Quantitative Easing and Local Banking Systems in the Euro Area*

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[Link to most updated version]

Abstract

This paper studies the role of local banking systems in the propagation of ECB Quantitative Easing (QE) programs. I firstly document that local deposit markets are fragmented across country lines, but the assets held by banks backing the deposits are in more integrated markets. I then consider a multi-country New Keynesian model with heterogeneous banking sectors but common monetary policy. All banks can access collateral from the same union-wide asset market, using them to back liquid deposit liabilities that are issued locally. QE has real effects if it increases the quantity or quality of collateral available to the banking sector. I find that QE has a powerful effect across the currency union, raising output and inflation by 62bps and 60bps, respectively. The pass-through is very similar across countries, despite fragmented deposit markets, as all banks face the same reduction in the cost of collateral from the union-wide asset market. The overall impact increases significantly if the beginning of QE coincides with adjusting the policy rate rule to be a weaker counteracting force by making it less responsive to inflation.

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I. Introduction

In recent years, the ECB has increasingly relied on central bank asset purchases as the main monetary policy tool for achieving its mandate. Understanding how it impacts union-wide inflation is therefore of central importance to policymakers. Existing literature has primarily focused on how asset purchases are expansionary by raising the capacity of banks to lend to the private sector. In particular, asset purchases are seen to improve the lending capacity of banks in two ways: firstly by replacing risky assets on bank balance sheets with safe, liquid reserves, and secondly by bolstering the market value of assets purchased that are also held by banks, thereby enhancing bank net worth.

Although considerable attention has been given to the bank lending channel, what is less well understood is how QE transmits into the real economy through the liability side of banks. In particular, there is a lack of focus on the effect QE has on the ability of banks to provide liquidity services to households in the form of deposit liabilities.

The goal of this paper is to assess the role that liquidity provided by banks plays in the pass-through of central bank asset purchases into output and inflation in the Euro Area. Although banks undertake a variety of business activities, this paper focuses on the liquidity provision business, the line of business that constitutes the bulk of bank balance sheets. It involves the issuance of deposits, backed by assets of varying collateral quality. The collateral quality of an asset is the ability for banks to borrow short-term against it, in the event of facing deposit withdrawals. This banking function is important for the real economy because the liquidity service offered by deposits enhances private consumption. ECB QE programs interact with this line of business by providing banks with high quality collateral, namely reserves, against which they can issue new liquid liabilities to households.

I begin by documenting two key characteristics of the deposit provision business of banks. Firstly, deposit markets are highly fragmented across country lines. There is a lack of foreign presence in local markets, either through direct cross-border branching or the ownership of foreign subsidiaries, due to burdensome regulatory requirements. This opens the door to heterogeneity in local characteristics and so responses to union-wide monetary policy. Secondly, on the other hand, the collateral asset markets backing deposits are not fragmented but, in contrast, are much more integrated. A large portion of assets held are allocated to either reserves, debt securities or interbank lending, all of which are tradable assets.

To quantify the effect of asset purchasing programs union-wide, and the potential heterogeneity across countries caused by the segmentation observed in banking sectors, I develop a two-region New Keynesian model with heterogeneous banks. The modelling framework builds on the open economy New Keynesian setup of Clarida et al. (2002) by adding banks whose debt, termed deposits, provide liquidity services to domestic households. Intuitively, deposit holders value them for their liquidity as they are useful for making payments for consumption. More deposits is expansionary as their liquidity services are complementary to consumption. As deposits offer a liquidity service to households, they are willing to accept a lower interest rate to receive this service. This makes them a cheaper source of funding and so banks would ideally fund themselves entirely with deposits.

The issuance of deposits, however, is limited by the leverage constraint. Banks can only issue deposits if backed by collateral that they hold. The higher the supply and quality of these assets held, the more deposits they can issue. Collateral is provided by both the private sector, such as firm loans, as well as the central bank in the form of reserves. This is where central bank asset purchases matter: it changes the supply of collateral available to banks to back deposits.

The model captures the collateral channel of asset purchases: buying privately held assets in exchange for reserves adjusts the supply of collateral for banks. From the perspective of banks, central bank reserves are the highest quality collateral, but they also use private sector assets, such as firm equity or firm loans, as collateral to back deposits. When the central bank engages in asset purchases, it sells reserves in exchange for private sector assets, thereby affecting the composition of available collateral to banks. The worse the collateral quality of assets purchased, the larger the increase in quality-adjusted collateral supply, thereby enhancing the ability of banks to issue more deposits to households. More deposits then enhances consumption in the local economy due to the consumption-deposits complementarity.

The strength of the collateral channel depends on model parameters that are carefully chosen. I begin with three key steps. Firstly, I observe that the ECB mainly purchased assets from non-bank investors during QE, and is defined so in the model. This matters because, from the perspective of banks, QE is an outright increase in collateral supply, not merely a swap of poorer into higher quality collateral. Secondly, I obtain bank leverage from country-level banking statistics. This determines how many new deposits are issued with the new collateral supply. Finally, in order to understand the degree of complementarity between deposits and consumption, I estimate deposit demand elasticities using long time-series data. I find that deposit demand is quite inelastic to its price, implying a significant degree of complementarity.

I determine remaining model parameters and structural shocks using Bayesian estimation. I estimate the model with data on nine variables: five macro variables (output and inflation per region plus the policy rate) and four financial sector variables (deposit spread per region, private collateral quality, reserve supply), for the period January-1999 to March-2020 i.e. since the inception of the Euro. The deposit spreads capture the degree of scarcity in deposit supply, while the latter two observables capture the variation in the supply of collateral available to banks to back deposits. The idea here is to capture how shocks to collateral supply in the form of reserves channels through the banking sector and into the macro variables. The estimated parameters that govern the strength of the pass-through are those that determine a) the degree of complementarity between consumption and deposits, and b) the stochastic process of QE shocks.

The sample period is split into two based on the prevailing monetary policy framework of the time: the scarce reserves regime (1999-2014) vs. the ample reserves regime (2015 onwards). The ample regime is one where asset purchases financed by reserves are an active part of the central bank toolkit. In this regime, reserves supply can be set independently of the policy rate on reserves. This is in contrast to the scarce regime where reserves supply is not a separable policy tool but instead is endogenously determined to implement policy decisions on two rates: the interbank (MRO) rate and the reserves rate (overnight deposit facility). This distinction in regime is important because only in the ample regime is asset purchases a feasible policy tool.

My modelling framework allows for both types, where I show that the differences can be summarized simply as a different rule on reserve supply. I then decide that the structural break in regime from a scarce to an ample one occurs in early 2015 at the beginning of the ECB's Public Sector Purchasing Programme (PSPP), the main asset purchasing program undertaken pre-COVID-19. As a result, I estimate the parameters governing the QE shock process in the ample regime sub-sample alone, with the rest of the parameters estimated using the scarce regime sub-sample.

My estimation uses as many structural shocks as target variables. This allows me to fully explain the variation in the target variables within my sample period through the lens of my log-linearized model, and in particular understand the contribution made by the variation in central bank reserves. As a preliminary step, I find that the historical decompositions of macro variables, and the estimates of key preference and policy parameters, are broadly in line with existing Euro Area literature.

I find that QE policy between 2015 and 2018 raised union-wide output by up to 60bps and inflation by 62bps, peaking in the year 2017. The ECB's program involved an expansion of the central bank balance sheet by over 40% of quarterly GDP. As this was used to finance purchases of assets against mostly non-bank counterparties, this had a large effect on the supply of collateral for banks. By boosting the supply of deposits offered by banks, this had an expansionary effect because the liquidity service offered by deposits complements consumption. This counteracted the negative supply shocks driven by the decline in collateral quality of non-reserve assets in the Periphery.

The effect of QE is broadly similar across regions, despite the fragmented deposit markets and heterogeneous deposit demand elasticites across regions. Crucially, this is because of the integrated collateral market, in particular the market for reserves. As banks in either region can access central bank reserves at the same price, then the marginal cost of collateral is equated across regions. As a result, if there is a negative shock to the supply of collateral originating from one region, this scarcity increases the demand for reserves in that region. This drives up the price of reserves and so the marginal cost of collateral for all banks, causing the scarcity to be felt equally union-wide. This means that, although the transmission mechanism depends on the collateral quality and counterparty of assets purchased, the geographical location of the assets held is irrelevant.

The size of the impact of QE purchases on output and inflation in the currency union is bolstered if the Taylor rule is less responsive to inflation. The Taylor rule parameters are estimated from the first scarce regime sub-sample. I use these estimates within the ample regime as my baseline. However, QE was implemented within a period where forward guidance was also actively used. Indeed, this motivated Andrade et al. (2016) and Coenen et al. (2018) to consider the impact of ECB QE when the policy rate is temporarily unresponsive to inflation. Instead, I consider a counterfactual where I decrease the parameter governing sensitivity to inflation from the mode to the 5th percentile of the estimated posterior distribution. I find that aggregate responses rise to 80bps and 110bps for union-wide output and inflation, respectively. This stark increase in the inflation response, despite the Taylor principle still holding, is because inflation itself begins to replace a more passive Taylor rule as a stabilisation tool in response to asset purchases. Higher inflation dilutes the effect of a shock to nominal reserves on real reserve supply, which stabilises the economy in the longer run but at the expense of temporarily higher inflation today.

A. Related Literature

This paper adds to the existing literature that attempts to understand the impact of ECB asset purchases within a DSGE framework. The bulk of existing work focuses on how asset purchases operate through the bank lending channel: by buying risky assets from banks and replacing them with safe and liquid reserves, banks can use this renewed balance sheet capacity to extend credit to firms. Coenen et al. (2018) investigate this channel by firstly building on the ECB's workhorse DSGE framework described in Christoffel et al. (2008) and incorporating a detailed financial sector. Andrade et al. (2016) do similar analysis but instead apply the work of Gertler and Karadi (2013) to the Euro Area context.[1] I instead focus on the collateral channel. By supplying banks with high quality collateral, they can

[1] Burlon et al. (2016) do similar analysis but instead focus on asset purchases being effective because of financial segmentation rather than through net worth constraints.

issue new liquid liabilities that are valuable to households. The mechanism also strengthens significantly with a slightly less responsive Taylor rule, but not necessarily one that needs to face a zero lower bound constraint.

More generally, less focus has been given to understanding how asset purchases impact the macro economy through the liability side of bank balance sheets. De Fiore et al. (2019) show how asset purchases flood the interbank market with liquidity that dampens spillovers caused by shocks to money markets, where the type of shocks are motivated by recent observations concerning the interbank funding market within the Euro Area.[2] This paper instead considers a different liability issued by banks - deposits - and abstracts from banks experiencing unfavourable liquidity shocks. The liquidity service offered by them is important to households. Asset purchases help the banks issue deposits because a by-product of the purchases is a release of high-quality collateral (reserves) that can back deposit issuance.

This paper contributes to a large literature concerning New Keynesian models with financial frictions, dating back to Bernanke et al. (1999). More recent work, motivated by the financial crisis, has paid more attention to frictions in the banking system as sources of amplification, as in Gertler and Karadi (2011), Christiano et al. (2012) and Wang (2018), amongst others. Bocola (2016) considers the impact induced by the exposure of Euro Area banks to sovereign debt amidst the sovereign debt crisis. This paper takes a different approach by abstracting from net worth constraints and assuming no equity adjustment costs. Given the major push within the EU to shore up the capital buffers of banks via the Bank Recovery and Resolution Directive (BRRD), to some success, it is worth understanding how QE works when banks are in fact well-capitalised. Instead, the friction here is a scarcity of collateral assets that can be used to back the medium of exchange. The goal here is to isolate the collateral channel of asset purchases, and understand how it transmits into the real economy.[3]

This paper adds to the literature on the cost channel of interest rates, in other words, the appearance of interest rates directly in the marginal cost of firms. The interest rates traditionally appear in level terms, based on the need to prepay working capital (see Christiano et al. (2005) and Ravenna and Walsh (2006)). Instead, I have interest rates appearing in the form of spreads. Firstly, the deposit spread positively affects marginal cost through the complementarity of deposits and consumption. Higher deposit spreads reduce deposit demand, lowering consumption demand because of the complementarity. This reduces the desire to supply labour to finance the purchasing of goods, thereby driving up wages. Secondly, the collateral premium on loans reduces the marginal cost of firms. In my setup,

[2]For a detailed discussion regarding recent trends in Euro Area money markets, see Corradin et al. (2020).

[3]In future work, I wish to incorporate the bank net worth channel in order to assess its relative importance to the collateral channel by having the model match a larger set of observed targets that distinguish between the two mechanisms.

more output gives the firm access to a cheap source of additional funding in the form of bank loans. The "cheapness" is derived from the collateral value attached to firm loans by banks. Banks are therefore willing to lend at a lower rate, ceteris paribus.

Finally, this paper relates to the literature that incorporates a convenience yield on assets that back the medium of exchange, as in Lenel et al. (2019).[4] Similarly to Piazzesi et al. (2021), I allow for two types of regimes: one where reserves exhibit just a collateral premium (i.e. ample regime) vs. one where reserves also have a liquidity premium (i.e. scarce regime). In both regimes reserves are valuable because they back the issuance of the medium of exchange, deposits. In this paper, I add an international dimension and examine regions across the Euro Area. The collateral market for reserves turns out to be very important: as it is accessible to all banks within the union, the effect of QE is broadly similar across countries despite fragmented local deposit markets.

The paper is structured as follows. Section 2 outlines the data sources used for the facts that I document regarding the banking sector in Section 3. The modeling framework is described in Section 4, followed up in Section 5 by a detailed analysis of the structural shocks considered. Section 6 outlines how the model is calibrated and estimated, using it to present the results of my main monetary policy counterfactuals.

II. Data

I demonstrate two key features of the banking sector within the Euro Area that motivate the subsequent modelling framework: (i) local deposit markets are fragmented, and (ii) the markets for assets backing these deposits are significantly more integrated. In order to do so, I utilise data sources that allow me to observe a detailed breakdown of bank balance sheets at the country level, splitting each component of assets and liabilities by residency and counterparty. Complementary bank-level data on customer deposits allows me to more convincingly argue the fragmentation of local deposit markets.

Throughout my analysis, I focus on six member states: Germany, France, Netherlands, Italy, Spain and Portugal, representing over 86% of Euro Area GDP. I divide the sample into two regions based on GDP levels: Core (France, Germany, Netherlands) vs. Periphery (Italy, Spain, Portugal).

A. ECB Balance Sheet Indicator (BSI) Database

Compiled by the ECB, the BSI database provides a monthly breakdown of bank balance sheets at the country level for each Euro Area member state, from 1999 to Present. It

[4] See, for example, Kiyotaki and Moore (2005) and Williamson (2012).

conveys a detailed split by residency and counterparty of the main asset classes held and liabilities issued.

Three entities report to the BSI: credit institutions, other deposit-taking corporations and money-market funds. Ideally, I would like to strip out money market funds as my focus is on deposit-taking institutions. However, this is not possible with the available data. Luckily, this is not a major issue as it consolidates less than 3% of the total assets of this reporting population, and is concentrated mostly in small country havens (Ireland and Luxembourg) that are not part of the central analysis.[5]

The BSI operates under a "host" residency principle, where an MFI parent only consolidates subsidiaries operating within the same country of residence.[6] This means that subsidiaries in separate countries are treated as different entities. This is crucial for my analysis as I want to understand how the banking sector looks like across countries, which requires me to split the operations of multi-country banking groups along country lines. This BSI Dataset achieves this.

I focus on the liquidity provision business of banks, which involves the issuance of deposits to the private sector, backed by assets of varying collateral quality. As a result, the key item of interest is deposits, which is defined by the BSI as any non-marketable liability instrument. Deposits are split by residency (domestic, intra-Euro Area (EA), outside EA) and counterparty (includes households, non-financial corporations, other financial institutions (OFIs), monetary financial institutions (MFIs)). Within MFIs, I can see if it is facing the central bank, intra-group entities or other MFIs. This granularity in counterparty will prove to be extremely important for deciphering banking sector characteristics later on.

Beyond deposits, the BSI database also exhibits useful details on many other balance sheet items, such as loans, debt, equity held and MMF shares held for assets, as well as debt issued and capital plus reserves on the liability side.

B. BvD Bank Orbis Dataset

Compiled by Bureau van Dyke, the Orbis Dataset contains yearly snapshots of balance sheet data at the bank level. This dataset is complementary to the BSI as it is at a more granular entity level but at the expense of less granularity in terms of balance sheet items. As a result, I will only be using the item "Customer Deposits" in my analysis, in other words, the stock of deposits issued to households and non-financial corporations. Conveniently, it contains unconsolidated balance sheets, meaning I can isolate the balance sheets of individual subsidiaries of banking groups operating in a country other than the location

[5]The MMFs are concentrated in a subset of countries, where (35%, 29%, 28%) are domiciled in France, Luxembourg and Ireland, respectively, representing (4%,27%,22%) of their respective MFI balance sheet.

[6]Residency is where the MFI's "centre of predominant economic interest is in that country".

Table I. Bank Balance Sheet Structure

Assets	Liabilities
Central Bank (CB) Reserves	Central Bank (CB) Borrowing
Interbank Lending	Interbank Borrowing
Debt & Equity Held	Debt Issuance
Loans	Deposits
Remaining Assets	Capital and Reserves
	Remaining Liabilities

of its parent. This will allow me to get a sense of market structure at the country level, as I will elude to later.

III. Empirical Results

I demonstrate two key characteristics of banking sectors within the Euro Area. On the one hand, local deposit markets are fragmented along country lines. On the other hand, the assets held by banks to back the issuance of these deposits are in more integrated markets within the Union. As these observations concern the liquidity provision business of banks that I care about, I must firstly construct the balance sheet of this line of business from the headline composition.

I begin by defining the basic structure of the bank balance sheet. Table I breaks it down based on the data available from the MFI BSI Dataset. From this structure, I construct the liquidity provision business of banks by taking the following two broad steps:

Step 1: Subtract from assets any liabilities that are explicitly senior to deposits.

If a liability is more senior to deposits, it implies that it has priority in repayment over deposits from the assets on the balance sheet, conditional on bank default. In the context of banks, these liabilities take the form of secured funding, where they have the exclusive claim to a certain set of assets on the bank balance sheet, and so are essentially repaid before deposits.[7] As a result, they act to synthetically induce leverage in underlying asset positions backing deposits.

Secured funding takes either of the following forms:

[7] In support of this argument, the seniority of secured liabilities over deposits is recognised in Article 44(2) of the Bank Recovery and Resolution Directive (BRRD). The BRRD outlines arrangements to be taken at the national level when banks fail.

(i) Central Bank Borrowing

The funding provided by the ECB operates under several strands. Firstly, they offer funding through their Main Refinancing Operations (MROs), which involves 2-week secured funding at the MRO policy rate. Secondly, the ECB lends to banks overnight at the Marginal Lending rate at a premium to the MRO rate. Thirdly, and more recently, the ECB lent long-term (3-4 years) on a secured basis via Long-Term Refinancing Operations (LTROs) as a way of mitigating funding uncertainty for European banks. As shown in Figure A.3, in recent times ECB lending has been done almost exclusively through LTROs, a form of secured funding.

(ii) Interbank Borrowing

This consists of deposits where the counterparties are other Monetary Financial Institutions (MFIs). It includes transactions with Central Counterparties (CCPs), which are part of OFIs within the BSI but represent secured transactions through a third party as an intermediary. As I am analysing banks at the country level, I exclude transactions within-country. The resulting amount of Interbank positions as a share of assets/liabilities is illustrated in Figure A.2. What I observe is that, on average, Interbank Borrowing encompasses 5% of total liabilities, and so is an important funding source.

A key characteristic of this funding source is that the vast majority of interbank funding is secured. As demonstrated in Corradin et al. (2020), over 95% of total interbank funding is now secured. As a result, it lies senior to deposits.

(iii) Secured Debt Issuance

An additional source of secured funding is through the issuance of secured debt. In the BSI, I observe the overall debt issuance, but not the secured vs. unsecured split. To garner estimates for this split, I turn to the reporting requirements made by all Significant Institutions (SIs) to the European Banking Authority (EBA).[8] According to the EBA Report on Funding Plans (2019), based on the SI reporting requirements, approximately 35% of long-term debt issuance is secured.

To understand this more deeply, I exploit the bank-level data on the secured-unsecured debt splits provided by all the SIs across the full set of maturities. They are split amongst Globally Systemically Important Banks (G-SIBs) and non-G-SIBs.

[8]According to the ECB, "they are a list of banks made by the EBA that are considered to be sufficiently large to exhibit systemic importance both nationally and globally within the Euro Area".

According to Veron (2017), as of end-2015, they represent over 85% of bank assets in the Euro Area, and so provides us with a good picture of debt issuance union-wide. Table II presents the results for end-2019. In column 2, we can see that the secured shares are, on average, higher in the Periphery vs. the Core. The driver of this is the difference in operations of non G-SIB banks. In column 3, we can see that, amongst G-SIBs, the secured share is very stable across countries, while for non-G-SIBs it is highly variable. Nevertheless, overall, secured shares are fairly stable across countries.

Therefore, I assume that the fraction of debt issued that is secured in the BSI is that in Column 2 of Table II.

Table II. Debt Issuance: Secured vs. Unsecured Share, 2019. Source: EBA

	Secured Bond Shares			G-SIB Share Agg. Debt
Country	Total	G-SIB	NonG-SIB	
Core				
France	23%	30%	12%	61%
Germany	30%	33%	26%	63%
Netherlands	22%	29%	13%	54%
Periphery				
Italy	29%	29%	30%	31%
Spain	38%	33%	54%	77%

Notes: The first column reports the secured bond shares of all Significant Insitutions. The second column shows the same shares, but splitting the sample into G-SIBs and Non-G-SIBs. The fourth column tells use the share of aggregate debt across all Significant Institutions attributed to G-SIBs.

(iv) Remaining Liabilities

According to the BSI, it incorporates a variety of elements, including financial derivatives positions.[9] Understanding the decomposition is not possible with the BSI data. However, the ECB publishes country-level statistics in the SUP Supervisory Banking Statistics dataset, which provides some degree of granularity in the Remaining Liabilities category. The key differences with the BSI are two-fold. Firstly, the universe of credit institutions is smaller in SUP, consisting of only G-SIBs, and other Significant Institutions (SIs), in contrast to the BSI that includes deposit-taking institutions of any size.[10]. Secondly, the SUP reports the balance sheets of consolidated banking groups, while the BSI reports at the unconsolidated level of the subsidiary.

Taking as given these differences, I compare the Remaining Liabilities in the BSI vs.

[9] It also includes accrued interest of deposits/loans, net amounts receivable / payable w.r.t. future settlement of transactions in securities or FX and other statistical discrepancies.

