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FINANCIAL (IN)STABILITY, SUPERVISION AND LIQUIDITY INJECTIONS: A DYNAMIC GENERAL EQUILIBRIUM APPROACH*

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We develop a DSGE model with a heterogeneous banking sector. We introduce endogenous default probabilities for both firms and banks, and allow for bank regulation and liquidity injections into the interbank market. We aim to understand the interactions between the banking sector and the rest of the economy and the importance of supervisory and monetary authorities in restoring financial stability. The model is calibrated against real US data and used for simulations. The minimum capital requirements of Basel I regulation reduce the long-run level of output but improve the resilience of the economy to shocks, while Basel II capital requirements increase business cycle fluctuations.

In neoclassical models, the capital market is generally perfectly competitive, i.e. is not distorted by taxes, transaction or bankruptcy costs, imperfect information or any other friction which limits access to credit. The Modigliani and Miller (1958) theorem means that financial and credit market conditions become irrelevant and cannot affect real economic outcomes. However, credit market imperfections and financial agents' behaviour are often considered a crucial contributing factor to the severity of crises, as was evident during the Great Depression or more recently during the subprime crisis and associated financial turmoil. This central role of the credit market may in turn explain why banking remains regulated despite the significant deregulation in many other industries in recent decades. This may also explain why central banks react so rapidly to financial crises, despite the risk of creating moral hazard.

The main objective of this article is to build a dynamic stochastic general equilibrium (DSGE) model with imperfections in the credit market, such that the Modigliani and Miller (1958) theorem no longer holds. More precisely, following Goodhart *et al.* (2006), we develop an endogenous and heterogeneous banking sector, and incorporate bank regulation and liquidity injections. We embed this banking sector representation in an otherwise standard real business cycle model (hereafter RBC, see King and Rebelo (1999) for an extensive exposition). We use the RBC model as our starting point as it is now widely accepted as a benchmark in the literature. Moreover, in the limiting case of no default rates and no supervisory and monetary authorities, our model generates results similar to those of the RBC model. We then calibrate the model in order to understand the interactions between the banking sector and the rest of the economy, in combination with the role of supervisory and monetary authorities in restoring financial stability.

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Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), Bernanke *et al.* (1999), Cooley *et al.* (2004) and Iacovello (2005) introduce credit market frictions (asymmetry of information and agency costs, limited contract enforceability, collateral constraints ...) in dynamic general equilibrium models and show that frictions act as a financial accelerator. However, these models only focus on the demand side of the credit market and banks are limited to act as intermediaries between households (lenders) and firms (borrowers). Meh and Moran (2004) argue that banks themselves are also subject to frictions when raising loanable funds and show that the supply side of the credit market (bank balance sheet) also contributes to shock propagation. However, their capital–asset ratio is market determined rather than originating from regulatory requirements. Markovic (2006) develops a closely related model in which banks must raise capital reserves, or reduce their loan supply, to fulfil regulatory requirements. These results suggest that the bank capital channel contributes significantly to the monetary transmission mechanism, along with the corporate balance sheet channel. Goodfriend and McCallum (2007) and Christiano *et al.* (2009) formulate quantitative models to assess the relevance of a detailed banking sector and, hence, the importance of distinguishing among the various short term interest rates for monetary policy. Gerali *et al.* (2009) augment this literature by introducing imperfect competition among banks.[1]

All the papers mentioned above use homogeneous banks and the interbank market either collapses or amounts to a connection with the central bank. However, as mentioned in Goodhart *et al.* (2006), ignoring bank heterogeneity and the existence of a true interbank market obscures the relationships between banks which interest supervisory authorities and central banks. Moreover, most papers limit bank choices to collecting deposits and supplying loans, thereby omitting possibilities such as balance sheet choices or default. Goodhart *et al.* (2005) develop a model including a heterogeneous banking sector with an explicit interbank market, optimal balance sheet choices and endogenous default rates. Since the main focus of their paper is financial fragility, a financial regulator imposes a range of penalties in case of default or non-adherence to capital adequacy ratios. A central bank is also included in the interbank market. However, if the 'core' banking sector is extensively developed and micro-founded, the 'periphery' agents are modelled through reduced form equations. In addition, this is only a 2-period–2-state model which cannot track the dynamic effects of shocks or policies.

Our model includes a representative firm that borrows and a representative household that lends. Two banks with endogenous balance sheet decisions compose the banking sector; one being a net lender and the other a net borrower on the interbank market. We assume that firms and banks may default on their financial obligations, subject to default costs, and these defaults act as financial accelerators. Moreover, we have capital regulation rules set by a supervisory authority and we allow for monetary policy through liquidity injections into the interbank market. We therefore have a banking sector representation close to Goodhart *et al.* (2005) but we embed it in a micro-founded dynamic stochastic general equilibrium model. As underlined in Borio

[1] This literature review is far from being exhaustive and we concentrate on dynamic general equilibrium models. For an extended survey see, for instance, VanHoose (2008).

and Zhu (2008), this is the only framework in which dynamic interactions between the financial system and the broader economy can be properly assessed.

To calibrate the model, we use US data on interest rates, default rates, bank balance sheets and production. Then we conduct several simulation exercises to evaluate how realistic and attractive this 'augmented RBC model' is. First, we compare moments from US data with those issued from the model. Model simulations driven by productivity shocks tolerably reproduce US economic activity, including the banking sector. Moreover, adding a specific banking sector shock to the usual productivity shock reduces some shortcomings, such as the lack of volatility for bank profits and, more generally, improves simulated data along almost all dimensions. Second, we consider Basel I regulations. We show that imposing a minimum capital ratio reduces the long-run level of output but improves the resilience of the economy to shocks. However, introducing the more risk-sensitive Basel II capital requirements increases business cycle fluctuations. Nevertheless, these effects are quantitatively weak because they are mitigated by the buffer banks hold on top of the required minimum capital. Third, we explore the consequences of liquidity injections. We show that these effects are limited when liquidity is financed by households' taxation, whereas non-financed injections such as pure liquidity creation strongly stimulate the economy at impact but have short-lived effects. What can we conclude from these simulations? On the positive side, our model seems realistic, at least when comparing actual moments of the US economy with similar moments from the model. Moreover, the model is rich enough to introduce several types of shocks and hence allows for a better understanding of the general equilibrium interactions between the real part and the financial part of the economy. Finally, we provide one of the first attempts at introducing financial stability and supervision into DSGE models. On the negative side, our real business cycle approach implies that liquidity injections are represented by a supply of 'commodities'. A more realistic look at liquidity injections would require moving from a RBC model to a New-Keynesian one. Therefore, our model must be seen as a stepping stone towards future research.

Section 1 introduces the model. Section 2 describes the calibration. Sections 3 and 4 compare our numerical simulations with US data, explain the role of endogenous defaults, the Basel regulations and liquidity injections. Section 5 discusses the strengths and weaknesses of our approach and highlights potential areas of future research. Finally, Section 6 concludes.

1. Model

We depart from the standard RBC model, with a perfectly competitive capital (or credit) market between households/lenders and firms/borrowers, by introducing a banking sector. Households, firms and banks are distinct from one another in order to motivate lending, borrowing and the risk of defaults explicitly. This implies that firms and banks do not rebate profits to households. Instead, profits are directly consumed or, in the case of banks, may also be kept to reinforce own funds. More precisely, firms borrow from banks that convert household deposits into business financing for the purchase of capital. Under this framework, household deposits may differ from firms' borrowing. Furthermore, the interest rate on deposits may differ from the interest rate on borrowing, thereby generating an interest rate spread.

A second departure from the standard model is the introduction of an interbank market. Banks collecting deposits from households are different from banks supplying loans to firms. The former have excess liquidity, while the latter are in need of liquidity, and equilibrium is restored through the interbank market.[2] With no central bank intervention, only interbank market forces determine interbank interest rate fluctuations. Alternatively, the central bank may inject or remove liquidity to influence the interbank rate. Again, the interbank interest rate may differ from both the deposit rate and the borrowing rate.

We also introduce endogenous probabilities of default for firms and merchant banks but assume that deposit banks cannot default on households (see Section 1.3 for a justification). In this setup, a firm default may lead to a merchant bank default on the interbank market, which in turn curtails credit extension to the interbank market *via* the deposit banks and worsens the crisis. This representation also implies that banks take risks arising from uncertain net returns, whereas households always know the net investment return perfectly. Banks have different mechanisms such as own funds commitment, insurance funds and portfolio diversification to protect themselves against these risks. This justifies their role as financial intermediaries.

Finally, we have a supervisory authority fixing own fund requirements for banks. These requirements may be independent from the business cycle such as Basel I, which is based on asset type, or risk-sensitive like Basel II, which is based on asset type and asset quality. We therefore have six agents in our model: firms, merchant banks, deposit banks, households, a supervisory authority and a central bank. The interrelationships between these six agents are summarised in Figure 1.

1.1. *Firms*

Firms choose employment, new borrowing and the repayment rate on past borrowing to maximise the discounted sum of all expected payoffs. The payoff includes profits minus a disutility related to defaults. Indeed, as in Shubik and Wilson (1977), Dubey *et al.* (2005) and Elul (2008), we assume defaulters are not excluded from the market but bear costs. Non-pecuniary or disutility costs such as reputation losses or pangs of conscience are represented by the parameter d_f. Pecuniary costs, such as higher search costs to obtain new loans because of the bad reputation, affect profits and are represented by the parameter ω_f.[3] The firm maximisation programme is:

$$\max_{N_t, L_t^b, \alpha_t, K_t, \pi_t^f} \sum_{s=0}^{\infty} \mathrm{E}_t\{\beta^s[\pi_{t+s}^f - d_f\,(1-\alpha_{t+s})]\} \tag{1}$$

under the constraints:

[2] In the subsequent analysis, we call 'merchant banks' those who borrow on the interbank market and lend to firms and 'deposit banks' those who lend on the interbank market and collect deposits from households.

[3] Theoretically, we should write non-pecuniary default costs as $\max[0, d_f(1-\alpha_{t+s})]$ (with a similar form for pecuniary default costs) but this may generate a corner solution. In practice, we simply check *ex post* that during simulations, $\alpha_t \leq 1 \quad \forall t$. Section 5 provides a more general discussion about the way we model the default choice.

