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Bank and Sovereign Debt Risk Connection

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Abstract

Euro area data show a positive connection between sovereign and bank risk, which increases with banks' and sovereign long run fragility. We build a macro model with banks subject to incentive problems and liquidity risk (in the form of liquidity based banks' runs) which provides a link between endogenous bank capital and macro and policy risk. Our banks also invest in risky government bonds used as capital buffer to self-insure against liquidity risk. The model can replicate the positive connection between sovereign and bank risk observed in the data. Central bank liquidity policy, through full allotment policy, is successful in stabilizing the spiraling feedback loops between bank and sovereign risk.

Keywords: liquidity risk, sovereign risk, capital regulations.

1 Introduction

There is by now a widely shared understanding that one of the elements producing the escalation behind the euro area sovereign debt crisis has been the tight and intricate link between sovereign and bank risk, which resulted by the extensive exposure of banks onto the secondary market for government bonds.

Of course the link has no univocal causality. In the aftermath of the 2007 crises many euro area governments had spent considerable public resources to conduct explicit or implicit bail out policies of banks under distress; in many cases those actions had put public finances on an un-sustainable path, which eventually triggered a confidence crisis on government bonds with skyrocketing spreads in a few but important cases (notably Greece, Ireland and Portugal). However, more recently the reverse causality is becoming worrisome particularly for policy makers and financial regulators. In most euro area countries banks have invested widely in government bonds. This happened primarily for two reasons. First, to satisfy regulatory or internal capital requirements banks shall invest a certain fraction of capital into liquid-safe assets (Tier 1 capital). The loss in balance sheet values ensuing the 2007 crisis forced banks to increase the fraction of Tier 1 capital. In 2007-2008 euro area government bonds represented a significant part of Tier 1 capital due to the small spread differentials between various national bonds and the German bund. There was also a second reason which induced many euro area banks to invest highly in government bond in the aftermath of the 2007 crisis. While prior to this date several banks had the opportunity to invest in triple A asset backed securities[1], as the market for asset backed securities and other derivatives soared, most banks turned to other assets to replenish Tier 1 capital, primarily government bonds. Notice that government bonds, contrary to stock market equities, were also assigned low risk weights into the regulatory requirements, hence they were officially recognized as part of the Tier 1 capital. When the confidence loss hit many government bond markets in 2009-2010, risk spreads on several national bonds climbed, thereby implicitly increasing banks' exposure to macroeconomic and policy risk. Such mechanism can clearly trigger a *feedback loop*: as banks' risk climbs, official regulations induce

[1] Asset backed securities had been initially conceived as a mean of raising banks' liquidity beyond that obtained through regular checking and saving deposits. As during the 2000s more and more ABS were assigned triple A ratings, most banks around the globe started to consider them as a mean of safe (due to the seniority status) but lucrative investment.

intermediaries to hold increasing fractions of government bonds[2], whose risk in turn puts banks' balance sheets under further stress. This self-reinforcing propagation mechanism effectively induced central banks to intervene in secondary markets for government bonds. In the case of the ECB this was done mainly through full allotment interventions on repo markets, operations which per se helped to guarantee that such easing of liquidity would not affect long run money growth. Even so, monetary policy interventions to buy bonds (from banks) in the secondary market at *distorted* prices (lower risk spreads) effectively produced an implicit transfer to the banking system.

We build a macro model consistent with the main facts reported above to assess the likelihood and the extent that banks-sovereign interaction produces system wide risk. Our benchmark economy builds on Faia [1] by adding liquidity needs in the banking sector for precautionary motives. First banks serve the function of delegated monitor of investment project on behalf of uninformed investors. Following Holmstrom and Tirole [4], within this function banks face a dual moral hazard problem. On the one side, banks face moral hazard with entrepreneurs who run risky projects and receive private benefits by projects with low probability of success: for this reasons banks have to exert costly monitoring. Uninformed investors face moral hazard problems with banks, which might decide to save on monitoring costs, thereby transferring risk onto investors. Those mis-incentives are disciplined through a three party contract. Importantly however the presence of moral hazard on both sides of the balance sheet prevents banks from insuring away risk. Bank capital, chosen endogenously by banks, serves the purpose of discipline device for such intrinsic risk: the Modigliani Miller fails to hold for banks' financing decisions and intermediary capital acquires a special role which requires the payment of rents or intermediation premia. Such frictions on the intermediation services render the interaction between intermadiary capital, investment and the business cycle prone to instability: negative financial or liquidity shocks increase bank capital scarcity, raise intermediary premia and reduce available credit to firms. This type of intermediary driven credit crunch renders the model suitable to analyze the link between risk on sovereign bonds, an asset which can be part of banks' portfolios, and instability in the intermediation sector and the

[2] Effectively the risk factors assigned to government bonds by regulatory capital requirements such as Basel III had remained low throughout the euro area sovereign debt crisis. One possible explanation behind the inaction to adjust the risk factors could likely be due to the fact that, in absence of alternative high rated assets to invest upon, regulators felt that an increase in the risk factors assigned to government bonds might have implicitly pushed several banks into a technical default.

impact of this link on the macroeconomy. Additionally, notice that in our model intermediary's capital in our model behaves counter-cyclical (it rises in recessions) in response to both macro shocks and policy risk shocks: this link is in line with empirical evidence and renders the model suitable for policy analysis.

While fundamental risk is disciplined through the three party contract and by the intermediary premia as explained above, we assume that liquidity risk might still emerge. The emergence of news or imprecise signals on banks' health might induce liquidity based deposit withdrawals[3]. Sudden deposit withdrawals put liquidity pressure on banks, which in turn need to self-insure by holding significant buffers of assets with uncorrelated risk, namely government bonds. This results in a form of precautionary saving. The higher the uncertainty about expected bank returns among investors, the higher the buffers required in the banking sector. Higher liquidity buffers result in higher liquidity hoarding, as larger fraction of bank funding are invested in government bonds. This in turn results in a contraction of credit supply to firms. Onto this picture we also insert a stylized fiscal sector. We consider the case of risky government bonds, with a geometrically decreasing coupon[4]. A negative fiscal shock by precipitating a fall in bond prices has two effects. Firstly, more bonds are needed to provide a equivalent collateral value in the interbank market, so banks' demand for bonds increases. Secondly, unexpected falls in government bond price lead to trading losses that hit banks capital positions and entail durable credit supply contraction[5].

The framework outlined so far is first used to asses the transmission of standard macro shock. To asses the role of the link between sovereign risk and the presence of government bonds onto banks' balance sheet, we compare impulse response functions of the model with and without sovereign premia. We find that the introduction of sovereign risk exacerbate the effects of shocks: negative shocks force banks to increase capital buffer; when this is done using risky government

[3]Deposit withdrawals in our model do not produce economy wide destruction of resources, as depositors simply move funds from one bank to the other.

[4]A proper account of government default risk would require computing risk spreads based on the actual probability of default as resulting from the fulfillment of the discounted government budget constraint. A full account would actually also require to take into consideration the possibility of strategic default. However since our model features a rich banking sector, we decided to do parsimonious assumptions on the fiscal side. Such parsimony will actually produce more conservative, rather than exaggerated, results in terms of economy-wide risk amplification.

[5]Liquidity buffers are carried from period to period by bankers, who take alone all losses and gains realized on the bonds. For example, profits made on government bond holdings do not lead to lower rates for bank's customers or higher rates for bank's investors: bankers alone enjoy the benefit.

bonds, a feedback loop is activated that amplifies the recessionary consequences of macro shocks. Importantly we also find that the correlation between bank and sovereign risk characterizing the response of our model to liquidity and/or macro shocks, can replicate the equivalent correlation found in EU data. Finally, we assess the role of central bank liquidity provisions as stability inducing device. Central bank liquidity provision can have real effects in our model (by enhancing credit supply) only when accepting repos in government bonds at a *distorted price,* namely the price associated with a lower probability of sovereign default. At this price banks can borrow more from the central bank than they could on the market against the same quantity of bonds, hence liquidity buffers required are smaller and credit supply is higher. In the short run liquidity provisions enhance credit supply so it generally reduces the amplification of macro shocks and reduces the correlation between sovereign and bank risk[6].

The rest of paper is organized as follows. Section 2 outlines the model. Section 3 shows quantitative properties of the model primarily in his ability to match bank and sovereign risk correlation as observed in the data. Section 4 analyzes the role of central banks interventions onto sovereign bond markets. Section 5 concludes. Appendices, figures and tables follow.

2 A Macro Model with Endogenous Bank Capital and Liquidity Risk

The macro model economy is populated by three type of agents: households/workers/uninformed investors, entrepreneurs and banks[7]. Production of final goods takes place in a competitive sector which employes capital and labour. A second sector produces physical capital goods: firms in this sector obtain funds from banks to finance investment projects. Banks obtain funds through deposits, but they also invest their bank capital. A dual moral hazard arises between banks and entrepreneurs requiring funds on the one side and between banks and depositors (also referred to us uninformed investors) on the other. Given the presence of agency problems, full risk insurance against projects' failure is not possible. However the fundamental risk arising from the credit

[6] There is an implicit risk transfer from private banks to the central bank balance sheet, however it is assumed that the latter cannot default. Therefore risk on central bank balance sheet does not carry resource costs in our model.