[10] In total, in 2019, there were 114 institutions in the SUP dataset, covering over 80% of bank assets within the Euro Area (Source: Veron (2020))

the SUP. Reassuringly, at the Euro Area-wide level, they are of comparable size as a share of Total Liabilities (10.5% in BSI vs. 12% in SUP in 2019). Within the SUP, we also see what portion is attributed to derivatives, which is 60% across the countries I consider. For the remaining 40% (4% of Total Liabilities in BSI), I analyse a sample of individual bank balance sheets to see what they may be attributed to.[11] There are a wide range of small items, but most notable are liabilities of groups for immediate disposal, along with leasing liabilities.

As financial derivatives positions are backed by collateral, and the remaining 4% consists mostly of items with seniority, I include the full amount in Step 1.

Step 2: Add to equity the liabilities that are explicitly junior to deposits

Intuitively, by being junior, they take any losses before deposits take a hit, therefore acting like a pseudo-equity buffer for deposits. This broader equity buffer, called "Baseline Equity" hereafter, consists of two elements:

(i) Capital and Reserves

This represents anything with an "entitlement to a share in its profits and in its residual value in the event of liquidation" (MFI BSI Manuel, p.88) It consists of, amongst other elements, equity capital raised and profits accumulated in the accounting period. This is essentially acting like an equity buffer for liabilities.[12]

(ii) Unsecured Debt Issuance

This is the Debt issuance net of the secured component. The Bank Recovery and Resolution Directive (BRRD) outlines arrangements to be taken at the national level when banks fail. In particular, it outlines clearly the order of seniority of liabilities. Bringing together a set of Articles, it implies that all deposits from households and non-financial corporations, and all deposits from OFIs with a maturity of less than or equal to 7 days, lie senior to unsecured debt.[13] This represents the vast majority of bank deposits. As a result, unsecured debt also acts like an equity buffer for deposits.

Following these two steps, I have the adjusted balance sheet of the liquidity provision business of banks, outlined in Table III. Secured liabilities consist of central bank borrowing, interbank borrowing and secured debt, Net Remaining Assets are Remaining Assets net of Remaining Liabilities, while Baseline Equity now consists of Capital and Reserves plus Unsecured Debt Issuance.

[11] This includes, for example, UniCredit and Commerzbank.

[12] Remaining elements are income and expenses recognised directly in equity and funds arising from income not distributed to shareholders.

[13] See Appendix D for details.

Table III. Liquidity Provision Business: Balance Sheet Structure

Assets	Liabilities
Central Bank (CB) Reserves	Deposits
Interbank Lending	Baseline Equity
Debt & Equity Held	
Loans	
Net Remaining Assets	
− Secured Liabilities	

Armed with this balance sheet, I now document two key characteristics that motivate how I describe banks in the model: Fact 1 on the deposit funding, and Fact 2 on the asset side of the balance sheet in Table III.

A. *Fact 1: Deposit Markets are Fragmented*

I illustrate that deposit markets are not integrated within the Union, but instead are quite fragmented across countries. In particular, foreign competition in the domestic deposit market is small. I demonstrate this through observing a lack of direct cross-border offering of deposits and a lack of presence of foreign-owned subsidiaries in domestic markets.

In short, foreign banks can participate in local deposit markets in two ways: (i) direct cross-border deposit offerings, or (ii) ownership of a subsidiary in that local market. I demonstrate a lack of either of these two components.

Firstly, banks source the vast majority of their household/NFC deposits from domestic entities.[14] Exploiting the BSI data on the residency of deposit counterparties, Figure 1 demonstrates the complete lack of sourcing of deposit funding from abroad. For each country, the dark blue portion signifies the share of deposits being sourced from non-resident households/non-financial corporations, while the light blue portion is for domestic entities. As noted by Kaffenberger and Wahrenburg (2015), this is largely a result of highly burdensome "Know Your Client" requirements for non-resident deposit sources. Emter et al. (2018) extend this observation to all non-MFI counterparties, using the BIS's Locational Banking Statistics. As a result, this leaves foreign subsidiaries as the only avenue for material foreign presence in the local deposit market.

Secondly, turning to this avenue, foreign-owned subsidiaries hold a small fraction of the domestic deposit market. To establish this, I exploit the bank-level data from the BvD Orbis Dataset, which provides me with data on the supply of customer deposits at the individual

[14] As shown in Figure A.1, the vast majority of deposits are from households and non-financial corporations, averaging over 85% for the sampled countries.

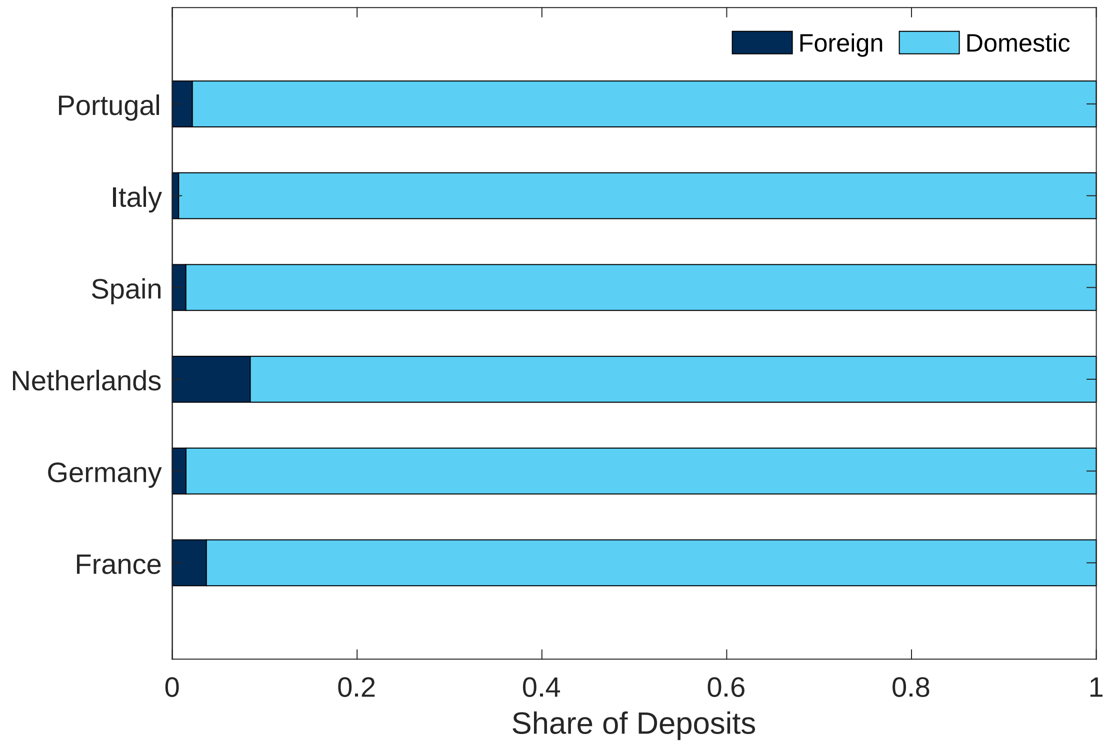

Figure 1. Split of households plus non-financial corporation deposits by residency of the depositor, in end-2019. Each country-level market on the y-axis includes local banks as well as foreign-owned subsidiaries operating in that local market. The dark blue region is the share of deposits sourced from non-resident deposit holders, while the light blue region is for domestic deposit holders.

bank/subsidiary level. I identify what entities are foreign entities, and then derive their market share of the overall local deposits market.[15] Results are shown in Figure 2 below, demonstrating the lack of foreign presence.

Therefore, I can conclude that deposit markets are fragmented across countries. This lack of harmonization sets the stage for local banking sectors to potentially react differently to common union-wide shocks.

B. Fact 2: Assets Held by Banks are in More Integrated Markets

Fact 2 turns to the asset side of the banks that back the issuance of deposits Figure 3 illustrates the decomposition of assets held by banks residing in that country. It splits asset holdings into the following categories: (i) domestic loans i.e. loans issued to domestic residents, (ii) non-domestic loans i.e. loans issued to foreign residents, (iii) tradable securities,

[15] It is of course important that the bank-level data, when aggregated, matches well the country-level data from the BSI. See Appendix C for details.

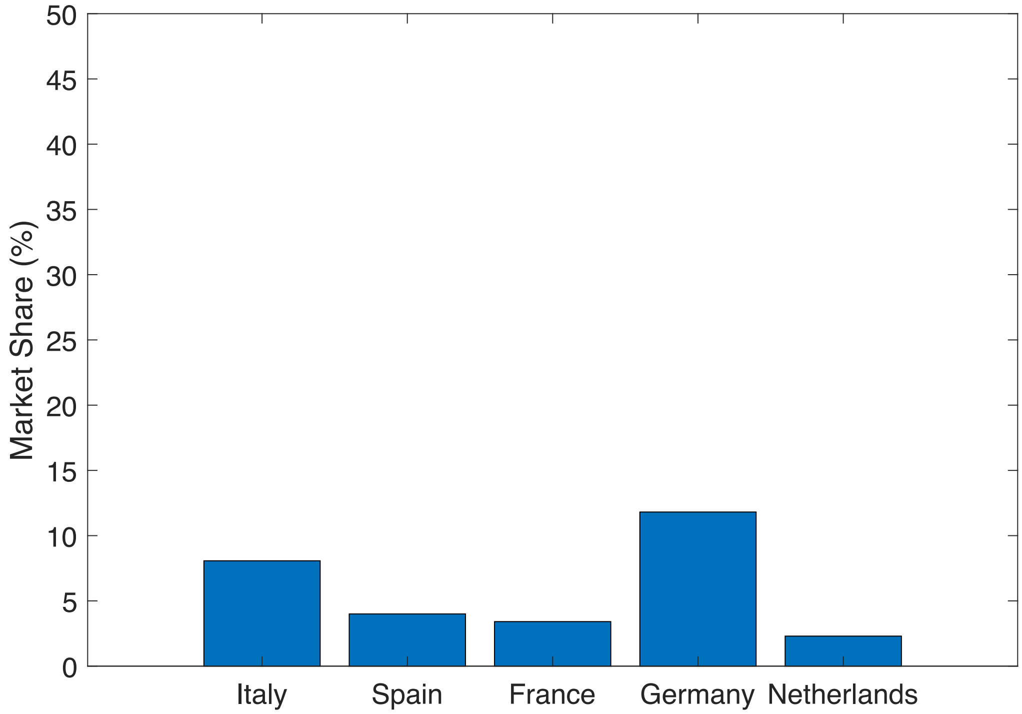

Figure 2. Market share of foreign-owned subsidiaries in the local customer deposit market, by country

which bunches together central bank reserves, interbank lending, debt securities held and equity held, (iv) remaining assets, and (v) secured liabilities, which are there to leverage up gross asset positions.

Tradable securities are a set of assets that, in theory, can be readily exchanged across banks in the Euro Area. In particular, reserves and interbank lending are short-term liquid assets traded across banks, while debt securities are defined by the BSI Dataset as assets that "can be traded or offset on secondary markets, or can be sold on the market". The decomposition of tradable securities is illustrated in Figure 4.

Examining Figure 4, what I find is that, in contrast to the deposit market that is fragmented along country lines, the asset side is significantly less concentrated on the domestic market, instead with a significant weight on tradable securities (50% of liabilities on average) that can, in theory, be exchanged across countries.[16]

Therefore, although deposit markets are fragmented, asset holdings are instead coming from more integrated markets.

[16]Note that, according to Figure 4, this is not mainly attributed to domestic government bonds, but instead is distributed across a wider set of assets.

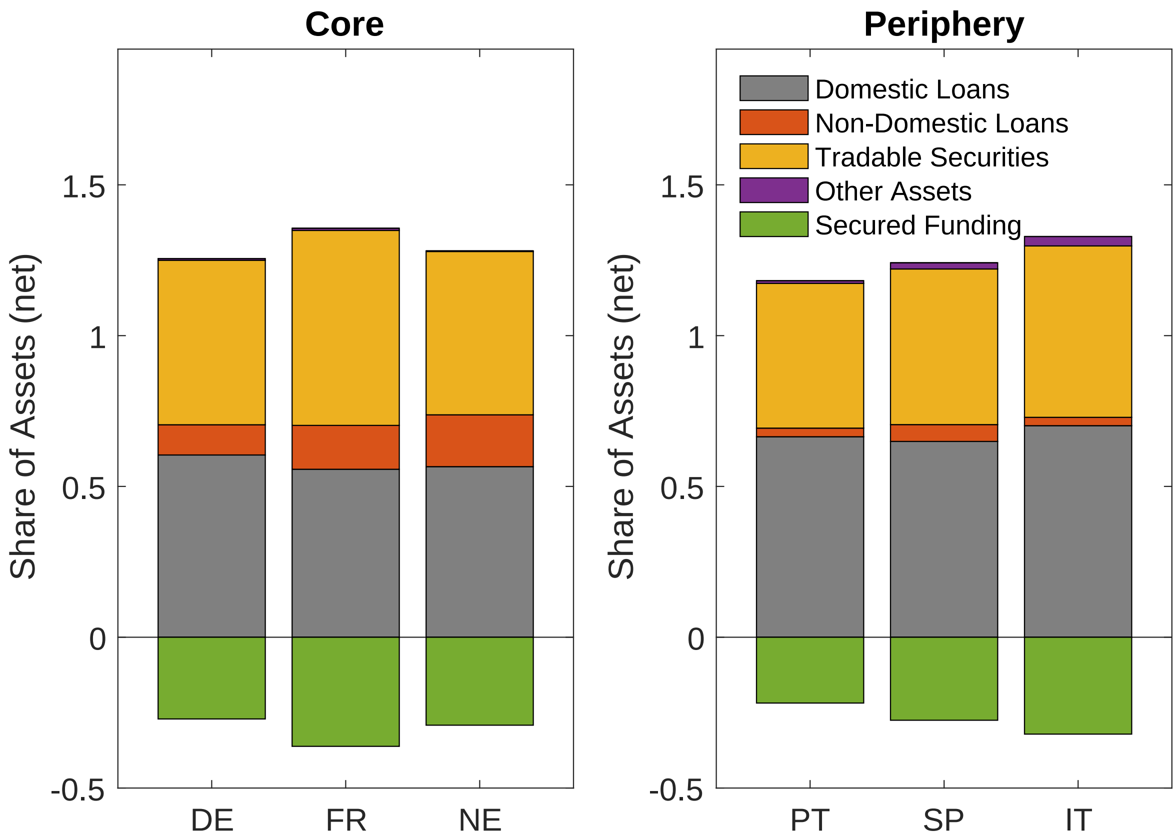

Figure 3. Composition of assets held by banks in end-2019, as a share of net asset position. It splits banking sector by country of residence. Countries: Germany (DE), France (FR), Netherlands (NE), Portugal (PT), Spain (SP), Italy (IT).

C. *Fact 3: The Majority of Asset Purchases under QE are Against Holdings of Non-Bank Counterparties*

The final fact concerns how the Quantitative Easing (QE) program conducted by the ECB impacts the set of assets held by banks. QE involves the purchasing of assets held in the private sector in exchange for central bank reserves. As reserves must be held by banks in the currency union, then the ultimate impact on the bank balance sheet depends on the composition of assets purchased. If, on the one hand, the ECB purchases assets held by banks, QE amounts to an asset swap with banks. If, on the other hand, assets are purchased from non-bank counterparties, QE acts as an outright increase in bank assets held in the form of reserves.

To assess the split between outright increases vs. asset swaps, I examine the impacts induced during the Asset Purchasing Programme (APP) of the ECB that was in place between March 2015 and December 2018. As 90% of asset purchases were in sovereign bonds of Euro Area members, I assess the change in holdings by the banking sector in these assets relative

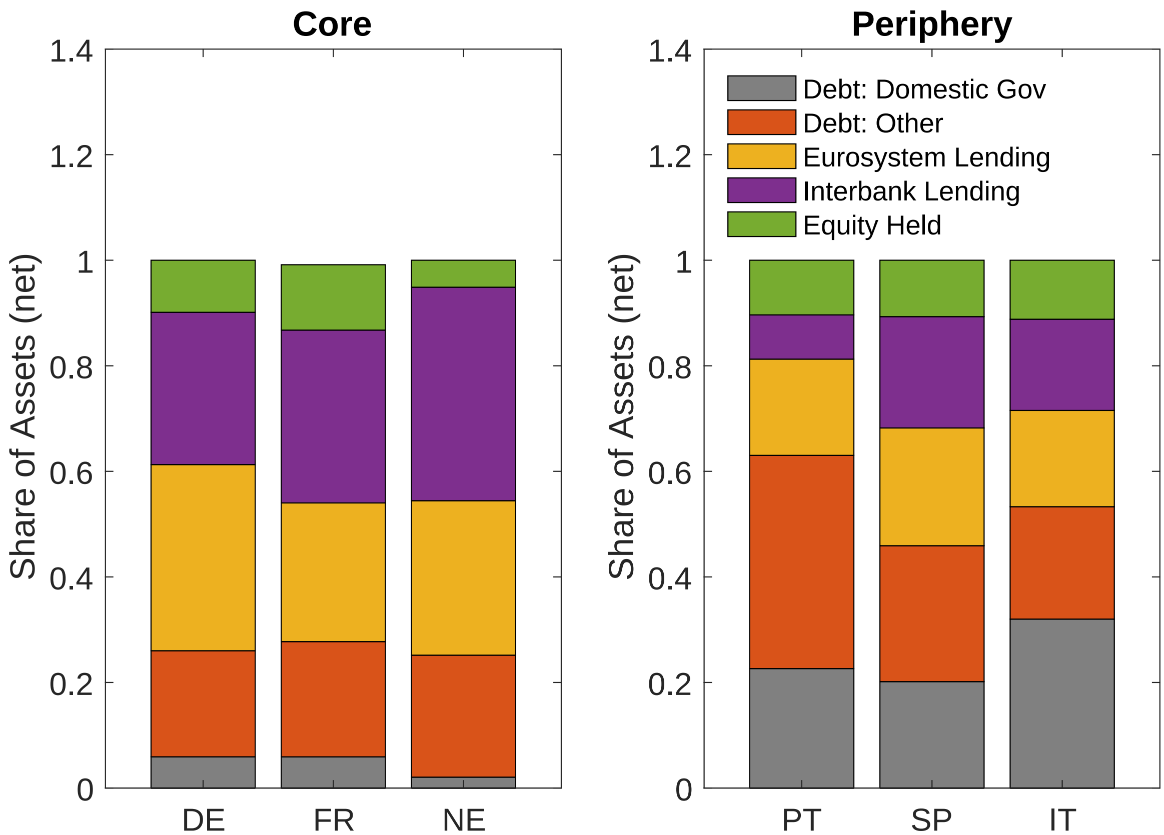

Figure 4. Composition of tradable securities held by banks, in end-2019. It splits banking sector by country of residence. Countries: Germany (DE), France (FR), Netherlands (NE), Portugal (PT), Spain (SP), Italy (IT).

the quantities purchased via the APP. Using the IMF database compiled by Arslanalp and Tsuda (2012) that conveys the evolution of ownership by counterparty of sovereign bond holdings, I compare holdings between end-2014 and end-2018 of the central bank vs. monetary financial institutions. I can then see how much the central bank purchases coincided with a fall in private bank holdings. I observe an increase in EUR1250bn of government bond holdings by the central bank, and a corresponding 255bn fall in holdings for domestic banks. This implies 20% of QE purchases were vs. private bank holdings and so collateral swaps, while the remaining portion consisted of outright collateral supply increases for banks within the union.[17][18]

[17] As a cross-check, I compare the change in government bond holdings of MFIs in the BSI Dataset against the holdings documented by the ECB for the Public Sector Purchasing Programme, obtaining a 15% share (Source: ECB PSPP Data)

[18] Koijen et al. (2021) reached a similar conclusion using securities level holdings data from the Securities Holding Statistics. They find that, between 2015Q1 and 2017Q4, over half of all government bonds purchased as part of PSPP were offset by selling from foreign investors outside the Euro Area.

IV. Model

Armed with these documented facts, I now present a model that is made to help us understand how QE purchases pass through the economy when the central role of banks is to provide liquidity services to households. This banking sector is structured in such a way as to be consistent with Facts 1 and 2 in Section III, while the characteristics of the QE shock is based on Fact 3.

My framework is a two-region open economy New Keynesian setup, in the spirit of Clarida et al. (2002), but also includes banks whose debt, termed deposits, provide liquidity services to households. Such deposits must be backed by assets of sufficient collateral quality, whose supply is a function of central bank asset purchases. In the setup, regions can differ by size, bank leverage, and deposit demand semi-elasticities.

A. Household Sector

I consider one representative household for each of the home (I) and foreign (J) country. The representative household of a given region exhibits lifetime expected utility

$$U_t = u(C_t, D_t/P_t) - \frac{\varphi}{1+\phi} N_t^{1+\phi} + \beta_t E_t \left[U_{t+1} \right], \tag{1}$$

such that

$$u(C_t, D_t/P_t) = \frac{1}{1-1/\sigma} \left(C_t^{1-1/\eta} + \omega \left(\frac{D_t}{P_t} \right)^{1-1/\eta} \right)^{\frac{1-1/\sigma}{1-1/\eta}}, \tag{2}$$

where C_t is the aggregate consumption bundle, D_t is nominal money holdings, N_t is labour supply, and P_t is the aggregate price level. η represents the intratemporal elasticity of substitution between consumption and real money balances, while σ is the intertemporal elasticity of substitution between consumption-deposit bundles across time. The discount factor for households, β_t, is an exogenous random variable. C_t is a composite of consumption of home (C_{Ht}) and foreign (C_{Ft}) goods

$$C_t = \left(a_H^{\gamma} C_{Ht}^{1-1/\gamma} + (1-a_H)^{\gamma} C_{Ft}^{1-1/\gamma} \right)^{\frac{1}{1-1/\gamma}}, \tag{3}$$

where a_H controls the relative preference of home vs. foreign goods.[19]

The household in country I faces the following budget constraint[20]

[19] a_H is a function of a primitive home bias preference $\bar{a}_H$ and the region's relative size. If regions are of the same size, then $a_H = \bar{a}_H$, and otherwise increases in relative region size. See Appendix G for further details.

[20] The household also offers out claims to banks X_t, which they pay back with interest in the following period. The quantity is not explicitly modelled but instead follows some exogenous process. These are

$$P_tC_t + D_t + S_t = W_tN_t + T_t + \Pi_t + D_{t-1}(1 + i^D_{t-1}) + S_{t-1}(1 + i^S_{t-1}), \quad (4)$$

where S_t is holdings of short-term risk free assets, T_t are government transfers and Π_t are proceeds from firm equity held by households.[21]

I now turn to the first order conditions implied by optimal decision-making of households. Firstly, the marginal rate of substitution between deposits and consumption must be equal to the relative cost of deposits liquidity. Holding deposits is costly due to the interest foregone vs. holding bonds i.e. $i^S_t - i^D_t$, but discounted one period as the interest payments arrive in period $t + 1$. Consequently, the first order condition is

$$\frac{C_tP_t}{D_t} \equiv vel_t = \omega^{-\eta}\left(\frac{i^S_t - i^D_t}{1 + i^S_t}\right)^{\eta}, \quad (5)$$

where vel is velocity of consumption. I can write (5) as a function of velocity as money is held in proportion to nominal spending, given that utility is homogeneous of degree one in consumption and money.

