Banking shock and monetary reactions in a New Keynesian model*

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[VERY PRELIMINARY DRAFT]

Abstract

We extend the standard New Keynesian model by introducing an heterogenous banking sector acting as intermediary between households and firms. We use this model to understand how a negative financial shock may spread to the whole economy, and how monetary policy may restore equilibrium. When the central bank precommits to react to one or several "banking variables", rational and forward looking agents anticipate the monetary reaction and behave accordingly. This anticipation plays such an important role that *in fine* the fall in the policy rate is lower than with a standard Taylor rule. When the central bank cannot precommit, anticipations do not play anymore and the central bank must reduce aggressively its policy rate.

Keywords: DSGE, banking sector, monetary policy

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*The views expressed in this paper are personal views of the authors and do not necessarily reflect those of the National Bank of Belgium, the Central Bank of Luxembourg or the Eurosystem.

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1 Introduction

Standard New Keynesian models ignore the banking sector, and monetary policy is transmitted through households buying bonds from the governement/central bank. However, and especially in Europe, private banks are important as the main form of intermediation in the economy, between lenders and borrowers but also between the central bank and the macroeconomy. Moreover, the banking sector is itself subject to specific shocks that may imply volatility transmission across sectors. Understanding the way in which changes in the monetary policy affect the economy therefore requires understanding the way in which the private banks behave. In this paper, we extend the standard New Keynesian model by introducing an heterogenous banking sector acting as intermediary between households and firms. Banks issue liabilities in the form of deposits and acquire assets through making loans. Moreover, we have an explicit interbank market the possibility of defaults. The central bank provides one-period loans to private banks and fixes the rate of return on loans, i.e. the policy interest rate.[1] We use this model to understand how a financial shock may spread to the whole economy, and how monetary policy may restore equilibrium.

Following the work by Smets and Wouters (2003) or Christiano et al. (2005), most New Keynesian models assume frictionless financial markets. Households may invest in bonds at a return rate fixed by the government/central bank. This policy rate is transmitted to the economy through non arbitrage conditions. A number of papers (see, among others, Carlstrom and Fuerst (1997), Bernanke et al. (1999) or Iacovello (2005)) introduce financial frictions through restrictions to lending ability. They show that financial disturbances generate macroeconomic volatility. More recently, several papers introduce explicitly intermediaries (banks) between lenders and borrowers. Using Bayesian estimation, Christiano et al. (2009) show that the financial sector accounts for a significant share of economic fluctuations. Curdia and Woodford (2009) develop a stylized model (no firm production and intermediation between households) and show that optimal monetary policy remains simple, at least as simple as in a standard NK model without financial frictions. In all these models, monetary policy is again implemented through bond demand from households. Goodfriend and McCallum (2007) with a perfectly competitive banking sector and Gerali et al. (2008) with an imperfectly competitive banking sector build quantitative models with a number of different interest rates and a link between the central bank and the banking sector. They show that shocks to banks may have sizeable effects on output. Goodhart et al. (2005) develop a 2-period-2-state model including an heterogeneous banking sector with an explicit interbank market, optimal balance sheet choices and endogenous default rates. de Walque et al. (2010) extend Goodhart et al. (2005) by embedding their model into a DSGE model. However, they mainly focus on supervision (Basel regula-

[1] In the paper, we say they are open open market operations although this is an abuse of language since our loans are not collateralized.

tion) and feature a rather unrealistic monetary policy, with central banks directly supplying or removing real money balances in the interbank market. Our model is closely related to de Walque et al. (2010). We simplify it by removing the supervisory authority and focus instead on monetary policy.

More precisely, we start from the standard New Keynesian model with monopolistic competition in the goods market and price rigidities. Households also supply their labour monopolistically. We depart from this framework by introducing a banking sector. Firms borrow from banks that convert household deposits into business financing for the purchase of capital.[2] 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 are in excess of liquidity, while the latter are in need of liquidity and equilibrium is restored through the interbank market. A third departure is that firms and banks may default on their liabilities. In this setup, a firm default may lead to a bank default on the interbank market, which in turn curtails credit extension to the interbank market and worsens the crisis. Finally, banks obtain liquidity from the central bank through open market operations. The central bank fixes the policy rate through a standard Taylor rule. We calibrate the model on European data and we conduct several sensitivity exercises on parameters specific to the banking sector.

We then use the model to understand how a financial shock, that is a shock on the return of bank market investments, may spread to the whole economy, and how monetary policy may restore equilibrium. A negative security return shock means that the two banks have lower liquidities. The interbank market collapses and, as a lender of last resort, the central bank has to inject liquidity into the banking system through one-period loans. We show that transmission of the shock to the real economy is rather weak, but this is because the supply of loans by the central bank reach an unstable path, *i.e.* it does not come back to the initial equilibrium. To avoid this unstable path, we introduce a borrowing constraint for banks in the sense that the amount they borrow from the central bank cannot deviate too strongly from its steady state value. This constraint increases dramatically the shock transmission. Output and inflation falls in the aftermath of the interbank market and, despite the strong reduction in the policy rate, the market interest rates remain high, as well as the default risk for banks.

It is widely accepted that well designed monetary policy can counteract macroeconomic disturbances and dampen cyclical fluctuations, thereby improving economic stability. In case of a security return shock and the associated turmoil on the interbank market, we can expect that a policy rate reacting to one or several "banking variables" would deliver satisfactory economic performances for price and economic stability. We therefore assume an augmented version of

[2] Assuming full banking intermediation between ultimate lenders and borrowers is of course an extreme assumption only introduced for simplification purpose. In reality, bank-based intermediation represents slightly less than 50% of total intermediation in US, see Adrian and Shin (2009), and probably a bit more in the EU.

the Taylor rule where the policy interest rate should be lowered when a credit squeeze appears on the interbank market. It is worth noting that the central bank may announce or not that it will follow a new specific rule. In other words, in the first case, the central bank has the willingness and the ability to precommit to react when the interbank market deviates from its equilibrium. Economic agents therefore embed the augmented Taylor rule into the formation of their expectations. In the second case, the central bank is either unwilling or unable to precommit and agents use a standard Taylor rule to form expectations. The central bank still react to the interbank market but agents perceive any deviation from their expectation as a stochastic disturbance.

When the central bank precommits, rational and forward looking agents anticipate the monetary reaction and behave accordingly. This anticipation plays such an important role that *in fine* the fall in the policy rate is lower than with a standard Taylor rule. When the central bank cannot precommit, anticipations do not play anymore and the central bank reduces aggressively its policy rate. One important lesson derived from this exercise is that the management of expectations through a commitment to a rule can be a more effective tool for stabilizing inflation and the macroeconomy than actual movements in the policy rate. This result is consistent with the increasing focus on the pronouncements of central bankers regarding their future actions.

Sections 2 and 3 introduces the banking sector. Section 4 embeds the banking sector in a New Keynesian general equilibrium framework. Section 5 describes the calibration and Section 6 presents several numerical simulations. Section 7 concludes.

2 Banking sector

We assume two specialized private banks and one central bank. The merchant bank borrows from the interbank market at the interbank market rate or from the central bank at the policy rate. The merchant bank also extends credit to firms at the credit rate. The deposit bank receives deposits from households at the deposit rate and lends to the interbank market at the interbank market rate. The central bank fixes the policy rate. The private banks also invest in securities, and thy may face defaults on their loans. Households, firms and banks are distinct from one another in order to explicitly motivate lending, borrowing and the risk of defaults.

2.1 Definitions

We have five nominal return rates in our model: the policy rate R_t the deposit rate R_t^d, the credit rate R_t^c, the interbank rate I_t and the security return rate ρ_t. Current inflation is π_t. All other variables are real.

2.2 Banks borrowing from the interbank market (merchant banks)

Merchant banks borrow D_t^c from the central bank at the nominal policy rate R_t. Interest rates are predetermined, meaning they are fixed at the borrowing time t and not at the repayment time $t+1$. We think this a plausible representation of reality. Moreover, this assumption is crucial when a possibility of default is present. Without predetermination, the endogenous default decision is irrelevant because it can be totally offset by an interest rate change. Merchant banks also borrow D_t^i from the interbank market at the interbank rate I_t and may choose to not reimburse with a probability $1-\delta_t$. As in Shubik and Wilson (1977), Dubey et al. (2005), Elul (2008) or de Walque et al. (2010), defaulting banks are not excluded from the interbank market but have disutility costs, such as pangs of conscience, as well as pecuniary costs, such as search costs the next period to obtain new loans because of reputation losses.[3] Moreover, merchant banks lend L_t^b to firms at the credit rate R_t^c and may face a non-reimbursement with a probability $1-\alpha_t$. Finally, we assume constant real security holdings B^b with a rate of return ρ_t. We introduce two extra mechanisms in the model.[4] First, private banks give a fraction ν of their deposits to the central bank because of legal reserve requirements. Second, the central bank compensates, up to a fraction τ^b, private banks in the case of losses on their risky assets, *i.e.* in the case of non-reimbursement of their loans to firms. The bank maximization program is:

$$\max_{D_t^c, D_t^i, L_t^b, \delta_t, \pi_t^b} \sum_{s=0}^{\infty} \left(\beta^b\right)^s \; E_t\left[\mathcal{U}^b\left(\pi_{t+s}^b\right) - d_\delta\left(1-\delta_{t+s}\right)\right], \tag{1}$$

under the constraints:

$$\begin{aligned}
\pi_t^b \;=\;& \alpha_t \frac{L_{t-1}^b}{1+\pi_t} - \frac{L_t^b}{1+R_t^c} + \frac{D_t^i}{1+I_t} - \delta_t \frac{D_{t-1}^i}{1+\pi_t} + \frac{D_t^c}{1+R_t} - \frac{D_{t-1}^c}{1+\pi_t} + \frac{\rho_t - \pi_t}{1+\pi_t} B^b \\
& - \mathcal{C}^\delta\left((1-\delta_{t-1})D_{t-2}^i\right) + \tau^b\,(1-\alpha_{t-1})L_{t-2}^b - \nu\left(D_t^i - \frac{D_{t-1}^i}{1+\pi_t}\right),
\end{aligned} \tag{2}$$

with β^b the merchant bank discount factor, $\mathcal{U}^b$ the momentary utility of profits and d_δ the disutility parameter of default. Equation (2) defines profits with the convex default cost function $\mathcal{C}^\delta$ such that $\mathcal{C}^\delta(0) = 0$.

