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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 moral hazard and liquidity risk (sudden deposit withdrawals): banks invest in risky government bonds as a form of capital buffer 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.

JEL classification: E5, G3, E6.

*Keywords:* liquidity risk, sovereign risk, capital regulations.

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# 1 Introduction

One of the elements contributing to the escalation of the euro area sovereign debt crisis and to the diffusion of systemic risk in the euro zone countries has been the connection between sovereign and bank risk, which resulted by the extensive exposure of banks onto the secondary market for government bonds.

Several factors contributed to this interconnection. In the aftermath of the 2007 crises some euro area governments spent considerable public resources to bail out banks under distress. In many cases those actions had put public finances on an un-sustainable path and eventually triggered a confidence crisis on government bonds. The connection between bank and sovereign risk has been exacerbated also by the increasing fraction of banks' assets invested in sovereign bonds. The loss in balance sheet values ensuing the 2007 crisis forced banks to increase the fraction of Tier 1 capital (liquid-safe assets) to comply with regulatory requirements and prior to the sovereign crisis euro area government bonds represented a significant part of Tier 1 capital (see also evidence in Battistini, Pagano and Simonelli [1])[1]. As risk spreads on several national bonds soared starting in 2009-2010[2], banks' asset risk increased. Generally speaking data for euro area show a positive and increasing correlation between banks' risk (as measured by banks' CDS spreads) and sovereign risk (as measured by government bonds CDS spreads). This risk connection is subject to feedback loops, can increase the likelihood of contagion and have important consequences on the real economy: this induced the ECB to intervene through full allotment interventions on repo markets[3].

We build a macro model consistent with the main facts reported above to assess the likelihood and the extent through which the connection between bank and sovereign risk might increase system-risk. Our benchmark is a standard macro model featuring banks which face a dual moral hazard problem[4] and liquidity risks (sudden deposit withdrawals); the latter induces banks to

[1] 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. 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.

[2] See Cruces and Trebesch [4] for more general evidence on borrowing conditions of distressed countries.

[3] The temporary nature of those operations was meant to guarantee no effects on long run money growth and to reduce risks of moral hazard from national governments. See Eser and Schwaab [5] and Trebesch and Zettelmeyer [12] for evidence on the effects of ECB interventions on market spreads.

[4] The dual moral hazard problem of banks has been initially formalized in Holmstrom and Tirole [7]. Authors who have introduced this type of banking corporate model into macro set-ups include Gersbach and Rochet [8], Meh and

hold equity capital for precautionary motives. In the model banks serve as delegated monitors of risky investment projects on behalf of uninformed investors. As monitors banks face a dual moral hazard problem which is disciplined through an inter-temporal three party contract among banks, entrepreneurs and uninformed investors. The contract that we build is an inter-temporal extension of the three party contract in Holmstrom and Tirole [7][5]. On the one side, entrepreneurs receive private benefits by running projects with low probability of success: this entrepreneurial moral hazard is disciplined through bank monitoring. On the other side, uninformed investors face moral hazard problems with banks, which might decide to save on monitoring costs, thereby transferring risk onto them. In this context intermediary capital acquires a special discipline role which renders the banks financing decisions salient for the value of overall investment; as a consequence the Modigliani Miller theorem fails to hold. In the model banks are also subject to liquidity risk: the emergence of news or imprecise signals on banks' assets values trigger runs on deposits[6]. To self-insure against this liquidity risk banks must hold significant buffers of liquid assets with uncorrelated risk, such as government bonds. The higher is the volatility in the distribution of news shocks observed by depositors (banks' risk), the higher is banks' demand for equity capital due to precautionary motives. Notice that the increased demand in equity capital also reduces banks' resources allocated to firms' loans, thereby producing a credit crunch. The channel just described captures one of the possible connections between banks and sovereign risk. Another example of such connection materializes under fiscal shocks that reduce the price of government bonds: this indeed reduces the value of equity capital forcing banks either to reduce the supply of credit or to increase the demand of risky government bonds, thereby increasing their exposure to fiscal shocks.

To assess the link between sovereign and bank risk we simulate the model under standard macro and fiscal shocks and by comparing the case with risk-free versus the case with risky government bonds. The introduction of sovereign risk exacerbates the adverse effects of any shock by triggering negative feedback loops. The connection between banks and sovereign risk in our model occurs through two channels. First the presence of risky government bonds in the banks' balance sheet

Moran [9], Faia [6].

[5] The inter-temporal nature is essential as we wish to capture the effects of future changes in asset returns (such as government bonds) on the incentive structure of the banking sector.

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

implies that changes in government prices produce fluctuations in banks' wealth. The second link stems from the presence of the self-insurance constraint and can be articulated as follows. First, an increase in banks' liquidity risk (risk of deposit withdrawals) induces banks to increase their investment in bonds. The larger is their exposure, the larger are the effects of sovereign risk (changes in bonds prices) on banks' balance sheets. Second, falls in bonds prices force banks to increase their investment in government bonds in order to fulfill the self-insurance constraint: the increase in the share of government bonds in banks' portfolios reduces the amount of resources available for entrepreneurial credit thereby producing or exacerbating credit crunches. Importantly we also find that the correlation between bank and sovereign risk in the model can mimic the correlation found in EU data. At last, we assess the role of central bank liquidity provisions as stability inducing device. We assume that the central bank supplies liquidity to banks by accepting repos in government bonds at a price lower than the one prevailing in the market: the aim is that of signaling a reduced probability of sovereign default. At this price banks can borrow more than they could do under the prevailing market conditions. The enhanced availability of liquidity has the effect of reducing the tightness of the banks' self-insurance constraint and this, coupled with the increase in credit supply, softens the connection between banks' and sovereign risk and smooths shocks amplification[7].

The rest of paper is organized as follows. Section 2 shows data and stylized facts on the connection between banks' and sovereign risk in the euro area. Section 3 describes our model. Section 4 shows quantitative properties of the model, namely impulse responses and correlation between banks' and sovereign risk. Section 5 analyzes the role of central banks interventions onto sovereign bond markets. Section 6 concludes. Appendices, figures and tables follow.

## 2 Banks' and Sovereign Risk Connection in the Euro Area

In this section we wish to assess the extent and the importance of the connection between banks' and sovereign risk in the data. In the first instance we will focus on the euro area, the case for which this connection is more manifested. We will then also compare euro area evidence with the evidence for the US and the UK. To this purpose we take monthly data for banks' CDS spreads,

[7] 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.

used as proxy for banks' risk, and government bonds CDS spreads, used as proxy for sovereign risk, for the period January 2008 to August 2013 and for the following euro area countries: Austria, Belgium, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain. We then compute correlations among the two series for each country separately and for the euro area average. For all countries we observe a positive relation between banks and sovereign risk. Figure 1 shows a positive relation for the euro area averages. When looking at individual countries (not shown here for brevity) we observe that the correlation is higher for countries with a more fragile banking system (an example is Ireland). The positive correlation increases from 2008 to 2011, while it decreases over the 2012 and the 2013. We interpret the recent decrease as a result of the most recent interventions of the ECB on the secondary markets for government bonds, namely the Long Term Refinancing Operations and the most recently announced Outright Monetary Transactions.

To fully asses the nature and development of the above connection we compute the same correlations for the UK (see figure 2) and for the US (see figure 3). Interestingly the correlation is less markedly positive for the UK and even less for the US. Once again we interpret this as evidence of the positive effects that central banks interventions on bond markets on the risk connection and diffusion: for both the UK and the US indeed open market operations on government bonds had started earlier and have been conducted in greater extent than in the euro area.

Next we build a macro model featuring banks that act as delegated monitors, that choose capital endogenously and are subject to risk of runs on deposits. Banks in our model invest in government bonds to increase the share of Tier 1 capital: we show that with risky government bonds the model manifests a correlation between banks' and government risk that mimics the one observed in the data.

## 3 A Macro Model with Endogenous Bank Capital and Risk of Runs on Deposits

The macro model economy is populated by the following agents: households/workers/uninformed investors, entrepreneurs and banks[8]. Production of final goods takes place in a competitive sector

[8]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.

which employes capital and labour. A second sector produces physical capital goods: firms in this sector obtain funds from banks to finance risky investment projects. Banks obtain funds through deposits, but they also invest their capital. A dual moral hazard arises between banks and entrepreneurs requiring funds on the one side and between banks and depositors/uninformed investors on the other. This dual moral hazard problem is disciplined through a three party contract which also leads to the endogenous choice of bank capital. Our 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 un-correlated risk, such as government bonds. A constraint, which can be interpreted either as a value at risk or as a regulatory one, prescribes the level of Tier 1 equity capital in relation to the bank's liquidity risk. Notice that any increase in the required equity capital reduces the bank's available funding for firms' lending. The fiscal sector of our model features exogenous government spending and lump taxes. We allow the government for the possibility of funding budgets through risky bonds.

