Money Markets, Collateral and Monetary Policy*

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Abstract

We document dramatic changes in euro area interbank money markets during the financial and sovereign debt crises: the share of unsecured borrowing declined throughout, while in the South private market haircuts on sovereign bonds and bank borrowing from the European Central Bank increased, and deposits initially shrank. We construct a quantitative general equilibrium model to evaluate the macroeconomic impact of these developments and the associated policy response. Our model features heterogeneous banks and sovereign bonds, secured and unsecured money markets, and a central bank. We compare a benchmark policy – the central bank providing collateralized lending to banks at haircuts lower than the market – to an alternative policy that maintains a constant central bank balance sheet. We show that the fall in output, investment, and capital would have been twice as high under the alternative policy. More generally, the model allows the analysis of monetary policy tools beyond interest rate policies and quantitative easing.

Key words: money markets, collateral, monetary policy, central bank balance sheet
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1 INTRODUCTION

Money markets are an important cornerstone of the financial system. Banks rely on money markets for their short-term funding, while money market rates serve as benchmark rates for the pricing of credit to firms and households. Central banks target a short-term money market rate for monetary policy. What happens in money markets, therefore, matters for monetary policy transmission and for the economy as a whole.

Euro area money markets underwent dramatic changes during the Global Financial Crisis and the European sovereign debt crisis. We start out, documenting four facts in particular. First, activity in the unsecured money market segment – where banks borrow and lend to each other based on trust – progressively dried out. The share of unsecured interbank transactions declined throughout the euro area, with banks substituting toward secured transactions – where borrowers must secure the loan by pledging enough securities as collateral. Second, with the onset of the sovereign debt crisis in 2010, collateral haircuts – the difference between the security's price and its value as collateral – on Southern government bonds increased substantially, reducing the amount banks could borrow against the pledged assets.[1] Third, during this period, banks increased secured borrowing from the European Central Bank (ECB) eight-fold in the Southern European countries. This occurred while the ECB kept haircuts on accepted collateral nearly unchanged and well below those set in the market, creating a favorable "haircut gap" between private and ECB haircuts. Fourth, household deposits exhibited a U-shaped pattern - it fell when banks borrowed from the central bank, and vice versa when the central bank borrowing waned. This pattern was more pronounced in the South, where the ECB borrowing take-up was larger.

Our goal in this paper is to understand how these money market developments impacted the real economy and the role played by policies employed by the ECB to deal with money market tensions. To lay out the mechanism and quantify the effects, we develop a dynamic general equilibrium model with the banking sector at its heart. As in Gertler and Karadi (2011) and Gertler and Kiyotaki (2010)), banks are capital investors who can leverage by issuing deposits up to some limit. Similar to Bianchi and Bigio (2022), banks must also manage short-term deposit outflows, using liquid central bank reserves that are either held outright or borrowed

[1] A haircut is expressed as the percentage deduction from the market value of collateral (e.g., 3%). While collateral offers the lender protection against counterparty default, the collateral haircut offers the lender protection against the potential loss of value due to, e.g., the cost of liquidating collateral following counterparty default or a possibility that the issuer of the collateral defaults.

from the interbank market. Our key innovation here is to embed additional empirically relevant features of money markets: some banks can borrow unsecured while others have only access to secured funding, which requires posting collateral, typically government bonds. How much secured funding the bank can access depends on the asset's collateral value: the higher the asset value and the lower the haircut, the larger the available funding. In line with the European context, our model features one central bank but heterogeneous government bonds. Specifically, there are two regions, the "North" and the "South," each with its own government bonds and banks in each region holding a home-biased portfolio of the bonds.

Our model, which we calibrate to euro area data, indicates that the observed money market developments had a significant impact on the macroeconomy. Various forces are at play. First, as more banks become unable to borrow unsecured and need to access interbank markets on a secured basis, more collateral is held, crowding out capital investment. This is exacerbated by more banks chasing the same collateral, which makes collateral more costly to hold. Second, when haircuts on Southern government bonds rise, banks located in Southern regions must source additional collateral, which further crowds out capital. Crucially, this collateral scarcity spills over to banks in the Northern regions because Southern banks react to the rising cost of collateral by increasing outright holdings of reserves to manage liquidity. Higher demand for these reserves, previously held mainly by banks in the North, increases their opportunity cost and worsens the crowding-out of capital. Third, the ECB policy of offering secured loans of reserves to banks with attractive collateral terms when private market haircuts abruptly rise shields the economy from money market tensions. The ECB funding becomes a substitute for deposit funding, rising to 2.5% of bank assets in the South. This mitigates collateral scarcity because it releases new borrowed reserves into the banking system. The policy matters quantitatively - the adverse effect on output from higher Southern private haircuts would be twice as large in the absence of this measure.

In order to demonstrate these insights, we have organized our paper as follows. Section 2 provides a "bird's eye view" of our analysis. It first documents four key developments in the Euro area money markets. It then presents an overview and verbal description of the model, the forces that play out, and how those forces combine to generate the empirical observations. This should suffice to follow the full dynamic analysis in section 6, though a more formal analysis is needed for a deeper understanding and replicability. Section 3 therefore presents the model formally. Section 4 outlines the analysis of banks - whose behavior is at the heart of the model

- and shows that all key ingredients of the model are necessary for money market frictions to matter. Section 5 explains the calibration of the model. Section 6 presents a numerical analysis focusing on understanding the dynamic impact of the money market developments in the euro area during the financial and sovereign debt crises. Section 7 concludes.

Related literature. Our paper is related to three strands of the literature. First, it shares with numerous papers the emphasis on the role of financial frictions for the provision of credit to the real economy and for the transmission of standard and non-standard monetary policies (see, e.g., Curdia and Woodford (2011), Gertler and Karadi (2011), Gertler and Kiyotaki (2010), Del Negro et al. (2017)). In our model, as in Gertler and Karadi (2011) and Gertler and Kiyotaki (2010), banks face an enforcement problem and an associated constraint on leverage. In addition, banks are subject to a liquidity management constraint (see Bianchi and Bigio (2022)). Importantly, our model features heterogeneity across banks in their access to unsecured or secured money markets. Another novel feature of our framework is that we do not require the various constraints to be binding at all times (as in Brunnermeier and Sannikov (2014), He and Krishnamurthy (2019), Mendoza (2010), Bocola (2016), Justiniano et al. (2019)).

Second, our paper is related to a strand of the literature in banking that is concerned about the interactions between capital, liquidity and other regulatory requirements (see Cecchetti and Kashyap (2018), Vives (2014), Kara and Ozsoy (2020), and Vo (2021) for a survey). While our framework also features multiple constraints for banks, we do not address regulatory issues and, instead, focus on banks' liquidity management problem through interbank markets (as e.g. in Bhattacharya and Gale (1987); Flannery (1996); Repullo (2005); Freixas and Jorge (2008); Freixas et al. (2011); Afonso and Lagos (2015); Atkeson et al. (2015); Martin et al. (2014); Heider et al. (2015)). Relative to these studies, our focus is on the macroeconomic implications of interbank market frictions.

Third - and closest to our work - is the literature that studies how frictions in the unsecured or secured money markets impact the macroeconomy and interact with the effectiveness of monetary policy. Our results relate to those in Bruche and Suarez (2010), who show that freezes in the unsecured money market segment can cause large reallocations of capital across regions, with a sizeable impact on output and welfare. Bianchi and Bigio (2022) develop a tractable model of banks' liquidity management with an over-the-counter interbank market to study the credit channel of monetary policy. Arce et al. (2020) and Piazzesi et al. (2019)

study floor versus corridor systems in a New Keynesian framework. Piazzesi and Schneider (2017) provide a model of the determination of securities prices and inflation in an economy with a layered payment system. As in our paper, the provision and allocation of collateral play a central role. Our paper contributes by considering frictions in both unsecured and secured interbank markets. In our setup, frictions in the unsecured money market segment may, in principle, be offset by an increased recourse to private secured markets or to central bank funding. [2]

Importantly, several recent empirical papers study the effects of the "haircut gap" channel of monetary policy, the difference between private market and central bank haircuts for the same collateral assets (e.g., Drechsler et al. (2016) and Jasova et al. (2023)). Our model explains and quantifies the effects of the "haircut gap" channel in a general equilibrium model by comparing the impact of a collateralized lending policy whereby central banks' haircuts are more favorable relative to those in the private market with the counterfactual policy of no lending by the central bank.

2 FACTS AND FORCES: A BIRD'S EYE VIEW

This section provides an overview of the key facts motivating our analysis and of the main forces driving our results based on the model described in section 3.

2.1 Key developments in the Euro Area money markets

We focus on the largest Euro Area countries - Germany (DE), France (FR), Italy (IT), and Spain (ES) - plus Portugal (PT), for which the relevant data are available.[3] We document four key developments in money markets over the period 2003-2015.

I. Decline in the share of unsecured interbank borrowing. Between 2008, the year the Great Financial Crisis erupted, and 2015, the end of our sample, turnover in the unsecured money market decreased, while turnover in the secured money market increased. Figure 2 documents this development.[4] Normalizing the respective turnover in the secured and unsecured money market in 2007 to 100, we observe a negative co-movement between secured

[2] Altavilla et al. (2018) provide evidence that increases in interbank rate uncertainty, as observed during 2007-2009 and again during the European sovereign crisis, generate a significant deterioration in economic activity.

[3] Our observations are derived from several data sources, which we describe in section A of the online appendix.

[4] Turnover is defined as the sum of all transactions in the respective money market segment over the second quarter of each year, as reported by banks participating in the survey.

(dotted line) and unsecured (bold line) turnover, as of 2008. Importantly, the co-movement is negative in both of the large Northern European countries (Germany, DE, and France, FR), in which sovereigns enjoyed a higher credit rating, and in the three Southern European countries (Spain, ES, Italy, IT, and Portugal, PT), in which sovereigns had a lower credit rating.[5]

II. Bank borrowing from the ECB increased eight-fold in the South. Figure 2 plots bank borrowing from the ECB as a share of bank total assets (solid line, left-hand-side scale) for the largest Northern European countries (DE and FR) and three Southern European countries (Italy, Spain, and Portugal). The figure illustrates that there was no substantial increase until 2010 in bank borrowing from the ECB across both Northern European and Southern European countries. Bank borrowing fluctuated in a range from 0% to 3% across countries. During the sovereign debt crisis, however, bank borrowing increased about eight-fold for banks from the "South," from about 1% to about 8% of their total banking sector assets.

III. Increase in haircuts on government bonds in the South. The increase in Southern countries' bank borrowing from the ECB as of 2010 (solid line in the right-hand panel of Figure 3) was accompanied by the rise in interbank market haircuts on government bonds in these countries (dashed line in the right-hand panel of Figure 3), while haircuts stayed largely unchanged in the North. Meanwhile, the ECB kept its haircut schedule for government debt instruments (so-called Category I assets) unchanged all through the Great Financial Crisis and the Sovereign Debt Crisis regardless of the country of issuance.[6] This was the case for both higher-rated assets (rated AAA to A-) and for lower-rated assets (rated BBB+ to BBB-).[7]

IV. U-Shaped Response of Household Deposits to ECB Funding Figure 4 illustrates the evolution of the share of bank borrowing from households (household deposits) in total bank assets, along with the share of bank borrowing from the ECB, again as a share in total bank assets. The Figure shows that the share of bank borrowing from the household sector remained fairly stable overall, but exhibited a U-shaped pattern during the onset of ECB borrowing - it fell when banks borrowed from the central bank, and vice versa when the

[5]This observation is suggestive of a substitution between unsecured and secured money market activity. Such substitution was documented empirically by Di Fillipo, Ranaldo, and Wrampelmeyer (2022), who analyzed individual banks' borrowing and lending in the unsecured and secured euro interbank markets.

[6]Marginal adjustments in this category were made only in January 2014.

[7]We report haircut numbers for fixed coupon central government debt. We note that there was a level difference in haircuts charged by the ECB between higher-rated and lower-rated central government debt - 2.8% versus 7.8%, respectively. For simplicity, in our simulations, we keep the central bank haircuts fixed at 3%. This is not very material as what matters in the model is the haircut gap, i.e., the difference between private and central bank haircuts.

central bank borrowing waned. Importantly, this U-shape is more pronounced in the South where ECB borrowing take-up was larger.

2.2 MODEL OVERVIEW

The economy is composed of two regions, the "North" (standing in for countries such as Germany and France) and the "South" (standing in for countries such as Spain, Italy and Portugal), each with its own fiscal authority but one common central bank. Observations II and III show, how money market developed rather differently in the North and the South. Not only is it important to keep that distinction in our model in order to account for these observations, but it also plays a key role for the main forces driving our analysis. Our main focus is on banks who are leveraged capital investors and face a liquidity management problem. The latter is at the core of our model.

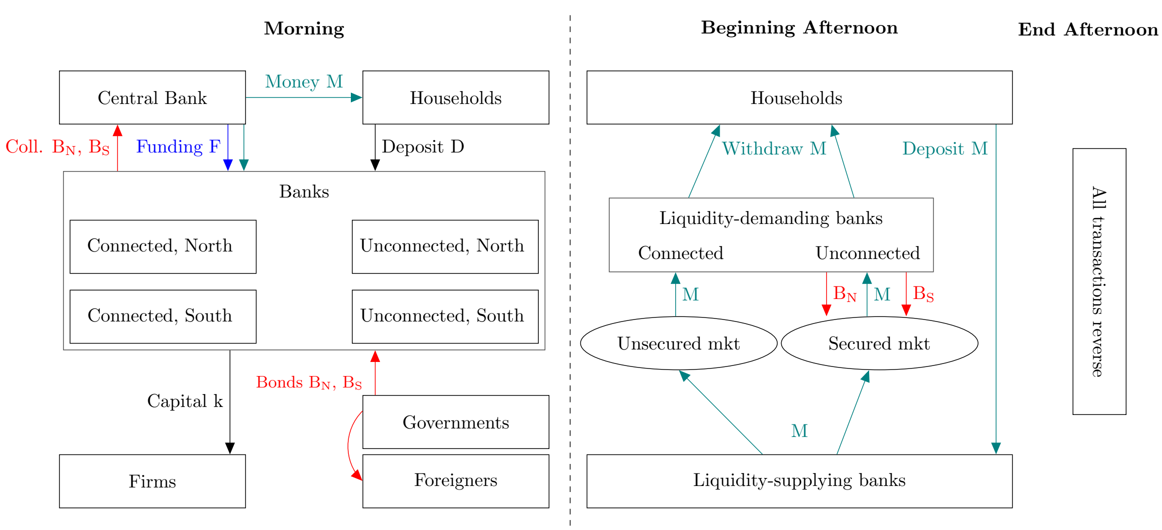

Figure 1: Model Overview

Figure 1 provides an overview of the model. Each period in the model is subdivided into a "morning" and an "afternoon". While all markets are open in the morning, only interbank markets are open in the afternoon. Decisions in the morning must anticipate liquidity needs in the afternoon. In the spirit of backward induction, we, therefore, first describe the latter. In the afternoon, depositors re-shuffle their deposits, making withdrawals from some banks and depositing with the other banks (as in Bianchi and Bigio (2022)). This is a simple way of formulating randomly arising payments from some consumers to others, using their deposit accounts. Banks need to service the withdrawals using reserves. If a bank faces a shortfall of reserves, banks with a surplus of reserves compared to their liquidity needs can supply reserves to this bank via the interbank money market.

We imagine that banks can be part of bank networks that offer mutually favorable borrowing arrangements, e.g., due to repeated interactions. We describe such banks as "connected" to a network. We incorporate the favorable borrowing arrangements by assuming that they do not need to post collateral when borrowing reserves from other banks in their network, i.e. they can access the unsecured money market. By contrast, "unconnected" banks, i.e., banks outside such networks, can only borrow reserves from other banks by pledging bonds in a secured (repo) market. Rather than modeling networks and the repeated interaction explicitly, we assume that bank network type ν is "connected"(c) or "unconnected"(u).[8] For simplicity, we assume that the network type is drawn iid each period, with a bank being "connected" according to some exogenous probability ξ_t and "unconnected" otherwise.[9] Defining these two types is an important novel element in the model as it helps us capture the structural shift towards banks relying on the unsecured rather than the secured money market and acting as "unconnected" in the data, as shown in Observation I above.

Pledged bonds in the interbank market are subject to a haircut $(1 - \tilde{\eta}_t)$: when banks pledge one unit of collateral, they receive $\tilde{\eta}_t$ units of reserves. Haircuts can vary across the two regions, as shown in Observation III. In the interest of model clarity, we impose their evolution as an exogenous variable rather than also modeling the default fears and market disruptions as their root cause. Reflecting the well-known home bias in domestic sovereign bond holdings, we assume that banks in the "North" use Northern government bonds and banks in the "South" use Southern government bonds as collateral for secured loans. This is a crucial feature of our model that allows us to capture rising haircuts observed in the "South" only and their impact on Southern banks. We assume that the region of the banks is drawn iid in each period.[10]

[8]Several reasons may explain why some banks have access to the unsecured money market. These include profitability, leverage, and liquidity position, and network relationships with other banks. We abstract from these considerations and assume an exogenous probability of being "connected" or "unconnected", which reflects at any point in time the aggregate turnover observed in the unsecured and secured market segment.

[9]In our model, the bank's type (connected vs. unconnected) is re-drawn each period rather than being a permanent type. There are two reasons for this. First, if a permanent type, connected banks would grow and crowd out unconnected banks entirely due to their competitive advantage. Second, it makes the model tractable by not having to track the type as a state variable.

[10]The reasons are similar to the reasons for assuming the iid nature of the connectedness: it makes the model simpler, and it avoids driving out the less profitable Southern banks entirely unless one also explicitly models country-specific firms and capital markets.

At the end of the afternoon, the deposit reshuffling is reversed, and the short-term interbank money market loans are repaid so that banks exit the period with the same portfolio that they had at the beginning of the afternoon.

In the morning, banks learn their connectedness type (connected or unconnected) and their region (North or South). They then make their portfolio decision. On their liability side, they have two ways of financing aside from their own net worth: household deposits D subject to the liquidity shocks in the afternoon described above as well as funding F from the central bank. On their asset side, they can invest in firm capital k, in government bonds, i.e., B_N for North banks and B_S for South banks, and in reserves M. Unconnected banks may buy bonds in the morning in anticipation of requiring reserves in the afternoon in order to pledge them then in the secured market, as described above. Alternatively, they can acquire reserves in the morning, either directly on the market ("money" M) or via loans F from the central bank, collateralized with government bonds. For our benchmark policy specification, we allow banks to borrow from the central bank at constant haircuts $1 - \eta$, even when private sector haircuts $1 - \tilde{\eta}_t$ increase.[11] Under our alternative policy, the central bank offers no funding and holds the reserve supply constant. Connected banks have no need to anticipate afternoon liquidity needs because, in the event of a deposit withdrawal, they simply obtain within-afternoon unsecured funding from the interbank market to cover it. They only invest in bonds or reserves if their returns are attractive relative to investing in firm capital.

The bonds are supplied by the "North" and "South" governments and traded in the government bond market in which also the foreign investors - who have an elastic demand - participate. In addition, banks decide whether to raise additional funding F at the central bank, in exchange for bonds as collateral. Finally, "unconnected" banks decide on the amount of reserves M and bonds B_N or B_S to bring to the afternoon to cover for possible deposit withdrawals.

The bank portfolio choice entails tradeoffs. Holding reserves as opposed to bonds to cover for the possibility of withdrawals in the afternoon foregoes interest banks could earn on bonds. On the other hand, if private-sector haircuts are large, relatively more bonds need to be held, which crowds out profitable capital investment by banks. Alternatively, banks could use central

[11] Central bank haircuts on pledged bonds are a standard feature and policy tool for lending to banks via repurchase agreements. This is presumably done to cover the risk and cost of selling the collateral if things go awry and the bank does not buy back the pledged collateral, but we do not model that explicitly.

bank loans instead of deposits as a funding source. This becomes attractive if the gap between private sector and central bank haircuts is sufficiently large.

This interplay of tradeoffs and market interactions generates the main forces that help our model explain the data. Aside from the impact of leverage well known from models building on Gertler-Karadi (2011) and Gertler-Kiyotaki (2011), the market for collateral (bonds, money) gives rise to four forces that are novel to the analysis here.

1. **Capital Crowding Out:** suppose the banking sector needs to hold more collateral assets (bonds, money). This can be due to a higher share of unconnected banks or due to a lower quality of existing collateral (e.g. higher private haircuts on bonds). As banks have limits on leverage, this crowds out productive capital investment.

2. **Bond-Reserves Substitution:** when there is an increase in collateral scarcity, banks pay a higher *collateral premium* in equilibrium, i.e., they forego more interest investing in bonds relative to capital. If the premium is high enough, banks may find it optimal to switch from bonds to reserves to manage liquidity. This helps to mitigate the loss in bank profitability.

3. **North-South Liquidity Spillover:** when both regions hold reserves as collateral, there are strong spillovers of collateral scarcity across regions. For example, suppose the South experiences a drop in the collateral quality of its bonds. In response, banks in the South rebalance to reserves as a way to manage liquidity. However, the reserves must come from other banks, i.e., unconnected banks in the North, who, therefore, must rebalance from reserves to collateral assets for liquidity needs. As a result, banks in the North end up facing a collateral scarcity issue as well.

4. **Haircut Gap:** the gap between the private market and the central bank haircut is what we call the "haircut gap". If the gap is large enough, banks will start to use the central bank as a source of funding, even though the collateral needs are more onerous vs. deposits. This helps to relax the need to hold collateral for deposit issuance. Moreover, by lending new reserves, the central bank raises the aggregate supply of reserves available to banks. This reduces collateral scarcity across the monetary union.

