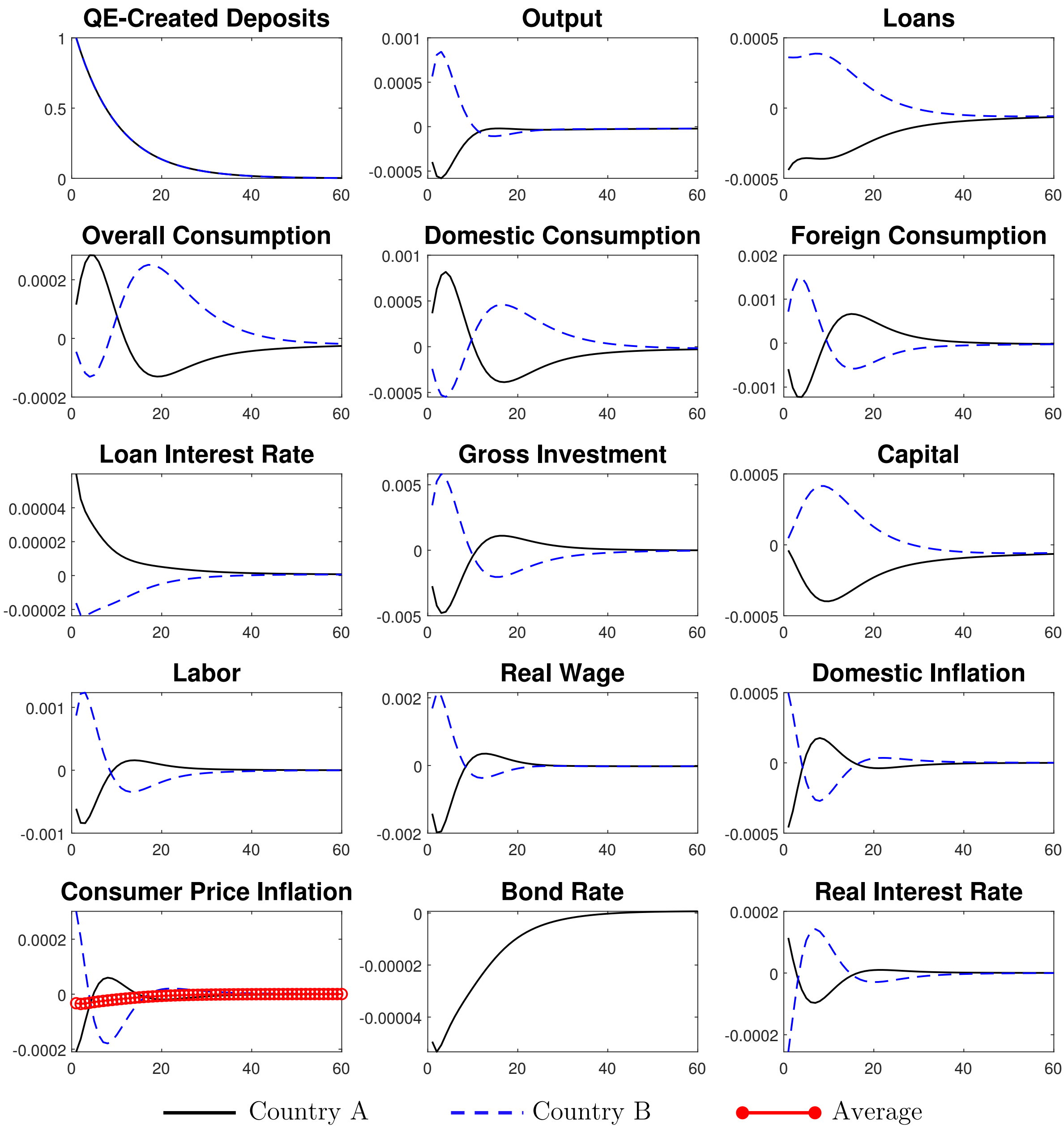


Figure 3: Impulse Responses to a Symmetric, Positive 1% Shock to QE-Created Deposits/Excess Liquidity.