This gives the following FOC's:

$$\dot{\mathcal{U}}_t^b \left(\frac{1}{1+R_t}\right) \;=\; \beta^b\, E_t\left[\frac{\dot{\mathcal{U}}_{t+1}^b}{1+\pi_{t+1}}\right], \tag{3}$$

[3] See Section 3 for a discussion.

[4] These mechanisms are not important for the results. However, they help to calibrate the model by introducing more parameters, *i.e.* more flexibility. We could obviously follow alternative approaches.

$$\dot{\mathcal{U}}_t^b \left(\frac{1}{1+I_t} - \nu\right) = \beta^b \, E_t \left[\frac{\delta_{t+1} - \nu}{1+\pi_{t+1}} \, \dot{\mathcal{U}}_{t+1}^b\right] + \left(\beta^b\right)^2 \, E_t \left[\dot{\mathcal{C}}_{D_t^i}^{\delta} \, \dot{\mathcal{U}}_{t+2}^b\right], \tag{4}$$

$$\dot{\mathcal{U}}_t^b \left(\frac{1}{1+R_t^c}\right) = \beta^b \, E_t \left[\frac{\alpha_{t+1}}{1+\pi_{t+1}} \, \dot{\mathcal{U}}_{t+1}^b\right] + \left(\beta^b\right)^2 \, \tau^b \, E_t \left[(1-\alpha_{t+1}) \, \dot{\mathcal{U}}_{t+2}^b\right], \tag{5}$$

$$\dot{\mathcal{U}}_t^b \, \frac{D_{t-1}^i}{1+\pi_t} = d_\delta \, + \, \beta^b \, E_t \left[\dot{\mathcal{C}}_{1-\delta_t}^{\delta} \, \dot{\mathcal{U}}_{t+1}^b\right], \tag{6}$$

where we define $\dot{\mathcal{U}}_t^b = \partial \mathcal{U}^b(\pi_t^b)/\partial \pi_t^b$, $\dot{\mathcal{C}}_{D_t^i}^{\delta} = \partial \mathcal{C}^\delta \left((1-\delta_{t+1})D_t^i\right)/\partial D_t^i$ and $\dot{\mathcal{C}}_{1-\delta_t}^{\delta} = \partial \mathcal{C}^\delta \left((1-\delta_t)D_{t-1}^i\right)$ $/\partial(1-\delta_t)$. (3) to (5) are standard Euler type equations and equation (6) is the FOC with respect to the repayment decision. It equates the marginal repayment cost to the expected marginal default cost.

2.3 Banks lending to the interbank market (deposit banks)

Deposit banks lend D_t^i to the interbank market at the interbank rate I_t, and may face non-reimbursement with a probability $1-\delta_t$. They receive deposits D_t^l which they must pay at the deposit rate R_t^d. As in de Walque et al. (2010), we assume no possibility to default on household deposits. Deposit banks also have constant real security holdings B^l with a rate of return ρ_t. Finally, as the merchant banks, the deposit banks must give a fraction ν of their deposits to the central bank because of legal reserve requirements; and the central bank compensates, up to a fraction τ^l, private banks in the case of losses on their risky assets, *i.e.* in the case of non-reimbursement of their interbank loans. The bank maximization program is:

$$\max_{D_t^r, D_t^i, D_t^l, \pi_t^l} \sum_{s=0}^{\infty} \left(\beta^l\right)^s \, E_t \left[\mathcal{U}^l \left(\pi_{t+s}^l\right)\right], \tag{7}$$

under the constraint:

$$\begin{aligned} \pi_t^l \;=\; & \frac{D_t^l}{1+R_t^d} - \frac{D_{t-1}^l}{1+\pi_t} + \delta_t \frac{D_{t-1}^i}{1+\pi_t} - \frac{D_t^i}{1+I_t} + \frac{\rho_t - \pi_t}{1+\pi_t} B^l \\ & + \tau^l \, (1-\delta_{t-1}) D_{t-2}^i - \nu (D_t^l - \frac{D_{t-1}^l}{1+\pi_t}), \end{aligned} \tag{8}$$

with β^l the deposit bank discount factor and $\mathcal{U}^l$ the momentary utility of profits. This gives the following FOC's:

$$\dot{\mathcal{U}}_t^l \, \frac{1}{1+I_t} = \beta^l \, E_t \left[\frac{\delta_{t+1}}{1+\pi_{t+1}} \, \dot{\mathcal{U}}_{t+1}^l\right] + \left(\beta^l\right)^2 \, \tau^l \, E_t \left[(1-\delta_{t+1}) \, \dot{\mathcal{U}}_{t+2}^l\right], \tag{9}$$

$$\dot{\mathcal{U}}_t^l \left(\frac{1}{1+R_t^d} - \nu\right) = \beta^l \, E_t \left[\frac{1-\nu}{1+\pi_{t+1}} \, \dot{\mathcal{U}}_{t+1}^l\right], \tag{10}$$

where we define $\dot{\mathcal{U}}_t^l = \partial \mathcal{U}^l(\pi_t^l)/\partial \pi_t^l$.

3 Partial equilibrium analysis

We successively look at the transmission of monetary policy and the role of the endogenous default.

3.1 Monetary transmission

By simplicity, we first remove the endogenous default decisions and the related mechanisms. More precisely, we assume constant defaults, that is $\delta_t = \bar{\delta}$ and $\alpha_t = \bar{\alpha}$ $\forall t$, no change in default costs ($\dot{\mathcal{C}}^\delta = 0$) and no loss coverage by the central bank ($\tau^b = \tau^l = 0$). The banks' first order conditions (3) to (5) and (9) to (10) become:

$$\frac{1}{\bar{\alpha}} \frac{1}{1+R_t^c} = \frac{1}{1+R_t} = \frac{\frac{1}{1+I_t} - \nu}{\bar{\delta} - \nu} = \frac{\frac{\bar{\delta}}{1-\nu}\left(\frac{1}{1+R_t^d} - \nu\right) - \nu}{\bar{\delta} - \nu}.$$

We see the transmission from the policy rate R_t to the three market rates is complete. Note that we loose this completeness when $\bar{\delta}$ and $\bar{\alpha}$ become endogenous in the above equation. Moreover, the endogenous defaults imply that we have to add the terms related to the default costs and the loss coverage mechanism, *i.e.* τ^b, τ^l and $\dot{\mathcal{C}}^\delta$ are no more equal to 0. As a result, the curvatures of $\dot{\mathcal{U}}_t^b$ and $\dot{\mathcal{U}}_t^l$, also play a role in the transmission of the monetary policy.

We conclude that endogenous defaults and banks' monetary utility functions are important to understand the monetary transmission mechanism. We provide a quantitative assessment of these considerations in section 6.1.

3.2 Endogenous defaults

Let us assume no discounting ($\beta^b = \beta^l = 1$), no legal reserve requirements ($\nu = 0$), no inflation ($\pi_t = 0$ $\forall t$) and linear momentary utility for banks. This simplifies equation (9), which characterizes the supply side of the interbank market:

$$\frac{1}{1+I_t} = \tau^l + (1-\tau^l)E_t\left[\delta_{t+1}\right].$$

Since $0 \leq \tau^l \leq 1$, it means that banks expecting a lower repayment - or reimbursement - rate will charge a higher interest rate on their interbank loans. We also see that the loss coverage mechanism attenuates the transmission. In the extreme case of full coverage ($\tau^l = 1$), the expected repayment rate does affect anymore the interest rate.

By combining equation (4) (interbank deposits), equation (6) (default) and introducing the simplifications mentioned above, we represent the demand side of the interbank market:

$$\frac{1}{1+I_t} = 1 - E_t\left[\frac{d_\delta(1-\delta_{t+1})}{D_t^i}\right].$$

Since $d_\delta > 0$, it means that a bank facing an increase in its borrowing cost may reduces its current demand or reduces its expected repayment rate.

The relationship between the default rate and the volume of funds on the interbank market is ambiguous. Indeed, subtracting the demand equation from the supply equation and taking a first order approximation gives:

$$\hat{D}_t^i = \frac{\delta}{1-\delta}\left(\frac{(1-\tau^l)\bar{D}^i}{d_\delta} - 1\right) E_t\left[\hat{\delta}_{t+1}\right],$$

where $\bar{x}$ denotes the steady state of a variable x_t and $\hat{x}_t = (x_t - \bar{x})/\bar{x}$ denotes its relative deviation from the steady state. As a result, the expected repayment rate is procyclical as long as $(1-\tau^l)\bar{D}^i/d_\delta > 1$, that is as long as the default disutility is small and/or the loss coverage mechanism is limited. The intuition is that with a limited coverage, any decrease in expected repayment strongly increases the interbank rate (supply side) which results in a lower demand. We have a similar intuition with a low default disutility.

4 General equilibrium

We augment the model with monopolistic firms and households. Our representation closely follows Smets and Wouters (2003), hereafter SW, with fixed costs in production, investment adjustment costs, partial indexation of prices, partial indexation of wages, habit in consumption, government consumption and a Taylor rule to represent monetary policy.[5] The sole difference is the absence of a variable utilization rate of capital. Indeed, firms in the model are independent and therefore other agents cannot decide for the utilization rate of already installed capital.

[5]SW find these frictions necessary for allowing their estimated model to capture characteristics of the real data. Although the purpose of our paper is different, we also keep all the friction to have a fair comparison between our IRF's and those from SW.

4.1 Final firms

The final good sector is perfectly competitive and produces an homogeneous good Y_t by aggregating, through a CES Dixit-Stiglitz technology, a continuum of intermediate goods $y_t(j)$, with j distributed over the unit interval:

$$Y_t = \left[y_t(j)^{\frac{1}{1+\lambda_p}} \; dj \right]^{1+\lambda_p}, \tag{11}$$

where $\lambda_p \in [0, +\infty]$.