Armed with these four forces, we can now tell the story, through the lens of our model, of how observed changes in interbank markets impacted the real economy and understand the role played by central bank funding.

In light of Observation I, we assume that there is a gradual permanent increase in the share of unconnected banks. As a result, more banks must hold bonds as collateral, reducing capital investment in the long run via the Capital Crowding-Out force. The increased need for bonds drives up the collateral premium so much so that banks substitute towards reserves as collateral (Bond-Reserves Substitution force). Overall, less capital investment and higher collateral premia make banks less profitable, which, through the usual Gertler-Karadi-Kiyotaki mechanisms, amplifies the effects of the transition.

Given Observation III, we assume that there is a temporary rise in Southern bond haircuts starting around 2010. This exacerbates the collateral shortage and the scramble for reserves in the South, as described by the Bank-Reserves Substitution force. This shortage spills over to Northern banks due to the North-South Liquidity Spillover Effect, causing all banks to switch out of capital more aggressively. However, with the benchmark policy specification, Southern banks wishing to escape the punishing private sector bond haircuts can now borrow from the central bank instead, posting Southern bonds at unchanged and rather favorable haircuts, as described by the Haircut Gap effect. As a result, banks substitute deposits for central bank funding. Our model, therefore, reproduces Observation II and Observation IV for the South. Reducing collateral scarcity across the union alleviates the North-South Liquidity Spillover and, ultimately, the Capital Crowding Out effect and, thus, the drop in output. The central bank policy is important - without the borrowing facility, the output drop caused by the rise in haircuts would be almost twice as large.

This completes the verbal description of our model and the key forces. A reader might well proceed to the results of the full dynamic analysis in section 6 at this point, though a more formal description and analysis in the next two sections will be needed for a deeper understanding and replicability.

3 THE MODEL

Time is discrete and infinite. There is no aggregate uncertainty. Each region, denoted by $j \in \{N, S\}$, is of size s_j, where $s_N + s_S = 1$. An overview of the timing is available in Online Appendix B. Nominal variables are denoted with upper cases, while real variables are with lower case.

3.1 The household

In each region, there is a continuum of identical households. Since the two governments impose identical taxes, households are identical in both regions, so we drop the subscript j.

Households arrive in period t with cash, M_{t-1}^h, and bank deposits D_{t-1}^h that are remunerated at the gross return R_{t-1}^d. Households also earn wages from labor supplied, net of proportional taxes paid, $(1-\tau_t) W_t h_t$. Assets and post-tax wages are then used to finance consumption, $P_t c_t$, along with savings allocated to deposits, D_t^h, and money, M_t^h. The household's budget constraint is then given by

$$M_t^h + D_t^h \quad = \quad M_{t-1}^h + R_{t-1}^d D_{t-1}^h + (1-\tau_t) W_t h_t + \phi N_t + \Pi_t^{CP} - P_t c_t \tag{1}$$

where $\left(\phi N_t, \Pi_t^{CP}\right)$ are bank dividends and profits of the capital producers, respectively, that are both owned by the households.

The household chooses $c_t > 0, h_t > 0, D_t^h \geq 0, M_t^h \geq 0$ to maximize the objective function

$$\max \sum_{t=0}^{\infty} \beta^t \left[u\left(c_t, h_t\right) + v\left(\frac{M_t^h}{P_t}\right)\right] \tag{2}$$

subject to the budget constraint (1).[12] We assume that households derive convenience from their holdings of money, reflected as "money-in-the-utility."

3.2 Final goods firm

A representative final-good firm rents capital k_{t-1} and hires labor h_t to produce a homogeneous final output good y_t according to the production function

$$y_t = k_{t-1}^{\theta} h_t^{1-\theta}. \tag{3}$$

It receives revenues $P_t y_t$, pays wages $W_t h_t$ and pays rent $P_t r_t k_{t-1}$ to banks who are the capital owners.

3.3 Capital-producing firm

The capital-producing firm has access to an investment technology that produces capital. By making investments i_t in units of consumption goods, it produces units of capital $\Phi(i_t/k_{t-1})k_{t-1}$

[12] As a functional form, we assume that, $u(c_t, h_t) = log(c_t) - \frac{h_t^{1+\varsigma}}{1+\varsigma}$, and $v(m_t^h) = \frac{1}{\chi}\log(m_t^h)$.

that are sold at price Q_t^k to capital owners, who in this setup are banks. Each firm, assuming they are price-takers, then solves the following problem

$$\max_{i_t \geq 0} Q_t^k \Phi\left(\frac{i_t}{k_{t-1}}\right) k_{t-1} - i_t \tag{4}$$

where $\Phi'(.)0$, $\Phi''(.) > 0$ and $\Phi(\delta) = \delta$, where δ is the depreciation rate.[13] Given the choice of i_t, capital evolves according to

$$k_t = (1-\delta) k_{t-1} + \Phi\left(\frac{i_t}{k_{t-1}}\right) k_{t-1}.$$

Given the price of capital, the nominal return realized at time t for investing in a unit of capital at time $t-1$ is given by

$$R_t^k = \frac{P_t}{P_{t-1}} \frac{Q_t^k}{Q_{t-1}^k} (r_t + 1 - \delta) \tag{5}$$

3.4 Fiscal policy

Fiscal policy is entirely mechanical. Its role is to define government debt supply, spending and taxation.

At the beginning of period t, the government of region $j \in \{N, S\}$ has some outstanding debt with face value $\overline{B}_{j,t-1}$ of which a fraction κ will be repaid. It then decides on how many new discount bonds to issue, equalling $\Delta\overline{B}_{j,t}$. The outstanding debt at the beginning of period $t+1$ for the government in region j will then be $\overline{B}_{j,t} = (1-\kappa)\overline{B}_{j,t-1} + \Delta\overline{B}_{j,t}$. We assume that real debt supply is held constant and proportional to the region's size i.e. $\overline{B}_{j,t} = s_j P_t \overline{b}^*$, where $\overline{b}^*$ is a parameter. This implies that

$$\Delta\overline{B}_{j,t} = \kappa s_j P_t b^* \tag{6}$$

Government j purchases the amount of goods

$$g_{j,t} = s_j g^* \tag{7}$$

where $g^\star$ is a parameter. Government j receives its share of seigniorage $s_j S_t$ from the central bank. The government then sets proportional taxes on labor income such that the budget

[13] As a functional form, we assume that $\Phi(x) = a_1 x^{1-\zeta} + a_2$, $a_1 = \left(\frac{1}{1-\zeta}\right)\delta^{\zeta}$ and $a_2 = -\delta\left(\frac{\delta}{1-\delta}\right)$. The parameter ζ controls the degree of convexity in the capital adjustment cost function.

constraint holds. As debt prices may be region-specific, we assume that there are cross-region transfers $T_{j,t}$, so that the labor income tax τ_t is the same in both regions. The government budget balance at time t is

$$P_t s_j g^* + \kappa \overline{B}_{j,t-1} = s_j \tau_t W_t h_t + Q_t^j \Delta \overline{B}_{j,t} + s_j S_t + T_{j,t} \tag{8}$$

where the cross-region transfers net out to zero,

$$T_{N,t} + T_{S,t} = 0 \tag{9}$$

Summing up across regions,

$$P_t g^* + \kappa \overline{B}_{t-1} = \tau_t W_t h_t + (s_N Q_t^N + s_S Q_t^S) \Delta \overline{B}_t + S_t. \tag{10}$$

3.5 The central bank

The central bank (CB) has a variety of policy instruments at its disposal, reflecting the expansion of policy tools in recent times. Of particular interest in this paper is the policy where the central bank offers one-period collateralized loans of reserves to private banks. This can be quite attractive for banks as reserves are important for managing deposit withdrawals they may face. Of course, the take-up depends on the terms of the loan and the conditions of banks and the economy.

The set of central bank policy tools is the following:

1. **Collateralised Loan Rate**: It sets the interest rate R_t^F or, equivalently, the discount price $Q_t^F \equiv 1/R_t^F$ on loans to banks. Throughout we assume

$$Q_t^F = 0.997 \tag{11}$$

2. **Collateral Policy**: It demands region-N bonds or region-S bonds as collateral for bank loans and subjects these to haircuts. For each euro's worth of region-j bonds, the CB provides a loan of $0 \leq \eta_t^j \leq 1$, where η_t^S and η_t^N are policy parameters. For tractability, we shall set this haircut choice at a constant throughout, $\eta_t^S = \eta_t^N \equiv \eta$, with $1 - \eta$ being the haircut.[14]

[14]The ECB's haircut schedule features a differentiation according to the credit quality of securities pledged as collateral, resulting in slightly higher haircuts charged on lower-rated sovereigns versus higher-rated sovereigns. The main theme in our analysis, however, is the emphasis on the much larger haircuts imposed by the private sector rather than on the much smaller differentiation among securities in the central bank's haircut schedule.

The conditions (Q_t^F, η) pin down the terms of the collateralized loans. The take-up by the banking sector, $\bar{F}_t$, is then an endogenous choice variable. Our key analysis is understanding the impact on the real economy of difference choices of η (see below).

3. **Bond Holdings Policy**: It sets the quantity $B_{j,t}^C$ of bonds held outright (rather than as collateral for bank loans) of each region $j \in \{N, S\}$, where the superscript C denotes the central bank's bond holdings. Throughout, we assume that the central bank holds a constant real stock of debt, $\bar{b}^C$, split across regions proportional to each region's issuance.[15] In other words

$$B_{j,t}^C = s_j P_t \bar{b}^C \quad \text{for each} \quad j \in \{N, S\} \tag{12}$$

This implies that central bank purchases at the beginning of each period are set to replenish the real stock after redemptions and inflation.[16]

4. **Money Supply Rule**: It decides on the supply of money, $\bar{M}_t$, available to the private sector. This is held as reserves by banks and as currency by households. Throughout, we assume the following money supply rule:

$$\bar{M}_t = \bar{M}_{t-1}\pi_t + Q_t^F \bar{F}_t - R_{t-1}^F Q_{t-1}^F \bar{F}_{t-1} \tag{13}$$

In other words, absent central bank funding, the money supply is constant in real terms. The last two terms then reflect additional money supply offered via new central bank funding.

Finally, the flow budget constraint of the central bank is given by:

$$\begin{aligned} \overline{M}_t - \overline{M}_{t-1} \quad &= \quad S_t + Q_t^F \overline{F}_t + Q_t^N B_{N,t}^C + Q_t^S B_{S,t}^C \\ &\quad -R_t^N Q_{t-1}^N B_{N,t-1}^C - R_t^S Q_{t-1}^S B_{S,t-1}^C - R_{t-1}^F Q_{t-1}^F \overline{F}_{t-1} \end{aligned} \tag{14}$$

[15]The ECB conducted targeted asset purchases during the 2010-2014 period under the so-called "Securities Markets Programme." Those purchases were intended to ensure depth and liquidity in malfunctioning segments of the bond markets. However, such purchases were sterilized and did not affect central bank liquidity outstanding. They are, therefore, not the focus of our study.

[16]In particular, you can show that $\Delta B_t^C = b^C P_t \left(1 - (1-\kappa) P_{t-1}/P_t\right)$.

where $R_t^j = \frac{(1-\kappa)Q_t^j + \kappa}{Q_{t-1}^j}$ is the returns from holding government bonds of region $j \in \{N, S\}$. S_t is the seignorage of the central bank, which is the net proceeds from asset allocations that are transferred to the government.[17]

In this paper, our focus is on the impact of a monetary policy operation allowing banks to borrow from the central bank at favorable haircuts during crises. Therefore, we compare two policies: benchmark (CO) vs. alternative (CB). The idea here is that the benchmark describes collateralized lending operations during the Great Financial Crisis (GFC) and the Sovereign Debt Crisis, whereas the alternative reflects monetary policy pre-GFC. In particular:

CO Policy (*Collateralised Operations*) : $\eta = 0.97$

CB Policy (*Constant Balance Sheet*) : $\eta = 0$

Under CO policy, the haircut is set constant at the pre-crisis private market level of $1 - \eta = 3\%$. This can become quite an attractive policy for banks when private haircuts greatly exceed this at times post-GFC, in which case $\bar{F}_t$ can exceed zero. In contrast, under the CB Policy, banks have no incentive to access the facility as it requires infinite collateral, in which case the central bank balance sheet size is constant and $\bar{F}_t = 0$.

3.6 Banks

There is a continuum of banks ("lenders") $i \in [0, 1]$. They are owned by households that are perfectly diversified across banks. Choices in the previous period result in the net worth of a bank at the beginning of the period. Subsequently, their network type and region are drawn. We assume that both are iid across time and banks to ensure the existence of a non-trivial steady state. Banks then make choices regarding assets and liabilities in the morning, subject to a leverage constraint and, crucially, a liquidity constraint. The latter ensures they have sufficient liquidity to manage any possible deposit withdrawals that may occur in the afternoon

3.6.1 The morning

In the morning, the date-t type of bank is uncovered as the result of two iid shocks. First, the network type ν is drawn. Bank i is connected ("$\nu = c$") with probability ξ_t and unconnected

[17] We have not included interest on reserves in this version of the model in order to avoid the extra notation and issues arising from such an inclusion. It was of no relevance during the euro area sovereign debt crisis and thus the theme at hand, but it could be important to include it in future extensions for other applications.

("$\nu = u$") with probability $1 - \xi_t$. Unconnected banks will need to pledge bonds in the afternoon in order to borrow in the secured money market, while connected banks can borrow in the afternoon in the unsecured market without posting collateral.

Second, the region j is chosen. With probability ("size") s_N, a bank is located in $j = N$ ("North"), and with probability $s_S = 1 - s_N$ it is located in $j = S$ ("South"). In each region j, banks can trade and hold only the bond issued by their own government, $B_{j,t}$. Deposit and credit markets are integrated.

Knowing their network type and region, banks then choose their portfolio of assets and liabilities and pay dividends. We assume dividends are a constant fraction ϕ of net worth. The ex-dividend net worth is then allocated to capital ($k_{i,t}$), nominal bonds ($B_{i,t}$), and nominal excess reserves ($M_{i,t}$). The bank leverages up using nominal deposits ($D_{i,t}$) and nominal secured loans from the central bank at face value ($F_{i,t}$).

The bank's balance-sheet constraint at the end of the morning is therefore given by

$$P_t Q_t^k k_{i,t} + Q_t^j B_{i,t} + M_{i,t} + \phi N_{i,t} = D_{i,t} + Q_t^F F_{i,t} + N_{i,t}, \tag{15}$$

Banks face a variety of additional constraints on their portfolio choice in the morning. Firstly, the collateral constraint at the central bank requires loans not to exceed the value of the bonds pledged, adjusted by the central bank's haircut. In equilibrium, banks will pledge just enough collateral to make the collateral constraint bind (even if indifferent between that and pledging more: then, "bind" is a resolution of an indifference). Thus, for all types of banks,

$$F_{i,t} = \eta_t Q_t^j B_{i,t}^F \tag{16}$$

Secondly, bonds pledged at the central bank are constrained to be non-negative but also not to exceed the amount of bonds acquired in the morning,

$$0 \leq B_{i,t}^F \leq B_{i,t}. \tag{17}$$

Thirdly, banks face a leverage constraint. As in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), we assume there is a moral hazard constraint in that bank managers may run away with a fraction λ of their assets at the end of the morning. Let $V_{i,t}$ be the value of a bank at the end of the morning after the type of the bank is known and assets are purchased, but before dividends are paid. The bank leverage constraint requires the value of the bank $V_{i,t}$

not to fall below the share λ of the value of the assets that the bank manager can run away with:

$$\lambda \left(P_t Q_t^k k_{i,t} + Q_t^j B_{i,t} + M_{i,t} \right) \leq V_{i,t} \tag{18}$$

Finally, there are non-negativity constraints for investing in capital, deposits, cash, bonds, and for financing from the central bank, for any bank i:

$$k_{i,t} \geq 0, D_{i,t} \geq 0, M_{i,t} \geq 0, B_{i,t} \geq 0, F_{i,t} \geq 0. \tag{19}$$

3.6.2 The afternoon

In the afternoon, banks face a liquidity management problem, as in Bianchi and Bigio (2022). At the beginning of the afternoon, they experience idiosyncratic liquidity shocks. A bank with end-of-morning deposits $D_{i,t}$ experiences a shock $\omega_i D_{i,t}$. Negative (positive) ω_i denotes incoming (outgoing) payments. Here, $\omega_i \in (-\infty, \omega^{\max}]$ is a random variable, which is iid across banks and is distributed according to $F(\omega)$, where $\omega^{\max} \in [0, 1]$ is a parameter. Payment shocks average out across all banks, so that total deposits remain unchanged. Bank i settles payments using reserves - either those obtained in the morning ($M_{i,t}$) or borrowed in the afternoon from the interbank market.

We add to the Bianchi and Bigio (2022) structure the distinction between "connected" and "unconnected" bank types. Connected banks can borrow unsecured in the afternoon interbank market. We think of connected banks as operating in a network of banks mutually trusting each other such that collateral is unnecessary.

By contrast, unconnected banks must secure interbank borrowing with bonds. In the secured market, we assume that a lending bank imposes a haircut $0 \leq 1 - \widetilde{\eta}^j \leq 1$, with $j \in \{S, N\}$. We allow for haircuts to differ across regions. Haircuts and their regional dependency can be due to different reasons, including the rational assessment of the market on default risks of the underlying bonds. Our focus is on the analysis of the equilibrium in "benign" circumstances. We, therefore, sidestep modeling those reasons and instead treat the haircuts as exogenous.

The borrowing bank then pledges the amount $\left(B_{i,t} - B_{i,t}^F \right)$ of bonds, as it can only pledge the portion that has not yet been pledged to the central bank. In return, the bank receives the cash amount $\widetilde{\eta}^j \left(B_{i,t} - B_{i,t}^F \right)$ in the form of reserves, repaying the same amount at the end of the afternoon. The end bond position is therefore the one held in the morning, $B_{i,t}$. Taken literally, there is no risk of bond default here that this haircut is insuring the lender against, but this is just to keep the model simple. Every bank can lend unsecured to any connected bank, or secured to any bank, if they so choose.[18] We impose that the interest rate on interbank loans is zero.[19]

Bankruptcy is not allowed. Hence, if bank i is unconnected, it has to make sure it has enough reserves brought over from the morning and/or enough unpledged collateral to be able to cover the maximum possible afternoon payment outflows, $\omega^{\max} D_{t,i}$. In other words, an unconnected bank i must satisfy

$$\omega^{\max} D_{i,t} \leq M_{i,t} + \widetilde{\eta}_t^j Q_t^j \left(B_{i,t} - B_{i,t}^F\right), \tag{20}$$

We denote (20) as the unconnected bank's "afternoon constraint."[20] This is an additional constraint banks satisfy when making their portfolio choice in the morning.

At the end of the afternoon, the liquidity shocks are reversed, and the interbank loans are repaid. Thus, an initial afternoon liquidity shock creates only a temporary liquidity need that banks must satisfy, in line with the idea of payments circulating in the system.[21] We assume that all within-afternoon interest rates are zero. Therefore, banks will be entirely indifferent between using any of the available sources of liquidity. The balance sheet at the end of the afternoon and before asset returns accrue is the same as the balance sheet at the end of the morning. The only impact of these choices and restrictions is that unconnected banks need to plan ahead of time in the morning to make sure they have enough reserves or collateral in the afternoon. In other words, the afternoon can be summarised as simply adding an additional constraint on the portfolio choice made in the morning: the afternoon constraint.

[18]Implicitly, we are assuming that the discount window of the central bank is not open in the afternoon, i.e., that banks need to obtain central bank reserves, if any, in the morning as a precaution in anticipation of possible liquidity shocks in the afternoon. This captures the fact that the discount window is rarely used for funding liquidity needs and that these liquidity transactions happen "fast,"compared to central bank liquidity provision.

[19]This can be justified if some banks hold positive reserves $m_{i,t} > 0$: in that case, there is an excess supply of reserves (payment inflows plus morning reserves) compared to the demand for reserves (payment outflows). The market clearing interbank rate then must fall to the price of the alternative storage technology for keeping reserves, i.e., to zero. If no banks wish to hold positive reserves in the morning, supply and demand for interbank loans are equal across a range of interest rates. We pick the lowest one, compatible with the storage alternative, implicitly assuming that the borrowing banks have all the bargaining power. Alternatively, one could introduce a minimum reserve requirement so that $m_{i,t} > 0$ always.

[20]We assume that banks will always find defaulting on the payments worse than any precautionary measure they can take against it, and thus rule out payment caps and bank runs by assumption. One might alternatively read the absence of bankruptcy as the result of vigilant regulators.

[21]We follow a long tradition in the banking literature of focusing on the role of interbank money markets in smoothing out idiosyncratic liquidity shocks, as in Bhattacharya and Gale (1987) and Allen and Gale (2000). While analytically convenient, in reality interbank relationships may exhibit more persistent patterns, with some banks being structural borrowers and others as structural lenders in interbank markets (Craig and Ma (2022)).

An overview of the timing of bank decisions is shown in Figure B.1 of the Online Appendix.

