Journal of Economic Dynamics & Control 93 (2018) 131–153

Contents lists available at ScienceDirect

Journal of Economic Dynamics & Control

journal homepage: www.elsevier.com/locate/jedc

Interbank markets and bank bailout policies amid a sovereign debt crisis

Aeimit Lakdawala[a], Raoul Minetti[a,*], María Pía Olivero[b]

[a] Department of Economics, Michigan State University, United States
[b] School of Economics, Drexel University, United States

ARTICLE INFO

Article history:
Received 24 January 2018
Accepted 26 January 2018
Available online 6 February 2018

JEL classification:
E32
E44
F44

Keywords:
Sovereign debt
Credit crunch
Interbank markets
International contagion

ABSTRACT

Interbank markets have been at the core of the international transmission of recent financial crises, including the euro area sovereign debt crisis. This paper studies the transmission of shocks in a two-country DSGE model where government bonds are used as collateral in interbank markets. We isolate an “interbank collateral channel” of transmission, which works through banks portfolio allocation between loans and government bonds, the resulting value of banks bond holdings and the tightness of collateral constraints in the interbank market. We find that, while in some scenarios this channel compounds a “bank net worth channel” in amplifying negative shocks, in other scenarios the “interbank collateral channel” can mitigate the effects of shocks. Bank bailout policies financed by government debt can erode this stabilizing effect.

1. Introduction

In the last 20 years or so, a key feature of the EU banking sectors has been the tendency of European banks to hold large amounts of sovereign bonds in their portfolios; of not only their domestic governments, but also of governments of other European countries. Banks of core European countries (e.g., France and Germany) have especially turned into major holders of the sovereign debt of periphery countries, such as Greece, Italy, Portugal and Spain. For example, using data on a sample of banks that provide about 70% of total euro-area lending, Altavilla et al. (2016) find that on average, in the 2007–2015 period, in non-stressed countries of the euro area, banks held about one third of their sovereign bond portfolios in non-domestic government bonds (while in stressed countries, this ratio was lower but still exceeded one sixth).[1]

During the euro area sovereign debt crisis, banks’ exposure to sovereign debts put significant pressure on the financial position of the banking sector, resulting in a large cutback on the amount of credit granted to non-financial corporations. The complex links between sovereign debt dynamics and banks’ intermediation role are still relatively underexplored. Changes in the value of sovereign debt can affect banks’ net worth and capital constraints, thereby influencing the ability of the banking sector to extend credit to firms and households. This “banks’ net worth channel” of transmission has been increasingly investigated in recent years and has been shown to be quantitatively important in the transmission of sovereign

* Corresponding author.
E-mail addresses: aeimit@msu.edu (A. Lakdawala), minetti@msu.edu (R. Minetti), mpo25@drexel.edu (M.P. Olivero).

[1] The stressed countries include Cyprus, Greece, Ireland, Italy, Portugal, Slovenia and Spain; the non-stressed countries include Austria, Belgium, Estonia, Finland, France, Germany, Luxembourg, Malta, the Netherlands, and Slovakia.

https://doi.org/10.1016/j.jedc.2018.01.035
0165-1889/

debt crises. An influential study in this research strand is Gennaioli et al. (2014) who also offer a rationale for why banks optimally hold government bonds (see also Bolton and Jeanne, 2011, Bofondi and Sette, 2012, Bedendo and Colla, 2015, Bocola, 2014, and Basu, 2009, among others). However, changes in the value of sovereign debt can also affect banks' access to liquidity, besides their net-worth position, because government bonds constitute one of the most important forms of collateral pledged by banks in interbank markets. Indeed, it is estimated that around 75 percent of repo transactions in the euro area use government bonds as collateral (Hördahl and King, 2008). The "interbank collateral channel" of transmission can be quantitatively important and yet we still have a limited understanding of its possible role during crises. Further, once we take this channel into account, relevant questions arise naturally about the impact of policy interventions. During the euro area crisis, various governments engaged in bank bailout policies such as provision of guarantees and equity injections. However, to the extent that these policies are financed through issuance of new government debt, they can dilute the safety and acceptability of government bonds as collateral in the interbank market. Put differently, the attempt to directly support the banking sector can backfire via the effect of the bailout policies on banks' access to interbank market liquidity.

In this paper, we aim to study the link between sovereign debt and credit market dynamics through the interbank market. Our emphasis is on the role of sovereign bonds as collateral in the interbank market and on the influence that banks' bond holdings can have on the domestic and international propagation of shocks through their impact on banks' access to interbank market liquidity. A key result of the analysis is that the "interbank collateral channel" can amplify the effects of certain shocks while mitigating the impact of others. Further, depending on the type of shock, this channel can act as a mechanism of both domestic and international propagation or instead exert different effects domestically and abroad.

We posit a standard model of interbank borrowing with two key features (following Gertler and Kiyotaki, 2011) that are empirically motivated. First, an important reason for banks to hold sovereign bonds is for their use as collateral for wholesale funding in interbank markets.[2] We then introduce a collateral constraint that explicitly captures this friction. Second, we build on the observation that a large share of bonds issued by countries in the euro area periphery (Greece, Ireland, Portugal, and Spain) were held by banks in the core (especially France and Germany). This meant that aggregate shocks that affected the value of periphery bonds had consequences not just for the periphery countries but also for core countries through their effect on core banks' balance sheets. Thus, we consider a two-country setting where shocks in the periphery can spill over to the core and vice-versa.

Within this framework, we consider two types of shocks. An important type of shock considered in the literature on financial frictions is a shock that induces exogenous variations in the value of productive capital (see Gertler and Kiyotaki, 2011 and Gertler and Karadi, 2013, among others). As is common in the literature, in our economy this shock tends to erode domestic banks' net worth, thus leading to a contraction in bank lending. In our setting, however, while domestic banks' net worth does fall, bond prices and holdings go up because banks' appetite for government bonds (relative to participation in firms' capital) tends to increase when the negative capital quality shock hits. In turn, the increase in bond prices and holdings has the effect of loosening the borrowing constraints faced by home banks in the interbank market. We label this mechanism a "portfolio switching effect" . Importantly, this effect highlights a potential benefit of banks holding large amounts of sovereign bonds in their portfolios. During the sovereign debt crisis of the euro area banks were often criticized for being responsible for a crowding out of loans to firms. It was often argued that the switch of banks' portfolios towards government bonds during the crisis severely affected credit availability for firms. In our model it turns out that the portfolio switch is instead a mechanism that attenuates the credit contraction of domestic banks, because it boosts collateral values in interbank markets and, hence, banks' access to liquidity, which in turn facilitates credit extension. Interestingly, when we consider the impact of the portfolio switch on the foreign economy, we obtain instead that in our preferred calibration this effect tends to generate international contagion: the price of foreign bonds rises, but the quantity held by foreign banks drops and overall this induces a contraction of collateral values in foreign interbank markets and, hence, of foreign banks' access to liquidity. This, in turn, hinders credit extension in the foreign economy.

We contrast the effects of a capital quality shock with those of a "bond quality" shock. A reduction in the value of sovereign bonds affects bank balance sheets in an adverse manner; the result is a tightening of banks' collateral constraint which limits their ability to borrow in interbank markets. This leads to a drop in funding for the productive sector and ultimately a reduction in output. The implication, consistent with empirical evidence by Gennaioli et al. (2014), is that the more severe are the frictions in the interbank market (making banks hold more bonds), the worse the effect on output of a shock hitting the value of sovereign debt. Note that this effect can arise in banks of a country that is different from the source country of the sovereign debt shock, due to the international transmission. Thus, while following a capital quality shock the interbank collateral channel can act to mitigate the effects of the shock in the domestic economy and at the same time as a mechanism of international contagion, following a bond return shock the interbank collateral channel generates amplification of the shock in both the foreign and the domestic economy, thus exacerbating comovement between the two economies.

As noted, during the euro area crisis, various governments conducted bailout policies aimed at supporting the banking sector. In our model economy, equity injections into the banking sector have a direct stabilizing effect, attenuating the effects of shocks in periphery countries and reducing contagion to countries in the core. We show, however, that, to the extent that this policy is financed by increased government borrowing, it can potentially impair the safety of sovereign

[2] The empirical analysis of Section 2 provides some motivating evidence. For a more detailed discussion, see, for example, Bolton and Jeanne (2011).

bonds and, hence, their acceptability as collateral in the interbank market. The implied lower pledgeability of collateral tends to worsen the frictions faced by banks in the interbank market. As a result, this policy can end up having an adverse effect on banks' access to liquidity that counteracts the portfolio switching effect described above and erodes the direct, stabilizing effect of the policy.

To our knowledge, relatively few papers within the open economy macroeconomics literature look at issues similar to those we investigate. Bolton and Jeanne (2011) (hereafter BJ) do look at interbank markets. They study the transmission of default shocks across financially integrated economies where contagion across countries happens through an integrated banking system that holds bonds and pledges them as collateral in interbank lending. They do so using a stylized 3-period, endowment model economy with exogenous returns to investment. Thus, their setting and the mechanisms they uncover are very different from those we study in our DSGE environment with endogenous investment, output and interest rate spreads. Besides isolating a novel mechanism of amplification or stabilization, we also study an interbank collateral channel in a DSGE setting. This setting is instrumental to understanding under what conditions, and following which type of shocks, the interbank collateral channel acts as an amplifier or stabilizer. Other papers in this literature especially focus on endogenizing governments' default decisions or fiscal policies. Engler and Große Steffen (2016) study the default decision of a government that takes into account the impact of its default on the acceptability of government bonds as collateral. Brutti (2011) develops a model where firms hold government bonds as a reserve of liquidity and the government cannot discriminate between domestic and foreign bond holders in the event of default. In such a context, when aggregate productivity drops, the government has a stronger incentive to default and this amplifies the effect of the shock by reducing private investment.[3] In Niemann and Pichler (2017) government bonds provide collateral and liquidity services and a sovereign default can trigger an extended period of recurrent haircuts on sovereign debt. In their context, the government issues bonds up to the point in which marginal debt has negative welfare effects. Relative to this group of papers, we abstract from governments' default decisions and focus on the working of the interbank collateral channel to disentangle scenarios under which this channel amplifies or mitigates the domestic and international transmission of shocks. In so doing we also reassess bank bailout policies in a setting in which such policies can influence the pledgeability of government bonds as collateral in interbank markets.

The paper is also more broadly related to studies on the interaction between banking and sovereign default through banks' net worth channel. In Guerrieri et al. (2013) (hereafter GIM) and Kollmann et al. (2011) (hereafter KEM)[4] banks hold both government bonds and equity (in order to meet regulatory capital requirements). Since GIM abstract from interbank markets, they cannot study issues related to how banks' ability to tap wholesale funding in interbank markets can transmit sovereign debt problems to the real sector. Introducing interbank markets and accounting for the use of government bonds as collateral in interbank borrowing allows us to identify an "interbank collateral channel" of transmission of shocks, in addition to the "banks' net worth channel" of transmission investigated by GIM. In this strand, the paper is also related to a number of studies on the relationship between banking and sovereign default in closed economies: Basu (2009), Gennaioli et al. (2014),[5] Bocola (2014),[6] and Padilla (2013).[7] These studies do not focus on the role of interbank markets.

Finally, our work is also motivated by the findings of previous empirical studies. Kalemli-Ozcan et al. (2013) document that while the relationship between bilateral banking integration and business cycle synchronization has been historically negative, it has turned positive during the recent 2007–2009 financial crisis. In a nutshell, their point is that during or after a financial crisis, increased banking integration across countries is associated to business cycles being more positively correlated across countries, so that international integration in banking acts more as a destabilizer than as a hedging device across countries. Our story of an internationally integrated banking sector through the use of foreign bonds as collateral in wholesale funding introduces a channel of international contagion of sovereign risk and can therefore contribute to explaining these important facts uncovered by Kalemli-Ozcan et al. (2013).

The rest of the paper is structured as follows. Section 2 provides empirical support for the links that we study in this paper. Section 3 presents the model. Section 4 presents the calibration strategy and the results. Section 5 concludes. The Appendix contains some details on the mathematical derivations. Additional robustness checks and some

[3] Arellano and Bai (2014) develop a multicountry model in which countries borrow from a common lender. The incentive of a country to default rises in response to foreign defaults because the cost of rolling over the debt is higher when other countries default.

[4] Kalemli-Ozcan et al. (2013) also study theoretically the role of banks in international shock transmission, but their banks are not subject to constraints (while borrowers are), and there are no interbank markets.

[5] In Basu (2009), when the government defaults it gains consumption (since some of the debt is held internationally) but it lowers banks' capital. Gennaioli et al. (2014) present a model of endogenous sovereign default where banks hold bonds to store liquidity for future investments. A sovereign default hurts the balance sheet of banks holding government bonds, which in turn hampers financial intermediation. In their framework, better financial institutions allow banks to be more leveraged and therefore more exposed to sovereign risk. As noted, the analysis of Gennaioli, Martin, and Rossi (2014) also provides a rationale for why banks optimally hold government bonds (unlike many other models).

[6] In Bocola (2014), limited contract enforcement gives rise to a constraint on banks' leverage and limits banks' borrowing capacity in retail deposit markets. Differently, we model an interbank market in each country which allows us to study both lending flows in this market and the correlation between sovereign and interbank rates. Second, instead of a leverage constraint in the market for retail deposits, our model introduces a collateral constraint on interbank borrowing.

