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This paper incorporates a bank into a dynamic stochastic general equilibrium model. The bank collects deposits and makes loans to an entrepreneur, subject to a regulatory bank capital requirement. The presence of the bank dampens the response of real activity to TFP shocks, but it magnifies the effect of credit losses. An unanticipated credit loss reduces the bank's capital, which raises the spread between loan and deposit rates, and triggers a sizable, but short-lived, fall in real activity. When the bank operates internationally, then a loan default shock in one country triggers a sizable fall in both domestic and foreign output.

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1. Introduction

Standard macroeconomic models developed before the current financial crisis abstracted from banks and other financial intermediaries. The current financial crisis has revealed the limitations of this class of models. The crisis was triggered by credit losses in the US mortgage market. These credit losses lowered the capital of US and foreign banks active in the US market, thus leading to an increase in the credit spreads, and a persistent fall in real activity world-wide. This paper presents a DSGE model with banks that accounts for these phenomena.

I consider a closed economy, before analyzing a two-country world. There are three (representative) agents: (i) a household that works and invests her savings in bank deposits; (ii) a banker who lends to an entrepreneur; (iii) the entrepreneur accumulates capital and produces a final good (using capital and labor). Deposits provide liquidity services to the household. The bank faces a regulatory capital requirement, and thus partially finance loans using own funds (equity). Hence, the loan rate exceeds the deposit rate. The interest spread is a decreasing function of the bank's 'excess' capital (i.e. of bank capital held in excess of the mandatory level).

In the structure here, an unanticipated credit loss lowers the bank's capital, and raises the loan/deposit rate spread. Essentially, an unanticipated fall in the bank's wealth worsens the financial friction, which leads to a fall in investment, employment and output. In calibrated model versions, the deposit rate falls, in response to the credit loss, and household consumption rises; this raises the wage, and triggers a fall in employment and output, and a fall in investment. By contrast, in a model variant in which households directly lend to entrepreneurs (without using financial intermediaries), a credit loss has (virtually) no effect on the loan rate, and output and investment change much less. Numerical simulations suggest that the magnification of the real effects of credit losses, due to financial intermediation, can be sizable.

However, financial intermediation dampens the response of output and investment to productivity (TFP) shocks. A positive TFP shock raises household income, and thus the household holds more deposits, i.e. the bank's excess capital falls. This triggers a widening of the loan/deposits interest rate spread, which dampens the expansion of lending, compared to a setting with frictionless lending, and explains the more muted response of investment and output.

The two-country variant of the model assumes a global bank: the bank collects deposits from local and foreign households, and makes loans to local and foreign entrepreneurs. Credit losses in one country trigger a world-wide widening of loan/deposit rate spreads, and a world-wide fall in lending and output. The effect on real activity is very similar across countries.

To be added: discussion of related literature. Goodfriend and McCallum (2007); Van den Heuvel (2008). Recent quantitative closed economy DSGE models with banks: de Walque, Pierrard and Rouabah (2010); Gerali, Neri, Sessa and Signoretti (2010); Roeger (2009). Value added here: emphasis on transmission of credit loss shock; analytical results. Open economy: Devereux, Yetman (2010) assume international investors subject to leverage constraint, hard to interpret as banks; simpler technology (eg no capital accumulation) Difference: my paper assumes banks, focus on credit losses, full business cycle model

2. The closed economy model

The closed economy model assumes three (representative) infinitely-lived agents: a household, a bank and an entrepreneur. There is a final good that is used for consumption (by each of the three agents), and for capital accumulation (by the entrepreneur). All agents are price takers.

The household

The household consumes the final good, provides labor to the entrepreneur and invests her savings in bank deposits. Her date t budget constraint is:

$$C_t + D_{t+1} = W_t N_t + D_t R_t^D , \qquad (1)$$

where C_t and W_t are consumption and the wage rate, respectively (the final good is used as numéraire). N_t are hours worked. D_{t+1} are the bank deposit held by the household, at the end of period t. R_t^D is the gross interest rate on deposits, between t-1 and t (R_t^D is set at t-1).

The household's expected life-time utility at date t is:

$$E_t \sum_{s=0}^{\infty} \beta^s [u(C_{t+s}) + \Psi^D u(D_{t+1+s}) - \Psi^N N_{t+s}\}, \tag{2}$$

with $\Psi^D, \Psi^N > 0$; $u(x) = (x^{1-\sigma} - 1)/(1-\sigma)$, with $\sigma > 0$ is an increasing and concave function. The household maximizes (2) subject to the restriction that her period-budget constraint holds at t and at all subsequent dates. Ruling out Ponzi schemes, the household decision problem has these first-order conditions:

$$R^D_{t+1} E_t \beta u'(C_{t+1})/u'(C_t) + \Psi^D u'(D_{t+1})/u'(C_t) = 1, \tag{3}$$

$$u'(C_t) W_t = \Psi^N. \tag{4}$$

The bank

In period t, the bank receives deposits D_{t+1} and she makes a (one-period) loan L_{t+1} to the entrepreneur. The bank faces a capital requirement: her date t capital $L_{t+1} - D_{t+1}$ should not be smaller than a fraction γ of assets L_{t+1}. A capital requirement of this form can either represent a legal requirement (Basel II), but it might also result from pressure by depositors (to ensure bank solvency).