### 3.1 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 $\tau_t$ 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:

$$u\'(C_t) = \beta E_t \left\{ u\'(C_{t+1}) \frac{(1+r_t^n)P_t}{P_{t+1}} \right\} \tag{4}$$

$$q_t u\'(C_t) = \beta E_t \left\{ u\'(C_{t+1})(q_{t+1}(1-\delta) + Z_{t+1}) \right\} \tag{5}$$

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

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: if this was the case bond demand would come both from banks and households. Such an additional assumption, although realistic, does not affect directly the connection between bank and sovereign risk, which is the focus of this paper.

### 3.2 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, $\alpha$ 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:

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

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

### 3.3 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.

#### 3.3.1 Bankers and Entrepreneurs

Bankers and entrepreneurs are both risk neutral and finite lived agents[9]. Their respective probability of exiting their business each period are $\gamma^b$ and $\gamma^e$. Their respective net wealth 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 to facilitate wealth aggregation. For both agents 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

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

### 3.4 The Dual Moral Hazard

The financial contract is an inter-temporal extension[10] of the three party contract (involving depositors, entrepreneurs and bankers) in Holmstrom and Tirole [7]. 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, 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

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

[10] 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.

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 $b < B$, depending on whether the bank monitors or not. 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 success and lower private benefits $bI_t$[11]. Monitoring entails a non-verifiable cost $cI_t$ in final goods for the bank[12]. 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 rents, which serve as incentive devices. Bankers raise funds through their own capital and depositors. Part of the bank's funds is used to cover for the monitoring costs and part is used as asset buffer against liquidity shocks. We assume that asset buffer shall be made of government bonds, $B_t^b$ (the latter indicates the banks' demand of government bonds), and we allow for the possibility of risky bonds with variable price which we assume consisting of government bonds, $z_t$. We will return on the specification of the government bonds later on. As a result of the above assumptions the feasibility constraint for the funds allocated to 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 pay the monitoring cost $cI_{t-1}$, as this is the only way to avoid entrepreneurs' shirking.

## 3.5 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

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

[12] 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..

among the three contract participants according to the fractions $s_t^h, s_t^e, s_t^b$, which sum up to one. The index $h$ indicates the share going to the uninformed investors, the index $e$ indicates the share going to the entrepreneurs and the index $b$ indicates the share going to the bankers. 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 $p_h$. Monitoring also 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.

We extend the three party contract á la Holmstrom and Tirole [7] into an inter-temporal context. Given the inter-temporal nature of the contract and in order to preserve the contract recursivity we assume that only entrepreneurs and bankers might have an incentive to shirk. Entrepreneurs and bankers know ex ante that they will exit the market with a positive probability: for those agents the reputational costs of shirking are nil. A consequence of our assumption is that only exiting entrepreneurs need to be disciplined through the monitoring activity: therefore the incentive compatibility constraint characterizing the optimal contract will apply only to them. We will return on this point later.

Before detailing the design of the optimal financial 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, $B_t^b$, and $\pi_{t+1}$ is the inflation rate. Notice that banks' funds are invested both in entrepreneurial projects, $I_t$, and in government bonds: total bank asset returns shall therefore include returns to both assets. Bank's demand in government bond, $B_t^b$, is justified by the need to acquire an asset buffer to hedge against liquidity risk: we will return on this point later. To highlight the risky nature of government bonds we can rewrite the payoff, 11, as follows:

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

where $\hat{\Pi}_{t+1}^{success} = \left[r_{t+1}^k + q_{t+1}(1-\delta)\right] RI_t + \frac{(1+r_t^n)}{\pi_{t+1}}(z_t - 1) B_t^b$ . 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 affect 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:

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

where $s_t^h = 1 - s_t^e - s_t^b$ . The profit shares, $s_t^h, s_t^e, s_t^b$, will then be chosen optimally within the three party contract. As usual, we assume that 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 wealth invested in the project $BK_t$, the amount of deposits invested in the project $D_t$, the liquidity buffer $B_t^b$ and the shares of returns accruing respectively to the entrepreneur, the banker and the depositor, $s_t^e, s_t^b, s_t^h$, to maximize the entrepreneurs expected return:

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

the optimization problem is subject to the following constraints. The first is the entrepreneurs' incentive compatibility constraint, which implies that the expected next period returns associated to 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 $b$:

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

The second constraint is the bankers' incentive compatibility constraint, which implies that bankers' expected next period returns under monitoring are higher than in absence of it:

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

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. The proceeds accruing from the outside opportunity are determined by the following investment strategy: bankers invest initial wealth, $BK_{t-1}$, at a market rate $\frac{(1+r_t^m)}{\Pi_{t+1}}$, exit the intermediation activity and consume all wealth available at time $t$[13]:

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

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 (which we assume being equal to the policy rate):

$$\begin{aligned} E_t\left(\Lambda_{t,t+1}\Pi_{t+1}^h\right) &\geq E_t\left(\Lambda_{t,t+1}\frac{(1+r_t^n)}{\Pi_{t+1}}D_t\right) \quad (18) \\ s_t^h E_t\left(\Lambda_{t,t+1}\left(\left[r_{t+1}^k + q_{t+1}(1-\delta)\right]p_h RI_t + (1+r_t^n)(z_t-1)B_t^b\right)\right) &\geq D_t \\ s_t^h\left(q_t p_h RI_t + (z_t-1)B_t^b\right) &\geq D_t \end{aligned}$$

Notice that depositors' returns are initially weighted by their stochastic discount factor, $\Lambda_{t,t+1} = \beta\frac{u'(C_{t+1})}{u'(C_t)}$. The contract is also subject to the project feasibility constraint and to the linear returns' distribution:

$$I_t - NW_t + (z_t-1)B_t^b \leq BK_t + D_t - cI_t \tag{19}$$

$$s_t^h + s_t^e + s_t^b = 1 \tag{20}$$

Monitoring costs $cI_t$ are paid at date $t$ and directly impact the available amount of loanable funds. The set of constraints includes the value at risk constraint induced by the bank self-insurance against liquidity risk: the analytics and economic rational of this constraint is described in detail in appendix A:

$$(z_t-1)B_t^b \geq \rho_t D_t \tag{21}$$

[13] Following much of literature it is assumed that this constraint is never binding, an assumption which we can verify in the numerical simulations. Thus, this equation does not constrain the optimization problem.

where $\rho_t$ indicates the probability that a news shock will trigger a deposit withdrawal. 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, $\rho_t$. The optimal financial contract is solved as follows. In equilibrium, equations (15) and (16) hold with equality (see Holmström and Tirole [7]) implying that:

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

and

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

It follows that the share of returns accruing to depositors reads as follows:

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

The value at risk constraint, (21), binds in equilibrium[14]. Substituting it in the feasibility constraint, equation (19), yields:

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

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 sovereign risk) under the self-insurance constraint implies that banks can raise less deposits (for given probability of liquidity shock, $\rho_t$): this implicitly reduces the available resources for investment. This implies that 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

[14] This is so since bankers' discount factor, which is determined by their probability of exiting business, is lower than the households' discount factor, $\beta$, which determines the long run risk free rate.

term banks' funding (deposits), and consequently in banks' assets (loans to investment ratio) to the aggregate shocks. This mechanism will be described in further details in the numerical simulations.

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:

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

Investment $I_t$ decreases when aggregate liquidity risk $\rho_t$ 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 that the investment equation 27, is recursive since $\rho_t$ does not depend on $I_t$ (only on $R_t^b/R_t$ i.e. on $q_t$).

### 3.6 Bankers and Entrepreneurial Wealth Accumulation

Bankers' and entrepreneurs' wealth accumulation consists of the aggregate wealth of non-exiting bankers and entrepreneurs. Wealth aggregation takes place at the end of period $t$. At the beginning of period $t$ the aggregate capital stock $K_t$, 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. An inter-temporal optimal financial contract is then signed among bankers, entrepreneurs and depositors (households). After the contract is signed, the realization of an idiosyncratic news shocks $\varepsilon_{n,i,t}$ is drawn 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.

Given the above timing assumptions, the period $t$ capital of the bank is the sum of the proceeds from past period investment and from 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 from investment in government bonds read as follows:

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

Government bond price $z_t$ can fluctuate due to a default premium and a term premium (see details in the next section). The loss associated with unexpected falls in the bond price $z_t$ clearly affects banks' capital stock, credit supply and investment in periods following a shock to sovereign premia[15].As explained above banks' demand for government bonds is justified by the need to maintain asset buffers of the size: $(z_t - 1) B_t^b = \rho_t D_t$. If $z_t$ falls, $B_t^b$ must increase to satisfy the value at risk constraint, 21. The channel just describes provides a rationale for the increase in banks' demand of government bonds in times of sovereign distress[16].