[7] In Padilla (2013) banks lend to the government and to the corporate sector. When banks are highly exposed to government debt, a sovereign default triggers a credit crunch and output collapse. Padilla (2013) thus provides a mechanism competing with that in Mendoza and Yue (2012) to endogenize default costs. In his work banks' holdings of sovereign debt are pinned down by supply and not by frictions in interbank markets. Therefore, his setup is silent about how default affects financial intermediation through interbank markets, which is the key mechanism in our paper.

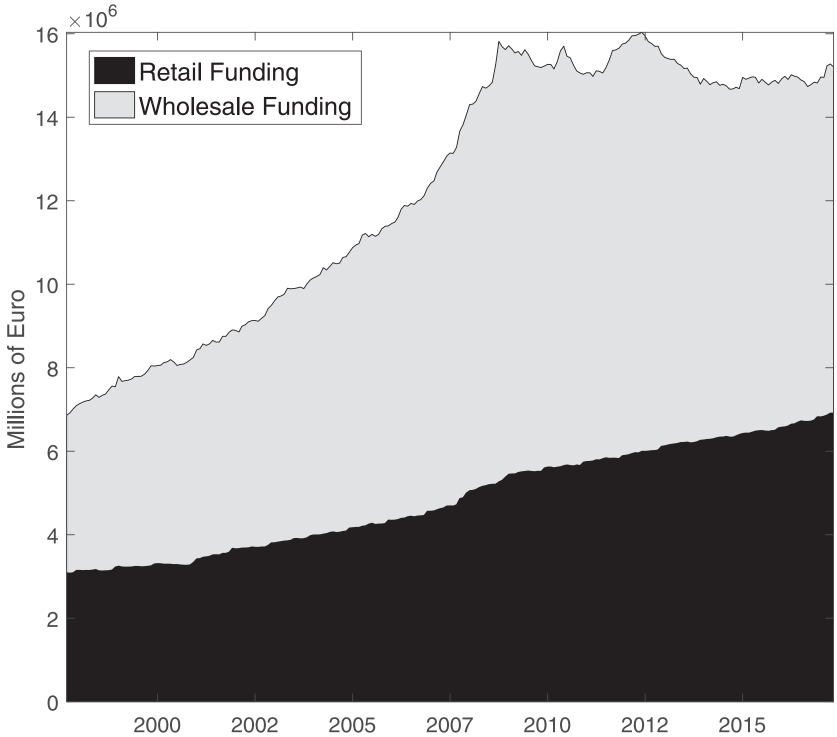

Fig. 1. This figure shows Euro area banks' sources of funding from the MFI Balance Sheet data as reported by the European Central Bank; retail funding in red and wholesale funding in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

details on the data are relegated to the online Appendix (http://www.mariapia-olivero.com/uploads/5/5/5/6/55562983/interbankmarkets-sovereign-irbc-online_appendix.pdf).

2. Empirical motivation

The dependence of European banks on wholesale funding has grown significantly in the last couple of decades. In addition to the traditional source of funding from household deposits, banks have been increasingly reliant on funding from other sectors of the financial system. Fig. 1 shows the breakup of retail vs. wholesale funding for European banks using monetary and financial institutions (MFI) balance sheet data from the European Central Bank. Retail funding is measured as deposits obtained from "Households and non-profit institutions serving households" . Wholesale funding is the sum of deposits by i) monetary financial institutions (MFIs), ii) insurance companies and pension funds (ICPFs) and iii) money-market funds (MMFs). The figure shows that the relative share of wholesale funding has grown steadily from the mid-1990s to the mid-2000s before declining a little in the past decade.

With the growth of wholesale funding, the collateral used by banks to raise this funding took on greater importance as well. As reported by the ECB in the Eurosystem Collateral, government securities are the largest share of eligible marketable assets that can be used for collateral, as shown in the top panel of Fig. 2. In fact, government securities make up roughly half of all banks' marketable assets that can be used for collateral. The bottom panel shows the use of these assets as collateral. Government securities are a significant component of the total, with their share rising from around 18% in 2008 to a little under 30% by 2016. Thus, even after the sovereign crisis episode of 2011–2012, sovereign bonds remain an important collateral instrument for banks. This paper can help understand the effects that banks' sovereign bond holdings have for the transmission and propagation of shocks hitting the euro area through the interbank market.

An important transmission mechanism in the model involves shocks to the sovereign bond market having adverse effects on banks' access to wholesale funding. Fig. 3 attempts to shed light on this mechanism. To capture turbulence in the sovereign bond market in a simple way, we plot yield spreads on sovereign bonds for the major euro area countries relative to the yield on German government bonds (in dashed blue lines). To capture banks' distress and access to wholesale funding we plot two different euro area wide banking system measures. The first one is the spread between the rate at which European banks lend to each other (Euribor rate) and the overnight "risk free" swap OIS rate. This measure (shown in the dashed red line) is meant to capture banks' cost of obtaining wholesale liquidity. The second one is the iTraxx European Senior Financial credit default swap index (shown in the solid black line) meant to capture perceived riskiness of European banks. We have scaled this index by a constant (0.02) for ease of exposition. The figure shows a clear relationship

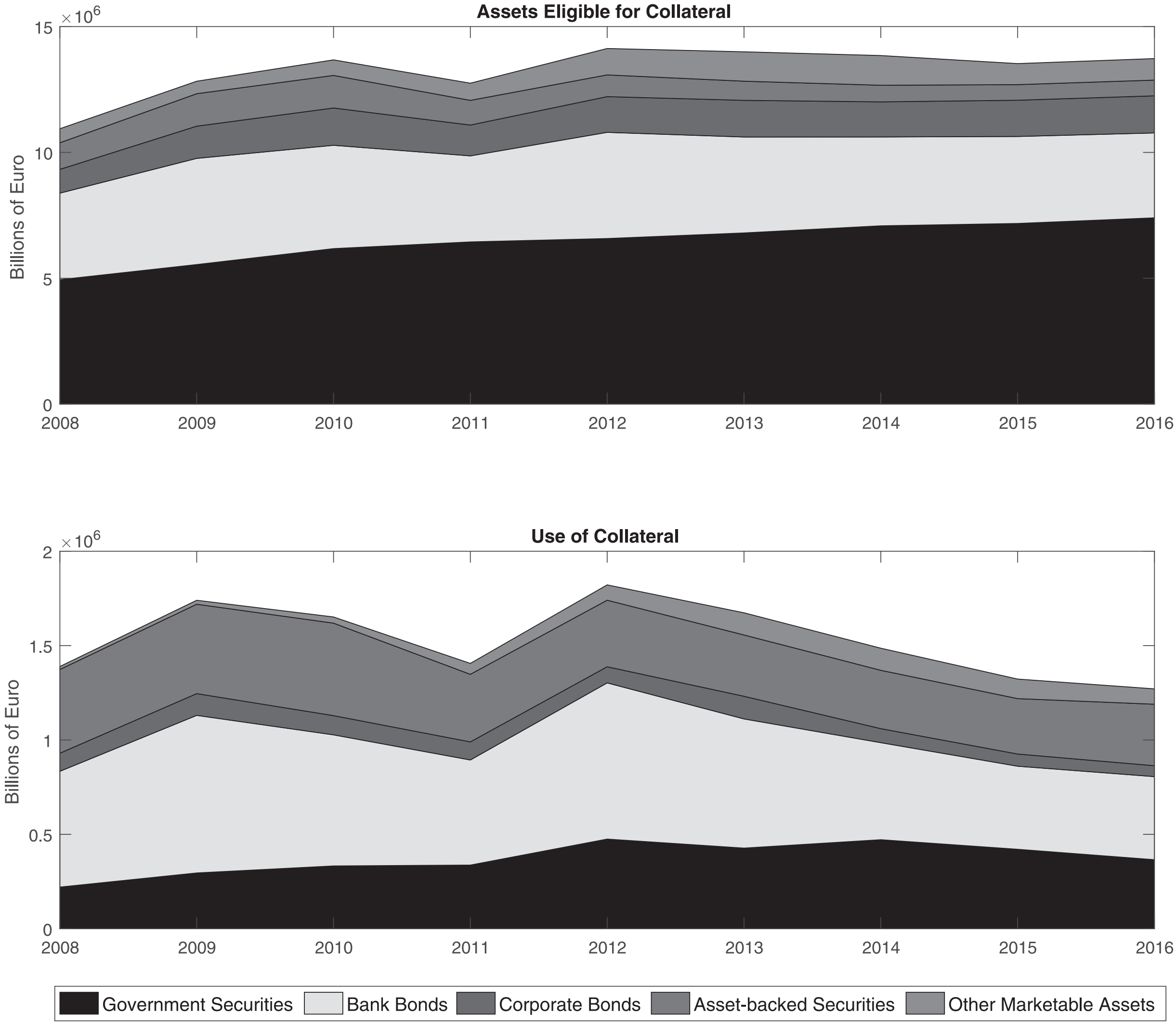

Fig. 2. This figure shows Euro area banks' marketable assets eligible for collateral (top panel) and use of collateral (bottom panel) as reported by the European Central Bank. Government securities are shown in red at the bottom of both panels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

between turmoil in the sovereign bond market and bank' distress and more difficult access to wholesale funding in the euro area. When sovereign yield spreads began rising in around 2010, this was followed by a rise in both the iTraxx CDS index and the Euribor-OIS spread.

The model further connects banks' limited access to wholesale funding to borrowing difficulties for non-financial firms. To explore this link in the data, in Fig. 4 we again plot the sovereign yield spreads (shown in dashed blue line) together with two private sector funding variables. The first one (shown in dashed red line) plots the percentage change in the private credit to GDP ratio for the major euro area countries. The second one plots the interest rate on loans granted to non-financial firms (shown in solid black line). We notice a negative correlation between yield spreads and credit change, especially around the sovereign episode in the euro area. As increases in sovereign default risk started raising the spreads in periphery countries, there was a slowdown or fall in the growth rate of private sector credit relative to GDP. Moreover, we see some evidence of a positive relationship between yield spreads and loan rates, emphasizing the increased cost of borrowing faced by firms. Overall, this figure shows the connection between trouble in the sovereign bond market ultimately leading to stress in banks' ability and willingness to extend private sector loans.

3. The model

The model is a stylized two-country model, where we will interpret one country as the core EU block and the other as the periphery block. In each country the economy consists of four sectors: households, non-financial firms, banks and

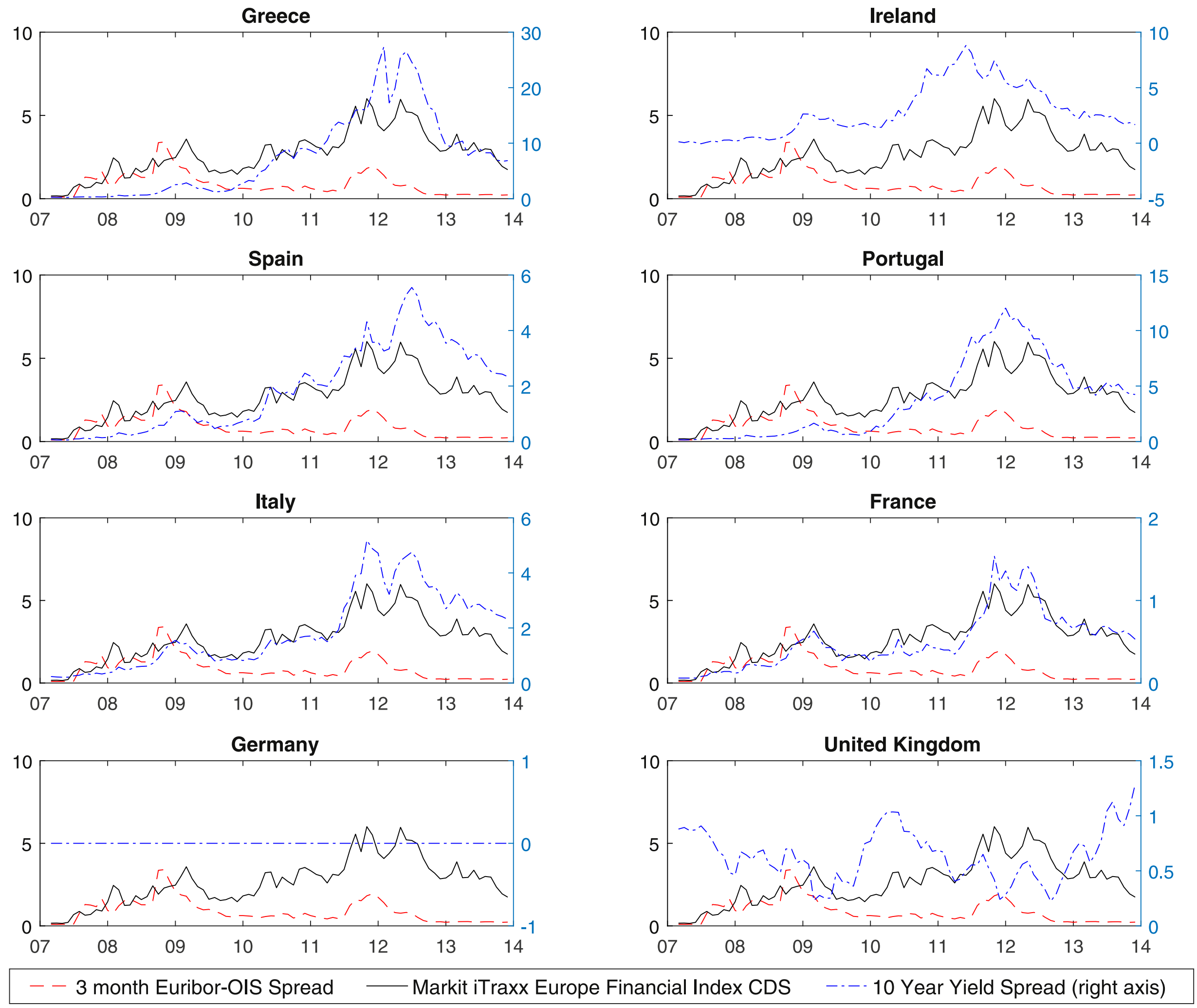

Fig. 3. The dashed red line show the spread between the 3 month Euribor and OIS interest rates. The solid black line shows the Markit iTraxx Europe Financial Senior Index CDS. The dashed blue line shows the sovereign yield spread for a given country relative to German government bonds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a government. In this section, we present the optimization decisions faced by agents in the periphery. Analogous problems apply to agents in the core, and a '*' superscript is used to denote core variables.