I assume that the bank can hold less capital than the required level, but that this is costly (e.g. because the bank then has to engage in creative accounting). Let $x_t = (L_{t+1} - D_{t+1}) - \gamma L_{t+1} = (1-\gamma) L_{t+1} - D_{t+1}$ denote that bank's 'excess' capital at t. The bank bears a cost $\phi(x_t)$ as a function of x_t, with $\phi(0) = 0$ and $\phi' < 0$, $\phi'' > 0$. Hence, that cost is decreasing and strictly convex. When the bank strictly meets its capital requirement, then the cost is zero (a positive cost only arises when $x_t < 0$; when $x_t > 0$, then the bank receives a benefit). At t, the bank also bears an operating cost $\Gamma(D_{t+1}, L_{t+1})$ that is increasing and linear in deposits and loans D_{t+1}, L_{t+1}. The bank's period t budget constraint is:

$$L_{t+1} + D_t R^D_t + \Gamma(D_{t+1}, L_{t+1}) + \phi(L_{t+1}(1-\gamma) - D_{t+1}) + d^B_t = L_t R^L_t (1 - \delta^L_t) + D_{t+1}, \tag{5}$$

where d^E_t is the profit (dividend) generated by the bank at t. R^L_t is the gross loan interest rate between t-1 and t. $0 \le \delta^L_t \le 1$ is an exogenous stochastic loan default rate: at t, the entrepreneur only pays back a fraction $1-\delta_t^L$ of the contracted amount $L_t R_t^L$. R_t^L is set at t-1. However, the effective rate of return on the loan, net of default, is only realized at t.

The banker does not have access to other assets, and thus she consumes her dividends. Her expected life-time utility at t is: $E_t \sum_{s=0}^{\infty} \beta^s u(d_{t+s}^B)$.The banker maximizes life-time utility subject to current and future budget constraints. Ruling out Ponzi schemes, that problem has these first-order conditions:

$$R_{t+1}^D E_{t+1} \beta u'(d_{t+1}^B)/u'(d_t^B) = 1 - \Gamma_{D,t} + \phi_t' \text{ and} \tag{6}$$

$$R_{t+1}^L E_{t+1}(1-\delta_{t+1}^L)\beta u'(d_{t+1}^B)/u'(d_t^B) = 1 + \Gamma_{L,t} + (1-\gamma)\phi_t', \tag{7}$$

where $\Gamma_{D,t}$ and $\Gamma_{L,t}$ are the marginal costs of deposits and loans, respectively and $\phi_t' \equiv \phi'((1-\gamma)L_{t+1} - D_{t+1})$. By accepting more deposits at t, the banker can increase her date t consumption, at the cost of a reduction of consumption at t+1. Specifically, when the bank raises deposits D_{t+1} by 1 unit (holding constant loans), then her capital falls by one unit, which raises ϕ by $-\phi' > 0$; in addition she incurs a marginal operating cost $\Gamma_{D,t}$. Hence, the banker's marginal benefit of deposits (in utility terms) is $u'(d_t^S)\{1-\Gamma_{D,t}+\phi_t'\}$. The discounted expected marginal cost of deposits to the bank is $R_{t+1}^D E_{t+1} \beta u'(d_{t+1}^B)$. At a maximum of the bank's decision problem, the expected marginal benefit equals the marginal cost. If the bank raises loans by one unit at t (holding constant deposits), then this lowers her date t dividend by $1+\Gamma_{L,t}+(1-\gamma)\phi_t'$. The bank's effective (gross) real rate of return on loans is thus $R_{t+1}^L(1-\delta_{t+1}^L)/\{1+\Gamma_{L,t}+(1-\gamma)\phi_t'\}$, which explains the Euler equation (7).

The entrepreneur

The entrepreneur accumulates physical capital, and she uses labor and capital to produce the final good. The law of motion of the capital stock is:

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{8}$$

where K_t is the capital stock used in production at t; $0 \leq \delta \leq 1$ is the depreciation rate of capital, and I_t is gross investment. Final good output, denoted Y_t, is produced using a Cobb-Douglas technology:

$$Y_t = \theta_t (K_t)^{\alpha} (N_t)^{1-\alpha}, \tag{9}$$

with $0 < \alpha < 1$. Total factor productivity θ_t is an exogenous random variable.