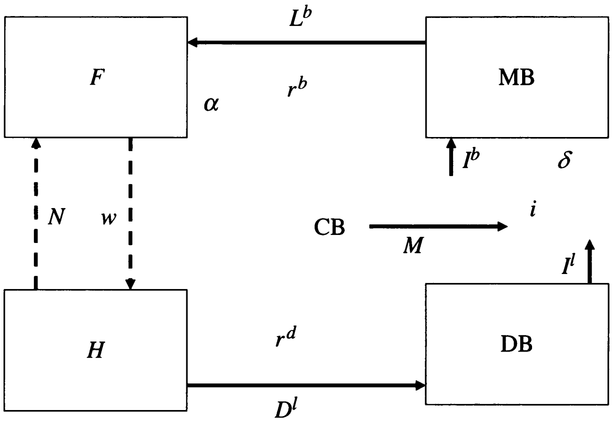

Fig. 1. *Flows Between Agents*

$$K_t = (1 - \tau)K_{t-1} + \frac{L_t^b}{1 + r_t^b}, \tag{2}$$

$$\pi_t^f = \varepsilon_t \mathcal{F}(K_t, N_t) - w_t N_t - \alpha_t L_{t-1}^b - \frac{\omega_f}{2}[(1 - \alpha_{t-1})L_{t-2}^b]^2. \tag{3}$$

Equation (2) is the law of motion for capital. Capital K_t depreciates at a rate τ and firms borrow L_t^b at a price $1/(1 + r_t^b)$ to refill their capital stock.[4] Equation (3) defines profit π_t^f. Firms produce goods using capital and labour N_t as input, and $\varepsilon_t = (\varepsilon_{t-1})^{\rho_\varepsilon} \exp(u_t^\varepsilon)$ is a total factor productivity shock defined as a stochastic AR(1) process. Firms also pay a wage w_t to workers and reimburse their previous period borrowing L_{t-1}^b. They choose what proportion α_t of their previous borrowing they want to repay, knowing that tomorrow they will have to pay a quadratic search cost on any defaulted amount, in addition to bearing a default disutility.

The optimisation yields the following first order conditions, with λ_t defined as the shadow value of capital:

$$\varepsilon_t \mathcal{F}_{N_t} = w_t, \tag{4}$$

$$\varepsilon_t \mathcal{F}_{K_t} = \lambda_t - \mathrm{E}_t[\beta(1 - \tau)\lambda_{t+1}], \tag{5}$$

$$\frac{\lambda_t}{1 + r_t^b} = \mathrm{E}_t[\beta\, \alpha_{t+1} + \beta^2\, \omega_f (1 - \alpha_{t+1})^2 L_t^b], \tag{6}$$

$$L_{t-1}^b = \beta\, \omega_f (1 - \alpha_t)\left(L_{t-1}^b\right)^2 + d_f. \tag{7}$$

[4] The interest rate is predetermined meaning it is fixed (contract between firms and banks) at the borrowing time t and not at the repayment time $t + 1$. We think this is a plausible representation of reality. Moreover, without predetermination, the endogenous default choice is irrelevant because it is totally offset by an interest rate increase. We also assume firms borrow from banks to finance investment. In reality, firms may also finance investment with own funds or through direct access to financial markets but this is beyond the scope of this article. See Section 5 for a discussion.

Equation (4) equalises the marginal productivity of labour and wages. Equation (5) defines the marginal productivity of capital as its shadow value today minus its discounted shadow value tomorrow, and (6) states that the shadow value of capital today is equal to its discounted expected cost (a fraction α_t will be paid back tomorrow and a cost on the remaining fraction will be paid two periods ahead). Equation (7) equalises the marginal cost of paying back today to the discounted marginal search cost of tomorrow plus the marginal disutility term.

1.2. *Merchant Banks: Borrowing from the Interbank Market and Lending to Firms*

Merchant banks choose fund allocation from amongst loans L_t^b to firms, market book B_t^b, borrowing I_t^b from the interbank market and own funds F_t^b, as well as the repayment rate on past borrowing so as to maximise the sum of all expected payoffs.[5] The payoff includes a concave function of profits, a disutility from default and a utility from own funds. We borrow the concave representation of profits from Goodhart *et al.* (2005). As for firms, we do not exclude defaulters but instead impose both disutility and pecuniary costs, where d_b represents the disutility cost and ω_b the pecuniary cost. We follow again Goodhart *et al.* (2005) by assuming a positive linear utility d_{F^b} for the buffer of own funds F_t^b above the minimum capital requirement imposed by the financial supervisory authority. This fixes the coverage ratio of risky assets k, together with $\bar{\omega}_t$ and $\tilde{\omega}_t$, the respective weights on loans to firms and on the market book.[6] The bank maximisation programme is:

$$\max_{\delta_t, I_t^b, L_t^b, B_t^b, F_t^b, \pi_t^b} \sum_{s=0}^{\infty} \mathrm{E}_t(\beta^s\{\ln(\pi_{t+s}^b) - d_b\,(1-\delta_{t+s}) + d_{F^b}[F_{t+s}^b - k(\bar{\omega}_{t+s}L_{t+s}^b + \tilde{\omega}_t B_{t+s}^b)]\}), \quad (8)$$

under the constraints:

$$F_t^b = (1-\xi_b)F_{t-1}^b + \upsilon_b \pi_t^b, \quad (9)$$

$$\begin{aligned} \pi_t^b = {} & \alpha_t L_{t-1}^b + \frac{I_t^b}{1+i_t} - \delta_t I_{t-1}^b - \frac{L_t^b}{1+r_t^b} - \frac{\omega_b}{2}\left[(1-\delta_{t-1})I_{t-2}^b\right]^2 + \zeta_b(1-\alpha_{t-1})L_{t-2}^b \\ & + (1+\rho_t)B_{t-1}^b - B_t^b, \end{aligned} \quad (10)$$

with ζ_b, ξ_b and $\upsilon_b \in [0,1]$. Profits made by banks are directly consumed or used to increase own funds. Equation (9) states that at every period, banks devote an exogenous fraction υ_b of profits to own funds. Furthermore, a small fixed proportion ξ_b of the own funds are put in an insurance fund managed by a public authority. Equation (10) defines the period profit. The bank borrows I_t^b on the interbank market at a price $1/(1+i_t)$. It chooses the fraction δ_t of past borrowing it wants to pay back,

[5] Although firms, banks and households are distinct agents, we simply assume they discount the future at the same rate.

[6] In practice, the regulator sets a minimum capital requirement and penalties are paid in case of violation. Since we want to rule out a corner solution in our model, we simply assume that banks want to keep a buffer above the required minimum in order to avoid penalties. This buffer assumption does not seem unrealistic and can be found in the data (see Section 2). As underlined in Borio and Zhu (2008), crossing the capital threshold is extremely costly for a bank in terms of restrictive supervisory actions, market reaction or reputation losses and would be regarded as the 'kiss of death'.

knowing that tomorrow it will have to pay a quadratic search cost on the defaulted amount. Due to the existence of the insurance fund, the bank is able to recover a fraction ζ_b of the firms' defaulted amount.[7] Banks also invest B_t^b in securities (market book), expecting a return $E_t[(1+\rho_{t+1})B_t^b]$ in the next period. Since an endogenous representation of the securities market is beyond the scope of this article, we simply assume a constant market book volume $B_t^b = \bar{B}^b$ and a stochastic AR(1) market book return process $\rho_t = (\bar{\rho})^{1-\rho_\rho}(\rho_{t-1})^{\rho_\rho}\exp(u_t^\rho)$. The interest in having a market book in our model, even if it is exogenous, is twofold. First, it aids the calibration because the share of the market book in total banking assets is usually large, see Section 2. Second, this is an easy and intuitive way to introduce an unexpected shock on bank profits. It is worth noting that our shock has some degree of persistence. As underlined in Christiano *et al.* (2009), shocks originating within financial markets have generally moderate to high serial correlation.[8]

The maximisation program yields:

$$\lambda_t^b I_{t-1}^b = E_t\left[\beta\,\lambda_{t+1}^b\,\omega_b(1-\delta_t)\left(I_{t-1}^b\right)^2\right] + d_b, \tag{11}$$

$$\frac{\lambda_t^b}{1+i_t} = E_t\left[\beta\,\lambda_{t+1}^b\delta_{t+1} + \beta^2\lambda_{t+2}^b\,\omega_b(1-\delta_{t+1})^2 I_t^b\right], \tag{12}$$

$$\frac{\lambda_t^b}{1+r_t^b} = E_t\left[\beta\lambda_{t+1}^b\,\alpha_{t+1} + \zeta_b\,\beta^2\lambda_{t+2}^b\,(1-\alpha_{t+1})\right] - d_{F^b}k\bar{w}_t, \tag{13}$$

$$d_{F^b}v_b = \left(\lambda_t^b - \frac{1}{\pi_t^b}\right) - E_t\left[\beta(1-\xi_b)\left(\lambda_{t+1}^b - \frac{1}{\pi_{t+1}^b}\right)\right]. \tag{14}$$

The Lagrange multiplier associated with constraint (10) is represented by λ_t^b. Equation (11) is the trade-off between paying back today and paying a cost tomorrow. Equations (12) and (13) are the Euler equations for borrowing from the interbank market and lending to firms, respectively.

1.3. *Deposit Banks: Receiving Deposits and Lending to the Interbank Market*

Deposit banks choose fund allocation (loans I_t^l to the interbank market, market book B_t^l, deposits D_t^l from households and own funds F_t^l) to maximise the sum of all expected payoffs. The instantaneous payoff is defined as a concave function of profits plus the utility from own funds. As the merchant banks, they derive linear utility d_{F^l} from the

[7] Section 5 justifies and discusses this insurance scheme.