4.2 Intermediate firms

There is a continuum of monopolistically competitive intermediate firms of unit mass.[6] Each firm sets prices p_t according to the Rotemberg-pricing assumption to maximize profits π_t^f.[7] Firms also choose employment N_t and borrowing L_t^b from banks at the credit rate R_t^c, and may decide to not reimburse with a probability $1 - \alpha_t$. As for banks, defaulting firms are not excluded from the credit market but incur both disutility costs and pecuniary costs. The firm maximization program is:

$$\max_{p_t, N_t, L_t^b, \alpha_t, y_t, K_t, \pi_t^f} \sum_{s=0}^{\infty} \left(\beta^f\right)^s \; E_t \left[\pi_{t+s}^f - d_\alpha \left(1 - \alpha_{t+s}\right) \right], \tag{12}$$

under the constraints:

$$\begin{aligned}
y_t &= \mathcal{F}(K_t, N_t) - \Phi, && (13)\\
y_t &= \left[\frac{p_t}{P_t}\right]^{-\frac{1+\lambda_p}{\lambda_p}} Y_t, && (14)\\
K_t &= (1-\tau)K_{t-1} + \frac{L_t^b}{1+R_t^c}\left[1 - \mathcal{S}\left(\frac{L_t^b}{L_{t-1}^b}\right)\right], && (15)\\
\pi_t^f &= \frac{p_t}{P_t} y_t - w_t N_t - \alpha_t \frac{L_{t-1}^b}{1+\pi_t} - \mathcal{C}^\alpha\left((1-\alpha_{t-1})L_{t-2}^b\right) \\
&\quad - \frac{\kappa}{2}\left(\frac{p_t}{(1+\bar{\pi})^{1-\gamma_p}(1+\pi_{t-1})^{\gamma_p}\; p_{t-1}} - 1\right)^2 Y_t, && (16)
\end{aligned}$$

with β^f the firm discount factor and d_α the disutility parameter of default. K_t is the capital stock and equations (13) and (14) respectively represent goods supply and goods demand.

[6]From now on we drop the j-th index.

[7]Predetermined interest rates imply that the marginal cost is firm specific. As a result, we use Rotemberg (1982) rather than Calvo (1983) pricing. We assume quadratic costs of revising prices relative to a combination of long run inflation and lagged inflation.

Equation (15) states that capital depreciates at rate τ and is augmented by gross investment, which is wholly financed through bank loans. Note that we have a convex investment adjustment cost function $\mathcal{S}(\cdot)$, which is equal to 0 at the steady state. In addition, we assume the first derivative $\mathcal{S}'(\cdot)$ also equals 0 at the steady state. Equation (16) defines profits. The cost function $\mathcal{C}^{\alpha}$ is convex with $\mathcal{C}^{\alpha}(0) = 0$. P_t is the aggregate price, we define $1 + \pi_t = P_t / P_{t-1}$ and we assume a quadratic price adjustment cost κ. This yields the following FOC's:

$$\frac{\mathcal{F}_{N_t}}{\mathcal{F}_{K_t}} = \frac{w_t}{\lambda_t - \beta^f \; E_t \left[(1-\tau)\lambda_{t+1} \right]}, \tag{17}$$

$$\begin{aligned} & \tfrac{\lambda_t}{1+R^c_t} \left(1 - \mathcal{S}\left(\tfrac{L^b_t}{L^b_{t-1}} \right) \right) - \tfrac{\lambda_t}{1+R^c_t} \; \mathcal{S}'\left(\tfrac{L^b_t}{L^b_{t-1}} \right) \tfrac{L^b_t}{L^b_{t-1}} \\ = & \; \beta^f \; E_t \left[\tfrac{\alpha_{t+1}}{1+\pi_{t+1}} - \tfrac{\lambda_{t+1}}{1+R^c_{t+1}} \; \mathcal{S}'\left(\tfrac{L^b_{t+1}}{L^b_t} \right) \left(\tfrac{L^b_{t+1}}{L^b_t} \right)^2 \right] + \left(\beta^f \right)^2 \; E_t \left[\dot{\mathcal{C}}^{\alpha}_{L^b_t} \right], \end{aligned} \tag{18}$$

$$\frac{L^b_{t-1}}{1+\pi_t} = d_{\alpha} \; + \; \beta^f \; \dot{\mathcal{C}}^{\alpha}_{1-\alpha_t}, \tag{19}$$

where we define $\dot{\mathcal{C}}^{\alpha}_{L^b_t} = \partial \mathcal{C}^{\alpha}\left((1-\alpha_{t+1}) L^b_t \right) / \partial L^b_t$ and $\dot{\mathcal{C}}^{\alpha}_{1-\alpha_t} = \partial \mathcal{C}^{\alpha}\left((1-\alpha_t) L^b_{t-1} \right) / \partial (1-\alpha_t)$. The capital-labour equation (17) and the investment equation (18) are standard and similar to SW. Equation (19) represents the default decision and equates the marginal cost of repayment and the marginal cost of default.

Assuming a CRTS Cobb-Douglas production function $\mathcal{F}(K_t, N_t) = K_t^{\mu} N_t^{1-\mu}$, the marginal cost is:

$$mc_t = \left(\frac{w_t}{1-\mu} \right)^{1-\mu} \left(\frac{\lambda_t - \beta^f E_t \left[(1-\tau)\lambda_{t+1} \right]}{\mu} \right)^{\mu}. \tag{20}$$

Because of the Rotemberg-pricing assumption, all intermediate firms set the same prices and produce the same quantities, which implies $p_t = P_t$ and $y_t = Y_t$. From this we obtain the Phillips curve:

$$\begin{aligned} & \tfrac{1}{\lambda_p} \; y_t + \kappa \; \left(\tfrac{1+\pi_t}{(1+\bar{\pi})^{1-\gamma_p} (1+\pi_{t-1})^{\gamma_p}} - 1 \right) \; \tfrac{1+\pi_t}{(1+\bar{\pi})^{1-\gamma_p} (1+\pi_{t-1})^{\gamma_p}} \; y_t \\ = & \; \tfrac{(1+\lambda_p) \; mc_t}{\lambda_p} \; y_t + \beta^f \; \kappa \; E_t \left[\left(\tfrac{1+\pi_{t+1}}{(1+\bar{\pi})^{1-\gamma_p} (1+\pi_t)^{\gamma_p}} - 1 \right) \; \tfrac{1+\pi_{t+1}}{(1+\bar{\pi})^{1-\gamma_p} (1+\pi_t)^{\gamma_p}} \; y_{t+1} \right]. \end{aligned} \tag{21}$$

4.3 Households

There is a continuum of households indexed by ι where ι is distributed over the unit interval. Each household ι has a specific labour supply and therefore has a monopoly power. Utility depends positively on consumption $C_t(\iota)$, relative to an external habit variable, and negatively on labour supply $L_t(\iota)$. Moreover, we impose a target for deposits - households do not like deposits $D^l_t(\iota)$ deviating from their long-run optimal level - through a quadratic disutility term:

$$\mathcal{U}^h_t(\iota) = \frac{(C_t(\iota) - h\, C_{t-1})^{1-\sigma_c}}{1-\sigma^c} - \frac{L_t(\iota)^{1+\sigma_l}}{1+\sigma_l} - \frac{\chi}{2}\left(\frac{D^l_t(\iota)}{\bar{D}^l} - 1\right)^2. \tag{22}$$

Consumption and savings

The household maximization program is:

$$\max_{C_t(\iota), D^l_t(\iota)} \sum_{s=0}^{\infty} \left(\beta^h\right)^s \; E_t\left[\mathcal{U}^h_{t+s}(\iota)\right], \tag{23}$$

under the budget constraint:

$$T_t + C_t(\iota) + \frac{D^l_t(\iota)}{1+R^l_t} = (w_t(\iota)L_t(\iota) + A_t(\iota)) + \frac{D^l_{t-1}(\iota)}{1+\pi_t}, \tag{24}$$

with β^h the household discount factor. Equation (24) represents the budget constraint. $w_t(\iota)$ is the real wage and households pay a lump sum tax T_t. Moreover, we assume there exist state-contingent securities that insure households again labour income fluctuations. As a result, consumption and deposits are identical across the different types of households. This yields the following FOC:

$$\frac{h}{C_t - h\, C_{t-1}} \;\; \frac{1}{1+R^d_t} + \chi\left(\frac{D^l_t}{\bar{D}^l} - 1\right) = \beta^h E_t\left[\frac{h}{C_{t+1} - h\, C_t} \;\; \frac{1}{1+\pi_{t+1}}\right]. \tag{25}$$

We introduce the disutility of deviating from the deposit equilibrium for a technical reason. If $\chi = 0$, both equations (10) and (25) give the steady state for R^d_t, leaving the steady state for D^l_t undetermined. By imposing $\chi > 0$, we force equation (25) to determine the steady state of D^l_t.[8]

Labour supply and wages

The aggregate labour demand is given by the Dixit-Stiglitz function:

$$L_t = \left[\int_0^1 L_t(\iota)^{\frac{1}{1+\lambda_w}}\, d\iota\right]^{1+\lambda_w}, \tag{26}$$

where $\lambda_p \in [0, +\infty]$. The labour demand for the household ι is therefore:

[8]Note that in our calibration, χ is kept low so that it only marginally affects the dynamic properties of the model. Alternatively, we could introduce a bank production function and assume that $D^l_t/(1+R^d_t)$ deposits only produce $(D^l_t/(1+R^d_t))^{\varphi}$ assets. As long as $\varphi \neq 1$, this would allow equation (10) to determine D^l_t at the steady state.

$$L_t(\iota) = \left(\frac{w_t(\iota)}{w_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}}, \tag{27}$$

where w_t is the aggregate real wage. Using equations (26) and (27), we get:

$$w_t = \left[\int_0^1 w_t(\iota)^{-\frac{1}{\lambda_w}} \, d\iota\right]^{-\lambda_w}, \tag{28}$$

Households act as price-setters in the labour market. At each period, a household has a probability $1-\xi_w$ to reoptimize its wage and thus set a new wage $\tilde{w}_t(\iota)$. Wages that are not reoptimized adjust according to:

$$w_t(\iota) = \frac{(1+\pi_{t-1})^{\gamma_w}(1+\bar{\pi})^{1-\gamma_w}}{1+\pi_t} \; w_{t-1}(\iota). \tag{29}$$

The maximization problem results in:

$$\begin{aligned} &\tilde{w}_t \, E_t\left[\sum_{s=0}^{\infty}\left(\beta^h\right)^s \xi_w^s L_{t+s}(\iota) \, \frac{h}{C_{t+s}-hC_{t+s-1}} \, \frac{P_t}{P_{t+s}} \, \left(\frac{P_{t+s-1}}{P_{t-1}}\right)^{\gamma_w} \, (1+\bar{\pi})^{s(1-\gamma_w)}\right] \\ &\qquad = E_t\left[\sum_{s=0}^{\infty}\left(\beta^h\right)^s \xi_w^s L_{t+s}(\iota)^{1+\sigma_l}\right]. \end{aligned} \tag{30}$$