The entrepreneur's period t budget constraint is:

$$L_t R_t^L (1-\delta_t^L) + K_{t+1} + W_t N_t + d_t^E = L_{t+1} + \theta_t (K_t)^{\alpha} (N_t)^{1-\alpha} + (1-\delta) K_t, \tag{10}$$

where d_t^E is the entrepreneur's dividend income at t. The entrepreneur consumes her dividend income. Her lifetime utility at t is given by $E_t \sum_{s=0}^{\infty} \beta^s u(d_{t+s}^E)$. Maximization of life-time utility subject to (10) yields these first-order conditions:

$$E_t \beta (u'(d_{t+1}^E)/u'(d_{t+1}^E)) \{\theta_{t+1} \alpha K_{t+1}^{\alpha-1} N_{t+1}^{1-\alpha} + 1 - \delta\} = 1, \tag{11}$$

$$R_{t+1}^L E_t (1-\delta_{t+1}^L) \beta (u'(d_{t+1}^E)/u'(d_{t+1}^E)) = 1, \tag{12}$$

$$W_t = (1-\alpha) \theta_t K_t^{\alpha} N_t^{-\alpha}. \tag{13}$$

Market clearing

Market clearing for the final good requires:

$$Y_t = C_t + d_t^B + d_t^E + I_t + \Gamma(D_{t+1}, L_{t+1}) + \phi(D_{t+1}(1-\gamma) - L_{t+1}). \tag{14}$$

3. Interest rate spreads and bank capital

Note that, in contrast to much recent theoretical research on financial frictions (eg Kiyotaki and Moore (2007)), the model here assumes that all agents have the same subjective discount factor, and that the entrepreneur does not face a collateral constraint. In models of the Kiyotaki-Moore type, there are no financial intermediaries; entrepreneurs are less patient than households; entrepreneurs face a collateral constraint for debt (entrepreneurs' debt cannot exceed a fraction of their physical capital stock), which allows to ensure existence of a stationary equilibrium. This paper assumes a bank that faces a 'flexible' type of collateral constrain (it bears a resource cost when deposits fall below a fraction of the bank assets), but the other agents do not face collateral constraints—this allows to focus on the effects of the bank capital restriction.

As deposits provide liquidity services to households, and as financial intermediation is costly, the deposit rate is lower than the loan rate, in the present model. Let $\mathcal{R}^L_{t+1} \equiv R^L_{t+1}E_{t+1}(1-\delta^L_{t+1})$ be the expected effective gross loan rate (i.e. loan rate, net of default). Up to a certainty-equivalent approximation, the bank's Euler equation (7) implies $\mathcal{R}^L_{t+1}E_{t+1}\beta u'(d^B_{t+1})/u'(d^B_t) \cong 1+\Gamma_{L,t}+(1-\gamma)\phi_t^{'}$. Thus (using (6)), $\mathcal{R}^L_{t+1}/R^D_{t+1} \cong \{1+\Gamma_{L,t}+(1-\gamma)\phi_t^{'}\}/\{1-\Gamma_{D,t}+\phi_t^{'}\}$, and hence:

$$\mathcal{R}^L_{t+1}-R^D_{t+1} \cong \Gamma_{D,t}+\Gamma_{L,t}-\gamma\phi'(L_{t+1}(1-\gamma)-D_{t+1})>0\,. \tag{15}$$

Holding constant the marginal costs of deposits and loans $(\Gamma_{D,t},\Gamma_{L,t})$, a rise in excess bank capital $L_{t+1}(1-\gamma)-D_{t+1}$ *lowers* thus the (effective) loan/deposit interest rate spread $\mathcal{R}^L_{t+1}-R^D_{t+1}$ (recall that $\phi''>0$).

Up to a linear approximation, a date t shock to the expected (exogenous) loan default rate at t+1, $E_t\delta^L_{t+1}$, has no effect on the expected effective loan rate $\mathcal{R}^L_{t+1}$ observed in equilibrium, and hence no effect on consumption, output, loans or deposits; such a shock only affects the contractual loan rate R^L_{t+1} (e.g. when the expected default rate rises by 1 percentage point, the contractual rises by approximately 1%). Only *unanticipated* changes in the default rate affect the real economy. An unanticipated increase in the date t default rate, $\delta_t - E_{t-1}\delta_t>0$ brings about a wealth transfer from the bank to the entrepreneur. As shown below, such a transfer can have a sizable effect on output, when the bank faces a capital requirement.