We now extend our analysis past the QE-period.[39] In the face of the strongly increasing inflation rates in the euro area in 2022, the ECB started to increase its short-term interest

[39] We adjust the calibration to fit the corresponding time period. Refer to Appendix B for details.

rates. Furthermore, the ECB is decreasing the size of its balance sheet by not reinvesting maturing principal payments (negative net asset purchases, QT). Depending on how QT is implemented, it implies a heterogeneous decrease in deposits and excess liquidity across euro are countries. In particular, excess liquidity will decrease more strongly in country A than in B.[40] We simulate the effect of a QT-induced decrease in deposits and, thereby, excess liquidity. The results are shown in Figure 4. QT implies a decrease in balance sheet costs, as the length of banks' balance sheets decreases. This decrease is larger in A than in B. The general-equilibrium effect of an increasing long-term interest rate simultaneously implies higher costs for banks. The decrease in balance sheet costs outweighs the increase in interest costs in country A, vice versa for B. Therefore, the reverse bank lending channel implies that the contractionary effects of QT are weakened, more strongly so in A than in B.

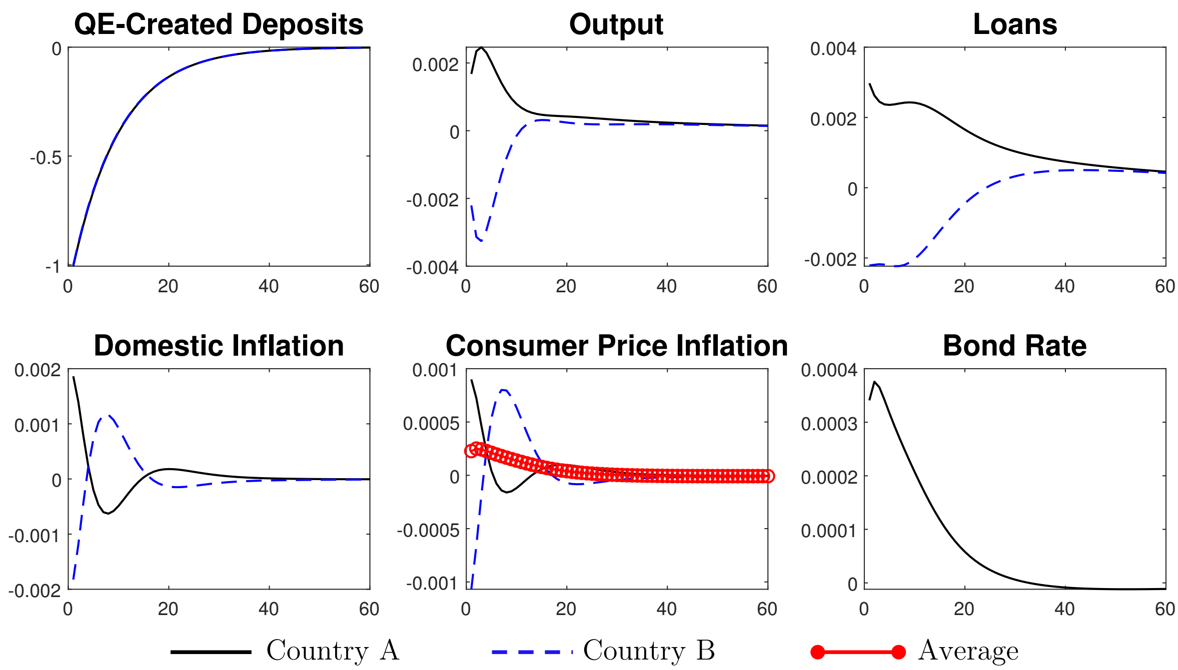


Figure 4: Impulse Responses to a Symmetric, Negative 1% Shock to QE-Created Deposits/Excess Liquidity.

[40]The following requirements need to be met for the reverse bank lending channel to heterogeneously dampen the efficacy of QT: (i) If the ECB continues to solely decrease its balance sheet by not reinvesting maturing principal payments from bonds, countries will continue to issue bonds which are, in parts, purchased by counterparties outside the euro area, or (ii) if the ECB starts to actively sell bonds, parts of these transactions will be conducted with counterparties outside of the euro area.