[7] The latter two are finitely lived and risk neutral agents: the assumption prevents buffer asset accumulation that would overcome the need of external finance. It also allows aggregation via simple averaging of individual optimizing decisions.

relation can be disciplined through a three party contract and the endogenous choice of bank capital. The bank also faces liquidity risk due to an exogenous probability of sudden deposit withdrawals, which is triggered by the arrival of news (imprecise signals) on banks' balance sheet conditions. Banks can self-insure against this liquidity risk by holding assets with uncorrelated risk, such as government bonds. This implicitly reduces banks available funding for firms' lending. The fiscal sector features exogenous government spending and lump taxes and accumulates risky bonds.

2.1 Households

A continuum of households consume, work in the production sector, invest in bank deposits and physical capital. They take consumption decisions to maximize the following lifetime expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \{U(C_t) - V(H_t)\} \tag{1}$$

where C_t denotes households consumption and H_t labour hours. Their budget constraint, in real terms, reads as follows:

$$C_t + q_t I_t^h + D_{t+1} = (1 + r_t^n) D_t + Z_t K_t^h + \frac{W_t}{P_t} H_t - \tau_t \tag{2}$$

where q_t denotes the price of capital, I_t^h denotes capital investment done by households, $(1+r_t^n)$ is the gross nominal interest rate received on deposits, D_t are real deposits, Z_t is the real rental rate of capital, K_t^h is the amount of physical capital invested by households, $\frac{W_t}{P_t} H_t$ is real labour income and τ_t are lump sum taxes. The capital investment evolves according to:

$$K_{t+1}^h = (1 - \delta) K_t^h + I_t^h \tag{3}$$

The first order conditions of the above problem read as follows:

$$u\acute{}(C_t) = \beta E_t \left\{ u\acute{}(C_{t+1}) \frac{(1 + r_t^n) P_t}{P_{t+1}} \right\} \tag{4}$$

$$q_t u\acute{}(C_t) = \beta E_t \{ u\acute{}(C_{t+1})(q_{t+1}(1 - \delta) + Z_{t+1}) \} \tag{5}$$

$$\frac{W_t}{P_t} u\acute{}(C_t) = -v\acute{}(H_t) \tag{6}$$

Equation 4 is the standard Euler conditions with respect to deposits. Equation 5 is the first order condition with respect to capital holding. Finally, equation 6 is the first order condition with respect to labour hours. The set of first order conditions must hold alongside with a no-Ponzi condition on wealth. Notice that for simplicity we prevented households from investing in government bonds: in this case bond demand would come both from banks and households. Such an additional assumption however is not going to change the main transmission mechanism between sovereign and bank risk.

2.2 Final good firms

The final goods in this economy are produced by a continuum of competitive firms operating under a Cobb-Douglas production function, $Y_t = A_t(H_t)^{\alpha}(K_t)^{1-\alpha}$, where A_t is an aggregate productivity shock which follows an AR(1) process, α is the share of capital in production, K_t denotes rental physical capital and H_t is the labour input. Each firm chooses production input optimally by minimizing costs. Optimality conditions read as follows:

$$\frac{W_t}{P_t} = mc_t A_t \alpha (H_t)^{\alpha-1}(K_t)^{1-\alpha}, Z_t = mc_t A_t (H_t)^{\alpha}(1-\alpha)(K_t)^{-\alpha} \tag{7}$$

where mc_t is the lagrange multiplier on the production function and represents firms' marginal costs.

2.3 Capital good production

Entrepreneurs produce capital goods after acquiring funds from the bankers. The latter raise funds through deposits and their own capital. The sections below provide details about the capital production technology and the financial contract behind the lending activity.

2.3.1 Bankers and entrepreneurs: utility and consumption

Bankers and entrepreneurs are both risk neutral and finite lived agents[8]. Their respective probability of exiting their business each period are γ^b and γ^e. Their respective worth at period t are denoted BK_t and NW_t . We assume that both those agents consume their entire wealth when they exit and save their entire wealth otherwise. This assumption is introduced as it facilitates wealth

[8] This assumption is needed to prevent that sufficient precautionary savings offsets the external funding constraints.

aggregation. For both agents indeed wealth is accumulated only through the surviving agents, hence by law of large number aggregate wealth is given by the individual wealth weighted by the survival probability. Similarly consumption is given by the wealth of agents who exit the economy at time t conditional on being in the business at date t. Given risk neutrality, the sum of total discounted expected utility respectively for bankers and entrepreneurs is given by:

$$V_t^b = E_t \sum_{i=1}^{+\infty} \gamma^b \left(1-\gamma^b\right)^{i-1} BK_{t+i} \tag{8}$$

and

$$V_t^e = E_t \sum_{i=1}^{+\infty} \gamma^e \left(1-\gamma^e\right)^{i-1} NW_{t+i} \tag{9}$$

2.4 The optimal contract

The financial contract is an inter-temporal adaptation[9] of the three party contract (involving depositors, entrepreneurs and bankers) in Holmstrom and Tirole [4]. It is assumed that the project starts at the end of period t , that capital goods are produced at the beginning of period $t+1$ and are then rented to intermediate good producers. Only after final good production has taken place does the profit distribution occurs.

Entrepreneurs plan for an initial investment of I_t units of consumption good in period t, which returns RI_t units of capital goods at the beginning of period $t+1$ if the project succeeds and 0 units if it fails. The entrepreneurs finances the project using partly his own funds, NW_t, and partly by borrowing, $(I_t - NW_t)$. If the project is successful, capital goods are rented to intermediate good producers and the payoffs are distributed only afterwards to the parties involved. Entrepreneurs can privately choose between three different projects: a project with high probability of success p_h and 0 private benefit, projects with low probability of success p_l and private benefits respectively equal to bI_t and BI_t , with $b < B$. The bank can use a monitoring technology that prevents the entrepreneur from undertaking the project with low probability of success p_l and high private benefits BI_t , but cannot prevent the firm from undertaking the project with low probability of

[9] We consider an inter-temporal contract as it allows us to consider the role that assets with risky returns (such as government bonds), held in bankers' balance sheet, can play in the intermediation process.

success and lower private benefits $bI_t{}^{10}$. Monitoring entails a non-verifiable cost cI_t in final goods for the bank[11]. Costly monitoring creates a second moral hazard problem between the bank, on the one side, and uniformed investors (depositors), on the other. Such moral hazard problem is disciplined by the amount of bank capital invested in the project, BK_t. The presence of moral hazard on both sides of the contract allows both entrepreneurs and bankers to extract a rents, which serve as incentive devices. Bankers raise funds through their own capital and depositors. Part of the bankers funds is used to cover for the monitoring costs and part is used as asset buffer, which we assume consisting of government bonds, $(z_t - 1) B_t^b$ (where B_t^b is the bankers demand for government bonds and $(z_t - 1)$ is their risky price; we will return on the specification of the government bonds later on) . As a result of the above assumptions the feasibility constraint of the project reads as follows:

$$(I_t - NW_t) + (z_t - 1) B_t^b \leq BK_t - cI_t + D_t \tag{10}$$

In equilibrium banks do pay the monitoring cost cI_{t-1}, since, although it shrinks the available funds to the project, it does ensure that entrepreneurs cannot shirk.

2.5 The financial contract and profit sharing

A three party contract among depositors, banks and entrepreneurs delivers a return of zero if the project fails and a gross return, R, if the project succeeds. Total project (net) return is shared according to the fractions s_t^h, s_t^e, s_t^b, which sum up to one . Limited liability ensures that no agent earns a negative return. Since the bank monitors firms, it is assumed ex-ante that projects succeed with probability p_h. This rules out the project with benefit B. The firm is then left to choose between the project with benefit b and the one with zero benefit.

Given the inter-temporal nature of the contract and in order to preserve the contract recursivity we assume that only the entrepreneurs and the bankers which become aware of their exit from business in the next period have an incentive to shirk. The assumption is reasonable, as non-

[10]Monitoring reduces the incentive to shirk, but not fully: this retain a role for entrepreneurial and bank capitalists net worth as a discipline devices.

[11]Banks have access to a monitoring technology which takes different forms: inspection of firms' balance sheet position and potential cash flow, management quality, verification that the firm conforms with financial covenants, etc..

exiting entrepreneurs and bankers would suffer a reputational loss by shirking. This implies that only exiting entrepreneurs need to be disciplined and that the incentive compatibility constraints characterizing the contract will apply only to them. We will return on this point later.

Prior to outline the design of the contract, we shall characterize the inter-temporal payoffs and the sharing rules to which all three agents involved in the contract agree ex ante. If a project launched at date t succeeds, the total real pay-off at date $t+1$ is:

$$\Pi_{t+1}^{success} = \left[r_{t+1}^{k} + q_{t+1}(1-\delta) \right] RI_t + \frac{\left(1+r_{t+1}^{g}\right)}{\pi_{t+1}} (z_t - 1) B_t^b \tag{11}$$

where $\left(1+r_{t+1}^{g}\right)$ is the risky return on government bonds and π_{t+1} is the inflation rate. Notice that the additional asset buffer, B_t^b, is acquired by the bank only when engaging in the lending activity. We can rewrite this payoff to highlight the risky nature of government bonds:

$$\Pi_{t+1}^{success} = \hat{\Pi}_{t+1}^{success} + \frac{\left(r_{t+1}^{g} - r_t^n\right)}{\pi_{t+1}} (z_t - 1) B_t^b \tag{12}$$

where $\hat{\Pi}_{t+1}^{success} = \left[r_{t+1}^{k} + q_{t+1}(1-\delta) \right] RI_t + \dfrac{(1+r_t^n)}{\pi_{t+1}} (z_t - 1) B_t^b$. The equation above shows that changes in the price of government bonds and/or in the sovereign premia, $\left(r_{t+1}^{g} - r_t^n\right)$, do affects banks' balance sheets by affecting profits from bond trading.