To provide intuition for this effect, I now analyze in greater detail the optimizing behavior of the bank. I do this for the special case where the bank has log utility $(\sigma=1)$. It is straightforward to show that, in that case, the bank's date t consumption equals a fraction $1-\beta$ of her beginning-of-period (net) wealth:

$$d^B_t=(1-\beta)\{L_tR^L_t(1-\delta^L_t)-D_tR^D_t\}\,; \tag{16}$$

hence, (from the budget constraint (5)), end-of-period wealth plus costs equal a fraction β of beginning-of period wealth:

$$L_{t+1}-D_{t+1}+\Gamma(D_{t+1},L_{t+1})+\phi(L_{t+1}(1-\gamma)-D_{t+1})=\beta\{L_tR_t^L(1-\delta_t^L)-D_tR_t^D\}.$$

Up to a linear approximation (around steady state loans and deposits), the left-hand side of this expression equals $L_{t+1}(1+\Gamma_L+(1-\gamma)\phi')-D_{t+1}(1-\Gamma_D+\phi')=L_{t+1}R_L-D_{t+1}R^D$. As $\beta R_L=1$ (from the entrepreneur's Euler equation (12)), we have

$$A_{t+1}\equiv L_{t+1}-D_{t+1}\beta R^D=\beta^2\{L_tR_t^L(1-\delta_t^L)-D_tR_t^D\},\qquad(17)$$

Shocks in period t only affect A_{t+1} and d_t^B to the extent that beginning-of period wealth is affected. Hence, A_{t+1} and d_t^B only respond to unanticipated credit losses, but not to unanticipated TFP shocks:

$$d_t^B-E_{t-1}d_t^B=-(1-\beta)L_tR_t^L(\delta_t^L-E_{t-1}\delta_t^L).$$

$$A_{t+1}-E_{t-1}A_{t+1}=-\beta^2L_tR_t^L(\delta_t^L-E_{t-1}\delta_t^L).$$

An unanticipated credit loss lower A_{t+1} and d_t^B. The reduction in the banker's end-or-period wealth (by a fraction β of the credit loss) is much larger that the reduction in consumption (fraction $1-\beta$ of the loss). To understand why this matters for real activity, recall that the loan/ deposit interest rate spread is a decreasing function of excess bank capital $x_t\equiv L_{t+1}(1-\gamma)-D_{t+1}$. Note that

$$x_t=(1-\gamma)A_{t+1}+(\beta R^D(1-\gamma)-1)D_{t+1}\approx(1-\gamma)A_{t+1}-\gamma D_{t+1}.$$

The simulations below set $\gamma=0.1$ and show that A_{t+1} and x_t are highly positively correlated in response to credit loss shocks. As an *unanticipated* credit loss at date t lowers the bank's end-of-period wealth, A_{t+1}, it triggers a fall in excess bank capital x_t, which raises the loan/deposit interest rate spread (this result is robust to assuming risk aversion different from unity). As pointed out above, the financial friction thus becomes more severe when an unanticipated credit loss occurs.

An *unanticipated* TFP shock raises the household's wage income and thus increases her holdings of deposits. On impact, the shock has no effect on the banker's end-of-period wealth, and thus the increase in deposits lowers the bank's excess capital, thus triggering a rise in the loan/deposit interest rate spread, which explains why (as shown below), the presence of the bank dampens the effect of the TFP shock on real activity.

4. Calibration

I consider a baseline calibration with log utility, $\sigma=1$. The elasticity of output with respect to capital is set at $\alpha=0.3$. One period represents 1 quarter in calendar time. Accordingly, I set the depreciation rate of physical capital at $\delta=0.025$ (a standard value used in quarterly models). I set steady state TFP as $\theta=1$.

I set the required bank capital ratio at $\gamma=10\%$ (Basel II requirement: 8%). The calibration assumes that the deposit rate and the effective loan rate (net of default) are 2% and 4% per annum. The annual loan default rate is set at 3%, so that the loan rate is 7.12% per annum. (The steady state default rate does not affect real activity.) On a quarterly basis, the steady state interest rates are thus: $r^d=0.496\%$, $r^L=0.985\%$ and $r^L=1.757\%$, respectively (where $r^d=R^d-1$, $r^L=R^L-1$, $r^L=R^L-1$).

I thus set the subjective discount factor at $\beta=0.99024$ (as $\beta R^L=1$). The bank's Euler equations (6),(7) imply $R^D\beta=1-\Gamma_D+\phi'$ and $R^L\beta=1+\Gamma_L+(1-\gamma)\phi'$; any combination of marginal costs Γ_D,Γ_L,ϕ' consistent with these conditions generates the same first-order dynamics. I assume that the marginal costs Γ_t^D,Γ_t^L are constant across time (and equal to steady state values Γ^D,Γ^L).