We model interbank markets as in Gertler and Kiyotaki (2011). There is a continuum of non-financial firms of mass 1 located on a continuum of sectors. Capital is not mobile across sectors, but labor is perfectly mobile across sectors and firms. In each period investment opportunities arrive randomly to a fraction π^i of sectors. In a fraction $\pi^n = (1 - \pi^i)$ of sectors there are no new investment opportunities. Only firms in sectors with investment opportunities can acquire new capital. To do so, they need to issue shares and sell them to banks. The arrival of investment opportunities is i.i.d. across time and across islands. As is standard in the literature on financial frictions, this introduces a link between developments in the financial sector and the real economy, and allows for frictions in financial intermediation to have real effects.

Banks intermediate funds between households (depositors) and non-financial firms. The interaction with households and firms happens at two different times. The timing is as follows. In the first stage, banks raise deposits from households and decide their government bond holdings. After the deposits and bonds markets close, idiosyncratic uncertainty about the investing opportunities is revealed. Since some banks will be associated with sectors that receive the investment opportunity, they will want to borrow funds from banks that have surplus funds because they are associated with sectors that did not receive this opportunity. A crucial assumption of our paper is that banks will be required to post collateral in the form of government bonds to borrow in the interbank market. Note that if bonds did not serve this role as collateral, the only reason why the first stage would matter would be that it brings net funding for banks into the second stage. But since bonds provide this extra service as collateral, banks will want to hold bonds to insure themselves against the investment uncertainty that can potentially induce liquidity shortages.

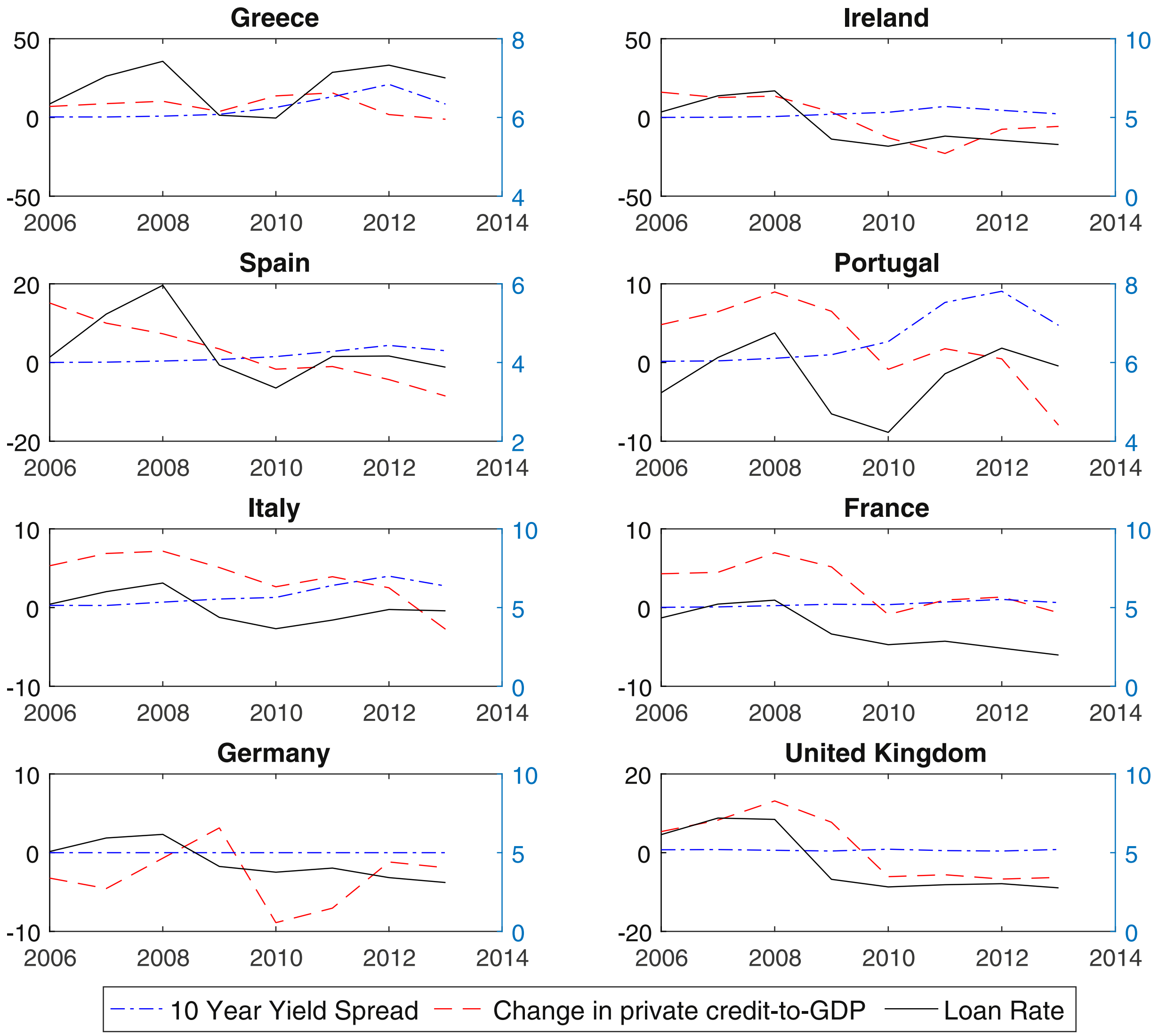

Fig. 4. The dashed The dashed blue line shows the sovereign yield spread for a given country relative to German government bonds. The solid black line shows the loan rate and the dashed red line shows the percentage change in the private credit to GDP ratio. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The setup of the non-financial firms is standard. There are two types of non-financial firms: final goods producers and capital producers. Goods producers operate in a competitive market and choose the amount of labor to hire and the amount of capital goods to buy from capital producers.

Finally, the government of each country purchases goods and finances itself by levying lump-sum taxes and issuing bonds which can be traded internationally.

3.1. Non-financial firms

3.1.1. Final goods producers

In every period t, final goods producers face an opportunity to invest with probability π^i. Contingent on getting funding from intermediaries, these firms issue state-contingent securities X_t^i at a market price Q_t^i. They use these funds to buy new capital goods. Firms in this sector operate a technology that is constant returns to scale in labor and capital and is given by

$$Y_t = AK_t^{\alpha} H_t^{1-\alpha} \tag{1}$$

where A denotes total factor productivity. The factor demand curves are given by

$$w_t = (1-\alpha)\frac{Y_t}{H_t} \tag{2}$$

$$Z_t = \alpha \frac{Y_t}{K_t} \tag{3}$$

where the wage rate is denoted by w_t and the return to capital by Z_t.

3.1.2. Capital producers

The capital producing firms choose their investment levels to maximize the expected present discounted value of lifetime profits given by the value of new capital sold to firms in investing sectors minus the cost of investment inclusive of adjustment costs. Their optimization problem is:

$$\max_{I_t} E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left\{ Q^i_{t+i} I_{t+i} - \left[1 + f\left(\frac{I_{t+i}}{I_{t+i-1}} \right) \right] I_{t+i} \right\}. \tag{4}$$

Therefore, in equilibrium the price of investment goods has to equal the marginal cost of producing capital goods according to

$$Q^i_t = 1 + f\left(\frac{I_{t+i}}{I_{t+i-1}} \right) + \frac{I_{t+i}}{I_{t+i-1}} f'\left(\frac{I_{t+i}}{I_{t+i-1}} \right) - E_t \Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t} \right)^2 f'\left(\frac{I_{t+1}}{I_t} \right). \tag{5}$$

Let δ be the rate of physical depreciation. Then, capital accumulated in sectors that receive investment opportunities is $I_t + \pi^i(1-\delta)K_t$, while in sectors without them it is $\pi^n(1-\delta)K_t$. Aggregating and denoting by ψ_t a shock to the quality of physical capital available for production at time t, the law of motion for aggregate capital is

$$K_{t+1} = \psi_{t+1}[I_t + (1-\delta)K_t]. \tag{6}$$

The capital quality shock is meant to represent disruptions in the good producing sector that are unrelated to financial issues (see, e.g., Gertler and Kiyotaki (2011) and Gertler and Karadi (2011)). One example is that certain goods become obsolete over time and this shock is a reduced form way of capturing the effect of that obsolescence on the capital stock. This provides a convenient way of capturing exogenous variation in the value of capital. Following Gertler and Kiyotaki (2011) we will assume that ψ_t follows the autoregressive process

$$\psi_t = \rho^{\psi} \psi_{t-1} + \varepsilon^{\psi}_t. \tag{7}$$

3.2. Households

To keep the model tractable, we will follow the standard assumption of a representative household. Households are comprised of workers who earn wages and bankers who earn profits by managing financial intermediaries. However there is perfect consumption insurance within the household. We follow the setup in Gertler and Kiyotaki (2011) where bankers exit with a probability $(1-\sigma)$ and transfer all their earnings to the household. This is done to ensure that banks cannot accumulate enough assets to end up in a situation where the collateral constraint never binds. To keep the relative number of workers and bankers constant, $(1-\sigma)f$ workers randomly convert into bankers where f is the fraction of bankers.

Households earn the wage rate w_t, a rate of return R^D_{t-1} on their deposits and profits from owning both intermediaries and non-financial firms, Π_t. They use their funds for consumption C_t, to pay lump-sum taxes T_t, and hold deposits D_t. Households smooth consumption through the use of banking sector deposits. They choose consumption, savings and labor supply to maximize lifetime utility according to

$$\max_{C_t, D_t, H_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t_H U(C_t, H_t) \tag{8}$$

s.t.

$$C_t + D_t + T_t = R^D_{t-1} D_{t-1} + w_t H_t + \Pi_t. \tag{9}$$

Households' optimization yields Eqs. (10) and (11). Eq. (10) is the standard labor supply condition stating that the intratemporal marginal rate of substitution between consumption and leisure has to equal the wage rate; Eq. (11) is the Euler condition governing the intertemporal allocation of savings,

$$-\frac{U'_{H_t}}{U'_{C_t}} = w_t \tag{10}$$

$$1 = \beta^H E_t \left[\frac{U'_{C_{t+1}}}{U'_{C_t}} R^D_t \right]. \tag{11}$$

3.3. Banks

In period t the objective of each individual bank in sector h in the periphery is to choose deposits (d_t), domestic and foreign bond holdings (b_t^p and b_t^{p*}, respectively), interbank position (m_t^h) and holdings of shares in non-financial firms (x_t^h), where the $h \in \{i, n\}$ superscript represents whether an investing opportunity is available or not in that sector. Since deposits and bond holdings are chosen before uncertainty over types is realized, banks in sectors without investment opportunities find themselves with a surplus of funds, while banks in sectors with investment opportunities face a shortage.[8] The former will then lend to the latter at an interest rate R_t^M. The key assumption in our model is that banks are required to pledge government bonds as collateral to borrow in the interbank market. This collateral requirement can cause the cost of credit for the production sector to increase over and above the risk-free rate. This is how the friction in interbank markets that we introduce works to inflict an actual cost on the real economy. The fact that banks are allowed to use both domestic and foreign bonds as collateral introduces a link between the domestic and foreign banking sectors. A shock to the value of foreign bonds changes the value of collateral that domestic banks can pledge. This change affects the cost of interbank borrowing and ultimately affects funding for firms in the domestic economy.

Interbank markets are domestic, so that lending banks in each country can borrow from non-lending banks only in their own country. While we could have well assumed international interbank markets, we chose to stay with markets that operate only at the domestic level because we want to focus on the international transmission channel that arises from the fact that both local and foreign bonds are used as collateral, and to disentangle this channel from that of flows of funds across countries in interbank markets.

Each bank of type h maximizes the expected present discounted value of the stream of future dividends (e) discounted with the stochastic intertemporal discount factor Λ. In equilibrium, this is given by the households' (bank owners) intertemporal marginal rate of substitution.[9]

$$\max_{d_t, b_t^p, b_t^{p*}, x_t^h, m_t^h} V_t = E_t \sum_{i=0}^{\infty} \sigma^i \Lambda_{t,t+i} e_{t+i}^h \qquad \Lambda_{t,t+i} \equiv \beta^i \frac{U'_{C_{t+i}}}{U'_{C_t}} \tag{12}$$

s.t.

$$e_t^h = \left[Z_t + (1-\delta)Q_t^h\right]\psi_t x_{t-1} - R_{t-1}^D d_{t-1} - R_{t-1}^M m_{t-1} + \psi_t^{Bg} b_{t-1}^p + b_{t-1}^{p*} - AC\left(b_{t-1}^p, b_{t-1}^{p*}\right) \tag{13}$$

$$e_t^h = \left(Q_t^h x_t^h + q_t b_t^p + q_t^* b_t^{p*}\right) - \left(m_t^h + d_t\right) \tag{14}$$

$$m_t^h \le \frac{1}{\chi}\left(q_t b_t^p \omega_t + q_t^* b_t^{p*}\right) \tag{15}$$

$$\psi_t^{Bg} = \rho^{\psi^{Bg}} \psi_{t-1}^{Bg} + \varepsilon_t^{\psi}. \tag{16}$$

Eq. (13) introduces bank h's profits in period t where asset yields are given by the returns on firms' shares and discounted bond payments minus the cost of deposits and interbank borrowing used to finance asset purchases. Z_t is the dividend payment at t on firms' shares bought in $t-1$; Q_t^h is the market price of a bank of type h's claim of a unit of non-financial firms' present capital[10]; R_{t-1}^d and R_{t-1}^M are the interest rates on deposits and interbank borrowing, respectively; and ψ_t is an aggregate exogenous shock to the quality of capital.