The three parties agree at date t to share the returns of the successful project in the following way:

$$\begin{aligned} \Pi_{t+1}^{e} &= s_t^e \hat{\Pi}_{t+1}^{success} \\ \Pi_{t+1}^{b} &= s_t^b \hat{\Pi}_{t+1}^{success} + \frac{\left(r_{t+1}^{g} - r_t^n\right)}{\Pi_{t+1}} (z_t - 1) B_t^b \\ \Pi_{t+1}^{h} &= s_t^h \hat{\Pi}_{t+1}^{success} \end{aligned} \tag{13}$$

where $s_t^h = 1 - s_t^e - s_t^b$. The profit shares will be chosen optimally within the three party contract.

Entrepreneurs have all the bargaining power in the contract relation. The optimal contract, at the beginning of period t , determines the investment size I_t, the banker's participation BK_t, the depositor participation D_t, the liquidity buffer B_t^b and the shares of returns accruing respectively to the entrepreneur, the banker and the depositor s_t^e, s_t^b, s_t^h in order to maximize the entrepreneurs expected return:

$$\max_{\{I_t, BK_t, D_t, B_t^b, s_t^e, s_t^b, s_t^h\}} V_t^e \tag{14}$$

Subject to the following constraints.

First the *entrepreneurs' incentive constraint,* which implies that the expected next period returns from the choosing the project with high probability of success, p_h, are higher than those associated with the project with the low probability of success p_l, but with private benefit b:

$$\begin{aligned} E_t\left(\left[r_{t+1}^k + q_{t+1}(1-\delta)\right] p_h s_t^e R I_t\right) &\geq E_t\left(\left[r_{t+1}^k + q_{t+1}(1-\delta)\right] p_l s_t^e R I_t\right) + q_t I_t b \\ q_t p_h s_t^e R I_t &\geq q_t p_l s_t^e R I_t + q_t I_t b \end{aligned} \tag{15}$$

Second the *bankers' incentive constraint,* which implies that bankers' expected next period returns when they perform the monitoring activity are higher than in absence of it:

$$\begin{aligned} E_t\left(\left[r_{t+1}^k + q_{t+1}(1-\delta)\right] p_h s_t^b R I_t\right) &\geq E_t\left(\left[r_{t+1}^k + q_{t+1}(1-\delta)\right] p_l s_t^b R I_t\right) + c I_t \\ q_t p_h s_t^b R I_t &\geq q_t p_l s_t^b R I_t + c I_t \end{aligned} \tag{16}$$

The third constraint is the *bankers participation constraint,* which at the beginning of time t ensures that bankers engaging in the lending activity receive a future discounted sum of utilities which is larger than the proceeds from an outside investment opportunity. We define the outside investment opportunity through the following specification: bankers invest initial wealth, BK_{t-1}, at a market rate $\dfrac{(1+r_t^m)}{\Pi_{t+1}}$, exit the intermediation activity and consume all wealth available at time t[12]:

$$V_t^b \geq BK_t = BK_{t-1}\frac{(1+r_t^m)}{\Pi_{t+1}} \tag{17}$$

[12] Following much of literature it is assumed that this constraint is never binding (something which we will verify in the simulations). Thus, this equation does not constrain the optimization problem.

The fourth constraint is represented by the *investors' participation constraint,* which implies that depositors prefer to enter the financial contract than earning the risk-free return (policy rate):

$$
\begin{aligned}
E_t\left(\Lambda_{t,t+1}\Pi^h_{t+1}\right) &\geq E_t\left(\Lambda_{t,t+1}\frac{(1+r^n_t)}{\Pi_{t+1}}D_t\right) \qquad (18)\\
s^h_t.E_t\left(\Lambda_{t,t+1}\left(\left[r^k_{t+1}+q_{t+1}(1-\delta)\right]p_hRI_t+(1+r^n_t)(z_t-1)B^b_t\right)\right) &\geq D_t\\
s^h_t.\left(q_tp_hRI_t+(z_t-1)B^b_t\right) &\geq D_t
\end{aligned}
$$

Notice that depositors' returns are initially weighted by their stochastic discount factor, $\Lambda_{t,t+1}=\beta\frac{u\acute{}(C_{t+1})}{u\acute{}(C_t)}$.

The contract is also subject to a *feasibility* condition which reads as follows.

$$I_t-NW_t+(z_t-1)B^b_t\leq BK_t+D_t-cI_t \qquad (19)$$

Monitoring costs cI_t are paid at date t and directly impact the available amount of loanable funds.

At last we need to consider the *bank self-insurance against liquidity risk,* whose rational and derivation is described in appendix A**:**

$$(z_t-1)B^b_t\geq\rho_tD_t \qquad (20)$$

The above constraint states that the bank wants to maintain an asset buffer, due to regulatory or precautionary motives, hence it invests in government bonds for an amount equivalent to the share of potential deposit withdrawals, ρ_t.

Finally we also need to consider the *returns distribution condition,* according to which profits share are allocated linearly:

$$s^h_t+s^e_t+s^b_t=1 \qquad (21)$$

The above contract is solved as follows. In equilibrium, equations (15) and (16) hold with equality (see Holmström, B. and J. Tirole [4]), giving :

$$s_t^e = \frac{b}{R\,(p_h - p_l)} \tag{22}$$

and

$$s_t^b = \frac{c}{q_t R\,(p_h - p_l)} \tag{23}$$

As a consequence, the share of returns accruing to depositors is the following:

$$s_t^h = 1 - \frac{b}{R\,(p_h - p_l)} - \frac{c}{q_t R\,(p_h - p_l)} \tag{24}$$

Inequality (20) is also binding in equilibrium. Substituting it in (19), which is also binding, yields:

$$I_t = \frac{BK_t + NW_t + D_t - (z_t - 1)\,B_t^b}{(1+c)} = \frac{BK_t + NW_t + D_t(1-\rho_t)}{(1+c)} \tag{25}$$

The equation above clarifies the role of the insurance buffer and the effects that changes on government bond prices can have on banks' decision and on the optimal investment schedule. A fall in bond prices (due to an increase in its risk) when the self-insurance constraint binds implies that banks can raise less deposits (for given probability of liquidity shock, ρ_t): this implicitly reduces the available resources for investment. In response to a negative (or positive) aggregate shock the fall (increase) in investment will be larger in presence of government bond risk: in this case indeed the fluctuations in the bond risk premium increase the sensitivity of short term banks' funding (deposits), and consequently in banks' assets (loans to investment projects) to aggregate conditions. The effects of of government bond risk will also be evaluated further below through the numerical comparison of the model with and without bond risk.

From (18), we obtain the deposit to investment ratio:

$$\frac{D_t}{I_t} = \frac{s_t^h q_t p_h R}{1 - s_t^h.\rho_t} \tag{26}$$

which, once merged with $I_t = \dfrac{BK_t + NW_t}{\left(1 + c - (1-\rho_t)\,\dfrac{D_t}{I_t}\right)}$, provides the following optimal investment schedule:

$$I_t = \frac{BK_t + NW_t}{\left(1 + c - \left(\frac{1-\rho_t}{1 - s_t^h.\rho_t}\right) q_t p_h R s_t^h\right)} \tag{27}$$

Investment size I_t decreases when aggregate liquidity risk ρ_t increases. Although the price of the bond, z_t, does not enter explicitly the investment equation, it does affect the bank's leverage ratio ($\frac{D_t}{I_t}$) through the self-insurance constraint. Finally note also that the expression above for investment is recursive because ρ_t does not depend on I_t (only on R_t^b/R_t i.e. on q_t).

2.6 Bankers and entrepreneurial wealth accumulation

Bankers' and entrepreneurs' wealth accumulation consists of the aggregate wealth of non-exiting bankers and entrepreneurs. Since wealth aggregation takes place at the of period t, it is useful to recall the chain of events taking place in the model. At the beginning of period t an aggregate capital stock K_t, which has been inherited from previous periods, is rented to final good producers. Production then takes place and gross interest rates on rented capital are paid back. Upon receipt of returns, households make consumption and investment decision, while bankers sell and purchase government bonds. A inter-temporal optimal financial contract is then signed between bankers, entrepreneurs and depositors (households). After the contract is signed, an idiosyncratic news shocks $\varepsilon_{n,i,t}$ realize and interbank lending takes place. At the end of the period projects' returns, R, are realized and shared between agents (s_t^b, s_t^e and s_t^h). Entrepreneurs and bankers consume if they exit the economy and invest in capital otherwise.