Finally, given equation (28), the law of motion of the aggregate wage is:

$$(w_t)^{-\frac{1}{\lambda_w}} = \xi_w\left(w_{t-1} \, \frac{(1+\pi_{t-1})^{\gamma_w}(1+\bar{\pi})^{1-\gamma_w}}{1+\pi_t}\right)^{-\frac{1}{\lambda_w}} + (1-\xi_w)\,(\tilde{w}_t)^{-\frac{1}{\lambda_w}}. \tag{31}$$

4.4 Central bank

The central bank receives legal reserve requirements and partially compensates banks and firms facing defaults. It also receives transfers T_t^r to keep a balanced budget every period:

$$\nu\,(D_t^l + D_t^i) + T_t^r = \tau^l\,(1-\delta_{t-1})D_{t-2}^i + \tau^b\,(1-\alpha_{t-1})L_{t-2}^b - \nu\,(\frac{D_{t-1}^l + D_{t-1}^i}{1+\pi_t}). \tag{32}$$

The central bank also fix the monetary policy interest rate through a standard Taylor rule:

$$\begin{aligned} 1+R_t &= (1+R_{t-1})^{\psi} \times \\ &\left(\frac{1+\bar{\pi}}{\beta^b}\left(\frac{1+\pi_{t-1}}{1+\bar{\pi}}\right)^{r_\pi}\left(\frac{y_t}{\bar{y}}\right)^{r_y}\left(\frac{1+\pi_t}{1+\pi_{t-1}}\right)^{r_{\Delta\pi}}\left(\frac{y_t}{y_{t-1}}\right)^{r_{\Delta y}}\right)^{1-\psi}\exp(u_t^R), \end{aligned} \tag{33}$$

with $u_t^R \sim N(0,\sigma_R)$.[9]

[9] The standard Taylor rule reacts to the deviation of output from the potential output. In this paper, we are

4.5 Closing the model

The final goods market is in equilibrium. It means that production is consumed by households, by the government and by firms and banks. Indeed, since firms and banks are not owned by households, they directly consume their profits.[10] The remaining output is used for investment or lost as costs:

$$y_t = C_t + \pi_t^f + \pi_t^b + \pi_t^l + \bar{G} + K_t - (1-\tau)K_{t-1} + costs_t, \tag{34}$$

with:

$$\begin{aligned} costs_t \quad = \quad & +\mathcal{C}^{\delta}\left((1-\delta_{t-1})D_{t-2}^{i}\right) + \mathcal{C}^{\alpha}\left((1-\alpha_{t-1})L_{t-2}^{b}\right) \\ & + \frac{L_t^b}{1+R_t^c}\,\mathcal{S}\left(\frac{L_t^b}{L_{t-1}^b}\right) + \frac{\kappa}{2}\left(\frac{p_t}{(1+\bar{\pi})^{1-\gamma_p}(1+\pi_{t-1})^{\gamma_p}\,p_{t-1}} - 1\right)^2 y_t. \end{aligned} \tag{35}$$

The lump sum tax on households finances government consumption and transfers to the central bank:

$$T_t = \bar{G} + T_t^r. \tag{36}$$

5 Calibration

First, we fully follow Smets and Wouters (2003) to calibrate the standard NK equations (firms, households and monetary policy). Second, we calibrate the equations specific to our model, *i.e.* the equations related to the banking sector, to match euro area data. The time period of the model is quarterly.

5.1 Firms, households and monetary policy

We take the calibration and the estimation of Smets and Wouters (2003) for the euro area. The investment cost function is $\mathcal{S}(L_t^b/L_{t-1}^b) = \theta/2\left(L_t^b/L_{t-1}^b - 1\right)^2$. Smets and Wouters (2003) have a Calvo price setting and they obtain the Phillips curve:

$$\hat{\pi}_t = \frac{\beta^f}{1+\beta^f\gamma_p}\,E_t[\hat{\pi}_{t+1}] + \frac{\gamma_p}{1+\beta^f\gamma_p}\,\hat{\pi}_{t-1} + \frac{1}{1+\beta^f\gamma_p}\,\frac{(1-\beta^f\xi_p)(1-\xi_p)}{\xi_p}\,\hat{mc}_t,$$

not interested in real shocks and we only look at monetary and financial ones. The potential output is therefore equivalent to its steady state.

[10] We assume profits are fully consumed and we rule out investment through internal finance.

where ξ_t is the Calvo parameter. We instead have a Rotemberg price setting and the linearization of our Phillips curve (21) gives:

$$\hat{\pi}_t = \frac{\beta^f}{1+\beta^f\gamma_p}\, E_t[\hat{\pi}_{t+1}] + \frac{\gamma_p}{1+\beta^f\gamma_p}\, \hat{\pi}_{t-1} + \frac{1}{1+\beta^f\gamma_p}\, \frac{1}{\kappa\,\lambda_p}\, \hat{mc}_t,$$

where κ is the Rotemberg parameter. We choose κ such that $\kappa\lambda_p(1-\beta^f\xi_p)(1-\xi_p) = \xi_p$ to have a strict equivalence between these these two equations. Table 1 summarizes this calibration.

5.2 Banking sector

Specific functions

We assume quadratic default costs functions:

$$\begin{aligned}
\mathcal{C}^{\delta}\left((1-\delta_{t-1})D^{i}_{t-2}\right) &= c_{\delta}\left((1-\delta_{t-1})D^{i}_{t-2}\right)^2, \\
\mathcal{C}^{\alpha}\left((1-\alpha_{t-1})L^{b}_{t-2}\right) &= c_{\alpha}\left((1-\alpha_{t-1})L^{b}_{t-2}\right)^2,
\end{aligned}$$

with $c_\delta,\ c_\alpha \geq 0$. In our model, bank profits are positive but close to zero and a pure CRRA utility function for bank profits would imply a very steep slope, unless we are close to linear utility. We simply move the CRRA leftwards - by one unit - to keep a more standard slope. We therefore define the concave utility functions for banks as:

$$\begin{aligned}
\mathcal{U}^{b}(\pi^b_t) &= \frac{(\pi^b_t+1)^{1-\sigma_b}-1}{1-\sigma_b}, \\
\mathcal{U}^{l}(\pi^l_t) &= \frac{(\pi^l_t+1)^{1-\sigma_l}-1}{1-\sigma_l},
\end{aligned}$$

with $\sigma_b, \sigma_l \geq 0$.

Imposed steady states

The ECB provides statistics on yearly interest rates on euro-denominated loans by euro area residents to non-financial corporations with up to 1 year maturity (the ECB does not provide data with shorter maturity). The average between 2003 and mid-2008 is 4.90%, which gives a quarterly value of $\bar{R}^c = 1.20\%$.[11] Similarly the average yearly repo rate is 2.67%, which gives a

[11] We do not include more recent data to avoid exceptional behaviour during the subprime crisis around 2009.

quarterly policy rate of $\bar{R} = 0.66\%$. At the steady state, we impose equality between the policy rate and interbank rate $\bar{R} = \bar{I}$. During the same period, the quarterly inflation rate, computed from the GDP deflator, is $\bar{\pi} = 0.51\%$.

Castrén et al. (2010) provide data on the euro area corporate default probabilities. Their Expected Default Frequencies (EDF's) measure the probability that a firm defaults within the next 12 months. From 2003 to 2005 and for the euro area as a whole, the EDF moved from 2.5% in 2003 to less than 0.5% in 2005.[12] The EDF may also strongly vary between sectors. For instance, the EDF is generally higher in the capital goods sector and generally much lower in the financial sector. We use these information to fix the steady states for the firm default rate at 2.5% and for the bank default rate at 0.5%, that is $\bar{\alpha} = 0.975$ and $\bar{\delta} = 0.995$.[13]

The ECB also provides aggregated balance sheet of euro area Credit Institutions. We assume that loans to firms L_t^b are loans to euro area residents, excluding MFI's and government, augmented by holdings of securities other than shares issued by euro area residents, excluding MFI's and government.[14] We assume household deposits D_t^l are deposits from euro area residents, excluding MFI's and government, and interbank deposits D_t^i are deposits from euro area MFI's. The average ratios between 2003 and mid-2008 are $\bar{D}^l/\bar{L}^b = 0.8$ and $\bar{D}^i/\bar{L}^b = 0.6$.[15]

Imposed parameters

The central bank imposes reserve requirements on commercial banks of 2% of deposits and debt securities with maturities up to two years. The model needs a sufficiently high ratio to avoid a negative default disutility d_δ and we have to raise reserve requirements up to $\nu = 0.20$. The model also includes a loss coverage mechanism. In case of default, we assume that $\tau^l =$ 95% of the bad loans are eventually reimbursed by the central bank to the deposit banks. A high coverage assures that the repayment rate on the interbank market will be procyclical, as explained in Section 3. The smoothing parameter for deposits is set close to 0 ($\chi = 0.1$), so as to avoid any substantial dynamic effects (see Footnote 8). Having no *a priori* on the curvature of the momentary utility function for banks, we take the same parameter as for households, that

[12] They do not provide data after 2005Q4.

[13] Castrén et al. (2010) measure the default probability within one year whereas our measure is within one quarter. This could imply an overestimation of the default probabilities in our model. On the other hand, default rates are highly non linear. For instance, Carlson et al. (2008) show that the average default probability for US banks is close to 0 in normal times but can easily approach 5% during periods of stress (1987, 1991, 1999). The lack of harmonized bankruptcy data for the euro area renders difficult a more precise estimation of average defaults.

[14] Obviously, our measure of L_t^b also includes loans to households. However, data do not allow to distinguish households from firms.

[15] It is worth noting data are outstanding amounts (stocks) and may have different average maturities. In the model, all these variables have a 1 quarter maturity.

is $\sigma^b = \sigma^l = \sigma^c = 1.35$.