3.7 Price setting

We assume that prices are determined one period in advance. In particular, we have that:

$$\pi_t = \pi_{t-1}^e \tag{21}$$

In other words, inflation next period is already pre-determined at π_t^e. It endogenously adjusts to ensure that the money market clears. For our perfect foresight experiments, the sole restriction this imposes is that the inflation rate at the time of the shock does not respond.[22]

3.8 The rest of the world

We assume that a share of the stock of government bonds is held by the rest of the world and that foreigners have an elastic demand for those bonds.[23] Because unconnected banks can buy or sell bonds to foreigners, they can change their bond holdings independently from the government's outstanding stock of debt.

We do not wish to model the foreign sector explicitly. We simply assume that international investors have demands for bonds issued in region j, $B_{j,t}^w$, that react to movements in the real return,

$$\frac{B_{j,t}^w}{P_t} = \alpha \left(1 + \frac{1}{\varrho} \log\left(\frac{R_{t+1}^j}{r^j \pi_{t+1}}\right)\right) \tag{22}$$

where $\varrho > 0$, $\varkappa \geq 0$, $\frac{R_{t+1}^j}{\pi_{t+1}}$ is the real one-period holding return on the bond from t to $t+1$, and r^j is the real rate of return on bond j in the baseline calibrated steady state. Notice that if $\varrho = 0$, the bond demand is infinitely elastic. In that case, the real return is fixed and foreign holdings take whatever value is needed to clear the bond market.

[22] It turns out that this is important for stability in the evolution of inflation. By ensuring that inflation does not jump at the time of the shock, it prevents unrealistically large shifts in the inflation rate.

[23] We introduce the elastic demand for the foreign sector for two reasons. First, a large fraction of euro area sovereign debt is held by non-euro area residents, and these bondholders actively re-balance their bond positions. Koijen et al. (2021) document that during the Public Sector Purchase Programme implemented by the ECB in March 2015 and for each unit of sovereign bonds purchased by the ECB, the foreign sector sold 0.64 of it. Second, when solving the model, we will focus on the parameter space in which connected banks choose not to hold bonds. In a closed economy, unconnected banks would have to absorb whatever amount of bonds is issued by the government (after deducting the fixed amount held by the central bank). The price of the bond would have to adjust to clear the market. Such a direct link between the bond market and the unconnected banks' decisions would become quantitatively implausible.

The flow budget constraint of the foreign sector is

$$Q_t^N B_{N,t}^w + Q_t^S B_{S,t}^w - R_t^N Q_{t-1}^N B_{N,t-1}^w - R_t^S Q_{t-1}^S B_{S,t-1}^w = -P_t c_t^w \tag{23}$$

where c_t^w is the consumption of the homogeneous good produced in the union. The left-hand side is the net investment of foreign investors in domestic bonds, i.e., the flow in the financial account, while the right-hand side is the corresponding trade balance.

4 UNDERSTANDING BANKS

The decision problem of households and firms is standard. The full optimality conditions for households and firms are reported in Online Appendix C. The key to the model is the decision problem and behavior of the banks. After demonstrating the importance of having both a leverage and afternoon constraint for money market shocks to matter, we analyse a simplified model to help us understand the portfolio choice of banks, and how central bank policy interacts with this choice.

4.1 Aggregating across banks

Recall that $V_{i,t}$ is the value of bank i, at the end of the morning, after the type of the bank is known and assets are purchased but before dividends are paid. It is the nominal price a household would be willing to pay for that bank before dividend payments and taking into account the future randomness of net worth due to the future type draws, and is given by

$$V_{i,t} = E\left[\sum_{s=0}^{\infty} \beta^s \frac{u_c\left(c_{t+s}, h_{t+s}\right)}{u_c\left(c_t, h_t\right)} \frac{P_t}{P_{t+s}} \phi N_{i,t+s}\right] \tag{24}$$

Regardless of their size, we assume that all banks behave competitively and take prices as given. Because of the linearity of the objective function as well as all the constraints, the problem of a bank is linear in net worth.[24] Therefore, the distribution of net worth across banks and, thus, its prior history does not matter for aggregate allocations.

Equation (24) can be rewritten in a recursive fashion. Define $\bar{V}_{i,t}$ as the value of bank i in the morning, before the type draw for t is known. It is given by

$$\bar{V}_{i,t} = E_t[V_{i,t}] = \psi_t N_{i,t} \tag{25}$$

[24]The arguments for linearity of the bank problem are given in Online Appendix D.

for some factor ψ_t which gives the value of a marginal unit of net worth of a bank in the morning, before a bank's type is known, and where the expectation reflects the connection type and region draw.

This implies that

$$\int_0^1 \bar{V}_{i,t} di = \psi_t \int_0^1 N_{i,t} di \tag{26}$$

which gives the value of a marginal unit of net worth at the beginning of period t, for the aggregate banking sector.

Given the linearity of the bank problem, it suffices to analyze the problem of a bank with average net worth N_t of network type ν and in region j. Note that connected banks make the same choices regardless of their region, since the region only matters for unconnected banks in the afternoon. Letting $N_{\nu,j,t+1}$ denote the resulting net worth for each type (ν, j) of bank when starting out with average net worth N_t, and knowing $N_{c,N,t+1} = N_{c,S,t+1} \equiv N_{c,t+1}$, average net worth in $t+1$ is then

$$N_{t+1} = \xi_t N_{c,t+1} + (1 - \xi_t) \left(s_N N_{u,N,t+1} + s_S N_{u,S,t+1} \right) \tag{27}$$

Define $\tilde{V}_{\nu,j,t}$ as the value of a bank with average net worth, network type ν and located in j at the end of the morning, after the distribution of dividends. We have

$$V_{\nu,j,t} = \phi N_{\nu,j,t} + \tilde{V}_{\nu,j,t} \tag{28}$$

where

$$\tilde{V}_{\nu,j,t} = \beta E_t \left[\frac{u_c \left(c_{t+1}, h_{t+1} \right)}{u_c \left(c_t, h_t \right)} \frac{P_t}{P_{t+1}} \psi_{t+1} N_{\nu,j,t} \right] \tag{29}$$

with net worth $N_{\nu,j,t+1}$, resulting from the investments of period t, given by

$$N_{\nu,j,t+1} \quad = \quad R^k_{t+1} P_t Q^k_t k_{\nu,j,t} + M_{\nu,j,t} + R^j_{t+1} Q^j_t B_{\nu,j,t} - R^d_t D_{\nu,j,t} - R^F_t Q^F_t F_{\nu,j,t} \tag{30}$$

Equation 29 makes use of Proposition 1 because a bank of type (ν, j) at time t is valued at time $t+1$ at $\psi_{t+1} N_{\nu,j,t+1}$. As a result, (28), (29), and (30) deliver a recursive formulation of (24).

In the morning, after the type is known, bank l chooses $k_{\nu,j,t}$, $B_{\nu,j,t}$, $B^F_{\nu,j,t}, F_{\nu,j,t}$, $D_{\nu,j,t}$, $M_{\nu,j,t}$ to maximize $V_{\nu,j,t}$, subject to the following constraints:

$$\begin{aligned}
V_{\nu,j,t} &\geq \lambda\left(P_t Q^k_t k_{\nu,j,t} + Q^j_t B_{\nu,j,t} + M_{\nu,j,t}\right) \\
0 &\leq B_{\nu,j,t} - B^F_{\nu,j,t} \\
P_t Q^k_t k_{\nu,j,t} + Q^j_t B_{\nu,j,t} + M_{\nu,j,t} + \phi N_{\nu,j,t} &= D_{\nu,j,t} + Q^F_t F_{\nu,j,t} + N_{\nu,j,t} \\
F_{\nu,j,t} &\leq \eta_t Q^j_t B^F_{\nu,j,t}
\end{aligned}$$

the non-negativity constraints

$$M_{\nu,j,t} \geq 0, B_{\nu,j,t} \geq 0, F_{\nu,j,t} \geq 0, D_{\nu,j,t} \geq 0, k_{\nu,j,t} \geq 0. \tag{31}$$

For the afternoon and unconnected banks

$$\omega^{\max} D_{\nu,j,t} \leq M_{\nu,j,t} + \tilde{\eta}^j_t Q^j_t \left(B_{\nu,j,t} - B^F_{\nu,j,t}\right). \tag{32}$$

The problems above are linear programming problems, maximizing a linear objective subject to linear constraints. So, the solution is either a corner solution or there will be indifference between certain asset classes, resulting in no-arbitrage conditions. The optimality conditions of the problem of the banks are reported in Online Appendix D. The definition of the equilibrium and the full system of the equilibrium conditions are reported in Appendices D and E, respectively.

4.2 The essential nature of the afternoon and leverage constraints

So far, we have assumed the existence of a leverage constraint for each bank type and an afternoon constraint for the unconnected bank types. We show that both constraints are necessary for changes in the share of unconnected banks ξ or in the market haircuts $\tilde{\eta}^j$ to matter for the equilibrium.

4.2.1 A model with no leverage constraint

Suppose that there is no leverage constraint for any bank, but unconnected banks face an afternoon constraint. The following proposition ensures that shocks to $\left(\xi, \tilde{\eta}^j\right)$ do not matter.

Proposition 1 (no leverage constraint) *Consider the model described in Section 3 but without a leverage constraint. Fix all parameters, except to consider two values for the sequence of parameters* $\left(\xi_t, \tilde{\eta}_t^N, \tilde{\eta}_t^S\right)$*, indexed by A and B. If there is an equilibrium for* $\left(\xi_{t;A}, \tilde{\eta}_{t;A}^N, \tilde{\eta}_{t;A}^S\right)$*, then there is an equilibrium for* $\left(\xi_{t;B}, \tilde{\eta}_{t;B}^N, \tilde{\eta}_{t;B}^S\right)$*, where all aggregate quantities are the same.*

The proof is in Online Appendix H. Intuitively, without a leverage constraint, banks are fully unconstrained, and so invest in capital until the risk-adjusted return for shareholders, i.e., households, is the same as the risk-free rate. In other words, banks price assets and liabilities using the household's stochastic discount factor. Consequently, this model is isomorphic to households investing in capital themselves directly without any banks, and so shocks to characteristics of the interbank market are irrelevant.

4.2.2 A model without afternoon constraint

Suppose banks in region j face a leverage constraint but there is no afternoon constraint for unconnected banks. The following proposition ensures that shocks to $\left(\xi, \tilde{\eta}^j\right)$ do not matter.

Proposition 2 (no afternoon constraint) *Consider the model described in Section 3 but without an afternoon constraint for unconnected banks. Then the equilibrium is independent of any shocks to* $\left(\xi, \tilde{\eta}^j\right)$*.*

Intuitively, without any afternoon constraint, the two bank types are identical to each other. Therefore, any movement in ξ does not affect the equilibrium because adjusting shares across banks that are identical has no impact. In addition, $\tilde{\eta}^j$ disappears from the optimization problem of banks. There is no need for banks to post collateral as they all have access to unsecured markets. As a result, as we show in Online Appendix G, with no afternoon constraint, there is no collateral premium attached to bonds by banks.

4.3 Analyzing the bank problem

Armed with this setup for banks, we now take a step back and analyse a simplified model of banks to help us understand the portfolio choice of banks, and how central bank policy interacts with it. To do this, we make a simplifying assumption: no aggregate shocks. In this setting, the returns on assets and liabilities (that banks take as given) are known with certainty. The bank then simply chooses a portfolio that maximizes the return on net worth subject to the afternoon and leverage constraints.

We drop the time subscript and make two assumptions that turn out to always be true in equilibrium in the full model: (i) $R^k > R^j$ and (ii) $R_d < R_F$. Banks will then only borrow from the central bank if it offers additional advantages. For connected banks, there are no such advantages as they never need collateralized funding when they have access to unsecured markets. Therefore, their portfolio choice in the morning is simply

$$D_{c,j} = \frac{V_{c,j}}{\lambda} - (1-\phi)\, N \quad \text{and} \quad Q^k k_{c,j} = \frac{V_{c,j}}{\lambda}$$

Connected banks invest entirely in capital as bond returns are lower. In the afternoon, they use unsecured funding to cover temporary deposit withdrawals.

Understanding the portfolio choice of unconnected banks in the morning, however, requires some careful analysis and is key for our dynamic results. It starts by deciphering how banks optimally plan to cover deposit withdrawals in the afternoon, given their decision on $D_{u,j}$ and $F_{u,j}$ in the morning. As dictated by the afternoon constraint, banks can do so, using money ($M_{u,j}$) or bonds ($B_{u,j}$). Which of the two the bank holds depends on the "collateral premium" for bonds, Λ^j, equaling [25]

$$\Lambda^j = \frac{R^k - R^j}{\widetilde{\eta}^j}. \tag{33}$$

Intuitively, to issue $(1/\omega^{\max})$ of deposits, a bank must hold $(1/\tilde{\eta}^j)$ units of bonds. The cost of doing so is the returns forgone. Λ^j is precisely this: the returns forgone from having to invest $(1/\tilde{\eta}^j)$ units in bonds instead of capital. By the same logic, if a bank uses money to back $(1/\omega^{\max})$ deposit units, the returns forgone are $R^k - 1$.

$$M_{u,j} = \begin{cases} 0 & \text{if} \quad \Lambda^j < R_k - 1 \\ \in [0, \omega^{\max} D_{u,j}] & \text{if} \quad \Lambda^j = R_k - 1 \\ \omega^{\max} D_{u,j} & \text{if} \quad \Lambda^j > R_k - 1 \end{cases}; \quad B_{u,j} = \frac{F_{u,j}}{Q^j \eta} + \frac{1}{Q^j \tilde{\eta}^j} \left(\omega^{max} D_{u,j} - M_{u,j}\right) \tag{34}$$

There are three cases, as shown in equation (34). If $\Lambda^j > R^k - 1$, money is a cheaper source of collateral than bonds. Thus, money is used exclusively to satisfy the afternoon constraint. Conversely, if $\Lambda^j < R^k - 1$, only bonds are used, while if $\Lambda^j = R^k - 1$, then any bond-money

[25] In Online Appendix G, we show that the collateral premium is strictly positive if the afternoon constraint is binding or unconnected banks are collateral-constrained in their borrowing from the central bank.

mix is optimal. Note also that extra bonds must be held as collateral for any central bank funding, at a haircut η, as bonds are the only acceptable collateral for the central bank.

Armed with this analysis, we can now understand how the bank chooses between the two funding sources: deposits ($D_{u,j}$) and central bank funding ($F_{u,j}$). An additional unit of deposits earns X_d:

$$X_d = R_k - R_d - \omega^{\max} \min \left\{ R_k - 1, \Lambda^j \right\} \tag{35}$$

The first term, $R_k - R_d$, is the return earned if the bank invests the deposit unit in capital. The final term reflects the fact that banks cannot invest all in capital but must hold collateral to back the deposit unit. This is costly because of the forgone returns, as explained above. The min operator is a result of choosing the least-cost type of collateral: bonds or money.

Conversely, an additional unit of central bank funding earns X_f:

$$X_f = R_k - R_f - \frac{\widetilde{\eta}^j}{\eta} \Lambda^j \tag{36}$$

Here, the collateral cost is without a min operator because bonds must be posted to the central bank. The term $\tilde{\eta}^j/\eta$ is because the central bank applies its own haircut, $1 - \eta$, not the private haircut $(1 - \tilde{\eta}^j)$, to the bond collateral.

Now, suppose that $\max\{X_d, X_f\} > 0$. Then the bank will access funding until the leverage constraint binds because more funding enhances portfolio returns. In other words, $(D_{u,j}, F_{u,j})$ is such that

$$D_{u,j} + F_{u,j} = \frac{V_{u,j}}{\lambda} - (1 - \phi) N \tag{37}$$

To determine the allocation across deposits and central bank funding, the bank compares X_d and X_f. If $X_d > X_f$, then $F_{u,j} = 0$, while if $X_d < X_f$, then $D_{u,j} = 0$. If $X_d = X_f$ any non-negative $(D_{u,j}, F_{u,j})$ combination satisfying (37) is optimal.[26],[27]

This scenario always prevails in the dynamics. Here, we can already make two key observations. First, a lower $\tilde{\eta}$ reduces the returns to deposit issuance because it requires banks to hold more costly collateral instead of capital. Second, central bank policy matters: lowering

[26]For completeness, if $\max\{X_d, X_f\} \leq 0$, an optimal choice is simply for the bank to only invest net worth into capital and not utilize any other funding sources.

[27]In the full dynamic model, it is always the case that $X_d \geq X_f$ as central bank funding is never made sufficiently attractive such that $X_d < X_f$. That is why we can assume cases where $D_{\nu,j} > 0$.

R_f and/or raising η makes central bank funding more attractive and can make $X_f \geq X_d$, especially if banks are facing high private haircuts $(1 - \tilde{\eta}^j)$.

This section makes clear the trade-offs banks face in their portfolio choice and how non-negativity constraints on portfolio holdings can turn from slack to binding and vice versa. To fully understand the effects of central bank policy, private haircuts, and other shocks, however, we must turn to the general equilibrium setup where asset returns, bank value, and asset supply all become endogenous.

5 CALIBRATION

5.1 Parameters

This section describes the calibration of the model parameters to euro area data. A period is one quarter. Table 1 provides the values for all parameters. Here, we focus on key choices.

We focus on cases where banks choose to raise deposits and to extend loans, i.e., we focus on equilibria, where $D_{\nu,j,t} > 0, k_{\nu,j,t} > 0$ for all ν and j. However, we explicitly allow for corner solutions for $M_{\nu,j,t}$, $B_{\nu,j,t}$ and $F_{\nu,j,t}$.

One central parameter capturing the liquidity management constraints faced by unconnected banks is $\omega^{\max}$. We calibrate it using the information embedded in the liquidity coverage ratio (LCR) - a prudential instrument that requires banks to hold high-quality liquid assets (HQLA) in an amount that allows them to meet 30 days of liquidity outflows under stress. We implicitly assume here that regulators can estimate with high precision the 30 day outflows in a period of stress. We therefore calibrate $\omega^{\max}$ so that the maximum amount of liquidity demand in the model, $\omega^{\max} D_{t,u}$, equates to the observed holdings of HQLA.[28] More specifically, we use the European Banking Authority report from December 2013, which provides LCR data for 2012Q4 and covers 357 EU banks from 21 EU regions. We take $\omega^{\max}$ to be the ratio of aggregate HQLA over total assets, implying that $\omega^{\max} = 0.1$.

[28] In our model, whenever the afternoon constraint binds, banks hold liquid assets in the amount of $M_u + \tilde{\eta} Q \left(B_u - B_u^F\right)$ to cover afternoon withdrawals $\omega^{\max} D$. Since $F = 0$ in our calibrated steady state, and net worth is a small fraction of total liabilities, we approximate D with total assets. Alternatively, we can approximate $\omega^{\max}$ using the run-off rates on deposits, as specified in the LCR regulation (e.g., a run-off rate of 10% means that 10% of the deposits are assumed to possibly leave the bank in 30 days). Run-off rates for deposits range from 5% for the most stable, fully insured deposits to 15% for less stable deposit funding. Our calibration of $\omega^{\max}$ at 0.1 is consistent with these rates.

We set the fraction of government bonds repaid each period, κ, to 0.042, corresponding to an average maturity of the outstanding stock of euro area sovereign bonds of around 6 years.[29]

We choose the parameter $\varkappa$ of the foreign demand for bonds to ensure that if foreign bond holdings take a value consistent with their observed share in total debt, then Q^j and π also take their average value at that steady state. We take data reported by Koijen et al. (2021) on average foreign holdings of euro area government bonds over the periods 2013Q4-2014Q4 and 2015Q2 to 2015Q4. We compute the percentage change in foreign holdings between the two periods to be -3.3%. We then calculate the percentage change between the same periods in the average real return on euro area government bonds to be -38%. We then set ϱ to replicate the observed elasticity of foreign bond holdings with respect to changes in the real return on bonds, i.e., $\varrho = 1.76$, thus interpreting it as a demand elasticity for the purpose of our analysis. We check the robustness to alternative values (not reported) and find little impact on our quantitative analysis.

We parameterize central bank policies as follows. Under a CO policy, there are two key parameters to be set: the interest rate on central bank loans, $1/Q^F$, and the haircut on collateral charged by the central bank, $1 - \eta$. We set the former equal to 1.0025 and the latter equal to 0.03, corresponding to the haircuts charged by the ECB on high-quality government bonds. Under these conditions, banks do not take up central bank funding in the baseline steady state. Under the constant balance-sheet policy, we ensure that banks do not borrow from the central bank, by setting $\eta = 0$, and we hold the real value of central bank bond holdings b^C constant.

We treat the monetary union as composed of symmetric regions and assume that $Q^N = Q^S = Q$ and $B_N^C = B_S^C = B^C$. We calibrate the remaining six parameters to match the model-based predictions of some key variables to their empirical counterparts over the pre-crisis period 1999-2006 (see Table 2).[30] The parameters are the share of net worth distributed by banks as

[29] Average maturity is computed as a weighted average of all maturities of euro area government bonds, with weights given by outstanding amounts in 2011. Source: Bloomberg, ECB and authors' calculations. Bond-level data used in Andrade et al. (2016) give a similar average maturity in 2015, pointing to a stable maturity structure of euro area debt over time.