As in Schmitt-Grohé and Uribe (2003), $AC(.)$ represents a convex "portfolio adjustment cost" for changing bond holdings. In our model bond holdings enter the collateral constraint and that allows us to pin down the total portfolio of bond holdings. Nevertheless, we still need these adjustment costs to pin down the composition of banks' bond portfolio in each country, i.e. the relative holdings of domestic and foreign bonds. In the calibration section we provide more details on the specification of these costs and the data targets that we use to calibrate them. We also conduct a thorough sensitivity analysis on the calibration of the $AC(.)$ functions and show that the results are clearly robust to several alternative specifications. These results are available in an online appendix at the authors' websites (http://www.mariapia-olivero.com/uploads/5/5/5/6/55562983/interbankmarkets-sovereign-irbc-online_appendix.pdf).

Eq. (14) is the balance sheet constraint according to which banks' equity equals the difference between their assets and their liabilities.

Eq. (15) imposes the collateral constraint according to which interbank borrowing cannot exceed $\frac{1}{\chi}$ of the value of domestic and foreign bond holdings (priced at q_t and q_t^*, respectively). As noted, we want to capture the fact that bonds issued by the sovereigns of periphery countries might become less desirable as collateral when these countries start using

---

[8] Notice that d_t, b_t^p and b_t^{p*} are not indexed by h.

[9] The effective discount factor between any periods t and $t+i$ incorporates σ^i to account for the conditional probability of still being in business up to period $t+i$.

[10] This market price is measured at the end of the period after types are realized and, therefore, it is indexed by h and it is a function of the volume of investment opportunities that the bank faces.

bank bailout policies, to the extent that these policies are financed by issuance of new debt. We then let these bonds enter the collateral constraint with a factor of ω_t. When we discuss policies in subsections 3.4 and 3.5 below, we provide more details on the functional form we assume for ω_t and its role in the model.

Last, Eq. (16) introduces an exogenous shock to the returns to bonds issued by the sovereign in the periphery. This captures in reduced form any exogenous shock on the safety of government bonds (e.g., due to news about the government solvency) which impacts on the expected return on government bonds. This way of modelling the shock is similar, for example, to that followed by Kollman et al. (2011) in capturing the effects of shocks to the solvency of loans and securities held by banks.

The banks' FOCs with respect to d_t, x_t^h, b_t^p and b_t^{p*} are given by Eqs. (A.3), (A.5), (A.7) and (20) respectively, with Ω_{t+1} being the marginal value of net worth at time $t+1$. The lagrange multiplier on the collateral constraint in the interbank market for bank of type $h \in \{i, n\}$ is defined as λ_t^h.

FOC w.r.t. d_t:

$$E_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_t^D - R_t^M \right) = E_t \Lambda_{t,t+1} \chi \bar{\lambda}_t \tag{17}$$

where $\bar{\lambda}_t = \left(\pi^i \lambda_t^i + \pi^n \lambda_t^n \right)$. Since in equilibrium the collateral constraint is never binding for banks in sector n, $\lambda^n = 0$ and $\bar{\lambda}_t = \pi^i \lambda_t^i$.

FOC w.r.t. x_t^h:

$$E_t \Lambda_{t,t+1} \Omega_{t+1} \left\{ \frac{\left[Z_{t+1} + (1-\delta) Q_{t+1}^h \right]}{Q_t^h} \psi_{t+1} - R_t^M \right\} = E_t \Lambda_{t,t+1} \left\{ \lambda_t^h \chi \right\}. \tag{18}$$

FOC w.r.t. b_t^p:

$$E_t \Lambda_{t,t+1} \Omega_{t+1} \left[\frac{\left(1 - \frac{\partial AC(.)}{\partial b_t^p} \right)}{q_t} \psi_{t+1}^{Bg} - R_t^M \right] = E_t \Lambda_{t,t+1} \left[\bar{\lambda}_t (\chi - \omega) \right]. \tag{19}$$

FOC w.r.t. b_t^{p*} is:

$$E_t \Lambda_{t,t+1} \Omega_{t+1} \left[\frac{\left(1 - \frac{\partial AC(.)}{\partial b_t^{p*}} \right)}{q_t^*} - R_t^M \right] = E_t \Lambda_{t,t+1} \left\{ \bar{\lambda}_t [\chi - 1] \right\}. \tag{20}$$

The intuition behind Eq. (A.3) is that in expected, discounted terms, the cost of deposits exceeds the cost of interbank borrowing for banks by a measure of the tightness of the collateral constraint in the interbank market given by two elements: (1) the parameter χ, which equals the reciprocal of the loan-to-value (LTV) ratio, and (2) the non-zero shadow value $\bar{\lambda}_t$ of a binding constraint. This equation could also be interpreted as stating that the cost of the two sources of funding have to be equal in expected terms, with $E_t \Lambda_{t,t+1} \Omega_{t+1} R_t^D$ representing the cost of retail funds, and $E_t \Lambda_{t,t+1} \left\{ \Omega_{t+1} R_t^M + \chi \bar{\lambda}_t \right\}$ the "effective" cost of interbank borrowing which consists of the interest rate on interbank loans plus the cost implied by a binding collateral constraint in the interbank market.

Eq. (A.5) implies that the "effective" cost of interbank borrowing (which can be also thought of as the marginal cost of acquiring equity in the non-financial sector) has to optimally equal the marginal return of that equity given by the capital shock-adjusted sum of dividends plus capital gains/losses.

Similarly as in Eq. (A.5), the intuition behind Eqs. (A.7) and (20) is that the "effective" cost of interbank borrowing (including the cost of collateral) has to equal the expected marginal return on domestic and foreign bonds net of adjustment costs, respectively.

Analogous optimization conditions apply to banks in the core where we use b^c to denote core banks' total holdings of core bonds (priced at q^*), and $b^{c,*}$ to denote core banks' total holdings of periphery bonds (priced at q).

3.3.1. Evolution of Banks' net worth

We use capital letters to denote aggregate quantities and N to denote aggregate net worth. Aggregate net worth for all banks of type h is:

$$N_t^h = \pi^h \left\{ (\sigma + \xi) \left[Z_t + (1-\delta) Q_t^h \right] \psi_t X_{t-1} + (\sigma + \xi) \left(B_{t-1}^p + B_{t-1}^{p*} \right) - \sigma R_{t-1}^D D_{t-1} \right\} \tag{21}$$

where π^h is the share of banks that are of type h and σ is the fraction of banks that survives until the current period. Included in the above expression is the net worth of new or entering entrepreneurs which is given by family transfers of $\frac{\xi}{(1-\sigma)}$ of the value of assets of exiting entrepreneurs.

3.4. Government

The government finances government spending and unconventional bank bailout policies through taxes and by issuing bonds. B_t^g is used to denote the total supply of bonds by the government in the periphery. Government spending and taxes are assumed to be determined by the following processes

$$G_t = \rho^G G_{t-1} + (1-\rho^G) m_G Y_t \tag{22}$$

$$T_t = \rho^T T_{t-1} + (1-\rho^T) m_T Y_t. \tag{23}$$

In addition to the autoregressive component, we allow for government spending and taxes to be affected by the current level of output.

We consider a bank bailout policy consisting of equity injections by the government into banks ($N^{g,h}$). The government policy is financed by issuing more debt (B^g). The equity injections are governed by the following simple rule:

$$N^{g,h} = \Phi^N N^h \tag{24}$$

where $N^{g,h}$ denotes equity injections into banks of productive sector $h \in \{i, n\}$. The parameter Φ^N is calibrated to match a one time equity injection by the government equivalent to 1% of total net worth in the entire banking sector.

The government budget constraint reads

$$G_t + \pi^i N_t^{gi} + \left(1-\pi^i\right) N_t^{gn} + \psi_t^{Bg} B_{t-1}^g = T_t + q_t B_t^g.$$

This expression adds to the exogenous component of government spending (G) the equity injections into banks (N^g) and interest payments on the debt (net of shocks on bond returns). It also adds to the tax revenue (T) income from borrowing in both domestic and world bond markets.

Equity injections yield the obvious benefit of directly boosting the lending capacity of the banking sector. At the same time, in our framework we also allow this policy to present a trade-off: the pledgeability as collateral of bonds issued by countries in the periphery is decreasing in the share of issuance that is used to finance this policy. In particular, we let the parameter ω_t in banks' collateral constraint be endogenous to the extent of the policy intervention:

$$\omega_t = \left\{ 1 - \Xi \frac{\left(\pi^i N_t^{g,i} + (1-\pi^i) N_t^{g,n}\right)}{q_t B_t^g} \right\}. \tag{25}$$

This modeling choice is based on the fact that during the euro area debt crisis in 2009 and 2010, government securities from countries under an assistance programme were no longer accepted in European repo markets (see Engler and Große Steffen, 2016).[11] The negative impact on default risk attached to sovereign bonds of financial rescue packages in 2000 in Europe has also been studied by Ejsing and Lemke (2011).[12] In what follows, we further discuss the specification of the bank bailout policy and its impact on the pledgeability of government bonds in the interbank market.

3.5. Discussion

The unconventional policy described above is intended to capture the interventions of various governments in recent years, both in the euro area and in the United States. The policy we consider in our framework consists of ex-post bank bailouts while we do not try to capture ex-ante bailout policies. In fact our goal is to understand the potential feedback effect from ex-post (during crises) bailouts to sovereign bond pledgeability in interbank markets. By contrast, in this paper we do not aim at investigating the possible distortions in banks' or borrowers' behavior possibly caused by ex-ante (before crises) bailout policies.[13]

In recent years, governments have engaged in direct equity injections in the banking system as well as in the provision of bank debt guarantees.[14] As argued by Acharya et al. (2014) there is extensive evidence of a feedback effect from these bailout policies to the acceptability of government bonds. For example, in September 2008, after the Irish government announced that it would guarantee the deposits of the six largest Irish banks, in the credit default swap (CDS) markets the CDS fee for the Government of Ireland increased sharply.[15] In other words, the markets perceived that, due to the provision of the guarantees, the problems of the banking sector had been transferred to the government. As a result, the Irish government (previously with one of the lowest debt to GDP ratios in Europe), suffered from a withdrawal of funds as markets developed concerns about its bailout of banks. According to Cooper and Nikolov (2013), such a loop between banks and sovereigns was also evident in Greece.

More in general, episodes of mutual feedback between banks and sovereigns were not restricted to Ireland or Greece: in recent years, various countries, especially in Southern Europe, in which the governments carried out bailouts of the

---

[11] The value of the parameter Ξ is calibrated to match a few alternative haircut policies. More details about this are provided below in the calibration section.

[12] Gorton and Metrick (2012) provide evidence that increased risk on US-Treasury bonds led to a "run on repo" markets, contributing in part to the US financial crisis.

[13] This is clearly an important topic that we leave for future research.

[14] In the United States, equity injections were carried out soon after Lehman's bankruptcy in September 2008.

[15] One bank, Anglo Irish, cost the Irish government about 11% of Ireland's GDP. The cost of the bailout was initially estimated to be of Euro 90 bln but it was later re-estimated to be 50% higher.

banking sectors experienced a transfer of risk from their banking sectors to the governments. In turn, this damaged the banking sector itself, through a drop in the price of government bonds and an increase in collateral haircuts.[16] In the data, these channels can manifest themselves, for example, in increasing comovement between the financial sector's credit risk and the sovereign's credit risk, as captured by the financial sector and the sovereign CDS, respectively. In fact, Acharya et al. (2014) find that on average euro area banks stress-tested in 2010 held euro area government bonds that were as large as one-sixth of their assets. They also show that bank CDS co-move with sovereign CDS in accordance with banks' holdings of sovereign bonds.[17] Other empirical papers supporting the existence of this loop include, for instance, Bekooij, Frost, van der Molen, and Muzalewski (2016), Avino and Cotter (2014) and Adrian and Schüler (2012). On the theoretical front, Leonello (2017) constructs a model in which the complementarity between banking and sovereign debt crises is driven by government support to financial institutions. In particular, the fewer investors purchase sovereign bonds, the less the government is able to fund bank guarantees. In turn, the more depositors run, the larger the guarantees the government has to offer to the banking sector, increasing the risk of a sovereign default.