[8] Similarly, Gerali *et al.* (2009) study the effects of a weakening in the balance sheet position of the banking sector, by introducing the possibility of an unexpected and persistent contraction in bank capital. Goodfriend and McCallum (2007) and Meh and Moran (2010) also introduce AR(1) 'financial distress' shocks, which cause exogenous declines in bank capitalisation.

buffer of own funds above the capital requirement imposed by the supervisory authority. The latter fixes the coverage ratio of risky assets k, as well as $\bar{\bar{\omega}}_t$ and $\tilde{\omega}_t$, the weights associated with interbank loans and market book respectively. Their maximisation programme is:

$$\max_{I_t^l, D_t^l, B_t^l, F_t^l, \pi_t^l} \sum_{s=0}^{\infty} \mathrm{E}_t(\beta^s \{\ln(\pi_{t+s}^l) + d_{F^l}[F_{t+s}^l - k(\bar{\bar{\omega}}_{t+s} I_{t+s}^l + \tilde{\omega}_t B_{t+s}^l)]\}), \tag{15}$$

under the constraints:

$$F_t^l = (1 - \xi_l) F_{t-1}^l + \upsilon_l \pi_t^l, \tag{16}$$

$$\pi_t^l = \delta_t I_{t-1}^l + \frac{D_t^l}{1 + r_t^l} - D_{t-1}^l - \frac{I_t^l}{1 + i_t} + \zeta_l (1 - \delta_{t-1}) I_{t-2}^l + (1 + \rho_t) B_{t-1}^l - B_t^l, \tag{17}$$

with ζ_l, ξ_l and $\upsilon_l \in [0,1]$. Equation (16) displays the own funds dynamics. Own funds F_t^l are increased each period by the share υ_l of profits that banks do not directly consume. Furthermore, a small fixed proportion ξ_l of the own funds are put in an insurance fund managed by a public authority. Equation (17) defines the bank's profit π_t^l. Deposit banks pay a return r_t^l on deposits from households and receive a return i_t from loans on the interbank market, varying along with the merchant banks default rate $(1-\delta_t)$. Note that a fraction ζ_l of the defaulted amount, arising from the defaulting merchant banks, is paid back to the deposit banks from the insurance fund managed by the public authority. We assume that the deposit banks can never default, which means that they always repay 100% of client deposits.[9] The last terms $(1 + \rho_t) B_{t-1}^l - B_t^l$ on the right-hand side represent the net market book situation. We assume an exogenous market book volume $B_t^l = \bar{B}^l$ and the net return simplifies into $\rho_t \bar{B}^l$.

The maximisation program yields:

$$\frac{\lambda_t^l}{1 + r_t^l} = \mathrm{E}_t(\beta\, \lambda_{t+1}^l), \tag{18}$$

$$\frac{\lambda_t^l}{(1 + i_t)} = \mathrm{E}_t\left[\beta \lambda_{t+1}^l\, \delta_{t+1} + \zeta_l \beta^2\, \lambda_{t+2}^l\, (1 - \delta_{t+1})\right] - d_{F^l} k \bar{\bar{\omega}}_t, \tag{19}$$

$$d_{F^l} \upsilon_l = \left(\lambda_t^l - \frac{1}{\pi_t^l}\right) - \mathrm{E}_t\left[\beta\, (1 - \xi_l) \left(\lambda_{t+1}^l - \frac{1}{\pi_{t+1}^l}\right)\right]. \tag{20}$$

The Lagrange multiplier associated with constraint (17) is represented by λ_t^l. Equations (18) and (19) are the Euler equations for deposits from households and loans to the interbank market, respectively.

[9] This is admittedly a simplification. It is equivalent to assuming sufficiently high default costs to ensure a default rate of zero every period. However, such an assumption is not completely unrealistic. In particular, a bank defaulting on deposits incurs a risk of nationalisation which could result in a significant loss for owners. This may provide an explanation as to why defaults on deposits are not frequently observed in the data, except during rare periods of deep crises.

1.4. *Households*

Households choose consumption C_t and deposits D_t^l to maximise (21) subject to conditions (22) and (23). As is often the case in the RBC literature, we use a logarithmic momentary utility function for consumption. We also impose a target on deposits through a quadratic disutility term, as households do not like deposits differing from their long-run optimal level.[10] Finally, we assume exogenous labour supply.[11]

$$\max_{C_t, D_t^l} \sum_{s=0}^{\infty} \beta^s \, \mathrm{E}_t \left[\ln(C_{t+s}) - \frac{\chi}{2} \left(\frac{D_{t+s}^l}{1 + r_{t+s}^d} - \frac{\bar{D}^l}{1 + r^d} \right)^2 \right], \tag{21}$$

$$T_t + C_t + \frac{D_t^l}{1 + r_t^l} = w_t N_t + D_{t-1}^l, \tag{22}$$

$$N_t = \bar{N}. \tag{23}$$

T_t is a lump-sum tax. The maximisation programme yields:

$$\frac{1}{C_t} \frac{1}{1 + r_t^d} = \beta \mathrm{E}_t \left(\frac{1}{C_{t+1}} \right) - \chi \left(\frac{D_t^l}{1 + r_t^d} - \frac{\bar{D}^l}{1 + r^d} \right). \tag{24}$$

Equation (24) is the Euler equation for consumption augmented with the deposit target term.

1.5. *Central Bank*

The central bank may inject ($M_t > 0$) or withdraw ($M_t < 0$) liquidity such that:

$$M_t = I_t^b - I_t^l. \tag{25}$$

At the steady state, we assume no liquidity injections, that is $M = 0$.

1.6. *Supervisory Authority*

The supervisory authority fixes the capital requirement ratio k and the weights $\bar{\omega}_t$, $\bar{\bar{\omega}}_t$ and $\tilde{\omega}_t$ associated with the different kinds of risky assets. These are loans to firms, interbank loans and market book (securities) investment. We assume that under Basel I regulations, all weights are constant, that is $\bar{\omega}_t = \bar{\omega}$, $\bar{\bar{\omega}}_t = \bar{\bar{\omega}}$ and $\tilde{\omega}_t = \tilde{\omega}$. Basel II regulations offer more sophisticated and informative measures of risks and capital

[10] We introduce the convex disutility term for technical reasons. If $\chi = 0$, both (18) and (24) give the steady state for r_t^d, leaving D_t^l undetermined. By imposing $\chi > 0$, we force (24) to determine the steady state of D_t^l. Note that in our calibration, χ is kept close to zero to affect the dynamic properties of the model only marginally. Alternatively, we could introduce a bank production function such that $D_t^l/(1 + r_t^d)$ deposits only produce $[D_t^l/(1 + r_t^d)]^\lambda$ assets. As long as $\lambda \neq 1$, this would allow (18) to determine D_t^l at the steady state.

[11] With a productivity shock only, we could consider endogenous labour supply as, for instance, in King and Rebelo (1999) and most of the RBC literature. However, a market book shock mainly generates a wealth effect at impact and hence a countercyclical employment. In order to avoid non-intuitive employment fluctuations, we keep labour supply exogenous. Alternative solutions exist, as the search and matching approach following Merz (1995) or Andolfatto (1996) but they are beyond the scope of this article, focusing on the banking sector.

adequacy. In particular, we assume that the credit weights assigned to loans to firms and loans to banks are risk-sensitive. If the expectations of defaults increase, the associated weights also increase:

$$\bar{\omega}_t = \bar{\omega}\,\mathrm{E}_t\left[\left(\frac{\alpha}{\alpha_{t+1}}\right)^{\eta_b}\right] \quad \text{and} \quad \bar{\bar{\omega}}_t = \bar{\bar{\omega}}\,\mathrm{E}_t\left[\left(\frac{\delta}{\delta_{t+1}}\right)^{\eta_l}\right], \tag{26}$$

with $\eta_b, \eta_l > 0$. We do not explore the Basel II regulation on the market book since we take it as exogenous. Therefore the related regulation parameter collapses into $\tilde{\omega}_t = \tilde{\omega}$.

1.7. *Closing the Model*

To close the model, we assume two different scenarios. In the first one, liquidity injections are fully financed by taxation. In other words, the lump-sum tax T_t is levied on households to fund both the insurance scheme and the liquidity injections:[12]

$$T_t = \frac{M_t}{1+i_t} - \delta M_{t-1} + \zeta_b(1-\alpha_{t-1})L^b_{t-2} + \zeta_l(1-\delta_{t-1})I^b_{t-2} - \xi_b F^b_{t-1} - \xi_l F^l_{t-1}. \tag{27}$$

Note that contributions from banks already partly fund the insurance scheme. In the second scenario, liquidity injections are not financed and the lump-sum tax only funds the insurance scheme:

$$T_t = \zeta_b(1-\alpha_{t-1})L^b_{t-2} + \zeta_l(1-\delta_{t-1})I^b_{t-2} - \xi_b F^b_{t-1} - \xi_l F^l_{t-1}. \tag{28}$$

Since our model is in real terms, the second scenario implies that liquidity creation is equivalent to a windfall of 'commodities'. It is worth noting that both scenarios have the same steady state.

2. Calibration

We calibrate the model on average historical real quarterly US data from 1985Q1 to 2008Q2.[13] The calibration of the banking sector is mainly based on balance sheet and macro-financial data whereas we build the calibration of the real sector (firms and households) from national account data. The summary of the calibration as well as the implied values for variables are given in Tables 1 and 2.

2.1. *Banking Sector*

To match the data, we set the steady state values for the quarterly real borrowing interest rate at $r^b = 1.6\%$, the quarterly real interbank interest rate at $i = 0.7\%$ and the quarterly real deposit interest rate at $r^d = 0.35\%$. This last restriction implies a discount

[12] In our model, because $M = 0$ at the steady state, we cannot distinguish between central bank liquidity and private bank liquidity. In other words, interest and default rates apply to both types of funds. Alternatively, we could assume $M \gg 0$ such that $M_t > 0\ \forall t$. It would imply that interbank deposits are structurally higher than interbank loans and this would allow us to distinguish between private bank funds and central bank funds. This alternative route would not change our results.

[13] Some of the data were only available starting from 1985. See Appendix A for details.