[30] The average government expenditure to GDP ratio is computed using data for euro area (EU12) governments from Eurostat. The value of bank leverage is taken from Andrade et al. (2016). The share of banks' bond holdings in total debt is set at the value reported in Koijen et al. (2021) for 2015, 23%. To compute the share of the foreign sector's bond holdings, we first use data from the ECB's Statistical Data Warehouse to calculate the share the of central bank's holdings in total government debt. We include in this item not only outright purchases of government bonds but also collateralized loans extended in refinancing operations (the main instrument through which the ECB injects liquidity in normal times). The ratio to total sovereign debt is 10%. Koijen et al. (2021) report that households hold 3% of government bonds. We then impute to the foreign sector the remaining share, which amounts to 64%. The government bond spread is computed using data from

dividends, ϕ, the share of assets bankers can run away with, λ, the coefficient determining the utility from money holdings for households, χ, the expenditure on public goods, g^*, the real stock of government bonds purchased by the central bank, b^C, and the stock of real debt in the economy, $\overline{b}^*$. The targeted variables are: i) average ratio of government expenditure to GDP; ii) bank leverage; iii) government bond spread (annual); iv) share of banks' bond holdings in total debt; v) share of foreign sector's bond holdings in total debt; and vi) average inflation (annual). As Table 2 reports, the model perfectly replicates the six targeted moments and provides a good fit for two non-targeted moments: the ratios of central bank bond holdings to GDP and government debt to GDP.

5.2 Shock processes

The dynamics of the model are driven by the dynamics of the share ξ_t of "connected" banks and the private market haircut, $1 - \widetilde{\eta}_t^j$.

For the baseline pre-crisis steady state, we use data from the Euro Money Market Survey and sum up the turnover in the secured and in the unsecured segments (where 2003 is the first available observation in the survey and 2007 is the last year before the Global Financial Crisis). We set $\xi = 0.42$, corresponding to the 2003-2007 average share of cumulative quarterly total turnover executed in the secured market.

We set the haircuts on government bonds in private markets and at the central bank equal to each other, at $1 - \widetilde{\eta}^S = 1 - \widetilde{\eta}^N = 1 - \eta = 0.03$ (corresponding to a 3% haircut). The private haircuts are consistent with those observed in 2010, while the central bank haircuts are consistent with those imposed by the ECB on sovereign bonds with credit quality 1 and 2 (corresponding to a rating of AAA to A-) in 2010. This calibration ensures that, in the baseline, private banks do not take up any central bank funding in the steady state.

For the dynamic analysis in the model, we assume that ξ_t and $\tilde{\eta}_t$ are constant at their benchmark steady-state levels for $t < 1$. At $t = 1$, agents learn that ξ_t follows a new and deterministic path, but assume that $\tilde{\eta}_t^j$ remains constant for $j \in \{N, S\}$. [31] At $t = 13$, agents

SDW. We build average government bond yields by weighting the yields of all euro area government bonds, for all maturities, with the respective amounts in 2011. We then build the spread relative to the overnight rate, the EONIA. Average inflation is computed using quarterly changes in the HICP index taken from SDW.

[31] We treat the evolution of the share of unconnected banks, ξ_t as exogenous. One may think that the observed decline in unsecured money market lending reflects the introduction of ECB policies that injected large amount of central bank reserves, and that those reserves made money market lending redundant. Two facts documented in figure 1 support our view that the observed developments in money markets were exogenous to monetary policy. First, the trend decline in unsecured funding in both the North and South of Europe preceded the GFC and the ECB policies that increased reserves. Second, money markets did not become redundant; rather, the decline in unsecured funding induced a corresponding increase in secured interbank lending.

learn that $\tilde{\eta}_t^S$ also follows a new and deterministic path. We formulate these paths such that the model matches the observed evolution of the secured shares and private market haircuts, with $t = 1$ corresponding to the first quarter of 2009.

In our model, there is a tight relationship between ξ_t and the secured shares within the North.[32] Therefore, we consider a process for ξ_t that matches as closely as possible the data on secured shares in the North. We assume that $\log \xi_t$ converges to the new steady state ξ_∞ at a constant rate,

$$\log(\xi_t) = (1 - \rho_\xi)\log(\xi_\infty) + \rho_\xi \log(\xi_{t-1}) \tag{38}$$

where $\xi_{-1} = 0.42$ and $\xi_\infty = 0.1$. We choose ρ_ξ to minimize the squared distance between the model and the data, and find a value of $\rho_\xi = 0.95$. The left panel of Figure 5 compares the process (38) used in the model to the data evolution of the unsecured share in interbank markets in Northern European regions, also shown in Figure 2, Panel B.

We assume that $\tilde{\eta}_t^N$ remains constant for all $t \geq 1$ and that $\tilde{\eta}_t^S$ remains constant for $t \leq 12$. From $t = 13$ onward, we assume that $\log\left(\tilde{\eta}_t^S\right)$ follows an AR(2) process in order to replicate the hump-shaped process observed in the data,

$$\log\left(\tilde{\eta}_t^S\right) = (1 - \rho_{\tilde{\eta},1} - \rho_{\tilde{\eta},2})\log(\tilde{\eta}_\infty) + \rho_{\tilde{\eta},1}\log\left(\tilde{\eta}_{t-1}^S\right) + \rho_{\tilde{\eta},2}\log\left(\tilde{\eta}_{t-2}^S\right) + \epsilon_{\tilde{\eta}_t^S}, \tag{39}$$

where the shocks are zero, $\epsilon_{\tilde{\eta}_t^S} = 0$, except for $t = 13$. We search for $\rho_{\tilde{\eta},1}$, $\rho_{\tilde{\eta},2}$ as well as the shock $\epsilon_{\tilde{\eta}^S,13}$ in order to fit the data closely, and pick

$$\rho_{\tilde{\eta},1} = 1.65; \rho_{\tilde{\eta},2} = -0.7; \epsilon_{\tilde{\eta},13} = -0.11$$

The right panel of Figure 5 compares the AR(2) of equation (39) to the data, represented as a splined interpolation through the available data points.

6 DYNAMIC RESPONSES

We now turn to the main goal of the paper: what is the dynamic response of the real economy to the key observed money market developments, and what are the main drivers of the response. To do this, we solve the impulse responses of the model to the shock process outlined in Section 5.2 that describes these developments. After outlining the experiment, we firstly consider the

[32] This is for two reasons: 1) no banks in the North take up central bank funding, and 2) connected and unconnected banks issue very similar amounts of deposits.

responses under the baseline monetary policy setup where the central bank follows a policy of collateralized lending to banks (CO policy). We then compare the outcomes to a counterfactual scenario of the central bank maintaining a constant balance sheet (CB policy). We solve the model non-linearly under perfect foresight.[33][34]

6.1 Description of Experiment

We assume that the model is at its benchmark pre-crisis steady state for $t < 1$. At $t = 1$ and corresponding to the first quarter of 2009, agents learn that ξ_t follows a new path, while at $t = 13$, they learn that $\tilde{\eta}_t^S$ follows a new path, both of which are described in Subsection 5.2 and shown in Figure 5. The scenario in blue is one where only the unanticipated shock to the unconnected share, $(1 - \xi)$, is realized at time $t = 1$. In this case, at $t = 1$, agents understand fully and with certainty that the share of connected banks, ξ, will transition to a permanently lower level in accordance with Figure 5. The scenario in red is where we also have the unanticipated persistent shock to $\tilde{\eta}^S$, realized at time $t = 13$. Agents in the model, from $t = 13$ onward, understand that, with certainty, $\tilde{\eta}^S$ will evolve according to the right-hand side of Figure 5.[35] Therefore, the difference between the red and blue lines conveys the effect caused by the $\tilde{\eta}^S$ shock. Note the key difference in the characteristics of the two shocks. The shock to ξ represents a gradual transition to a permanently lower level, whereas the $\tilde{\eta}^S$ shock is a persistent but non-permanent change in haircuts.

Figure 6 plots on the right-hand side the four empirical observations that we document, and the corresponding model counterparts on the left-hand side in each row: (i) secured shares in the Euro Area, (ii) the take-up of central bank funding as a percent of assets held by unconnected banks in the South, (iii) private haircuts on bonds issued in the South, and (iv) the change in customer deposits as a share of bank assets in the South, assuming that the central bank follows the benchmark policy of collateralized lending to banks.[36] Overall, the

[33] We use Dynare to calculate the numerical solution. We chose the Levenberg-Marquardt mixed complementarity problem solver. This solver is more suited to models with occasionally binding constraints than the more commonly used Newton algorithm. The path to final equilibrium is imposed in finite time T, but we set the end point large enough (T = 400) to ensure that the economy converges to the steady state.

[34] In Online Appendix J, we also conduct some steady state comparative statics analysis where we consider what happens to the steady state when we permanently change the share of unconnected banks in the monetary union $(1 - \xi)$ or the haircut on bonds issued in the South $(1 - \tilde{\eta}^S)$. This can help build intuition for the main results.

[35] It arrives at time $t = 13$ to reflect the fact that, in the data, the increase in haircuts experienced by sovereign bonds in the South occurred approximately three years after the beginning of the notable rise in the secured share. Also, we adjust the estimated process slightly so that it is a non-permanent change in $\tilde{\eta}^S$.

[36] See Online Appendix I for details on how we evaluate the secured share. We assume that unconnected banks cover deposit withdrawals with reserves before accessing the secured market.

dynamic model does well in replicating all the empirical observations we documented: a rise in secured shares, a take-up of central bank funding at the peak of private haircuts, and a stable albeit U-shaped response of deposit shares when central bank funding is taken up. Except for Observation II, all these observations are non-targeted, which leaves us with confidence that the model is capturing well the key forces in the data.

Figure 7 conveys the impulse responses of key variables of interest in our two scenarios and under the benchmark CO policy: in blue when just the shock to ξ is realized, and in red when we also have the shock to $\tilde{\eta}^S$ realized at time $t = 13$. The scenario in red is consistent with the empirical observations documented in Section 2.1. The vertical orange lines represent the time at which the $\tilde{\eta}^S$ shock is realized. The intersection with the y-axis denotes the point where the economy is in time $t = 0$, either in levels or as a percent change from the baseline steady state.

As the shift in ξ is permanent, the economy ultimately transitions to a new steady state, regardless of whether or not the $\tilde{\eta}^S$ shock occurs. The new steady state is represented by the horizontal dashed lines, which indicate the new long-run level (or percent change from the baseline steady state).

6.2 Impact of changes in ξ only

We can gain the main intuition for the impulse responses by understanding the shift in the steady state induced by the long-run shift in the unconnected share, $1 - \xi$. The key outcome across steady states in the model is the decline in the capital stock, falling 10% on aggregate. This is due to the "crowding-out" effect on capital, for two reasons. First, as $(1 - \xi)$ rises, connected banks get replaced by unconnected banks. In the baseline steady state, their balance sheets are very similar in size but differ crucially in the composition of assets held: unconnected banks need to hold collateral to satisfy their afternoon constraint. This mechanically crowds out capital investment on aggregate.

Second, each individual bank invests less in capital as a result of lower deposits. This is especially the case for unconnected banks. As the number of unconnected banks increases, the demand for collateral also increases to satisfy the afternoon constraint. This drives up the collateral premium banks pay to hold bonds. When this premium is high enough, unconnected banks prefer bringing money over to the afternoon, which they can hold because an increase in the deposit rate induces households to hold less of it.[37] The higher cost of deposits, however, leads unconnected banks to downsize their balance sheets and reduce capital investment funded by deposits. The increase in the cost of deposits spills over also to connected banks in the form of a higher cost of investing in capital and reduced net worth.

On aggregate, the capital stock declines at the new steady state, and investment declines by the same proportion. This depresses output as a consequence. Moreover, there are no stabilizing interventions undertaken by the central bank in equilibrium. As we know from the steady-state analysis, no CB funding is taken up by banks when ξ changes across steady states. As private haircuts, $1 - \tilde{\eta}^S$, remained unchanged, there is no advantage in tapping more collateral-intensive central bank funding as there is no difference between central bank and private market haircuts.

However, the transition toward the steady state is far from smooth. Indeed, output and investment initially undershoot the value they reach in the new steady state, despite the share of connected banks being still far above the new steady-state level. The coming gradual decline of ξ - and thereby the gradual need to forgo returns in favor of holding bonds or money for liquidity reasons - lowers the value of operating a bank. This immediately causes an endogenous reduction of leverage and assets held. Moreover, as banks understand that capital investment will be crowded out in the future, the current price of capital falls. This drives down net worth and, combined with lower leverage, leads to persistently lower capital investment. Investment then gradually recovers to the new lower steady-state level as the net worth of banks is replenished.[38]

Finally, the top left plot of Figure 6 shows that a permanent fall in ξ produces a permanent rise in the secured shares. Intuitively, both bank types use only deposits as a liability source. The increasing share of unconnected banks creates a larger need to use the secured market to manage short-term deposit withdrawals. Therefore, there is a very tight relationship between ξ and the secured share. As we will see, this relationship does not necessarily hold if unconnected banks had an incentive to use an alternative liability source, such as central bank funding.

[37] The size of the central bank balance sheet remains constant but the composition of liabilities switches from the issuance of currency to households toward issuance of reserves to banks.

[38] Note that connected banks partially counteract the decline in investment on impact as they do not suffer from higher collateral premia. However, this is not enough to prevent aggregate investment from falling.

6.3 Impact of changes in ξ and $\tilde{\eta}$

We now investigate what happens if the economy additionally experiences the unanticipated persistent drop in $\tilde{\eta}^S$ at time $t = 13$, comparing the red impulse responses in Figure 7 to the ξ-shock-only responses in blue.

Bonds available to unconnected banks in the South are now worse collateral. This drives up collateral prices and makes deposit issuance more expensive, inducing banks to downsize their liabilities. Moreover, Q^S falls because these bonds are now less effective as collateral, driving net worth lower. As a result, capital investment by unconnected banks in the South falls.

However, unconnected banks in the South rebalance their portfolios to mitigate the effects of collateral scarcity. First, they increase the money they bring over to the afternoon. Second, at the peak of the rise in private haircuts, banks substitute expensive deposits with central bank funding because of the preferential haircuts central banks charge on bonds relative to the private market. Indeed, this take-up is significant, equalling 2.5% of total bank assets, and generates the U-shaped response of deposit shares, as seen in the second and fourth rows of Figure 6. Our model is therefore consistent with Observations II and IV. These two effects mitigate the collateral scarcity faced by unconnected banks in the South, helping them downsize investment by less. Although unconnected banks rebalance toward central bank funding in the morning, they continue tapping into the private secured market to manage their afternoon liquidity needs, albeit to a lesser extent than before the shock. As a result, in our model, the secured share continues to rise because (i) the share of unconnected banks rises and (ii) unconnected banks still rely heavily on the secured interbank market. We therefore replicate Observation I, as we see in the first row of Figure 6.

Turning to the aggregate effect, output and investment fall because of aggregate disinvestment, mainly driven by unconnected banks in the South. This is partially counteracted by connected banks' rise in value as capital returns increase. This endogenously allows them to increase their leverage, thus both investing more in capital and raising more deposits.

Quantitatively, however, a key determinant of the negative effect is the response of unconnected banks in the North. They do not face any shock to $\tilde{\eta}^N$ but still get impacted indirectly via higher collateral premia in the economy. Intuitively, unconnected banks in the South experience a collapse in the pledgeable value of their collateral. As a result, they move toward holding money to satisfy the afternoon constraint, thereby driving up its cost. But crucially, unconnected banks in the North already hold increased amounts of money as collateral following the ξ shock. Hence, they also pay a higher price for this collateral. This tightens the afternoon constraint for them as well. Therefore, despite the increase in returns to capital and despite not being directly exposed to the private haircut shocks, they hardly change their capital investment. In other words, unconnected banks in the North face a pecuniary externality through higher collateral premia because of the shock to collateral quality for those in the South.[39]

As the shock subsides and the haircuts revert back toward the pre-shock level, investment recovers and, in fact, overshoots the path absent the $\tilde{\eta}^S$ shock. The intuition is as follows. As the haircuts recover somewhat and returns to capital remain elevated, the bank now has access to favorable investment opportunities while at the same time being less constrained by collateral needs. As a result, banks can increase leverage, which causes the overshooting effect to bring capital back to its new steady state.

6.4 Comparison of impulse responses: CO policy vs CB policy

We now compare the dynamics under the benchmark policy of collateralized lending to banks (CO policy) to a counterfactual scenario of the central bank maintaining a constant balance sheet (CB policy). In the ξ-only-shock scenario, there is no difference: since central bank haircuts are the same as private-sector haircuts under both policies, banks strictly prefer not to borrow from the central bank. Therefore, Figure 8 compares the dynamics resulting from the CO policy in blue to the dynamics resulting from CB policy, subtracting out the dynamics resulting from the ξ-only-shock scenario. Put differently, Figure 8 shows the additional dynamics under these two policies, arising from the additional $\tilde{\eta}^S$-shock.

With Figure 7, we have shown that a shock to $\tilde{\eta}^S$ has an adverse effect on output and investment and that the capital stock declines under the benchmark CO policy. As Figure 8 demonstrates, the impact on the real economy is stronger under the CB policy. In particular, output and investment fall around twice as much on impact. The key difference here is of course the access to central bank funding under the benchmark CO policy. For unconnected banks in the South and when $\tilde{\eta}^S$ falls, the afternoon constraint is tighter and collateral premia rise.

[39] What is crucial here is that banks in the North and South both use reserves as a source of collateral. If they did not, then collateral markets would be entirely segmented: banks would hold as collateral only bonds issued within their region. In this case, banks face region-level collateral scarcity i.e. collateral premia, and shuts down the spillover of premia across regions.

If this shock is large enough, unconnected banks divert their liability sources from expensive deposits (as the afternoon constraint is tighter) to central bank funding under that policy.

Unconnected banks in the South take up this central bank funding because it became a profitable opportunity. But crucially, in equilibrium, central bank funding releases more collateral on aggregate in the form of reserves. For each unit of central bank funding, it supplies a unit of reserves available to back deposits. In exchange, it absorbs a unit of bond collateral. However, the central bank funding is taken up precisely when the collateral value of bonds is much lower than reserves. Therefore, it raises aggregate collateral supply available to back deposits, hence why the rise in the collateral premia is dampened.

By mitigating the rise in the collateral premium, the CO policy especially benefits unconnected banks in the North. Looking at the bottom left, capital investment $k_{U,N}$ rises under the CO policy, while it falls under the CB policy. If unconnected banks in the South access central bank funding, banks in the North also benefit indirectly by having to pay less for collateral in the form of reserves. The spillover from South to North and to the unconnected banks in the North, therefore, plays a critical role in the overall dynamics, even though the latter are not directly affected by the rise of the private-sector haircuts in the South. The larger fall on impact in investment and output under the alternative CB policy increases returns to investing in capital and thereby raises the value of operating a bank with some delay. The resulting endogenous rise in leverage then leads to a larger recovery under the alternative CB policy than the benchmark CO policy.

7 CONCLUSIONS

This paper documented four key money market developments in the Euro Area during the Global Financial Crisis and the European sovereign debt crisis. First, activity in the unsecured money market segment progressively dried out, substituting toward secured transactions. Second, during the sovereign debt crisis, haircuts on Southern government bonds increased substantially. Third, during this period, banks increased secured borrowing from the ECB eight-fold in the Southern European countries, when the ECB kept haircuts on accepted collateral unchanged. Fourth, household deposits fell when banks borrowed from the central bank, and increased when the central bank borrowing waned.

We develop a dynamic general equilibrium model with banks at the center to understand the impact of these developments. Banks are capital investors subject to a leverage constraint but also a need to manage short-term deposit withdrawals using reserves held or borrowed from money markets. Our key innovation is to incorporate empirically relevant features of money markets: some banks can borrow unsecured while others have only access to secured funding, which requires posting collateral, typically government bonds. But how much funds banks can access varies with haircuts: the lower the haircut, the larger the available funding.

Our model, which we calibrate to euro area data, indicates that the observed money market developments had a significant impact on the macroeconomy. First, as more banks become unable to borrow unsecured and need to access interbank markets on a secured basis, more collateral is held which crowds out capital investment. Second, when haircuts on Southern government bonds rise, banks located in Southern regions must source additional collateral, which further crowds out capital. Crucially, this collateral scarcity spills over to banks in the Northern regions, because Southern banks react to the rising cost of collateral by increasing outright holdings of reserves to manage liquidity. Higher demand for these reserves, previously held mainly by banks in the North, increases their opportunity cost and worsens the crowding-out of capital. Third, the ECB policy of offering secured loans of reserves to banks with attractive collateral terms when private market haircuts abruptly rise shields the economy from money market tensions. The ECB funding becomes a substitute for deposit funding, rising to 2.5% of bank assets in the South. This mitigates collateral scarcity because it releases new borrowed reserves into the banking system. The policy matters quantitatively - the adverse effect on output from higher Southern private haircuts would be twice as large in the absence of this measure.