Finally, we have to calibrate the level of security holdings and their average return. Using the ECB data on aggregated balance sheet of euro area Credit Institutions, we assume the securities $B^b + B^l$ represent holdings of shares issued by euro area residents, as well as external, fixed and remaining assets. This gives the average ratio, between 2003 and 2008, of $(B^b + B^l)/\bar{L}^b = 0.6$. We split it equally between merchant banks ($B^b/\bar{L}^b = 0.3$) and deposit banks ($B^l/\bar{L}^b = 0.3$). We approximate the security return by the stock market return. The average quarterly nominal return of the Dow Jones EURO Stoxx stock market index from 2003 to mid-2008 is 1.7% and the return of the DJIA is 2.2% (excluding dividends). We therefore set the steady state of ρ_t at $\bar{\rho} = 2.5\%$.

Implied parameters

From the eight imposed steady states explained above, we are able to infer the values for the eight remaining parameters to calibrate. We obtain the discount values for respectively the merchant banks, the deposit banks and the households: $\beta^b = 0.9985$, $\beta^l = 0.9990$ and $\beta^b = 0.9996$. We see that $\beta^f < \beta^b < \beta^l < \beta^h$, which implies that firms have the strongest preference for the present and households have the lowest. We also obtain $\tau^b = 78\% < \tau^l$, meaning the loss coverage by the central bank is higher in case of default on the interbank market that in case of default on the credit market (between banks and firms). Finally, we can infer values for the default costs c_α and c_δ, implying that default costs for firms and merchant banks respectively represent 0.7% and 0.4% of output, and default disutilities $d_\alpha = 0.17$ and $d_\delta = 0.02$.

Other implied steady states

The calibration implies that $\bar{K}/\bar{y} = 8.8$ and $\bar{L}^b/\bar{y} = 0.22$, which is strictly equivalent to Smets and Wouters (2003). The consumption steady state ratio is $\bar{C}/\bar{y} = 0.50$ and firm profits steady state ratio is $\bar{\pi}^f/\bar{y} = 0.10$. In Smets and Wouters (2003), the consumption ratio is 0.6 but firm profits are distributed to households. We therefore have a similar implication. Bank profits are close to zero ($\bar{\pi}^b/\bar{y} \cong \bar{\pi}^l/\bar{y} \cong 0.1\%$). According to ECB data, euro-denominated deposits from euro area households, with agreed maturity up to 2 years, offered an average yearly return of 2.54% from 2003 to mid-2008, which is equivalent to a quarterly return of 0.63%. Our obtained steady state for the deposit rate is $\bar{R}^d = 0.55\%$, close to what is observed in data. A last implication is that the required lump-sum tax levied on households to balance the central bank and government budgets amounts to 18.6% of output at the steady state ($\bar{T}/\bar{y} = 18.6\%$).

Table 2 summarizes the calibration.

6 Model simulations

6.1 Monetary policy transmission

We implement a monetary policy shock, according to equation (33). We assume a constant security return, that is $\rho_t = \bar{\rho}$, $\forall t$. We successively look at the role on monetary transmission of banks' momentary utility functions and financial stability.

6.1.1 Merchant banks' momentary utility function

Merchant banks borrow from the interbank market and from the central bank and lend to firms. The partial equilibrium analysis in Section 3 shows that the behaviour of these banks, through their momentary utility finction, may be important for the transmission of monetary policy. Here we look at the role of the utility function using the general equilibrium setup. We compare our IRF's to those obtained by Smets and Wouters (2003). Figure 1 displays the results.

As it is well-known, a monetary policy tightening leads to hump-shaped falls in output, consumption, investment and employment in the SW model. Inflation rate also reduces. They have neither repayment rates nor banking sector related variables. The same shock in our model with the benchmark calibration ($\sigma^b = 1.35$) also depresses the economy although there are some differences. First, our three market interest rates closely follow the policy rate. In SW, the credit rate decreases but it has a different meaning. Indeed, households own firms and receive a return on the whole capital stock. In our model, households do not own firm and only receive a return on their loans. Second, the repayment rates decrease as expected. We see that monetary policy has stronger effects on the bank repayment rates rather than on firm repayment rates, which seems intuitive since we have a direct link between the merchant bank and the central bank. Third, interbank loans and household deposits are highly volatile. Fourth and as a result, monetary policy has much stronger effects at impact in our model but the persistence is lower than in SW.

Increasing the level of concavity of the momentary utility finction for the merchant banks by a factor of 10 ($\sigma^b = 13.5$) leaves almost unchanged the interest rates but smoothes the monetary transmission, which becomes closer to SW.

6.1.2 Deposit banks' momentary utility finction

Although the two banks are separate agents and are only linked through the interbank market, σ^b or σ^l produces quite similar effects on the monetary transmission. Indeed, Figure 2 shows that increasing the level of concavity for the deposit banks also smoothes the transmission of monetary policy.

6.1.3 Financial stability

We now focus on the link between the central bank and endogenous default risks for firms and banks. Figure 3 shows that endogenous defaults are extra mechanisms allowing to absorb a shock and smooth its effects. As a result, a monetary policy tightening reduces less the real output and inflation, at least initially, when there is a possibility to increase defaults. Endogenous defaults therefore do not act as a financial accelerator but rather as a financial "decelerator". Quantitatively, we see that although the falls in the repayment rates are rather limited (maximum of 0.1 percentage points for the bank repayment rate and 0.01 percentage points for the firm repayment rate), their effects on the real economy are quite substantial. It is worth pointing out that the lower volatility of output and inflation does not necessarily mean that a central planner would choose to default. Here all agents are independent from each other and they do not take into account the effects of their decisions on the rest of the economy.

This sensitivity analysis shows how important is the calibration of the banking sector for the transmission of the monetary shock. So far, we take as given the estimation results from SW and conduct a small sensitivity analysis on selected banking parameters. We can expect that an estimation of this augmented model should produce results substantially different from those obtained by SW.

6.2 Financial shock and alternative Taylor rules

In this section, we use our model to understand how an adverse financial shock hitting the banking sector may spread to the whole economy and how monetary policy can respond. The financial shock is represented as a negative security return shock following $\rho_t = (1-\rho_\rho)\bar{\rho} + \rho_\rho \rho_{t-1} - u_t^\rho$, with an autoregressive parameter $\rho_\rho = 0.5$ and stochastic disturbance $u_1^\rho = 1$.

6.2.1 Financial shock

Figure 4 shows that a negative security return shock dries the interbank market, which in turn reduces loans to the real economy, output and *in fine* inflation. The policy interest rate decreases according to the Taylor rule (33). Interestingly, the interbank interest rate does not follow the policy rate and instead remains high, because of the credit squeeze on the interbank market. Finally, we observe a fall in the two repayment rates. The fall is however much stronger for the bank repayment, which is intuitive given the high interbank rate.

Quantitatively, the transmission of the shock is relatively weak. Indeed, the security holdings, which represent about 12% of output, is almost reduced to nothing at impact. However, output only decreases by about 0.25%. To better understand this weak transmission, recall that we obtain from the final goods market equilibrium (34):

$$\frac{\rho_t - \pi_t}{1+\pi_t} \left(B^b + B^l\right) + \frac{D_t^c}{1+R_t} - \frac{D_{t-1}^c}{1+\pi_t} = 0$$

It means that return from security holdings is in cash (pure liquidity shock) and that total cash flow (from investment return and from the central bank) must be equal to 0. The equation therefore implies that the central bank must compensate through an increase in D_t^c every fall in ρ_t. More precisely, we can rewrite the above equation as:

$$D_t^c = \alpha_t D_{t-1}^c - \beta_t,$$

where $\alpha_t = (1+R_t)/(1+\pi_t)$ and $\beta_t = (\rho_t - \pi_t)(1+R_t)(B^b + B^l)/(1+\pi_t)$. Note that α_t and β_t are $I(0)$, and that $\bar{\alpha} > 1$. As a result, the steady state $\bar{D}^c = \bar{\beta}/(\bar{\alpha}-1)$ is unstable. In other words, if D_t^c deviates from its steady state because of a shock, it will not come back. The last plot of Figure 4 illustrates this mechanism. Following the negative security return shock, open market volume D_t^c strongly increases and stays indefinitely at high levels. We conclude that unsustainable monetary reaction explains the weak transmission of the shock to the real economy.[16]

Obviously, preventing D_t^c to grow forever, that is imposing some rigidity for D_t^c should increase the transmission of the shock to the real economy. One possibility is to render D_t^c stationary by introducing a borrowing constraint: the merchant bank borrows from the central bank at the policy rate R_t but there is a disutility when the borrowing demand deviates from its steady state. Then the maximization program (1) of the merchant bank becomes:

$$\max_{D_t^c, D_t^i, L_t^b, \delta_t, \pi_t^b} \sum_{s=0}^{\infty} \left(\beta^b\right)^s E_t \left[\mathcal{U}^b\left(\pi_{t+s}^b\right) - d_\delta\left(1-\delta_{t+s}\right) - \phi\left(\frac{D_t^c}{\bar{D}^c} - 1\right)^2\right],$$

which only modifies the first order condition (3), without changing the steady state of the economy. When $\phi = 0$, we are back to the previous exercise. $\phi > 0$ forces D_t^c to be stationary. In technical terms, D_t^c is no more an auxiliary variable but becomes a state variable; and the higher is the parameter ϕ, the closer to 0 is the associated eigenvalue, and the higher are the

[16]Note that if D_t^c is non stationary, only the expression $D_t^c/(1+R_t) - D_{t-1}^c/(1+\pi_t)$ enters the model and this expression is stationary. In other words, D_t^c is a purely auxiliary variable and its non stationarity does not cause any problem for the stability conditions. In Appendix A, we show that an equivalent mechanism exists in SW.

rigidities on D_t^c.[17]

Figure 5 ("Taylor") shows the effects of the same security return shock but with $\phi = 0.025$. We see that borrowing constraints drastically change the results. Although the monetary authority reduces the policy rate by 3 percentage points, output falls by 10% and inflation falls by 5 percentage points, that is we enter in deflation. We also note that the interbank bank market activity is reduced by 75% and that despite the fall in the policy rate, the three market rates remain high, at least during the initial periods. Finally, the fall in the bank repayment rate almost reaches one percentage point and is very persistent. This kind of scenario is quite similar to what was observed in 2008-2009 in the aftermath of the subprime crisis.