I assume that, in steady state, the bank's excess capital is zero, and that the entrepreneur's debt represents 20% of the physical capital stock (or 43% of annual GDP). [Cite empirical evidence.] The preference parameters Ψ^D,Ψ^N are set in a manner that delivers $L(1-\gamma)=D$ and $L/K=0.2$. [1] That calibration implies that, in steady state, the

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[1] Namely, I set $\Psi^D=0.0106$ and $\Psi^N=2.469/Y^{GDP}$. Ψ^N depends on steady state GDP (Y^{GDP}). For a given value of Ψ^N the model has a unique steady state. Ψ^N affects the scale of hours worked, output, consumption, capital, investment, deposits and loans. The ratios between these variables and interest rates are not affected by Ψ^N. Hence, the choice of Ψ^N (or equivalently the choice of steady state GDP) does not affect the cyclical properties of interest rates, deposits, loans and real activity. Date t GDP equals the sum of the three agent's consumption plus gross investment. GDP corresponds also to final good output minus the bank's cost $\Gamma_t+\phi_t$.

consumptions of the banker and of the entrepreneur represent 0.17% and 6.83% of GDP, respectively, and that deposits represent 54% of annual household consumption.

The simulations below are based on a linearization of the model around a deterministic steady state. I thus have to pick a value for the second derivative of the cost of excess bank capital (evaluated at the steady state). The baseline calibration assumes $\phi''(0)=2/Y^{GDP}$. This implies that a reduction in excess bank capital by 1% of quarterly steady state GDP (Y^{GDP}) raises the (quarterly) loan/deposit interest rate spread by 20 basis points ($=\gamma\cdot 2\cdot 0.01=0.002$), as can be seen from (15). Equivalently, a rise in excess bank capital by 1% of annual GDP raises the interest rate spread by 3.2% per annum ($=0.002\cdot 16$).

I assume that TFP follows an AR(1) process: $\ln\theta_t=\rho_\theta\ln\theta_{t-1}+\varepsilon_{\theta,t}$, where $\varepsilon_{\theta,t}$ is white noise. As is common in the RBC literature (eg King and Rebelo (1999)), I set $\rho_\theta=0.95$, $E(\varepsilon_{\theta,t})^2=(0.007)^2$. The default rate likewise follows an AR(1) process: $\delta_t^L=(1-\rho_\delta)\delta^L+\rho_\delta\delta_{t-1}^L+\varepsilon_{\delta,t}$. I assume $\rho_\delta=0.95$, $E_t(\varepsilon_{\delta,t})^2=(0.01)^2$. As pointed out above, only unanticipated shocks to the default rate matter for real activity. Hence, the variance of real activity induced by credit losses only depends on $E_t(\varepsilon_{\delta,t})^2$ (the persistence of default only matters for the behavior of the contractual loan rate R_t^L, but it is irrelevant for the behavior of the expected effective loan rate $R_{t+1}^L=R_{t+1}^L E_t(1-\delta_{t+1})$ and for real activity).

5. Quantitative results

5.1. Impulse responses

Table 1 reports dynamic % responses to 1% TFP and credit default innovations (the responses of excess bank reserves (*x*) and of deposits and loans are normalized by steady state GDP; the responses of the wage rate, consumption, dividends, investment, hours and GDP are normalized by steady state values; interest rate responses are expressed in % per annum terms).

Results for the baseline model

Panel (a) of the Table shows responses under the baseline calibration. As in standard neoclassical models, a positive TFP shock raises output, consumption, investment and employment. As TFP decays gradually after the shock, the household saves more, by holding more deposits, and the bank makes more loans. The simulations confirm the analytical result (see above) that, on impact, a positive TFP shock lowers the bank's excess capital (x). In fact, the simulation shows that the fall in excess bank capital is persistent. Hence, the loans/deposit interest rate spread rises persistently. On impact, a 1% TFP shock raises the loan rate by 19 basis points (bp), while the deposit rate increases by 14 bp.

Panel (b) shows that a 1% positive innovation to the loan default rate has a sizable, but transient, effect on GDP. On impact GDP falls by 1.30%; GDP 4 quarters after the shock rises by 0.10%. Within the first year, annual GDP falls by 0.68%. A 1% credit loss corresponds to 0.43% of annual GDP. But the effect on GDP is not very persistent: in the second year, annual GDP falls by merely 0.02% (and there after GDP is slightly above its level without the shock). According to the IMF's April 2010 Global Financial Stability Report, credit losses of US banks during the current financial crisis amount to 6% of US GDP, while credit losses of Euro Area banks amount to 5.3% of EA GDP. The model here predicts that a credit loss of this size generates a fall in annual GDP of about 5%, in the first year.