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TABLES

Table 1: Parameter values

Parameter	Description	Value
θ	Capital share in income	0.330
δ	Capital depreciation rate	0.020
β	Discount rate households	0.994
ϵ	Inverse Frisch elasticity	0.400
χ^{-1}	Coefficient in households' utility	0.006
g	Government spending	0.566
κ^{-1}	Average maturity bonds (years)	5.952
ϕ	Fraction net worth paid as dividends	0.025
ξ	Fraction banks with access to unsecured market	0.420
$\widetilde{\eta}$	Haircut on bonds set by banks	0.970
η	Haircut on bonds set by central bank	0.970
λ	Share of assets bankers can run away with	0.701
$\omega^{\max}$	Max possible liquidity demand as share of deposits	0.100
α	Intercept foreign demand function	4.676
B_C	Bonds held by central bank	0.968
B^*	Stock of debt	7.443
ϱ	Parameter foreign bond demand	1.757
Q^F	Price central bank loans	0.997

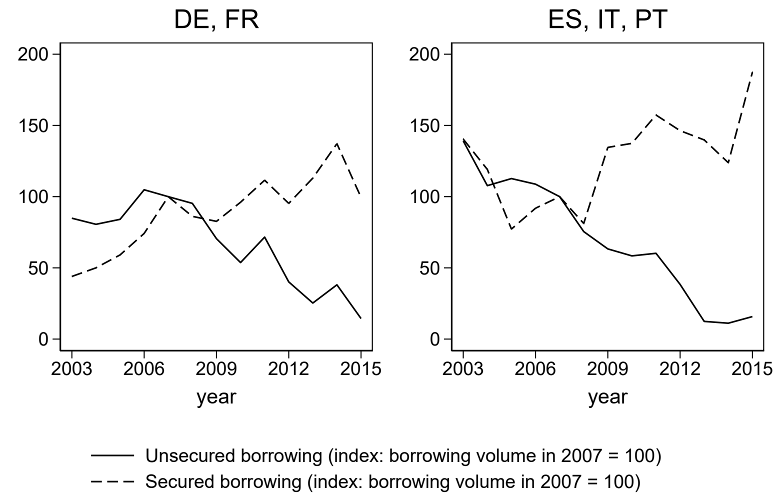
Table 2: Calibration

Targeted variables	**Data**	**Model**
Govt expenditure/GDP	0.20	0.20
Bank leverage	6.00	6.00
Govt bond spread (annual)	0.002	0.002
Share bonds held by banks	0.23	0.23
Share bonds foreign sector	0.64	0.64
Inflation (annual)	0.02	0.02
Non-targeted variables	**Data**	**Model**
CB bond holdings/GDP	0.06	0.08
Govt debt/GDP	0.69	0.66

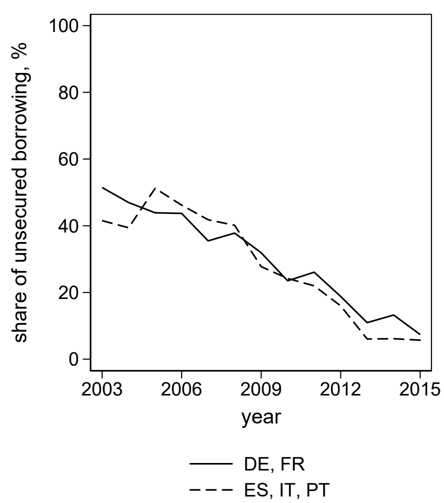
FIGURES

Figure 2: Unsecured and secured interbank borrowing

Panel A

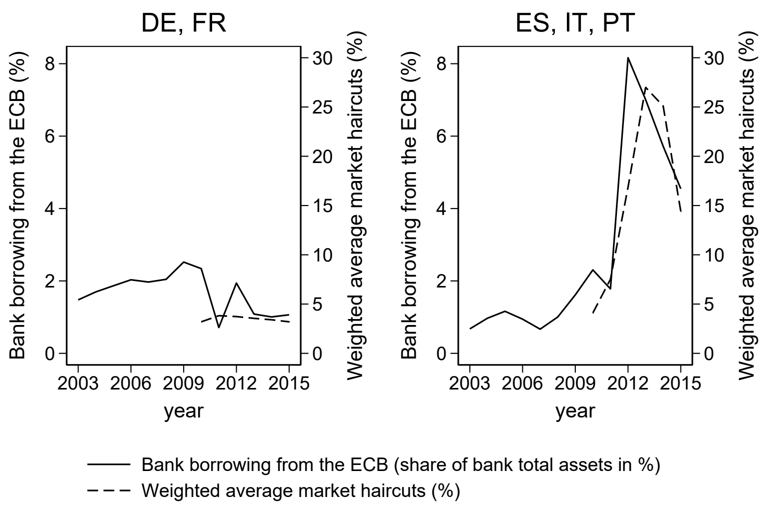


Panel B



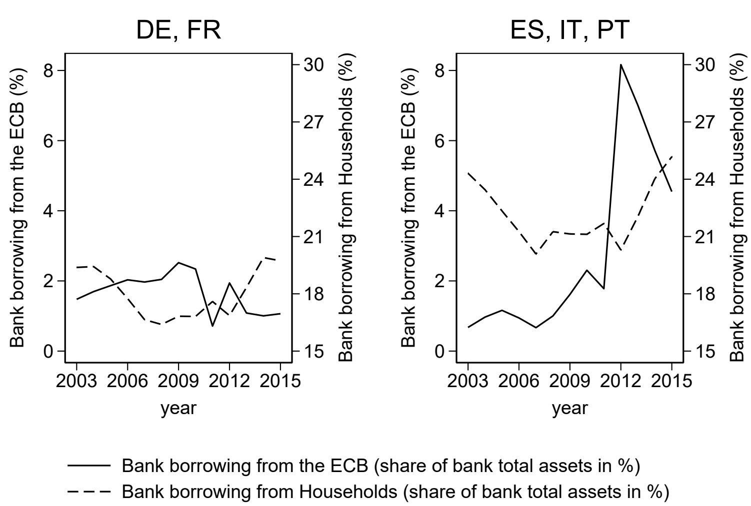
Notes: Panel A presents cumulative quarterly turnover in the unsecured and secured interbank borrowing over 2003-2015 (the time span of the data collection), distinguishing between Northern regions (left-hand-side panel) and Southern regions (right-hand-side panel). Turnover is defined as the sum of all borrowing transactions over the second quarter of each year (the quarter in which the data were collected) reported by banks participating in the ECB's Money Market Survey (MMS) and normalized to 100 in 2007. The MMS panel comprised 98 euro area banks. Panel B presents the relative share of unsecured borrowing in total, distinguishing between Northern regions (solid line) and Southern regions (dashed line). Source: Euro Area Money Market Survey.

Figure 3: Bank borrowing from the ECB and market haircuts, % of total assets



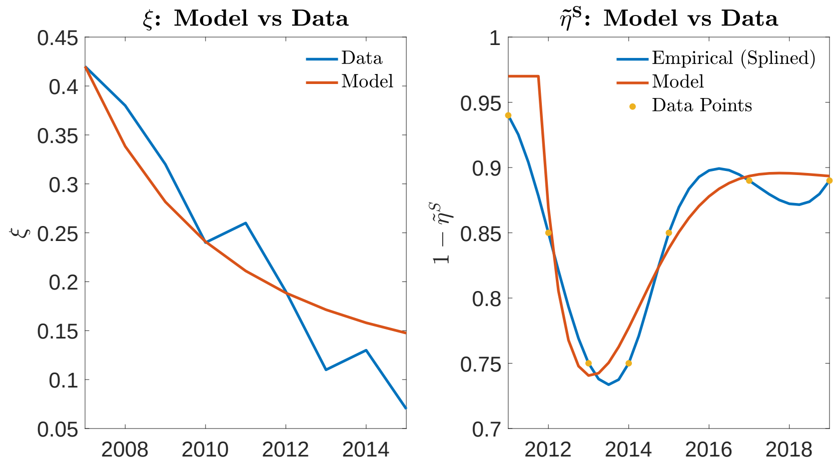
Notes: The figure presents bank borrowing from the ECB as % of bank total assets (solid line, left scale in each figure) and weighted average market haircuts in % (dotted line, right scale in each figure) over 2003-2015. The left-hand-side panel displays the evolution for Northern regions, while the right-hand-side panel displays the evolution for Southern regions. Region-level haircuts are obtained as simple averages across maturities. Region-group-level haircuts are constructed as weighted averages across the Northern (Southern) regions, with weights given by the shares of the respective banking sector assets in total in 2010 (the weights are 48% and 52% for DE and FR, and 49%, 44% and 7% for IT, ES and PT, respectively). Source: ECB and LCH.Clearnet.

Figure 4: Bank borrowing from households and the ECB, % of total assets



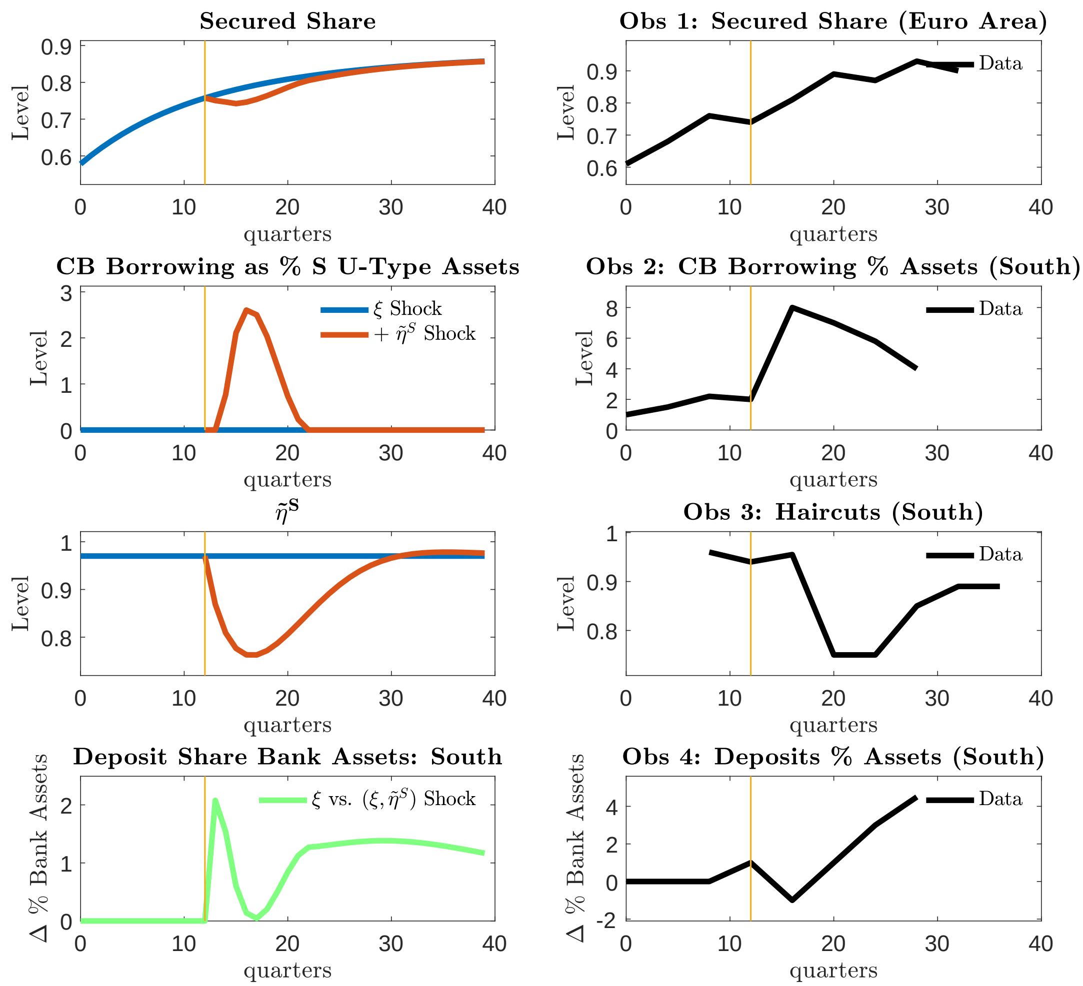
Notes: The figure presents bank borrowing from the ECB (solid line, left scale in each figure) and from households (dotted line, right scale in each figure) as % of bank total assets over 2003-2015. The left-hand-side panel displays the evolution for Northern regions, while the right-hand-side panel displays the evolution for Southern regions. Source: ECB.

Figure 5: Model vs. data: evolution of $(1-\xi)$ and $\tilde{\eta}^S$



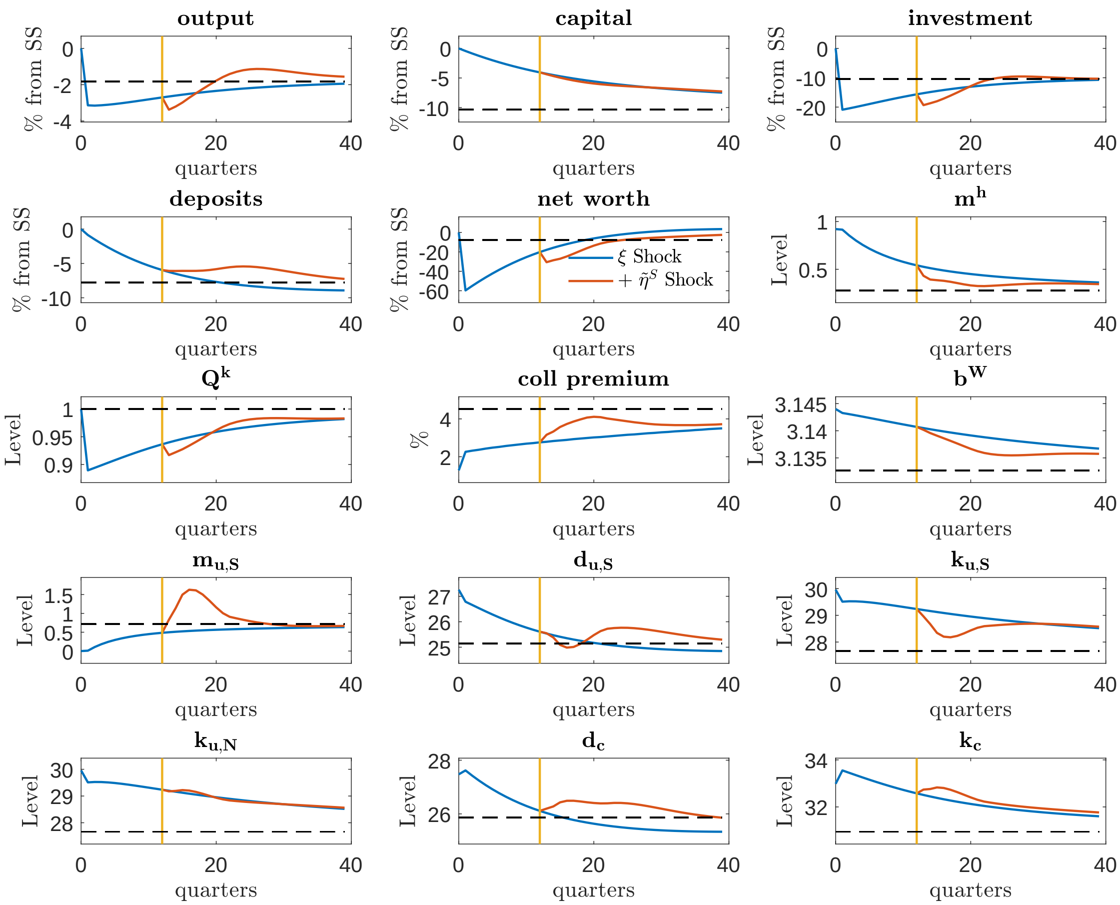
Notes: Conveys the evolution of a) the unsecured share in the secured market and b) the level of haircuts applied to government collateral in the South. The blue line is the data taken from Section 2.1, while the red line is the fitted model-implied evolution of these variables described in Section 5.2. The Data Points for $\tilde{\eta}^S$ come from the time series evolution of private market haircuts (LCH.Clearnet) on Southern government bonds (weighted average across Italy, Spain and Portugal), while the Model line is a spline interpolation through these points that we attempt to fit with an AR(2) process that is fit into the model.

Figure 6: Four facts: model vs data



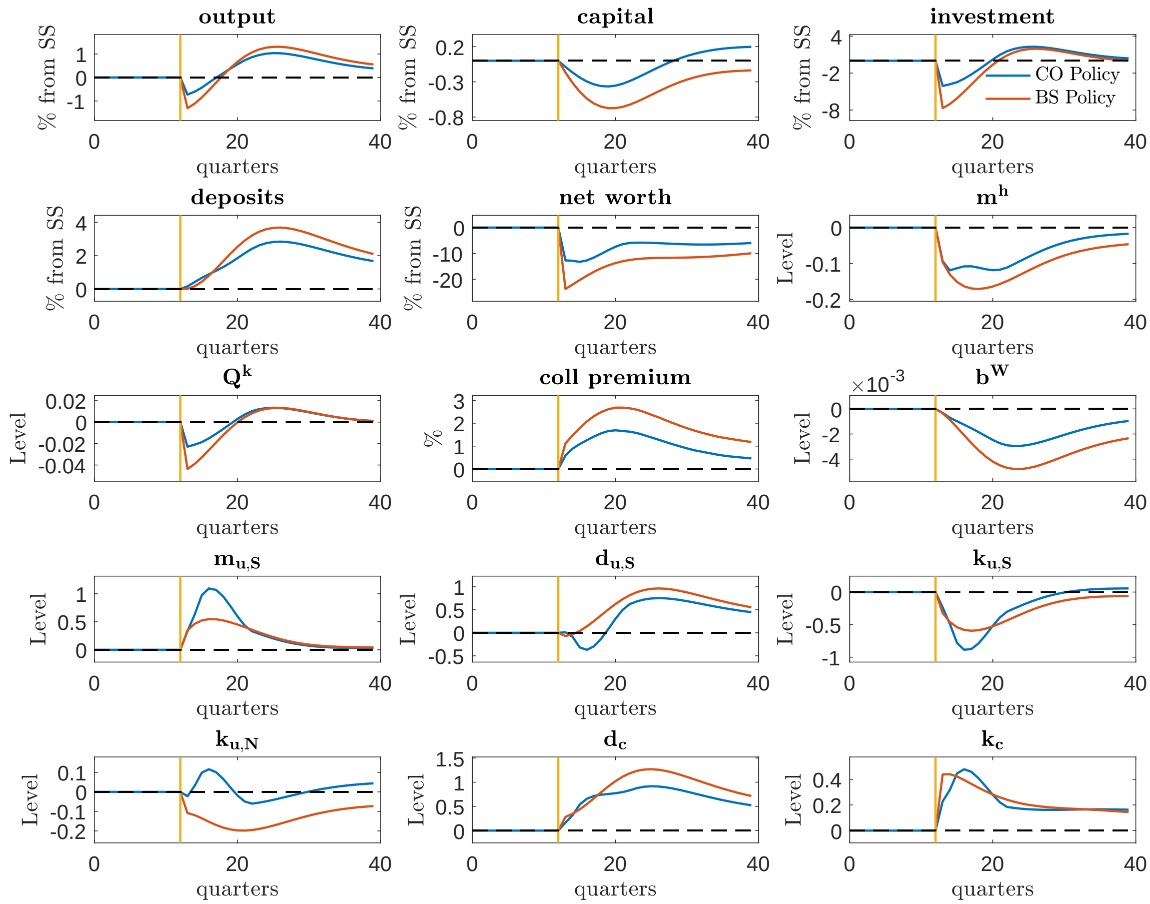
Notes: The figure compares the model outcomes on the first column to their empirical counterparts on the second column regarding the four facts documented in subsection 2.1. The first column shows the impulse responses of key variables to exogenous shocks under CO Policy. The timing and process of the shocks in the full experiment are explained in Section 5.2. The solid blue lines denote the response to the permanent shock to ξ only, which occurs at time 0. The solid red lines denote the response of variables when there is an additional shock to $\tilde{\eta}^S$, which occurs at time $t = 13$. The green lines denote the response of variables when there is the combined $(\xi, \tilde{\eta})$ shock relative to the ξ shock alone. The shock to $\tilde{\eta}^S$ occurs in correspondence to the thin orange line. First row: the secured share in interbank market. Second row: borrowing from central bank as a % of total assets held by unconnected banks in the South. Third row: process for $\tilde{\eta}^S$. Fourth row: deposits as a share of total bank assets in the South and North, respectively. The observations are annual and the yellow line represents 2011.

Figure 7: Impulse responses: $\xi + \tilde{\eta}$ shock (red) vs. ξ shock only (blue)



Notes: Conveys the impulse responses of key variables to exogenous shocks under CO Policy. The timing and process of the shocks in the full experiment are explained in Section 5.2. The solid blue lines denote the response to the permanent shock to ξ only that occurs at time 0. The solid red lines denote the response of variables when there is an additional shock to $\tilde{\eta}^S$ that occurs at time $t = 13$. The timing of the shock to $\tilde{\eta}^S$ is conveyed by the thin orange line. The dashed black lines indicate the permanent % change / new level of the variable in response to the permanent shock to ξ. First row: % change in aggregate output, capital, and investment. Second row: % change in aggregate deposits, bank net worth and money held by households. Third row: price of capital, bond collateral premium (as defined in Section 4.3), and world bond demand. Fourth row: money, deposits and capital held by U-types in the South. Fifth row: capital held by U-types in the North, and deposits issued and capital held by connected banks.

Figure 8: Impulse responses: CO policy and constant balance-sheet policy



Notes: Conveys the response of variables in the full experiment in comparison to a counterfactual where only the ξ shock occurs. In other words, it illustrates the additional effect induced by the shock to $\tilde{\eta}^S$. The timing and process of the shocks in the full experiment are explained in Section 5.2. The solid blue lines denote the response under CO policy, while the red solid lines denote the response under a constant balance-sheet policy. The timing of the shock to $\tilde{\eta}^S$ is conveyed by the thin orange line at $t = 13$. First row: % change in aggregate output, capital and investment. Second row: % change in aggregate deposits, bank net worth and money held by households. Third row: price of capital, bond collateral premium (as defined in Section 4.3), and world bond demand. Fourth row: money, deposits and capital held by U-types in the South. Fifth row: capital held by U-types in the North, and deposits issued and capital held by connected banks.