3.6. Equilibrium

In this section we use capital letters to denote aggregate quantities. In the market for bank securities, total securities issued on investing and non-investing sectors equal aggregate capital acquired by each type:

$$X_t^i = I_t + (1-\delta)\pi^i K_t \tag{26}$$

$$X_t^n = (1-\delta)\pi^n K_t \tag{27}$$

Market clearing in the bonds market requires that bonds issued by governments in the periphery and the core, respectively, are held by domestic and foreign banks:

$$B_t^g = \left(B_t^p + B_t^{c,*}\right) \tag{28}$$

$$B_t^{g*} = \left(B_t^{p,*} + B_t^c\right). \tag{29}$$

Market clearing in the market for interbank loans in each country requires

$$\left(M_t^i + M_t^n\right) = 0 \tag{30}$$

$$\left(M_t^{i,*} + M_t^{n,*}\right) = 0. \tag{31}$$

The balance sheet constraint of the entire banking sector is given by

$$\left(D_t + \sum_{h=i,n} N_t^h\right) = \left(\sum_{h=i,n,gi,gn} Q_t^h X_t^h + q_t B_t^p + q_t^* B_t^{p*}\right) \tag{32}$$

$$\left(D_t^* + \sum_{h=i,n} N_t^{h*}\right) = \left(\sum_{h=i,n} Q_t^{h*} X_t^{h*} + q_t^* B_t^c + q_t B_t^{c*}\right). \tag{33}$$

Finally, the aggregate resource constraint of the world economy is given by

$$(C_t + C_t^*) + \left[I_t\left(1 + f\left(\frac{I_t}{I_{t-1}}\right)\right) + I_t^*\left(1 + f\left(\frac{I_t^*}{I_{t-1}^*}\right)\right)\right] + (G_t + G_t^*) + \left[AC\left(b_{t-1}^p, b_{t-1}^{p*}\right) + AC\left(b_{t-1}^c, b_{t-1}^{c*}\right)\right] = (Y_t + Y_t^*). \tag{34}$$

4. Calibration and results

4.1. Calibration

This section describes the parameter values used in the calibration for the periphery bloc, with the assumption that core parameters are the same. When these parameters are different across blocs, we provide an explanation. All parameter values are presented in Table 1.

For the households, we use GHH preferences which results in the marginal utility of consumption and the marginal disutility of labor effort to be of the following form:

$$U'_{C_t} = \left(C_t - \gamma C_{t-1} - \frac{\psi^{H_2}}{\psi^H} H_t^{\psi^H}\right)^{-\sigma_c} - \beta^H \gamma \left(C_{t+1} - \gamma C_t - \frac{\psi^{H_2}}{\psi^H} H_{t+1}^{\psi^H}\right)^{-\sigma_c} \tag{35}$$

[16] Such a loop can also occur when the guarantees offered to the banking sector are implicit rather than explicit.

[17] Acharya et al. (2014) find that an increase in sovereign CDS of 10% translates into a 2.21% increase in bank CDS.

Table 1
Baseline Calibration.

Parameter Households	Value	Description
β^H	0.97	Discount factor
γ	0.45	Habit parameter
σ_c	2	Risk aversion
ψ^H	2	Exponent on labor in preferences
ψ^{H_2}	5	Parameter multiplying labor in preferences
Firms		
α	0.33	Capital share in production
δ	0.025	Capital depreciation rate
ρ^{ψ}	0.7	Persistence of capital quality shock
ϕ_K	2	Investment adjustment cost parameter
Banks		
ξ	0.003	Transfer to new bankers
σ	0.97	Banker survival rate
π^i	0.25	Probability of new investment opportunities
χ	1.5	Interbank collateral constraint tightness
ϕ_{B_p}	0.115	AC parameter for domestic bonds in periphery
$\phi_{B^{p*}}$	0.10	AC parameter for foreign bonds in periphery
ϕ_{B_c}	0.11	AC parameter for domestic bonds in core
$\phi_{B^{c*}}$	0.20	AC parameter for foreign bonds in core
Government		
m_G	0.18	G/Y (steady-state)
m_T	0.20	T/Y (steady-state)
Φ^N	0.01	Bank bailout policy parameter
$\rho^{\psi^{Bg}}$	0.75	Persistence of bond return shock

$$U'_{H_t} = (H_t^{\psi^H-1}). \tag{36}$$

This assumption guarantees that there are no wealth effects on labor supply and that none of the results are driven by households' labor effort rising in response to the negative effects of credit frictions on their wealth.

The household discount factor β^H is set to 0.97. This implies an annualized steady-state deposit rate of 3.09%. The other parameters of the utility function are assigned values that are fairly conventional in the literature. The intertemporal elasticity of substitution σ is set to 2, the price elasticity of labor supply parameter ψ^H is set to 2 following Mendoza and Yue (2012), ψ^{H_2} is set to 5, and the degree of habit persistence in consumption γ is 0.45. The parameters that govern the frictions in interbank markets are chosen based on Gertler and Kiyotaki (2011). Thus, it is assumed that one fourth of the sectors face investment opportunities ($\pi^i = 0.25$), that the survival rate of bankers is $\sigma = 0.97$, and that the transfer to entering bankers ς is 0.003. In the production sector, the effective share and depreciation rate of capital are set to the standard values of α =0.33 and $\delta = 0.025$, respectively. The adjustment cost to capital function is specified as

$$AC(K_{t+1}, K_t) = \frac{\phi^K}{2}\left(\frac{K_{t+1}}{K_t} - 1\right)^2$$

with $\phi^K = 2$.

The steady-state share of government spending m_G is set to 0.18 and that of tax revenue to m_T =0.20, which together yield a positive sustainable debt-to-GDP ratio in steady state equal to $\frac{(m_T - m_G)}{(1-q)}$.

The adjustment costs to bond holdings are introduced into the model to help pin down the relative holdings of domestic to foreign bonds in each country. The functional form for these adjustment costs in each of the countries is given by:

$$AC(b^p, b^{p*}) = \phi_{Bp}\left(\frac{b^p}{B^g}\right)^2 b^p + \phi_{Bp*}\left(\frac{b^{p*}}{B^{g*}}\right)^2 b^{p*}$$

$$AC(b^c, b^{c*}) = \phi_{Bc}\left(\frac{b^c}{B^{g*}}\right)^2 b^c + \phi_{Bc*}\left(\frac{b^{c*}}{B^g}\right)^2 b^{c*}.$$

The four adjustment cost parameters ϕ_{Bp}, ϕ_{Bp^*}, ϕ_{Bc} and ϕ_{Bc^*} are set together to minimize the distance between the model's predictions and the following data targets for the European Union: The first one is the spread between periphery and core yields $\left(\frac{1}{q} - \frac{1}{q^*}\right)$. In the data this is calculated as the difference between yields on German bonds and average yields for Spanish and Italian bonds. The second is the spread between bond yields and deposit rate, which in the data is calculated as the spread between German bond yields and interest rates on deposits in the German market obtained from the FRED database and averaged over the period 2003–2014. Next is the share of bonds issued by sovereigns in the periphery that are held within their own countries, i.e. the ratio $\frac{B_p}{B_g}$. And finally the share of bonds issued by core countries that are held in the core, $\frac{B_c}{B_{g*}}$. These two numbers are measured using data from the European stress tests, presented in Table 2.

Table 2
Banks' domestic sovereign exposure as a percentage of their total sovereign exposure calculated from the EU stress test data reported by the EBA.

	2011	2014	2016
France	23.4%	47.0%	49.2%
Germany	56.7%	58.5%	52.7%
Greece	84.7%	74.1%	N/A
Ireland	59.5%	84.1%	74.8%
Italy	73.7%	76.5%	59.3%
Portugal	62.4%	73.2%	N/A
Spain	66.2%	69.9%	55.0%
UK	17.0%	23.1%	25.2%

Table 3
Model implied interest rates in steady-state.

Benchmark ($\chi = 1.5$)				**High** χ ($\chi = 1.8$)			
Periphery		Core		Periphery		Core	
R^d	1.0309	R^{d*}	1.0309	R^d	1.0309	R^{d*}	1.0309
R^m	1.0296	R^{m*}	1.0197	R^m	1.0185	R^{m*}	1.0001
Z	0.0561	Z^*	0.0570	Z	0.0571	Z^*	0.0558
R_i^k	1.0348	R_i^{k*}	1.0633	R_i^k	1.0667	R_i^{k*}	1.1142
R_n^k	1.0296	R_n^{k*}	1.0197	R_n^k	1.0185	R_n^{k*}	1.0001
q	0.9372	q^*	0.9482	q	0.9441	q^*	0.9554
$\frac{1}{q}$	1.0670	$\frac{1}{q^*}$	1.0546	$\frac{1}{q}$	1.0592	$\frac{1}{q^*}$	1.0467

In an online appendix available at the authors' websites (http://www.mariapia-olivero.com/uploads/5/5/5/6/55562983/interbankmarkets-sovereign-irbc-online_appendix.pdf), we also provide a detailed sensitivity analysis for the following parameters: ϕ_{Bp}, ϕ_{Bp^*}, ϕ_{Bc} and ϕ_{Bc^*}, χ, π, σ and ξ. These are the parameters that determine the properties of the demand for bonds including its elasticity to bond prices q and q^*. We show that all of our results are robust to alternative calibration assumptions for these parameters.[18]

The parameter Ξ in Eq. (25) is calibrated using data from the European Central Bank on the use of sovereign bonds as collateral and the corresponding haircut for each country. The detailed data are presented in the online appendix (http://www.mariapia-olivero.com/uploads/5/5/5/6/55562983/interbankmarkets-sovereign-irbc-online_appendix.pdf). With these data we select bonds issued by the central governments of periphery countries and calculate the average haircut for December of 2016. Doing so we obtain an average haircut for the PIIGS countries of 6.81%. At the lower end of the haircut distribution, we find Ireland, Spain and Italy with haircuts of 2.69%, 3.61% and 3.79%, respectively. Portugal is in the middle of the range with a haircut of 9.48% and Greece is at the top, with a haircut of 41.97%. Based on these data, we calibrate Ξ to three alternative values. In the benchmark case, the average haircut is approximately 10% (like in Portugal). We look at two other cases: what we call "low haircut countries" (like Italy and Spain) with an average haircut of 3% and "high haircut" countries (like Greece) with an average haircut of 40%.

The relationship among all relevant interest rates in steady state for both the benchmark parametrization of the model and an alternative higher χ are presented in Table 3. The intuition behind these results is the following. From Eq. (A.5) and since $\lambda^n = 0$, it follows immediately that in equilibrium $R_n^k = \frac{Z}{Q^n} + (1 - \delta) = R^m$. Using the same logic, but understanding that the collateral constraint is assumed to be always binding for banks associated with production sectors that do receive investment opportunities, $R_i^k > R^m$. From FOC (A.3) it becomes clear that the rate of return to shares in investing sectors also exceeds the interest rate on deposits such that $R_i^k > R_d$. Moreover, the cost of deposits for banks is higher than that of interbank borrowing since the former are not subject to collateral constraints. Last, from Eqs. (A.7) and (20), the rate of return (net of adjustment costs) on sovereign bonds issued by the periphery exceeds the return on those issued by the core by a factor that is a function of $(1 - \omega)$, which reflects the possible dilution in the pledgeability of periphery bonds caused by bank bailout policies.

The key feature of our model is that banks are required to pledge bonds to borrow in the interbank market. The parameter χ governs the tightness of this constraint, reflecting features that determine the willingness of lenders to make loans in the interbank market for a perceived quality of sovereign bonds. Notice that $\chi > 1$ is needed to generate positive spreads between the expected return on equity shares owned by the banking sector and its cost of funding. In the baseline calibration, we set the parameter in the collateral constraint $\chi = 1.5$. In an alternative scenario, we strengthen the friction by setting $\chi = 1.8$. A higher value of χ indicates that for a given level of bond holdings, banks can borrow less in the interbank market, that is, the collateral constraint is tighter. Since the constraint takes the form $\chi M_i \le \pi^i[qB^p\omega + q^*B^{p*}]$ and since $\pi^i = 0.25$, the baseline calibration implies a steady-state ratio of interbank borrowing to bond holdings of approximately 17%.

[18] See Tables 2.1–2.8 in the appendix.