Table 1

Calibrated Parameter Values

Banks			
$k = 0.08$	$\bar{\omega} = 0.8$	$\bar{\bar{\omega}} = 0.05$	$\tilde{\omega} = 1.20$
$d_b = 6.67$	$\omega_b = 679$	$\bar{B}^b = 0.19$	$\bar{B}^l = 0.19$
$d_{F^b} = 6.71$	$\zeta_b = 0.8$	$\xi_b = 0.06$	$\upsilon_b = 0.5$
$d_{F^l} = 53.4$	$\zeta_l = 0.8$	$\xi_l = 0.07$	$\upsilon_l = 0.5$
$\beta = 0.996$	$\bar{\rho} = 0.03$		
Firms			
$d_f = 0.05$	$\omega_f = 75.4$	$\mu = 0.333$	$\tau = 0.03$
Households			
$\chi = 0.01$	$\bar{N} = 0.20$	$\bar{D}^l = 0.39$	

Notes. k = minimum own funds ratio, $\bar{\omega}$ = Basel weight for loans to firms, $\bar{\bar{\omega}}$ = Basel weight for interbank loans, $\tilde{\omega}$ = Basel weight for market book, d_b = bank default disutility, ω_b = bank default cost, $\bar{B}^x$ = market book volume for bank $x \in \{b,l\}$, d_{F^x} = utility of own funds for bank $x \in \{b,l\}$, ζ_x = insurance coverage on defaulted amount for bank $x \in \{b,l\}$, ξ_x = own funds share devoted to the insurance fund for bank $x \in \{b,l\}$, υ_x = profit share devoted to own funds for bank $x \in \{b,l\}$, β = discount factor, $\bar{\rho}$ = average market book return, d_f = firm default disutility, ω_f = firm default cost, μ = capital share, τ = capital depreciation rate, χ = deposit gap disutility, $\bar{N}$ = labour supply, $\bar{D}^l$ = deposit target.

Table 2

Implied Steady State Values for Variables

Interest and repayment rates				
$r^d = 0.35\%$	$i = 0.7\%$	$r^b = 1.6\%$	$\delta = 0.99$	$\alpha = 0.95$
Assets and liabilities				
$D^l/L^b = 2$	$I/L^b = 0.5$	$B^b/L^b = 1$	$F/B = 0.25$	$B^l/B^b = 1$
Production, penalty costs and profits				
$K/\mathcal{Y} = 10$	$\pi^f/\mathcal{Y} = 4\%$	$tpcf/\mathcal{Y} = 0.6\%$	$T/\mathcal{Y} = 0.4\%$	$C/\mathcal{Y} = 0.66$
$tpcb/F = 0.3\%$	$\pi/F = 12\%$	$\varepsilon = 1$		

Notes. r^b = borrowing rate, i = interbank rate, r^d = deposit rate, α = firm repayment rate, δ = bank repayment rate, L^b = loans to firms, $I = I^b = I^l$ = interbank volume, D^l = consumer deposits, B^x = market book volume for bank $x \in \{b,l\}$, π^f = firm profit, K = capital stock, τK = firm investment, $\mathcal{Y}$ = output = $\mathcal{F}(K,N)$, C = consumption, $tpcf$ = total penalty costs for firms = $(\omega_f/2)[(1-\alpha)L^b]^2$, $tpcb$ = total penalty costs for banks = $(\omega_b/2)[(1-\delta)I^b]^2$, π = total profits for banks = $\pi^b+\pi^l$, F = total own funds = F^b+F^l, B = total market book = B^b+B^l, T = lump sum tax, ε = productivity shock.

factor of $\beta = 1/(1+r^d)$ for the deposit banks and we assume an equivalent discount factor for all the other agents. The average quarterly real return of the Dow Jones from 1985Q1 to 2008Q2 is 2.2% but we can expect that banks also have higher-yield securities. Therefore we assume that the market book offers a real return of $\rho = 3\%$. Using the Z-score method of representing the probability that own funds are not sufficient to absorb losses (see Appendix B for details), we find that the quarterly probability of default for banks is 0.1%. This is obviously low but can be explained because the Z-score is computed from aggregate data and therefore represents a single US bank. Carlson *et al.* (2008) compute Z-scores for individual bank data based on the 25 largest US banks and take the median value. Their default probability is close to 0 in normal times but can easily approach 5% during periods of stress (1987, 1991, 1999).

Alternatively, we define the bank default rate by the ratio of bankruptcies to banks. The Federal Deposit Insurance Corporation provides data on the number of bank failures and the Bureau of Labor Statistics provides data on the number of closings in the financial sector. These give 1% and 4%, respectively but the latter number is probably too high since the financial sector is larger than the banking sector and failures are only part of closings. Ultimately, we choose a value of 1%: $1 - \delta = 1\%$.[14]

The aggregate balance sheet of US banks is displayed in Appendix A. It is worth noting that interbank and consumer deposits, as well as interbank and firm loans, are stock variables. As far as we know, no gross flow data are available. In the model, all these variables have a one-quarter maturity and we cannot distinguish flows from stocks. Therefore we calibrate the model by fixing the same *ratio* between variables, both in the data and in the model. However we note that their *values* have different meanings: stocks in data and flows in the model. In other words, we impose $D^l/L^b = 2$ and $I^b/L^b = I^l/L^b = 0.5$.[15] Finally, we also impose a market book for each bank equal to firm loans: $B^l = B^b = L^b$. The market book share seems larger than what is observed in the data but we must again keep in mind that L^b is a stock in the data and a flow in the model.

According to the Basel agreement, minimum own funds cannot be lower than 8% of risk-adjusted assets ($k = 0.08$). The latter are defined by associating a risk category or weight to each balance sheet asset, such that the riskier the asset, the larger the weight it receives. Weights vary from 0 to 150%. The interbank market in OECD countries is almost risk-free and a low weight of $\bar{\bar{\omega}} = 0.20$ seems plausible. Both directly lending to firms or investing in securities (market book) bear similar risks associated with the counterparty. However, the latter investment bears an extra risk related to the market. This is why we assume that the Basel weight for loans to private firms is $\bar{\omega} = 0.80$ whereas the weight for the market book is set higher at $\tilde{\omega} = 1.2$. Finally, although the *official* minimum ratio is 8%, most banks adopt a higher *effective* ratio to avoid any penalty risk and we set this effective ratio at 15%. The Basel calibration implies that total own funds represent 25% of the total market book, which is slightly lower than the 33% that can be observed in the data (see Appendix A).

Every period, banks allocate 50% of their profits to own funds ($\upsilon_b = \upsilon_l = 0.50$). Our model also includes an insurance mechanism. In case of default, 80% of the bad loans are eventually reimbursed by an insurance fund ($\zeta_b = \zeta_l = 0.80$). This implies that every quarter banks must pay about 6% of their own funds as an insurance premium ($\xi_b = 5.9\%$ and $\xi_l = 6.5\%$).

From all these restrictions, we are able to infer values for the default cost parameter ω_b for banks, the default disutility parameter d_b for banks, and the utility parameters d_{F^b} and d_{F^l} for merchant and deposit banks' own funds, respectively. We also note that, on average, default costs amount to 0.3% of own funds and that the return on own funds, defined as the ratio of profits to own funds, is 12%. This is probably too high a return

[14] In Section 3, we compare our simulations to the Z-score series, because the FDIC (Federal Deposit Insurance Corporation) series is extremely volatile and the BLS (Bureau of Labor Statistics) series is limited in time. Moreover, the last two series correspond with the *number* of firms that default rather than the *value*.

[15] In the data, interbank loans do not match interbank deposits because US banks have borrowing/lending relationships with banks abroad. Because we model a closed economy, we must force a perfect match between deposits and loans.

but it could easily be decreased by introducing fixed costs for banks in the form of building, equipment or employment.

2.2. *Real Sector*

Following the RBC literature, employment (or total hours) $\bar{N}$ is normalised to 0.2.[16] The production function $\mathcal{Y}_t = \mathcal{F}(K_t, N_t) = K_t^{\mu} N_t^{1-\mu}$ is Cobb-Douglas with labour share $= 2/3$, i.e. $1-\mu = 2/3$, and the productivity shock is normalised to 1 ($\varepsilon = 1$). We assume that the capital stock is 10 times higher than production and the depreciation rate of capital is 3%, implying an investment to output ratio of 0.3. Specifically: $K/\mathcal{Y} = 10$ and $\tau = 3\%$ gives $\tau K/\mathcal{Y} = 0.3$. This is higher than what is normally observed in the data and used in RBC models ($K/\mathcal{Y} = 8$ and $\tau = 2.5\%$ gives $\tau K/\mathcal{Y} = 0.2$) but we need this to avoid a negative search cost ω_f.

The US courts provide quarterly data on business bankruptcies. To calculate the default rate, we divide these data by the number of firms and obtain a value of 5%. Using the same kind of data provided by the Bureau of Labor Statistics, we get a similar value. These figures however correspond to the *number* of firms that default rather than the *value*. Altman *et al.* (2005) compute the weighted average of US corporate bond defaults and find a mean value of 4.2% between 1982 and 2001, suggesting that the number approach is close to the value approach. In our calibration, we therefore set $1-\alpha = 0.05$.[17] From this, we are able to infer values for the firm search cost parameter ω_f and the firm default disutility parameter d_f. This also implies that default costs for firms represent, on average, 0.6% of output, firm profits represent 4% of output and consumption represents 66% of output. These figures are close to those observed in the data. Another implication is that, in the steady state, the required lump sum tax levied on households that equilibrates the insurance scheme budget amounts to 0.4% of output. Finally, the smoothing parameter for deposits is set close to 0 ($\chi = 0.01$), so as to avoid any dynamic effects (see footnote 10).

3. Simulations

In the RBC tradition, we first check if the model is able to reproduce some important stylised facts and calculate the size of the financial accelerator generated by our endogenous default rates. We subsequently explain the effects of Basel I regulation on both the steady state of the economy and its cyclical properties, and illustrate how the latter are affected by moving from Basel I to Basel II. Finally, we consider the effects of liquidity injections.