Online Appendix:
Money Markets, Collateral and Monetary Policy

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A Data sources

Our observations are derived from several data sources. First, we use data on haircuts charged by the LCH.Clearnet - one of the largest clearers of repo transactions in the euro area - on government bonds of several euro area countries. We consider the four largest euro area countries - Germany (DE), France (FR), Italy (IT), and Spain (ES) - plus Portugal (PT), for which the relevant data are also available. We obtained the data from the LCH.Clearnet website, where snapshots of the haircut schedules have been made available since 2010.[1] The evolution of haircuts over time suggests substantial cross-country heterogeneity, with haircuts for German and French government bonds moving very little and haircuts on Italian, Spanish, and, in particular, Portuguese government bonds skyrocketing during the sovereign debt crisis. We summarized these data as follows. Country-level haircuts are obtained as simple averages across maturities. Country-group-level haircuts are constructed as weighted averages across the relevant countries, with weights given by the shares of the respective banking sector assets in total. For the Southern countries we consider, the weights are 49%, 44%, and 7% for IT, ES, and PT, respectively, in 2010 (see Table 1 for the time series evolution of haircuts in the Southern countries). For the Northern countries we consider, the weights are 48% and 52% for DE and FR, respectively, in 2010.

Second, we take data on secured and unsecured interbank market turnover from the ECB Money Market Survey, which was a survey run by the Eurosystem between 2003 and 2015 to gauge money market developments in the euro area. More than 100 banks from across the euro area and additional European countries participated in the survey, conducted in the second quarter of each year. Participating banks were selected to cover the biggest players in money markets of the respective countries. The survey was discontinued in 2015.[2] The ECB regularly published the survey results in aggregated form. As we are interested in cross-country heterogeneity - given the large heterogeneity in repo market haircuts we uncovered - we obtained the proprietary disaggregated Money Market Survey data, which we present at a country-group level. To the best of our knowledge, the disaggregated data have not been explored in the literature before.

Third, we rely on the ECB's Statistical Data Warehouse (SDW) to obtain country-level time series of banking sector assets as well as deposit flows and central bank borrowing. These data are available monthly. To combine this data with the Money Market Survey data - which are based on the observations from the second quarter of each year - we aggregate the monthly data to quarterly frequency by averaging over the quarter (for flows) or by taking end-of-quarter observations (for stocks).

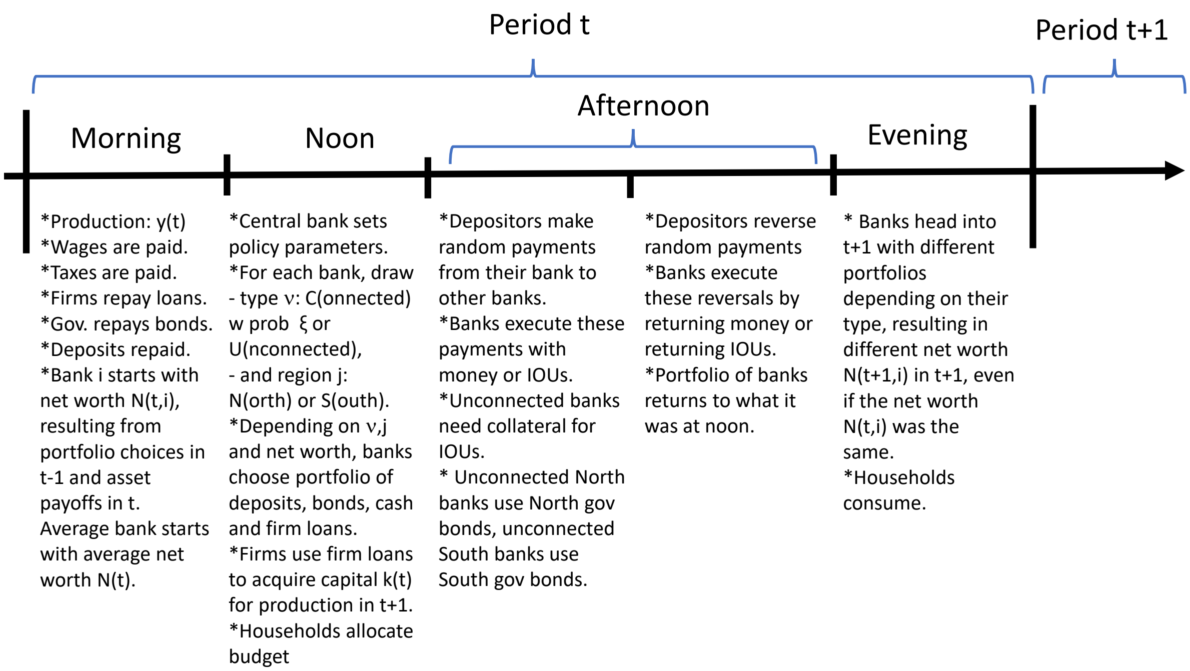
[1] These data have been used in other academic studies; see, e.g., Drechsler, Drechsel, Marquez-Ibanez, and Schnabl (2016), Boissel, Derrien, Ors, and Thesmar (2017), and Jasova, Mendicino, and Supera (2021).

[2] As of the second half of 2016, information on money markets has been gathered via the data collection called Money Market Statistical Reporting.

Finally, to aggregate the series to country-group level ("North" and "South"), we weigh country-level observations for Germany and France by the size of their banking sectors in total to obtain the values for the "North" and, similarly, we apply the same weights methodology for Italy, Spain, and Portugal to obtain the values for the "South."

B Model Timeline

Figure B.1: Timeline of the model



C Optimality conditions of households and firms

We assume the following functional form of the households' utility function:

$$u\left(c_t, h_t\right) + v\left(\frac{M_t^h}{P_t}\right) = log(c_t) + \frac{1}{\chi} log(\frac{M_t^h}{P_t}) - \frac{h_t^{1+\epsilon}}{1+\epsilon}.$$

The household maximizes his preferences, equation (2), subject to the budget constraints

$$D_t^h + M_t^h \leq R_{t-1}^d D_{t-1}^h + M_{t-1}^h + \left(1-\tau_t\right) W_t h_t + \phi N_t + \Pi_t^{CP} - P_t c_t \tag{C.1}$$

Note that there are further restrictions on the choice variables, i .e. $c_t > 0, h_t > 0$, $M_t^h > 0$ and $D_t^h \geq 0$. We do not list these constraints separately for the following reasons. For $c_t > 0$, $h_t > 0$, and $M_t^h > 0$, we can assure non-negativity with appropriate choice for preferences and per the imposition of Inada conditions. We constrain the analysis a priori to $D_t^h > 0$, (see section 5 below) despite the possibility that it could be negative when allowing for more generality. [3]

We define a real variable as the corresponding nominal (capital letter) variable, divided by the contemporaneous price level, i.e. $x_t = \frac{X_t}{P_t}$, and

$$\pi_t = \frac{P_t}{P_{t-1}}$$

as the inflation from period $t-1$ to t.

For households, the first order conditions over bonds, labour and money are:

$$1 = \beta E_t \left[\frac{c_t}{c_{t+1}} \frac{R_t^d}{\pi_{t+1}} \right] \tag{C.2}$$

$$c_t h_t^\zeta = (1-\tau_t) w_t \tag{C.3}$$

$$\frac{c_t}{\chi m_t^h} = \frac{R_t^d - 1}{R_t^d} \tag{C.4}$$

Final goods firms choose labor $h_t > 0$, and capital $k_t > 0$ to maximize their profits. The first order conditions over labor and capital are:

$$\frac{W_t}{P_t} h_t = (1-\theta) y_t \tag{C.5}$$

$$r_t k_t = \theta y_t \tag{C.6}$$

Finally, the capital-producing firm solves the problem in (4), resulting in the following price for capital:

$$Q_t^k = \left(\frac{i_t}{\delta k_{t-1}} \right)^\zeta \tag{C.7}$$

Intuitively, if the price of capital Q_t^k is 1, investment replaces depreciated capital, exceeds replacement if below 1 and vice versa.

[3] We have not analyzed this matter for the dynamic evolution of the economy. It may well be that net worth of banks temporarily exceeds the funding needed for financing the capital stock, and that therefore deposits ought to be negative, rather than positive. For now, the attention is on the steady state analysis, however, and on returns to capital exceeding the returns on deposits.

D The optimality conditions of the banks

We firstly establish the linearity of the bank's value function. Using this result, we then present the problem of the banks and the resulting optimality conditions.

We claim that the problem of a bank i is linear in net worth and

$$\bar{V}_{i,t} = \psi_t N_{i,t} \tag{D.1}$$

for some factor ψ_t which gives the value of a marginal unit of net worth of a bank in the morning, before a bank's type is known. In particular, $\bar{V}_{i,t} = 0$ if $N_{i,t} = 0$.

Since there are no fixed costs, a bank i of network type ν and region j with twice as much net worth can invest twice as much in the assets. Furthermore, if a portfolio is optimal at some scale for net worth, then doubling every portion of that portfolio is optimal at twice that net worth. Thus, the value of the bank is twice as large, conditional on knowing its type at time t. Taking expectations over the type that will be revealed, which is a linear operator, the linearity is preserved before knowing the type.

Thus, we only need to characterize the dynamic problem of an average connected bank and an average unconnected banks at region S and N. Banks are indexed by their type $\nu \in \{c, u\}$ and location $j \in \{S, N\}$

A generic bank $\{\nu, j\}$ chooses $k_{\nu,j,t}$, $b_{\nu,j,t}$, $b^F_{\nu,j,t}$, $f_{\nu,j,t}$, $d_{\nu,j,t}$, $m_{\nu,j,t}$ to maximize

$$v_{\nu,j,t} = \phi n_t + E_t \left[\tilde{\psi}_{t+1} n_{\nu,j,t+1} \right] \tag{D.2}$$

where $\tilde{\psi}_t = \beta \frac{c_{t-1}}{c_t} \psi_t$, subject to the evolution of net worth[4]

$$n_{\nu,j,t+1} = R_{k,t+1} Q^k_t k_t + \frac{m_{\nu,j,t}}{\pi_{t+1}} + \frac{R^j_{b,t+1}}{\pi_{t+1}} Q^j_t b_{\nu,j,t} - \frac{R^d_t}{\pi_{t+1}} d_{\nu,j,t} - \frac{R^F_t}{\pi_{t+1}} Q^F_t f_{\nu,j,t} \tag{D.3}$$

and the constraints

$$\begin{aligned}
&(\mu^{BC}_{\nu,j,t}): && d_{\nu,j,t} + Q^F_t f_{\nu,j,t} + n_t - \left(Q^k_t k_{\nu,j,t} + Q^j_t b_{\nu,j,t} + m_{\nu,j,t} + \phi n_t \right) && \geq 0 && \text{(D.4)}\\
&(\mu^{RA}_{\nu,j,t}): && v_{\nu,j,t} - \lambda \left(Q^k_t k_{\nu,j,t} + Q^j_t b_{\nu,j,t} + m_{\nu,j,t} \right) && \geq 0 && \text{(D.5)}\\
&(\mu^{F}_{\nu,j,t}): && f_{\nu,j,t} && \geq 0 && \text{(D.6)}\\
&(\mu^{M}_{\nu,j,t}): && m_{\nu,j,t} && \geq 0 && \text{(D.7)}\\
&(\mu^{C}_{\nu,j,t}): && Q^j_t \left(b_{\nu,j,t} - b^F_{\nu,j,t} \right) && \geq 0 && \text{(D.8)}\\
&(\mu^{CC}_{\nu,j,t}): && \eta_t Q^j_t b^F_{\nu,j,t} - f_{\nu,j,t} && \geq 0 && \text{(D.9)}
\end{aligned}$$

[4]Notice that the pricing kernel, $\tilde{\psi}_t$, is the same for all banks. This is because they value a unit of net worth the same way because all banks face the same distribution for their type at $t + 1$.

where the variable included in brackets on the left of each constraint denotes the lagrangean multiplier associated to it.

Unconnected banks located in either region j face in addition the afternoon constraint:

$$(\mu_{u,j,t}): \qquad m_{u,j,t} + \tilde{\eta}_t^j Q_t \left(b_t - b^F_{u,j,t} \right) - \omega^{max} d_{u,j,t} \quad \geq 0 \tag{D.10}$$

Note that we no longer feature the constraint

$$\left(\mu^B_{u,j,t}\right): \qquad Q^j_t b_{u,j,t} \quad \geq 0 \tag{D.11}$$

Equation (D.6) and (D.9) imply that $b^F_{u,j,t} \geq 0$. But then, with (D.8), we also get $b_{u,j,t} \geq 0$.

The FOCs for unconnected banks where $j \in \{S, N\}$ are:

$$\frac{\partial}{\partial k_{u,j,t}}: \quad \left(1 + \mu^{RA}_{u,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R_{k,t+1}\right] \quad = \mu^{BC}_{u,j,t} + \lambda \mu^{RA}_{u,j,t} \tag{D.12}$$

$$\frac{1}{Q^j_t}\frac{\partial}{\partial b_{u,j,t}}: \quad \left(1 + \mu^{RA}_{u,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^j_{b,t+1}\right] \quad = \mu^{BC}_{u,j,t} + \lambda \mu^{RA}_{u,j,t} - \mu^{C}_{u,j,t} - \tilde{\eta}^j_t \mu_{u,j,t} \tag{D.13}$$

$$\frac{\partial}{\partial m_{u,j,t}}: \quad \left(1 + \mu^{RA}_{u,j,t}\right) E_t \left[\tilde{\psi}_{t+1}\right] \quad = \mu^{BC}_{u,j,t} + \lambda \mu^{RA}_{u,j,t} - \mu_{u,j,t} - \mu^{M}_{u,j,t} \tag{D.14}$$

$$(-1) * \frac{\partial}{\partial d_{u,j,t}}: \quad \left(1 + \mu^{RA}_{u,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^d_t\right] \quad = \mu^{BC}_{u,j,t} - \omega^{max} \mu_{u,j,t} \tag{D.15}$$

$$(-1) * \frac{1}{Q^F_t}\frac{\partial}{\partial f_{u,j,t}}: \quad \left(1 + \mu^{RA}_{u,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^F_t\right] \quad = \mu^{BC}_{u,j,t} - \frac{\mu^{CC}_{u,j,t}}{Q^F_t} + \frac{\mu^{F}_{u,j,t}}{Q^F_t} \tag{D.16}$$

$$\frac{1}{Q^j_t}\frac{\partial}{\partial b^F_{u,j,t}}: \quad \mu^{CC}_{u,j,t}\eta \quad = \mu^{C}_{u,j,t} + \tilde{\eta}^j_t \mu_{u,j,t} \tag{D.17}$$

The FOCs for connected banks are:

$$\frac{\partial}{\partial k_{c,j,t}}: \quad \left(1 + \mu^{RA}_{c,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R_{k,t+1}\right] \quad = \mu^{BC}_{c,j,t} + \lambda \mu^{RA}_{c,j,t} \tag{D.18}$$

$$\frac{1}{Q^j_t}\frac{\partial}{\partial b_{c,j,t}}: \quad \left(1 + \mu^{RA}_{c,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^j_{b,t+1}\right] \quad = \mu^{BC}_{c,j,t} + \lambda \mu^{RA}_{c,j,t} - \mu^{C}_{c,j,t} \tag{D.19}$$

$$\frac{\partial}{\partial m_{c,j,t}}: \quad \left(1 + \mu^{RA}_{c,j,t}\right) E_t \left[\tilde{\psi}_{t+1}\right] \quad = \mu^{BC}_{c,j,t} + \lambda \mu^{RA}_{c,j,t} - \mu^{M}_{c,j,t} \tag{D.20}$$

$$(-1) * \frac{\partial}{\partial d_{c,j,t}}: \quad \left(1 + \mu^{RA}_{c,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^d_t\right] \quad = \mu^{BC}_{c,j,t} \tag{D.21}$$

$$(-1) * \frac{1}{Q^F_t}\frac{\partial}{\partial f_{c,j,t}}: \quad \left(1 + \mu^{RA}_{c,j,t}\right) E_t \left[\tilde{\psi}_{t+1} R^F_t\right] \quad = \mu^{BC}_{c,j,t} - \frac{\mu^{CC}_{c,j,t}}{Q^F_t} + \frac{\mu^{F}_{c,j,t}}{Q^F_t} \tag{D.22}$$

$$\frac{1}{Q^j_t}\frac{\partial}{\partial b^F_{c,j,t}}: \quad \mu^{CC}_{c,j,t}\eta \quad = \mu^{C}_{c,j,t} \tag{D.23}$$

The complementary slackness conditions for each (ν, j) combination are

$$\mu^F_{\nu,j,t} f_{\nu,j,t} = 0 \tag{D.24}$$

$$\mu^M_{\nu,j,t} m_{\nu,j,t} = 0 \tag{D.25}$$

$$\mu^C_{\nu,j,t} \left(b_{\nu,j,t} - b^F_{\nu,j,t}\right) = 0 \tag{D.26}$$

$$\mu^{RA}_{\nu,j,t} \left[\phi n_t + \tilde{v}_{\nu,j,t} - \lambda \left(Q^k_t k_{\nu,j,t} + Q^j_t b_{\nu,j,t} + m_{\nu,j,t}\right)\right] = 0 \tag{D.27}$$

and for each location j, for unconnected banks

$$\mu_{u,j,t} \left[\omega^{\max} D_{u,j,t} - M_{u,j,t} - \widetilde{\eta}^j_t Q^j_t \left(B_{u,j,t} - B^F_{u,j,t}\right)\right] = 0.$$

E Equilibrium

Defining the equilibrium requires us to firstly define some aggregate variables. As argued in section 4.1, it suffices for us to look at the decision problem of the average region-type bank. Then, to move from these averages to economy-wide aggregates, for capital:

$$k_t = \xi_{c,t} k_{c,t} + \xi_{u,t}(1 - s_N) k_{u,S,t} + \xi_{u,t} s_N k_{u,N,t} \tag{E.1}$$

where to get aggregate capital we scale each region-type average bank by their mass relative to the mass of banks on aggregate. We then do the same for $b_t, b_{t,\gamma}, f_t, d_t$ and m_t. This allows us to proceed to the equilibrium.

An equilibrium is a vector of sequences such that when:

1. Given $P_t, \tau_t, W_t, R^d_{t-1}, N_t$, the representative household chooses $c_t > 0, h_t > 0, D^h_t \geq 0, M^h_t \geq 0$ to maximise lifetime utility subject to their budget constraint (C.1)

2. Final good firms choose capital and labor to maximize their expected profits from production, which makes use of the technology (3)

3. Given capital prices Q^k_t, capital-producing firms decide on how much investment i_t to make by maximising profits (4)

4. Given the paths for the endogenous variables c_t, h_t, r_t, P_t, Q^j_t, Q^F_t, η_t, and exogenous sequence for $\widetilde{\eta}^j_t$, the average region-type bank choose $k_{\nu,j,t}$, $b_{\nu,j,t}$, $b^F_{\nu,j,t}$, $f_{\nu,j,t}$, $d_{\nu,j,t}$, $m_{\nu,j,t}$ to maximize its value function, with the full problem described in appendix D

5. The central bank chooses money supply $\overline{M}_t$ from (11), the haircut parameter η_t, the discount factor on central bank funds Q^F_t, constant real bond holdings b^C, as well as the seignorage payments S_t to satisfy the budget constraint (13)

6. The government in each region chooses a rule for bond issuances following (F.19), a constant government spending level $g^\star$ and chooses the proportional tax rate τ_t to satisfy the budget constraint (F.23) given lump-sum transfers

7. The foreign sector demands bonds in each region from demand function (21), resulting in a claim on domestic goods c_t^w to satisfy the budget constraint in (22)

8. The goods, capital and asset markets clear

$$c_t + g_t + i_t + c_t^w = y_t \tag{E.2}$$

$$k_t = (1-\delta)\, k_{t-1} + \Phi\left(\frac{i_t}{k_{t-1}}\right) k_{t-1} \tag{E.3}$$

$$\bar{b}_{N,t} = b_{N,t} + b_{N,t}^C + b_{N,t}^w \tag{E.4}$$

$$\bar{b}_{S,t} = b_{S,t} + b_{S,t}^C + b_{S,t}^w \tag{E.5}$$

$$\overline{f}_t = f_t \tag{E.6}$$

$$d_t^h = d_t \tag{E.7}$$

$$\overline{M}_t = M_t + M_t^h \tag{E.8}$$

F Dynamic System of Equations

Here we describe the full system of equations that characterizes the model dynamics. There are 90 variables and 91 equations. One equation is redundant by the Walras law, e.g. the goods market clearing condition (F.30).

The variables are (without time subscript)

$$\left\{\begin{array}{c} y, k, c, c^w, l, d, n, m^h, b_S^w, b_N^w, f, m, \bar{v}, \bar{b}, \tau, T_N, T_S \\ \psi, \tilde{\psi}, w, r, Q^S, Q^N, Q^F, r^S, R^N, R^d, R^k, \pi, I, s, \overline{f}, \overline{m}, \pi^e, Q^k \end{array}\right\}$$

plus

$$\left\{k_{u,S}, m_{u,S}, f_{u,S}, b_{u,S}, b_{u,S}^F, d_{u,S}, n_{u,S}, v_{u,S}, \widetilde{v}_{u,S}, \mu_{u,S}^F, \mu_{u,S}^M, \mu_{u,S}^C, \mu_{u,S}^{RA}, \mu_{u,S}^{BC}, \mu_{u,S}^{CC}, \mu_{u,S}\right\},$$
$$\left\{k_{u,N}, m_{u,N}, f_{u,N}, b_{u,N}, b_{u,N}^F, d_{u,N}, n_{u,N}, v_{u,N}, \widetilde{v}_{u,N}, \mu_{u,N}^F, \mu_{u,N}^M, \mu_{u,N}^C, \mu_{u,N}^{RA}, \mu_{u,N}^{BC}, \mu_{u,N}^{CC}, \mu_{u,N}\right\},$$
$$\{k_u, m_u, f_u, d_u, v_u, n_u\}$$
$$\left\{k_c, m_c, d_c, n_c, v_c, \widetilde{v}_c, \mu_c^M, \mu_c^{RA}, \mu_c^{BC}\right\}$$

plus the value of the three monetary policy instruments

$$R^F, b^C, \eta$$

and the rule for government spending and debt increase,

$$\bar{b}^{\Delta}, g$$

and the exogenous variables

$$\xi, \tilde{\eta}^{S}, \tilde{\eta}^{N}.$$

The dynamics is characterized by the equilibrium conditions listed below.