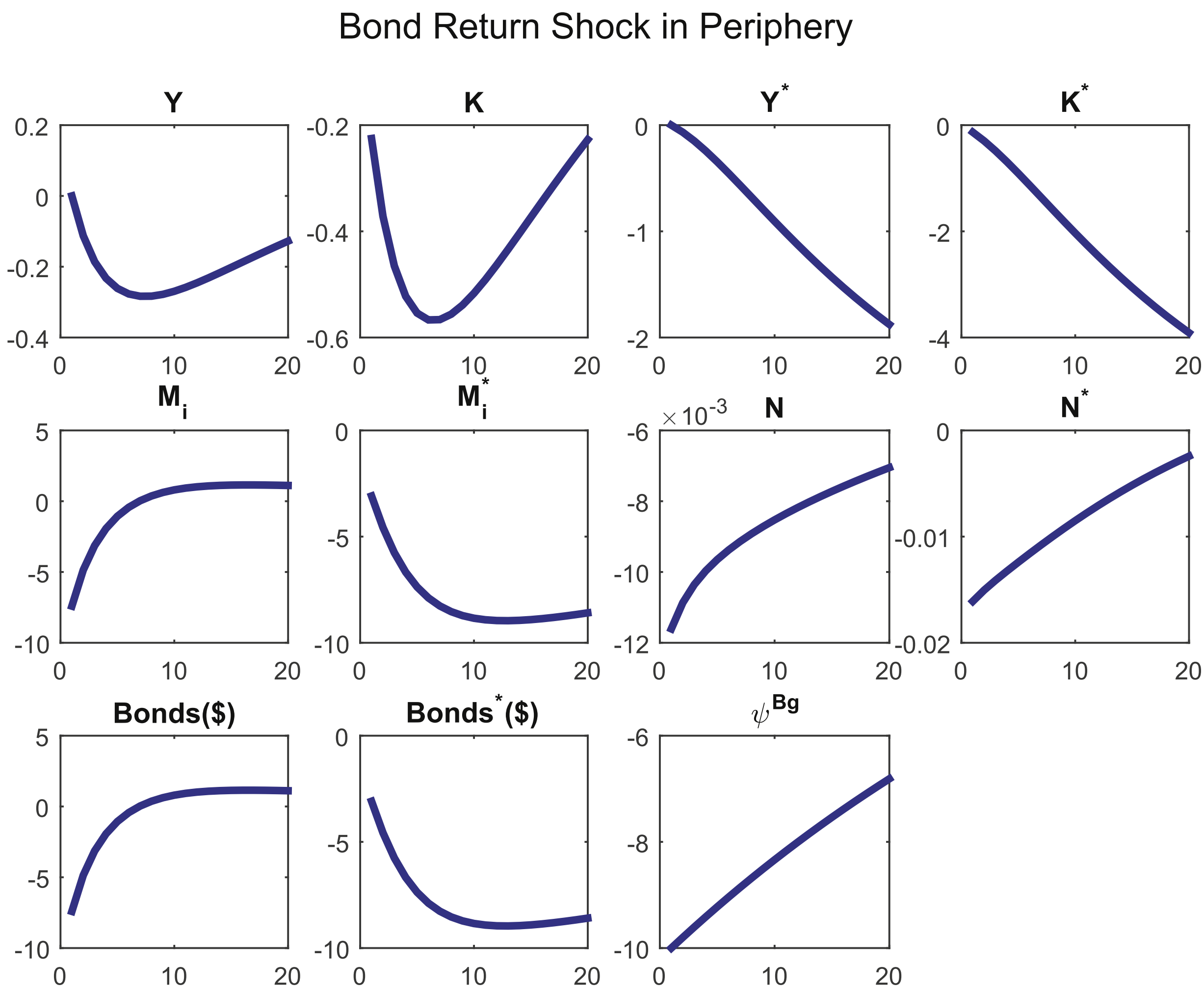

Fig. 5. The figure shows impulse responses to a bond return shock that occurs in the periphery. The variables with a * superscript refer to core variables. The solid blue lines shows the benchmark ltv ratio of 1.5, while the dashed red line shows the alternative ltv ratio of 1.8. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Bond returns shocks

4.2.1. Effects on the domestic and foreign economy

In this section we study the economy's response to a shock ψ^{Bg} as in Eq. (16) that exogenously lowers the rate of return of bonds issued by countries in the periphery. For both the periphery and the core, Fig. 5 shows the impulse response functions of output, capital, banks' interbank borrowing, banks' net worth, and value of banks' bond portfolios.

This shock makes periphery bonds less desirable, lowers the demand B^p (also inducing banks to switch towards core bonds) and works to endogenously lower their market price q. These effects result in a reduction in the nominal value of the bond portfolio held by banks in the periphery. In the benchmark calibration of the model, the net worth of banks falls in response to this shock. In addition, in our model with a collateral constraint imposed on banks' borrowing in interbank markets, the drop in the nominal value of the bond portfolio tightens banks' collateral constraint and limits their ability to borrow in interbank markets. Banks are then forced to borrow less in the interbank market, as the impulse response functions of interbank borrowing show. As a result, banks have to lower the amount of shares of ownership in the production sector (X^i and X^n). With less investment financing available, firms in the periphery countries curtail their demand for capital and investment, which lowers the marginal product of labor and also induces them to lower their demand for labor. Employment and output follow.

The results for the international transmission of the shock are also presented in Fig. 5. Recall that core banks also hold periphery bonds to use as collateral in the interbank market. Thus, the negative effects described above are also transmitted to banks in the core. With a drop in the value of their bond portfolio, core banks cut lending to non-financial firms and this ultimately results in a fall in output. It is important to note that in our model we have shut down trade of goods and services and the exogenous process assumed for ψ^{Bg} does not allow for cross-country spillovers. Thus the spillover effects on the core are solely working through banks' holding of sovereign bonds and their role as collateral in the interbank market.

To summarize, in both the periphery and the core, the bond return shock tends to tighten the collateral constraint in the interbank market and this compounds the effect of the drop in banks' net worth. We will later contrast this result with the one that obtains following a capital quality shock.

4.2.2. Bailout policies

In the top panel of Fig. 6 we consider the effect of an equity injection policy in response to a bond return shock. The policy has three effects: First, it directly boosts the lending capacity of the banking sector. Second, the share ω of domestic bonds that can be pledged as collateral in interbank markets falls as a portion of government bonds issuance is devoted to financing the unconventional policy. Thus, all else equal, the introduction of the policy tightens banks' collateral constraint in the interbank market. Third and last, since the policy intervention is financed with bond issuance, the supply of bonds increases in the periphery countries and the price of their bonds falls. The second and third effects lead the collateral constraint to become tighter.

With the calibration considered here, the direct effect described first seems to dominate so that the policy has an overall impact of alleviating the negative effects of the bond return shock. In particular, the intervention more than compensates for the adverse effects of the bond shock on bank balance sheets. This results in an increase in funding for non-financial firms after a short dip. The green dotted lines in the figure show the case where the government bond pledgeability in the interbank market is not affected by the policy (i.e., constant ω). Clearly this case has better outcomes compared to a case with no intervention. But when we allow ω to endogenously react (shown in red dashed lines), this results into lower bond pledgeability in the interbank market. Overall outcomes, shown in the red dashed line, are worse relative to the green dotted line as the policy partly undermines the pledgeability of government bonds in the interbank market. Finally, the top panel of Fig. 6 also shows the spillover effects on the core. Since core banks benefit from the intervention in the periphery through the interbank collateral channel, their funding to non-financial firms in the core is propped up. Notice that the periphery economy has to pay a cost for these policies as they are financed by more government borrowing. However, the core economy reaps the benefits of these policies without having to sustain their direct cost and thus output and capital rise more in the core.

To summarize, equity injections in the banking sector benefit the domestic economy primarily by facilitating credit intermediation between banks and firms. However, to the extent that they are financed by government borrowing, there is another channel through which they can deteriorate the pledgeability of bonds as collateral in the interbank market. This introduces a potential cost of policy intervention that is relatively unexplored in the literature. Finally, our model uncovers a theoretical mechanism through which policy interventions in the periphery significantly benefit the core.

In this benchmark analysis of policies, the average haircut imposed on bonds issued by periphery countries is calibrated to 10%. In the bottom panel of Fig. 6 we conduct a robustness check on this assumption looking also at the effects of the policies on “low haircut” and “high haircut” countries, where the average haircut is calibrated to 3% and 40%, respectively, based on the data for Italy, Spain and Greece.

The solid lines are for the case of no policy and the dashed lines are the benchmark policy with an intermediate value of the haircut. The dashed dotted lines and the starred lines represent the cases of low and high haircuts, respectively. Interestingly, we obtain that the effects of policies are quite sensitive to the calibration of the process followed by ω. Specifically, equity injections are more effective at raising output in economies where the penalty of a haircut imposed on their bonds is rather weak. In “high haircut” economies, the penalty is so strong that the policy becomes counterproductive and the responses of real variables are more negative than without policy intervention.

4.3. Capital quality shocks

4.3.1. Effects on the domestic economy

In the analysis of bond return shocks, we studied a scenario in which the interbank collateral channel amplifies the effects of shocks. We now turn to study the response of the economy to a negative capital quality shock in the periphery. We are going to see that in this scenario the working of a “portfolio switching” effect can turn the interbank collateral channel into a stabilizer, rather than an amplifier, at least for the domestic economy.

The impulse response functions are presented in Fig. 7. To gain intuition, as a comparison, we also plot the responses in a frictionless Real Business Cycle model.[19] Relative to the frictionless model, output and capital fall more in our model. In the standard RBC model banks are just frictionless intermediaries between households and firms: when taking deposits from households they pay a rate of return equal to the rate that they charge when lending to firms, so that they play no role in the transmission of shocks. Thus, the adverse effect of the negative capital quality shock occurs through the drop in the expected rate of return to capital, which leads firms in the production sector to lower their demand for investment, capital and employment, and their output.

[19] For the bond return shock we were not able to compare the predictions of our model with frictionless models since in those models banks do not hold sovereign debt.

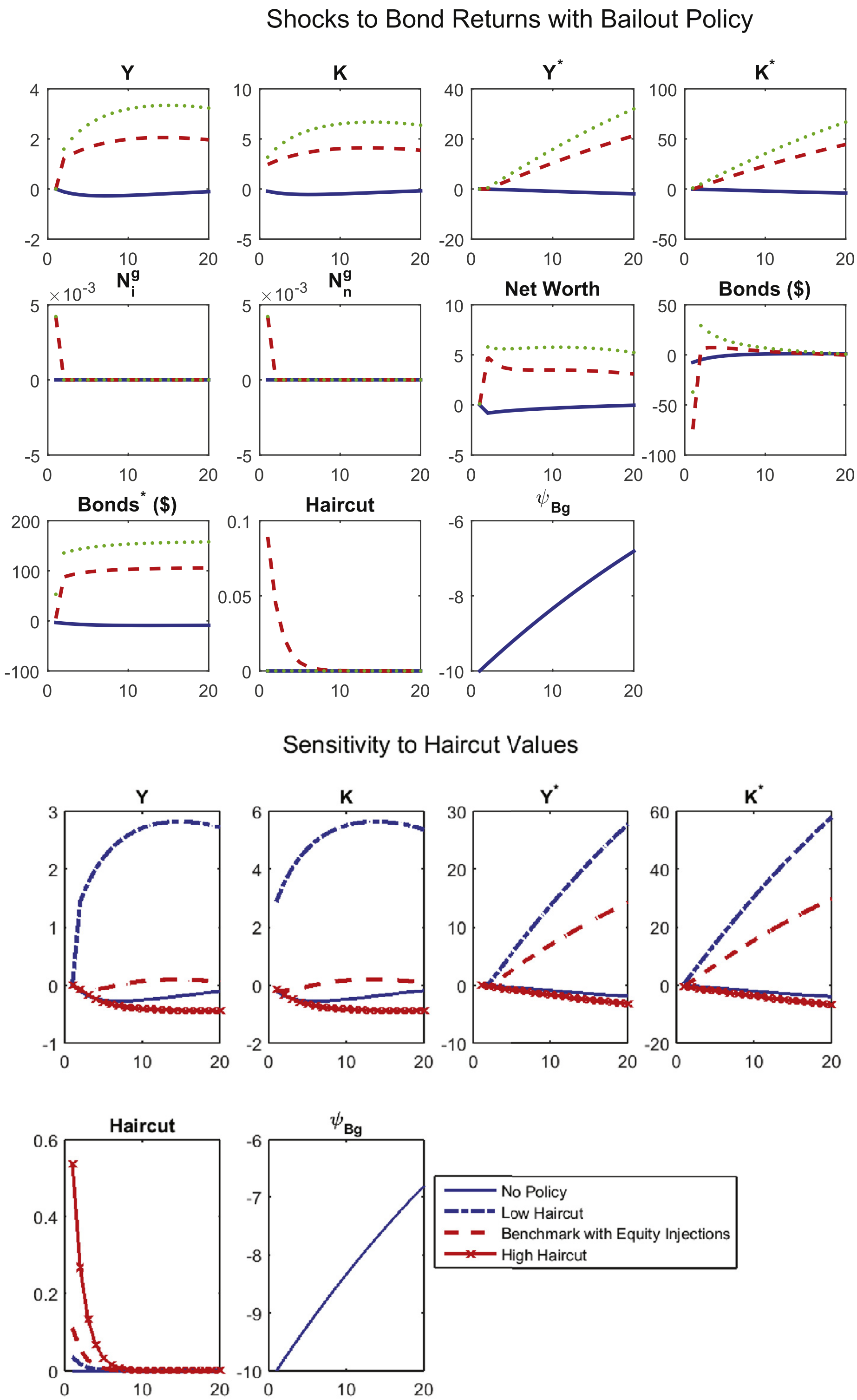

Fig. 6. The top panel shows impulse responses to a bond return shock that occurs in the periphery. The variables with a * superscript refer to core variables. The blue line shows the baseline case without any credit policy, while the other two lines show the case with the bank bailout policy. The green line shows the case with constant ω and the red line shows the case with endogenous ω. In the bottom panel impulse responses are shown for alternative values of the haircut. The red dashed lines, blue dashed dotted lines and red starred lines represent the cases of intermediate, low, and high values of the haircuts, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