### 3.7 Long-term Government Bonds

Government bonds are infinitely lived and pay each period a geometrically decreasing coupon, whose rate of decay is $\delta_c$. Let us denote $z_t$ the price of a bond paying a coupon of 1 in period $t$. We have[17]:

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

where $\Lambda_{t,t+1}$ is the households discount factor and $\Delta_{t+1}$ 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 $\Delta_t$ is applied to previous period government debt $B_{t-1}$. Existing bonds are sold and purchased at price $z_t$: afterwards new bonds are issued. Coupons are paid to the bond owners at period $t$.

[15] Note that $\Pi_t^{bonds}$ is expected to be positive in steady-state for two reasons: first since government bonds pay a risk premium because they are subject to default risk and second since government bonds, being long term assets, also carry a term premium.

[16] See Battistini, Pagano and Simonelli [1] for empirical evidence on this.

[17] See Rudebusch and Swanson [11].

Notice that since coupons are paid in period $t$, the effective market value of the bond (upon coupon payment) is $z_t - 1$[18]. The duration of the infinitely lived bond just described can be parametrized using the formula $\delta_c = \frac{1}{\beta}\left[1 - \frac{1}{1+MacDur}\right]$, 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:

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

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 $r_t^n$ :

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

Finally, the term-premium can then be defined as:

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

### 3.8 Government Debt Accumulation

Governments finance an exogenous stream of government spending, $G_t$, through lump sum taxes, $T_t$, and government debt. 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 period $t$ government budget:

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

[18] 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 is $(z_t - 1)\, B_t^b$.

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[19]. 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 the past debt $B_{t-1}^{Stock}$ at market price $\delta_c z_t$ and sells new bonds $B_t^{Stock}$ at a price $(z_t - 1)$.

### 3.9 Monetary and Fiscal Policy

We assume that monetary policy follows the traditional Taylor rule. The fiscal stance is set according to the following rules:

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

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

Equation 38 states that lump sum taxes are set as a fraction of households' labour income. Equation 39 states that fluctuations in labour income tax are set to respond to changes in the output gap (from the steady state), $(Y_t - Y)$, and changes in the deviations of debt from the long run target. Finally we shall assume that the bond market clears:

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

### 3.10 Calibration

In this section we detail the calibration used in the numerical simulations.

*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 capturing risk aversion. The parameter $\nu$ is set equal to 6 and has been chosen so as to generate a steady-state level of employment of $H \approx 0.3$. The discount factor is set to $\beta = 0.99$, so that the annual real interest rate is equal to 4%. The production function is

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

a Cobb-Douglas, $F(\bullet) = K_t^{\alpha}(H_t)^{1-\alpha}$, with $\alpha = 0.3$. The quarterly aggregate capital depreciation rate $\delta$ 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, $\gamma^e, \gamma^b$, 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 in the financial accelerator literature. 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. 6) Banks operating costs of 5 percent of investment. 7) A share of deposits subject to withdrawals, $\rho$, of 0.2.

*Sovereign risk and the 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, $\Delta_t$, 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. To set those numbers we used evidence in Rudebusch and Swanson [11] and Cruces and Trebesch [4].

*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 $\varepsilon_t^g$ is an i.i.d. shock with standard deviation $\sigma_g$. Empirical evidence for the US in Perotti (2004) suggests $\sigma_g = 0.0074$ and $\rho_g = 0.9$.

# 4 Quantitative results

The main goal of the quantitative analysis is twofold. First, we wish to assess whether the presence of both bank and sovereign risk and their connection can have destabilizing effects on the macroeconomy by amplifying the response to macro and fiscal shocks. The second goal is to see whether our model can replicate the positive relation between bank and sovereign risk which we highlighted in section 2: this will be done in the next section. In this section we fulfill the first of these goals by examining impulse responses of selected variables in the model to macro and fiscal shocks. By comparing the responses with and without sovereign risk in banks' balance sheet we are able to assess whether the connection between bank and sovereign risk can exacerbate the response to aggregate shocks. The impulse responses are useful also as they allow us to describe the main transmission channels which characterize our model.

Figure 4 (at the end of the text) 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. 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 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 project returns accruing to the bank, $R_t^b$, must raise: as the moral hazard problem becomes more severe, bankers need to be compensated more for the monitoring activity and therefore can extract larger surpluses. The raise in the bankers' returns induces banks to raise the bank capital ratios, as the latter work as discipline device within the optimal contract. Overall bank capital behaves counter-cyclically (with respect to the business cycle), as it would do under a Basel II-type capital requirement: in recession, bank risk raises and the bank capital buffer must raise as well. The bank capital counter-cyclicality is an important empirical regularity that renders our model realistic. Importantly in our model the counter-cyclicality of bank capital arises as an endogenous result of market discipline: as the moral hazard problem becomes more severe, banks increase capital and reduce liquidity. The transmission mechanisms and the incentive channels described apply qualitatively to both models (with and without sovereign risk in banks' balance sheet). However the quantitative magnitude of the fluctuations differ across the two models. The recessionary effects of the shock are indeed much more pronounced in the model with risky government bonds. The fall in consumption (and its return to the steady state) imply a fall in the stochastic discount factor, $\Lambda_{t,t+1}$. From equation 30, the fall in the stochastic discount factor implies a fall in the price of bond, $z_t$, which in turn determines a fall in the value of bonds banks have invested in. As discussed earlier, in presence of the self-insurance constraints, falls in the value of bonds determine falls in the amount of short-term liabilities (deposits) that the bank can collect. Both the fall in the value of banks' balance sheet as well as the fall in deposits determine a fall in entrepreneurial credit. The credit crunch in turn exacerbate the fall in investment compared to the model without risky bonds.

Figure 5 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. The channels behind those movements are similar to the ones described above. 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. The severity of the recession is again much more pronounced in presence of government bond risk.

Overall the combined presence of bank and sovereign risk and their connection exacerbate the response of the business cycle to shocks. The connection between banks and sovereign risk in our model occurs through two channels. The first one stems from the presence of risky government bonds in the banks' balance sheet: this determines the direct link between fluctuations in the price of government bonds and fluctuations in the banks' balance sheet. The second link is more subtle and stems from the presence of the self-insurance constraint. This link can be articulated as follows. First, an increase in banks' liquidity risk (risk of deposit withdrawals) induces banks to increase their investment in bonds. The larger is the exposure, the larger are the effects of sovereign risk (changes in bonds prices) on banks' balance sheets. Second, falls in bonds prices force banks to increase their investment in government bonds in order to fulfill the self-insurance constraint: the increase in the share of government bonds in banks' portfolios reduces the amount of resources available for entrepreneurial credit thereby producing or exacerbating credit crunches.

## 4.1 The Connection Between Bank and Sovereign Risk

The data presented in section 2 have shown that after 2008 Europe has experienced a positive connection between sovereign and banks' risks and that this correlation has been increasing, at least until the recent ECB interventions in the secondary market. As explained earlier, the developments of this connection can be traced as follows. The fall in the value of other A rated assets, as ensuing the 2007-2008 financial crisis, induced banks, both for self-insurance as well for regulatory purposes, to increase their exposure to sovereign bonds. Evidence for such an increase in exposure is well documented in data and in empirical analyses such as Battistini, Pagano and Simonelli [1]. As sovereign risk increased and bonds spreads soared this affected, directly as well as indirectly through the self-insurance constraint, the value of banks' balance sheet thereby increasing their sectorial risk and exacerbating the credit crunch. A feedback loop results from those channels. One of our goal is to verify whether our model can capture this positive correlation of risk.

In our model banks' risk can be proxied through the probability of deposit withdrawals:

$$\rho_t = \int_{\varpi_t}^{+\infty} g_t(\varepsilon)\, d\varepsilon = 1 - G_t(\varpi_t) \tag{41}$$

where $\varepsilon$ can be interpreted as imprecise signals about changes in banks' returns: as it goes below a certain threshold depositors coordinate in withdrawing their deposits, thereby causing liquidity shortage. Sovereign risk in our model is instead proxied via government bond premia, calculated as $r_t^g - r_t^n$.

Figure 6 shows the correlation between bank and sovereign risk in response to a shock, $S_t$, to the uncertainty about expected bank returns, $\sigma_t^{\varepsilon}$. The shock, $S_t$,which follows an AR(1) processes, affects banks' liquidity risk (proxied by the probability of early deposit withdrawals) as follows:

$$\rho_t = 1 - \Phi\left(\frac{\varpi_t}{S_t \sigma_t^{\varepsilon}}\right) \tag{42}$$

The shock can be interpreted as "news" arrivals: an increase in $S_t$ means that depositors received news of higher uncertainty in banks' profits. Higher uncertainty increases the probability of early withdrawals. As $\rho_t$ rises the self-insurance constraint forces banks to increase the amount of equity capital, hence to increase banks' demand of government bonds. This has two effects. On the one side, the increase in government bond demand raises the price, $z_t$, thereby decreasing the spreads, $r_t^g - r_t^n$. On the other side the shock $S_t$ is recessionary. As the self-insurance constraint becomes tighter banks also reduce their exposure to short term liabilities, $D_t$, and this forces a credit crunch. The ensuing fall in production and consumption, by reducing the stochastic discount factor, reduces the price of government bonds, $z_t$, and increases its spreads. As the second effect prevails government bond spreads increase in equilibrium and this result in a positive correlation between bank and sovereign risk.