On impact, the supply of loans fall sharply in response to the shock, by 3.05% of steady state (quarterly) GDP, which explains the sizable reduction in physical investment that drives the fall in GDP. Deposits fall noticeably less, by -1.31% of steady state GDP. As a result, the bank's excess capital falls (-1.43% of GDP). Interestingly, the expected effective loan rate falls in response to the credit loss, -8% bp p.a., but the deposit rate falls more strongly, -128 bp. The loan/interest rate spread increases thus by 120 bp. (The loan rate that is not corrected for expected default rises by 281 bp).

An economy without bank capital requirement

Panel (b) of Table 1 reports impulse responses for a model variant in which the bank does not face a capital requirement. Specifically, I now assume that the cost function of excess bank capital x is linear in x (i.e. $\phi''=0$), which implies that the loan/deposit interest rate spread is independent of the stocks of deposits and loans.

Under this specification, an unanticipated credit loss triggers a permanent (constant) rise in the entrepreneur's consumption and a permanent fall in the bank's dividend. The bank cuts lending, in order to dampen the effect of the default shock on her consumption. The credit loss now has **no** first-order effect on GDP, investment, household consumption, deposit and interest rates.

The responses to TFP shocks are qualitatively similar to those in the baseline structure. However, the short run responses of deposits, loans, investment and output are somewhat stronger. For example, GPD rises by 1.87% on impact (compared to 1.63% in the baseline model). Intuitively, this is due to the fact that the interest rate spread is constant under the alternative specification (in the baseline model, a positive TFP shock raises the interest rate spread, which dampens the increase in real activity).

An economy without bank

Panel (c) of Table 1 considers a model variant in which there is no bank. The household now lends directly to the entrepreneur. (In that model variant, I set the weight of deposits in the household's utility function to zero, $\Psi^D=0$, as otherwise no steady state exists, given the assumption that the household and the entrepreneur have the same subjective discount factor.)

In the 'No Bank' case, the effects of a TFP on real activity are noticeably stronger, in the short run, compared to the baseline structure (e.g. GDP now rises by 2.03% in response to a 1% TFP shock).

A 1% credit loss shock has a very small positive effect on GDP (+0.02%), which is due to the fact that the shock lowers the household consumption, which lowers the wage rate (see the household's first-order condition (4)), and raises labor demand.

5.2. Stochastic simulations

Table 2 reports predicted moments generated by the model (standard deviations of HP filtered variables, and their correlation with GDP). The predicted moments confirm the analysis above: the presence of a bank with a capital constraint dampens the fluctuations of real activity under TFP shocks, but it generates wider fluctuations in real activity in response to default shocks. The predicted standard deviation of GDP [investment] under simultaneous TFP and default shocks is 2.03% [9.67%] under the baseline calibration, compared to 1.69% [5.91%] in the model variant in which there is no binding bank capital constraint $(\phi"=0)$. This suggests that the bank capital requirement has a non-negligible effect on business cycle behavior.

Meh and Moran (2010) provide empirical evidence on empirical behavior of the ratio of bank capital divided by bank assets, in the US. At a quarterly frequency (1990-2005), that ratio has a relative standard deviation of 0.43 (compared to the standard of GDP); its correlation with GDP and bank loans are -0.23 and -0.70, respectively. (All statistics discussed here and below are based on HP filtered series.) In other terms, US bank capital, normalized by assets, is counter-cyclical.

As reported by Roeger (2009), in US quarterly data (1973-2009) the credit spread is negatively correlated with GDP, -0.51. Deposits and bank loans to the private non-financial business sector are positively correlated with GDP (0.08, 0.45).

The baseline model here, with TFP and credit loss shocks, matches the volatility of the bank capital/bank asset ratio, but the model predicts that that ratio is pro-cylical (predicted standard deviation: 0.43; predicted correlation with GDP: 0.64). When there are just TFP shocks, the bank capital/assets ratio is not volatile enough, but countercyclical. The baseline model predicts a counter-cyclical credit spread (-0.55), and procyclical deposits (0.20) and loans (0.37).

	Baseline model			
	All shocks	**Just TFP shock**	**Just default shock**	**US DATA**
Bank capital/assets				
Relative standard dev.	0.43	0.04	0.62	0.34
Correl. with GDP	0.64	-0.89	0.99	-0.23
Correlations with GDP:				
Credit spread	-0.55	0.89	-0.80	-0.51
Deposits	0.20	0.38	0.14	0.45
Loans	0.37	0.34	0.44	0.08

6. Two-country version of the model

I now assume a world with two countries. Both countries produce and consume an identical final good that can costlessly be traded internationally. As before, I assume that each country is inhabited by a household and by an entrepreneur. There is one global bank (that receives deposits in both countries, and channels them to entrepreneurs in both countries). The bank acts competitively, and thus the deposit rate and the expected effective loan rates are identical across countries. [2] The only difference compared to the baseline model is that I now assume that the entrepreneur bears a quadratic investment adjustment cost. The adjustment cost is calibrated in such a fashion that the model generates a realistic relative volatility of investment--in the absence of an investment adjustment cost, investment is extremely volatile, when there are country-specific technology shocks. (A small adjustment cost is sufficient for that purpose.)