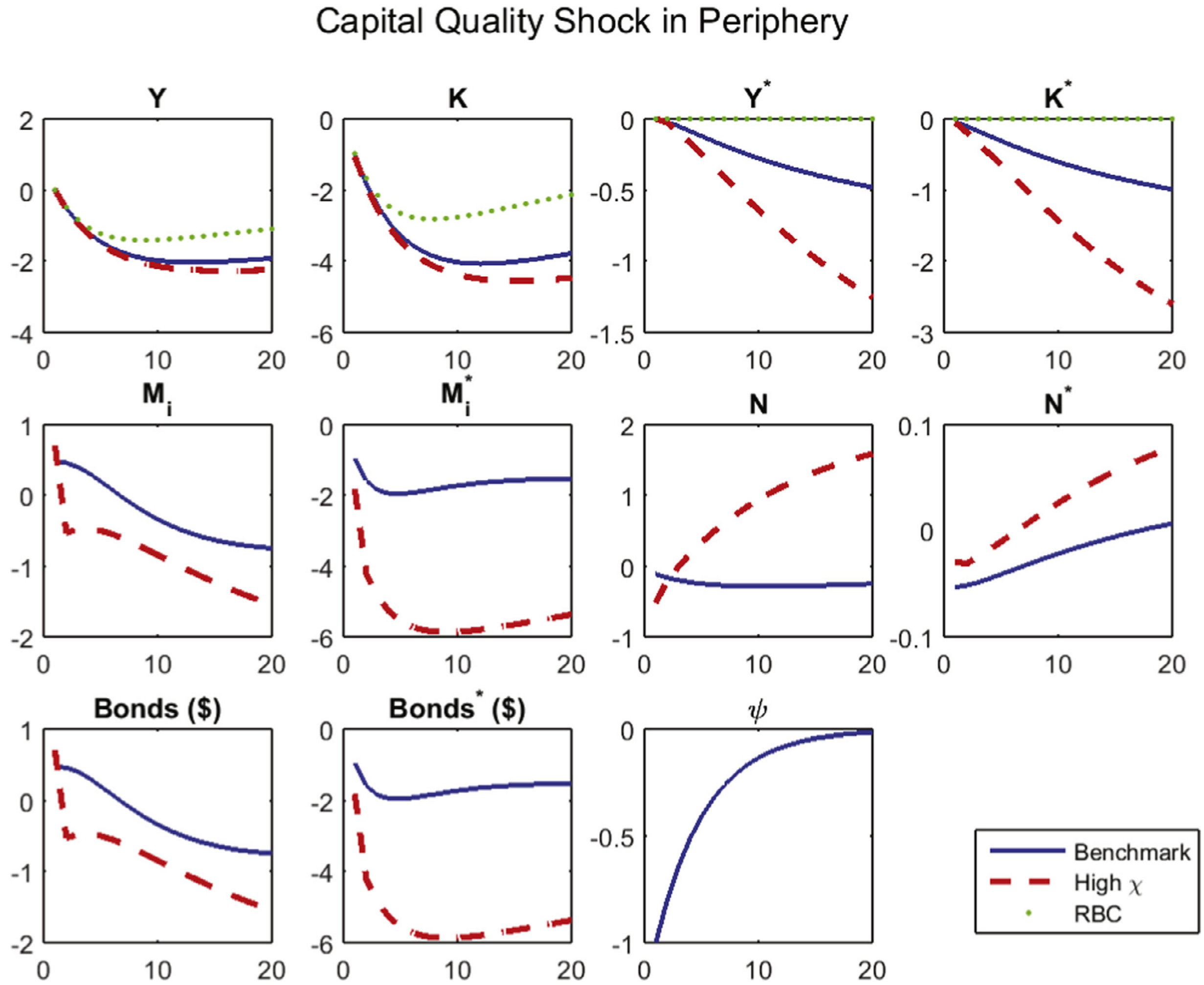

Fig. 7. The figure shows impulse responses to a capital quality shock that occurs in the periphery. The variables with a * superscript refer to core variables. The solid blue lines shows the benchmark case, while the dashed red line shows the frictionless RBC model. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the benchmark calibration of our model, the net worth of banks falls by almost 10% in response to this shock that hurts the value of their most important asset: equity shares of ownership in the production sector. Even though the net worth of banks falls, as banks switch away from shares (now the lower quality and less attractive financial asset) towards government bonds, here we get an increase in both the price and quantity of bonds. In contrast with what was observed following a bond return shock, this has the effect of boosting the nominal value of banks' bonds portfolio, and actually loosening the collateral constraint in Eq. (15). Thus, the spread between the expected return on capital on investing islands and the deposit rate tends to drop. This is a feature that is unique to our model and is not present in other models with financial frictions like Gertler and Kiyotaki (2011). This extra feature arises because i) we introduced a richer asset structure for banks and, hence, allowed for a substitution channel to be at work between lending to firms and investment in government bonds; ii) the financial asset alternative to loans, that is, government bonds act as collateral in the interbank market. In response to a negative shock to one of the assets held by banks, capital in this case, banks are allowed to substitute away from capital and into sovereign bonds as an alternative asset. The resulting increase in the value of banks' bond portfolio allows for the collateral constraint to be alleviated, for banks' access to interbank liquidity to increase, and for their supply of credit to fall by less than in other models lacking this alternative asset to which banks can switch.[20] In what follows we call this the "portfolio switching" effect.

The "portfolio switching" effect, coupled with the fall in the demand for capital and for shares by firms in the investing sectors that is triggered by the shock, makes investment fall but by less than otherwise. The drop in investment leads

[20] This last result is evident from the drop in both the shadow value of the constraint (λ) and the spread between the expected return on capital and the risk-free rate.

to a drop in capital and, as a result, also in the marginal product of labor, the demand for labor and employment. With both factors of production falling, output follows. This is how the link between frictions in credit markets and the real economy works. Thus, in our framework it turns out that the portfolio switch is a mechanism that tends to attenuate the credit contraction, because it boosts collateral values in interbank markets and therefore, banks' access to liquidity, which in turn facilitates credit extension. This is fundamentally different from a situation where the portfolio switch only means a crowding out of loans to the private sector. During the crisis in the euro area banks were often blamed for crowding out credit to firms because of an excess appetite for government bonds. Our results indicate that these criticisms might have been missing some nuisance.

To better grasp the workings of the "portfolio switching" effect, in Fig. 7 we also compare the impulse responses between our economy and an economy with a lower loan-to-value ratio (higher χ) in the interbank market. The value of banks' bonds portfolio remains persistently higher in our economy. Intuitively, when the loan-to-value ratio is higher, the "portfolio switching" effect tends to be stronger, because banks have a stronger appetite for government bonds as collateral (bond values have a larger impact on banks' borrowing capacity in the interbank market). As a result, in our economy the negative impact of the capital quality shock on output is also attenuated relative to the alternative economy with a lower loan-to-value ratio (higher χ). Interestingly, this is the opposite of what is generally found in models with collateral constraints, where economies with higher loan-to-value ratios tend to exhibit stronger sensitivity to negative shocks (see, e.g., Minetti and Peng (2013), and references therein).

4.3.2. International transmission

In Fig. 7 we also plot the response of core variables (denoted by a '*') to a reduction in ψ in the periphery countries. The increase in the price of bonds in the periphery (q) results, by a standard arbitrage argument, in an increase in bond prices in the core (q^*) as well. This drives down the demand for both domestic and foreign bonds by banks in the core (B^c and B^{c*}, respectively); the effect on quantities dominates the effect on prices in bond markets; the nominal value of core banks' bond portfolios falls; the collateral constraint tightens; the amount of interbank borrowing (M^{i*}) that banks in the core are able to obtain drops; and their supply of credit to the production sector (X^{i*}) falls. With less financing available for investment, the demand for investment, capital and labor drops in the foreign economy; and both employment and output follow. All in all, the results then suggest that, while acting as a partial stabilizer of a capital quality shock in the periphery, the mechanism triggered by the "portfolio switching" effect generates transmission of the shock to the core economy. Fig. 7 shows the effects on the core with alternative loan-to-value ratios. The figure reveals that, like in the periphery economy, in the case with a lower χ (higher loan-to-value ratio) there is a smaller reduction in bank funding provided to core firms and eventually an attenuated effect on core capital and output.

4.3.3. Bailout policies

Similar to the results for the bond return shock, the responses of all real variables, employment, investment, consumption and output, are attenuated in the presence of a policy of equity injections into the banking sector, as shown in the top panel of Fig. 8. The dotted green lines show the case where we have allowed for the policy to still work but in this case the pledgeability of domestic bonds is not a function of the cost of implementing the policy (i.e. ω in Eq. (15) is a constant). In this last case, the real effects are attenuated even more than in the benchmark model. In other words, if the pledgeability of government bonds as collateral is not affected, then the policy is more effective at helping the economy out of the recession generated by the negative shock to capital. When instead the policy partially erodes the pledgeability of government bonds (shown with the dashed red lines), the portfolio switching effect described above tends to lose power.

The top panel of Fig. 8 also shows the spillover effects on the core. For the case of constant ω (shown with dotted green lines), the value of core banks' bond portfolios is higher relative to the no policy case and attenuates the negative effect on funding to non-financial firms. However, in the case where the pledgeability of periphery bonds is affected by the bailout policy, the effect on the core countries is worse relative to the no policy case. Note that this policy is not financed by the core economy and the core economy does not directly bear the brunt in terms of higher taxes or lower government spending. In spite of these effects, equity injections are not able to overturn the contagion of the negative shock to the countries in the core.

Just as we did for the case of bond shocks, we also conduct a robustness check on the value of the bond haircuts applied to bonds issued by periphery countries to finance the bank bailout policy. The results are presented in the bottom panel of Fig. 8. Again, we are able to show that the effects of bank bailout policies are quite sensitive to the calibration of the process followed by ω. The policies are more effective at raising output in "low haircut" economies (dashed-dotted lines). In "high haircut" economies (starred lines), the penalty is so strong that the policy becomes counterproductive and the responses of real variables are more negative than without policy intervention.

Finally, we simulate the response of the economy to a series of both types of shocks. In the online appendix (http://www.mariapia-olivero.com/uploads/5/5/5/6/55562983/interbankmarkets-sovereign-irbc-online_appendix.pdf) we show our model implied comovement of interest rates together with those in the data. Our model is able to match well some salient features of the data; namely, a positive correlation between interest rates and government bond yields, and a negative correlation between these yields and the availability of credit for the private sector as a percentage of GDP. This feature of the model survives to the introduction of policy with and without haircuts applied to the bonds issued by sovereigns in the periphery.

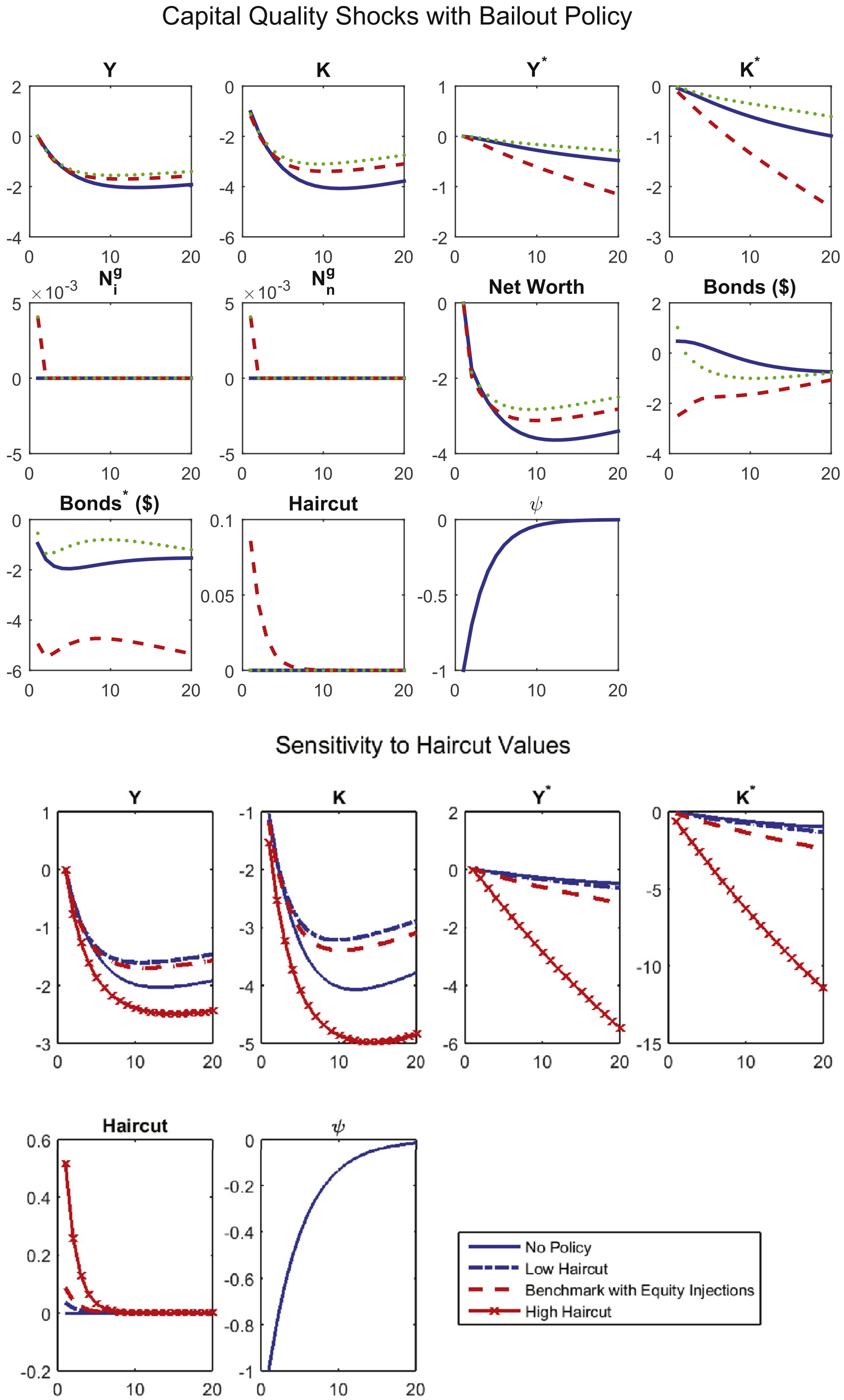

Fig. 8. The top panel shows impulse responses to a capital quality shock that occurs in the periphery. The variables with a * superscript refer to core variables. The blue line shows the baseline case without credit policy, while the other two lines show the case with the bank bailout policy. The green line shows the case with constant ω and the red line shows the case with endogenous ω. In the bottom panel impulse responses are shown for different values of the haircut. The red dashed lines, blue dashed dotted lines and red starred lines represent the cases of intermediate, low, and high values of the haircuts, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5. Conclusion

In this paper we are motivated by two empirical observations. First, sovereign bonds constitute the most important form of collateral in interbank markets. Second, interbank markets have been at the center of the transmission of recent financial crises, including the European sovereign debt crisis.