6 Summary

The Eurosystem's QE-program, which started in October 2014, implied a large increase in excess liquidity in the euro area banking sector. This large quantity of excess liquidity 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, so far there is little analysis of the impact of QE-induced increases (QT-induced decreases) of banks' excess liquidity and deposits on the effectiveness of monetary policy.

Against this background, our paper first empirically analyzes how bank lending responds to monetary policy shocks depending on the country's level of excess liquidity using LP techniques. While the transmission is amplified in a low-liquidity country like Italy, bank lending is dampened in a high-liquidity country like Germany. Using a New Keynesian model, we argue that these empirical observations can be explained by a *reverse bank lending channel*: A QE-induced increase in banks' excess liquidity and deposits implies an expansion in bank balance sheets, leading to increasing bank balance sheet costs. These increasing bank balance sheet costs outweigh the decreasing bank interest costs implied by QE when excess liquidity is large.

Consequently, our model shows that QE-(QT-)induced increases (decreases) in excess liquidity and deposits dampen the stabilizing effects of monetary policy on the economy and that these dampening effects differ across countries due to the asymmetric distribution of excess liquidity and bank deposits as a consequence of the specific technical implementation of QE/QT in the euro area.

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Appendix

A Alternative monetary policy shocks

A.1 Altavilla et al. (2019)

Similar to Miranda-Agrippino and Nenova (2022), Altavilla et al. (2019) extract monetary policy surprises, providing a continuous measure of market surprises that primarily affect long-term interest rates. This monetary policy surprise is often used as an external instrument to capture monetary easing effects (see, among many others, Lenza and Slacalek, 2024). Re-estimating the LPs in equation 3.1 and replacing the monetary policy shock with that of Altavilla et al. (2019) yields impulse responses shown in Figure A.1. The effects of monetary policy on loans conditional on excess liquidity are similar to those in Figure 2, with β_2^h being significantly negative over the horizon for Germany and positive for Italy.

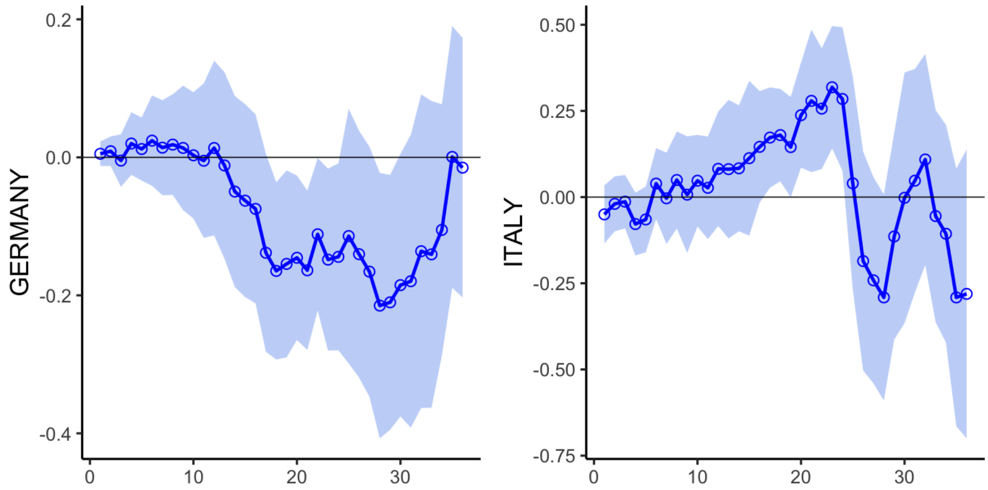

Figure A.1: Response of loans to a monetary policy shock as identified by Altavilla et al. (2019), normalized to represent monetary easing, conditional on a 1 SD increase in excess liquidity, β_2^h. Y-axis is expressed in %. The blue circled lines and the blue shaded areas represent the IRFs and the 90 percent CI for the baseline sample, respectively.