However, the deposit spread not only matters for determining velocity, but also consumption if there is deposits-consumption complementarity i.e. $\eta < \sigma$. The marginal utility of consumption is equal to

$$J_tC_t^{-1/\sigma} \quad \text{where} \quad J_t = \left[1 + \omega^{\eta}\left(\frac{i^S_t - i^D_t}{1 + i^S_t}\right)^{1-\eta}\right]^{\frac{1/\eta - 1/\sigma}{1 - 1/\eta}}.$$

When $\eta < \sigma$, $\partial J_t/\partial(i^S_t - i^D_t) < 0$, meaning that the marginal utility of consumption is declining in the deposit spread. This is because households care not only about consumption, but also the deposits-consumption bundle. When deposits are more expensive, less is held, which also hurts the benefit of consuming today.

If consumption and money are complements, the deposit spread also has an effect on the supply of labour through the intratemporal labour supply first order condition

$$\frac{W_t}{P_t} = \frac{\varphi N_t^{\phi} C_t^{1/\sigma}}{J_t}. \quad (6)$$

Suppose the cost of deposits becomes more expensive. Consumption is then less desirable because the good that is complementary to it, deposits, is more costly. As a result, there is less of an incentive to supply labour in order to finance this consumption, and so

introduced in the exposition of the banking problem. I exclude this in presenting the budget constraint for ease of exposition.

[21] Within consumption CES optimisation implies the price level $P_t = \left[a_H P_{Ht}^{1-\gamma} + (1 - a_H)P_{Ft}^{1-\gamma}\right]^{\frac{1}{1-\gamma}}$.

households substitute towards more leisure.

Beyond intratemporal effects, this complementarity also filters through into the otherwise familiar intertemporal Euler equation

$$\beta E_t \left[\frac{J_{t+1}}{J_t} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\sigma} \frac{P_t}{P_{t+1}} (1 + i_t^S) \right] = 1. \tag{7}$$

The additional element that now matters is the expected change in the cost of liquidity, embedded in the term J_{t+1}/J_t. If liquidity costs are expected to rise, households prefer to re-allocate consumption away from tomorrow and into today. In other words, it is as if they discount future consumption by more as it is a period in which complementary deposits are expected to be relatively more scarce.

B. Firm Sector

The production sector of the economy is mostly standard. Each region produces a domestic variety of final and intermediate goods. The final good firm uses a continuum of intermediate goods, $Y_t(f)$, to produce final good Y_t through the following CES production function

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}}. \tag{8}$$

The final goods sector is perfectly competitive, thereby taking the price of final and intermediate goods as given. As a result, the intermediate goods firm f faces the following demand function from the final goods sector

$$Y_t(f) = \left(\frac{P_{Ht}(f)}{P_{Ht}} \right)^{-\mu} Y_t, \tag{9}$$

As a result, the continuum of intermediate firms $f \in [0, 1]$ operate in a monopolistically competitive market, facing a constant demand elasticity ϵ. Each firm f faces a linear production function $Y_t = Z_t N_t$, where labour productivity, Z_t, is an exogenous random variable. I assume Calvo price setting i.e. with probability $1 - \theta$ each individual firm has the opportunity to reset their price in a given period. This opportunity arrives according to an i.i.d. process. Given the price that is set, firms satisfy whatever demand they face from final goods firms.

Additionally, within each period, firms can borrow up to a fraction γ_L of their current output, in the form of one-period loans from banks.[22]

[22] Alternatively, I could instead choose the constraint $L_{f,t+1} \leq \gamma_L W_t n_{ft}$ i.e. loans are tied to the firm wage bill. I can micro-found this constraint in a very similar fashion to Christiano et al. (2005) where firms need funding to prepay their wage bill. In my context, they can only borrow up to a fraction γ_L of their wage bill,

As argued in Lian and Ma (2021), 80% of borrowing is tied to firm cash flow, not to assets held, and so this is a reduced form way of reflecting this observation.[23]

Bringing all this together, the optimization problem of each firm f in region K amounts to

$$\max_{p_{\text{ft}},L_{\text{f,t+s}}} \sum_{s=0}^{\infty} E_t \left[\frac{M^K_{\text{t+s}}}{P^K_{\text{t+s}}} \left(\theta^s \left(p_{\text{f,t}} y_{\text{f,t+s}} - W^K_{\text{t+s}} n_{\text{f,t+s}} \right) + L_{\text{f,t+s+1}} - (1 + i^{L,K}_{\text{t+s-1}}) L_{\text{f,t+s}} \right) \right],$$

subject to

$$L_{f,t+1} \leq \gamma_L p_{ft} y_{ft},$$

where $L_{f,t+1}$ is the quantity of loans taken out in period t by firm f and $i^{L,K}_{\text{t+s-1}}$ is the interest rate on those loans. As firms are owned by domestic households, they inherit the nominal stochastic discount factor of domestic households, M^K_{t+1}. In this model, I will be considering scenarios where firm loans exhibit a collateral premium i.e. $i^{S,K}_t - i^{L,K}_t > 0$. Because of this effective borrowing subsidy, it turns out that loan financing is cheaper than equity financing, meaning that the firm takes out as many loans as possible, causing the constraint to bind. Intuitively, firms are not just productive in intermediate goods supply, but are also productive in supplying collateral to banks. The resulting marginal cost for firms is shown in Equation 10:

$$\text{Marginal Cost}_{ft} = \underbrace{\frac{W_t}{Z_t}}_{\text{labour costs}} \underbrace{- \gamma_L \left(\frac{i^{S,K}_t - i^{L,K}_t}{1 + i^{S,K}_t} \right)}_{\text{funding subsidy}}. \tag{10}$$

See Appendix E for further details on the derivation of this marginal cost function. Intuitively, with this collateral premium attached to loans, this serves to reduce the effective marginal cost of firms because each additional unit of output allows the firm to access cheaper loan funding vs. equity. This implies a cost channel for interest rates, in other words, channels through which interest rates appear directly in the marginal cost of firms. In contrast to the conventional channels that have interest rate *levels* appearing in marginal cost, here I have the cost channel appearing in the form of interest rate *spreads*.[24] A higher deposit spread makes collateral more lucrative for producing deposits, inducing a higher collateral premium and so lower marginal costs. This channel is important for how Quan-

the rest coming from an intra-period equity injection. Regardless of my choice of constraint, the economics are the same: marginal cost falls with collateral premia.

[23] Lian and Ma (2021) attribute this to the fact that if a firm goes bankrupt, the debt is repaid from the income of the re-structured firm, and less so the remaining stock of assets.

[24] See, for example, Christiano et al. (2005) and Ravenna and Walsh (2006) on characteristics of cost channels of interest rates in level terms.

titative Easing (QE) shocks pass through into the real economy.

C. *Banking Sector*

The banking sector serves to provide liquidity services to households in the form of deposits. Banks, however, are subject to an exogenous leverage constraint, which determines the amount of collateral required to back deposits. Collateral is a high quality asset that is provided by both the private sector, such as firm loans, as well as the central bank in the form of reserves. Different types of collateral are distinguishable by collateral quality. Reserves are of the highest quality as they are highly liquid and risk-free, while other assets held by banks, such as firm loans, long-term government bonds, interbank claims, are of lower quality as they exhibit credit and/or interest rate risk. This previews why central bank asset purchases can matter: by buying reserves in exchange for lower quality assets, it raises the effective supply of collateral for banks.

This setup is intended to capture the environment for a typical Euro Area bank within the current ample reserves regime. In other words, reserves are in sufficiently large supply that they exhibit no additional marginal liquidity benefit, and exhibit exclusively a collateral premium. This regime can persist both at and away from the zero lower bound because the interest rate on reserves is a separate policy instrument.

Each region K exhibits a banking sector consisting of a continuum of banks, indexed by i, all of which are owned by households in region K.[25] Bank i holds on the asset side of its balance sheet central bank reserves (M_t^i) and other assets (A_t^i), which consists of claims sold by households to banks, (X_t^i), and loans issued to intermediate firms, (L_t^i). Banks fund themselves with either debt, in the form of inside money i.e. deposits, or equity. The balance sheet is summarized in Table IV below.

Table IV. Bank Balance Sheet Structure

Assets		Liabilities	
CB Reserves	R_t^i	Deposits	D_t^i
Other Assets	A_t^i	Equity	E_t^i

Bank i's objective is to maximize shareholder value, and so chooses a portfolio to maximize

$$\max_{\{D_{t+1}^i, R_t^i, A_t^i\}} E_t \left[\sum_{s=0}^{\infty} M_{t+s}^K \mathrm{CF}_{t+s}^i \right], \tag{11}$$

where

[25] Equilibrium outcomes are unchanged if I allow for households in the other region to hold banks in region K. This assumption serves to merely assist with the exposition of the model.

$$CF^i_{t+1} = R^i_t(1+i^R_t) + A^i_t(1+i^{A,K}_t) - D^i_t(1+i^{D,i}_t) - R^i_{t+1} - A^i_{t+1} + D^i_{t+1},$$

taking interest rates of all assets and liabilities as given, where at time t all realised returns in $t+1$ are pre-determined. I assume no equity adjustment costs, but banks' optimal decisions are subject to the following leverage constraint

$$D^i_t \leq \ell^K_t \left(R^i_t + \rho_{A,t} A^i_t \right). \tag{12}$$

Equation 12 limits the amount of deposits that can be issued by the amount of collateral held on the balance sheet. This constraint can be interpreted in a variety of ways: (i) leverage regulation, (ii) a limiting case of increasing marginal cost of debt (Piazzesi et al. (2021)), or (iii) a relative preference for funding themselves with either deposits or more junior forms of debt.[26] Regardless of the interpretation, this constraint is meant to capture the more general notion that there is a limit to the amount of leverage a bank can take, where this limit is tighter the lower the quality of assets held. And when the bank needs to adjust liabilities in this model to satisfy the leverage constraint, it happens exclusively through changes in deposit supply.

This constraint also captures the transmission mechanism of any changes in collateral supply. By Equation (12), increases in collateral supply raise deposit supply, thereby raising consumption through the consumption-deposits complementarity.

When mapping the model to the data, I most closely follow the last interpretation of the constraint, particularly since my empirical counterpart of equity includes debt that is junior to deposits (e.g. unsecured debt). On the asset side, other assets are distinct from reserves as they exhibit lower collateral quality i.e. $\rho_{A,t} < 1$, where $\rho_{A,t}$ is an exogenous random variable.[27] In other words, banks can leverage up more when holding reserves vs. other assets. In this framework, these other assets held by bank i are the sum of loans issued to intermediate firms, L^I_t and claims sold by households to banks, X^i_t.

Banks in region K operate in a monopolistically competitive deposit market. I assume that households exhibits CES preferences over deposit varieties D^i_t offered by each bank i such that

$$D_t = \left(\int_0^1 \left(D^i_t \right)^{\frac{\eta_b - 1}{\eta_b}} di \right)^{\frac{\eta_b}{\eta_b - 1}}, \tag{13}$$

[26](iii) comes from the fact that, in the liquidity provision business of banks, junior debt acts like an equity buffer for deposits. Therefore, a choice of leverage here is synonymous with the choice on the split between deposits and junior debt as funding sources.

[27]Justifying the assertion of $\rho_{A,t} < 1$, observe that the ECB charges larger haircuts on assets that are of lower credit quality and/or less liquid than comparable assets to reserves (e.g. AAA sovereign debt). See Figure 3 of the ECBC European Covered Bond Fact Book 2020 for further details.

where η_b is the elasticity of substitution across different varieties. I do not interpret this as a single household depositing in many banks. Rather, my interpretation of this setup is of a household sector working like a community with members in different regions, and banks exerting regional market power for historical reasons. The key effect I am after here is that deposits are a cheap source of funding due to a combination of a) it being a source of liquidity for households, and b) banks exerting market power over their deposit variety.

From the perspective of households, the price of liquidity offered by variety i is $(i_t^S - i_t^D)/(1+i_t^S)$, as $(i_t^S - i_t^{D,i})$ is the interest foregone vs. bonds, which is discounted because the interest is received next period. CES preferences imply an aggregate price index $\frac{i_t^S - i_t^D}{1+i_t^S}$ that aggregates individual deposit prices, leading to the familiar CES demand equation

$$D_t^i = \left(\frac{i_t^S - i_t^{D,i}}{i_t^S - i_t^D} \right)^{-\eta_b} D_t, \tag{14}$$

where the main feature in this setting is that prices are in the form of interest rate spreads.

In equilibrium, due to the non-satiation of preferences for deposits, the convenience yield is always strictly positive i.e. $i_t^{S,K} - i_t^{D,K} > 0$. Therefore, deposits are a cheaper source of funding than equity, meaning that, if they could, banks would fund themselves entirely with deposits. The leverage constraint limits the ability to do so, and so will bind in equilibrium.

Armed with this setup, I now outline the key first order conditions. As all banks face an identical problem, I drop the superscript i.

In equilibrium, the required nominal rate of return on equity is i_t^S. In each period t, banks use equity to make a portfolio investment in assets, using deposits as a source of leverage. These assets and deposits exhibit realized returns that are pre-determined in period t. As a consequence, the portfolio chosen by banks in period t that is financed by equity is risk-free in nominal terms. This implies that, with no equity adjustment costs, short-term bonds and bank equity are equivalent from the perspective of households, and so their returns must equate in equilibrium given positive but finite bank equity supply. Therefore, the cost of equity is the short-term risk-free rate, i_t^S.

Knowing the cost of equity, assets held (in finite supply) must also achieve this as a total rate of return in equilibrium: [28]

$$i_t^{S,K} = i_t^R + \ell_t^K \gamma_t^K (1 + i_t^{S,K}), \tag{15}$$

[28] For any asset A, the cost of investment today is 1, while the present value of the future payoff is $E_t\left[M_{t+1}^K(1+i_t^{A,K})\right] = \frac{1+i_t^{A,K}}{1+i_t^{S,K}}$. The net pecuniary cost is therefore $\frac{i_t^{S,K}-i_t^{A,K}}{1+i_t^{S,K}}$, which is the cost of it relaxing the leverage constraint, equal to the benefit $\ell^K \rho_A \gamma_t$. Equating the costs with benefits yields the first order condition 15.

$$i_t^{S,K} = i_t^{A,K} + \ell_t^K \rho_{A,t} \gamma_t^K (1 + i_t^{S,K}), \tag{16}$$

where γ_t^K is the Lagrange multiplier on the leverage constraint. The left hand side is the required return, which is set equal to realized returns, adding up the pecuniary returns from interest received, and the non-pecuniary returns from relaxing the leverage constraint and so gaining access to cheap deposit funding. In a similar vein, trading the use of deposits and equity as sources of funding:

$$\frac{i_t^{S,K} - i_t^{D,K}}{1 + i_t^{S,K}} = \gamma_t^K \left(\frac{\eta_b^K}{\eta_b^K - 1} \right). \tag{17}$$

The left-hand side of (17) is the marginal benefit of using deposits as a source of funding vs. equity, which is also the price charged to households The first term on the right-hand side reflects the marginal cost of issuing deposits as it requires the bank to hold costly collateral. The second term captures the mark-up charged in the monopolistically competitive deposit market. Combining the condition for assets and deposits, I have the key pass-through equation:

$$i_t^{S,K} - i_t^{D,K} = \left(\frac{1}{\ell_t^K} \right) \left(i_t^{S,K} - i_t^R \right) \left(\frac{\eta_b^K}{\eta_b^K - 1} \right) = \left(\frac{1}{\rho_{A,t} \ell_t^K} \right) \left(i_t^{S,K} - i_t^{A,K} \right) \left(\frac{\eta_b^K}{\eta_b^K - 1} \right). \tag{18}$$

Equation (18) relates the collateral premium of reserves to the convenience yield on deposits. The leverage constraint implies that $(1/\ell_t^K)$ units are required to back each unit of deposits. The cost of holding reserves is the interest foregone i.e. $i_t^{S,K} - i_t^R$, and so this is scaled by $(1/\ell_t^K)$ to obtain the marginal cost of producing deposits. As banks operate in a monopolistically competitive deposit market, the price of deposits i.e. the convenience yield is then set at a mark-up above marginal cost.

D. *International Risk-Sharing*

I now turn to the asset market structure of households, and the consequent adapted version of the Backus-Smith condition.

In this model I additionally assume the existence of complete markets for assets that are traded internationally. The consequent risk-sharing across countries implies that realized stochastic discount factors equate. Assuming the initial conditions are at the steady state, I have a variant of the Backus-Smith Condition:

$$\frac{u_1^I(C_t^I, D_t^I / P_t^I)}{P_t^I} = \frac{u_1^J(C_t^J, D_t^J / P_t^J)}{P_t^J}. \tag{19}$$

As is standard, it implies that consumption is allocated towards regions where the consumption bundle is relatively cheaper. On top of this, though, is the implication that consumption is allocated toward countries where deposits are more abundant. Intuitively, deposits are complementary to consumption and so higher supply enhances the utility of consumption. This will prove to be important for the QE mechanism discussed later.

Finally, combining the Backus-Smith condition with the fixed exchange rate regime implies that the shadow rate in each region equates i.e. $i_t^{S,I} = i_t^{S,J}$. Hereafter, I will drop the region subscript on i_t^S. See Appendix I for further details.

E. Government

I now define monetary policy operations of the central bank, defined in such a way as to replicate the ample regime operated by the ECB for most of the post-Great Recession period. Policy is defined over two independent tools. Firstly, they set the interest rate on reserves according to the familiar Taylor rule:

$$\begin{aligned} i_t^R = r^R + \rho_R \left(i_{t-1}^R - r^R \right) + (1-\rho_R) \left(\phi_\pi \hat{\pi}_t^{\text{UNION}} + \phi_y \hat{y}_t^{\text{UNION}} \right) \\ + \phi_{\Delta\pi} \left(\hat{\pi}_t^{\text{UNION}} - \hat{\pi}_{t-1}^{\text{UNION}} \right) + \phi_{\Delta Y} \left(\hat{y}_t^{\text{UNION}} - \hat{y}_{t-1}^{\text{UNION}} \right) + v_t^{MPS}, \end{aligned} \tag{20}$$

where r^R is the policy rate on reserves in the steady state, $(\hat{\pi}^{\text{UNION}}, \hat{y}^{\text{UNION}})$ is union-wide inflation and output, respectively, and v_t^{MPS} is an exogenous random variable capturing monetary policy shocks to the policy rate. Secondly, they decide on some exogenous rule for reserve supply (R_t^S), given by the general functional form

$$R_t^S = f(R_{t-1}^S, \Pi_t^{UNION}, Y_t^{UNION}) e^{v_t^{QE}}, \tag{21}$$

where v_t^{QE} is an exogenous random variable capturing shocks to reserve supply. In other words, v_t^{QE} captures the Quantitative Easing shock that will be at the heart of my analysis.

Beyond reserves and interest rate policy, the union-wide government (including the central bank) also supplies risk-free assets to households, (B_t^S), and holds intermediate firm equity, $E_t^{INT,G}$, as part of its monetary policy operations on reserve supply (described in detail in Section V). Governments then finance this portfolio position via lump-sum taxes on households, denoted by T_t.

The transmission mechanism of QE shocks works through raising the supply of collateral for banks (described in detail in Section V). However, the size of the increase in collateral supply for a given QE shock depends on what assets are purchased. If, on the one hand, the central bank purchases assets held by banks as collateral, such as intermediate firm loans, then QE is merely a swap of lower into higher quality collateral. On the other hand, if QE purchases are of assets not held by banks as collateral, QE shocks amount to an outright increase in new collateral supply and so a large quantitative effect. As I know from Fact 3, historically, only 20% of purchases are collateral swaps with banks, and so are mostly outright collateral supply increases.

F. Collateral Markets

Before turning to the description of the equilibrium, I describe the markets for collateral that are central to the operations of QE. In this framework, banks in the currency union have three sources of collateral: central bank reserves (R_t^S), claims sold by households in each region (X_t^I, X_t^J) and loans issued to intermediate firms in each region (L_t^I, L_t^J). I assume that household claims in region K exhibits the following log-linearized process

$$\hat{x}_t^K = \alpha_X \hat{x}_{t-1}^K - \alpha_X \pi_t^K, \tag{22}$$

where $\hat{x}_t^K$ is the log-linearized real supply of claims, and $\alpha_x \in [0,1]$ reflects the degree of nominal stickiness in supply. If $\alpha_X = 1$, claims are fixed in nominal terms, whereas if $\alpha_X = 0$, there is no nominal stickiness in supply and is instead fixed in real terms.

On the other hand, intermediate loan supply is endogenous. Integrated across the full set of firms in region K:

$$L_t^K = \int_0^1 L_{f,t}^K = \int_0^1 \gamma_L y_{ft}^K p_{ft}^K = \gamma_L P_t^K Y_t^K.$$

This implies that some components of collateral supply are endogenous and co-move positively with output. This is meant to capture the domestic loans portion of assets documented in Fact 2.

In Fact 2, I illustrate that a significant portion of assets held by banks are in tradable securities in an integrated union-wide market. Therefore, I assume a single union-wide market for reserves and for household claims, while the firm loan market is local.[29] It turns out, however, that it does not matter at all whether intermediate firm loans is a segmented local market or a market integrated across the union. Instead, all I need is an integrated collateral market for reserves because once this is true, all that matters is union-wide collateral supply - conditional on this, the split of collateral across regions is additionally uninformative.

Intuitively, banks in each region pay the same price for the collateral value of reserves: $i_t^S - i_t^M$. This means that the marginal cost of a quality-adjusted unit of collateral is equal

[29] γ_L is calibrated to fit the portion of assets attributed to domestic loans in each region in the data.

across regions. As a result, in equilibrium, they always face the same scarcity of collateral, which itself is affected by union-wide supply. It does not matter where the location of the local collateral shock is - it is sufficient to just know the effect on union-wide supply.

G. Equilibrium

The equilibrium consists of a set of allocations and prices such that households, firms and banks solve their optimization problems, the governments satisfy their respective budget constraints, the local labour and deposit markets in each region clear, each tradable goods market clears:

$$\begin{aligned}\text{Pop}^I C^I_{Ht} + \text{Pop}^J C^J_{Ft} &= \text{Pop}^I Y^I_t,\\ \text{Pop}^I C^I_{Ft} + \text{Pop}^J C^J_{Ht} &= \text{Pop}^J Y^J_t,\end{aligned}$$

the reserves market clears:

$$\text{Pop}^I R^I_t + \text{Pop}^J R^J_t = (\text{Pop}^I + \text{Pop}^J) R^S_t, \tag{23}$$

the single government bond market clears:

$$\text{Pop}^I B^I_t + \text{Pop}^J B^J_t = (\text{Pop}^I + \text{Pop}^J) B^S_t, \tag{24}$$

the single household claims market clears, each local intermediate firm loans market clears, and finally the full set of state-contingent asset markets clear.