We build a DSGE model with governments issuing sovereign debt, interbank markets and international transmission links to study how sovereign bond holdings impact banks' intermediation capacity and economic activity. In the recent literature and policy debate, significant attention has been paid to the consequences of large holdings of sovereign debt in banks' portfolios. Our analysis of the "interbank collateral channel" highlights an additional (and potentially overlooked) effect that banks' holdings of sovereign bonds can have. Specifically, the effects of negative shocks that reduce the value of private loans given by banks can be mitigated if the value of sovereign bonds goes up. In fact, this rise in bond value works to loosen collateral constraints faced by banks in interbank markets, where government bonds constitute a primary form of collateral. Overall, we find that the "interbank collateral channel" can mitigate the response of the economy to certain shocks (such as shocks to the value of private loans) while amplifying the effects of other shocks (such as shocks to the return of sovereign bonds).

We have also used our framework to revisit the effects of policies initiated to fight a credit crunch. Like in previous studies, bank bailout policies such as equity injections into banks help fight the negative consequences of a credit crunch by directly boosting banks' lending capacity. However, to the extent that these policies are financed through the issuance of sovereign debt, they can potentially reduce the acceptability and pledgeability of government bonds as collateral in the interbank market. This can have an adverse effect on banks' access to liquidity in the interbank market that counteracts the direct stabilizing role of the policies. Our model further predicts that for certain shocks bank bailout policies in the periphery make countries in the core significantly better off, and for core countries this holds even when the debt-financed policy erodes the pledgeability of government bonds in the interbank market.

Although the analysis makes a step towards understanding the unintended consequences of bank bailout policies for banks' access to interbank market liquidity, we have not attempted a full quantitative assessment of these effects. An interesting direction for future research could be to further investigate the quantitative implications of these effects, thus also helping to fine-tune the implementation of policies during crises.

Acknowledgements

For helpful comments, we would like to thank the editors, two anonymous referees, the 21st ICMAIF Conference participants (Rethymno, Greece), and several other seminar and conference participants. All remaining errors are ours.

Appendix

In this appendix we provide the entire derivation of the banks FOCs of Section 3.3.

The Lagrangian for the system in equations (12)–(16) becomes:

$$\ell = \sum_{h=i,n} \pi^h E_t \left\{ \left[(1-\sigma) e_t^h + \sigma e_{t+1}^h \right] + \sum_{i=1}^{\infty} \sigma^i \Lambda_{t,t+i} \left[(1-\sigma) e_{t+i}^h + \sigma e_{t+1+i}^h \right] \right\}$$
$$+ \sum_{h=i,n} \pi^h \sigma E_t \Lambda_{t,t+1} \lambda_t^h \left[q_t b_t^p \omega_t + q_t^* b_t^{p*} - \chi m_t^h \right]$$
$$s.t.$$

$$e_t^h = f_t(x_{t-1}, m_{t-1}, d_{t-1}, b_{t-1}^p, b_{t-1}^{p*}) \tag{A.1}$$
$$= \left[Z_t + (1-\delta) Q_t^h \right] \psi_t x_{t-1} - R_{t-1}^M m_{t-1} - R_{t-1}^D d_{t-1} + \left(b_{t-1}^p + b_{t-1}^{p*} - AC(b_{t-1}^p, b_{t-1}^{p*}) \right)$$

$$e_{t+1}^h = g_t(e_t^h) \tag{A.2}$$
$$= \frac{\left[Z_{t+1} + (1-\delta) Q_{t+1}^h \right]}{Q_t^h} \psi_{t+1} \left(e_t^h + m_t + d_t - q_t b_t^p - q_t^* b_t^{p*} \right) - R_t^M m_t - R_t^D d_t + b_t^p + b_t^{p*} - AC(b_t^p, b_t^{p*})$$

To get equation (17) of Section 3.3, we proceed in the following steps:

FOC w.r.t. d_t

$$\sum_{h=i,n} \pi^h \sigma E_t \Lambda_{t,t+1} \left[(1-\sigma) \frac{\partial f_{t+1}}{\partial d_t} + \sigma \frac{\partial g_{t+1}}{\partial e_{t+1}^h} \frac{\partial f_{t+1}}{\partial d_t} \right] = \sum_{h=i,n} \pi^h \sigma E_t \Lambda_{t,t+1} \lambda_t^h \chi \frac{\partial m_t^h}{\partial d_t}, \tag{A.3}$$

where we have used λ_t^h to denote the Lagrange multiplier associated to the collateral constraint.

Using $\frac{\partial m_t^h}{\partial d_t} = -1$ (by the bank's balance sheet constraint) and $\frac{\partial f_{t+1}}{\partial d_t} = (R_t^M - R_t^D)$ and defining the shadow/marginal value of net worth at time $t+1$ as $\Omega_{t+1} \equiv (1-\sigma) + \sigma(\frac{\partial g_{t+1}}{\partial e_{t+1}^h}) = (1-\sigma) + \sigma(\frac{[Z_{t+2}+(1-\delta)Q_{t+2}^h]}{Q_{t+1}^h}\psi_{t+2})$[21] Eq. (A.3) becomes:

$$E_t\Lambda_{t,t+1}\Omega_{t+1}(R_t^D - R_t^M) = E_t\Lambda_{t,t+1}\chi\bar{\lambda}_t \tag{A.4}$$

where $\bar{\lambda}_t = \left(\pi^i\lambda_t^i + \pi^n\lambda_t^n\right)$. Since in equilibrium the collateral constraint is never binding for banks in sector n, $\lambda^n = 0$ and $\bar{\lambda}_t = \pi^i\lambda_t^i$.

To get equation (18) of Section 3.3, we proceed in the following steps:

FOC w.r.t. x_t^h

$$\sigma E_t\Lambda_{t,t+1}\left[(1-\sigma)\frac{\partial f_{t+1}}{\partial x_t^h} + \sigma\frac{\partial g_{t+1}}{\partial e_{t+1}^h}\frac{\partial f_{t+1}}{\partial x_t^h}\right] = \sigma E_t\Lambda_{t,t+1}\lambda_t^h\chi\frac{\partial m_t^h}{\partial x_t^h}. \tag{A.5}$$

Using $\frac{\partial m_t^h}{\partial x_t^h} = Q_t^h$ (by the bank's balance sheet constraint) and $\frac{\partial f_{t+1}}{\partial x_t^h} = ([Z_{t+1} + (1-\delta)Q_{t+1}^h]\psi_{t+1} - R_{t+1}^M Q_t^h)$, Eq. (A.5) becomes

$$E_t\Lambda_{t,t+1}\Omega_{t+1}\left\{\frac{[Z_{t+1} + (1-\delta)Q_{t+1}^h]}{Q_t^h}\psi_{t+1} - R_t^M\right\} = E_t\Lambda_{t,t+1}\left\{\lambda_t^h\chi\right\}. \tag{A.6}$$

To get equation (19) of Section 3.3, we proceed in the following steps:

FOC w.r.t. b_t^p

$$\sum_{h=i,n}\pi^h\sigma E_t\Lambda_{t,t+1}\left[(1-\sigma)\frac{\partial f_{t+1}}{\partial b_t^p} + \sigma\frac{\partial g_{t+1}}{\partial e_{t+1}^h}\frac{\partial f_{t+1}}{\partial b_t^p}\right] + \sum_{h=i,n}\pi^h\sigma E_t\Lambda_{t,t+1}\lambda_t^h\left[q_t\omega_t - \chi\frac{\partial m_t^h}{\partial b_t^p}\right] \tag{A.7}$$

Using $\frac{\partial m_t^h}{\partial b_t^p} = q_t$ (by the bank's balance sheet constraint) and $\frac{\partial f_{t+1}}{\partial b_t^p} = (1 - \frac{\partial AC(.)}{\partial b_t^p} - R_t^M q_t)$, Eq. (A.7) becomes:

$$E_t\Lambda_{t,t+1}\Omega_{t+1}\left(\frac{1-\frac{\partial AC(.)}{\partial b_t^p}}{q_t} - R_t^M\right) = E_t\Lambda_{t,t+1}\left[\bar{\lambda}_t(\chi-\omega)\right] \tag{A.8}$$

Similarly, the FOC w.r.t. b_t^{p*} is:

$$E_t\Lambda_{t,t+1}\Omega_{t+1}\left(\frac{1-\frac{\partial AC(.)}{\partial b_t^{p*}}}{q_t^*} - R_t^M\right) = E_t\Lambda_{t,t+1}\left\{\bar{\lambda}_t[\chi-1]\right\} \tag{A.9}$$

References

Acharya, V., Drechsler, I., Schnabl, P., 2014. A pyrrhic victory? bank bailouts and sovereign credit risk. J. Finance 69 (6), 2689–2739.
Adrian, A., Schüler, Y., 2012. Credit spread interdependencies of European states and banks during the financial crisis. J. Bank. Finance 36 (12), 3444–3468.
Altavilla, C., Pagano, M., Simonelli, S., 2016. Bank exposures and sovereign stress transmission. ECB Working Paper Series No 1969.
Arellano, C., Bai, Y., 2014. Linkages across sovereign debt markets. Manuscript, Federal Reserve Bank of Minneapolis.
Avino, D., Cotter, J., 2014. Sovereign and bank CDS spreads: Two sides of the same coin. J. Int. Financial Markets, Institutions, and Money 32 (C), 72–85.
Basu, S., 2009. Sovereign debt and domestic economic fragility. Massachusetts Institute of Technology.
Bedendo, M., Colla, P., 2015. Sovereign and corporate credit risk: evidence from the eurozone. J. Corp. Finance 33, 34–52.
Bekooij, J., Frost, J., van der Molen, R., Muzalewski, K., 2016. Hazardous tango: Sovereign-bank interdependencies across countries and time. DNB working paper No. 541. Amsterdam.
Bocola, L., 2014. The pass-through of sovereign risk. J. Pol. Econ. 124 (4), 879–926.
Bofondi, M.L.C., Sette, E., 2012. Credit supply during a sovereign debt crisis. SSRN electronic journal.
Bolton, P., Jeanne, O., 2011. Sovereign default risk and bank fragility in financially integrated economies. IMF Econ. Rev. 59 (2), 162–194.
Brutti, F., 2011. Sovereign default and liquidity crises. J. Int. Econ. 84 (2), 65–72.
Cooper, R., Nikolov, K., 2013. Government debt and banking fragility: the spreading of strategic uncertainty. National Bureau of Economic Research.
Ejsing, J., Lemke, W., 2011. The janus-headed salvation: sovereign and bank credit risk premia during 2008-009. Econ. Lett. 110 (1), 28–31.
Engler, P., Große Steffen, C., 2016. Sovereign risk, interbank freezes, and aggregate fluctuations. Eur. Econ. Rev. 87, 34–61.
Gennaioli, N., Martin, A., Rossi, S., 2014. Sovereign default, domestic banks, and financial institutions. J. Finance 69 (2), 819–866.
Gertler, M., Karadi, P., 2011. A model of unconventional monetary policy. J. Monetary Econ. 58 (1), 17–34.
Gertler, M., Karadi, P., 2013. Qe 1 vs. 2 vs. 3...: a framework for analyzing large-scale asset purchases as a monetary policy tool. Int. J. Central Bank. 9 (1), 5–53.
Gertler, M., Kiyotaki, N., 2011. Financial intermediation and credit policy in business cycle analysis. Handbook Monet. Econ. 3 (3), 547–599.
Gorton, G., Metrick, A., 2012. Securitized banking and the run on repo. J Financ. Econ. 104 (3), 425–451.
Guerrieri, L., Iacoviello, M., Minetti, R., 2013. Banks, sovereign debt, and the international transmission of business cycles. In: International Seminar on Macroeconomics, Vol. 9. NBER, pp. 181–213.

[21] The marginal value of net worth is the weighted average of the marginal value of exit (with probability $(1-\sigma)$) and the marginal continuation value (with probability σ). In the case of bank exit the value is equal to 1. The continuation value is the return on assets that can be increased by acquiring an additional unit of equity.

Hördahl, P., King, M.R., 2008. Developments in repo markets during the financial turmoil. BIS Q. Rev. 37.
Kalemli-Ozcan, S., Papaioannou, E., Perri, F., 2013. Global banks and crisis transmission. J. Int. Econ. 89 (2), 495–510.
Kollmann, R., Enders, Z., Müller, G.J., 2011. Global banking and international business cycles. Eur. Econ. Rev. 55 (3), 407–426.
Leonello, A., 2017. Government guarantees and the bank-sovereign nexus. Research Bulletin, European Central Bank 35, 1–4.
Mendoza, E.G., Yue, V.Z., 2012. A general equilibrium model of sovereign default and business cycles. Q. J. Econ. 127, 889–946.
Minetti, R., Peng, T., 2013. Lending constraints, real estate prices and business cycles in emerging economies. J. Econ. Dyn. Control 37(12), 2397–2416.
Niemann, S., Pichler, P., 2017. Collateral, liquidity and debt sustainability. Econ. J. forthcoming.
Padilla, C.S., 2013. Sovereign defaults and banking crises. Technical Report. MPRA Working Paper.
Schmitt-Grohé, S., Uribe, M., 2003. Closing small open economy models. J. Int. Econ. 61, 163–185.