3.1. *Business Cycle Moments*

Simulations are driven by autoregressive productivity shocks $\varepsilon_t = (\varepsilon_{t-1})^{\rho_\varepsilon} \exp(u_t^\varepsilon)$ with $\rho_\varepsilon = 0.95$, $u_t^\varepsilon \sim \mathrm{N}(0, \sigma_\varepsilon^2)$ and $\sigma_\varepsilon = 0.01$, which is standard in the RBC literature. We

[16] On average, we work about 20% of total available hours: $0.2 \cong (40 \times 42)/(52 \times 7 \times 24)$.
[17] In Section 3, we compare our simulations to the US courts series, because the BLS series is limited in time.

assume a constant return on the market book, a Basel I regime ($\eta_b = \eta_l = 0$) and no liquidity interventions ($M_t = 0$). Using our real dataset, we compute the first and second moments for interest rates, repayment rates, balance sheet components and production, and compare these moments to those obtained from our simulated data. Real moments are reported in the columns labelled 'data' of Table 3 and simulated moments are reported in the columns indicated by 'mod.1'. The model is calibrated to match the first moments observed in the data approximately. The discrepancy between the model and the US data for δ_t (different sources), L_t^b, I_t^b I_t^l and D_t^l (stocks *versus* flows and open *versus* closed economy) has already been documented in Section 2.

As for the second moments, productivity shocks produce interest rates that are positively correlated with output, although the correlations are a bit too high. The model economy also does not generate as much interest rate volatility and persistence as is observed in US data. On the other hand, the model reproduces the second moments for consumption and investment remarkably well. These results are close to what is usually obtained with a standard RBC model as in King and Rebelo (1999).

If we turn to the variables specific to the banking sector, the model is able to reproduce the procyclicality of the two repayment rates, although it does not generate sufficient volatility for α_t. In the calibration, we impose a quadratic cost for default. A less convex cost would only partially fill the gap. In US data, balance sheet components are more volatile than output, mainly procyclical and highly persistent. Our model produces a reasonably good account of these facts. However, there are also evident discrepancies. First, interbank loans are countercyclical and interbank deposits are procyclical in real

Table 3

Cyclical Properties

	mean		relative standard deviation			correlation with output			first-order autocorrelation		
	data	mod.1&2	data	mod.1	mod.2	data	mod.1	mod.2	data	mod.1	mod.2
r_t^b	6.56	6.56	1.20	0.63	0.70	0.36	0.73	0.64	0.90	0.62	0.65
i_t	2.83	2.83	1.20	0.57	0.63	0.49	0.69	0.62	0.88	0.61	0.64
r_t^d	1.41	1.41	1.20	0.57	0.62	0.47	0.71	0.64	0.88	0.62	0.64
α_t	95.8	95.0	0.52	0.09	0.10	0.44	0.64	0.58	0.82	0.92	0.90
δ_t	99.9	99.0	0.01	0.03	0.03	0.11	0.59	0.52	0.87	0.91	0.90
$L_t^b(*)$	0.67	0.30	4.03	2.82	3.16	0.36	0.87	0.78	0.79	0.92	0.90
$I_t^b(*)$	0.49	0.15	6.95	5.28	6.08	0.44	0.86	0.75	0.87	0.92	0.92
$I_t^l(*)$	0.11	0.15	8.21	5.28	6.08	−0.24	0.86	0.75	0.81	0.92	0.92
$D_t^l(*)$	1.59	0.60	1.38	1.55	2.13	−0.11	0.86	0.61	0.87	0.98	0.93
F_t	0.22	0.15	4.62	0.32	0.50	0.01	−0.03	0.01	0.64	0.98	0.96
π_t	0.01	0.02	47.3	1.11	2.05	0.13	0.75	0.44	0.78	0.94	0.77
$\mathcal{Y}_t$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.86	0.72	0.72
C_t	0.69	0.66	0.82	0.81	0.89	0.81	0.91	0.83	0.83	0.88	0.85
inv_t	0.20	0.30	4.00	2.82	3.16	0.89	0.86	0.78	0.92	0.92	0.90

Notes. mod.1 : model simulated with a productivity shock. mod.2 : model simulated with a productivity shock and a market book shock. All variables have been logged with the exception of the real interest rates and default rates. Interest rates are annualised. Real data: see Appendix A. r_t^b = borrowing rate, i_t = interbank rate, r_t^d = deposit rate, α_t = firm repayment rate, δ_t = bank repayment rate, L_t^b = loans to firms, I_t^b = interbank deposits, I_t^l = interbank loans, D_t^l = consumer deposits, $F_t = F_t^b + F_t^l$ = bank own funds, $\pi_t = \pi_t^b + \pi_t^l$ = bank profits, $\mathcal{Y}_t = \mathcal{F}(K_t, N)$ = output, C_t = consumption, $inv_t = K_t - (1-\tau)K_{t-1}$ = investment. Variables marked with (*) are stocks in data but flows in our model (because they all have one-period maturity) and we must remain cautious when comparing (especially steady states).

data. The model clearly cannot reproduce this. In our closed economy model, without liquidity injections, interbank loans always match interbank deposits. Second, the model cannot reproduce the countercyclicality of deposits. In standard RBC models, savings are positively correlated with output, unless we change households' preferences. Third, the model does not generate sufficient volatility for profits and own funds. The extreme volatility of profits and hence own funds, in US data, is explained by the stock market crash on Black Monday in October 1987. As a result, bank profits fell by about 95% in the following quarters. In the model, all fluctuations are driven by the sole productivity shock which cannot alone reproduce this kind of event.

Interestingly, adding an uncorrelated banking sector shock to our productivity shock improves the results along almost all dimensions. More precisely, we keep the productivity shock but we now also add a market book shock. This is equivalent to an unexpected change in bank profits. This is defined as $\rho_t = (\bar{\rho})^{1-\rho_\rho}(\rho_{t-1})^{\rho_\rho}\exp(u_t^\rho)$. We set the autoregressive parameter to 0.50. The innovations are normally distributed and their variance is the same as for the productivity shock ($\rho_\rho = 0.50$, $u_t^\rho \sim \mathrm{N}(0, \sigma_\rho^2)$ and $\sigma_\rho = 0.01$). A degree of persistence of 0.5 means it takes about one year for the financial shock to disappear. New moments are reported in the columns labelled 'mod.2' of Table 3. The combination of the two shocks increases the volatility of all variables which improves all statistics, except deposits and consumption. This also reduces the link with output fluctuations which improves all statistics, except investment. Moreover, this decreases the persistence of most simulated data, which again improves all statistics, except investment.

We conclude from this exercise that:

(*i*) the model driven by productivity shocks produces a tolerably good account of US economic activity,

(*ii*) adding a banking shock to the usual productivity shock obviously improves the cyclical properties of the banking sector but also improves the second moments of most other variables as a result of higher volatility, lower correlation with output and lower persistence.

3.2. *Endogenous Repayment Rates and Financial Accelerators*

We first explore the effects of endogenous repayment rates from a static and partial analysis. The repayment rate α appears on both sides of the loan market for firms. We assume a Cobb-Douglas production function, and impose $\beta = 1$ and $d_f = 0$. The demand side of the credit market, as represented by first order conditions (5), (6) and (7), simplifies in the steady state to:

$$\left(L^b\right)^{1-\mu} = \frac{c}{\left(1 + r^b\right)}, \tag{29}$$

$$(1 - \alpha) = \frac{1}{\omega_f L^b}, \tag{30}$$

where $c = \mu(\bar{N}^{1-\mu})/\tau^\mu$ is a constant. Equation (29) is the negatively sloped credit demand, while (30) indicates that the quadratic penalty costs cause the default rate

$(1-\alpha)$ to be decreasing with the demand for loans. On the supply side, assuming no insurance fund, the first order condition (13) simplifies to:

$$\frac{1}{1+r^b} = \alpha - \frac{d_{F^b} k\bar{\omega}}{\lambda^b}. \tag{31}$$

This implies that the interest rate r^b depends negatively on the repayment rate α. The intuition is that banks are ultimately not interested in the gross return on loans r^b but on the net return which depends positively on the firm's repayment rate. Interest rates and repayment rates are an imperfect substitute for the merchant bank's net return. From this we can infer that an increase in the demand for loans following a positive shock will decrease the firm's default rate. That is, the lower risk incurred by the merchant bank yields a relatively lower price of loans for firms and further increases their demand for loans. This typically reproduces the mechanism of a financial accelerator. If we were to impose a fixed value of α, the substitution effect in the composition of the merchant bank's net return would disappear and the financial accelerator would collapse.

The same mechanism can be described in the interbank market where there is imperfect substitution between δ and i. This leads to the second accelerator of the model. From this twin mechanism, we see that the model described above admits the possibility of contagion and the amplification of a banking sector shock to the real activity and *vice versa*. This confirms alternative approaches that show the importance of credit market imperfections in accelerating shocks. See for instance Bernanke *et al.* (1999) with asymmetry of information and agency costs or Wasmer and Weil (2004) with sequential search and matching processes.

As an illustration, we conduct two alternative simulations with a positive productivity shock for the firm. In the first simulation the firm and bank repayment rates are exogenous and constant and, in the second, the firm and bank repayment rates are endogenous. Figure 2 shows that the positive shock increases firm and bank repayment rates which in turn limits the rise in r_t^b and i_t, thereby stimulating the demand for funds, both from firms and banks. Ultimately, endogenous defaults amplify the productivity shock and stimulate further loans to firms and, hence, investment and output. Quantitatively, with exogenous defaults, the standard deviation of loans to firms is $\sigma(L_t^b) = 3.19$ and increases to $\sigma(L_t^b) = 3.73$ with endogenous defaults. Similarly, the standard deviation of output $\sigma(\mathcal{Y}_t)$ moves from 1.28 to 1.32. In other words, endogenous defaults accelerate loans to firms' fluctuations by 17% and output fluctuations by 3%. Looking at the relative importance of each default, the endogenous firm default is responsible for 75% of the amplification whereas the bank default is responsible for 20%. Interestingly, the interactions between the two repayment rates explain the remaining 5%. Under a market book shock, a similar kind of amplification is obtained.