Period t capital of the bank is the sum of the proceeds from past period investment and the previous period holdings of government bonds B_t^b sold at market value z_t:

$$BK_t = \gamma^b \left[r_t^k + q_t (1-\delta)\right] p_h R_{t-1}^b q_{t-1} I_{t-1} + \Pi_t^{bonds} \tag{28}$$

where bank profits linked to the holding of government bonds are :

$$\Pi_t^{bonds} = \delta_c \left(z_{t+1} - \overline{z_{t+1}}\right) B_t^b \tag{29}$$

Government bonds are effectively ex post risky assets. Their price z_t can indeed fluctuate due to a default premium and a term premium (see details in the next section). An unexpected fall in the bond price z_t generates a loss that affects banks capital stock. Credit supply and investment in the following periods will also be reduced[13].As explained above the demand for government bonds on the side of the bank comes from the need for an asset buffer, $(z_t - 1) B_t^b = \rho_t D_t$. If z_t goes down, B_t^b goes up: banking sector's demand for government bonds increases in time of sovereign tension.

2.7 Long-term government bonds: prices and premia

Government bonds are infinitely lived and pay each period a geometrically decreasing coupon, whose rate of decay is δ_c.Let us denote z_t the price of a bond paying a coupon of 1 in period t.We have[14]:

$$z_t = 1 + \delta_c E_t \left(\Lambda_{t,t+1} \left(1 - \Delta_{t+1}\right) z_{t+1} \right) \tag{30}$$

where $\Lambda_{t,t+1}$ is the households discount factor and Δ_{t+1} is the expected default on government debt in period $t+1$ .The timing of events in the bond market at period t is as follows. The default haircut Δ_t is decided on previous period government debt B_{t-1}.Existing bonds are sold and purchased at price z_t and new bonds are issued. Coupons are paid to the current owners of the bonds.

It is important to notice that due to coupon payment in period t , the effective market value of the bond once the coupon has been paid is only $z_t - 1$[15]. The duration of the infinitely lived bond presented above can be fine-tuned using the parameter $\delta_c = \frac{1}{\beta}\left[1 - \frac{1}{1 + MacDur}\right]$,where $MacDur$ is the Macaulay duration. For example, $MacDur = 40$ quarters is obtained by setting $\delta_C = 0.9855$.

One unit of bonds is purchased at a cost $(z_t - 1)$ and can be sold at price $\delta_c z_{t+1}$ in the following period. Therefore the *ex-post return on bonds* is given by:

$$1 + r_t^g = (1 - \Delta_t) \frac{\delta_c z_t}{z_{t-1} - 1} \tag{31}$$

[13] Note that Π_t^{bonds} is expected to be positive in steady-state for two reasons: a. government bonds pay a risk premium because they are subject to default risk. b. government bonds also pay a term premium because they are long assets.

[14] See Rudebusch and Swanson [6].

[15] Notice that financial intermediaries purchase only bonds whose coupon has already been paid. Hence, the book value of a quantity B_t^b of bonds will be $(z_t - 1) B_t^b$.

To compute the term premium in the model, we define two additional prices. The first one is the default-free rate z_t^{DF} defined as:

$$z_t^{DF} = 1 + \delta_c E_t \left(\Lambda_{t,t+1} z_{t+1}^{DF} \right) \tag{32}$$

The second one is the risk-neutral rate, where the bond is priced using the risk-free rate r_t^n :

$$z_t^{RN} = 1 + \frac{\delta_c}{1 + r_t^n} E_t \left(z_{t+1}^{RN} \right) \tag{33}$$

The term-premium can then be defined as:

$$TP_t = \log \left(\frac{\delta_c z_t^{DF}}{z_{t-1}^{DF} - 1} \right) - \log \left(\frac{\delta_c z_t^{RN}}{z_{t-1}^{RN} - 1} \right) \tag{34}$$

2.8 Government debt accumulation

Real government debt evolves as follows:

$$B_t^{Stock} = B_t^{Issue} + \frac{\delta_c B_{t-1}^{Stock}}{\Pi_t} \tag{35}$$

New issuances are used to balance the government budget:

$$\frac{T_t}{P_t} + z_t B_t^{Issue} = 1 * (1 - \Delta_t) B_t^{Stock} + \frac{G_t}{P_t} + \frac{T_t^C}{P_t} \tag{36}$$

Fiscal revenues come from taxes T_t and new bond issuance $z_t B_t^{Issue}$, whereas expenditures come from government consumption G_t and the service of the debt stock B_t^{Stock}, including bonds emitted in current period[16]. The government budget constraint can also be written as:

$$\frac{T_t}{P_t} + (z_t - 1) B_t^{Stock} = \frac{\delta_c z_t B_{t-1}^{Stock}}{\Pi_t} + \frac{G_t}{P_t} \tag{37}$$

In each period the government repays past debt B_{t-1}^{Stock} at market price $\delta_c z_t$ and sells new bonds B_t^{Stock} at price $(z_t - 1)$.

[16] Exogenous government spending is calibrated so that sovereign default never materializes, even though households give a positive probability to this event.

2.9 Monetary and Fiscal Policy

We assume that monetary policy follows the traditional Taylor rule. As for the fiscal policy it acts according to the following rules:

$$\frac{T_t}{P_t} = \tau_t^w \frac{W_t}{P_t} H_t \tag{38}$$

$$(\tau_t^w - \tau^w) = \phi_Y^T (Y_t - Y) + \phi_B^T (B_t - B) \tag{39}$$

We also assume that the bond market clears:

$$B_t = B_t^b + B_t^{hh} \tag{40}$$

2.10 Calibration

This section is devoted to discuss the parameters and shock calibration used in quantitative simulations of the next section.

Household preferences and production. The time unit is the quarter. The utility function of households is $U(C_t, H_t) = \frac{C_t^{1-\sigma}-1}{1-\sigma} + \nu \log(1 - H_t)$, with $\sigma = 2$, as it is in most real business cycle literature aimed at capture risk aversion. The parameter ν is set equal to 6 and has been chosen in such a way to generate a steady-state level of employment $H \approx 0.3$. The discount factor is set to $\beta = 0.99$, so that the annual real interest rate is equal to 4%. The production function is a Cobb-Douglas, $F(\bullet) = K_t^{\alpha}(H_t)^{1-\alpha}$, with $\alpha = 0.3$. The quarterly aggregate capital depreciation rate δ is 0.025.

Banks. The parameters characterizing the contract among bankers, depositors and entrepreneurs, p^h, p^l, c, R, b, and the wealth accumulation parameters, γ^e, γ^b, are calibrated as follows. The p^h is set equal to 0.9 to reproduce firms' quarterly failure rate in industrialized countries, as reported in most of the macro literature on firm dynamic and/or credit frictions. The remaining parameters are set in the two models so as to induce the following steady state values. 1). A capital adequacy ratio, $\frac{BK}{BK+D}$, of 19% in line with BIS data [2]. 2). A ratio of investment over output, $\frac{I}{Y}$, approximately of 0.15, a value compatible with most RBC studies. 3). A ratio of capital over output, $\frac{K}{Y}$, of 6.6, value set in accordance with ranges considered in the RBC literature. 4). A ratio of investment over entrepreneurial net worth of, $\frac{I}{NW}$, equal to 2. And 5) a return on bank equities (ROE), $\gamma^b \left[Z_{t+1} + q_{t+1}(1-\delta)\right] p_h R_t^b$, of 16%, a value compatible with data reported in Berger [3], who looks at historical averages, while the second value in the range is more in line with the higher ROE observed in the decade prior to the 2007 crisis (see American Banking Association). 6). Banks operating costs of 5 percent of investment. 7) A share of deposits subject to withdrawals of 0.2.

Sovereign risk and fiscal sector. Parameters in the fiscal rules are set as follows: $\phi_Y^T = 0; \phi_B^T = 0.5$.The expected sovereign bond premium, Δ_t, is computed using a Beta distribution with the following parameters, $\alpha^{BG} = 3.70$,$\beta^{BG} = 0.54$,and a maximum debt to output ratio of 2.56.

Shocks. The shocks considered include the standard macro shocks (productivity and government spending) as well as financial and liquidity shocks. Productivity shock are modeled as AR(1) processes, $A_t = A_{t-1}^{\rho_\alpha} \exp(\varepsilon_t^\alpha)$,where the steady-state value A is normalized to unity,$\rho_\alpha = 0.95$ and $\sigma_{\varepsilon^\alpha} = 0.008$. Log-government consumption evolves according to the following exogenous process, $\ln\left(\frac{g_t}{g}\right) = \rho_g \ln\left(\frac{g_{t-1}}{g}\right) + \varepsilon_t^g$, where the steady-state share of government consumption, g, is set so that $\frac{g}{y} = 0.25$ and ε_t^g is an i.i.d. shock with standard deviation σ_g. Empirical evidence for the US in Perotti 2004 suggests $\sigma_g = 0.0074$ and $\rho_g = 0.9$.

3 Quantitative results

The main goal of the paper is to check whether our model can replicate the stylized fact observed in the data of a positive correlation between bank and sovereign risk. Prior to verify this, it is instructive to analyze the transmission mechanism of the model by describing the behavior of selected variables via impulse responses to standard macro shocks and/or to shocks to government debt risk. Understanding the transmission mechanism of the model will also guide us in the interpretation of the results related to the link between bank and sovereign risk.