Table 3 reports impulse responses to 1% innovations to country 1 TFP and to the country 1 loan default rate. The country 1 TFP shock raises country 1 GDP and investment (by 1.31% and 3.53%, respectively, on impact), but has basically no effect on country 2 GDP and investment.

By contrast, the 1% country 1 default shock triggers falls in output and investment in *both* countries; the reductions are very similar across countries; e.g., on impact GDP and investment drop by about 0.36% and 1.99%, respectively, in both countries. A credit loss lowers the bank's excess capital, which raises the credit spread in both countries; deposits and the deposit rate fall, while consumption rises, in both countries. This is accompanied by a rise in the wage rate, and a fall in employment and output, in both countries. The effect on (world) GDP is weaker than in the closed economy. As mentioned above, a 1% country 1 credit loss corresponds to 0.43% of the country's annual GDP; this triggers a fall or domestic and foreign GDP by -0.19%, during the first year after the shock. Thus, a credit loss of about 5% of annual domestic GDP in one country (as observed in the US, during the current crisis), is predicted to trigger a reduction of annual GDP by 2.6%, in both countries, during the first year after

[2] All other preference and technology parameters are set at the same values as in the baseline closed economy model (the second derivative is set at $\phi''=2/(world\,GDP)$.

the shock. In the second year after the shock, annual world GDP stays below its pre-shock level by 0.31. Hence, the effect on GDP is non-negligible, but short-lived.

Table 4 reports selected predicted moments generated by the two-country model. In a model variant with just credit loss shocks, output and investment are (almost) perfectly correlated across countries. With just TFP shocks, the cross-country correlations of output and investment are close to zero. With simultaneous default rate and FTP shocks, the cross country output correlation are 0.23 and 0.49, respectively.

7. Conclusion

This paper has presented a DSGE model with a bank. An unanticipated credit loss was shown to generate a sizable, but relatively short-lived, recession. With a global bank, a loan default shock in one country triggers a fall in *both* domestic and foreign output.

Table 1. Closed economy model: % impulse responses (t periods after shock)