3.3. *The Basel Regulation*

According to the Basel regulations, banks must hold capital reserves appropriate to the level of risk they take through their lending and investment practices. Nevertheless, concern emerged about the possibility of the negative impact that capital requirements

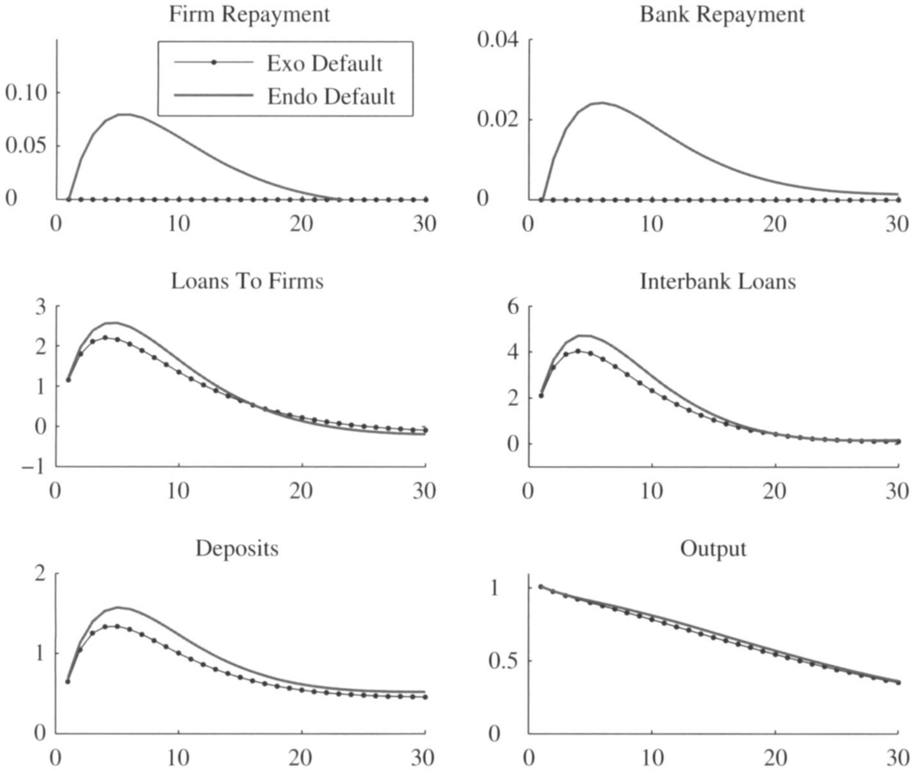

Fig. 2. *Endogenous Repayment Rates and Size of the Financial Accelerator*
Note. Variations from steady state, in % points for the repayments, in % for the other variables.

could exert on bank loans and economic activity.[18] We simulate our model with the intention of discerning how capital requirements affect the steady state and the resilience of the economy to shocks. The recently implemented 'Basel II' regulation makes minimum capital standards more risk-sensitive. Again, concerns have been raised that this new regulation will exacerbate business cycle fluctuations and we use our model to examine this issue.[19]

3.3.1. *Own fund requirements*

In the data and in our calibration, the minimum ratio of capital to risk weighted assets is $k = 8\%$. We instead assume a 'Basel-free' economy ($k \to 0$), a 'Basel-full' economy ($k = 15\%$) and we compute the steady state change of moving from Basel-free to Basel-full. Table 4 shows that stricter capital requirements obviously increase own funds and, since own funds are a constant fraction of profits, this is obtained by increasing profits ($\xi_b F^b = \upsilon_b \pi^b$ for the merchant bank and similarly for the other bank). It is

[18] See for instance Berger and Udell (1994), Brinkmann and Horwitz (1995) or Hancock *et al.* (1995) for US empirical evidence.

[19] See for instance Kashyap and Stein (2004) for a discussion and a review of previous works, or Catarineu-Rabell *et al.* (2005) and Pederzoli *et al.* (2010) for models allowing to evaluate the procyclicality of different rating systems.

Table 4

Steady State Effects of Increasing the Minimum Own Funds Ratio from $k = 0\%$ to $k = 15\%$

$F = +7\%$	$\pi = +7\%$	$\mathcal{Y} = -0.2\%$
$L^b = -0.2\%$	$\alpha = -0.1$	$r^b = +0.4$
$I^l = -51\%$	$\delta = -0.3$	$i = +0.3$

Notes. $F = F^b + F^l$ = bank own funds, $\pi = \pi^b + \pi^l$ = bank profits, $\mathcal{Y} = \mathcal{F}(K, N)$ = output, r^b = borrowing rate, i = interbank rate, α = firm repayment rate, δ = bank repayment rate, L^b = loans to firms, $I = I^b = I^l$ = interbank volume.

important to note that higher profits do not mean that banks are better off. Indeed, $\{\ln(\pi^b) - d_b(1-\delta) + d_{F^b}[F^b - k(\bar{\omega}L^b + \tilde{\omega}B^b)]\}/(1-\beta)$ defines the steady state payoff of the merchant bank where the increase in profits is not sufficient to compensate the lower utility from the buffer of own funds. Similar results hold for the other bank. In other words, banks dislike the 'Basel-full' situation although their profits are higher. In that respect, higher profits are realised to the detriment of lower loan supplies, both on the credit market and the interbank market. This raises the two associated interest rates and these higher credit costs lower repayment rates. In the end, economic activity shrinks by 0.2%. This is in line with empirical studies although our quantitative results are relatively low.

If Basel-type regulation reduces the level of output, it is intuitive that it allows for limiting business cycle fluctuations. This implies that after a similar productivity shock, fluctuations in the Basel-full economy are dampened with respect to the Basel-free economy. Indeed, a positive productivity shock stimulates loan supply but this increase is limited in the Basel-full case, because new credit risks must be partially covered by own funds. Interest rates are further raised and this reduces output fluctuations.

3.3.2. *From Basel I to Basel II*

Let us first assess the effects of introducing risk-sensitive capital requirements for the merchant banks from a steady state analysis. After an increase in α for a positive or procyclical shock, the capital adequacy requirement for the merchant banks remains unchanged under Basel I whereas the capital requirement decreases under Basel II. In other words, a higher α implies $\bar{\omega}_{II} < \bar{\omega}_I$. From the loan supply first order condition (31), we obtain:

$$\frac{1}{1+r_I^b} - \frac{1}{1+r_{II}^b} = \frac{d_{F^b}k}{\lambda^b}(\bar{\omega}_{II} - \bar{\omega}_I). \tag{32}$$

It is straightforward that $\bar{\omega}_{II} < \bar{\omega}_I \Rightarrow r_{II}^b < r_I^b$, meaning that after a positive shock on α, the borrowing rate will be lower under a Basel II regulation than under a Basel I regulation. From the loan demand first order condition (31), it also means that L^b and, hence, output will be further stimulated under a Basel II regime. A Basel II regulation on interbank loans would of course produce the same procyclical effects.

Can this partial equilibrium result on the procyclicality of Basel II be confirmed in our general equilibrium setup? We let $\bar{\omega}_t$ ($\bar{\bar{\omega}}_t$) vary negatively with firms' (banks') expected repayment rate α_{t+1} (δ_{t+1}) as displayed in (26) with $\eta_b = 100$ and $\eta_l = 200$.

These values allow realistic variations of 10% for the respective weights, for a 1% output fluctuation. Figure 3 shows that, under Basel II, the effects of α_{t+1} and δ_{t+1} on $\bar{\omega}_t$ and $\bar{\bar{\omega}}_t$ act as extra positive shocks on loans supplies, further reducing the interest rates r_t^b and i_t. From the firm's first order condition (6), this enhances the demand for loans which further stimulates output. Our dynamic general equilibrium setup therefore confirms the procyclical effect of Basel II type regulations, i.e. the multiplier effect amplifies the shock transmission mechanism. More precisely, the standard deviations for loans to firms and output are respectively $\sigma(L_t^b) = 3.73$ and $\sigma(\mathcal{Y}_t) = 1.32$ under a Basel I regulation and they increase to $\sigma(L_t^b) = 4.03$ and $\sigma(\mathcal{Y}_t) = 1.35$ under a Basel II regulation. Basel II therefore accelerates loans to firms' fluctuations by about 8% and output fluctuations by about 2%. Looking at the relative importance of the weight $\bar{\omega}_t$ related to loans to firms and the weight $\bar{\bar{\omega}}_t$ related to interbank loans, we see that the impact of Basel II on $\bar{\omega}_t$ is responsible for 70% of the amplification whereas the impact of Basel II on $\bar{\bar{\omega}}_t$ is responsible for 25%. The remaining 5% is explained by the interactions between the regulations on the two risky assets. We obtain similar amplifications with a market book shock.

In general, the quantitative effects of the Basel regulation are weak. One reason, as suggested by the static partial equilibrium model of Heid (2007), is that they are mitigated by the buffer banks hold on top of the required minimum capital.

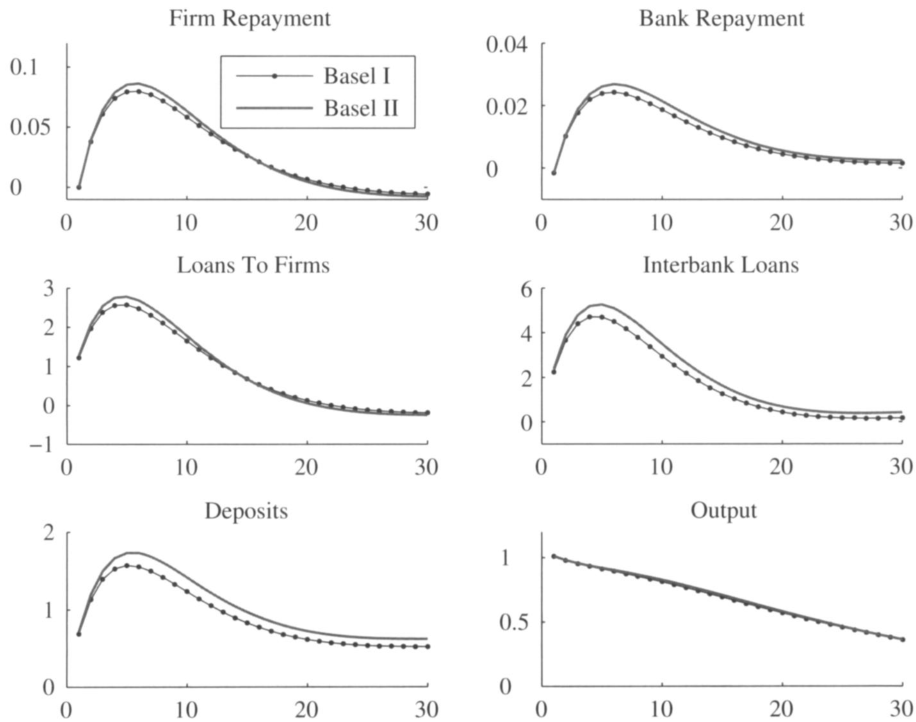

Fig. 3. *Procyclical Effects of Basel II*

Note. Variations from steady state, in % points for the repayments, in % for the other variables.