A.2 Sign Restrictions

In this section, we identify policy shocks using a straightforward monthly vector autoregressive (VAR) model. In particular, we disentangle a standard policy shock (i.e., one that primarily affects short rates) from a non-standard shock (one that primarily affects longer rates) by applying sign and zero restrictions. The latter serves as an alternative shock to Altavilla et al. (2019) and Miranda-Agrippino and Nenova (2022) for estimating the impulse responses of loans via LPs, as seen in equation 3.1. The identification restrictions are similar to those of Deroose (2021).

A linear vector autoregressive data generating process (DGP) of finite order p can be expressed as

$$y_t = \Pi_1 y_{t-1} + ... + \Pi_p y_{t-p} + u_t, \tag{A.1}$$

where the intercept is suppressed for convenience and $y_t = (y_{1t}, ..., y_{Kt})'$ is a $(K \times 1)$ vector of endogenous variables for $t = p+1, ..., T$. $\Pi_i, i = 1, ..., p$, are $(K \times K)$ coefficient matrices, and $u_t = (u_{1t}, ..., u_{Kt})'$ is a $(K \times 1)$ vector of independent and identically distributed white noise residuals. The VAR process can be written in its structural form as

$$A_0 y_t = \Gamma_1 y_{t-1} + ... + \Gamma_p y_{t-p} + \varepsilon_t. \tag{A.2}$$

Here, the $(K \times 1)$ vector of zero mean structural shocks, ε_t, is serially uncorrelated with a diagonal variance covariance matrix $\Sigma_\varepsilon = E(\varepsilon\varepsilon')$ of full rank such that the number of shocks coincides with the number of variables (Kilian and Lütkepohl, 2017). The matrix A_0 reflects the structural impact matrix, which captures the impact effects of each of the structural shocks on each of the model variables. The relationship between structural shocks ε_t and reduced form shocks u_t is given by,

$$A_0 u_t = \varepsilon_t. \tag{A.3}$$

Normalizing the covariance matrix of structural errors $E(\varepsilon\varepsilon') \equiv \Sigma_\varepsilon = I$, the reduced-form variance-covariance matrix is $\Sigma_u = A_0^{-1} \Sigma_\varepsilon A_0^{-1'} = E(uu')$. Given an estimate of this reduced form, all that is required to recover the structural model of Equation (A.3) is knowledge of the structural impact multiplier matrix A_0. Given that $u_t = A_0^{-1} \varepsilon_t$, the matrix A_0 allows us to express the typically mutually correlated reduced-form innovations u_t as weighted averages of the mutually uncorrelated structural innovation ε_t (Kilian and Lütkepohl, 2017).

The baseline VAR specification includes seven variables: two high-frequency surprise variables, namely the three-month OIS rate and the ten-year German government bond yield, and five monthly low-frequency variables, namely the three-month OIS rate, the ten-year German government bond yield, the Eurostoxx 50 stock market index in log

	Standard MP shock	Non-standard MP shock	Other
High-frequency variables			
3m OIS	> 0	0	0
10y DE	0	> 0	0
Low-frequency variables			
3m OIS, 10y DE, Eurostoxx 50, GDP, HICP			

Table A.1: Identifying restrictions

levels, euro area real GDP in log levels[41], the euro area total HICP in log levels. The VAR is estimated over a period from 2000m1 to 2019m12 (excluding the COVID-19 period, as suggested by Lenza and Primiceri (2022)). The high-frequency interest rate surprises are taken from the "Euro Area Monetary Policy event study Database" constructed by (Altavilla et al., 2019). The considered surprises are measured over the entire monetary policy window and summed to convert them into monthly variables.

To retrieve the structural parameters, we employ a mixture of zero and sign restrictions on the matrix A_0, which can be found in Table A.1.[42] The model is estimated in a Bayesian fashion with non-informative Normal-Wishart priors for estimation and inference (Uhlig, 1994, 2005). Given a draw from the posterior distribution of the reduced form parameters, we use the algorithm of Arias et al. (2018) to collect draws from the posterior distribution of the structural parameters. For details, see Uhlig (2005); Breitenlechner et al. (2019). The main distinction between a contractionary standard and a long-term yield compression shock is the sign imposed on the response of the yield curve (Goodhead, 2024). A standard monetary tightening shock pushes up the short-term rate, while an unexpected tightening of non-standard policy measures pushes up the long-term rate. The three-month OIS rate is chosen for the traditional monetary policy shock, and the yield on the ten-year German government bond is chosen to represent the safest long-term rate in the euro area, following Deroose (2021).