6.2.2 Alternative Taylor rules

The security return shock strongly reduces volumes in the interbank market and has dramatic effects on the real economy, at least when we assume some borrowing constraints. As a result, a monetary policy designed to avoid the fall on the interbank market volume might have potentially strong effects in the real economy. We replace the standard monetary policy reaction function (33) by the augmented Taylor rule:

$$\begin{aligned} 1+R_t &= (1+R_{t-1})^{\psi} \times \\ & \left(\frac{1+\bar{\pi}}{\beta^b} \left(\frac{1+\pi_{t-1}}{1+\bar{\pi}} \right)^{r_\pi} \left(\frac{y_t}{\bar{y}} \right)^{r_y} \left(\frac{1+\pi_t}{1+\pi_{t-1}} \right)^{r_{\Delta\pi}} \left(\frac{y_t}{y_{t-1}} \right)^{r_{\Delta y}} \left(\frac{D_t^i}{\bar{D}_t^i} \right)^{r_\rho} \right)^{1-\psi} \exp\left(u_t^R\right). \end{aligned} \tag{37}$$

It means that the central bank reacts as usual to inflation and output, but also reacts to a "banking related variable" which is the interbank market volume. It is worth noting we could replace the interbank market variable by other banking variables as the interbank interest rate or the interbank default rate without changing our main conclusions. Figure 5 compares the impact of a security return shock with the standard Taylor rule ($r_\rho = 0$, "Taylor") *vs.* the augmented Taylor rule ($r_\rho = 0.007$, "New Taylor"). Given the deep fall in the interbank market, we could expect a stronger reaction, at least initially, from the central bank when a banking variable in included in the Taylor rate. Strikingly, we have exactly the opposite result. The reason is that agents are forward looking and rational. They know that the central bank will be highly accommodative because of the negative shock and they behave consequently. As a result, the fall

[17] With this simple representation, we intend to summarize the different borrowing constraints that may exist in reality (discrete time of open market operations, limitation of available amount unless private banks are willing to pay a premium, request of a sufficiently liquid collateral,...). However, we admit this is a rough specification, especially when $D_t^c < \bar{D}^c$. A more elegant description of the different monetary policy tools would be worthwhile but is beyond the scope of our general equilibrium approach.

in output, and inflation, is lower and *in fine* the central bank does not need to strongly reduce its policy rate.

Alternatively, we could assume agents do not know that the central bank also reacts to a banking variable. In other words, agents form expectations using (37) with $r_\rho = 0$ whereas the central bank uses in fact the reaction function (37) with $r_\rho = 0.007$. Agents obviously see that the realized policy rate does not correspond to their expectations, but they believe this is because of stochastic disturbances.[18] Appendix B explains in detail how we produce these simulations. Since reactions to the fall in the interbank market are no more anticipated by agents, Figure 5 ("Taylor + shocks") shows that the central bank must reduce the policy rate in a more drastic way, which results in lower falls in output and inflation. We therefore see that, in case of a financial shock, the commitment to intervene and the credibility of a central bank is crucial to avoid later dramatic moves.

It is worth pointing out that in our two exercises ("New Taylor" *vs.* "Taylor + shocks"), the monetary rule followed is the same. The difference is that the rule is announced in the first case and not in the second case. Different exercises would be to determine the parameters to have the optimal - given - rule, as for instance in Taylor and Williams (2010); or to find the optimal discretionary policy, as for instance in Mishkin (2007).

7 Conclusion

We build a New Keynesian model with an heterogenous banking sector and show that features as banks' momentary utility functions, borrowing constraints or financial stability are important for the transmission of monetary policy. Moreover, we show that the central bank commitment to intervene in case of financial shock is important to stabilize the macroeconomy.

This paper mainly conducts simulation exercises based on a limited set of shocks. Since we show that some banking sector characteristics are important, an interesting extension would be to estimate these characteristics by Bayesian methods, and check if our augmented New Keynesian model performs better than a more standard one. Also, our monetary policy is limited to the policy interest rate, and the volume of open market operations remains a by-product. The recent subprime crisis tells us that distinguishing between price and quantity is important and would be a worthwhile research avenue.

[18] We are therefore not prone to the Lucas critique and time inconsistency: agents always keep the same expectations and perceive any deviation as a stochastic shock.

References

Adrian, T. and H. Shin (2009). Money, liquidity and monetary policy. *American Economic Review 99*(2), 600–6005.

Bernanke, B., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. In J. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Volume 1C, Chapter 21, pp. 1341–1393. Amsterdam: North-Holland.

Calvo, G. (1983). Staggered prices in a utility maximizing framework. *Journal of Monetary Economics 12*, 383–398.

Carlson, M., T. King, and K. Lewis (2008). Distress in the financial sector and economic activity. Finance and Economics Discussion Series 2008-43, Federal Reserve Board.

Carlstrom, C. and T. Fuerst (1997). Agency cost, net worth, and business fluctuations: A computable general equilibrium analysis. *American Economic Review 87*(5), 893–910.

Castrén, O., S. Dées, and F. Zaher (2010). Stress testing euro area corporate default probabilities using a global macroeconomic model. *Journal of Financial Stability 6*, 64–78.

Christiano, L., M. Eichenbaum, and C. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1-45), 346–353.

Christiano, L., R. Motto, and M. Rostagno (2009). Financial factors in business cycles. mimeo, ECB and Northwestern University.

Curdia, V. and M. Woodford (2009). Credit frictions and optimal monetary policy. BIS Working Paper No 278.

de Walque, G., O. Pierrard, and A. Rouabah (2010). Financial (in)stability, supervision and liquidity injections: a dynamic general equilibrium approach. The Economic Journal.

Dubey, P., J. Geanakoplos, and M. Shubik (2005). Default and punishment in general equilibrium. *Econometrica 73*(1), 1–37.

Elul, R. (2008). Collateral, credit history, and the financial decelerator. *Journal of Financial Intermediation 17*, 63–88.

Gerali, A., S. Neri, L. Sessa, and F. Signoretti (2008). Credit and banking in a DSGE model. mimeo, Bank of Italy.

Goodfriend, M. and B. B. McCallum (2007). Banking and interest rates in monetary policy analysis: A quantitative exploration. *Journal of Monetary Economics 54*, 1480–1507.

Goodhart, C., P. Sunirand, and D. Tsomocos (2005). A risk assessment model for banks. *Annals of Finance 1*(2), 197–224.

Iacovello, M. (2005). House prices, borrowing constraints and monetary policy in the business cycle. *American Economic Review 95*(3), 739–764.

Mishkin, F. (2007). Housing and the monetary transmission mechanism. *Proceedings, Federal Reserve Bank of Kansas City*, 359–413.

Rotemberg, J. (1982). Monopolistic price adjustment and aggregate output. *The Review of Economic Studies 49*(4), 517–531.

Shubik, M. and C. Wilson (1977). The optimal bankruptcy rule in a trading economy using fiat money. *Zeitschrift fur Nationalokonomie 37*, 337–354.

Smets, F. and R. Wouters (2003). An estimated dynamic stochastic general equilibrium model of the euro area. *Journal of the European Economic Association 1*(5), 1123–1175.

Taylor, J. and J. Williams (2010). Simple and robust rules for monetary policy. In B. Friedman and M. Woodford (Eds.), *Handbook of Monetary Economics*. Amsterdam: North-Holland.

Appendix A: Monetary policy in the SW model

In Smets and Wouters (2003), the governement/central bank finances its consumption G_t by issuing bonds B_t. Households buy these bonds at a price $1/(1+R_t)$ fixed by the government/central bank. The final goods market is in equilibrium and this implies:

$$G_t = \frac{B_t}{1+R_t} - \frac{B_{t-1}}{1+\pi_t} \tag{i}$$

We can rewrite this equation as:

$$B_t = \alpha_t B_{t-1} + \beta_t,$$

where $\alpha_t = (1+R_t)/(1+\pi_t)$ and $\beta_t = (1+R_t)G_t$. Note that α_t and β_t are $I(0)$, and that $\bar{\alpha} > 1$. As a result, the steady state $\bar{B} = \bar{\beta}/(1-\bar{\alpha})$ is unstable. In other words, if B_t deviates from its steady state because of a shock, it will not come back. Only when there is no government consumption, $B_t = 0, \forall t$.

We have a perfectly similar representation in our model. D_t^c is not stationary and $D_t^c = 0, \forall t$ only when there are not security holdings.

Appendix B: Alternative Taylor rules

The model is composed of $(m+1)$ variables $\{V_t, R_t\}$, $(m+1)$ equations and $(p+1)$ stochastic shocks $\{u_t^1, u_t^R\}$. The first order approximated solution of the model takes the form of a set of decision rules:

$$\begin{bmatrix} \hat{V}_t^* \\ \hat{R}_t^* \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} \begin{bmatrix} \hat{V}_{t-1}^* \\ \hat{R}_{t-1}^* \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \begin{bmatrix} u_t^1 \\ u_t^R \end{bmatrix}, \tag{ii}$$

where A_1, A_2, B_1 and B_2 are matrices of appropriate dimensions, and $\hat{X}_t = X_t - \bar{X}$ with $\bar{X}$ the steady state of variable X_t.