Figure 1 shows the impulse responses of selected variables to a 1% (negative) technology shock in the model with (dashed line) and without (solid line) risk on government bonds: comparing the two models gives an idea of the impact that the interaction between bank and sovereign risk might have onto the model.

As expected output, consumption and investment go down due to the contractionary nature of the shock. When investment demand and the return to investment fall, both entrepreneurial net worth and bank capital (not shown) fall. The bank capital ratio falls in the initial period, but then raises again. The reason is as follows. As the scale of required investment falls, the amount of

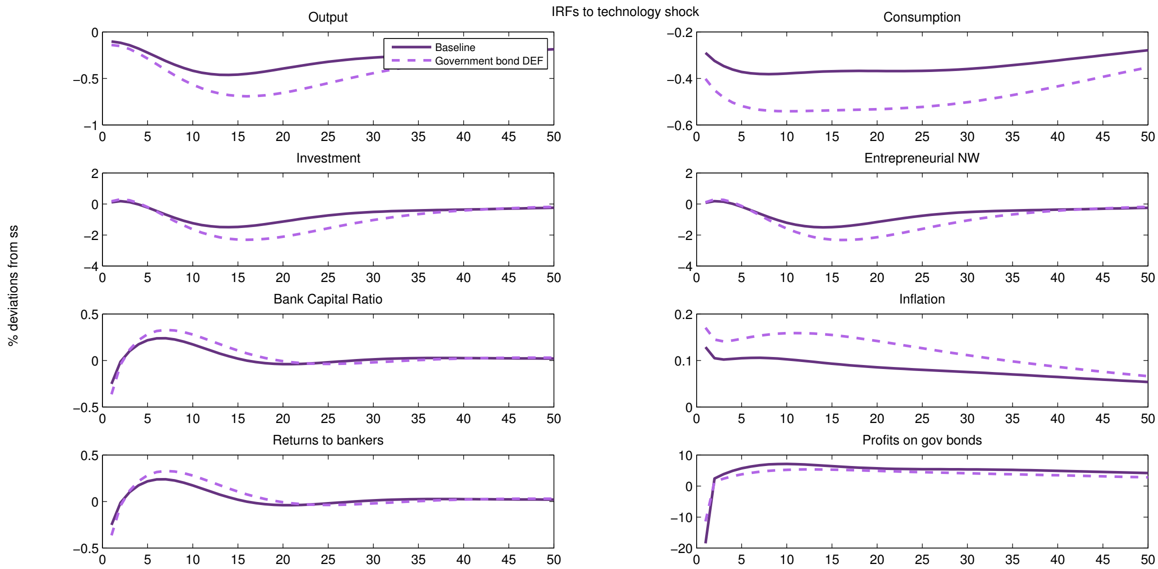

Figure 1: Impulse responses of selected variables to a 1% fall in aggregate productivity in the model without (solid line) government bond risk and with (dashed line) it.

bank capital invested in the project falls on impact (by more than investment in the initial period). The ensuing fall in asset prices increases the severity of the moral hazard problem, as it is more difficult to meet the incentive compatibility constraints for both the bank and the entrepreneur. This implies that the share of returns from the project (R_t^b) accruing to the bank shall raise: as the moral hazard raises, bankers can extract larger surpluses. The raise in the bankers' returns induces banks to raise the bank capital ratios. Overall bank capital behaves counter-cyclically, as it would do under a Basel II-type capital requirement, but here as an endogenous result of market discipline: as the moral hazard problem becomes more severe, banks increase capital and squeeze up liquidity. The above description applies qualitatively to both models (with and without government bond risk). However some differences in the quantitative properties arise. The recessionary effects of the shock are indeed much more pronounced when the model also features government bond spreads. The fall in consumption, by affecting the stochastic discount factor, produces a fall in the price of the bond, z_t, and in the ex-post banks' returns from government bond trading. As a result, and due to the self-insurance constraint, the amount of short-term liabilities (deposits) to which the

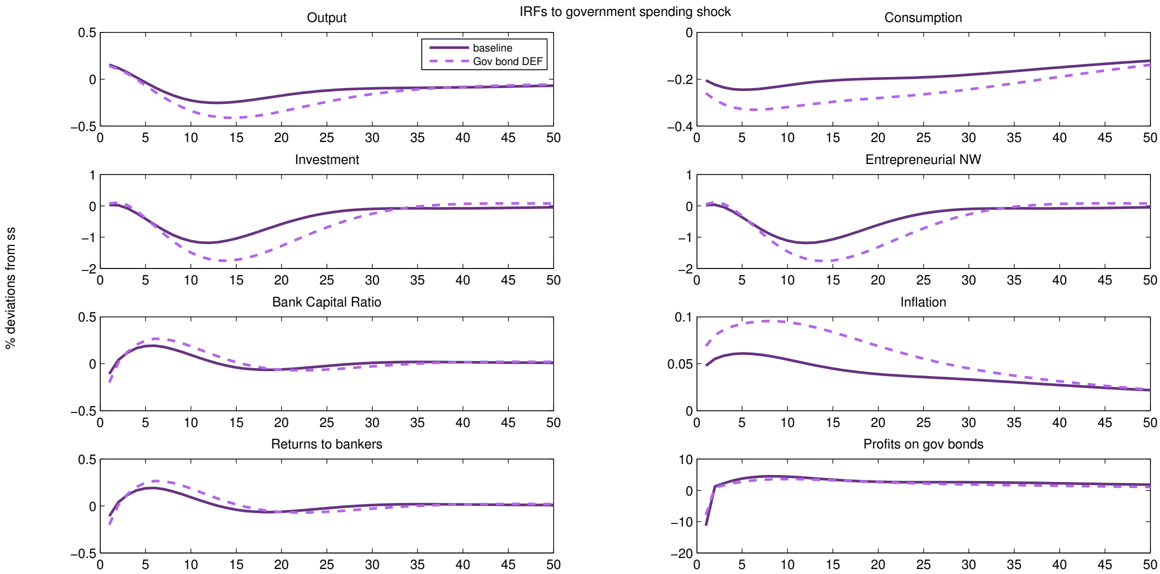

Figure 2: Impulse responses of selected variables to a 1% fall in government spending in the model without (solid line) government bond risk and with (dashed line) it.

bank can get exposed falls: the ensuing fall in the funds available for loans, produces a much larger fall in investment in the model with government bond risk.

Figure 2 below shows impulse responses of selected variables to a 1% government spending shock.

As expected output, investment, entrepreneurial wealth fall, while bank capital ratios and bankers returns from the investment project raise. As before the ensuing fall in the price of government bonds reduces bankers' profits from government bonds trading and the self-insurance constraint forces banks to reduce their short term exposure. As before the severity of the recession is much larger in presence of government bond risk.

3.1 The Link Between Bank and Sovereign Risk

Data show that in recent years (following the 2007 crisis) Europe has a experienced a positive connection between sovereign and bank risks. As explained earlier one of the main reasons behind such connection rests on the exposure of banks' balance sheet to government bonds: since those

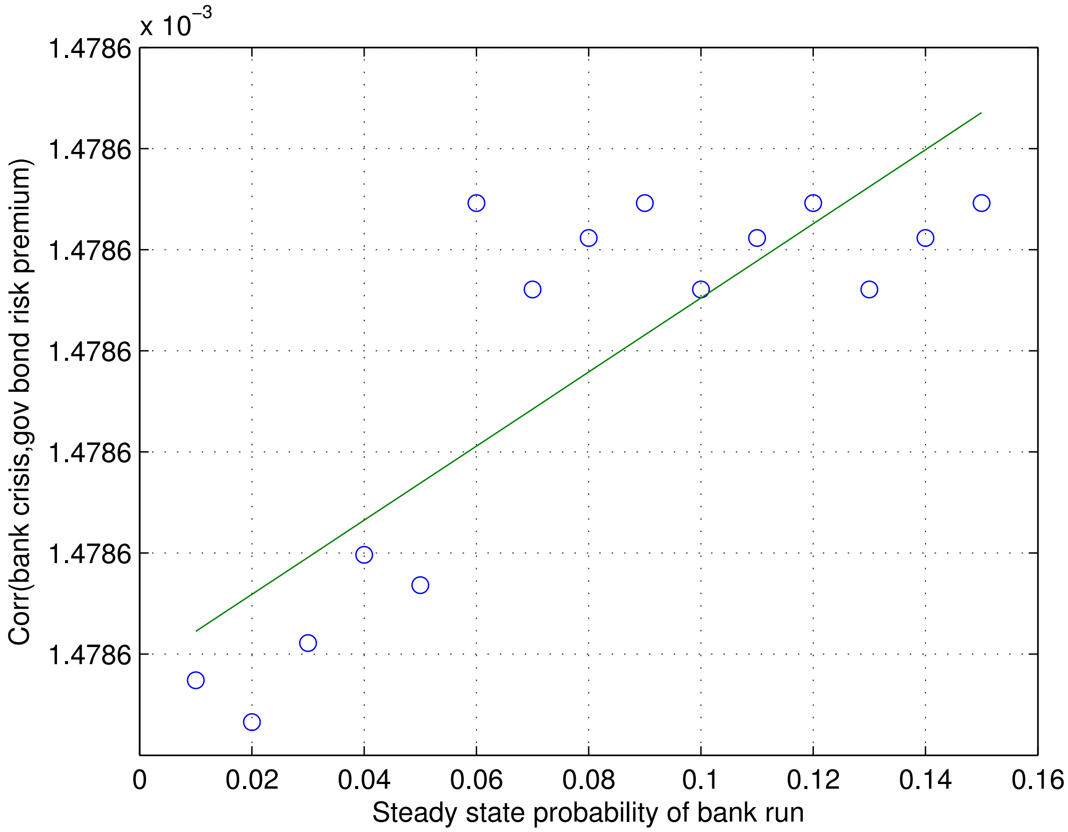

Figure 3: Correlation between bank risk and government bond risk in response to "news" shocks affecting banks' returns uncertainty and for different steady state values of ρ.

assets were considered Tier 1 capital, banks had a natural tendency to acquire them in order to satisfy their regulatory capital requirements or simply for self-insurance motives. Clearly this produces a two way interaction between banks' liquidity risk and government bond risk. The first type of risk is captured in our model by the probability of deposit withdrawals, while the second type of risk is proxied via government bond premia, calculated as $r_t^g - r_t^n$.