H. Steady State

This paper describes the equilibrium dynamics of this model by log-linearizing the system of equations around a steady state. Therefore, the first step is to describe the properties of this steady state.

As derived in Appendix G, steady state output in region K $\in \{I, J\}$ is

$$Y^K = \left(\frac{1}{\varphi}\tilde{J}^K\right)^{\frac{1}{\phi + 1/\sigma}}, \tag{25}$$

where

$$\tilde{J}^K = \left[1 + \omega^K \left(vel^K\right)^{1/\eta - 1}\right]^{\frac{1/\eta - 1/\sigma}{1 - 1/\eta}} \left(1 + \omega \gamma_L \rho_A \ell^K \left(\frac{\eta^K_d - 1}{\eta^K_d}\right)(vel^K)^{1/\eta}\right).$$

Within each region $K \in \{I, J\}$, deposit holdings are equal to:

$$D^K = \ell^K \left(R^K + \rho_A^K A^K \right),$$

which therefore determines velocity. The deposit spread of each country is equal to

$$i^S - i^{D,K} = \left(\ell^K \right)^{-1} \left(i^S - i^R \right).$$

Finally, the reserve supply $i^S - i^R$ is pinned down by the aggregate supply of collateral in the union, given household preferences for deposits and local banking sector structure.

I. Log-Linearized System

I solve the model linearizing it around the deterministic steady state. See Appendix H for the full system of log-linearized equations. The key step in this process is solving for the Phillips curve, with the derivation outlined in detail in Appendix F, and the resulting equation in (H.16).

At this point, it is instructive to understand the key equations that demonstrate how the liquidity provision business filters through into the real economy. It begins with the log-linearized first-order condition for banks in Equation 18 that determines the convenience yield for deposits in region K:

$$i_t^S - i_t^{D,K} = \left(\frac{r^S - r^R}{r^S - r^{D,K}} \right) \left(i_t^S - i_t^R \right) - (r^S - r^{D,K}) \hat{\ell}_t^K.$$

As we can see, for a given leverage ratio $\hat{\ell}_t^K$, the convenience yield moves proportionately with the collateral premium. In other words, the more scarce is collateral, the more expensive it is for banks to produce deposits for households, thereby raising the convenience yield. This previews how QE policy propagates into the real economy - it directly affects the convenience yield on deposits by impacting the scarcity of collateral.

This convenience yield filters through into the real economy along three key dimensions. Firstly, through the Euler equation in (H.14) and (H.15), it implies that consumption will be higher today if the convenience yield, i.e. the price of its complementary good, is lower today. Secondly, in the Phillips curve in (H.16) and (H.17), a higher convenience yieeld induces two counteracting forces on cost-push inflation, by impacting the marginal cost of firms described in detail in equation (10).[30] Finally, the convenience yield appears in the Backus-Smith condition (H.28), which allocates consumption to regions in which the positive complementarity effect induced by cheaper deposits is stronger.

[30] In my calibration, γ_L is set such that the positive effect through wages dominates the negative effect through the funding subsidy.

J. Mapping to Scarce Regime Framework

The model is written under the context of an ample reserves regime. In this setting, reserves supply is large, or ample, such that the banking sector is awash with these highly liquid assets. What it means is that reserves are no longer needed on the margin to manage liquidity withdrawals, but remain useful as a safe asset for banks. Importantly, what this implies is that reserves supply is an independent policy instrument. In other words, asset purchases, financed by reserves, is a separate policy tool.

Although a reasonable characterisation of monetary policy in recent years, it is not representative of the framework pre-2008. In this case, the central bank policy rate was the interbank rate, while the interest rate on reserves was set at a constant spread of 100bp below the policy rate. [31][32] This spread meant that banks held very few excess reserves i.e. reserves above the minimum requirement in order to avoid this cost. Therefore, reserves were in short supply such that, at the margin, they're valuable for their liquidity to manage short-term liquidity withdrawals. The spread captures this liquidity benefit. The key difference here is that asset purchases were no longer a separate policy instrument because supply/demand was endogenously governed by the interest rate spread. Therefore, my current model setup may not be a good representation of ECB monetary policy operations in the eariler years of the currency union.

It turns out that, using the framework of a scarce regime model described in Piazzesi et al. (2021), under certain conditions, a scarce reserves environment can be described within the ample regime framework where reserves supply no longer follows an exogenous process but instead is endogenously determined. According to Proposition 1:[33]

Proposition 1: *Assuming that the scarce reserves regime setting in Piazzesi et al. (2021) exhibits the following properties*:

1. *a reserveless limit*
2. *a constant corridor i.e. the spread between the policy rate and the reserve rate is fixed*

Then the system of equations is equivalent to the system for the ample reserves regime with real reserves, $\hat{r}^S_t$, instead exhibiting the following endogenous process:

$$\hat{r}^S_t = \hat{a}^{\text{UNION}}_t + \left(\frac{1}{\alpha_R}\right)\left(\frac{\epsilon}{\eta+\epsilon}\right)\left(\hat{y}^{\text{UNION}}_t - \hat{a}^{\text{UNION}}_t - \hat{\ell}^{\text{UNION}}_t(1-\eta)\right), \tag{26}$$

[31] Technically, the ECB policy rate was the Main Refinancing Operations (MRO) rate, a weekly rate at which banks could borrow reserves against accepted collateral from the central bank. This tracked very closely the interbank rates.

[32] Technically, the interest rate on excess reserves was the interest rate on the Overnight Deposit Facility. From 2000 - 2008, the spread between the MRO rate and the rate on the Overnight Deposit Facility was held fixed at 100bp (Source: ECB).

[33] The proof of Proposition 1 is outlined in Appendix J.

where α_R *is the share of bank collateral in the form of reserves in the ample regime,* $(\hat{y}_t^{UNION}, \hat{a}_t^{UNION}, \hat{\ell}_t^{UNION})$ *is union-wide output, collateral supply and bank leverage, respectively, and* $\epsilon \in [0, \infty)$*.*

Intuitively, the key difference here is that reserve supply is now endogenous. By setting both the interbank rate and the reserves rate, this pins down the relative price of reserves. As a result, the demand for reserves is endogenous in this regime, meaning that its supply can no longer be exogenously shocked through QE policy. The result in Proposition 1 relies on the two assumptions that are largely consistent with the earlier regime of the ECB.

Turning to the intuition for (J.35), the first term ensures that collateral supply moves the same in both the ample and scarce regime, all else equal. The second term, on the other hand, reflects how reserve supply needs to adjust in the scarce regime in response to changes in demand for liquidity in order to keep the liquidity premium constant (as we are in a constant corridor). The more collateral assets there are ($\hat{a}_t^{UNION}$) and/or the more able banks are at absorbing liquidity via higher leverage ($\hat{\ell}_t^{UNION}$), the less that banks require reserves for liquidity needs. On the other hand, the higher is $\hat{y}_t^{\text{UNION}}$, the larger is the demand for, and so supply of, deposits i.e. liquidity services. This makes banks more vulnerable to liquidity shocks, and so demand more liquid reserves.

Hereafter, I will set the free parameter ϵ to zero, but results are robust to variations in this value.[34]

V. Shocks

I now describe the set of structural shocks that exist in the model setup, and will be the sources for describing the the variation in key variables in the data. There are 9 such shocks: productivity (A_t^K), the local discount factor (β_t^K) and the leverage (ℓ_t^K) in each region K, along with the monetary policy shock $e^{v_t^{MPS}}$, union-wide collateral quality, $(\rho_{A,t})$, and the reserve supply shock $(e^{v_t^{QE}})$. All shocks follow the log AR(1) process of

$$log(V_t) = \rho_V log(V_{t-1}) + \sigma_{t,V}\epsilon_{t,V},$$

where $\{\epsilon_{t,V}\}$ is an exogenous independent innovation drawn from a normal distribution of mean 0, variance 1. In this setup, I assume that $\rho_{v^{MPS}} = 0$ as persistence in the policy rate itself generates a persistent effect of the structural shock.

[34]In Piazzesi et al. (2021), ϵ is governed by the distribution of liquidity shocks. As excess reserve supply tends to zero, so too does the value of ϵ as liquidity shocks become more concentrated around zero. This is why I choose 0 as my baseline value.

A. Collateral Quality Shock

The shock to collateral quality is assigned to all non-central bank reserves collateral. As noted in subsection F of the model setup, because of the integrated collateral market, all that matters is union-wide collateral supply for pass-through effects. As a result, I have just one identifiable collateral shock, whose empirical proxy will reflect union-wide collateral quality.

B. Quantitative Easing (QE) Shocks

Central to the paper is understanding the effect of shocks to central bank reserve supply on output and inflation across regions within the Euro Area. QE involves the purchasing of assets held in the private sector, financed by an increase in the supply of reserves. I decide on a functional form for reserves supply such that, in log-linearized terms, the supply of reserves exhibits the following process:

$$\hat{r}_t^S = \alpha_r \hat{r}_{t-1}^S - \alpha_r \pi_t + v_t^{QE},$$

where $\hat{r}_t^S = R_t^S / P_t$ is log-linearized real reserve supply, α_r reflects the degree of nominal stickiness in reserve supply, and v_t^{QE} is an exogenous random variable governed by the following AR(1) process:

$$v_t^{QE} = \rho_{QE} v_{t-1}^{QE} + \sigma^{QE} \epsilon_t^{QE} \quad \text{s.t.} \quad \epsilon_t^{QE} \sim N(0,1). \tag{27}$$

ϵ_t^{QE} represents the underlying Quantitative Easing shock. (27) implies that QE shocks induce an unanticipated sequence of new issuances of reserves that exhibit persistence ρ_{QE}. In other words, QE shocks imply a gradual increase in reserve supply through a gradual decaying sequence of new issuances. ρ_{QE} will be estimated to target the path of reserves supplied by the ECB via QE operations from 2015 onwards.[35]

As part of QE policy, the central bank must define what assets are purchased. As we know from Fact 3, approximately 20% of asset purchases are allocated to bank holdings of collateral. To that end, we presume that the 20% portion allocated to bank collateral consists of intermediate firm loans, while the remaining 80% is allocated to non-bank collateral in the form of household-owned intermediate firm equity.[36]

The transmission mechanism of QE shocks works through raising the supply of collateral for banks. More supply enhances the ability for banks to issue deposits to households,

[35] Note that, as a potential extension, I attempted to estimate an AR(2) process for QE purchases, as in Gertler and Karadi (2013). However, the sample size of the ample regime is too short to accurately estimate the process, and so I kept the process as simple as possible while retaining some degree of persistence.

[36] The stock of intermediate firm equity in the steady state, $Y/(\epsilon(1-\beta)$, is far more than sufficient to cover the amount of purchases undertaken by the ECB in the sample period.

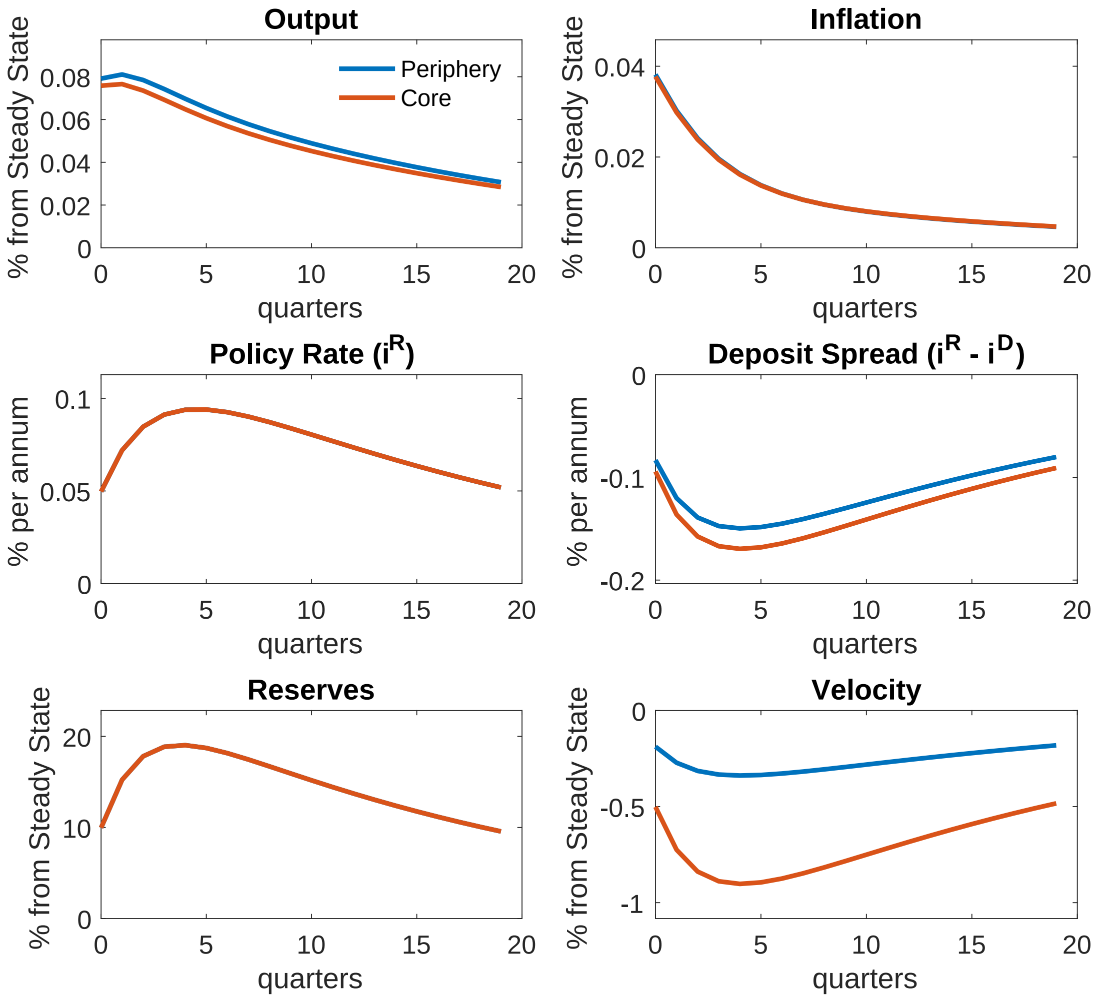

Figure 5. Impulse responses to a persistent 10% shock to asset purchases. Calibration is taken from Table V. Middle two panels are percentage deviations from steady state. Remaining panels are deviations from steady state. Spread is difference between policy rate and deposit rate.

who in turn increase consumption as the supply of the complementary component, deposits, has risen. In the process, both the collateral premium and the convenience yield fall because of a fall in the scarcity of collateral.

To understand this more clearly, Figure 5 considers the impulse response to a 10% shock to QE purchases. The calibration is drawn from the estimation discussed in Section VI below, but for now it is taken as given. As we see, in the bottom left panel of Figure 5, as the shock to the rate of purchases is persistent, reserve supply gradually rises, peaking 6 quarters in, and thereafter gradually converges to the steady state. Banks, now awash with more liquidity, attempt to attract deposit issuance through a higher offered deposit rate. This reduces the deposit spread, as seen in the middle right panel. Households in response increase deposit holdings, thereby lowering velocity, as seen in the bottom right panel. This drives up the desire to consume as deposits are complementary with it, thereby raising output and causing demand-pull inflation across the currency union.

Note that the same transmission mechanism holds true for other collateral shocks, precisely because of the integrated collateral market for reserves. In this modeling framework that contains such an integrated collateral market, the marginal cost of collateral is equal across regions. As a result, in equilibrium, they always face the same scarcity of collateral, which itself is impacted by union-wide supply. Conditional on the impact a shock has on this union-wide supply, the geographical / asset source is additionally uninformative.

VI. Model Estimation

In order to quantify the strength of the pass-through of QE and collateral quality shocks into output and inflation within the Euro Area, we must take a stand on the values of the model parameters. Parameters that are at the heart of the mechanism are either estimated using Bayesian methods, or are carefully calibrated with alternative data that captures the parameter of interest. Remaining values are then drawn from existing literature.

It turns out that the ECB QE program from early 2015 onwards raised union-wide inflation and output by 60bps and 62bps, respectively, at its peak. The impact on inflation rises to over 1% if the Taylor rule is made to be less responsive to inflation at the inception of the QE program.

A. Bayesian Estimation

I solve for the log-linearized system of equations laid out in Appendix H around the deterministic steady state outlined in Section IV. Linearity of the state space representation of the model and normality of the structural shocks allows us to estimate the model using Bayesian methods described in e.g. Smets and Wouters (2003), An and Schorfheide (2007) and Ilut and Schneider (2014).

B. Data

The sample period is 1999Q1 - 2020Q1 i.e. since the inception of the currency union. I collect data for six member states: Germany, France, Netherlands, Italy, Spain and Portugal, covering over 86% of GDP of the set of countries encompassing the currency union since inception date. I then subsequently divide this set of countries into Region C (Germany, France, Netherlands) and Region P (Italy, Spain, Portugal), with the split based on annual GDP per capita in 2019.[37]

All estimation exercises use 9 key variables: log real GDP per capita, inflation rates and the deposit interest rate spread (vs. ECB policy rate) for each region, along with union-wide collateral quality, the ECB policy rate and central bank reserve supply. Output and inflation are de-trended with a linear time trend to be consistent with the zero growth, zero inflation steady state in the model. The deposit rates are the rates applied to deposits exhibiting zero maturity as this best reflects assets held for their liquidity convenience. Reserves supply is evaluated by aggregating the reserves held by banks in the countries considered. Finally, I use a weighted average of Non-Performing Loan (NPL) ratios across the sampled countries as a proxy for collateral quality.[38] I assume that its steady state level corresponds to the pre-2008 mean. I then decide to scale it such that, at its peak, it equals the change in the haircut applied to Italian sovereign debt by the ECB amidst the sovereign debt crisis relative to the level pre-financial crisis.[39]

The choice of variables is guided by understanding the strength of the transmission of the collateral channel. I target output and inflation as these are the outcomes that I focus on. Reserves and NPL ratios are meant to capture the variation in the supply of collateral from the public and private sector available to banks to back deposits. Finally, deposit spreads capture the transmission into the scarcity of convenient assets for households.[40]

The model counterparts of these macro variables that I target follow immediately from how the model variables are described. Data sources are described in Appendix K, and all 9 target variables are illustrated in Figure 6 below.

I also have 9 structural shocks in the model: local productivity, demand and leverage shocks, as well as a union-wide monetary policy shock, QE shock and collateral quality shock. As there are as many structural shocks as observables, this allows us to fully explain the variation in target variables. This is feasible because all shocks have a sufficiently distinct impact on these target variables. In particular, local demand shocks are identified by the positive co-movement of local output and inflation, whereas local productivity shocks are identified by negative co-movements. The policy rate, reserve supply (QE) and collateral quality shocks are identified by what they directly shock, while local leverage shocks are identified by local deposit spreads.[41]

[37]This split remains true regardless of the year chosen. This split is a familiar regional comparison made across policy circles, often termed Core vs. Periphery

[38]This proxy is weighted by relative balance sheet size.

[39]At its peak, the NPL ratio is a little more than 4% above its steady state, whereas the haircut on Italian sovereign debt was 8% above its pre-crisis level amidst the sovereign debt crisis (see Armakolla et al. (2017)). Therefore, the scale is just below 2.

[40]In future work where I wish to include equity constraints and allow for the well-studied net worth channel, more variables would be targeted to distinguish between the two mechanisms.

[41]I do not use money demand shocks to target velocity because the money demand function appears to

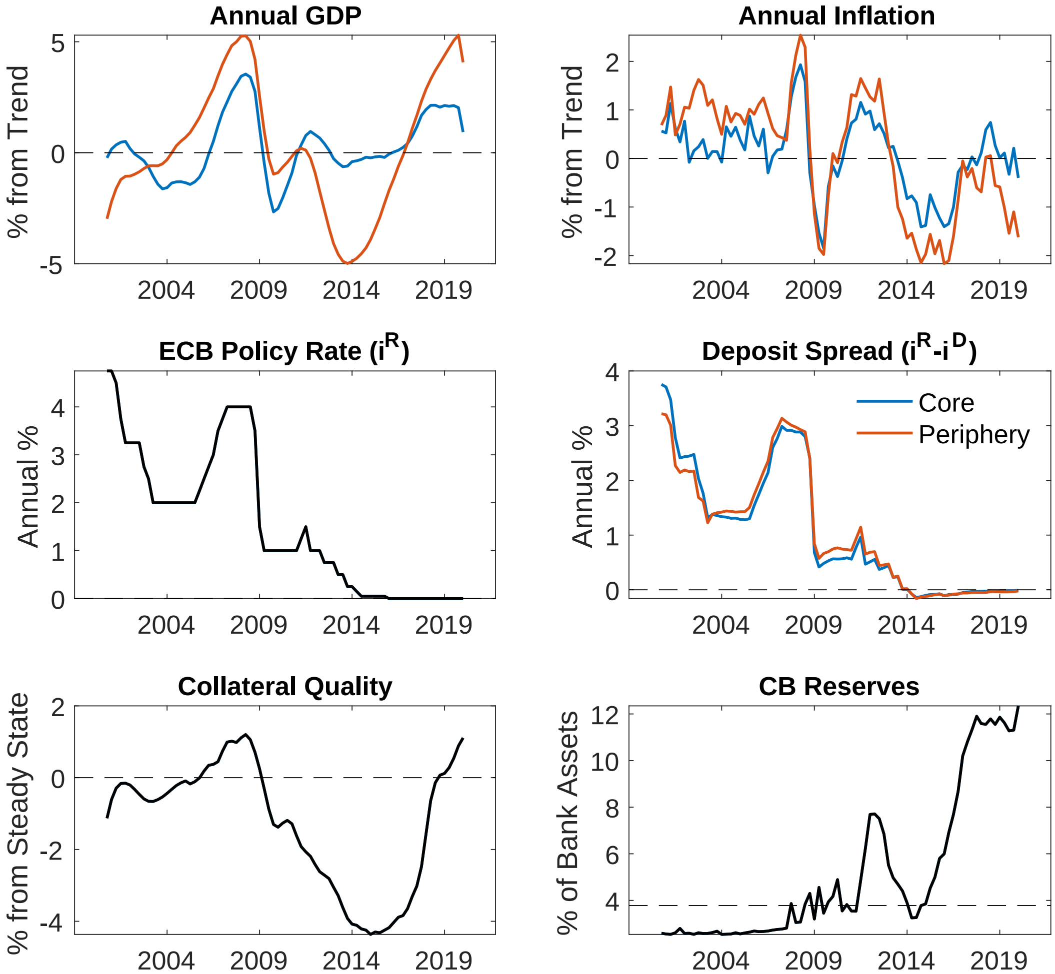

Figure 6. Empirical observations of target variables for Bayesian estimation. Annual GDP and Inflation are each de-trended at the region-level using a linear time trend. Collateral quality is proxied using the negative of the weighted-average of union-wide non-performing loan ratios. Central bank reserves held by banks are graphed as a % of total bank assets held.