In section 2 we also observed that the positive correlation between bank and sovereign risk is stronger for countries with a more fragile banking system (for instance Ireland). We can test this link too in our model. Figure 6 shows the correlation between bank risk, $\rho_t$, 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, $\rho$. The steady state value of $\rho$ clearly captures bank fragility in that it quantifies the long run probability that the banking system might be prone to runs. 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 [10]. The average probability of a bank run is 8%. In our simulations we set the steady state value for the bank run probability equal to the average in the data and within a range of plus and minus 1%. Notice that the different dots in figure 6 represent the correlations (between $\rho$ and $r_t^g - r_t^n$) resulting from the model solution in response to the "news" shocks, $S_t$, and for different steady state values of $\rho$. The figure also shows the OLS regression line which is positively sloped ($R^2$ is 0.6885). The figure shows that the model reproduces once more the positive correlation between bank and sovereign risk and that this correlation increases with $\rho$, thereby replicating our previous empirical observation.

At last, it is interesting to assess also how the bank/sovereign risk connection changes for different degrees of sovereign fragility. The latter is captured in our model by the size of the default haircut. We shall expect that higher levels of long run default haircuts, by reducing the price of government bonds, reduce the balance sheet values of banks. Figure 7 shows the correlation between bank risk, $\rho_t$, and sovereign risk, proxied by $r_t^g - r_t^n$, in response to $S_t$ shocks and for different steady state values of government default haircuts, $\Delta$. The relation shows that the connection between the two sources of risk in the model is higher for higher levels of $\Delta$.

Overall the last set of results shows that the positive correlation between bank and sovereign risk is typically stronger under weaker fundamentals and financial institutions.

# 5 Central Bank Liquidity Interventions

The sovereign debt crisis and the spiraling connection between bank and sovereign risk induced the European Central Bank to implement further unconventional measure and to provide liquidity assistance. Unconventional measure took several forms, but some in particular were targeted to reduce both the bank and sovereign risks. Among those there were for instance the Long Term Refinancing Operations. Through these operations, the central bank, aware of the liquidity emergency needs, comes in assistance of banks through interventions based on full allotment in the repo market. The eventual aim of those operations is to ease credit conditions: by providing liquidity to banks at low costs the central banks wishes to facilitate the flow of credit to firms (see Eser and Schwaab [5] and Trebesch and Zettelmeyer [12] for evidence on the effects of ECB interventions on markets spreads).

More specifically the central bank offers liquidity to banks in exchange of government bonds in repo markets. By accepting government bonds at a price $\overline{z_t} > z_t$, the liquidity buffer that banks need to maintain is smaller than when refinancing is done via the interbank market.

$$\underline{B_t^g} = \frac{\rho_t D_t}{(\overline{z_t} - 1)} < B_t^b \tag{43}$$

The rational behind the willingness of the central bank to accept government bonds at higher prices lies in the fact that the central bank estimate of government default risk is lower than the one priced by the market. Generally speaking the central bank might find it 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. The overall effect of those operations is that of easing the banks' self-insurance constraint and therefore of freeing up liquidity available for entrepreneurial credit. Indeed one can consider this policy intervention as a form of subsidy to the private sector, equivalent to a reduction in the aggregate uncertainty parameter $\rho_t$ by a factor $\left(\frac{z_t}{\bar{z}_t}\right)$. By supplying liquidity to banks at a discounted price effectively the central bank also wishes to reduce banks' liquidity risk. To get more details on banks' balance sheet changes under the policy intervention with full allotment policy see Appendix B.

Under those types of interventions the optimal financial contract delivers the following solution. The optimal investment schedule becomes:

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

with:

$$D_t = I_t \frac{s_t^h q_t p_h R}{1 - s_t^h \left(\frac{z_t-1}{\bar{z}_t-1}\right) \rho_t} \tag{45}$$

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

$$\Pi_t^{bonds} = \gamma^b \delta_c \bar{z}_t B_{t-1}^b \tag{46}$$

$$C_t^b = \left(1 - \gamma^b\right) \left[q_t p_h R^b I_t + (\bar{z}_t - 1) B_t^b\right] \tag{47}$$

Importantly notice that the policy intervention affects equilibrium bond spreads and prices: the effective price of bonds is indeed now $\bar{z}_t$. For this reason the government budget constraint shall be changed to take into account that the government can now save on bond service costs:

$$\frac{T_t}{P_t} + \bar{z}_t B_t^{Issue} = 1 * (1 - \Delta_t) B_t^{Stock} + \frac{G_t}{P_t} + \frac{T_t^C}{P_t} \tag{48}$$

By increasing government bond equilibrium prices, the central banks' is also reducing their spreads and consequently sovereign risk.

Our goal here is to examine whether such a policy can be really successful in reducing both bank and sovereign risk and as a consequence their spiraling connection. To this purpose we simulate the model with risky government bonds under technology and government spending shocks and by comparing impulse responses of selected variables with and without central bank intervention. Figures 8 and 9 show results respectively for the technology 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 qualitatively equivalent in the two cases, however the recessionary effect 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: this makes it easier for banks to leverage at short maturities and increases the amount of deposits (relatively to the case with no central bank interventions). The increase in deposits also raises the amount of banks' resources available for entrepreneurial credit. This in turn reduces the fall in investment, triggered either by the productivity or the government spending shock.

The majority of those allotment policies were conducted also to counteract the increase in systemic risk and the recessionary consequences of increases in sovereign spreads. As bond spreads rise, government are indeed forced to cut government spending. To verify the effectiveness of policy interventions in this case, we simulate impulse response functions to a 1% increase in government bond spreads (see Figure 10 below). Interestingly under this shock the full allotment policy appears to be fully effective in neutralizing the recessionary consequences of the increase in government risk. Bankers' consumption, profits as well as the value of capital buffer remain stable ensuring that neither short term banks' liquidity ($D_t$) nor entrepreneurial credit contracts. It is important to stress that our policy exercise has mainly a normative flavour in that it highlights some channels through which those tyeps of policy interventions might operate. Needless to say the results from the model might be more optimistic than the ones observed in reality as in fact several other factors in practice might hamper the effects of those type of policy interventions.

The shock transmission mechanism outlined above shows that central bank interventions might be particularly effective in smoothing the amplification observed in presence of sovereign risk as well as in neutralizing the negative effects of government bond spread shocks. By accepting bonds at higher prices the central bank reduces bond spreads and sovereign risk. Under the self-insurance constraint the reduction in sovereign risk also dampens banks' liquidity risk: for given $\rho$, 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, $D_t$.

Overall those interventions reduce the spiraling connection between sovereign and bank risk.

Figures 11 and 12 show the correlation between bank liquidity risk and sovereign risk equivalent to the ones considered in Figures 8 and 9, 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. Furthermore the correlation does not increase with respect to changes in the long run value of bank liquidity risk and/or the haircut on government bonds.

# 6 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 banks' balance sheets and capital buffers, thereby affecting also the resources available to entrepreneurial credit. The model can successfully re-produce the positive correlation between bank and sovereign risk under different degrees of banks fragility. We use the model also to assess the effectiveness of the recent central banks' liquidity policy and find that those are indeed successful in reducing the bank/sovereign risk connection.