F.1 Households and firms

For households, the first order conditions over bonds, labour and money are:

$$1 = \beta E_t \left[\frac{c_t}{c_{t+1}} \frac{R_t^d}{\pi_{t+1}} \right] \tag{F.1}$$

$$c_t h_t^{\zeta} = (1-\tau_t)\, w_t \tag{F.2}$$

$$\frac{c_t}{\chi m_t^h} = \frac{R_t^d - 1}{R_t^d} \tag{F.3}$$

The budget constraint is

$$c_t + m_t^h + d_t = \frac{m_{t-1}^h}{\pi_t} + R_{t-1}^d \frac{d_{t-1}}{\pi_t} + (1-\tau_t) w_t h_t + \phi n_t \tag{F.4}$$

First-order conditions arising from the problem of the final good firms are

$$y_t = k_{t-1}^{\theta} h_t^{1-\theta}, \tag{F.5}$$

$$w_t h_t = (1-\theta)\ y_t, \tag{F.6}$$

$$r_t k_{t-1} = \theta y_t, \tag{F.7}$$

$$k_t = (1-\delta)\, k_{t-1} + I_t \tag{F.8}$$

$$R_{k,t} = \frac{Q_t^k}{Q_{t-1}^k} (r_t + 1 - \delta) \tag{F.9}$$

The first-order condition for the capital-producing firms equals:

$$Q_t^k = \left(\frac{i_t}{\delta k_{t-1}} \right)^{\zeta} \tag{F.10}$$

F.2 Central Bank

The money supply rule is given by

$$\bar{m}_t = \bar{m}_{t-1} + Q_{f,t}\bar{f}_t - \frac{R^F_{t-1}}{\pi_t}Q_{f,t-1}\bar{f}_{t-1} \tag{F.11}$$

We define a rule over the interest rate charged on central bank funding,

$$R^F_t = \left(R^F\right)^\star \tag{F.12}$$

The rule on bond purchases is:

$$b^c_t = (b^c)^* \tag{F.13}$$

The haircut applies to central bank funding is:

$$\eta_t \quad = \quad \eta^* \tag{F.14}$$

The value of η^* differs depending on the policy regime. Under CB Policy, $\eta^* = 0$, whereas under CO Policy $\eta^* = 0.97$.

The central bank budget constraint is

$$\begin{aligned} s_t = &\left(\frac{R^F_{t-1}}{\pi_t}\right) Q^F_{t-1}\bar{f}_{t-1} + \left[s_N \left(\frac{R^N_t}{\pi_t}\right) Q^N_{t-1} + (1-s_N)\left(\frac{R^S_t}{\pi_t}\right) Q^S_{t-1}\right] b^C_{t-1} \\ &- \left(\frac{1}{\pi_t}\right)\bar{m}_{t-1} + \bar{m}_t - Q^F_t\bar{f}_t - \left[s_N Q^N_t + (1-s_N)Q^S_t\right] b^C_t \end{aligned} \tag{F.15}$$

with returns defined as

$$R^N_t = \frac{\kappa + (1-\kappa)Q^N_t}{Q^N_{t-1}} \tag{F.16}$$

$$R^S_t = \frac{\kappa + (1-\kappa)Q^S_t}{Q^S_{t-1}} \tag{F.17}$$

$$R^F_t = 1/Q^F_t \tag{F.18}$$

F.3 Government

Each region j is of size s_j. Bond issuance is the same in each region, adjusted for size, so that $\bar{B}_{j,t} = s_j\bar{B}_t$. Government expenditure is also the same adjusted for size i.e. $g_{j,t} = s_j g_t$. On aggregate, we have rules

$$\bar{b}_t^{\Delta} = b^* - (1-\kappa)\frac{\bar{b}_{t-1}}{\pi_t} \tag{F.19}$$
$$g_t = g^* \tag{F.20}$$

where, as a result, we have the following evolution of bond holdings:

$$\bar{b}_t = (1-\kappa)\frac{\bar{b}_{t-1}}{\pi_t} + \bar{b}_t^{\Delta} \tag{F.21}$$

The budget constraint for the government in region N is

$$P_t s_N g^* + \kappa \overline{B}_{N,t-1} = s_j \tau_t W_t h_t + Q_t^N \Delta \overline{B}_{N,t} + s_N S_t + T_{N,t}, \tag{F.22}$$

while for region S it is

$$P_t s_S g^* + \kappa \overline{B}_{N,t-1} = s_S \tau_t W_t h_t + Q_t^S \Delta \overline{B}_{S,t} + s_S S_t + T_{S,t}, \tag{F.23}$$

where the cross-region transfers net out to zero,

$$T_{N,t} + T_{S,t} = 0 \tag{F.24}$$

This implies the following aggregate government budget constraint

$$g_t + \kappa\frac{\bar{b}_{t-1}}{\pi_t}\tau_t w_t h_t + \left[s_N Q_t^N + (1-s_N)Q_t^S\right]\bar{b}_t^{\Delta} + s_t$$

F.4 Price Setting

Prices are determined one period in advance:

$$\pi_t = \pi_{t-1}^e \tag{F.25}$$

F.5 Market Clearance

$$\overline{f}_t = f_t \tag{F.26}$$
$$\overline{m}_t = m_t + m_t^h \tag{F.27}$$
$$s_N \bar{b}_t = (1-\xi_t)s_N b_{u,N,t} + b_{u,N,t}^w + s_N b_t^C \tag{F.28}$$
$$(1-s_N)\bar{b}_t = (1-\xi_t)(1-s_N)b_{u,S,t} + b_{u,S,t}^w + (1-s_N)b_t^C \tag{F.29}$$
$$y_t = c_t + c_t^w + g_t + I_t \tag{F.30}$$

where, as remarked at the beginning of this section, the last equation can be dropped per Walras' law.

F.6 Banks

Common conditions to c, $\{u, N\}$ and $\{u, S\}$ banks:

$$\bar{v}_t = \psi_t n_t \tag{F.31}$$
$$\tilde{\psi}_t = \beta \frac{c_{t-1}}{c_t} \psi_t \tag{F.32}$$

Equations for the problem of bank $\{u, N\}$:
The value of the bank before dividend distribution is equal to:

$$v_{u,N,t} = \phi n_t + \tilde{v}_{u,N,t} \tag{F.33}$$

where the value of the bank after dividend distribution is:

$$\tilde{v}_{u,N,t} = E_t \left[\tilde{\psi}_{t+1} n_{u,N,t+1} \right] \tag{F.34}$$

Net worth evolves according to:

$$n_{u,N,t+1} = R_{k,t} Q_t^k k_{u,N,t} + \frac{m_{u,N,t}}{\pi_{t+1}} + \frac{R_{t+1}^N}{\pi_{t+1}} Q_t^S b_{u,N,t} - \frac{R_t^d}{\pi_{t+1}} d_{u,N,t} - \frac{R_t^F}{\pi_{t+1}} Q_t^F f_{u,N,t} \tag{F.35}$$

The following are the corresponding constraints and Kuhn-Tucker conditions arising from solving the problem for the bank of type $\{u, S\}$: the budget constraint (F.36), the leverage constraint (F.37), the afternoon constraint (F.38), the CB funding constraint (F.39), the non-negativity constraints on money, (F.40), and CB funding (F.41), and the constraint on collateral posted to the central bank (F.42):

$$Q_t^k k_{u,N,t} + Q_t^N b_{u,N,t} + m_{u,N,t} - (1-\phi) n_t - Q_t^F f_{u,N,t} = d_{u,N,t} \tag{F.36}$$
$$\min \left\{ \mu_{u,N,t}^{RA}, v_{u,N,t} - \phi n_t - \lambda \left(Q_t^k k_{u,N,t} + Q_t^N b_{u,N,t} + m_{u,N,t} \right) \right\} = 0 \tag{F.37}$$
$$\min \left\{ \mu_{u,N,t}, m_{u,N,t} + \tilde{\eta}_t^N Q_t^N \left(b_{u,N,t} - b_{u,N,t}^F \right) - \omega^{\max} d_{u,N,t} \right\} = 0 \tag{F.38}$$
$$f_{u,N,t} = \eta_t Q_t^N b_{u,N,t}^F \tag{F.39}$$
$$\min \left\{ \mu_{u,N,t}^F, f_{u,N,t} \right\} = 0 \tag{F.40}$$
$$\min \left\{ \mu_{u,N,t}^M, m_{u,N,t} \right\} = 0 \tag{F.41}$$
$$\min \left\{ \mu_{u,N,t}^C, b_{u,N,t} - b_{u,N,t}^F \right\} = 0 \tag{F.42}$$

Equations for the problem of bank $\{u, S\}$:

The value of the bank before dividend distribution is equal to:

$$v_{u,S,t} \quad = \quad \phi n_t + \tilde{v}_{u,S,t} \tag{F.43}$$

where the value of the bank after dividend distribution is:

$$\tilde{v}_{u,S,t} \quad = \quad E_t\left[\tilde{\psi}_{t+1} n_{u,S,t+1}\right] \tag{F.44}$$

and net worth evolves according to:

$$n_{u,S,t+1} \quad = \quad R_{k,t} Q_t^k k_{u,S,t} + \frac{m_{u,S,t}}{\pi_{t+1}} + \frac{R_{t+1}^S}{\pi_{t+1}} Q_t^S b_{u,S,t} - \frac{R_t^d}{\pi_{t+1}} d_{u,S,t} - \frac{R_t^F}{\pi_{t+1}} Q_t^F f_{u,S,t} \tag{F.45}$$

The following are the corresponding constraints and Kuhn-Tucker conditions arising from solving the problem for the bank of type $\{u, S\}$: the budget constraint (F.46), the leverage constraint (F.47), the afternoon constraint (F.48), the CB funding constraint (F.49), the non-negativity constraints on money, (F.50), and CB funding (F.51), and the constraint on collateral posted to the central bank (F.52):

$$Q_t^k k_{u,S,t} + Q_t^S b_{u,S,t} + m_{u,S,t} - (1-\phi) n_t - Q_t^F f_{u,S,t} \quad = \quad d_{u,S,t} \tag{F.46}$$

$$\min\left\{\mu_{u,S,t}^{RA}, v_{u,S,t} - \phi n_t - \lambda\left(Q_t^k k_{u,S,t} + Q_t^S b_{u,S,t} + m_{u,S,t}\right)\right\} \quad = \quad 0 \tag{F.47}$$

$$\min\left\{\mu_{u,S,t}, m_{u,S,t} + \widetilde{\eta}_t^S Q_t^S \left(b_{u,S,t} - b_{u,S,t}^F\right) - \omega^{\max} d_{u,S,t}\right\} \quad = \quad 0 \tag{F.48}$$

$$f_{u,S,t} \quad = \quad \eta_t Q_t^S b_{u,S,t}^F \tag{F.49}$$

$$\min\left\{\mu_{u,S,t}^F, f_{u,S,t}\right\} \quad = \quad 0 \tag{F.50}$$

$$\min\left\{\mu_{u,S,t}^M, m_{u,S,t}\right\} \quad = \quad 0 \tag{F.51}$$

$$\min\left\{\mu_{u,S,t}^C, b_{u,S,t} - b_{u,S,t}^F\right\} \quad = \quad 0 \tag{F.52}$$

Equations for the problem of bank c:

This bank type never has an incentive to hold bonds. The following exposition is thus simplified. The value of the bank before dividend distribution is equal to:

$$v_{c,t} \quad = \quad \phi n_t + \tilde{v}_{c,t} \tag{F.53}$$

where the value of the bank after dividend distribution is:

$$\tilde{v}_{c,t} \quad = \quad E_t\left[\tilde{\psi}_{t+1} n_{c,t+1}\right] \tag{F.54}$$

Net worth evolves according to:

$$n_{c,t+1} = R_{k,t+1}Q_t^k k_{c,t} + \frac{m_{c,t}}{\pi_{t+1}} - \frac{R_t^d}{\pi_{t+1}} d_{c,t} \tag{F.55}$$

The following are the corresponding constraints and Kuhn-Tucker conditions arising from solving the problem for the bank of type c: the budget constraint (F.56), the leverage constraint (F.57), and the non-negativity constraints on money, (F.58):

$$Q_t^k k_{c,t} + m_{c,t} - (1-\phi)n_t = d_{c,t} \tag{F.56}$$

$$\min\left\{\mu_{c,t}^{RA}, v_{t,c} - \phi n_t - \lambda\left(Q_t^k k_{c,t} + m_{c,t}\right)\right\} = 0 \tag{F.57}$$

$$\min\left\{\mu_{c,t}^{M}, m_{c,t}\right\} = 0 \tag{F.58}$$

First Order Conditions for Banks $\{u, N\}$ **:**

Here we have the first order conditions for unconnected banks in capital (F.59), bonds (F.60), money (F.61), deposits (F.62), CB funding (F.63) and CB collateral-posting (F.64):

$$(1+\mu_{u,N,t}^{RA})E_t[\tilde{\psi}_{t+1}R_{k,t+1}] = \mu_{u,N,t}^{BC} + \lambda\mu_{u,N,t}^{RA} \tag{F.59}$$

$$(1+\mu_{u,N,t}^{RA})E_t\left[\tilde{\psi}_{t+1}\frac{R_{t+1}^N}{\pi_{t+1}}\right] = \mu_{u,N,t}^{BC} + \lambda\mu_{u,N,t}^{RA} - \mu_{u,N,t}^{C} - \tilde{\eta}_t^N\mu_{u,N,t} \tag{F.60}$$

$$(1+\mu_{u,N,t}^{RA})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right] = \mu_{u,N,t}^{BC} + \lambda\mu_{u,N,t}^{RA} - \mu_{u,N,t} - \mu_{u,N,t}^{M} \tag{F.61}$$

$$(1+\mu_{u,N,t}^{RA})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right]R_t^d = \mu_{u,N,t}^{BC} - \omega^{\max}\mu_{u,N,t} \tag{F.62}$$

$$(1+\mu_{u,N,t}^{RA})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right]R_t^F = \mu_{u,N,t}^{BC} - \frac{\mu_{u,N,t}^{CC}}{Q_t^F} + \frac{\mu_{u,N,t}^{F}}{Q_t^F} \tag{F.63}$$

$$\mu_{u,N,t}^{CC}\eta = \mu_{u,N,t}^{C} + \tilde{\eta}_t^N\mu_{u,N,t} \tag{F.64}$$

First Order Conditions for Banks $\{u, S\}$**:**

Here we have the first order conditions for unconnected banks in capital (F.65), bonds (F.66), money (F.67), deposits (F.68), CB funding (F.69) and CB collateral-posting (F.70):

$$(1+\mu^{RA}_{u,S,t})E_t[\tilde{\psi}_{t+1}R_{k,t+1}] = \mu^{BC}_{u,S,t}+\lambda\mu^{RA}_{u,S,t} \quad (F.65)$$

$$(1+\mu^{RA}_{u,S,t})E_t\left[\tilde{\psi}_{t+1}\frac{R^S_{t+1}}{\pi_{t+1}}\right] = \mu^{BC}_{u,S,t}+\lambda\mu^{RA}_{u,S,t}-\mu^{C}_{u,S,t}-\tilde{\eta}^S_t\mu_{u,S,t} \quad (F.66)$$

$$(1+\mu^{RA}_{u,S,t})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right] = \mu^{BC}_{u,S,t}+\lambda\mu^{RA}_{u,S,t}-\mu_{u,S,t}-\mu^{M}_{u,S,t} \quad (F.67)$$

$$(1+\mu^{RA}_{u,S,t})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right]R^d_t = \mu^{BC}_{u,S,t}-\omega^{\max}\mu_{u,S,t} \quad (F.68)$$

$$(1+\mu^{RA}_{u,S,t})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right]R^F_t = \mu^{BC}_{u,S,t}-\frac{\mu^{CC}_{u,S,t}}{Q^F_t}+\frac{\mu^{F}_{u,S,t}}{Q^F_t} \quad (F.69)$$

$$\mu^{CC}_{u,S,t}\eta = \mu^{C}_{u,S,t}+\tilde{\eta}^S_t\mu_{u,S,t} \quad (F.70)$$

First-Order Conditions for Banks c:

Here we have the first order conditions for connected banks in capital (F.71) money (F.72) and deposits (F.73):

$$(1+\mu^{RA}_{c,t})E_t[\tilde{\psi}_{t+1}R_{k,t+1}] = \mu^{BC}_{c,t}+\lambda\mu^{RA}_{c,t} \quad (F.71)$$

$$(1+\mu^{RA}_{c,t})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right] = \mu^{BC}_{c,t}+\lambda\mu^{RA}_{c,t}-\mu^{M}_{c,t} \quad (F.72)$$

$$(1+\mu^{RA}_{c,t})E_t\left[\tilde{\psi}_{t+1}\frac{1}{\pi_{t+1}}\right]R^d_t = \mu^{BC}_{c,t} \quad (F.73)$$

Unconnected bank aggregation equations:

$$k_{U,t} = s_N k_{u,N,t}+(1-s_N)k_{u,S,t} \quad (F.74)$$

$$d_{U,t} = s_N d_{u,N,t}+(1-s_N)d_{u,S,t} \quad (F.75)$$

$$f_{U,t} = s_N f_{u,N,t}+(1-s_N)f_{u,S,t} \quad (F.76)$$

$$m_{U,t} = s_N m_{u,N,t}+(1-s_N)m_{u,S,t} \quad (F.77)$$

$$v_{U,t} = s_N v_{u,N,t}+(1-s_N)v_{u,S,t} \quad (F.78)$$

$$n_{U,t} = s_N n_{u,N,t}+(1-s_N)n_{u,S,t} \quad (F.79)$$

Bank aggregation equations:

$$k_t = \xi_t k_{c,t} + (1-\xi_t)k_{u,t} \tag{F.80}$$

$$d_t = \xi_t d_{c,t} + (1-\xi_t)d_{u,t} \tag{F.81}$$

$$f_t = (1-\xi_t)f_{u,t} \tag{F.82}$$

$$m_t = \xi_t m_{c,t} + (1-\xi_t)m_{u,t} \tag{F.83}$$

$$\bar{v}_t = \xi_t v_{c,t} + (1-\xi_t)v_{u,t} \tag{F.84}$$

$$n_t = \xi_{t-1} n_{c,t} + (1-\xi_{t-1})n_{u,t} \tag{F.85}$$

Exogenous processes:

The parameters that measure connectedness and private bank haircuts follow the processes:

$$\frac{\xi_t}{\xi^\star} = \left(\frac{\xi_{t-1}}{\xi^\star}\right)^{(1-\rho_\xi)} \exp(\epsilon_{\xi,t}) \tag{F.86}$$

$$\frac{\tilde{\eta}_t^S}{\tilde{\eta}^\star} = \left(\frac{\tilde{\eta}_{t-1}^S}{\tilde{\eta}^\star}\right)^{(1-\rho_{\tilde{\eta},1})} \left(\frac{\tilde{\eta}_{t-2}^S}{\tilde{\eta}^\star}\right)^{(1-\rho_{\tilde{\eta},2})} \exp(\epsilon_{\tilde{\eta}_t^S}) \tag{F.87}$$

$$\tilde{\eta}_t^N = \tilde{\eta}^\star \tag{F.88}$$

F.7 Rest of the world

Foreign bond demand functions are

$$b_{N,t}^w = s_N \alpha \left(1 + \frac{1}{\varrho}\log\left(\frac{E\left[R_{t+1}^N/\pi_{t+1}\right]}{r^N}\right)\right) \tag{F.89}$$

$$b_{S,t}^w = (1-s_N) \alpha \left(1 + \frac{1}{\varrho}\log\left(\frac{E\left[R_{t+1}^S/\pi_{t+1}\right]}{r^S}\right)\right) \tag{F.90}$$

where r^N, r^S are the real rates of return on bonds in the baseline calibrated steady state.[5]

The foreign sector satisfies the budget constraint

$$Q_t^N b_{N,t}^w + Q_t^S b_{S,t}^w + c_t^w = \frac{R_t^N}{\pi_t} Q_{t-1}^N b_{N,t-1}^w + \frac{R_t^S}{\pi_t} Q_{t-1}^S b_{S,t-1}^w. \tag{F.91}$$

G Collateral premium

Combine the first-order conditions of an unconnected bank $\nu = u$ located in γ with respect to capital and bonds to get

$$\left(1+\mu_{\nu,j,t}^{RA}\right)\tilde{\psi}_{t+1}\left(R_{t+1}^k - R_{b,t+1}^j\right) = \mu_{\nu,j,t}^C + \mu_{\nu,j,t}\widetilde{\eta}_t^j \tag{G.1}$$

[5] In the Baseline calibration, $r^N = r^S$.

Since $\mu^C_{\nu,j,t} \geq 0$, $\mu^{RA}_{\nu,j,t} \geq 0$, $\mu_{\nu,j,t} \geq 0$, and $\tilde{\psi}_{t+1} > 0$, it must be that $\left(R^k_{t+1} - R^j_{b,t+1}\right) \geq 0$.