The last point requires a little further discussion. What I am targeting in terms of spreads is the reserve spread i.e. $(i_t^R - i_t^{D,K})$. This determines the relative convenience of deposits vs. reserves. As a result, it does not target the outright convenience of deposits, which is left untargeted. The QE and collateral quality shocks partly fill this gap by capturing some of the movements in outright convenience, hence why it is important to have such collateral supply shocks in order to fully explain the impact of the banking sector.

be quite stable across a long sample period, as illustrated in Figure K.7. It demonstrates the stability of the money demand function for longer time periods.

Finally, I have to take a stand on when there is the structural break from a scarce to an ample reserves regime. This break is modelled as fully unanticipated, and seen as a permanent shift in regime. I decide that this occurs at end-2014, just ahead of the beginning of the ECB Public Sector Purchasing Programme (PSPP) in early 2015. This represents the bulk of QE asset purchases made by the ECB (over 90%), and is used extensively after the inception date.

C. Priors: Standard Parameters

I start by fixing a small number of parameters to values commonly used in the literature. All calibrated parameters are outlined in Table V below. I set β equal to 0.99, which implies a 4% annual household discount rate. I set the value of the inverse Frisch elasticity ϕ equal to 0.75, which roughly lies between the low elasticities of the micro-labour literature, and the higher estimates used in DSGE models.[42] For the elasticity of substitution between domestic and foreign goods, γ, Backus et al. (1994)) state that most reliable studies lie between 1 and 2. It is also broadly consistent with Imbs and Mejean (2015) who evaluate aggregate responses from micro estimates.[43] I choose a value of 1 to be consistent with the baseline calibration of Gali (2008), along with my priors of σ below.

The elasticity of substitution between domestic and foreign goods is set to 1, following Gali (2008), and broadly in line with other values used in the literature. For the degree of openness, I set a_H to 0.8, a value commonly applied, and broadly in line with the level of trade in the Euro Area.[44] Finally, I set steady state velocity equal to the mean over the sample period (0.52 and 0.70 for Region C and P, respectively). Given the steady state deposit spread calibrated below, this determines the preference for deposits, ω^K, at the region level.

A key parameter to calibrate is η because it is central to the strength of the cost channel mechanism. I estimate outside the Bayesian exercise because I can potentially extend the sample size to beyond the horizon of the currency union. I run the regression of the log-linearized first-order condition of deposits

$$\log vel_t = \alpha + \frac{\eta}{r^S - r^D}\left(i_t^S - i_t^D\right), \tag{28}$$

where vel_t is velocity and $i_t^S - i_t^D$ is the deposit spread. I estimate this equation using a bandpass filter in order to control for longer-run trends in the data and instead isolate

[42]See MaCurdy (1981), Angrist (1991) for micro estimates of Frisch elasticities on the intensive margin (and a more recent survey on quasi-experimental estimates, see Chetty (2009), and King and Rebelo (1999) and Rogerson and Wallenius (2009) for macro models that require large Frisch elasticities to explain aggregate variation in labour supply.

[43]However, Imbs and Mejean (2015) note that this masks significantly larger elasticities at the product level.

[44]The level of intra-EU trade as a share of GDP is approximately 15% (Source: Eurostat).

Table V. Calibrated Parameters

Variable	Core	Periphery
Frisch Elasticity (ϕ)	0.75	0.75
Discount Factor (β)	0.99	0.99
Price Adjustment Frequency ($1-\theta$)	0.25	0.25
Velocity ($vel^{\star}$)	0.70	0.52
Deposit Rate (Annual) (r^D)	1.50%	1.45%
Leverage (ℓ)	3.4	4.6
Other Assets Collateral Value (ρ_A)	0.925	0.925
Consumption Home Bias (a_H)	0.80	0.80
Reserves Share Bank Assets ($R/(R+A)$)	0.04	0.04
Interest Elasticity of Deposits η	0.08	0.03
Reserves Spread (Annual) ($r^S - r^R$)	0.3%	-
Relative Region Size (Y^C/Y^P)	2.07	-

short-term business cycle variation. The empirical counterparts are similar to those outlined in subsection B. However, due to limitations in sourcing estimates for the deposit spread, I proxy for the deposit spread using the short-term discount rate. Albeit an abstraction, recent literature has demonstrated a close relationship between the short rate and the deposit rate, and so acts like a reasonably proxy.[45]. On average, the sample period begins in 1979, and is at an annual frequency. Further details on how the dataset for each country is extended is outlined in Appendix K.[46]

Table VI. BandPass Filter: Full Sample

Coefficient	Core	Periphery
α	0.01	0.002
	(0.06)	(0.38)
$\frac{\eta}{r^S - r^D}$	**5.60**	**1.99**
	(2.55)	(1.36)

Results, and the corresponding t-statistics, are outlined in Table VI above. In order to convert this to implied estimates of η, we scale the semi-elasticity by the mean spread in the sample. This implies that the estimated η in Region P (0.03) is lower than in Region C (0.08), which implies that money demand is more interest-inelastic in Region P.

[45] Drechsler et al. (2018) demonstrate that a 1% increase in the policy rate induces a 65-85bp increase in the deposit spread, depending on the US county. Nagel (2016) demonstrate a similar relationship between interest rates and the spread on assets bearing liquidity service benefits

[46] I choose bands such that I eliminate cycles of frequencies shorter than 6 quarters and larger than 36 quarters, in accordance with isolating frequencies consistent with business cycles.

D. Priors: Banking Sector Parameters

The key elements to calibrate are those that make up the deposit spread in each region K. I ensure that the following equation, the steady state version of the deposits first-order condition in equation (18), holds true:

$$r^S - r^{D,K} = \left(\frac{\eta_b^K}{\eta_b^K - 1}\right)\left(\frac{1}{\ell^K}\right)\left(r^S - r^R\right). \tag{29}$$

The first key element in this equation is the leverage parameter ℓ^K. Decomposing this expression:

$$\begin{aligned}\ell = \frac{D}{R+\rho_A A} &= \left(\frac{R+A}{R+\rho_A A}\right)\left(\frac{D}{R+A}\right)\\ &= \left(\frac{R+A}{R+\rho_A A}\right)\left(1-\frac{1}{\text{lev}}\right),\end{aligned}$$

where lev is equity over total assets held. lev is estimated for each region directly from the balance sheet that was used to document Fact 2, and illustrated in Table III. The key component here is equity: it not only includes capital and reserves but also unsecured debt because it acts as a pseudo-equity buffer for deposits. I find that $\text{lev}^K = (3.4, 4.6)$ for the Core and Periphery, respectively in 2019.[47]

My initial calibration of ρ_A is 0.925, which is consistent with the haircuts applied to sovereign bonds in the private secured funding market within the Euro Area pre-crisis, a chief source of collateral for banks.[48] For the split between reserves and private collateral assets, I take a snapshot of the region-level bank balance sheets at the end of 2014 i.e. ahead of the first major round of Quantitative Easing in 2015. I find that reserves constitute, on average, 4% of total assets backing deposits within the Euro Area. I choose this period for the snapshot as this is the point in time I decide to be the switch from a scarce to an ample regime in my estimation (explained further below). Bringing all this together, this implies that $\ell^K = (.70, .78)$ for the Core and Periphery, respectively.

$(r^S - r^{D,K})$ is set equal to the average observed deposit spread over the full sampling period for region K, equalling $(1.5\%, 1.45\%)$ annualised for the Core and Periphery, respectively. Given a decision on the steady state reserve spread, $(r^S - r^R)$, I then pin down $(r^S - r^{D,K})$. I take a stand on $(r^S - r^R)$ and set it equal to 0.3% annualised. What is impor-

[47]For the evolution of the leverage ratio over time, see Figure A.4.

[48]This is appropriately scaled in order to be consistent with the scaling of the NPL proxy used for representing collateral quality.

tant here is not the precise level but the understanding that it is significantly lower than the deposit spread, a reasonable assumption.[49]

Finally, the only remaining unknown in equation (29) is the mark-up in each region, and so can be pinned down, equalling $(4.2, 5.1)$ for the Core and Periphery, respectively. Intuitively, my model setup implies that the heterogeneity across regions in deposit spreads indexed by leverage is mitigated by differences in mark-ups. The higher leverage in the Periphery implies, ceteris paribus, lower deposit spreads in this region as they require less collateral quantities to issue a unit of deposits. This, however, is partially counteracted by Periphery banks exhibiting higher market power, thereby allowing them to charge higher deposit spread, all else equal.

E. *Priors: Estimation Parameters*

One key parameter that is estimated is σ. It determines the intertemporal elasticity of substitution but also, given η, the strength of the cost channel. My choice of prior here follows previous work (Smets and Wouters (2003), Kollmann et al. (2016), Ilut and Schneider (2014)), details of which are shown in Table VII below. My choice of priors on the parameters governing conventional monetary policy, $(\phi_\pi, \rho_T, \phi_{\Delta\pi}, \phi_{\Delta y},)$ are informed by priors in existing Euro Area literature (Christoffel et al. (2008) and Coenen et al. (2018)), while the prior mean of ρ_{QE} is set to 0.5.[50] I also follow most of the literature in choosing standard priors for the persistence of the structural shock processes.

In particular, the priors for the autocorrelation parameters are beta distributions with mean 0.8 and standard deviation 0.1. This high mean is to be consistent with the slow-moving processes of the target variables, especially those corresponding to the banking sector. The priors for the standard deviations are inverse gamma, with prior means that are derived from matching the model to target variables using prior parameters. I also permit cross-correlations across countries in local productivity, demand and leverage shocks, motivated by the close co-movement across regions in output, inflation and deposit spreads, which these structural shocks effectively target.

Finally, when estimating these parameters, I am allowing for a structural break from a scarce to an ample reserves regime at the end of 2014 that is both fully unanticipated and permanent. All parameters other than those governing QE shocks are estimated using observations within the scarce regime sub-sample. I then estimate the parameters governing QE shocks within the ample regime sub-sample as only within this regime are such shocks feasible.

[49] Results on parameter estimates and decompositions are robust to adjustments in the reserves spread
[50] This choice of prior is of less persistence than conventional policy parameters in the literature, but results are largely insensitive to this choice of prior.

Table VII. Structural Parameters: Prior vs. Posterior Distributions

Parameters	Prior Dist.	Prior Mean	Prior Std. Err	Posterior Model	10% C.I.	90% C.I.
Scarce						
σ	Normal	1.00	0.25	0.81	0.66	0.98
ϕ_π	Normal	1.50	0.25	1.87	1.58	2.19
$\phi_{\Delta\pi}$	Normal	0.30	0.10	−0.08	−0.12	−0.03
$\phi_{\Delta y}$	Normal	0.06	0.25	0.10	0.07	0.13
ρ_T	Beta	0.80	0.10	0.89	0.86	0.92
ρ_{z^P}	Beta	0.80	0.10	0.87	0.81	0.93
$\rho_{z^{COMM}}$	Beta	0.80	0.10	0.76	0.66	0.88
ρ_{b^P}	Beta	0.80	0.10	0.89	0.87	0.91
$\rho_{b^{COMM}}$	Beta	0.80	0.10	0.88	0.86	0.90
ρ_{ℓ^P}	Beta	0.80	0.10	0.93	0.89	0.96
$\rho_{\ell^{COMM}}$	Beta	0.80	0.10	0.90	0.86	0.94
ρ_{ρ_A}	Beta	0.80	0.10	0.98	0.97	0.99
Ample						
ρ_{QE}	Beta	0.50	0.20	0.58	0.40	0.76

Notes: Posterior percentiles in Columns 6 and 7 obtained from two chains of 500,000 draws generated using a Random walk algorithm with an acceptance rate of 24 percent. The first 250000 draws are discarded as burn-in draws.

F. Results: Parameter Estimates

The posterior distributions of the structural model have been estimated using the Metropolis-Hastings algorithm. The estimated results are derived from two chains of 500,000 draws generated using a Random walk algorithm with an acceptance rate of 24%, with the first 250,000 being discarded as burn-in draws. In Table VII I document a set of characteristics regarding the posterior distributions of all the parameters that are estimated.[51] In particular, columns 5 to 7 show the posterior mode estimates of the individual parameters as well as the 10th and 90th percentiles of the corresponding marginal posterior densities. I split the set of parameters into those that are estimated in the first (Scarce) and second (Ample) sub-sample in the Baseline estimation.

An indication of the informativeness of the empirical data used in the estimation is how different the posterior and prior distributions are, in terms of mode and/or variance of the distribution. Firstly, turning to the intertemporal elasticity of substitution (σ), the posterior mode turns out to be somewhat lower than its prior, which dampens the degree of complementarity between consumption and deposits. This is consistent with both Euro Area (e.g. Kollmann et al. (2016)) and US (Smets and Wouters (2003)) posterior estimates in existing literature of being below 1. Given my estimates of η, this is a key parameter for

[51] For the priors and posteriors of the shock variances, see Table B.1.

determining the strength of the pass-through of QE shocks.

Turning to the estimated parameters of the interest rate rule, I find a stronger response to inflation and a higher degree of interest rate smoothing than the priors, while the responses to changes in output are rather small and unimportant for the propagation of any of the structural shocks.[52] The posterior modes are very consistent with the New Area-Wide Model used by the ECB for forecasting (see Coenen et al. (2018)).

Finally, in relation to the AR(1) coefficients for the structural shock processes, for productivity, demand and leverage shocks, *COMM* refers to the common union-wide shock, whereas *P* refers to the shock that is idiosyncratic to the Periphery and orthogonal to the union-wide shock. For the productivity (z^P, z^{COMM}) and local demand (b^P, b^{COMM}) shocks, all bar z^{COMM} are of higher persistence than the priors in order to explain slow-moving variations in output. This is even starker for the financial sector shocks of leverage $(\ell^P, \ell^{\text{COMM}})$ and collateral quality (ρ_A) shocks. The persistence of the QE shock, reflecting the persistence of the rate of purchases, is slightly higher than the prior but not too accurately estimated. Nevertheless, the conclusions that I draw in the decompositions and comparative statics are robust to variations in ρ_{QE} to the 10th or 90th percentile of the posterior distribution.

G. *Decomposition of Target Variables*

In my estimation setup, I have as many structural shocks as target variables. As a result, through the lens of my structural model, I can fully explain the empirical variation in my target variables through the contributions of each of the structural shocks. Therefore, in this subsection, I will attempt to describe what drives the movements in output and inflation over time, splitting the shocks into two groups: non-financial sector shocks (productivity, demand shocks per region, monetary policy rate shock) and financial sector shocks (QE shocks and collateral quality shocks).

Granted, this is a stylised framework for the non-financial sector, and abstracts from financial sector frictions beyond those concerning collateral scarcity. As a result, when discussing the contribution of productivity, this not only concerns traditional TFP shocks, but also captures the cost of production more generally, In particular, it can be partly interpreted as including investment risk premia that increase the costs of funding capital in richer models (a key source of variation in output in the Euro Area, according to Kollmann et al. (2016)).

[52] I also follow Christoffel et al. (2008) in fixing $\phi_y = 0$ given that a) it is hard to estimate accurately and b) it is frequently measured to be close to 0 within the Euro Area.

G.1. Non-Financial Sector Shocks

In the earlier years, the Periphery is playing catch-up with the Core levels of output. It is being temporarily dragged down by domestic productivity, which persists for the first few years, but is soon counteracted by strong local demand, allowing it to recover back to and above trend. This is also driving up demand pull inflation in the Periphery. In the meantime, the Core relatively underperforms, where both output and inflation remain close to trend as they are not experiencing such a local demand boost.

Following on from this, in the run up to the crisis, both regions experience a sharp rise in output as both demand and productivity shocks exhibit an expansionary effect. Monetary policy attempts to lean against the wind through a tightening policy shock, but ultimately to little avail. As the 2008/09 crisis hits, these tailwinds sharply reverse, especially demand shocks that induce significant demand-pull deflation. However, this sharp reversal turns out to be short-lived and initially output and inflation move back to trend across the union.

But soon after the Global Financial Crisis, the Periphery start to experience adverse productivity shocks, which very quickly turn into a very large headwind that generates a large drop in local output. This persists for a long period of time, and is accentuated by the declining influence of local demand and a negative union-wide demand shock, which drives down inflation across the union. Monetary policy attempts to soften the blow beyond the Taylor rule but to little effect. Interestingly, productivity within the Core remains robust, whose production faces only minor negative spillovers from the Periphery due to the larger relative size of the Core.

Gradually over time, the sovereign debt crisis abates, where the adverse productivity gives way to positive local demand and union-wide productivity as the Euro Area recovers. Inflation returns to trend but does not over-extend as the recovery is predominantly coming from higher productivity, a deflationary force.

G.2. Financial Sector Shocks

I now turn my attention to the contributions made by private collateral quality and QE shocks towards output and inflation within each region. Figure 7 plots the outcomes of the four key target variables along with the contribution made by private collateral quality shocks (in blue) and QE shocks (in red). QE shocks begin in the ample regime in early-2015, while private collateral quality shocks start becoming relevant amidst the sovereign debt crisis.

The sovereign debt crisis in the Periphery coincided with a protracted decline in the credit quality of outstanding private sector loans, judging by the rise in NPL ratios (reaching over 18% in Italy in 2014). This shook the collateral quality of existing loans on bank

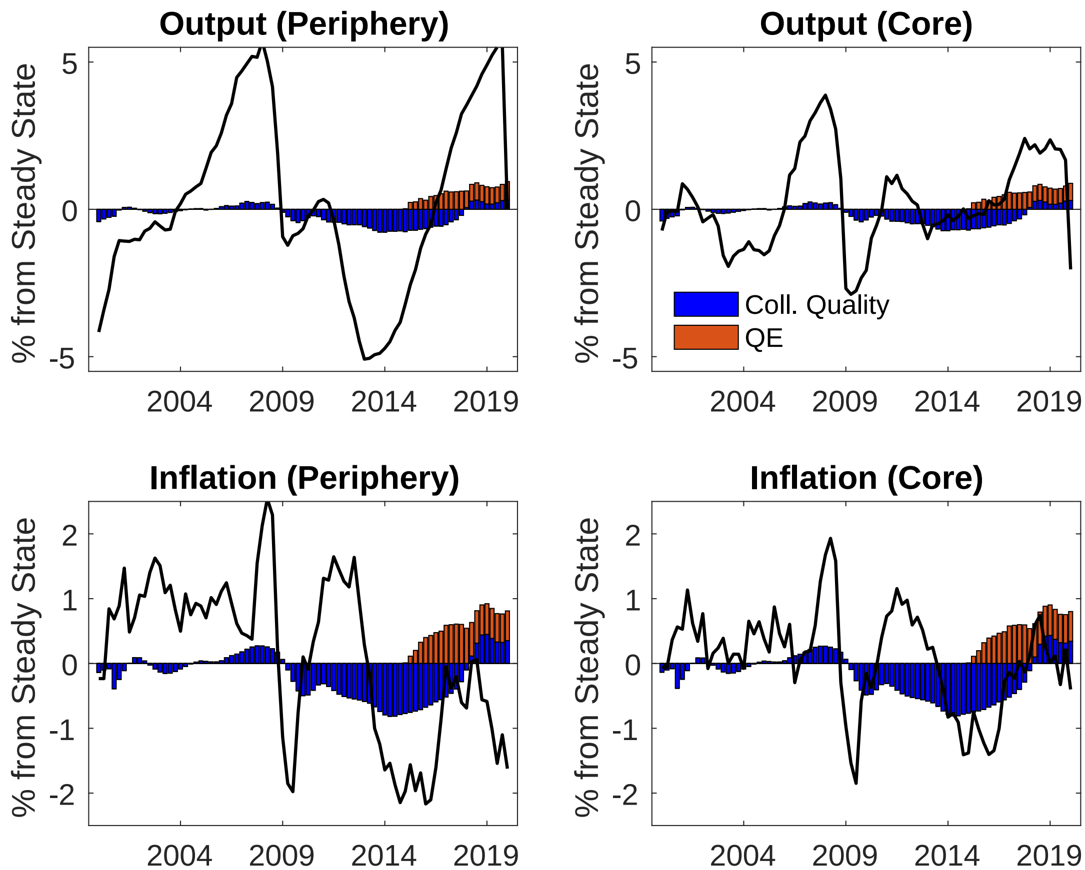

Figure 7. Contribution of collateral quality (in blue) and QE (in red) shocks to the empirical variation in target variables: output and inflation in each region. At a given time period, each bar conveys the cumulative effect of all past and current realizations of a given structural shock to the current value of the target variable.

balance sheets. By reducing the effective supply of collateral in the union, it inhibited the supply of liquid liabilities to households. This negatively impacted the desire to consume due to its complementarity with these liabilities, inducing a contraction in output and deflationary pressure across the union. Despite the fact that the collateral quality hit was concentrated within the Periphery, the effect was broadly similar across regions because of the integrated collateral market. In this setting, the geographical location of the shock is irrelevant - all that matters is its effect on union-wide collateral supply.

By reducing the collateral quality of firm loans, the adverse impact on output is amplified by how it raises the marginal cost of firms. When firms increase output, they gain access to additional units of subsidised funding. However, if the collateral quality falls, this benefit is weaker, thereby disincentivising the production of intermediate goods.

Once the ECB's QE (in particular, their Public Sector Purchasing Programme) commenced, they swiftly counteracted this collateral shock by flooding the banking system with high quality collateral in the form of reserves. This, combined with a gradual recovery of the collateral quality of private sector assets, bolstered inflation back up towards target in 2018, and remained a positive influence as the central bank retained reserves at an elevated level. Therefore, in this case, QE policy acted as a good substitute for conventional interest rate policy.

H. Counterfactual 1: No Quantitative Easing

As a way of illustrating the impact of QE on regions within the Euro Area, I consider what happens to each of the variables when we shut down the QE policy interventions but retain the same realizations of all other structural shocks in the model. In other words, I analyse what would happen to output and inflation in the Core and Periphery if there were no central bank asset purchases.

Figure 8 illustrates the difference in outcomes as a consequence of there being no QE policy over the course of the ample regime sample period. As we can see, at the trough in 2017, output and annual inflation would be 60bps and 62bps lower in each region, respectively. Intuitively, without QE, there is less collateral supply in the form of reserves, and very little additional non-reserve collateral for banks since most purchases were against non-bank counterparties (see Fact 3). As a result, with less collateral supply available for banks, they issue fewer deposits. This hurts the desire to consume and so output demand declines, driving down output and inflation via demand-pull factors. The impact extends over the course of the sample because asset purchases continue until end-2018, with reserve supply remaining elevated thereafter.[53]

Of course, the impact is very similar across countries because of the integrated collateral market. This is despite the fact that deposits are more complementary with consumption in the Periphery, and so would be more responsive to deposit supply shocks in that region. However, as deposit demand is more interest-elastic in the Core, so too is collateral supply, meaning that the contraction in collateral supply and so deposits is larger in the Core to such an extent that it largely counteracts the lower degree of complementarity.