In this appendix, we focus on the shock, which captures all changes in monetary policy measures that primarily affect the long rate, in order to compare it with the surprises of Altavilla et al. (2019) and Miranda-Agrippino and Nenova (2022). As can be seen in Figure

[41]Monthly values of the quarterly GDP series are obtained by interpolation with the industrial production index. The interpolation follows the Chow and Lin (1971) procedure.

[42]As we are only interested in modeling a standard and non-standard monetary policy shock, we stay conservative in following Uhlig (2005) and leave other possible shocks uninterpreted.

A.2, the shock series is similar to those of Altavilla et al. (2019) and Miranda-Agrippino and Nenova (2022), showing the largest realizations of the yield curve movements in January 2015 and December 2015.[43]

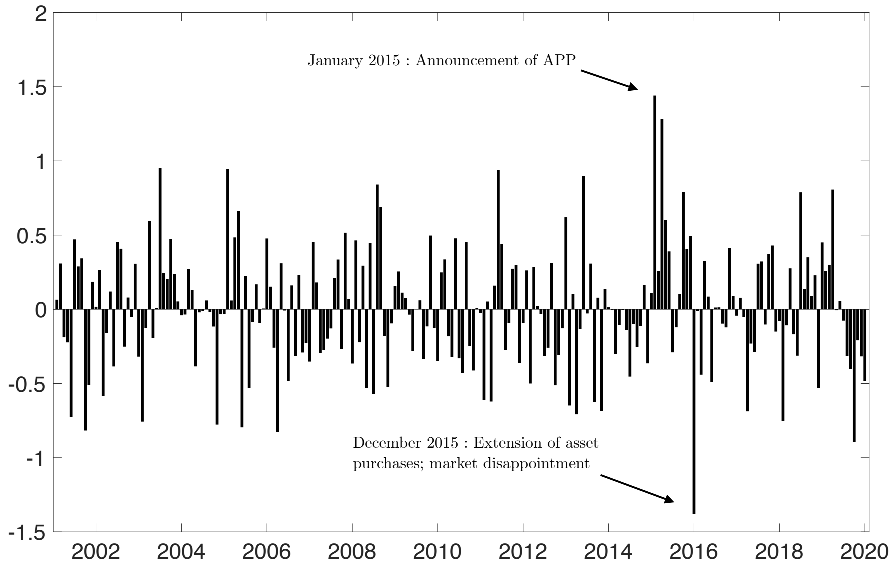

Figure A.2: Monetary policy shock, normalized to compress the long term yield.

Figure A.3 shows the responses of loans to a monetary policy shock as identified in this appendix, conditional on the level of excess liquidity. The IRFs are computed from LPs as in equation 3.1. Similar to the results presented in section 3, the transmission of monetary policy to loans is dampened in Germany, while it is enhanced in Italy, conditional on their excess liquidity holdings.

[43]Note: the shock is normalized so that it compresses the long yields.