We show that the collateral premium is strictly positive if the afternoon constraint is binding or unconnected banks are collateral-constrained in their borrowing from the central bank. First, if unconnected banks are constrained in the afternoon, $\mu_{\nu,j,t} > 0$. It follows that $\left(R^k_{t+1} - R^j_{b,t+1}\right) > 0$. Second, if unconnected banks are collateral-constrained at the central bank, $\mu^C_{\nu,j,t} > 0$ and the same conclusion follows.

H Proof of Proposition 1

Consider the equilibrium for the parameters indexed by A. Consider an individual bank and recall its budget constraint (dropping subscript i)

$$n_t = \phi n_t + k_t + Q^j_t b_t + m_t - d_t \tag{H.1}$$

where the portfolio choices and returns result in the net worth n_{t+1} for the next period,

$$n_{t+1} = R_{k,t+1} k_t + \frac{m_t}{\pi_{t+1}} + \frac{R^j_{t+1}}{\pi_{t+1}} Q^j_t b_t - \frac{R^d_t}{\pi_{t+1}} d_t \tag{H.2}$$

Given no aggregate uncertainty, banks simply want to maximize next period's net worth, n_{t+1}, subject to the constraints that they face. For unconnected banks, if they issue an additional unit of deposits next period, they add the following to net worth

$$R_{k,t+1} - \frac{R_{d,t}}{\pi_{t+1}} + \omega^{\max} \max\left\{ \frac{R_{k,t+1} - R^j_{t+1}/\pi_{t+1}}{\tilde{\eta}_t}, R_{k,t+1} - \frac{1}{\pi_{t+1}} \right\} \leq R_{k,t+1} - \frac{R_{d,t}}{\pi_{t+1}} \tag{H.3}$$

where the third term on the left reflects the collateral premium banks pay on bonds or money to back one deposit unit and is non-negative. Connected banks face no afternoon constraint and obtain the net return on the right of the equation (H.3).

Therefore, there must be two cases: either unconnected banks are priced out of issuing deposits, or unconnected banks issue deposits, but the constraint does not bind, and returns on any assets held by unconnected banks are the same as the return on capital. Consider the latter case.

Since there is no leverage constraint, there is, therefore, also an equilibrium, where the deposits together with their corresponding assets are reallocated from the unconnected banks to the connected banks, i.e., where deposits are only issued by connected banks.[6]. This equilibrium has the same aggregate quantities. With zero deposits, the afternoon constraint no longer

[6]Suppose, for example, that unconnected banks hold money, with $m_t \geq d_t$. Then, increase the deposits issued by connected banks by this amount d_t, increase their money holdings by $m_t - d_t$, and decrease the money holdings of unconnected banks by $m_t - d_t$. The budget constraints (H.1) for both types of banks continue to hold. The reshuffling is a solution to their optimization problem, per the remarks made.

matters for the unconnected banks, and thus, the parameters $\left(\xi_t, \tilde{\eta}_t^N, \tilde{\eta}_t^S\right)$ no longer matter for the net worth evolution of the unconnected banks. It is, therefore, also a feasible allocation for the economy with parameters B. It remains to show that it is optimal for unconnected banks in economy B not to issue deposits: it then follows that this allocation is an equilibrium. Hold market prices fixed and suppose there is a solution to the problem of unconnected banks, where they issue positive deposits. By the same argument as above, it then is similarly optimal for connected banks to do so, i.e., the allocation, where unconnected banks do not issue deposits, is also optimal.

I Derivation of Secured Share

This section derives the secured share of interbank markets. For any given bank, when they issue deposits d, they face realized withdrawals of:

$$\hat{\epsilon}\omega^{max}d \qquad \text{s.t.}\hat{\epsilon} \sim U\left[-1,1\right]$$

where $\hat{\epsilon} > 0$ implies withdrawals, and $\hat{\epsilon} < 0$ inflows. $\hat{\epsilon}$ is bounded above by 1 as ω^{max} is the max fraction of withdrawals one receives. We assume $\hat{\epsilon}$ follows a uniform distribution between -1 and 1 i.e. $\hat{\epsilon} \sim U[-1,1]$.

We assume that, for any region-type bank (ν, j), they can cover any deposit withdrawals firstly with reserve holdings, and then subsequently draw from the interbank market The expected volume of interbank funding for a bank of each region-type combination, $f^P_{\nu,j}$, is:

$$\begin{aligned}
f^P_{\nu,j} &= E\left[\hat{\epsilon}\omega^{max}d_{\nu,j} - m_{\nu,j} | \hat{\epsilon}\omega^{max}d_{\nu,j} - m_{\nu,j} > 0\right] Pr\left(\hat{\epsilon}\omega^{max}d_{\nu,j} - m_{\nu,j} > 0\right) \\
&= E\left[\hat{\epsilon}\omega^{max}d_{\nu,j} - m_{\nu,j} | \hat{\epsilon} > \frac{m_{\nu,j}}{\omega^{max}d_{\nu,j}}\right] Pr\left(\hat{\epsilon} > \frac{m_{\nu,j}}{\omega^{max}d_{\nu,j}}\right) \\
&= \left(\frac{\omega^{max}d_{\nu,j} - m_{\nu,j}}{2}\right)\left(1 - \frac{m_{\nu,j}}{\omega^{max}d_{\nu,j}}\right)^2
\end{aligned} \tag{I.1}$$

We know that connected banks draw from unsecured markets while unconnected banks draw from secured markets. The secured share s_{SEC} is therefore:

$$s_{SEC} = \frac{(1-\xi)\left(s_N f^P_{u,N} + (1-s_N)f^P_{u,S}\right)}{\xi\left(s_N f^P_{c,N} + (1-s_N)f^P_{c,S}\right) + (1-\xi)\left(s_N f^P_{u,N} + (1-s_N)f^P_{u,S}\right)} \tag{I.2}$$

where $(f^P_{c,N}, f^P_{c,S}, f^P_{u,N}, f^P_{u,S})$ are defined in equation (I.2) and depend on the portfolio choice made by the respective bank type.

J Steady State Comparative Statics

In order to build up an intuition for the mechanisms that will play an important role in the dynamic responses discussed in the main text, we run a comparative statics exercise where we permanently change the share of unconnected banks in the monetary union $(1-\xi)$ or the haircut on bonds issued in the South $(1-\tilde{\eta}^S)$.

The comparative statics exercise highlights the complex interactions between various occasionally binding constraints of the banks described and analyzed in Section 4, which is a novel feature of our model.

J.1 Comparative statics

Changing share of unconnected banks. We consider first the macroeconomic impact of equally shrinking the unsecured money market segment in both regions, under a CO policy. We do so by permanently shifting the steady-state share of unconnected banks, $1-\xi$, between 0.58 and 0.9. Figure J.2 shows the results.

The solid red line denotes the share of unconnected banks under our benchmark calibration $(1-\xi = 0.58)$. The dashed orange lines indicate the level of $1-\xi$ at which unconnected banks start holding money so that the multiplier μ_u^M becomes zero.

In the calibrated steady state (at the solid red line), the collateral premium on bonds is positive and the afternoon constraint binds for unconnected banks. Indeed, as we prove in Online Appendix F, the collateral premium on bonds is always positive as long as the afternoon constraint binds. The amount of deposits raised by connected and unconnected banks is of a broadly comparable magnitude. Unconnected banks, however, invest less in capital than connected banks, as they need to invest part of the funds in bonds to be pledged in the secured market in the afternoon. At this point, the return on bonds is higher than the return on money (not shown), and unconnected banks choose not to hold money to satisfy their afternoon liquidity needs.

If more banks in the economy are unconnected (moving rightward on the x-axis), a larger number of banks face an afternoon liquidity management constraint, which raises the aggregate demand for bonds and the bond price. In the region where $1-\xi < 0.61$, the amount of bonds held by each unconnected bank, b_u, declines, as more banks need to hold bonds as collateral, and the supply of bonds is fixed. When the share of unconnected banks increases further, i.e., when $1-\xi$ exceeds 0.61, the high price of bonds lowers the return on bonds to the point where it is equalized with the return on money. From this point onward (indicated by the dashed orange lines), unconnected banks also use money to self-insure against afternoon withdrawals.

Although the central bank stands ready to provide collateralized loans, central bank funding is not used because deposit funding is less expensive. Higher demand for money by unconnected banks is accommodated by an increase in the deposit rate, which induces households to reduce their money holdings. Scarce money balances are therefore reallocated from households to unconnected banks. Inflation also rises,[7] which increases the opportunity cost of holding money for unconnected banks and further tightens their afternoon constraint. Unconnected banks respond by reducing their deposit intake and, therefore, investment in capital, exerting upward pressure on the return on capital. As the net worth of unconnected banks declines, and there is an increasing share of those, the aggregate net worth - which is equally distributed to all banks in the morning - declines. This results in a tightening of the run-away constraint of connected banks, which induces them to also reduce their investment in capital and their deposit intake. Therefore, aggregate deposits and capital fall and so does output. The overall decline in output between a steady state with 0.58 share of unconnected banks and that with 0.89 share (pre- to post-2008 average share of secured turnover in total) is around 1.8%.

In sum, reduced access to the unsecured market can reduce investment and output via two channels. First, since unconnected banks need to satisfy liquidity shocks by holding bonds and/or by holding money, it crowds out capital investment. Second, as more banks become unconnected, bonds and money become more scarce, tightening the banks' afternoon constraint. As a consequence, banks raise fewer deposits, invest less in capital, and aggregate output falls.

Changing haircuts on Southern bonds. Next, we analyze the macroeconomic effects of changing collateral value by permanently increasing the private haircut in the South from the benchmark pre-crisis value of 3%, under a CO policy. The results are shown in Figure J.3. The solid red line denotes the secured market haircut under our benchmark calibration ($1-\widetilde{\eta}^S = 0.03$). The dashed orange lines indicate the level of $1-\widetilde{\eta}^S$ at which unconnected banks in the South start holding money so that the multiplier μ_u^M becomes zero. The dashed purple lines indicate the level of $1-\widetilde{\eta}^S$ at which unconnected banks in the South start borrowing from the central bank so that the multiplier μ_u^F becomes zero. The dashed green lines indicate the level of $1-\widetilde{\eta}^S$ at which unconnected banks in the South pledge their entire bond holdings at the central bank and no longer use the secured market.

In the calibrated steady state (at the solid red line), the collateral premium on bonds is positive and the afternoon constraint binds for unconnected banks. At higher haircut levels (moving rightward in the figure), it becomes more difficult for unconnected banks in the South to satisfy their liquidity needs in the secured market because the pledgeable collateral supply has fallen. This drives up the price for bond collateral, the collateral premium, in the South. When haircuts reach 0.06, it becomes optimal for unconnected banks in the South to start holding money as collateral, which helps to ease the shortage. As shown in Figure J.3, as haircuts rise and the collateral shortage intensifies, money holdings rise. Moreover, under CO

[7] This is an artefact of our steady-state analysis in which the Fisher equation holds. An alternative way to think about the adjustment in response to a higher demand for real money balances when the nominal money supply is fixed is that the price level must decrease so that the real money supply increases. That is, increased demand for scarce money balances necessitates deflation. In our setting, however, real money balances remain constant across steady states by assumption, and so demand must be weakened to clear the market, hence the rise in inflation.

policy, banks can access central bank funding as an alternative to deposit funding. The advantage of this source of funding is that haircuts are more favorable, but at the expense of having to use more collateral.[8] When the private haircut rises above 0.27, it becomes advantageous for unconnected banks in the South to substitute deposits for central bank funding.

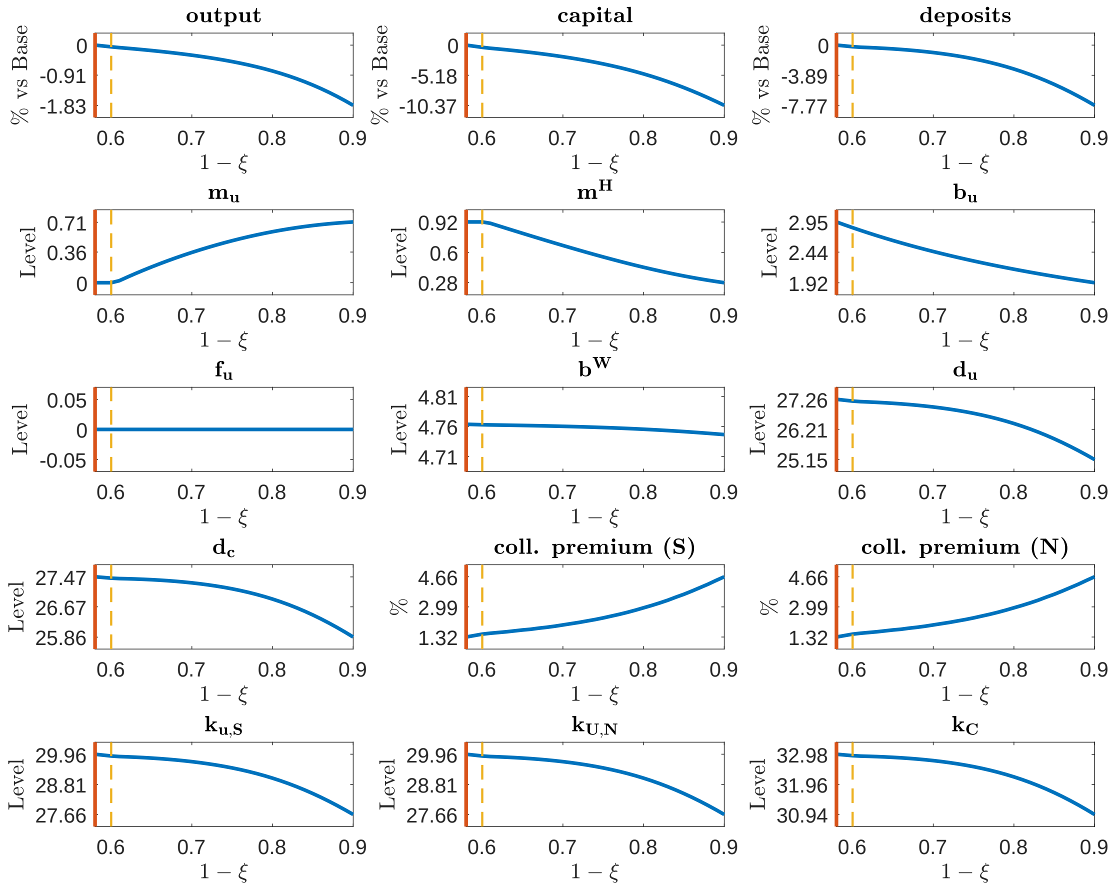
As the central bank provides funding to banks, its balance sheet expands and so does the money supply. Therefore, unconnected banks in the South can further increase their money holdings, without the need for a reallocation of money from households. As there is no need for an increase in the deposit rate, the increase in the collateral premium is very contained, and in fact falls because of the money injection. When the private haircut increases above 0.32 (indicated by the dashed green lines), unconnected banks in the South pledge all their bond collateral at the central bank and stop using the secured market to manage their afternoon liquidity needs, relying solely on money holdings instead. From this point onward, the economy is insulated from further increases in the secured market haircut.

The impact on the real economy is very limited: output falls by 0.15% when private haircuts, $1 - \tilde{\eta}^S$, rise to 0.4. Crucially, this is because there are minimal spillover effects on unconnected banks in the North and on connected banks. In fact, they mainly counteract the reduction in capital holdings of unconnected banks in the South and take advantage of capital risk premia. Unconnected banks in the North have their own collateral holdings whose haircuts $((1 - \tilde{\eta}^N))$ remain unchanged. This segmented collateral market ensures that they don't face the same collateral shortage as the South. Indeed, as seen clearly in Figure J.3, collateral premia in the North are lower than in the South as $1 - \tilde{\eta}^S$ rises. As a result, unconnected banks in the North remain in a strong position to increase their balance sheets and keep the effects on the real economy muted.[9]

[8]Consider the pledgeable value of collateral post-haircut at the central bank and in the private market, respectively. To access 1 unit of central bank funding, a bank needs to post 1 pledgeable unit of collateral, whereas covering deposit funding requires the bank to hold only ω^{max} pledgeable units of collateral, in accordance with the afternoon constraint.

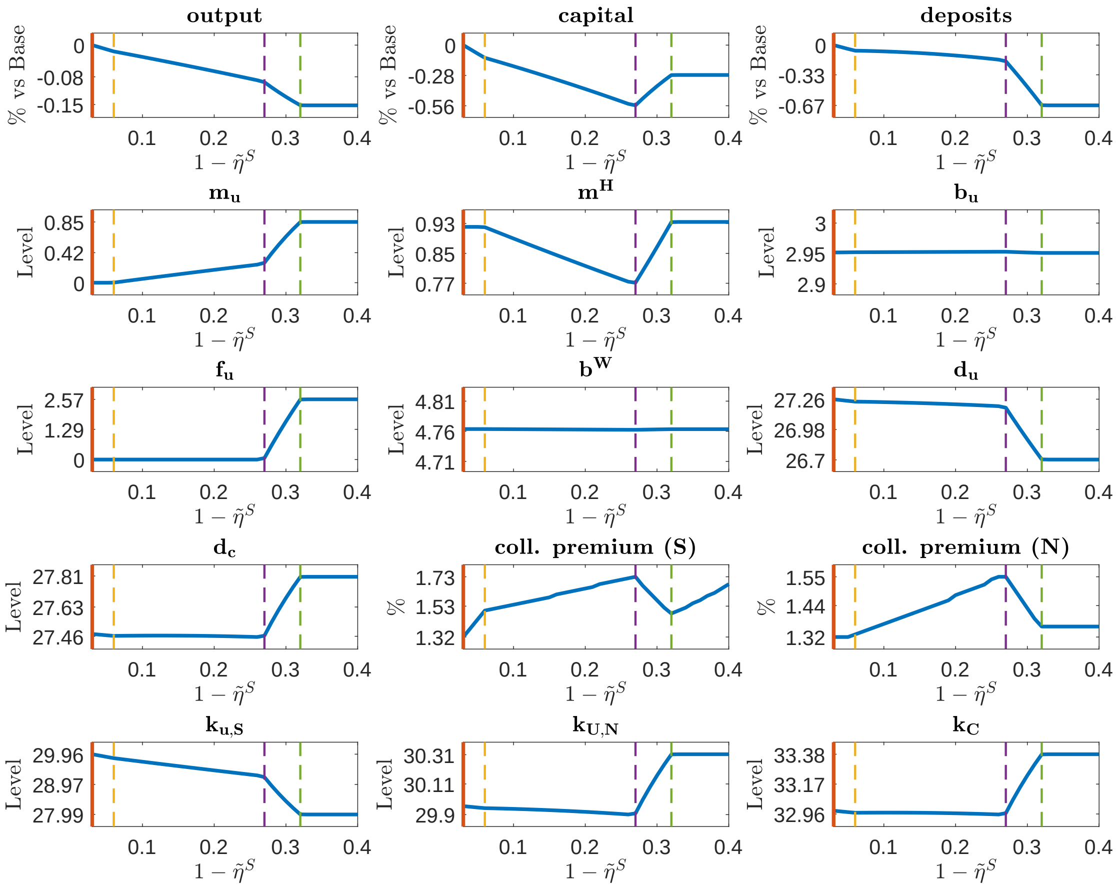
[9]This conclusion would be very different if collateral markets were not segmented. This does not require us to relax the assumption of segmented bond markets. Suppose another type of collateral, in this case money, is held by banks in the North and the South. If collateral in the South experiences higher haircuts, banks in the South experience a scarcity of collateral. This drives up the price for collateral that banks in the South are willing to pay. In equilibrium, this drives up the collateral premium for money, which is the price also faced by banks in the North. In other words, there is a perfect spillover of collateral premia to the North, causing banks to also divest. This significantly increases the negative effects on output.

Figure J.2: steady state Comparative Statics: CO policy; Vary $1 - \xi$



Notes: Red solid lines denote the calibrated steady state. Orange dashed lines denote the share of unconnected banks at which the non-negativity conditions on their cash holdings become slack. First row: output, capital, deposits. Second row: money holdings of unconnected banks, money holdings of households, and bonds held by unconnected banks. Third row: central bank funding taken up by unconnected banks, world bond demand, and deposits issued by unconnected banks. Fourth row: deposits issued by connected banks, and the collateral premium in the North and South (as defined in Section 4.3). Fifth row: capital held by unconnected banks in the South and the North, and connected banks. The y-axis label "% vs Base" means the % difference in the value of the variable relative to the baseline steady state.

Figure J.3: Steady-state comparative statics: CO policy; Vary $1 - \tilde{\eta}$



Notes: Solid red lines denote the calibrated steady state. Dashed orange lines denote the share of unconnected banks at which the non-negativity conditions on their cash holdings become slack. Dashed purple lines denote the share of unconnected banks at which banks draw funding from the central bank. The dashed green lines denote the share of unconnected banks at which unconnected banks no longer secure funding in the private market. First row: output, capital, deposits. Second row: money holdings of unconnected banks, money holdings of households, and bonds held by unconnected banks. Third row: central bank funding taken up by unconnected banks, world bond demand, and deposits issued by unconnected banks. Fourth row: deposits issued by connected banks, and the collateral premium in the North and South (as defined in Section 4.3). Fifth row: capital held by unconnected banks in the South and the North, and connected banks. The y-axis label "% vs Base" means the % difference in the value of the variable relative to the baseline steady state.