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# 7 Appendix A. 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 to supply entrepreneurial lending (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[20]. Let us assume that 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 $\pi$ 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, $p_h$.

$$E_{n,i,t}(p_h) = \exp(-\varepsilon_{n,i,t})\, p_h \tag{49}$$

The signal $\varepsilon_{n,i,t}$ follows the distribution $\Gamma_t$ 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[21]. Specifically, investors do not roll-over their funding when expected losses are higher than the share due to bankers, that is when:

$$(1 - \exp(-\varepsilon_{n,i,t}))\, p_h R_t q_t I_t > p_h R_t^b q_t I_t \tag{50}$$

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

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

or equivalently when[22]:

$$\varepsilon_{n,i,t} > \varpi_t = \ln\left(\frac{R_t}{R_t - R_t^b}\right) \tag{51}$$

For any bank $n$, the share of withdrawing depositors is given by:

$$\rho_t = \int_{\varpi_t}^{+\infty} g_t(\varepsilon) \,.d\varepsilon = 1 - G_t(\varpi_t) \tag{52}$$

Liquidity needs are introduced in our model to provide justification for ex ante banks' asset buffers. To avoid that news shocks could also affect the negotiations of the financial contract we introduce the following assumptions. 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. 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 (** $*N$ **)** |
|---|---|
| $L_t$ | $(1-\rho_t)\, D_t$ |
| $(z_t - 1)\, B_t^b$ | $BK_t$ |
| | $BD_t = \rho_t D_t$ |

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

Borrowing in the interbank market is granted only against an asset collateral (which we assume taking the form of government bonds)[23]. The following collateral requirement is imposed to borrowing banks:

$$BD_t \leq (z_t - 1)\, B_t^b \tag{53}$$

which results in the following constraint for the bank:

$$\rho_t D_t \leq (z_t - 1)\, B_t^b \tag{54}$$

Notice that $\rho_t$ measures the riskiness of bank funding as well as the size of the necessary liquidity buffer.

$$\rho_t = 1 - G_t\,(\varpi_t) \tag{55}$$

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

$$\rho_t = 1 - \Phi\left(\frac{\varpi_t}{\sigma_t^{\varepsilon}}\right) \tag{56}$$

The higher the uncertainty about expected bank returns $\sigma_t^{\varepsilon}$, the higher the need for liquidity in the banking sector.

# 8 Appendix B. Banks' Balance Sheet under Policy Interventions

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

[23] 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.

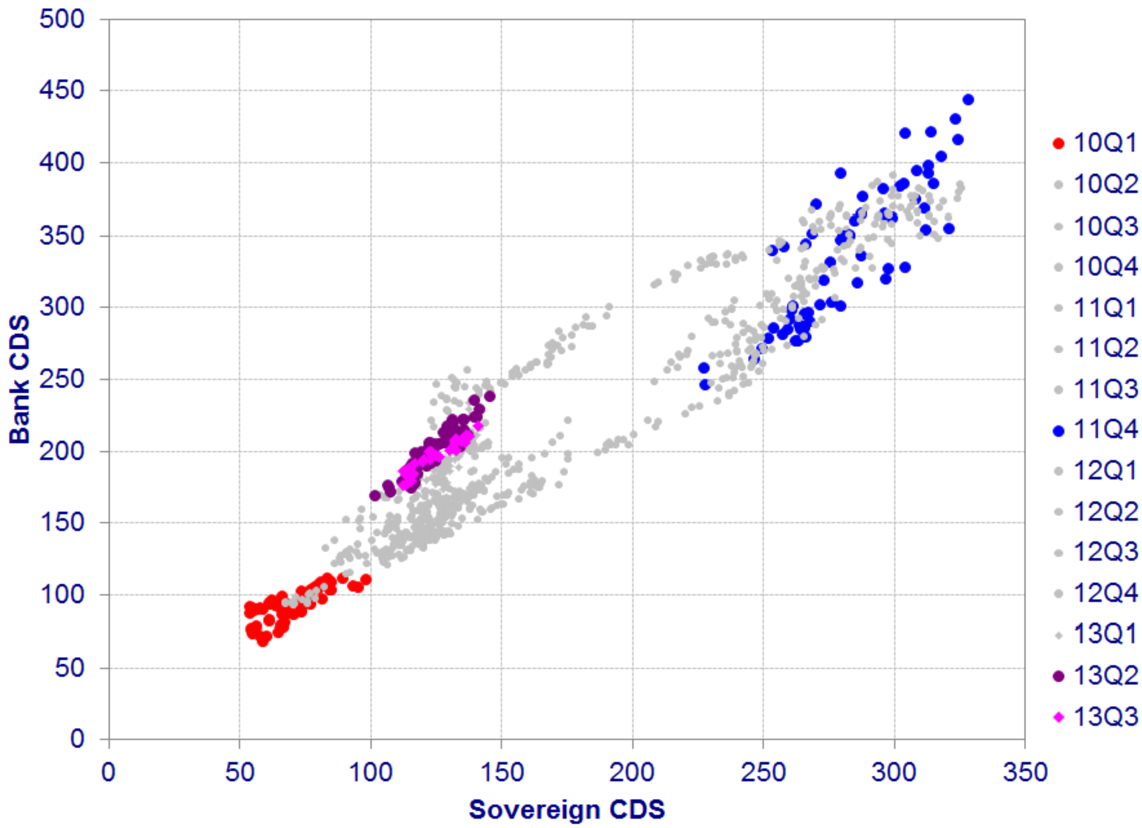


Figure 1: **Euro Area: Correlation between bank and government bond CDS spreads**