The first simulation ("Taylor") corresponds to (ii) with $r_\rho = 0$ and $u_t^R = 0$. The second simulation ("New Taylor") corresponds to (ii) with $r_\rho = 0.007$ and $u_t^R = 0$. The third simulation ("Taylor + shocks") corresponds to (ii) with $r_\rho = 0$ and $u_t^R = u_t^*$ such that $\{V_t^*, R_t^*\}$ is also the solution of (37) with $r_\rho = 0.007$ and $u_t^R = 0$. To find the right u_t^*, we iterate through the following steps:

1. Assume $u_t^* = 0$.

2. Assume $r_\rho = 0$, $u_t^R = u_t^*$ and compute $\{V_t^*, R_t^*\}$ the solution of (ii).

3. Assume $r_\rho = 0.007$, $u_t^R = 0$ and use $\{V_t^*\}$ to compute R_t^a the solution of (37).

4. Compute $u_t^* = u_t^* + (R_t^a - R_t^*)/2$.

5. Back to point 2 until $\|R_t^a - R_t^*\|_\infty < o_R$.

Firms										
μ	=	0.3	$\Phi/\bar{y}$	=	0.41	τ	=	0.025	β^f	=	0.99
θ	=	6.77	λ_p	=	0.37	ξ_p	=	0.908	γ_p	=	0.47
Households											
σ_c	=	1.35	σ_l	=	2.4	h	=	0.57	$\bar{G}/\bar{y}$	=	0.18
λ_w	=	0.50	ξ_w	=	0.74	γ_w	=	0.76			
Monetary policy											
ψ	=	0.95	r_π	=	1.68	r_y	=	0.10	$r_{\Delta\pi}$	=	0.14
$r_{\Delta y}$	=	0.16	σ_R	=	0.081						

Table 1: Calibration borrowed from Smets and Wouters (2003)

Imposed parameters											
σ^b	=	1.35	σ^l	=	1.35	ν	=	0.02	τ^l	=	0.95
χ	=	0.1	$B^b/\bar{L}^b$	=	0.3	$B^l/\bar{L}^b$	=	0.3	$\bar{\rho}$	=	2.5%
Implied parameters											
β^b	=	0.9985	β^l	=	0.999	β^h	=	0.9996	τ^b	=	0.78
c_α	=	26.07	c_δ	=	147.04	d_α	=	0.17	d_δ	=	0.02

Table 2: Calibration related to the banking sector

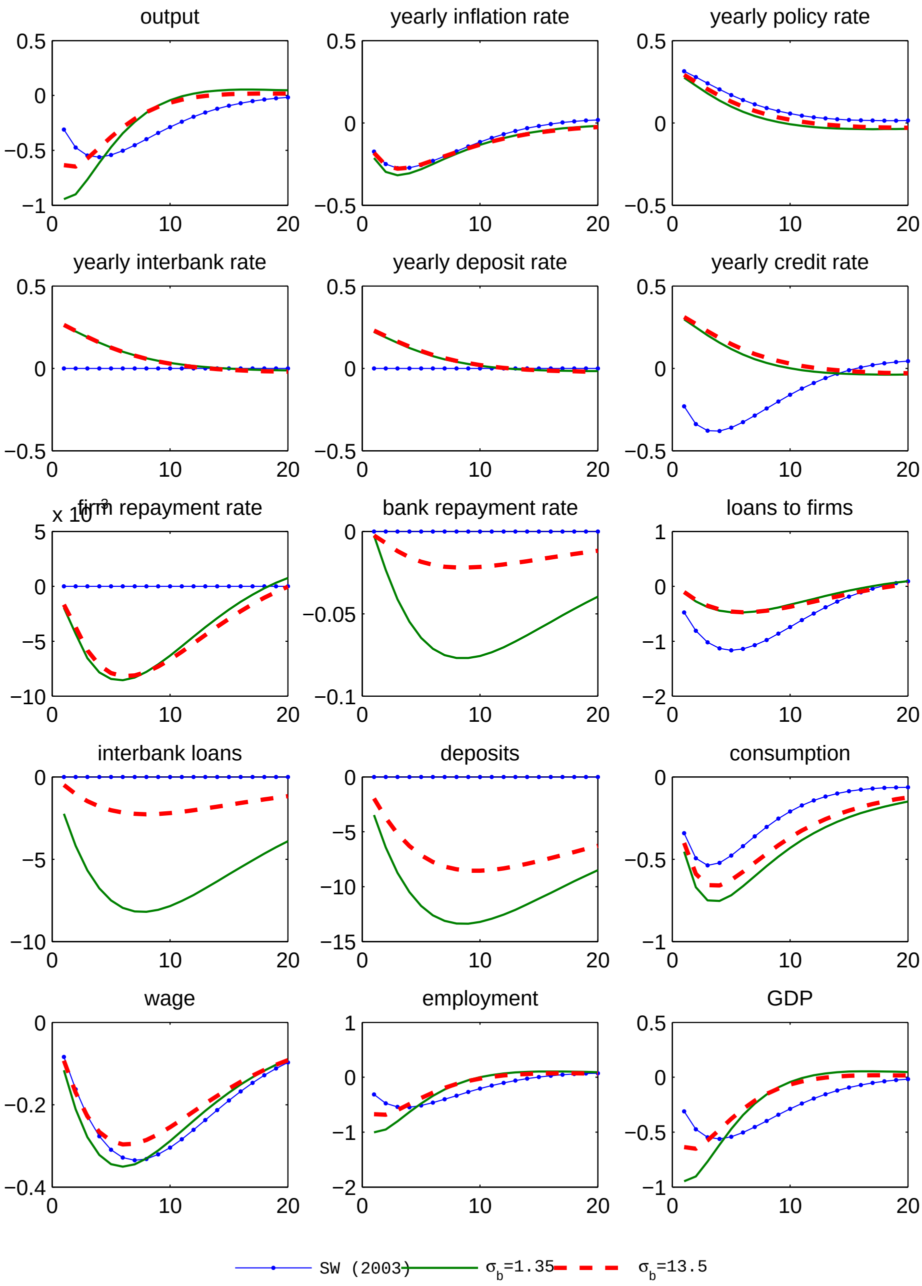

Figure 1: Monetary transmission and the momentary utility function for the merchant bank (variations from steady state, in % points for rates, in % for other variables)

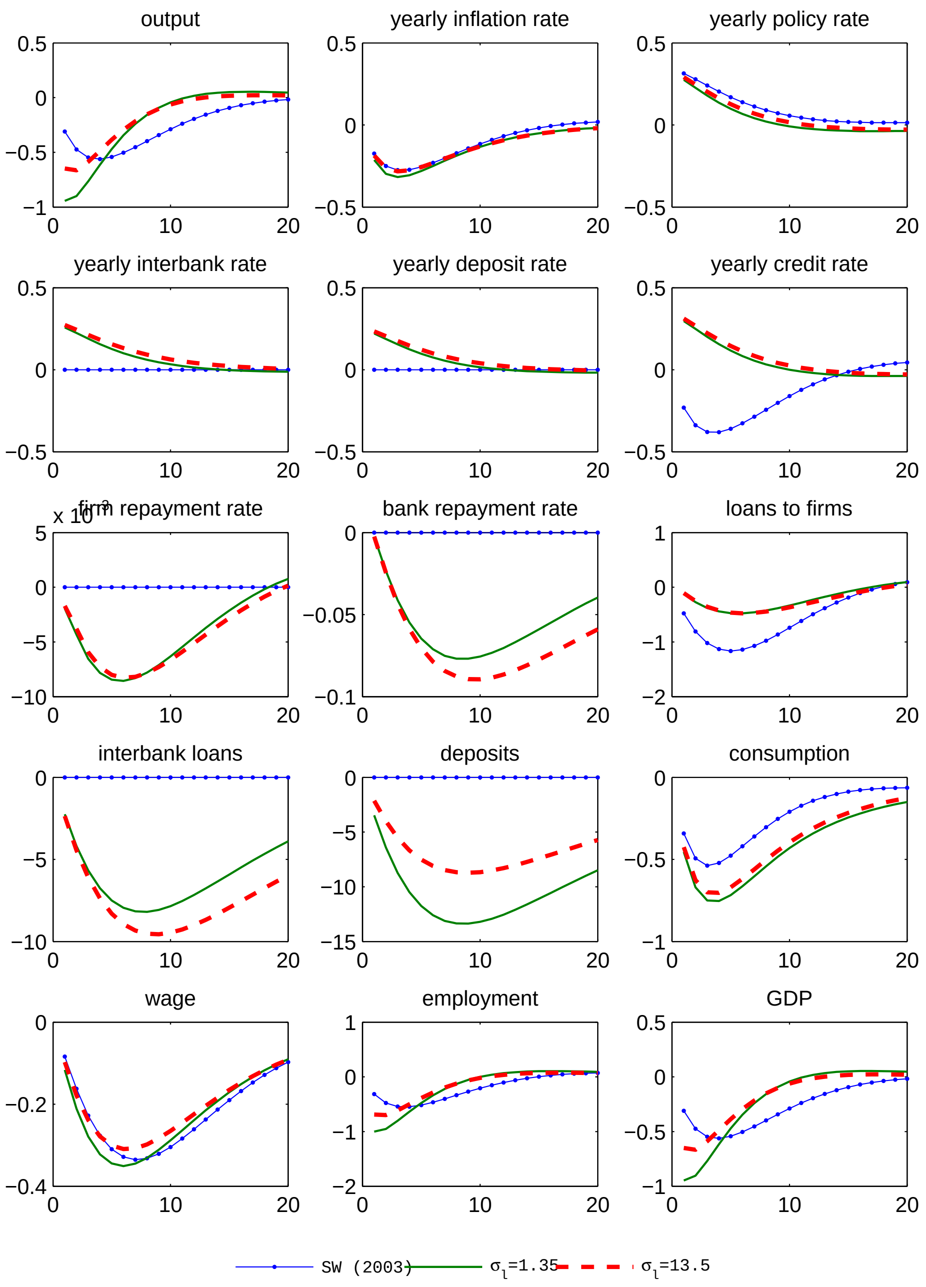

Figure 2: Monetary transmission and the momentary utility function for the deposit bank (variations from steady state, in % points for rates, in % for other variables)