Figure 3 shows the correlation between bank and sovereign risk in response to a shock, S_t, to the uncertainty about expected bank returns, σ_t^{ε}. The shock, S_t,which follows an AR(1) processes, affects banks' liquidity risk (proxied by the probability of early deposit withdrawals) as follows:

$$\rho_t = 1 - \Phi\left(\frac{\varpi_t}{S_t \sigma_t^{\varepsilon}}\right) \tag{41}$$

The shock can be interpreted as "news" arrivals: an increase in S_t means that depositors received news of higher uncertainty in banks' profits and might trigger early withdrawals. This shall of course increase the probability that banks need emergency liquidity and implicitly could affect the self-insurance constraint. As ρ_t rises the self-insurance constraint forces banks to reduce the amount of short term liabilities (D_t) available for investment thereby triggering a credit crunch: as shown before credit crunch driven recessions are amplified in presence of sovereign risk.

Figure 3 shows the correlation between bank risk, ρ_t, and sovereign risk, proxied by $r_t^g - r_t^n$, in response to S_t shocks and for different values of the banks' liquidity risk in the steady state, ρ. The underlying idea is that the more an economy is prone to banking crisis (higher steady state ρ), the higher should be the spiraling connection between bank and government bond risk. Notice that the different values of the probability of bank run (in the steady state) were computed by referring to evidence in Qian, Reinhart and Rogoff [**?**]. The average probability of a bank run is 8% with a standard deviation of 7%. The range for the steady state bank run was set as the average probability plus and minus 1%. The different dots in the graph represent the correlations (between ρ and $r_t^g - r_t^n$) resulting from the model solution in response to the "news" shocks and for different values of the steady state value of ρ. The graph also shows the OLS regression line which is positively sloped (R^2 is 0.6885). The model can then well replicate the positive association between bank risk and government bond risk and also shows that such correlation increases with the fragility of the banking system.

Figure 4 shows the correlation between bank risk, ρ_t, and sovereign risk, proxied by $r_t^g - r_t^n$, in response to S_t shocks and for different values of government default haircuts. The relation shows that the connection between the two sources of risk in the model is exacerbated under weaker fundamentals, in this case under higher long run sovereign risk.

4 Central bank liquidity interventions

The central bank, aware of the liquidity emergency needs, comes in assistance of banks through interventions based on full allotment in the repo market. Such interventions lead to easing in credit supply conditions. If the central bank accepts government bonds in repo at price $\overline{z_t} > z_t$ (because its own estimate of government default risk is lower than the one of households) the liquidity buffer

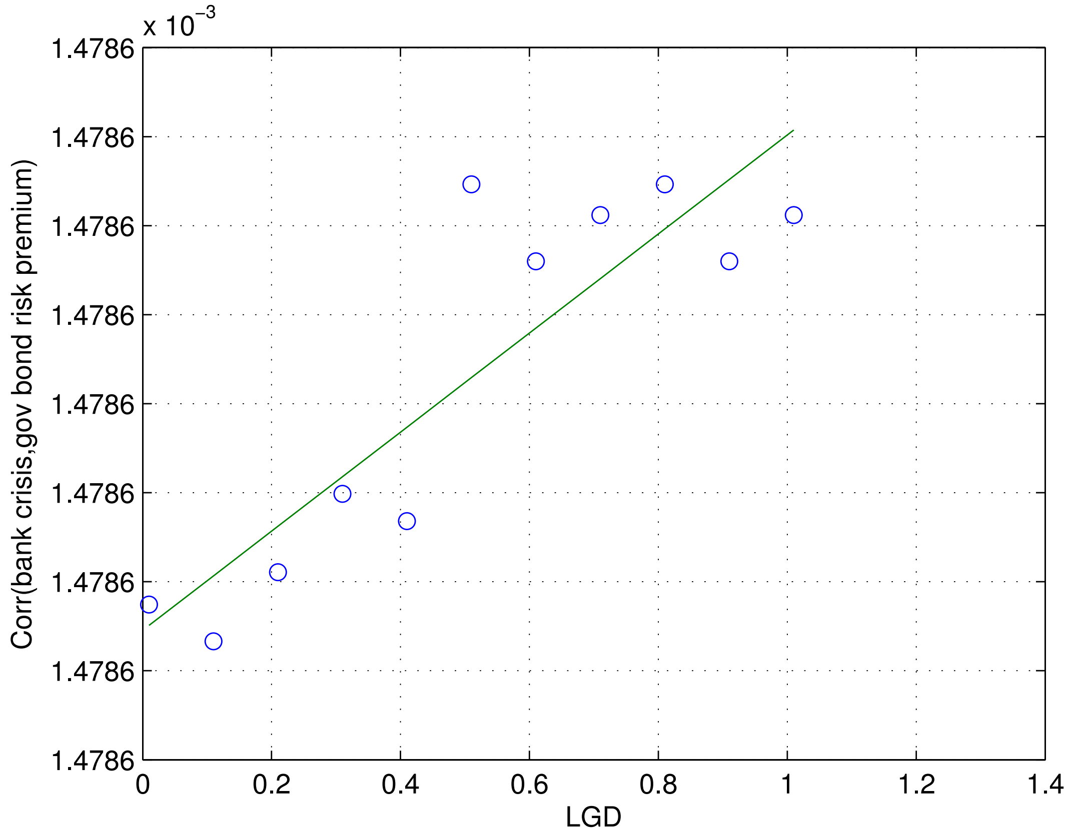

Figure 4: Correlation between bank risk and government bond risk in response to "news" shocks affecting uncertainty of banks' returns and for different values of the haircut on government bonds.

that banks need to maintain is smaller than when refinancing is done via the interbank market.

$$\underline{B_t^g} = \frac{\rho_t D_t}{(\overline{z_t} - 1)} < B_t^b \tag{42}$$

The optimal financial contract in this case delivers the following solution. The optimal investment schedule becomes:

$$I_t = \frac{BK_t + NW_t}{\left(1 + c - \left(\frac{1-\left(\frac{z_t}{\bar{z}_t}\right)\rho_t}{1-s_t^h\left(\frac{z_t}{\bar{z}_t}\right)\rho_t}\right) q_t p_h R s_t^h\right)} \tag{43}$$

with:

$$D_t = I_t \frac{s_t^h q_t p_h R}{1 - s_t^h \left(\frac{z_t}{\bar{z}_t}\right) \rho_t} \tag{44}$$

Ex-post bankers' returns on bond trading and bankers' consumption should change accordingly into:

$$\Pi_t^{bonds} = \gamma^b \delta_c \bar{z}_t B_{t-1}^b \tag{45}$$

$$C_t^b = \left(1 - \gamma^b\right) \left[q_t p_h R^b I_t + (\bar{z}_t - 1) B_t^b\right] \tag{46}$$

Since the policy affects equilibrium bond spreads and prices, the government budget constraint should also be changed to take into account that the government can now save on bond service costs:

$$\frac{T_t}{P_t} + \bar{z}_t B_t^{Issue} = 1 * (1 - \Delta_t) B_t^{Stock} + \frac{G_t}{P_t} + \frac{T_t^C}{P_t} \tag{47}$$

This policy of full allotment at a "distorted" price is a form of subsidy to the private sector, equivalent to a reduction in the aggregate uncertainty parameter ρ_t by a factor $\left(\frac{z_t}{\overline{z_t}}\right)$.The central bank might find optimal to trade at a price $\overline{z_t} > z_t$ if, for example, government debt held in its balance sheet is senior with respect to debt held in the private banks' balance sheet or if the central bank possesses superior information, compared to market participants, about the fiscal situation.