I. Counterfactual 2: Less Responsive Taylor Rule

I now investigate what happens to the impact of QE on macro variables when the responsiveness of the Taylor rule to inflation is lower (i.e. lower ϕ_π). The parameters governing the

[53] In this counterfactual, the policy rate still follows the same Taylor rule. As inflation falls in this counterfactual, so too does the policy rate, below 1%. This is a level observed in other European currencies (e.g. Swiss Franc). If one instead prefers to work under the assumption that policy rates can't fall further, I could alternatively define this counterfactual as one where QE doesn't occur but policy rates are kept unchanged. In this setting, the implied effects of QE are larger because of the combined effect of (i) more collateral supply and (ii) relaxing the effective lower bound constraint from inducing higher inflation.

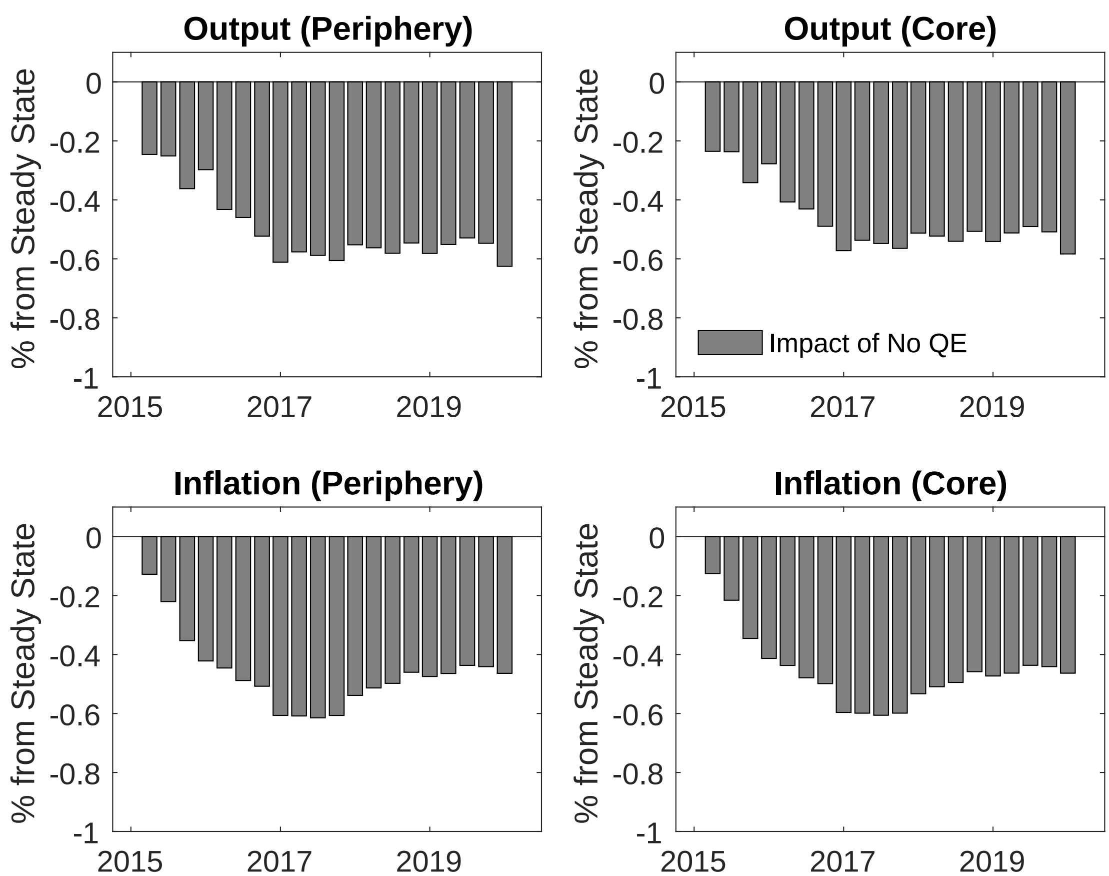

Figure 8. Counterfactual 1: how much the outcomes of output and inflation in each region change if there was no QE. Each bar at a given period conveys the effect from shutting down all QE shocks up to that period on the variable in question.

Taylor rule in equation (20) are estimated within the scarce regime sub-sample i.e. before any QE policy was undertaken. However, in practice, QE policy occurred in the context of the ECB facing an effective lower bound on its policy rate which, to first order, is like adjusting ϕ_π lower. In fact, existing literature interprets the ECB QE setting as one where QE coincides with ϕ_π being set to zero temporarily (see Coenen et al. (2018) and Andrade et al. (2016), for example).

My approach takes a less extreme assumption on ϕ_π and shifts it from the mode of the posterior distribution (1.87) to the 5% level (1.35). I then re-evaluate the impact on all target variables holding constant the realizations of the structural shocks. Figure 9 then demonstrates the impact of QE when at the baseline level of ϕ_π (in grey) vs. the *additional* impact caused by the reduction in ϕ_π to the 5% level (in red). What we see is that, at the peak in 2017, the effect on inflation rises from 60bps to 110bps, while the effect on output rises from 60bps to 80bps.

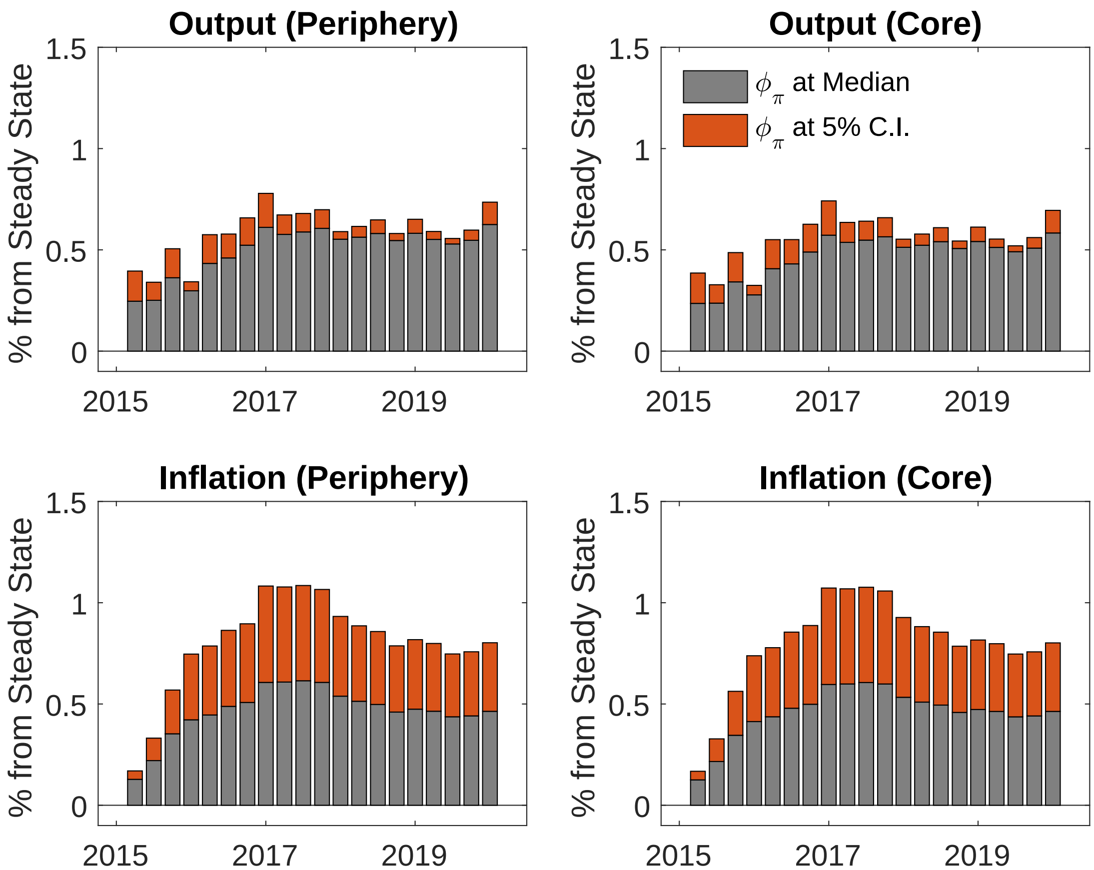

Figure 9. Counterfactual 2: additional contribution of QE shocks to output and inflation in each region when ϕ_π is lower. The grey bars convey the effects of QE shocks when ϕ_π is set to the median (1.87) of the posterior distribution. The red bars represent the *additional* contribution of the same shocks when ϕ_π is set to the 5% confidence interval level of the posterior distribution (1.35).

Intuitively, as the Taylor rule is responding less to inflation, the consequent rise in the real interest rate is dampened. This reduces the counter-balance to the stimulative effect caused by more central bank reserves. As a result, the overall effect of asset purchases is more expansionary, thereby raising output and inflation by more.

However, the degree of amplification caused by a less responsive Taylor rule is far greater than what I observe for productivity and demand shocks, even though the same mechanism just described also applies to them.[54] This is because there exists an additional channel specific to the progagation of QE shocks.

When the Taylor rule becomes less responsive, another avenue arises that stabilizes

[54]In particular, the response of inflation to either a demand or productivity is just 3% larger when ϕ_π is lowered to the 5% level.

the economy: the inflation rate itself. As inflation rises, it deflates the real supply of reserves, and so dilutes the effect of the nominal reserve supply shock on real reserves. This mechanism strengthens as the Taylor principle weakens, as it partly takes its place as the stabilization tool. This means that the economy is stabilized in the long run, but at the expense of temporarily higher inflation today. This has a small knock-on effect on output because, with higher expected inflation, reserve and so deposit supply will be relatively less abundant in the future, causing households to reallocate consumption into today.

VII. Conclusion

This paper investigates how central bank asset purchases work in the Eurozone. I focus on how these purchases work through the liability side of banks. My modelling approach is motivated by two key features of this deposit-offering business in the Eurozone. Using country-level statistics and bank micro-level data, I show firstly that deposit markets are segmented across country lines. Secondly, a large portion of assets held by banks are securities that are tradable across regions within the Eurozone. Bank balance sheets do not only consist of locally issued loans.

I incorporate local banks with these features into an open economy New Keynesian model. I estimate the model using data on macro and banking sector variables. The macro data I use is output and inflation for each region. QE shocks are identified from observed reserve supply, while shocks to bank assets are proxied with non-performing bank loan ratios. Some parameters are known up front from bank-level data. Remaining parameters and shocks are then found using Bayesian estimation.

I find that QE has a significant effect on the real economy, but in a way that differs from the existing literature. QE is effective because it increases the supply of high-quality collateral in the form of reserves. Banks can then use this to issue new deposits. This raises consumption because I estimate strong complementarity between consumption and deposits. Although deposit markets are segmented, the effect of QE ends up being very similar across regions. As banks hold securities that are tradable across regions, they end up facing the same cost of collateral that QE alleviates. The effect is bolstered if QE coincides with adjusting the Taylor rule to be a weaker counteracting force by making it less responsive to inflation.

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A. Figures

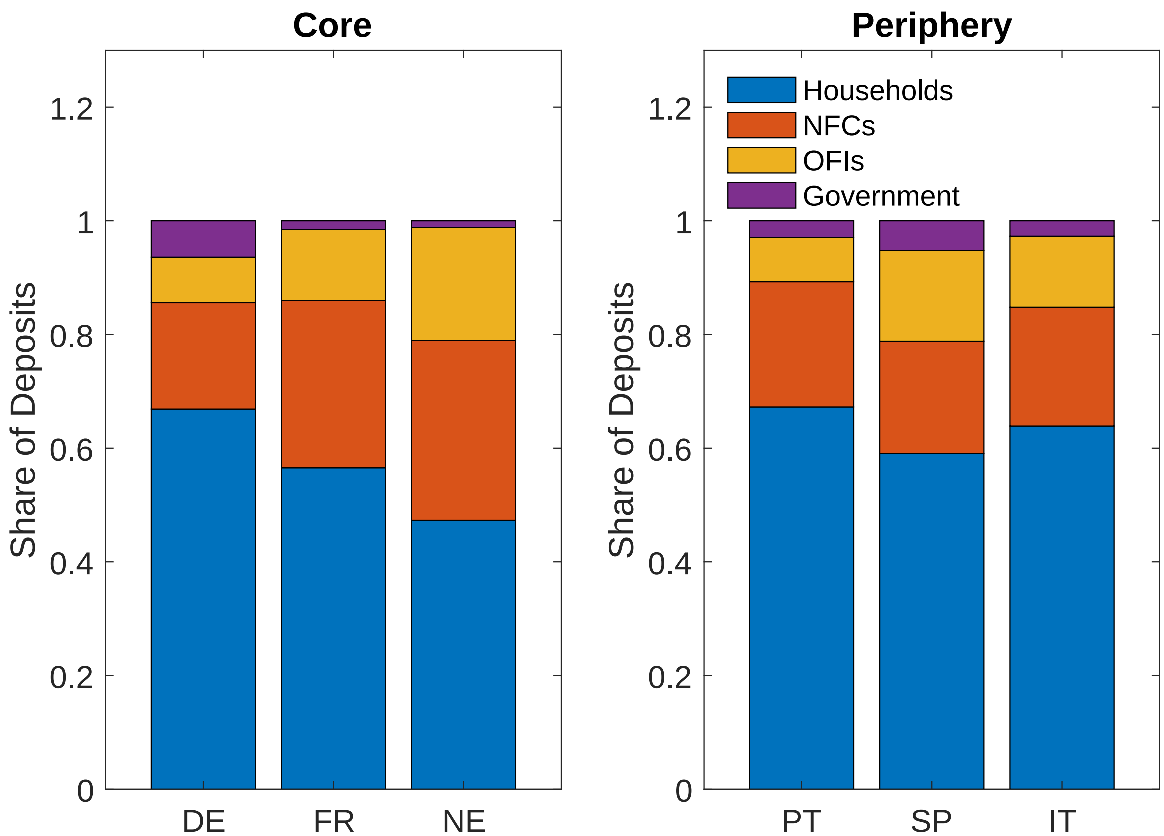

Figure A.1. Breakdown of deposits by counterparty of deposit holders, in end-2019. It splits banking sector by country of residence. Countries: Germany (DE), France (FR), Netherlands (NE), Portugal (PT), Spain (SP), Italy (IT).

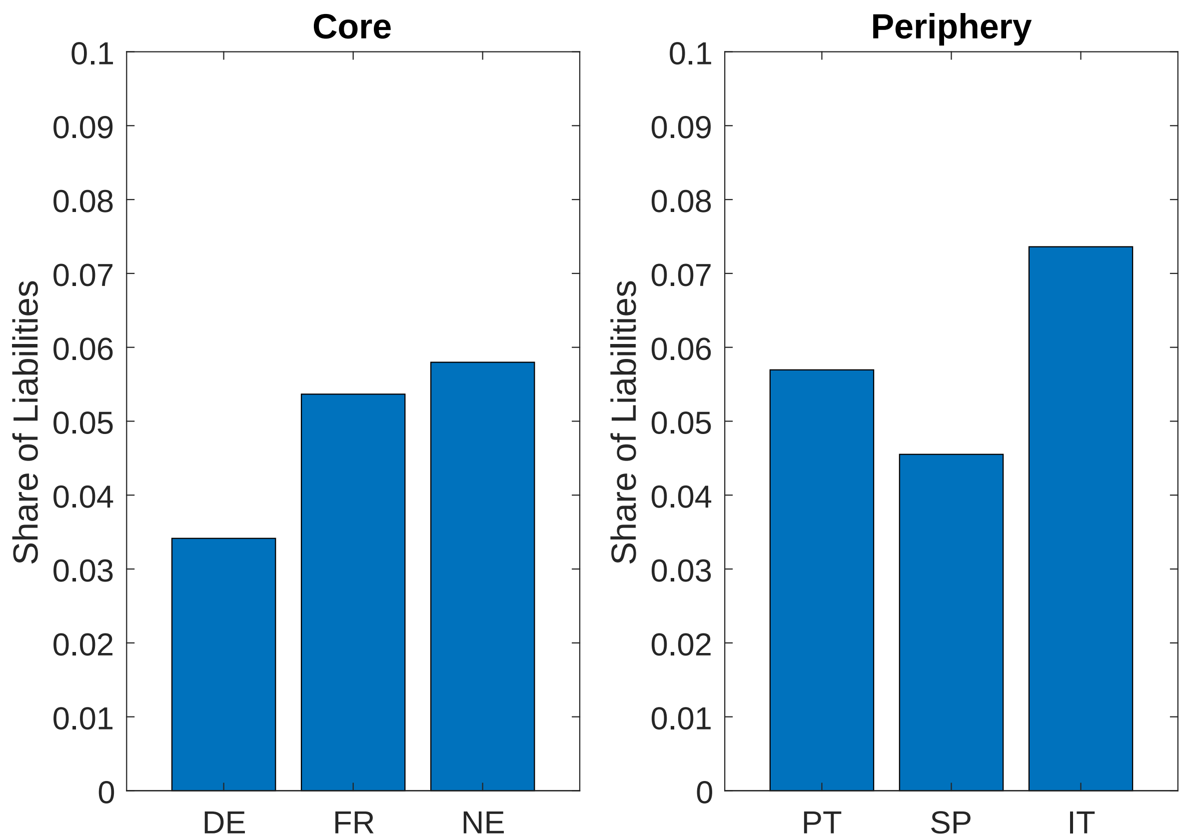

Figure A.2. Gross interbank borrowing as a share of liabilities, in end-2019. It splits banking sector by country of residence. Countries: Germany (DE), France (FR), Netherlands (NE), Portugal (PT), Spain (SP), Italy (IT).

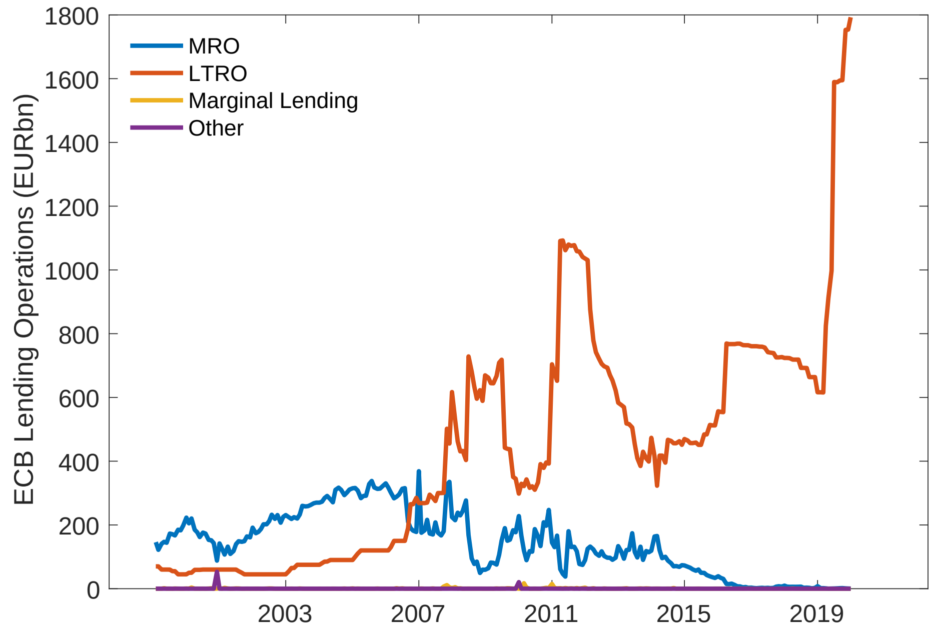

Figure A.3. Decomposition of ECB lending for monetary policy operations: Main Refinancing Operations (MRO), Long-Term Refinancing Operations (LTROs), Marginal Lending Facility and Other lending activities.

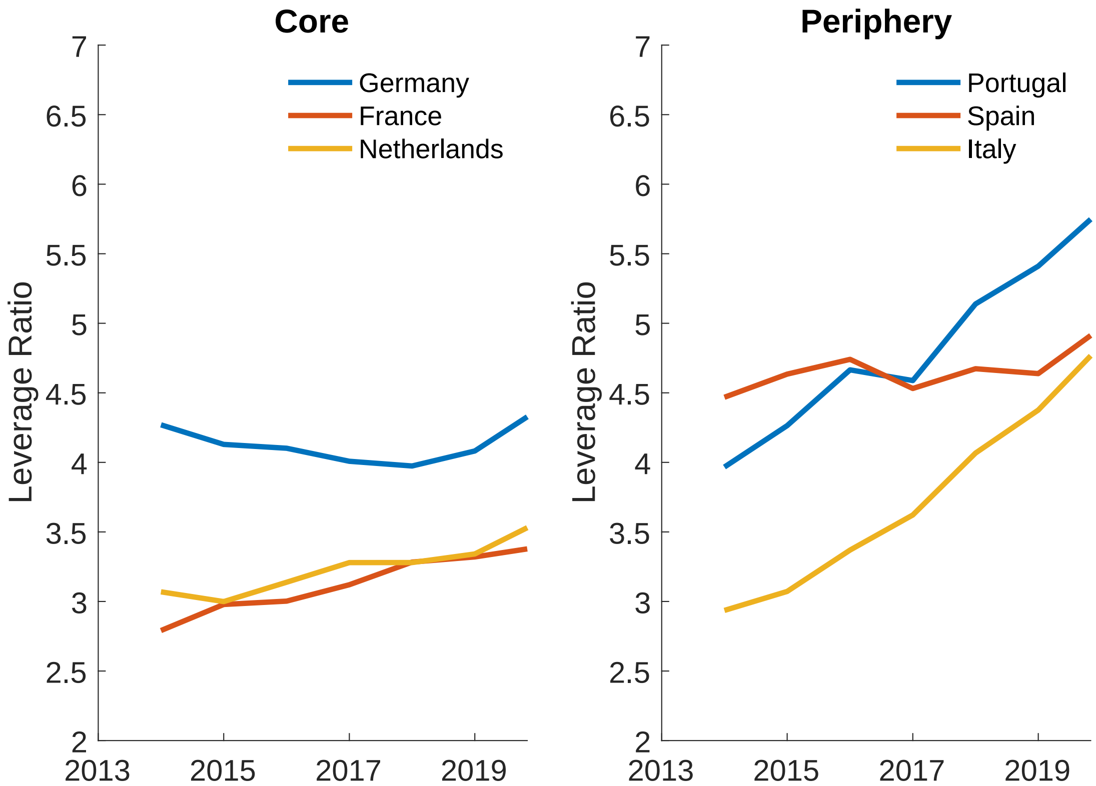

Figure A.4. Estimated bank leverage ratios at the country level. Leverage here equals Assets / Baseline Equity.