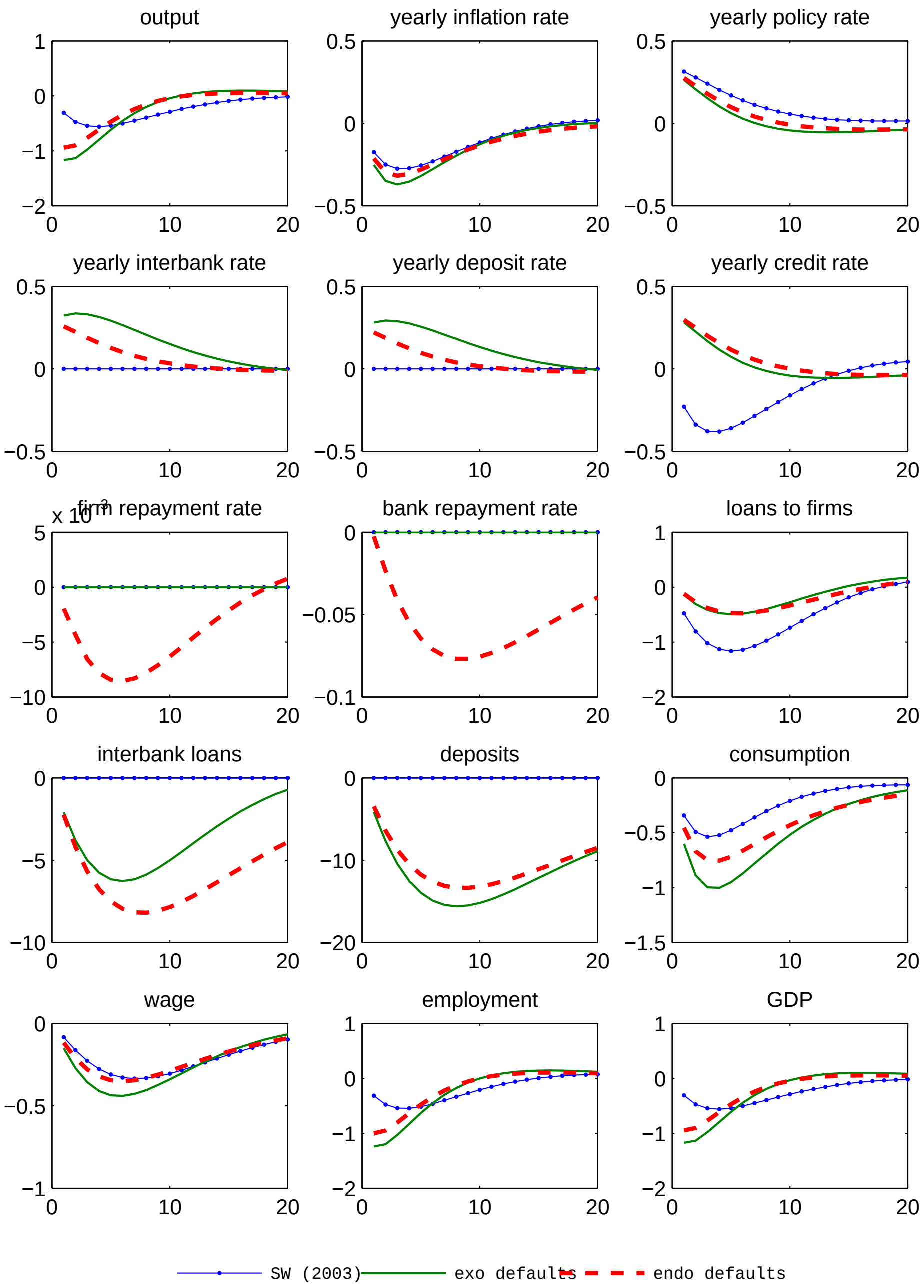

Figure 3: Monetary transmission and endogenous defaults (variations from steady state, in % points for rates, in % for other variables)

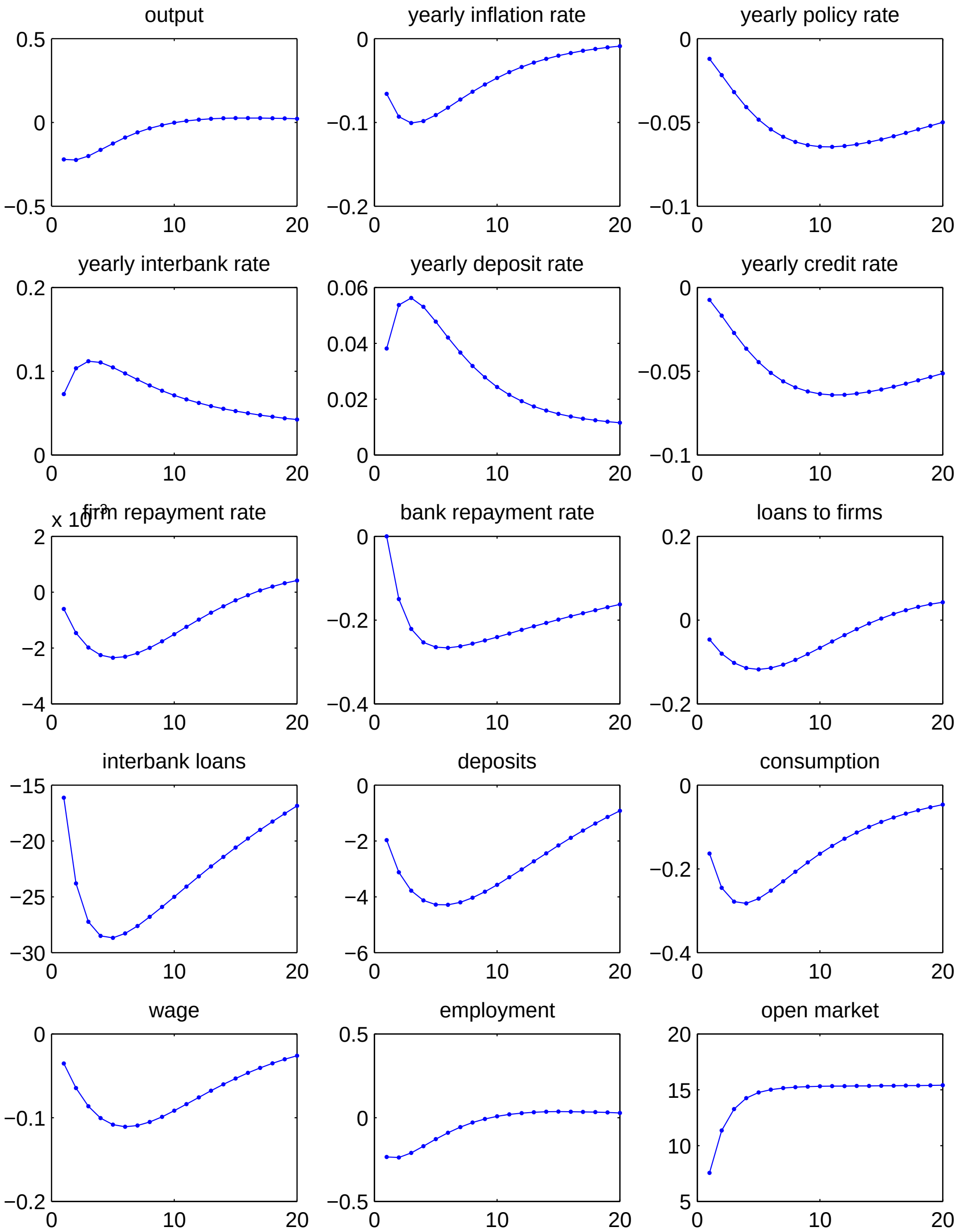

Figure 4: Security return shock with free access to the central bank (variations from steady state, in % points for rates, in % for other variables)

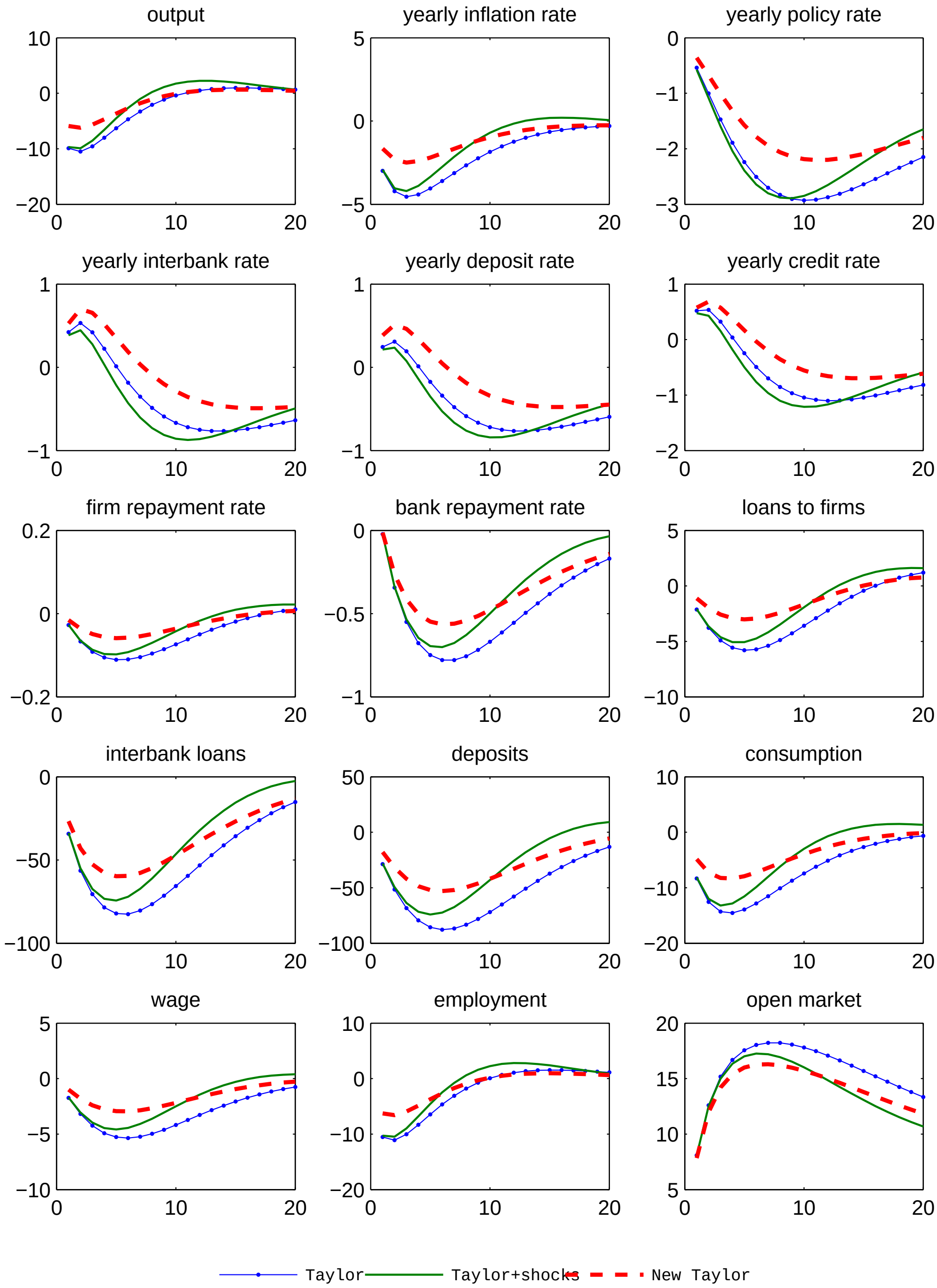

Figure 5: Security return shock with restricted access to the central bank, and alternative Taylor rules (variations from steady state, in % points for rates, in % for other variables)