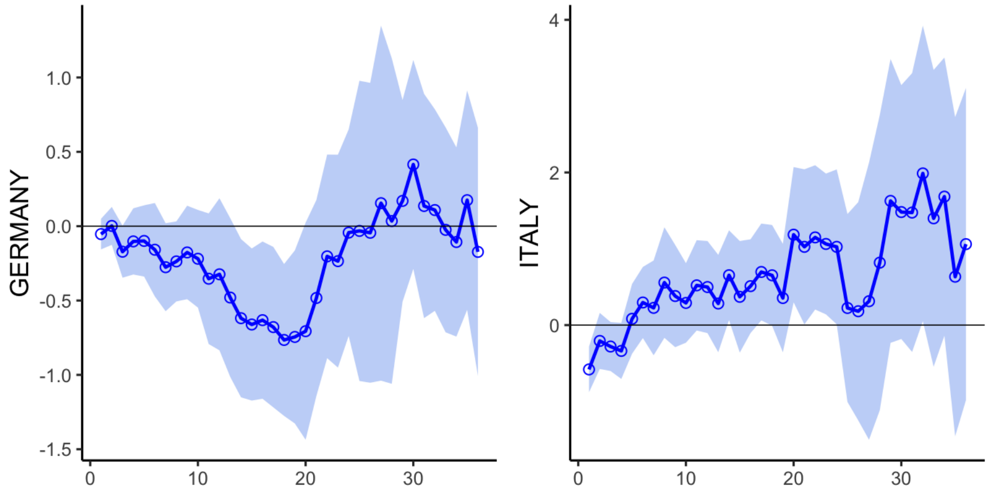

Figure A.3: Response of loans to a monetary policy shock identified by sign- and zero restrictions, normalized to represent monetary easing, conditional on a 1SD increase in excess liquidity, β_2^h. Y-axis is expressed in %. The blue circled lines and the blue shaded areas represent the IRFs and the 90 percent CI for the baseline sample, respectively.

B Calibration for the QT-Period

	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	0.17	0.73	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)
		Firms		
δ_K	Capital Depreciation Rate	0.0143	0.0136	Albonico et al. (2019)
n_k	Capital Adjustment Cost Parameter	0.31	0.19	Relation of CAC: 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
$\rho_{\tilde{d},k}$	Excess Liquidity 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: Remuneration of Minimum Reserves
i^{DF}	Excess Liquidity Interest Rate	$\frac{0.04}{4}$	$\frac{0.04}{4}$	ECB: Rate on Deposit Facility
υ_k	Balance Sheet Costs	0.000159	0.000217	Interest Rate Germany: $\frac{0.0492}{4}$, Interest Rate Italy: $\frac{0.0501}{4}$, Internally Calibrated
ϕ_π	Inflation Response Taylor Rule	1.5	1.5	Galí (2015)

Table B.1: Adjusted Calibration for the QT-Period.

We slightly adjust our calibration to fit the QT-period. While most parameters stay the same, changes in the targeted moments (interest rates on loans) and monetary policy rates imply adjustments in internally calibrated parameters. In particular, we adjust the balance sheet cost parameter to match interest rates on newly granted loans in Germany in Italy in 2023. Furthermore, the ECB increased the rate on the deposit facility to 4% in September 2023. Simultaneously, the ECB decided to remunerate minimum reserves at 0% instead of following the main refinancing rate. Our calibration reflects these changes.

The implied steady state of this calibration can be found below. As we keep most of the model unchanged, the steady state is very similar to the QE-period model. We update the data used for comparison, based on the same sources. The model matched the data similarly well as during the QE-period.

Description	Value Data	Data Source	Value Model
Relative GDP/Capita: Germany (A) to Italy (B)	1.42	OECD (2024b)	1.26
Relative Average (Annual) Salary: Germany (A) to Italy (B)	1.42	OECD (2024a)	1.26
Consumption Share Germany (A) in Overall Consumption (Germany (A) + Italy (B)), Taylor Rule Parameter	0.65	The World Bank (2024)	0.66
Relative Capital Stock: Germany (A) to Italy (B)	1.14	University of Groningen and University of California (2024a,b)	1.24
Investment Share in GDP: Germany (A)	0.243	CEIC (2024a)	0.167
Investment Share in GDP: Italy (B)	0.218	CEIC (2024c)	0.162
Consumption Share in GDP: Germany (A)	0.513	CEIC (2024b)	0.863
Consumption Share in GDP: Italy (B)	0.586	CEIC (2024d)	0.838
Average (Annual) Interest Rate of New Loans to Corporations: Germany (A) 2023	4.92%	European Central Bank (2024a)	4.92%
Average (Annual) Interest Rate of New Loans to Corporations: Italy (B) 2023	5.01%	European Central Bank (2024b)	5.01%
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 (2024)	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 (2024)	2%

Table B.2: Steady State in Comparison to Data, QT-Period.