B. Tables

Table B.1. Structural Shock Variances Prior vs. Posterior Distributions

Parameters	Prior Dist.	Prior Mean	Prior Std. Err	Posterior Model	10% C.I.	90% C.I.
Scarce						
σ_v	Inv. Gamma	0.39	2.00	0.09	0.07	0.10
σ_{b^P}	Inv. Gamma	0.44	2.00	0.08	0.06	0.10
$\sigma_{b^{COMM}}$	Inv. Gamma	0.40	2.00	0.43	0.33	0.52
σ_{a^P}	Inv. Gamma	1.67	2.00	1.29	1.04	1.54
$\sigma_{a^{COMM}}$	Inv. Gamma	1.61	2.00	1.80	1.42	2.15
σ_{lev^P}	Inv. Gamma	7.65	15.00	4.10	3.27	4.99
$\sigma_{lev^{COMM}}$	Inv. Gamma	3.07	15.00	4.19	3.34	5.01
σ_{ρ_A}	Inv. Gamma	0.98	5.00	0.45	0.38	0.52
Ample						
σ_{QE}	Inv. Gamma	28.91	30.00	11.67	8.92	14.56

C. Bureau van Dyke Bank Orbis vs. BSI Aggregates

I document the degree of coverage obtained from my collection of data from the BvD Bank Orbis dataset, along with a basic understanding of the degree of market concentration in the deposit markets.

As part of determining Fact 1 in Section III, I collect data on the unconsolidated balance sheets of banks within the Euro Area. As they are unconsolidated, I do not observe the balance sheet of banking groups but instead those of each individual subsidiary of the group. For the collection of banks that I consider, it is important that its coverage of the overall banking sector within each country is significant.

To see the extent of our coverage, I compare Customer Deposits from the Orbis Dataset, aggregated at country level, against BSI Customer Deposits.[55] I also include the CBD aggregate, which I know should exceed the BSI aggregate because it includes, for banking groups headquartered there, foreign deposits of subsidiaries located abroad. As we can see in Figure C.5, by comparing the Orbis Dataset to BSI, it does a reasonably good job at the decomposition, except for Germany. In bold, I document the number of banks in the WRDS sample. As we can see, a small number of banks constitutes a large share of the market.

It seems like the deposit market is quite concentrated. To get a sense of this I move to considering the market shares of the Top 5 banks in each country, illustrated in Figure C.6. What stands out is the higher concentration in Peripheral vs. Core banks. Also, almost all countries illustrated in Figure C.6 (other than 2 in Portugal and 1 in Germany) are domestically owned, meaning that deposit markets are controlled by a small number of large domestic banks.

[55]In particular, I add Household and Non-Financial Corporation deposits.

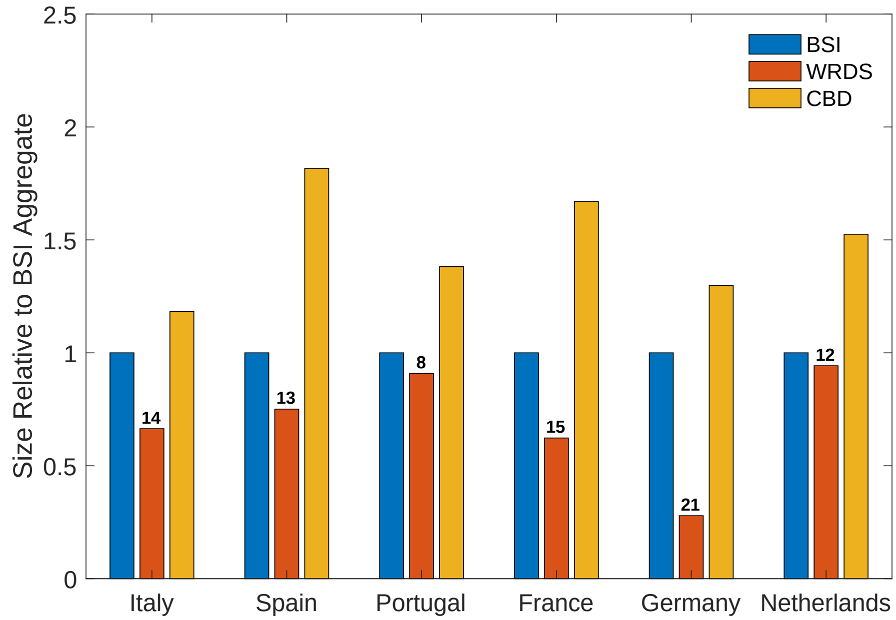

Figure C.5. Comparison of aggregates of customer deposits at the country level across three datasets: Balance Sheet Indicators Database (BSI), WRDS Bank Orbis Database, Consolidated Banking Data (CBD). The BSI aggregate is normalised to one. The numbers above the red bar indicate the number of individual banks/subsidiaries collected from WRDS per country of residence.

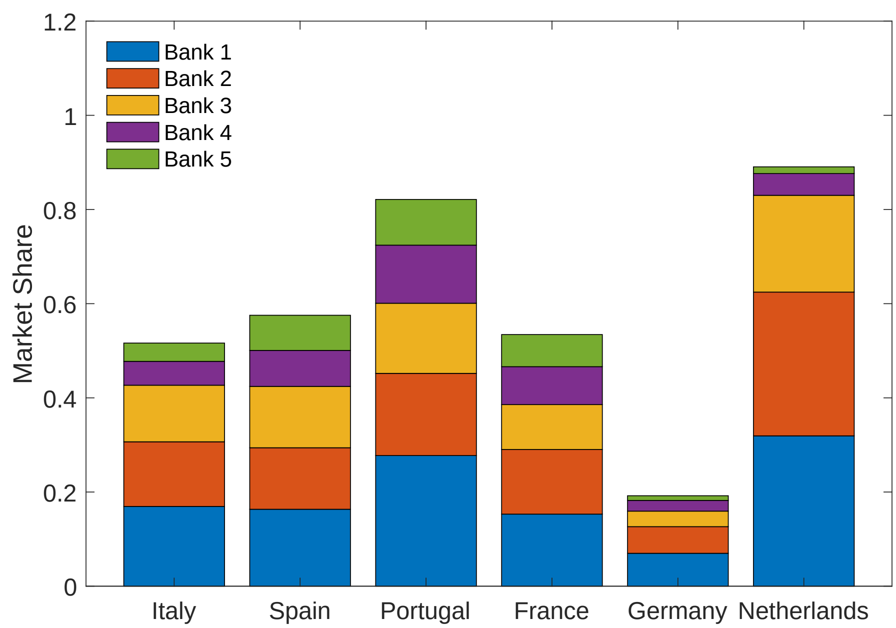

Figure C.6. Market Share of each of the Top 5 banks in the local customer deposits market. Banks numbered by rank of market share.

D. BRRD: Seniority of Deposits

This section explains my justification for the positioning of deposits being more senior to all unsecured debt. I will primarily focus on the Bank Recovery and Resolution Directive (BRRD), but will also discuss the MREL legislation that serves to make banks more stable.

The BRRD is a directive that defines the set of rules governing how bank insolvencies are to be resolved in each member state. In defining how bank insolvencies are resolved, it outlines what bank liabilities should be bailed in and bear the losses, and in what order. In doing so, it implies a clear ordering of seniority on the liabilities.

I argue that the following items lie senior to senior unsecured debt:

(i) all deposits from HHs and NFCs

(ii) all deposits from OFIs with a maturity of less than or equal to 7 days

This represents the vast bulk of bank non-MFI-sourced deposits. In Article 44(2), (i) up to a balance of $100k per counterparty, and (ii) are exempt from being bailed in (i.e. bearing losses conditional on default), but there is no mention of any unsecured debt. Of the portion of (i) above $100k, Article 44(3) supports the view of it being senior by saying that the resolution authorities have the power to exclude "eligible deposits held by natural persons and micro, small and medium-sized enterprises" that would "severally disrupt the functioning of financial markets".

In further support of this, Article 108 states that members must impose in national law that "the claims of ordinary unsecured, non-preferred creditors" lie junior to all household and Non-Financial Corporation deposits. As a result, all deposits in (i) and (ii) should lie senior to unsecured debt. Goodhart et al (2014) agrees with this assessment, and Udoye (2015) states that "the resolution authority exercise its discretion under Article 44 3(c) to exclude uncovered deposits from bail-in".

D.1. MREL Legislation

The primary mechanism through which the BRRD legislation affects banks, other than through solvency proceedings, is through the MREL Regulation motivated by it. Therefore, it is informative to see what this implies for seniority in practice.

In general, the MREL (Minimum Requirement of Own Funds and Eligible Liabilities) is all about regulation concerning how much subordinated i.e. eligible liabilities need to be held on the balance sheet. Subordinated liabilities are those that take a hit in the event of bankruptcy after equity is cleared. The set of rules is meant to help implement the stability goals of the BRRD.

As well as listing the same liabilities as those in Article 44(2) that are explicitly not part of the eligible liabilities, it also makes explicit the set of liabilities that can be part of the subordinated liabilities in calculating their regulatory ratios.

Now, officially at the end of all transition periods, no asset with the same seniority as those in Article 44(2) can be included as part of the MREL-eligible liabilities. This can include senior unsecured debt, and so the MREL does not explicitly reflect the BRRD legislation that senior unsecured debt lies junior to the deposits that are listed in Article 44(2). The reluctance to include this is because bailing in unsecured senior debt runs into the No Creditor Worse off (NCWO) idea. In other words, in the event of insolvency, if resolved by an authority, it needs to respect orders of seniority. In the transition period, in order to help banks meet targets, it allows for a non-zero proportion, albeit capped, of MREL-eligible liabilities that can be senior unsecured debt.

Thus, it exhibits largely the same conclusions on seniority. Interestingly, the MREL legislation allows for significant discretion at the bank level, particularly within this transitionary period. This also allows for leverage ratios to differ quite significantly across countries.

E. Intermediate Firm Optimization Problem

I describe the problem of the intermediate firm in more detail, and the consequent adapted Phillips curve.

There is a continuum of intermediate firms $f \in [0,1]$ operating in a monopolistically competitive market, facing a constant demand elasticity ϵ. Each firm f faces a linear production function $Y_t = Z_t N_t$, and I assume Calvo price setting. Additionally, within each period, firms can borrow up to a fraction γ_L of revenue in the current period, in the form of one-period loans from banks.

Bringing all this together, the optimization problem of each firm f in country $K \in \{I, J\}$ amounts to

$$\max_{p_{\text{ft}}, L_{\text{f,t+s}}} \sum_{s=0}^{\infty} E_t \left[\frac{M^K_{\text{t+s}}}{P^K_{\text{t+s}}} \left(\theta^s \left(p_{\text{f,t}} y_{\text{f,t+s}} - W^K_{\text{t+s}} n_{\text{f,t+s}} \right) + L_{\text{f,t+s+1}} - (1 + i^{L,K}_{\text{t+s-1}}) L_{\text{f,t+s}}) \right) \right], \tag{E.1}$$

subject to

$$L_{f,t+1} \leq \gamma_L p_{ft} y_{ft},$$

where $L_{f,t+1}$ is the quantity of loans taken out in period t by firm f and $i^{L,K}_{\text{t+s-1}}$ is the interest rate on those loans. As firms are owned by domestic households, firms inherit their nominal stochastic discount factor, M^K_{t+1}. Letting λ^{BC}_t be the Lagrange multiplier on the loan constraint:

$$\frac{1}{P^K_t} - E_t\left[\frac{M^K_{t+1}}{P^K_{t+1}}(1+i^{L,K}_t)\right] = \lambda^{BC}_t.$$

Knowing that $E_t\left[M^K_{t+1}\left(\frac{P^K_t}{P^K_{t+1}}\right)(1+i^{S,K}_t)\right] = 1$, then plugging this into the first order condition:

$$\frac{1}{P^K_t}\left(\frac{i^{S,K}_t - i^{L,K}_t}{1+i^{S,K}_t}\right) = \lambda^{BC}_t.$$

I will be considering settings in which the loans issued by firms exhibit a convenience yield and so the constraint binds. I know that the marginal benefit of each unit of loans is equal to λ^{BC}_t, and so knowing this and the fact that $L_{f,t+1} = \gamma p_{ft} y_{ft}$, the problem can be re-written as

$$\max_{p_{ft}} \sum_{s=0}^{\infty} \theta^s E_t\left[\frac{M^K_{t+s}}{P^K_{t+s}}\left(p_{f,t}y_{f,t+s} - W^K_{t+s}n_{f,t+s} + \gamma_L\left(\frac{i^{S,K}_{t+s} - i^{L,K}_{t+s}}{1+i^{S,K}_{t+s}}\right)p_{ft}y_{f,t+s}\right)\right].$$

Rearranging this equation, we have that:

$$\max_{p_{ft}} \sum_{s=0}^{\infty} \theta^s E_t\left[\frac{M^K_{t+s}}{P^K_{t+s}} y_{f,t+s}\left(p_{ft} - \varphi_{f,t+s}\right)\right], \tag{E.2}$$

where marginal cost, $\varphi_{f,t+s}$, equals

$$\varphi_{f,t+s} = \frac{W^K_{t+s}}{Z_{t+s}} - \gamma_L p_{ft}\left(\frac{i^{S,K}_{t+s} - i^{L,K}_{t+s}}{1+i^{S,K}_{t+s}}\right). \tag{E.3}$$

As a consequence, what adjusts from the standard model is that the definition of marginal cost now contains the second term. This captures how more output gives the firm access to cheap funding in the form of loans, thereby reducing effective marginal costs. Appendix F then describes how the implied Phillips curve is derived.

F. Derivation of Phillips Curve

Solving for the Phillips curve starts by solving for the optimal price in (E.2). Note that, for any firm who has the opportunity to adjust their price in period t, they will choose the same price, denoted by $p_t^{\#}$. The optimal price is therefore

$$p_t^{\#} = \left(\frac{\epsilon}{\epsilon - 1}\right) \left(\frac{E_t \sum\limits_{t=0}^{\infty} (\beta\phi)^s u_{1t} \tilde{\varphi}_{t,t+s} p_{t+s}^{\epsilon-1} y_{t+s}}{E_t \sum\limits_{t=0}^{\infty} (\beta\phi)^s u_{1t} p_{t+s}^{\epsilon-1} y_{t+s}} \right), \tag{F.4}$$

where

$$\tilde{\varphi}_{t,t+s} = \underbrace{\frac{W_{t+s}}{Z_{t+s}}}_{\tilde{\varphi}^1_{t+s}} \underbrace{- \gamma_L (1 - \frac{1}{\epsilon}) p_t^{\#} \left(\frac{i^S_{t+s} - i^L_{t+s}}{1 + i^L_{t+s}} \right)}_{\tilde{\varphi}^2_{t,t+s}}.$$

By incorporating loans into the intermediate firm problem $\tilde{\varphi}_{t,t+s}$ now depends on time t as well as $t+s$. As a result, some adaptations are required.

I work with a re-arranged expression of (F.4):

$$\frac{p_t^{\#}}{p_{t-1}} = \frac{\epsilon}{\epsilon - 1} \left(\frac{A_t^1 - A_t^2 \left(\frac{p_t^{\#}}{p_{t-1}}\right)}{B_t} \right), \tag{F.5}$$

where I have that:

$$\begin{aligned}
A_t^1 &= E_t \sum_{s=0}^{\infty} (\beta\phi)^s u_{1t} \left(\frac{\tilde{\varphi}^1_{t+s}}{p_{t-1}}\right) \left(\frac{p_{t+s}}{p_t}\right)^{\epsilon-1} y_{t+s}, \\
A_t^2 &= E_t \sum_{s=0}^{\infty} (\beta\phi)^s u_{1t} \left(\frac{\tilde{\varphi}^2_{t,t+s}}{p_t^{\#}}\right) \left(\frac{p_{t+s}}{p_t}\right)^{\epsilon-1} y_{t+s}, \\
B_t &= E_t \sum_{s=0}^{\infty} (\beta\phi)^s u_{1t} \left(\frac{p_{t+s}}{p_t}\right)^{\epsilon-1} y_{t+s}.
\end{aligned}$$

The key trick here is to have $p_t^{\#}$ in the denominator of $\frac{\tilde{\varphi}^2_{t,t+s}}{p_t^{\#}}$ instead of p_{t-1}.

The next step is to log-linearize the expression (F.5). Doing that requires getting rid of the summation terms. Indeed, it is possible to re-write the expressions in the following way:

$$A_t^1 = (1+\pi_t)\left[u_{1t}y_t\left(\frac{\tilde{\varphi}_t^1}{p_t}\right) + \phi\beta E_t\left(\frac{p_{t+1}}{p_t}\right)^{\epsilon-1} A_{t+1}^1\right],$$
$$A_t^2 = u_{1t}y_t\left(\frac{\tilde{\varphi}_{t,t}^2}{p_t^\#}\right) + \phi\beta E_t\left(\frac{p_{t+1}}{p_t}\right)^{\epsilon-1} A_{t+1}^2,$$
$$B_t = u_{1t}y_t + \phi\beta E_t\left(\frac{p_{t+1}}{p_t}\right)^{\epsilon-1} B_{t+1}.$$

Then this can be very cleanly log-linearized, which results in the following first Phillips curve equation:

$$\pi_{Ht} = \frac{(1-\theta)(1-\theta\beta)}{\theta}\hat{mc}_t + \beta E_t \pi_{Ht+1} \tag{F.6}$$

where log-linearized real marginal cost is

$$\hat{mc}_t \approx \hat{\omega}_t - \hat{z}_t - \gamma_L(i_t^S - i_t^L - r^S + r^L),$$

where $\hat{\omega}_t$ is log-linearized real wages relative to producer prices, p_{Ht}.

G. Derivation of Steady State Output

Steady state output is the point in time at which the real marginal cost of production is one for intermediate good firms. I assume a zero inflation steady state, which implies that all firms decide to hold prices fixed at the same level. Real marginal cost (RMC) is then

$$RMC = \frac{W}{P_H Z} - \gamma_L\left(\frac{r^S - r^L}{1+r^S}\right)$$

where the wage component is

$$\begin{aligned}\frac{W}{P_H Z} &= \frac{W}{P}\frac{P}{P_H}\frac{1}{Z} \\ &= \frac{\varphi N^\phi}{JC^{-1/\sigma}}\frac{P}{P_H} \quad \text{as} \quad W/P = \frac{\varphi N^\phi}{JC^{-1/\sigma}} \quad \text{and} \quad Z = 1 \\ &= \frac{\varphi Y^\phi C^{1/\sigma}}{J}\frac{P}{P_H} \quad \text{as} \quad Y = ZN = N,\end{aligned}$$

where $J = \left[1 + \omega vel^{1/\eta - 1}\right]^{\frac{1/\eta - 1/\sigma}{1 - 1/\eta}}$. Next I need to establish two properties.

Property 1: $P_H Y = PC$

I begin with the following budget constraint:

$$PC + D + B^H - X = WN + \Pi^{INT} + CF^{BANK} + (1 + i^D)D + (1 + i^S)B^H - (1 + i^X)X + T, \tag{G.7}$$

where B^H is the household's holdings of risk-free assets. CF^{BANK} is the net cash flows arriving from banks owned by households, equal to[56]

$$CF^{BANK} = R(1 + i^R) + L(1 + i^L) + X(1 + i^X) - D(1 + i^D) - R - L - X + D. \tag{G.8}$$

Π^{INT} are intermediate firm profits that arise as a consequence of their market power. On aggregate, profits are equal to[57]

$$\Pi^{INT} = P_H Y - WN - i^L L. \tag{G.9}$$

Finally, we have the government budget constraint. I assume that the government is the entity who a) supplies reserves to the domestic bank, sourced from the ECB, and b) supplies risk-free assets to households. As a result, we have that

$$T = B^H + R - B^H(1 + i^S) - R(1 + i^R). \tag{G.10}$$

Incorporating equations (G.8), (G.9) and (G.10) into equation (G.7), we obtain that $P_H Y = PC$.

Property 2: $P = P_H$

I presume that $Q = 1$ i.e. the price of the consumption composite is the same in both the Core and the Periphery. In other words, $P^I = P^J$. Plugging in the definition of these price composites:

$$P^{I^{1-\gamma}} = a^I_H \left(P^I_H\right)^{1-\gamma} + (1 - a^I_H)\left(P^J_H\right)^{1-\gamma} = a^J_H \left(P^J_H\right)^{1-\gamma} + (1 - a^J_H)\left(P^I_H\right)^{1-\gamma}.$$

Rearranging, we have that

[56] In the model, there is just a union-wide market for household claims. I resolve the split between regions to be that local households issue claims equalling the demand by local banks.

[57] Note that the firm is paying interest on its debt each period, but for the benefit of the proceeds in period 0 that earn the risk-free rate of i^S after being paid back to shareholders.

$$\left(\frac{P_H^J}{P_H^I}\right)^{1-\gamma} = \frac{1-a_H^J-a_H^I}{1-a_H^I-a_H^J} = 1.$$

Therefore, if $Q = 1$, then $P^I = P^J = P_H^I = P_H^J$.

Therefore, combining Properties 1 and 2, we have that, for country $K \in \{I, J\}$:

$$Y^K = \left(\frac{1}{\varphi}\tilde{J}^K\right)^{\frac{1}{\phi+1/\sigma}}. \tag{G.11}$$

Lastly, I need to check that this is consistent with the steady state market-clearing conditions for each country. For country I, it is

$$Y_H^I = \left(\frac{P_H^I}{P_H^J}\right)^{-\gamma}\left[a_H^I C^I + (1-a_H^J)Q^\gamma\left(\frac{X^J}{X^I}\right)C^J\right]. \tag{G.12}$$

and analogously for country J, where (X^I, X^J) is the population of countries I and J, respectively. Plugging in properties 1 and 2, both equations imply the following restriction on parameters (a_H^I, a_H^J):

$$\left(1-a_H^I\right)\left(\frac{X^I}{X^J}\right)\left(\frac{J^I}{J^J}\right)^{\frac{1}{\phi+1/\sigma}} = 1-a_H^J. \tag{G.13}$$

I decide on the following definitions of (a_H^I, a_H^J) that satisfy (G.13):

$$(1-a_H^J) = (1-\bar{a}_H)\left[\left(\frac{X^I}{X^J}\right)\left(\frac{J^I}{J^J}\right)^{\frac{1}{\phi+1/\sigma}}\right]^{1/2},$$

$$(1-a_H^I) = (1-\bar{a}_H)\left[\left(\frac{X^I}{X^J}\right)\left(\frac{J^I}{J^J}\right)^{\frac{1}{\phi+1/\sigma}}\right]^{-1/2}.$$

This implies that, if both countries have the same total output, they exhibit home bias $\bar{a}_H$,. As the relative size of country K increases, a_H^K rises, and vice versa.