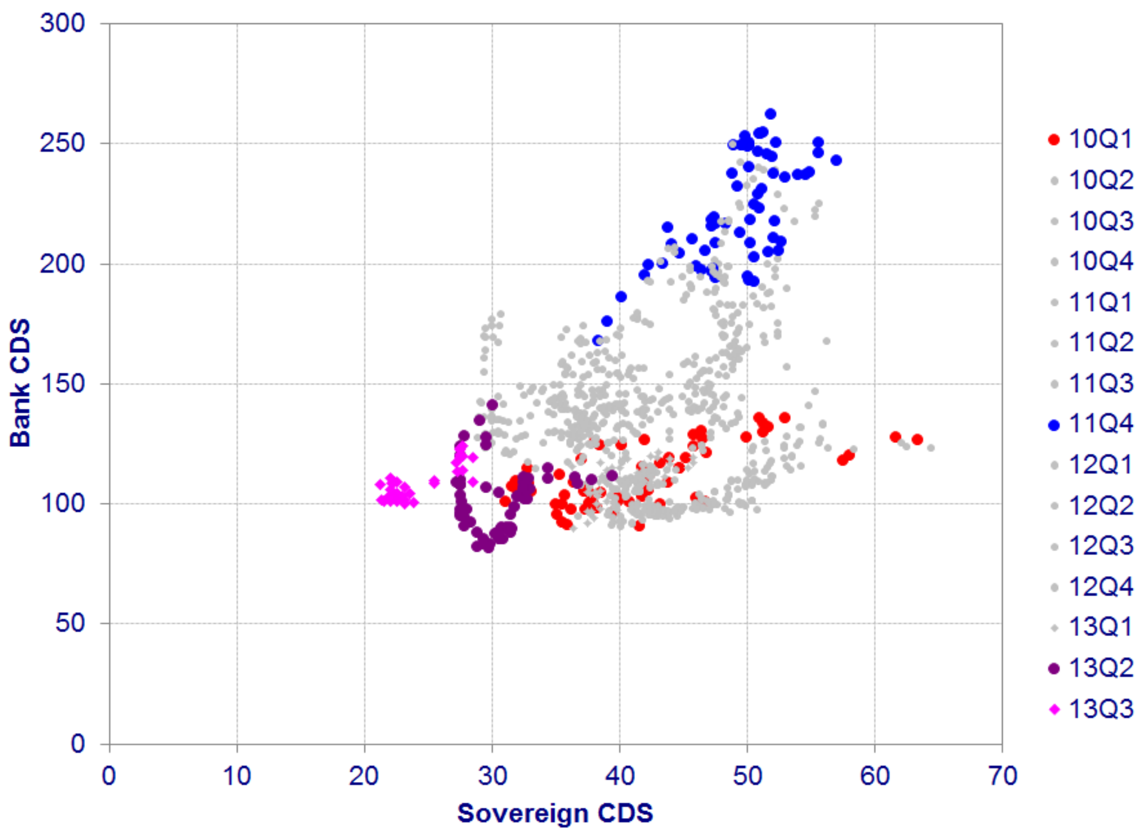


Figure 2: **US: Correlation between bank and government bond CDS spread**

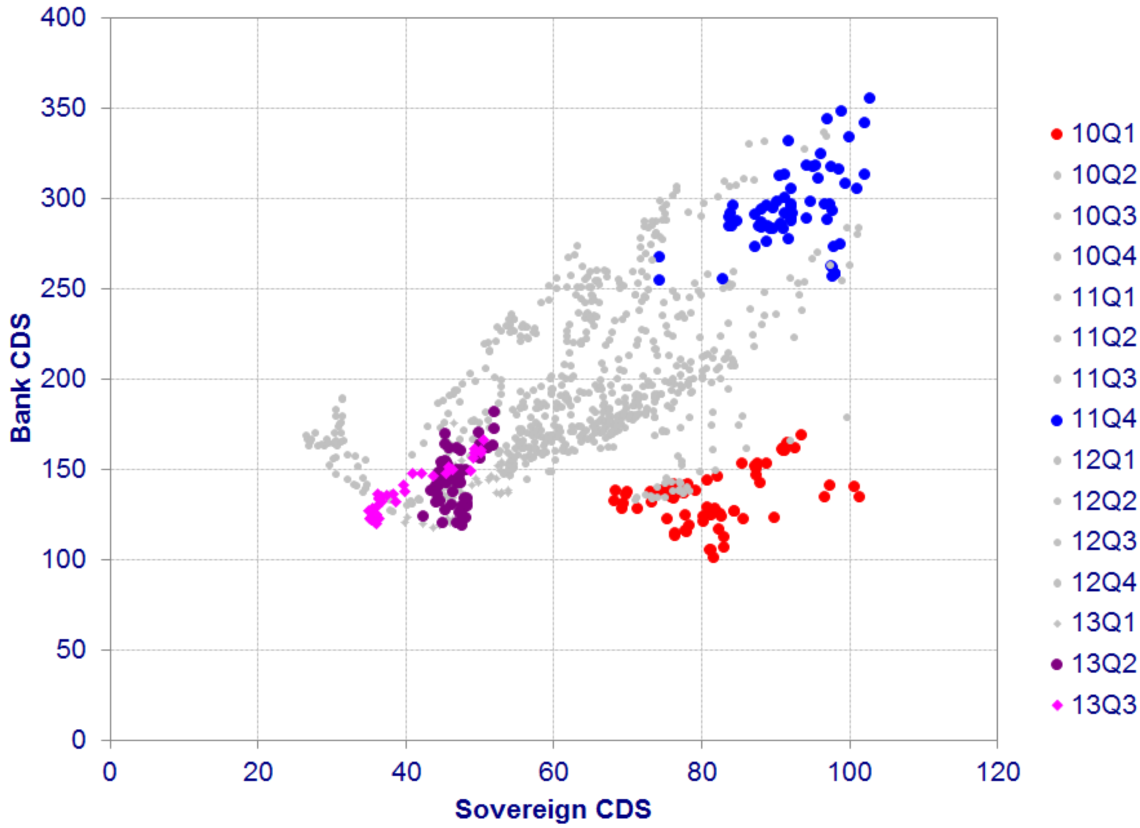


Figure 3: **UK: Correlation between bank and government bond CDS spreads**

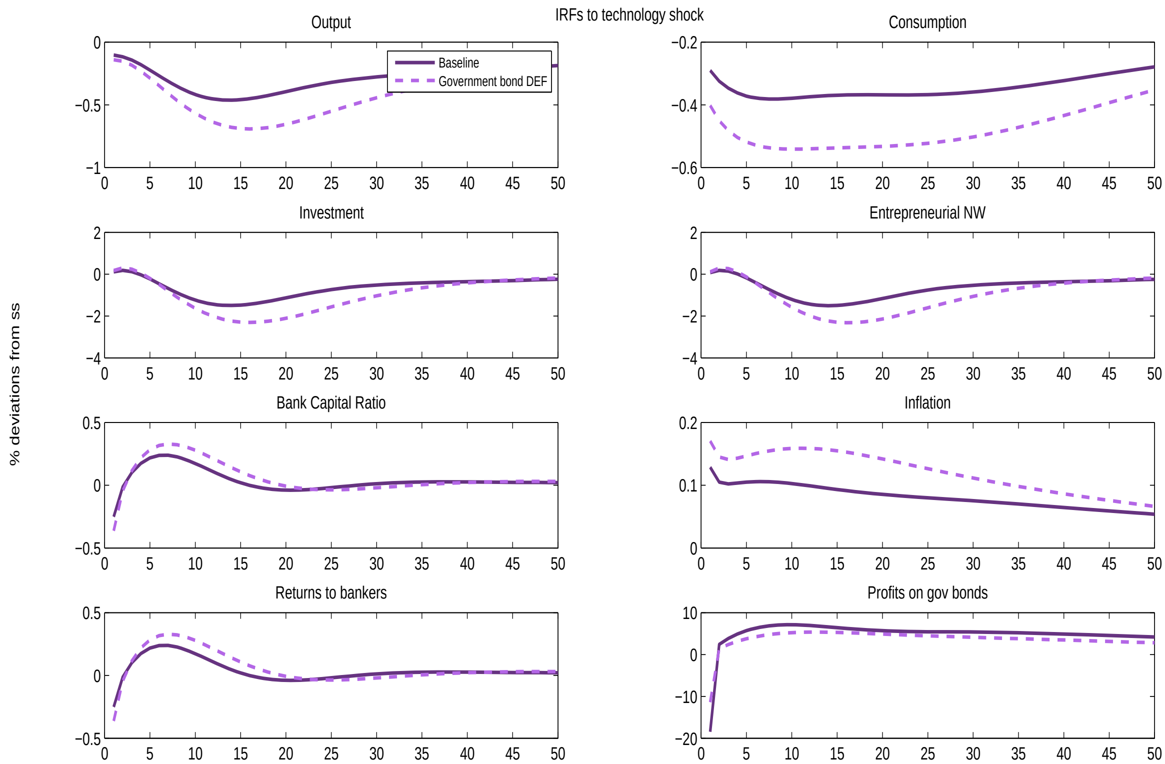


Figure 4: **Impulse responses of selected variables to a 1% fall in aggregate productivity in the model without (solid line) government bond risk and with (dashed line) it.**

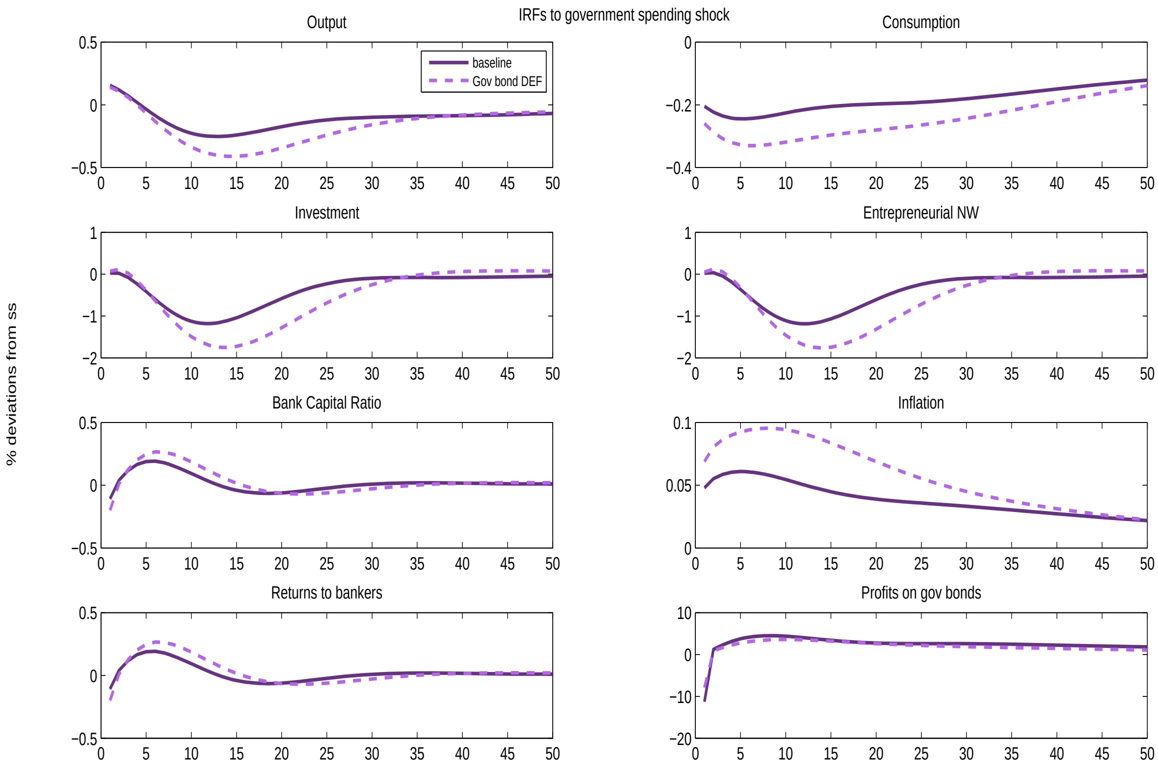


Figure 5: **Impulse responses of selected variables to a 1% fall in government spending in the model without (solid line) government bond risk and with (dashed line) it.**