3.4. *Liquidity Injections*

Central banks have the power to finance liquidity injections through money creation. However, this money creation may eventually generate an inflation tax. Our real business cycle approach does not permit this kind of representation and liquidity injections consist of supplying 'commodities' to the economy. We investigate the effects of this commodity supply under two opposing assumptions. First we assume that net real cash balance creation is financed by an immediate lump sum tax on households. This means that (27) defines T_t, and households must pay for the financing of the insurance scheme and liquidity creation. This can be seen as a shortcut to money creation with an immediate inflation tax. Second, we take the opposite stance and assume no financing constraint for the central bank. Thus, the central bank is able to create real cash balances by itself and (28) defines T_t. In this case, households must only fund the insurance scheme. This can be seen as a shortcut to money creation without an inflation tax, even in the long run. Obviously, we could model any intermediate situation, such as injections financed, but with some lags. It is also worth noting that injections have a 1-period maturity. More precisely, every central bank injection must be reimbursed in the next period by the commercial banks.

Liquidity injections are driven by autoregressive shocks $M_t = \rho_m M_{t-1} + u_t^m$, with the same parameter values as for the productivity shock, that is $\rho_m = 0.95$, $u_t^m \sim \mathrm{N}(0, \sigma_m^2)$ and $\sigma_m = 0.01$. We assume no other shocks, neither productivity nor market book, and a Basel I regime ($\eta_b = \eta_l = 0$). Figure 4 shows that when injections are fully financed by a lump sum tax on households, the net effects are close to zero because taxes cut deposits and hence interbank loans, which mitigates the positive effects of injections. However, effects are strictly positive because we have market imperfections.

Results drastically differ when there are no financing requirements ('money creation'). Effects at impact are strong. Notably, we observe higher loans to firms, repayment rates and output. An initial injection of one unit ($\Delta M_t = 1$) immediately increases loans to firms by 0.73 units ($\Delta L_t^b = 0.73$). The partial monetary transmission ($\Delta L_t^b / \Delta M_t < 1$) comes from the fact that deposit banks reduce interbank lending to increase their profits and hence their own funds. There is substitution between private bank funds and central bank funds. Moreover, merchant banks keep a fraction of the injected liquidity in order to deal with their own liquidity needs. However, despite the high shock persistence, the positive effects are short-lived for most variables. The main reason is that injections must be repaid to the central bank as early as the second period. Only output is stimulated for a longer period, because it benefits from the high initial increase in credit/investment. However, it also drops below its steady state level after period 30. It is worth noting that, as with the productivity shock, both endogenous defaults and Basel II regulation generate financial accelerators. For instance, when liquidity injections are not financed, exogenous defaults reduce the monetary transmission to $\Delta L_t^b / \Delta M_t = 0.69$ whereas Basel II increases the transmission to $\Delta L_t^b / \Delta M_t = 0.75$. The financing, as well as the regulation and the behaviour of banks, are therefore important in understanding the transmission of liquidity injections. We discuss this further in the next Section.

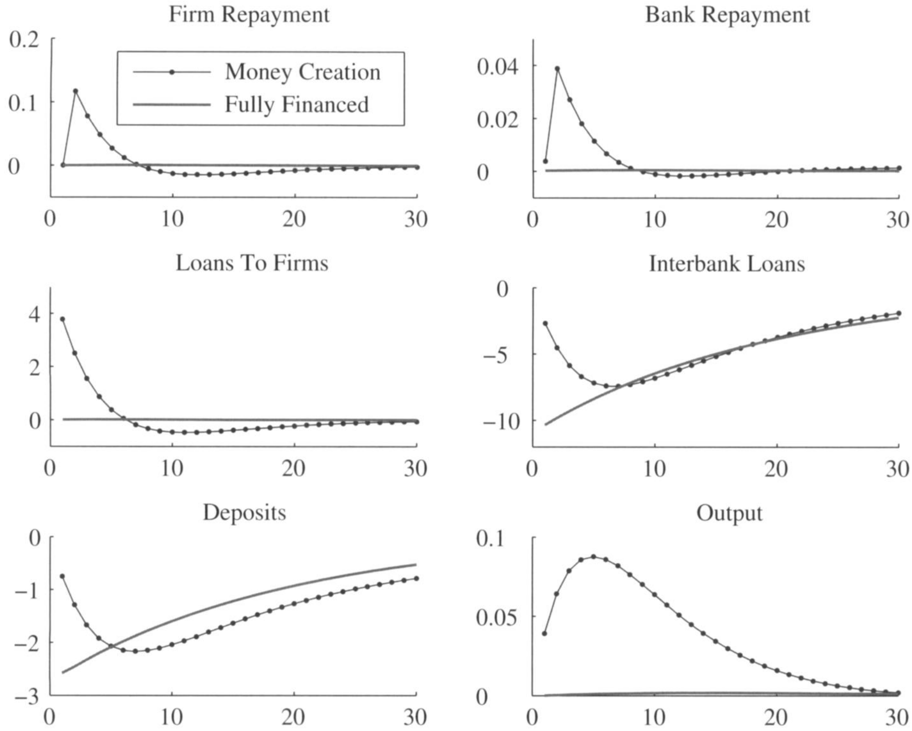

Fig. 4. *The Transmission of Liquidity Injections*
Note. Variations from steady state, in % points for the repayments, in % for the other variables.

4. An Illustration: The Subprime Crisis

The subprime mortgage crisis was initially triggered by a dramatic rise in mortgage delinquencies. Banks that had heavily invested in mortgage backed-securities sustained large losses in their market book, which in turn lead to a generalised credit tightening. To avoid an even more severe credit crunch, the Fed flooded the interbank market with liquidity. We use our model to understand how an adverse market book shock may spread to the whole economy, as well as the effects of liquidity injections in both the short and long run. To do this, we set the productivity shock to its steady state value while introducing a temporary negative shock in the return on banks' market book. This is equivalent to an unexpected fall in banks' profit: $\rho_t = (\bar{\rho})^{1-\rho_\rho}(\rho_{t-1})^{\rho_\rho}\exp(-u_t^\rho)$. We set the autoregressive parameter to 0.50 and use normally distributed innovations with variance 0.01. A degree of persistence of 0.5 means it takes about one year for the shock to disappear. This seems reasonable regarding the observed economic evolutions. We assume a Basel I regulation and pure money creation, meaning there are no financing requirements for the central bank. The liquidity operation M_t follows a simplified McCallum (1994) rule:

$$M_t = v(i_t - i), \tag{33}$$

with $v \geq 0$, such that M_t increases (decreases) when the interbank rate is higher (lower) than the long run value i.

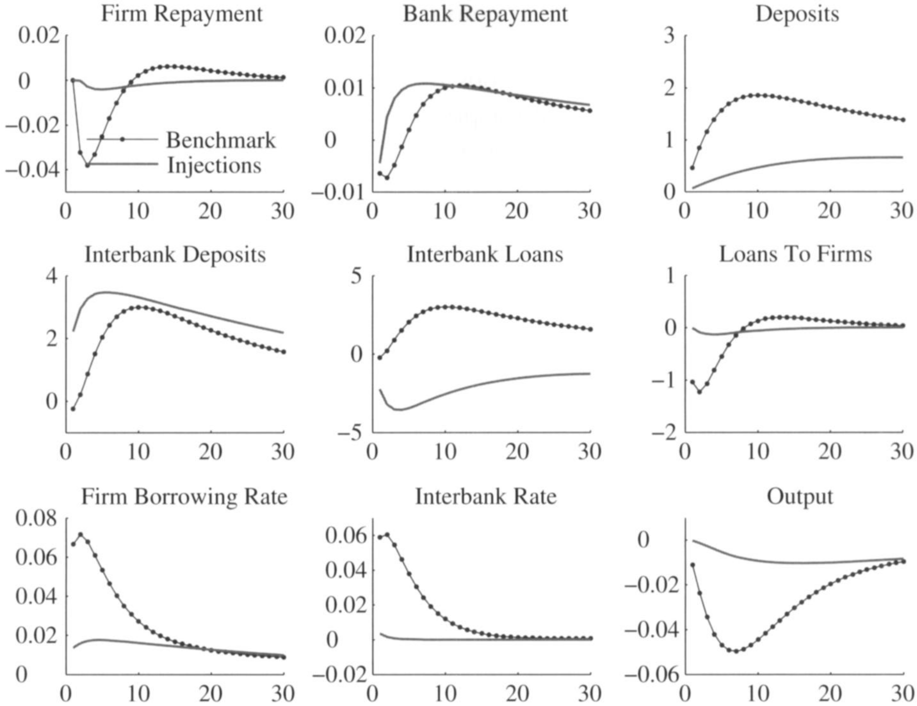

Fig. 5. *Market Book Shock and Liquidity Injections*
Note. Variations from steady state, in % points for the repayments and rates, in % for the other variables.

Figure 5 displays the impulse response function for several variables with $v = 0$, corresponding to no injections ('benchmark'). The fall in the market book return dries up the interbank market and equilibrium is only restored through higher interbank rates. In annual terms, they increase from 2.8% to 3.1%. Loans to firms also decline by about 1% and this increases borrowing costs for firms from 6.6% to 6.8%. Defaults increase for both firms and banks and output shrinks by a maximum of 0.05% in period 8. In terms of value, this means that an initial fall in the market book income by one unit implies, at impact, that $\Delta L_t^b = -0.52$, meaning that 52% of the shock is immediately transmitted to the real economy. It has a progressive impact on output and $\Delta \mathcal{Y}_t = -0.08$ after a few periods. This illustrates the links between the banking sector and the rest of the economy and is popularly referred to as the 'credit crunch' story.