H. Log-Linearized System of Equations

This section describes the full system of log-linearized equations from around the steady state. For each region, we have the Euler equation for the representative household

$$\hat{c}_t^I = E_t\hat{c}_{t+1}^I - \sigma\left(i_t^{S,I} - E_t\pi_{t+1}^I - r^S - \hat{b}_t^I\right) + \sigma B E_t \Delta\hat{vel}_{t+1}^I \tag{H.14}$$

$$\hat{c}_t^J = E_t\hat{c}_{t+1}^J - \sigma\left(i_t^{S,J} - E_t\pi_{t+1}^J - r^S - \hat{b}_t^J\right) + \sigma B E_t \Delta \hat{vel}_{t+1}^J, \tag{H.15}$$

the Phillips curve for the production sector

$$\pi_{Ht}^I = \beta E_t \pi_{H,t+1}^I + \kappa_\alpha \hat{y}_t^I - \lambda(1+\phi)\hat{z}_t^I + \lambda B \hat{vel}_t^A - \lambda(1-a_H^I)\frac{A_q}{\sigma}\hat{y}_t^J - \lambda\gamma_L\left(\hat{i}_t^{S,I} - \hat{i}_t^{L,I}\right) \tag{H.16}$$

$$\pi_{Ht}^J = \beta E_t \pi_{H,t+1}^J + \kappa_\alpha \hat{y}_t^J - \lambda(1+\phi)\hat{z}_t^J + \lambda B \hat{vel}_t^{A,J} - \lambda(1-a_H^J)\frac{A_q}{\sigma}\hat{y}_t^I - \lambda\gamma_L\left(\hat{i}_t^{S,J} - \hat{i}_t^{L,J}\right), \tag{H.17}$$

where $\hat{vel}_t^{A,I} = \hat{vel}_t^I + \left(a_H^I + (1-a_H^I)A_q(a_H^I + a_H^J - 1)\right)\left(\hat{vel}_t^J - \hat{vel}_t^I\right)$ and $\hat{vel}_t^{A,J} = \hat{vel}_t^J + \left(a_H^J + (1-a_H^J)A_q(a_H^I + a_H^J - 1)\right)\left(\hat{vel}_t^I - \hat{vel}_t^J\right)$. The intratemporal condition for deposits in each region is

$$\hat{vel}_t^I \equiv \hat{c}_t^I - \hat{d}_t^I = \frac{\eta}{r^{S,I} - r^{D,I}}\left(\hat{i}_t^{S,I} - \hat{i}_t^{D,I}\right), \tag{H.18}$$

$$\hat{vel}_t^J \equiv \hat{c}_t^J - \hat{d}_t^J = \frac{\eta}{r^{S,J} - r^{D,J}}\left(\hat{i}_t^{S,J} - \hat{i}_t^{D,J}\right). \tag{H.19}$$

For each banking sector, we have the following leverage constraint:

$$\hat{d}_t^I = \hat{\ell}_t^I + \frac{R^I}{D^I}\hat{R}_t^I + \left(\frac{\rho_A A^I}{D^I}\right)(\hat{\rho}_{A,t} + \hat{a}_t^I), \tag{H.20}$$

$$\hat{d}_t^J = \hat{\ell}_t^J + \frac{R^J}{D^J}\hat{R}_t^J + \left(\frac{\rho_A A^J}{D^J}\right)(\hat{\rho}_{A,t} + \hat{a}_t^J), \tag{H.21}$$

and the first order conditions for reserves and other assets:

$$i_t^{S,I} - i_t^{D,I} = \left(\ell^I\right)^{-1}\left(i_t^{S,I} - i_t^R\right) - \left(r^{S,I} - r^{D,I}\right)\hat{\ell}_t^I, \tag{H.22}$$

$$i_t^{S,J} - i_t^{D,J} = \left(\ell^J\right)^{-1}\left(i_t^{S,J} - i_t^R\right) - \left(r^{S,J} - r^{D,J}\right)\hat{\ell}_t^J, \tag{H.23}$$

$$i_t^{S,I} - i_t^{D,I} = \left(\rho_A^I \ell^I\right)^{-1}\left(i_t^{S,I} - i_t^{L,I}\right) - \left(r^{S,I} - r^{D,I}\right)\left(\hat{\ell}_t^I + \hat{\rho}_{A,t}\right), \tag{H.24}$$

$$i_t^{S,J} - i_t^{D,J} = \left(\rho_A^J \ell^J\right)^{-1}\left(i_t^{S,J} - i_t^{L,J}\right) - \left(r^{S,J} - r^{D,J}\right)\left(\hat{\ell}_t^J + \hat{\rho}_{A,t}\right). \tag{H.25}$$

Monetary policy is defined by independent rules for the policy rate and reserve supply:

$$i_t^R = r^R + \rho_R \left(i_{t-1}^R - r^R \right) + (1-\rho_R) \left(\phi_\pi \hat{\pi}_t^{\text{UNION}} + \phi_y \hat{y}_t^{\text{UNION}} \right)$$
$$+ \phi_{\Delta\pi} \left(\hat{\pi}_t^{\text{UNION}} - \hat{\pi}_{t-1}^{\text{UNION}} \right) + \phi_{\Delta Y} \left(\hat{y}_t^{\text{UNION}} - \hat{y}_{t-1}^{\text{UNION}} \right) + v_t^{MPS}, \tag{H.26}$$

$$\hat{r}_t^S = \alpha_r \hat{r}_{t-1}^S - \alpha_r \pi_t + v_t^{QE}, \tag{H.27}$$

where $\pi_t^{UNION} = \frac{X^I}{X^I + X^J} \pi_t^I + \frac{X^J}{X^I + X^J} \pi_t^J$. The Backus-Smith condition for complete markets is expressed as

$$\hat{q}_t = \frac{1}{\sigma} \left(\hat{c}_t^I - \hat{c}_t^J \right) - \frac{1}{1-\rho_b} \left(\hat{b}_t^I - \hat{b}_t^J \right) + B^J \hat{vel}_t^J - B^I \hat{vel}_t^I. \tag{H.28}$$

The asset market clearing for reserves is given by

$$\hat{R}_t^S = \frac{X^I}{X^I + X^J} \hat{R}_t^I + \frac{X^J}{X^I + X^J} \hat{R}_t^J. \tag{H.29}$$

Goods market clearing for each of the two markets is

$$\hat{y}_t^I = \hat{c}_t^I + (1 - a_H^I) \left(\frac{\gamma}{a_H^I + a_H^J - 1} + \gamma - \sigma \right) \hat{q}_t + \sigma(1 - a_H^I) B^I \hat{vel}_t^I - \sigma(1 - a_H^I) B^J \hat{vel}_t^J, \tag{H.30}$$

$$\hat{y}_t^J = \hat{c}_t^J - (1 - a_H^J) \left(\frac{\gamma}{a_H^I + a_H^J - 1} + \gamma - \sigma \right) \hat{q}_t + \sigma(1 - a_H^J) B^J \hat{vel}_t^J - \sigma(1 - a_H^J) B^I \hat{vel}_t^I. \tag{H.31}$$

The pricing identities that are reflective of being in a fixed exchange rate regime are the following:

$$\pi_t^I = a_H^I \pi_{Ht}^I + (1 - a_H^I) \pi_{Ht}^J, \tag{H.32}$$

$$\pi_t^J = a_H^J \pi_{Ht}^J + (1 - a_H^J) \pi_{Ht}^I, \tag{H.33}$$

$$\Delta \hat{q}_t = \pi_t^J - \pi_t^I, \tag{H.34}$$

and finally exogenous processes for each of the shocks $\left(\hat{b}_t^I, \hat{b}_t^J, \hat{z}_t^I, \hat{z}_t^J, v_t^{MPS}, \hat{\ell}_t^I, \hat{\ell}_t^J, v_t^{QE}, \hat{\rho}_{A,t} \right)$, where the parameters $(A_q, \sigma_\alpha, \kappa_\alpha, B^I, B^J))$ are

$$A_q = \frac{(a_H^I + a_H^J)(\sigma - \gamma)}{\sigma - (a_H^I + a_H^J)(2 - a_H^I - a_H^J)(\sigma - \gamma)} \quad ; \quad \sigma_\alpha = \frac{\sigma}{1 + A_q} \quad ; \quad \kappa_\alpha = \lambda\left(\phi + \sigma_\alpha\right),$$

$$B^I = \left(1/\eta^I - 1/\sigma\right)\left(\frac{r^{S,I} - r^{D,I}}{vel^I + r^{S,I} - r^{D,I}}\right) \quad ; \quad B^J = \left(1/\eta^J - 1/\sigma\right)\left(\frac{r^{S,J} - r^{D,J}}{vel^J + r^{S,J} - r^{D,J}}\right).$$

As a result, we have a system of 30 equations (Equations (H.14) - (H.34) and 9 exogenous processes) and 30 unknowns, which is solved through Dynare.

I. Derivation of Risk-Free Rate Equalization

I solve for this under the log-linearized system of equations. Combining the two Euler equations

$$\hat{c}_t^I = E_t\hat{c}_{t+1}^I + \sigma B^I E_t \Delta \hat{vel}_{t+1}^I - \sigma\left(\hat{i}_t^{S,I} - E_t\pi_{t+1}^I\right) + \sigma\hat{b}_t^I,$$

$$\hat{c}_t^J = E_t\hat{c}_{t+1}^J + \sigma B^J E_t \Delta \hat{vel}_{t+1}^J - \sigma\left(\hat{i}_t^{S,J} - E_t\pi_{t+1}^J\right) + \sigma\hat{b}_t^J.$$

I get the following equation:

$$\hat{i}_t^{S,I} - \hat{i}_t^{S,J} = E_t\pi_{t+1}^I - E_t\pi_{t+1}^J + \sigma^{-1}\left(E_t\Delta\hat{c}_{t+1}^I - E_t\Delta\hat{c}_{t+1}^J\right) + B^I E_t\Delta\hat{vel}_{t+1}^I - B^J E_t\Delta\hat{vel}_{t+1}^J + \sigma\left(\hat{b}_t^I - \hat{b}_t^J\right).$$

Now, with the Backus-Smith condition in (H.28), by taking first differences, and knowing that $E_t\left[\hat{b}_{t+s}\right] = \rho^s\hat{b}_t$:

$$E_t\Delta\hat{c}_{t+1}^I - E_t\Delta\hat{c}_{t+1}^J = \sigma E_t\Delta\hat{q}_{t+1} - \sigma B^I E_t\Delta\hat{vel}_{t+1}^I + \sigma B^J E_t\Delta\hat{vel}_{t+1}^J - \left(\hat{b}_t^I - \hat{b}_t^J\right).$$

Plugging in (H.34):

$$E_t\Delta\hat{c}_{t+1}^I - E_t\Delta\hat{c}_{t+1}^J = \sigma\left(E_t\pi_{t+1}^J - E_t\pi_{t+1}^I\right) - \sigma\left(\hat{b}_t^I - \hat{b}_t^J\right) - \sigma B^I E_t\Delta\hat{vel}_{t+1}^I + \sigma B^J E_t\Delta\hat{vel}_{t+1}^J.$$

Finally, plugging this into the first equation, I get that $i_t^{S,I} = i_t^{S,J}$.

J. Proof of Proposition 1

Proposition 1: *Assuming that the scarce reserves regime setting in Piazzesi et al. (2021) exhibits the following properties*:

1. *a reserveless limit*
2. *a constant corridor i.e. the spread between the policy rate and the reserve rate is fixed*

Then the system of equations is equivalent to the system for the ample reserves regime with reserves instead exhibiting the following endogenous process:

$$\hat{m}_t = \hat{a}_t^{\text{UNION}} + \left(\frac{1}{\alpha_R}\right)\left(\frac{\epsilon}{\eta+\epsilon}\right)\left(\hat{y}_t^{\text{UNION}} - \hat{a}_t^{\text{UNION}} - \hat{\ell}_t^{\text{UNION}}(1-\eta)\right), \tag{J.35}$$

where α_R is the share of bank collateral in the form of reserves in the ample regime, $(\hat{y}_t^{UNION}, \hat{a}_t^{UNION}, \hat{\ell}_t^{UNION})$ is union-wide output, collateral supply and bank leverage, respectively, and $\epsilon \in [0, \infty)$.

Proof: Firstly, we define the two key equations that summarize the banking problem within each region in the ample reserves regime. Secondly, after a series of rearrangements, we show that the banking problem in the scarce regime setup of Piazzesi et al. (2021) (PRS hereafter) can also be summarised by two key equations. We begin under a closed economy setup of PRD, and argue it can be extended to an open economy framework. Finally, we show that the scarce regime setup is equivalent to the ample regime setup with a certain process for reserves supply.

In the ample reserves regime, banks matter because they produce convenient liabilities for households, using collateral assets to back them. As a result, the banking module within each region can be summarized with the following two equations (dropping region superscripts):

$$\frac{\hat{i}_t^S - \hat{i}_t^D}{r^S - r^D} = \frac{\hat{i}_t^S - \hat{i}_t^F}{r^S - r^F} - \hat{\ell}_t \tag{J.36}$$

$$\hat{i}_t^S - \hat{i}_t^R = (r^S - r^R)\hat{\ell}_t + \left(\frac{r^S - r^R}{\eta}\right)\left(\hat{y}_t - \alpha_R \hat{r}_t - (1-\alpha_R)\hat{a}_t - \hat{\ell}_t\right) \tag{J.37}$$

Equation (J.38) determines the deposit spread, where the right-hand side is the marginal cost of producing deposits. Equation (J.37) determines the collateral premium on reserves. The right-hand side reflects the abundance of collateral assets in the region. The less scarce is supply in equilibrium, the lower is the collateral premium.

Turning to the scarce reserves regime model, we start with the closed economy setup laid out in PRS. The banking module can be described by the equations 18, 22a, 22b, 23 and 24 of the paper. Log-linearizing the system of equations and applying assumptions 1. and

2. of Proposition 1, we can summarize the banking sector in each region into the following log-linearized equations:[58]

$$\frac{\hat{i}_t^S - \hat{i}_t^D}{r^S - r^D} = \frac{\hat{i}_t^S - \hat{i}_t^R}{r^S - r^R} - \hat{\bar{\ell}}_t \tag{J.38}$$

$$\hat{i}_t^S - \hat{i}_t^F = (r^S - r^F)\hat{\bar{\ell}}_t + \left(\frac{r^S - r^F}{\eta + \epsilon}\right)\left(\hat{y}_t - \hat{a}_t - (1+\epsilon)\hat{\bar{\ell}}_t\right) \tag{J.39}$$

where

$$\epsilon = \left(\frac{1-\rho_F}{\rho_F}\right)\left(\frac{r^S - r^M}{r^F - r^M}\right)\left(\frac{1}{g(0)}\right) \tag{J.40}$$

where i_t^F, the interbank rate, ρ_F is the collateral value of interbank loans and $g(.)$ is the pdf of the liquidity shock distribution. In this setup, the interbank rate, i_t^F not the reserves rate, i_t^R , is the policy rate that follows the Taylor rule. Granted, this is under the closed economy setup. Crucially, however, banks still face an identical problem in the open economy framework, given the interest rate spreads that they face. The only difference here is that the collateral premium that banks face is a price determined in a collateral market that is integrated across regions.

Comparing equations (J.38) and (J.39), we can see they're identical i.e. they price deposits in the same way given collateral premia. Comparing (J.37) and (J.40), we can see that they're equivalent if reserves holdings, $\hat{r}_t$, follow a certain process in each region. However, as we know with the sample reserves regime setup, the integrated collateral market implies that what matters is union-wide reserves supply. Given the collateral premium and union-wide reserves supply, reserve holdings in each region is determined. In order to obtain the process for $\hat{r}_t^S$ that induces equivalence, we take the population-weighted sum of (J.37) and (J.40) and set the right-hand side equal to each other, finding that

$$\hat{m}_t^S = \hat{a}_t^{\text{UNION}} + \left(\frac{1}{\alpha_R}\right)\left(\frac{\epsilon}{\eta + \epsilon}\right)\left(\hat{y}_t^{\text{UNION}} - \hat{a}_t^{\text{UNION}} - \bar{\ell}_t^{\text{UNION}}(1-\eta)\right) \tag{J.41}$$

where $\hat{x}_t^{\text{UNION}} = X^I\hat{x}_t^I + (1 - X^I)\hat{x}_t^J$. Therefore, an ample reserves regime framework with reserves following the process in (J.41) is equivalent to a scarce regime framework.

K. Data Sources

K.1. Observed Target Variables: Data Sources

The data sources used to construct the observables are:

[58]For ease of exposition, this setup is not described here. The full derivation is available on request.

(1) Real Gross Domestic Product: Eurostat ESA 2010 National Accounts, Main Aggregates - Quarterly GDP at market prices, Chain-Linked volume (reference year 2015), calendar and seasonally adjusted,

(2) Harmonized Index of Consumer Prices (HICP): Eurostat, Overall Monthly Index, reference year 2015 (normalised to 100), neither seasonally nor working day adjusted,

(3) ECB Main Refinancing Operations (MRO) Rate: Statistical Data Warehouse (SDW), ECB Official Interest Rates, percent per annum,

(4) Bank interest rates - MFI Interest Rate Statistics, overnight deposits from households/non-financial corporations, percent per annum,

(5) Total Population: United Nations, World Population Prospects, 2019,

(6) Overnight Deposits: Balance Sheet Indicators (BSI) dataset, overnight deposits vis-a-vis non-MFIs excluding general government, denominated in Euro,

(7) Currency in Circulation: Balance Sheet Items (BSI) dataset, denominated in Euros,

(8) Central Bank Reserves: Balance Sheet Items (BSI) dataset, domestic loans to Eurosystem, country-level data,

(9) Money Supply: (6) + (7),

(10) Velocity: [(1) * (2)]/(9),

(11) Deposit Spread: (4) - (6),

(12) NPL Ratios: IMF Financial Soundness Indicators Database: Non-Performing Loans vs. Total Gross Loans.

K.2. Velocity vs. Deposit Spreads: Long-Run Trends

This documents the data sources required for the estimation of η at the country level. The sample period for each country is shown in Table K.2 below. I discuss the construction of the series for each component in turn:

Table K.2. η Estimation: Sample Period

	Spain	Portugal	France	Germany	Italy	Netherlands
Sample Period	1972 - 2017	1997 - 2017	1978 - 2017	1975 - 2017	1970 - 2017	1982 - 2017

Short-Term Discount Rate: I use the official discount rate for each country, sourced pre-1999 from either FRED (France, Germany, Spain) or their respective national central bank (Italy, Portugal, Netherlands). Only for France do I use the 3-month T-bill rate due to a lack of data.

Nominal GDP: From 1999 onwards, I take the nominal GDP series from Eurostat, and extend the horizon using a combination of the real GDP growth and GDP deflator series from the World Bank.

M1 Money Supply: From 1998 onwards, I take the money supply series used for the Bayesian estimation, summing up overnight deposits plus currency. Extending the series pre-1998 involves different steps depending on the country. For France, Germany and Spain, I use M1 money supply from FRED, and then scale the post-1997 series of overnight deposits plus currency such that levels match. As the post-1997 series is close to the traditional M1 definition, the scaling factors are small (2-4%). For Italy, it is a very similar process but the M1 series is taken from the Bank of Italy up to 2014, after which I turn to the other definition. For the Netherlands, I make use of the central bank's historical series of overnight deposits plus currency. Finally, a lack of data prevents me from extending the series for Portugal pre-1998.

The resultant series of velocity and interest rates is conveyed in Figure K.7 below.

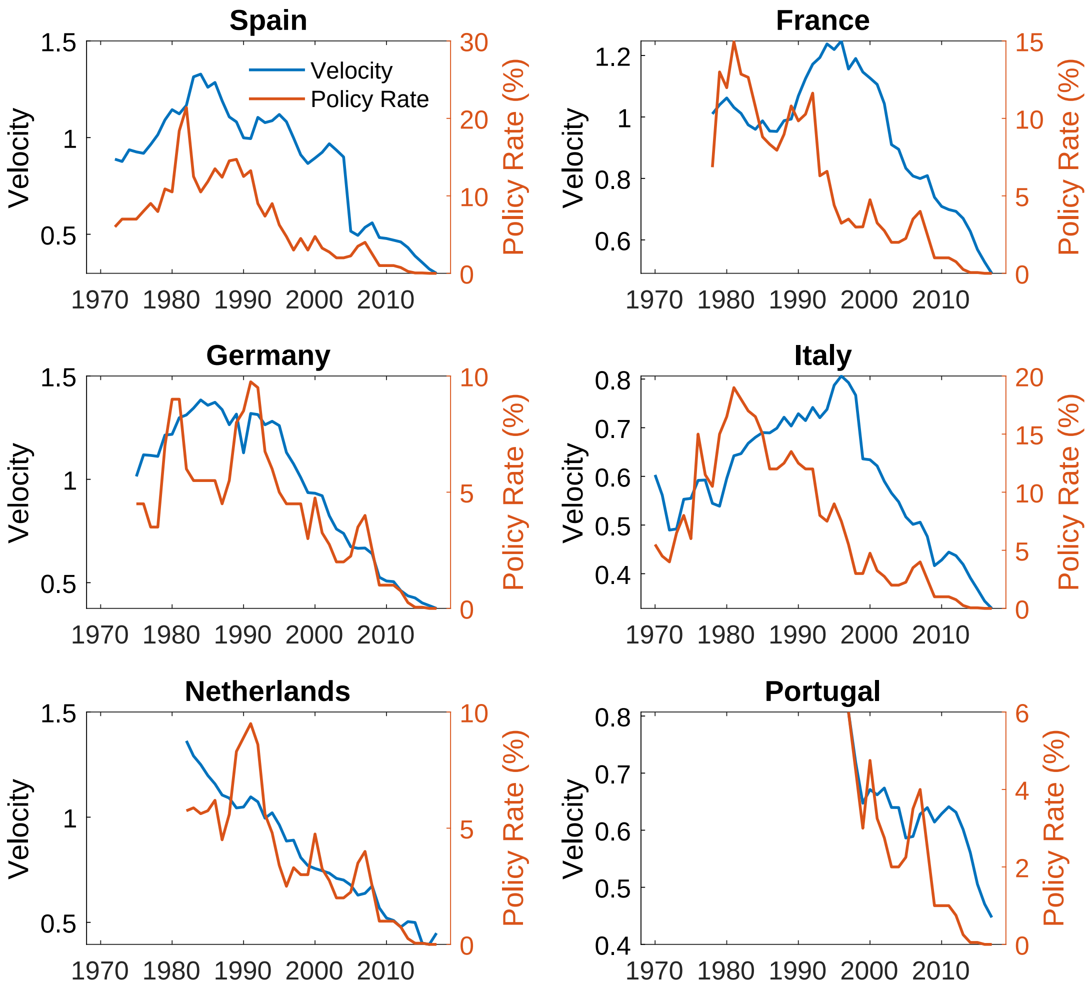

Figure K.7. Time series of velocity and the policy rate for six Euro Area countries. Velocity is measured using M1 money supply. Policy rate is in annual percentage terms.