To analyze the efficacy of such policy in reducing the spiraling connections between bank and sovereign risk we re-examine some of the previous numerical results by considering the model in which sovereign bond risk is present. First we re-consider the effects of technology and government spending shocks using impulse response functions. In this case we compare model results with and without central bank intervention. Figures 5 and 6 show results respectively for the technology

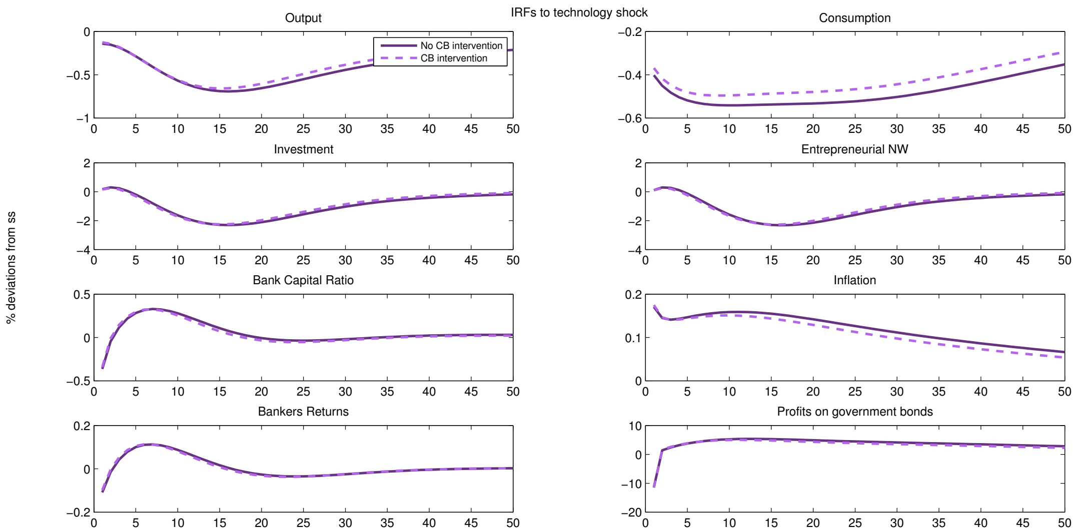

Figure 5: Impulse response functions to technology socks of selected variables in the model with government bond risk by comparing the case with central bank intervention (dashed line) with no central bank intervention (solid line).

and government spending shocks by comparing the model with central bank intervention (solid line) and without central bank intervention (dashed line). The qualitative response of macro and banking variables is roughly equivalent to the one observed in absence of central bank intervention, but the recessionary extent of the shocks is milder under central bank interventions.

Under both, technology and government spending shocks, the fall in output and consumption is milder over the medium run due to the positive wealth effects of the repo operations. In addition under central bank intervention the value of banks' capital buffer increases, hence banks can more easy leverage at short maturities increasing the amount of deposits (relatively to the case with no central bank interventions) and consequently reducing the fall in investment.

Much of the allotment policies by the ECB were conducted to counteract the recessionary effects due to increases in countries' government spreads. For this reason we also simulate impulse response functions to a 1% increase in government bond spreads (see Figure 7 below). In this case full allotment policy is fully effective in neutralizing the effects of the increase in government risk. Bankers consumption, profits as well as the value of capital buffer remain stable ensuring that no

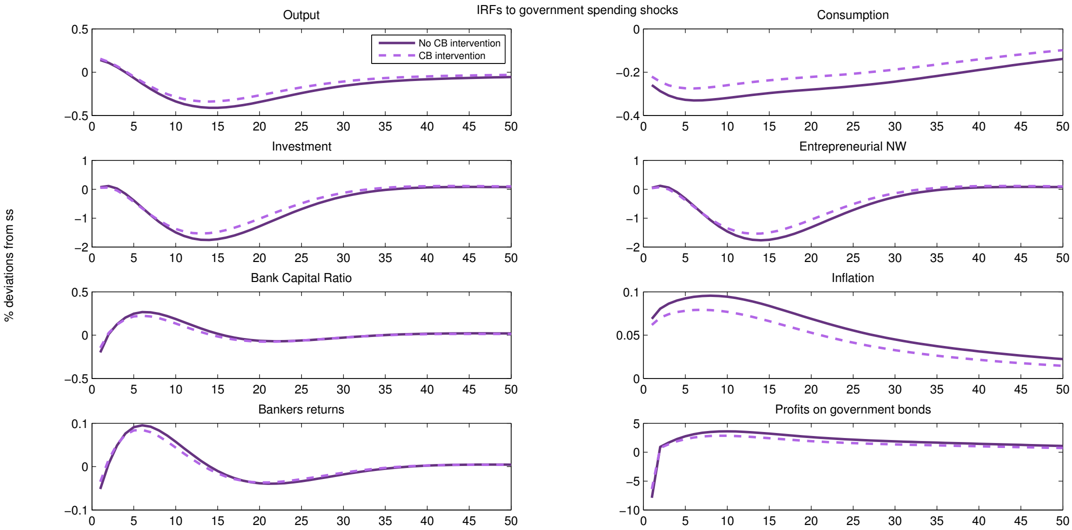

Figure 6: Impulse response functions to government spending shocks of selected variables in the model with government bond risk by comparing the case with central bank intervention (dashed line) with no central bank intervention (solid line).

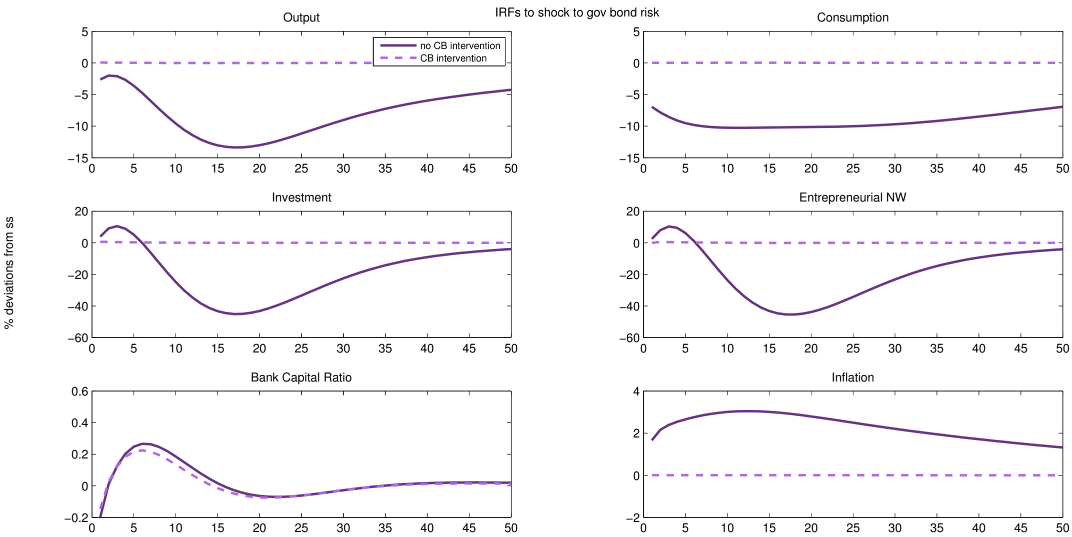

Figure 7:

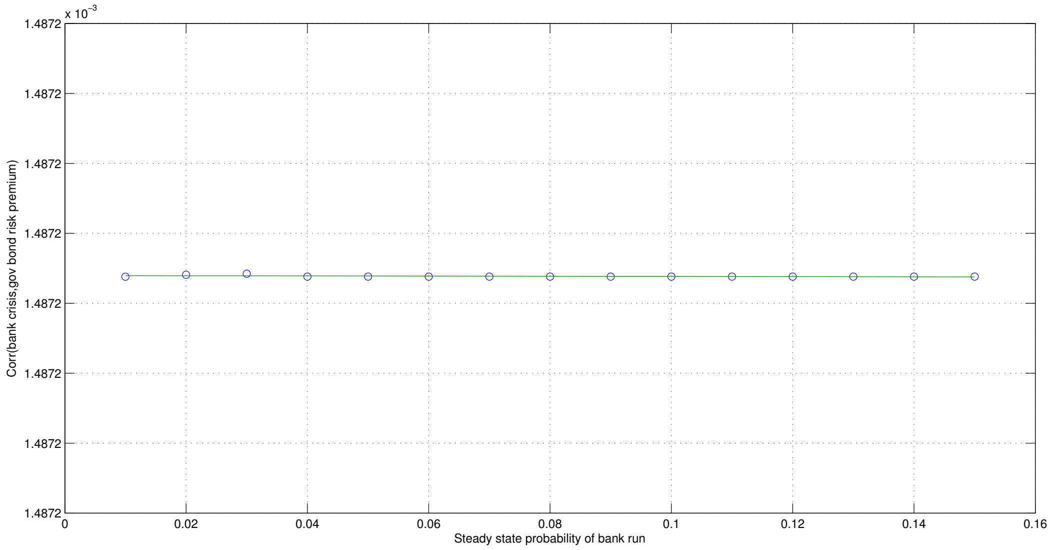

Figure 8: Correlation between bank risk and government bond risk under central bank intervention and in response to "news" shocks affecting banks' returns uncertainty and for different steady state values of ρ.

contraction in short term banks' liquidity (D_t) takes place.