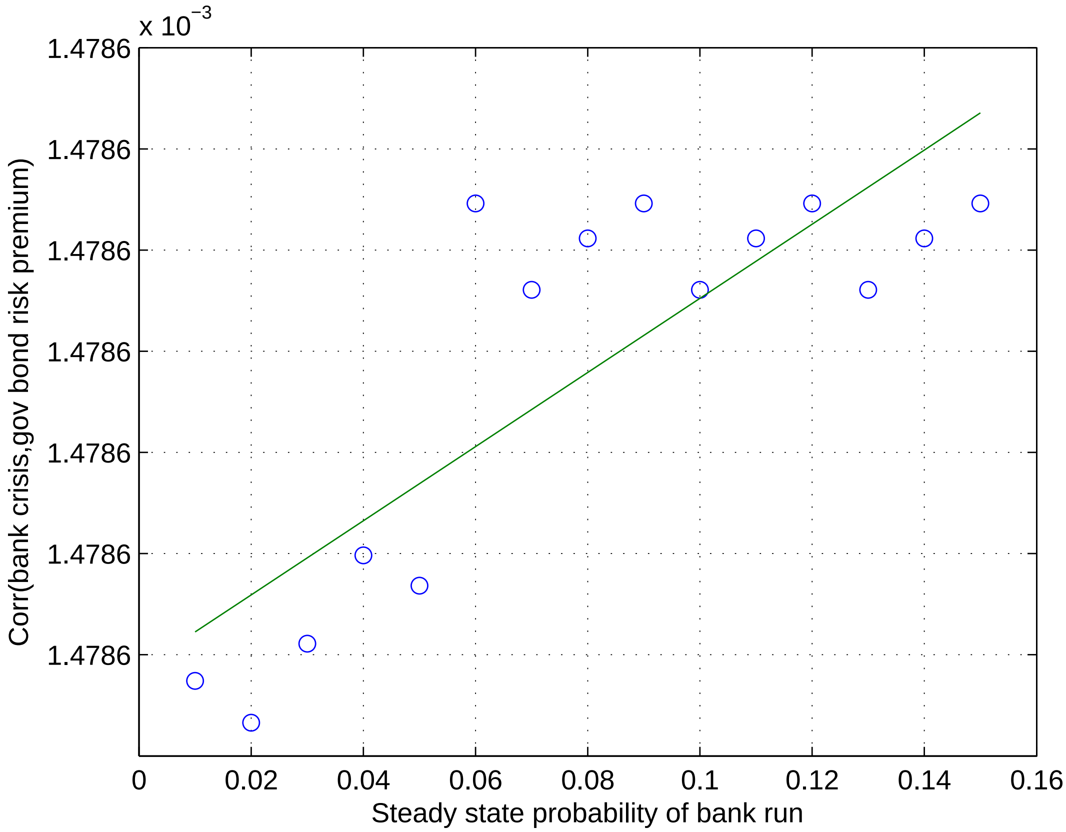


Figure 6: **Correlation between bank risk and government bond risk in response to "news" shocks affecting banks' returns uncertainty and for different steady state values of $\rho$.**

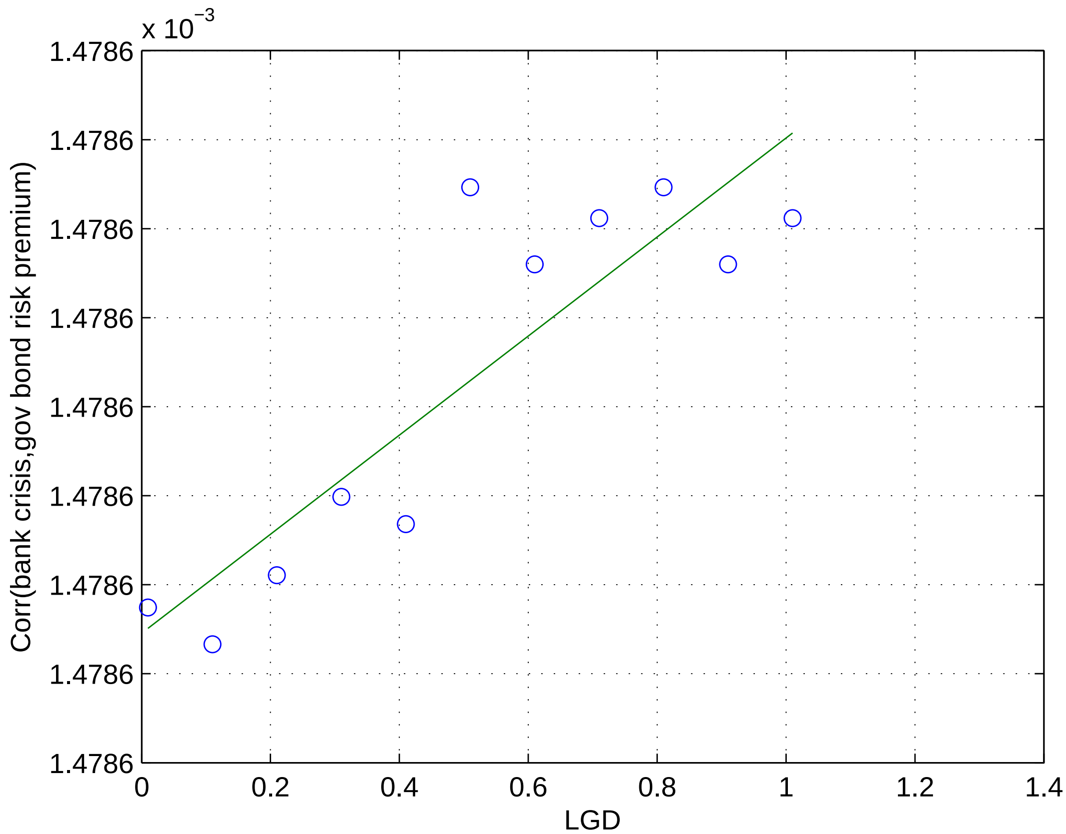


Figure 7: **Correlation between bank risk and government bond risk in response to "news" shocks affecting uncertainty of banks' returns and for different values of the haircut on government bonds.**

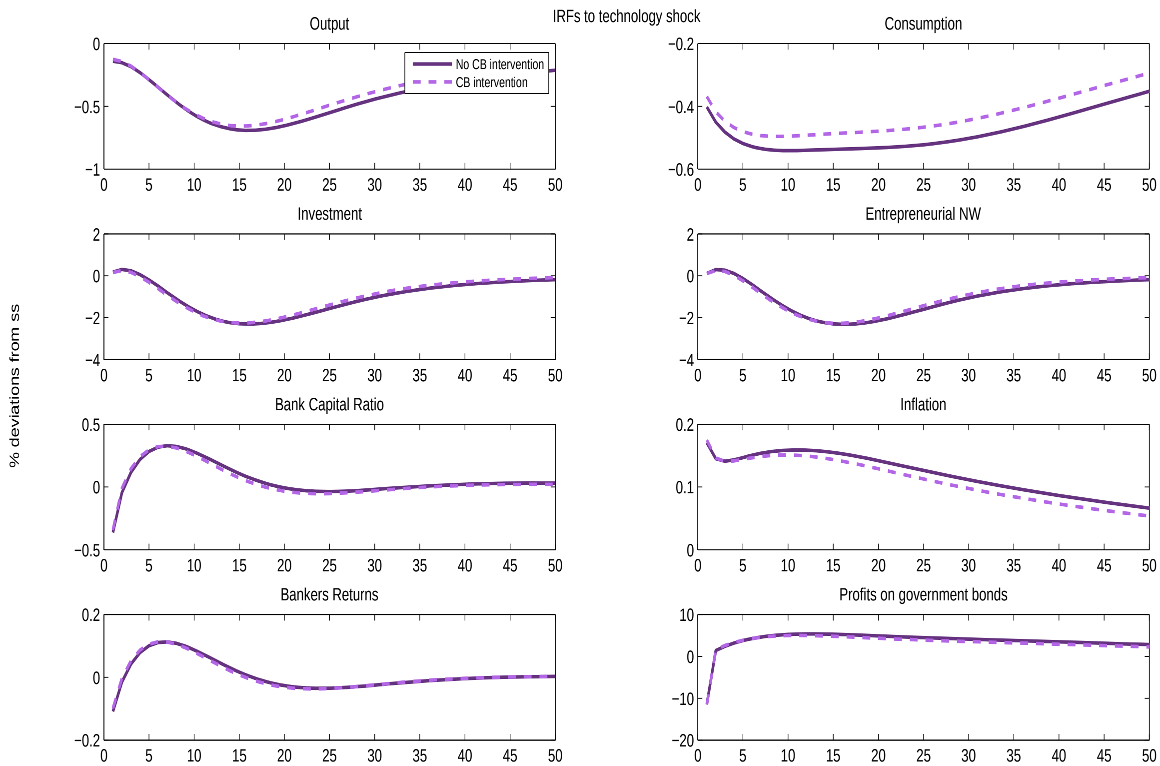


Figure 8: **Impulse response functions to technology socks of selected variables in the model with government bond risk by comparing the case with central bank intervention (dashed line) with no central bank intervention (solid line).**