To model liquidity injections, we set $v = 100$, implying that central bank interventions represent, on average, 10% of the interbank market volume. This modifies the reaction of the economy after this negative market book shock. Initially the central bank favours the merchant bank, supplying liquidity and preventing spikes in the interbank rate. As a result, it also supports loan supply to firms L_t^b, inducing a lower increase in the credit rate and a lower fall in the firms repayment rate α_t. In terms of value, this means that the same initial fall by one unit in the market book income implies, at impact, that $\Delta M_t = +0.91$. As a result, *initial* falls of loans to firms and output fade away to almost zero. Besides this short-run effect, the central bank intervention has delayed effects. First, injections must always be reimbursed in the next period. Second, real cash balance injections maintain artificially low interbank interest rates and hence depress loans by deposit banks. After a few periods, for instance 7 periods for loans to firms and 36 periods for output, the initial economy-stabilising effect of the injection will turn into a procyclical one. As a result, *in the long run*, liquidity interventions increase the persistence of the negative shock effects on economic activity.

4.1. *Optimal Monetary Policy*

Since we have mainly positive short-run effects and negative long-run effects, we consider the optimal rule for liquidity injections in case of market book shocks. Specifically, we try to determine the optimal value of v in (33). Moreover, we investigate how optimality is affected by the way injections are financed (see Section 3.4).

We assume that the central bank may pursue two objectives: output stability and financial stability. In the first case the stabilisation goal is to minimise a quadratic loss function of the form:

$$\mathcal{L}_0^Y = \sum_{t=0}^{\infty} \beta^t \, \mathrm{E}_0\left[(\hat{\mathcal{Y}}_t)^2\right],$$

i.e. the central bank minimises output fluctuations as in Woodford (2003).[20] Alternatively, we assume that the central bank is directly interested in financial stability, which is sometimes referred as to 'financial health' as for instance in Carlson *et al.* (2008). Thus the central bank seeks to minimise bank default fluctuations using:

$$\mathcal{L}_0^\delta = \sum_{t=0}^{\infty} \beta^t \, \mathrm{E}_0\left[(\hat{\delta}_t)^2\right].$$

Figure 6 plots the values of $\mathcal{L}_0^Y$ and $\mathcal{L}_0^\delta$, obtained by simulating a second order approximation to the model, for different values of v, with pure real cash creation *versus* full financing.

When there are no financing requirements for the central bank ('money creation'), liquidity injections in reaction to the interbank rate reduce output fluctuation. We see that the stabilisation is nearly complete when v is around 20, that is when initial injections represent about 5% of the interbank market volume. Higher values of v leave the output volatility practically unchanged. This means that small injections have strong positive short term effects and weak negative long term effects, whereas strong injections neither significantly improve the short run nor further destabilise the long run further. When net liquidity creation is financed with a lump sum tax, the effects are slower, since injections cannot 'fall from heaven' anymore. For instance, we need to set $v = 200$ to obtain an effect similar to $v = 20$ with money creation. In both the creation and financing cases, liquidity injections increase the volatility of the financial sector in a similar way. This is because injections imply an artificially low interbank rate and hence

[20] Since we do not have a nominal model, the central bank objective obviously does not include price fluctuations.

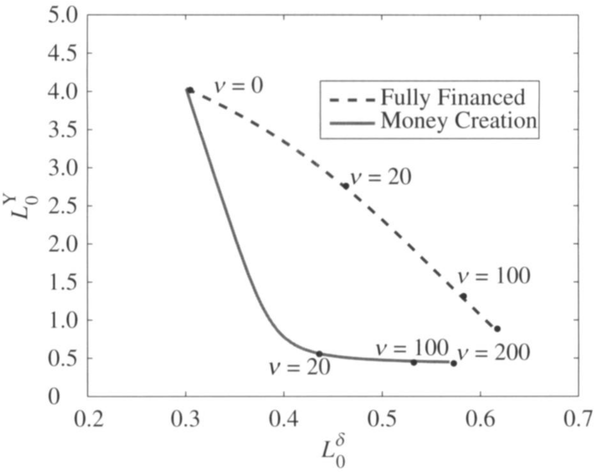

Fig. 6. *Optimal Monetary Policy: Stabilising Output vs. Default Rate*

an artificially high bank repayment rate. Equation (12) shows the direct link between the two.

Conducting the same exercise under a Basel II regulation would not change the conclusions regarding output and financial stability.

5. Model Discussion and Future Research

Our attempt to introduce more realistic banking features into an RBC model implies important modelling choices that may seem unorthodox in many ways. For instance, the inclusion of endogenous defaults for firms *and* banks, as well as their crucial role for the Basel II representation, requires both a simple mechanism and a mechanism able to generate procyclical repayment rates. We choose an intertemporal default-cost approach. Note that, for technical reasons, we need a double cost *and* non-linearity for at least one of them. Assuming only one cost, let us say the pecuniary ($d_b = 0$), leads to $i = r^d$, through (11), (12) and (18). Having $i > r^d$, as in the data, requires a non-pecuniary cost $d_b > 0$. We make it linear in order to keep the representation as simple as possible. However, also assuming a linear pecuniary cost would transform (7) into $L^b_{t-1} = \beta\,\omega_f\,L^b_{t-1} + d_f$. We see that only a lagged variable enters the equation, which implies indeterminacy. We make this cost quadratic for simplicity. On the negative side, we acknowledge this 'double cost' approach lacks pure microfoundations. Moreover, a central planner would choose $\alpha_t = \delta_t = 1\ \forall t$ as a solution, in order to avoid all the associated sunk costs. This would result in a different steady state which would render any dynamic welfare analysis somewhat odd. Another example of modelling choice is own funds dynamics. We assume that, at every period, a fraction of own funds finances the payment of an insurance premium. This allows own funds to be stationary. Moreover, the insurance premium also permits us to find a steady state. Indeed, without insurance, (19) implies $\beta\delta > 1/(1+i)$, meaning that the interbank rate must not be too low to have a positive supply. Additionally, (12) implies $\beta\delta < 1/(1+i)$, meaning the interbank rate must not be too high to have a positive demand. An insurance mechanism allows us to dispense with the first inequality and solve the model.

Obviously, there is no one unique banking sector modelling approach. Many papers follow Bernanke *et al.* (1999) in implementing endogenous defaults but this requires drawing a distinction between external and internal finance whereas our model is simpler and only allows for external finance. In Goodfriend and McCallum (2007) or Christiano *et al.* (2003, 2009), the banking sector key specification is a loan management function, that is the production of loans requires a combination of capital, labour and collateral. We instead have a much simpler linear fund management: one unit of deposit may produce one unit of loan. Gerali *et al.* (2009) propose monopolistic banks with quadratic adjustment costs on interest rates to match the stickiness in banking rates observed in the data, whereas only market forces determine interest rate fluctuations in our model. Following one or several of these modelling approaches would otherwise probably have permitted us to simplify our 'double cost' default representation or/and to get rid of the insurance mechanism. More generally, any modelling exercise tries to produce a tractable model, which is not too unrealistic and fits the relevant observed variables reasonably. In our view, our modelling choices adequately reflect these three requirements.

However, the model is certainly not as rich as we would like. We focus below on four potentially interesting extensions, although this list is far from being exhaustive given the complexity of financial markets. It is also worth noting that every extension further complicates the model and makes it more difficult to provide the necessary intuition, unless we otherwise simplify it. First, it is obvious from Sections 3.4 and 4 that implementing liquidity injections in a real model is done through a very rough shortcut. In reality, injections are not financed by tax, at least not financed by a coincident tax and, when not financed, they admittedly generate inflation. Since we show that our shortcuts are far from having a neutral impact on the results, we believe that a nominal extension of the model would be a worthwhile research avenue. To do so, we could follow the standard New-Keynesian approach as in Smets and Wouters (2003) or Christiano *et al.* (2005) with perfectly competitive firms replaced by monopolistic wholesalers setting rigid prices and selling intermediate goods to perfectly competitive retailers. Second, although we have endogenous balance sheet decisions, we acknowledge they remain overly simplified in several aspects. For instance, a proper representation of market book investment, which is exogenous in the model, could amplify the effects of shocks related to the banking sector. Preferably, endogenous market book decisions should be implemented along with endogenous market book returns. These extensions are probably not trivial. Goodhart *et al.* (2005) have exogenous market book volume and return although their model is only limited to two periods and two states. Also, we could allow for a more dynamic own funds management, such as making the fraction of profits devoted to own funds endogenous. Deposit banks would choose v_t^l to maximise $\ln[(1 - v_{t+s}^l)\pi_{t+s}^l]$. This yields an extra first order condition: $1 + v_t^l/(1 + v_t^l) = \lambda_t \pi_t^l$. This means that the profit share devoted to own funds increases when profits increase, implying more volatile own funds, as observed in the data. A similar result holds for merchant banks. Third, Adrian and Shin (2008) review the structure of banking intermediation in the US and show the increasing importance of market-based financing. As a result, our model with full banking intermediation might overestimate the role of banks and a richer setup could clarify the different relationships. For instance, firms could directly borrow from households, or finance themselves through the stock market or with internal finance. Fourth and finally, we do not consider maturity mismatch (short-term liabilities and long-term assets) although this is often seen as one of the main drivers of financial crises.

6. Conclusion

Over the past decade, financial stability issues have become an important research field for academics and a very visible objective for policy makers and central banks. A majority of central banks and several international financial institutions, such as the IMF and the BIS, have begun publishing regular reports in this field. However, most of this research and analysis remains descriptive and/or based on partial equilibrium analysis. We think that a consistent framework for financial stability analysis must account for all linkages and diffusion processes, not only between financial and non-financial sectors but also within the financial sector itself.

In this article, we propose a dynamic stochastic general equilibrium model, related to the RBC literature, with a heterogeneous banking sector and endogenous default rates as in Goodhart *et al.* (2005). We show that this model is promising in terms of reproducing some stylised facts of the US economy. We also discuss the role of the Basel regulations as well as the effects of liquidity injections in the case of adverse shocks. This model must, however, be seen as a first attempt to model the banking sector and could certainly be extended along several directions.

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Additional supporting information may be found in the online version of this article:

Appendix A: Real Data
Appendix B: Z-score: An Application to US Bank Default

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