The shock transmission mechanisms outlined above show that central bank interventions might be particularly effective in reducing the exacerbation effects associated with government bond risk as well as in neutralizing the effects of government bond spread shocks. By dampening government risk, central bank is effectively also dampening banks' liquidity risk: for given ρ, the bonds' regulated price offered by the central bank raises and stabilizes the banks' capital buffer values, thereby reducing fluctuations in short term banks' funding (D_t). This eventually reduces the spiraling correlation between sovereign and bank risk. Figures 8 and 9 show the correlation between bank liquidity risk and sovereign risk equivalent to the ones considered in Figures 5 and 6, but this time in presence of central bank allotment policy. The correlations are still positive but they are lower than in absence of central bank intervention and they do not show any increase with respect to changes in the long run value of bank liquidity risk and/or the haircut on government bonds.

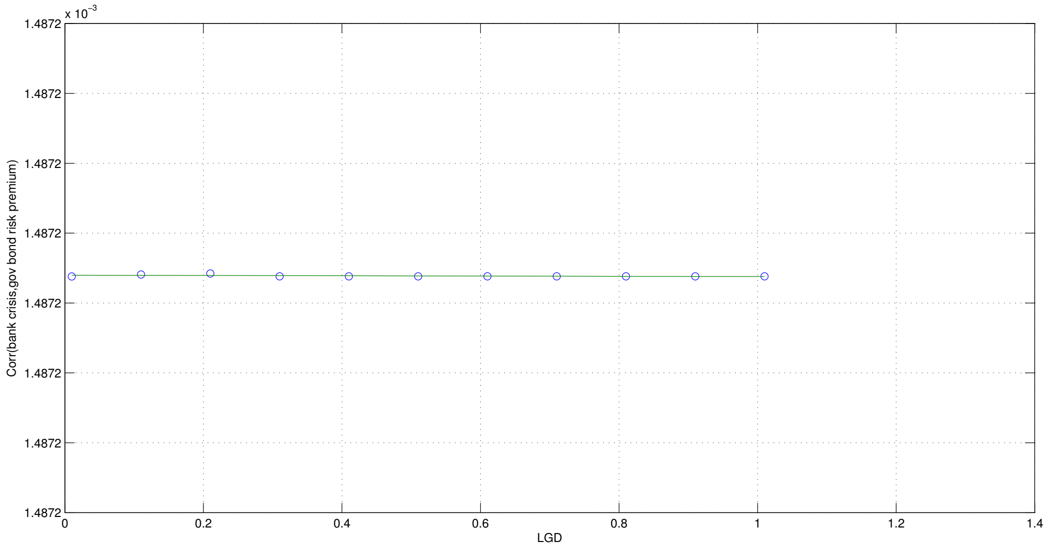

Figure 9: Correlation between bank risk and government bond risk under central bank intervention and in response to "news" shocks affecting uncertainty of banks' returns and for different values of the haircut on government bonds.

5 Conclusions

The euro area sovereign debt crisis and its consequences on exposed banks is producing spiralling connections between bank and sovereign risk. We propose a macro model with banks which experience a dual moral hazard problem between depositors on the one side and firms on the other and invest in government bonds as part of its self-insurance policy against liquidity risk. The emergence of sovereign risk affects the value of private banks' buffer capital, thereby affecting its balance sheet and the resources available to investment. The model can re-produce the positive correlation between bank and sovereign risk under different degrees of banks fragility.

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6 Appendix 1: Liquidity Risk and Regulatory Buffer for Bankers

Bankers in our model face the risk of sudden liquidity needs due to deposit withdrawals. Given this liquidity risk, when engaging in the lending activity intermediaries decide to hold an asset buffer, which is justified either by regulatory requirements or through self-insurance.

We assume N identical banks start operating at the beginning of period t . Each bank owns $\frac{1}{N}$ of total capital BK_t , receives $\frac{1}{N}$ of total deposits D_t and finances $\frac{1}{N}$ of the total investment I_t.

At the beginning of period t banks operate a financial contract, through which it engages in the lending activity to entrepreneurs (details of the contract are in the main text). Contract commitments are rigid (projects financed through the contracts cannot be liquidated between periods), but across subsequent periods banks face the risk that deposited funds can be withdrawn[17]. Let us assume depositors in each single bank n are represented by a continuum of mass 1. Variables specific to the investor i in the bank n are denoted using the subscript n, i . After financial contracts have been signed, banks become heterogenous. A fraction π of banks is subject to "market rumors": depositors receive a private signal $\varepsilon_{n,i,t}$ (news shocks) about the expected probability that the project funded by bank n will succeed, p_h.

$$E_{n,i,t}(p_h) = \exp(-\varepsilon_{n,i,t})\, p_h \tag{48}$$

The signal $\varepsilon_{n,i,t}$ follows the distribution Γ_t with density function g_t and cumulative distribution G_t . This distribution is the same for all depositors i and banks n . Under this notation, a positive shock $\varepsilon_{n,i,t}$ represents bad news about the bank. Depositors withdraw their funds from bank n when the expected return on investment $E_{n,i,t}(p_h)$ is so low that the bank could become insolvent[18]. Specifically, investors do not roll-over their funding when expected losses are higher than the share due to bankers, that is when $(1 - \exp(-\varepsilon_{n,i,t}))\, p_h R_t q_t I_t > p_h R_t^b q_t I_t$ or equivalently when $\varepsilon_{n,i,t} > \varpi_t = \ln\left(\frac{R_t}{R_t - R_t^b}\right)$[19] . For any bank n, the share of withdrawing depositors is:

[17] Deposit wtihdrawals do not entail resource destruction in our model, as deposits are simply moved from one bank to another.

[18] We assume that banks liabilities are uninsured, or equivalently that the insurance scheme is not credible.

[19] As all banks are ex-ante identical, we can drop the subscript n in the inequalities.

$$\rho_t = \int_{\varpi_t}^{+\infty} g_t(\varepsilon).d\varepsilon = 1 - G_t(\varpi_t) \tag{49}$$

We introduce liquidity needs into the model with the sole purpose of providing justification for an ex ante banks' asset buffer. For this reason we include a number of assumptions to isolate the negotiation on the financial contract from the news shock distribution. First, we assume that deposit withdrawals on one bank do not entail panics for the entire banking sector. This is so since cash withdrawn from a troubled bank are transferred onto banks perceived to be safe: deposit inflows into safe banks are exactly equivalent to deposit outflows from troubled banks and there is no destruction of resources at an aggregate level. Finally notice that, under rational expectations, shocks $\varepsilon_{n,t} \sim \Gamma_t$ should entail ex post different banks' profits distribution. We assume that all extra-profits (for banks with $\varepsilon_{n,t} < 0$) are put in a common guarantee fund and distributed to banks undergoing losses ($\varepsilon_{n,t} > 0$). Ex post pooling of profits, implies that ex ante the shock realization, $\varepsilon_{n,t}$ does not affect banks' financial contract negotiation, on which we can assume symmetry.

When the liquidity withdrawal takes place, bank n borrows from the interbank market an amount $BD_t = \rho_t D_t$. Prior to the deposit withdrawal, bank n balance sheet reads as follows:

Before deposit withdrawal

Assets (*N)	**Liabilities (*N)**
L_t	D_t
$(z_t - 1) B_t^b$	BK_t

After the deposit withdrawal, bank n balance sheet reads as follows:

After deposit withdrawal

Assets (*N)	**Liabilities (*N)**
L_t	$(1 - \rho_t) D_t$
$(z_t - 1) B_t^b$	BK_t
	$BD_t = \rho_t D_t$

Borrowing in the interbank market is granted only against an asset collateral (which we assume taking the form of government bonds)[20]. The following collateral requirement is imposed to borrowing banks:

$$BD_t \leq (z_t - 1) B_t^b \tag{50}$$

[20] Since individual deposit withdrawals do not induce a destruction of aggregate liquidity, banks in need of liquidity will surely find counterparts in the repo market.

which results in the following constraint for the bank:

$$\rho_t D_t \leq (z_t - 1) B_t^b \tag{51}$$

Notice that ρ_t measures the riskiness of bank funding as well as the size of the necessary liquidity buffer.

$$\rho_t = 1 - G_t(\varpi_t) \tag{52}$$

Consider the case in which $\Gamma_t = N(0, \sigma_t^\varepsilon)$. This implies that:

$$\rho_t = 1 - \Phi\left(\frac{\varpi_t}{\sigma_t^\varepsilon}\right) \tag{53}$$

The higher the uncertainty about expected bank returns σ_t^ε, the higher the need for liquidity in the banking sector.

6.0.1 Monetary policy 2: full allotment

Banks subject to rumors loose a part of their deposit and an equivalent amount is deposited to banks perceived as safe. These safe banks keep their extra cash at the central bank deposit facility (amount m_t) and the central bank provides liquidity to troubled banks in the repo market.

Troubled banks (fraction π)		*Safe banks (fraction $1-\pi$)*		*Central bank*	
Assets	**Liabilities**	**Assets**	**Liabilities**	**Assets**	**Liabilities**
$\pi.L_t$	$\pi.D_t - t$	$(1-\pi) L_t$	$(1-\pi) D_t + t$		
$\pi.(z_t - 1) B_t^b$	$\pi.BK_t$	$(1-\pi)(z_t - 1) B_t^b$	$(1-\pi) BK_t$	$CBLoan_t$	m_t
	$CBDebt_t\ (= t)$	$m_t\ (= t)$			

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