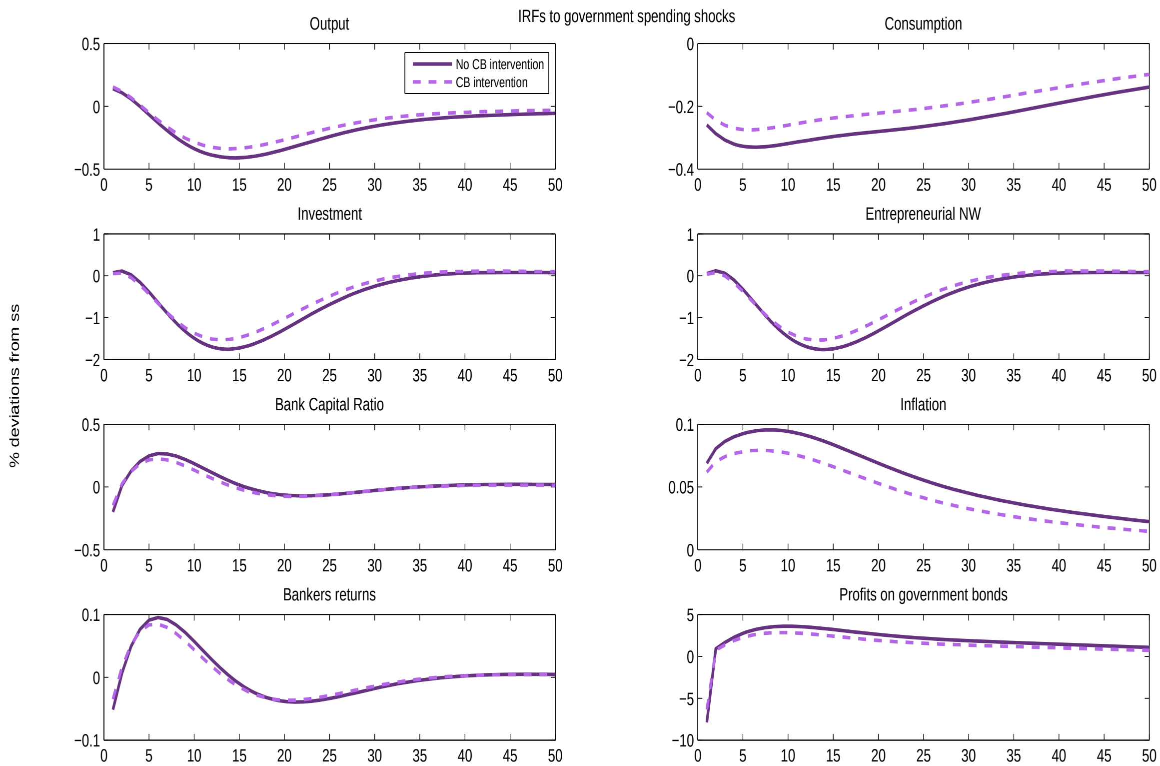


Figure 9: **Impulse response functions to government spending shocks of selected variables in the model with government bond risk by comparing the case with central bank intervention (dashed line) with no central bank intervention (solid line).**

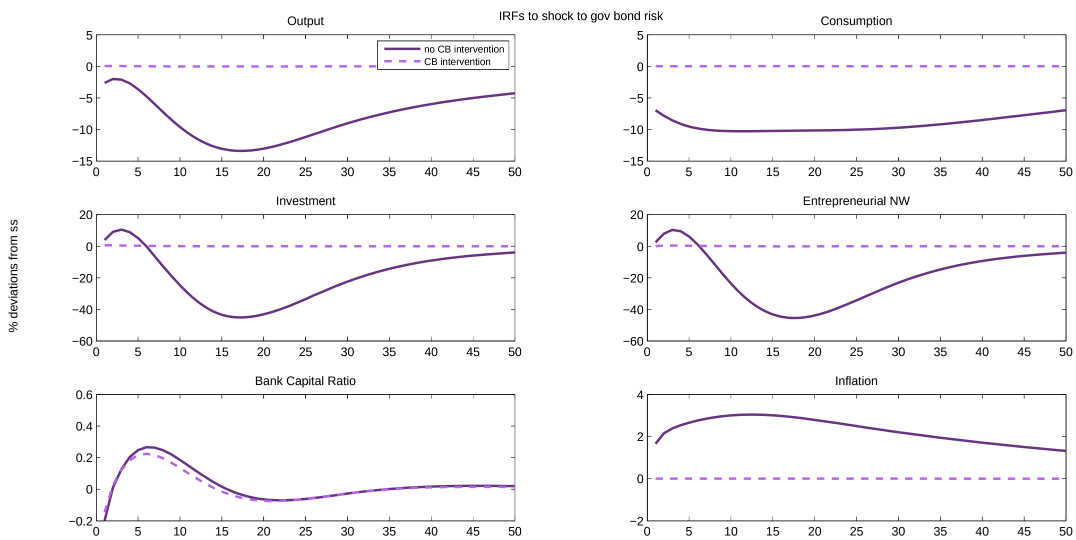


Figure 10:

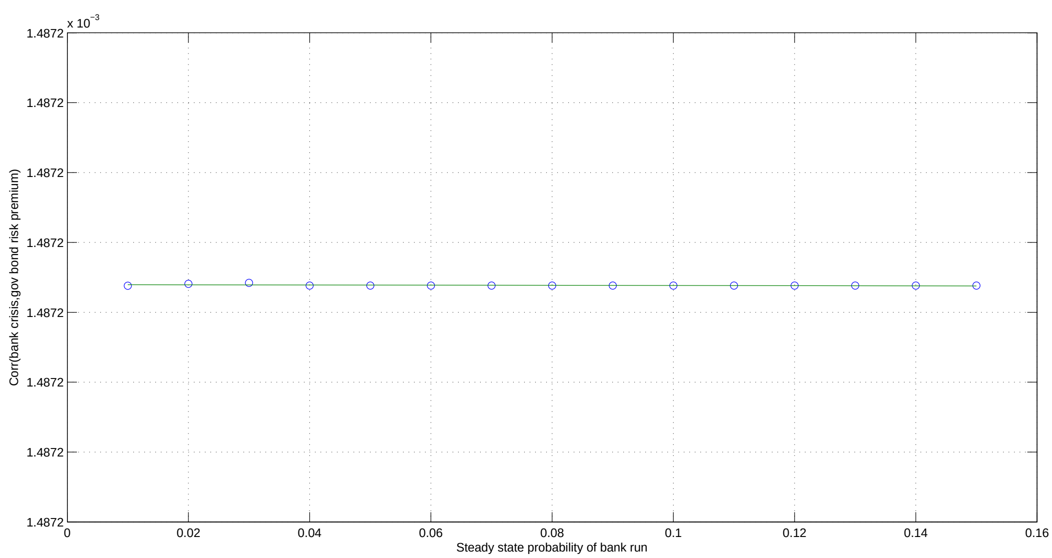


Figure 11: **Correlation between bank risk and government bond risk under central bank intervention and in response to "news" shocks affecting banks' returns uncertainty and for different steady state values of $\rho$.**

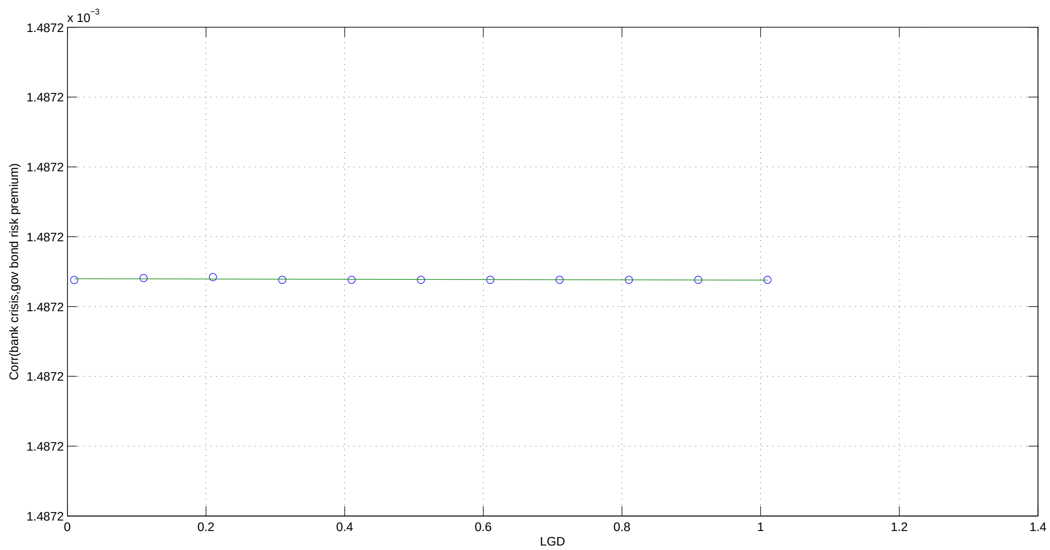


Figure 12: **Correlation between bank risk and government bond risk under central bank intervention and in response to "news" shocks affecting uncertainty of banks' returns and for different values of the haircut on government bonds.**

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