t	x	D	L	r^D	r^L	r^L	C	d^E	d^B	I	N	W	GDP
(a) BASELINE CALIBRATION WITH BANK													
1% TFP shock													
0	-0.06	0.62	0.62	0.14	0.19	0.19	0.73	0.07	0.00	5.10	0.89	0.73	1.63
1	-0.10	1.19	1.21	0.08	0.16	0.16	0.76	0.12	0.16	4.39	0.73	0.76	1.50
4	-0.11	2.38	2.52	0.01	0.10	0.10	0.80	0.22	0.84	3.04	0.45	0.80	1.24
8	-0.08	3.28	3.55	-0.02	0.04	0.04	0.77	0.30	1.63	1.99	0.24	0.77	1.01
40	0.02	2.63	2.94	-0.02	-0.03	-0.03	0.29	0.12	1.80	-0.18	-0.10	0.29	0.18
1% credit loss shock													
0	-1.43	-1.31	-3.05	-1.28	-0.08	3.81	0.55	0.19	-9.65	-7.81	-1.85	0.55	-1.30
1	-0.89	-2.53	-3.80	-0.77	-0.02	3.68	0.24	0.18	-7.09	-4.27	-1.00	0.24	-0.75
4	-0.24	-3.66	-4.33	-0.16	0.04	3.21	-0.10	0.18	-3.81	-0.18	-0.02	-0.10	-0.10
8	-0.07	-3.46	-3.93	-0.02	0.04	2.63	-0.14	0.22	-2.62	0.66	0.18	-0.14	0.05
40	-0.01	-1.45	-1.62	-0.01	-0.00	0.50	0.01	0.34	-1.00	0.20	0.06	0.01	0.07
(b) BANK WITHOUT BINDING CAPITAL REQUIREMENT $(\phi'' = 0)$													
1% TFP shock													
0	-0.10	0.87	0.86	0.22	0.22	0.22	0.62	0.08	0.00	6.56	1.24	0.62	1.87
1	-0.17	1.69	1.69	0.18	0.18	0.18	0.68	0.13	0.05	5.74	1.05	0.68	1.74
4	-0.33	3.48	3.49	0.10	0.10	0.10	0.78	0.25	0.17	3.78	0.61	0.78	1.40
8	-0.45	4.68	4.70	0.03	0.03	0.03	0.81	0.32	0.24	2.04	0.24	0.81	1.05
40	-0.24	2.31	2.30	-0.03	-0.03	-0.03	0.27	0.08	0.00	-0.32	-0.13	0.27	0.13
1% credit loss shock													
0	-1.57	0.00	-1.75	0.00	0.00	3.89	0.00	0.25	-9.65	0.00	0.00	0.00	0.00
1	-1.57	0.00	-1.75	0.00	0.00	3.70	0.00	0.25	-9.65	0.00	0.00	0.00	0.00
4	-1.57	0.00	-1.75	0.00	0.00	3.17	0.00	0.25	-9.65	0.00	0.00	0.00	0.00
8	-1.57	0.00	-1.75	0.00	0.00	2.58	0.00	0.25	-9.65	0.00	0.00	0.00	0.00
40	-1.57	0.00	-1.75	0.00	0.00	0.50	0.00	0.25	-9.65	0.00	0.00	0.00	0.00
(c) NO BANK (DIRECT HOUSEHOLD LENDING TO ENTREPRENEUR)													
1% TFP shock													
0	---	1.02	1.02	0.24	0.24	0.24	0.58	0.09	---	7.56	1.47	0.58	2.03
1	---	2.03	2.03	0.20	0.20	0.20	0.61	0.15	---	6.81	1.30	0.61	1.91
4	---	4.40	4.40	0.11	0.11	0.11	0.74	0.27	---	4.91	0.86	0.74	1.60
8	---	6.35	6.35	0.02	0.02	0.02	0.81	0.35	---	3.07	0.45	0.81	1.27
40	---	5.77	5.77	-0.06	-0.06	-0.06	0.37	-0.10	---	-0.35	-0.19	0.37	0.18
1% credit loss shock													
0	---	-1.72	-1.72	0.00	0.00	3.89	-0.01	0.25	---	0.07	0.03	-0.01	0.02
1	---	-1.71	-1.72	0.00	0.00	3.70	-0.01	0.25	---	0.06	0.03	-0.01	0.02
4	---	-1.69	-1.69	0.00	0.00	3.17	-0.01	0.25	---	0.06	0.03	-0.01	0.02
8	---	-1.67	-1.67	0.00	0.00	2.58	-0.01	0.25	---	0.05	0.03	-0.01	0.02
40	---	-1.62	-1.62	0.00	0.00	0.50	-0.00	0.26	---	0.02	0.02	-0.00	0.02

Notes: The Table shows % responses to 1% TFP and credit loss shocks (after t=0,1,4,8,40 quarters). Responses of excess bank capital (x), deposits (*D*) and loans (*L*) are normalized by steady state GDP (responses of deposits and loans pertain to end-of-period stocks). Responses of household consumption (C), entrepreneur's dividend (d^E), bank dividend (d^B), investment (*I*), hours worked (*N*), the wager rate (*W*) and *GDP* are normalized by steady state values. Deposit rate (r^D), expected effective loan rate net of default (r^L), and loan rate before default (r^L) are expressed in % per annum terms.

Table 2. Closed economy model: predicted moments (HP filtered)

	TFP & default shock		Just TFP shock		Just default shock	
	% Std.	**CorrY**	**% Std.**	**CorrY**	**% Std.**	**CorrY**
(a) BASELINE CALIBRATION WITH BANK						
x	1.54	0.64	0.11	-0.89	1.54	0.99
D	4.69	0.20	1.82	0.38	4.32	0.14
L	5.81	0.37	1.95	0.34	5.47	0.44
r^D	1.39	0.74	0.11	0.75	1.38	0.99
r^L	0.20	0.89	0.17	0.96	0.11	0.81
r^L	5.06	-0.46	0.17	0.96	5.05	-0.70
C	0.97	0.06	0.72	0.96	0.65	-0.95
d^E	0.27	-0.14	0.17	0.44	0.21	-0.63
d^B	10.52	0.64	0.98	-0.17	10.47	0.93
I	9.67	0.94	4.41	0.98	8.60	0.99
GDP	2.03	1.00	1.44	1.00	1.42	1.00
(b) BANK WITHOUT BINDING CAPITAL REQUIREMENT $(\phi'' = 0)$						
x	2.05	-0.05	0.27	-0.38	2.03	---
D	2.84	0.36	2.84	0.36	0.00	---
L	3.64	0.28	2.85	0.36	2.25	---
r^D	0.20	0.95	0.20	0.95	0.00	---
r^L	0.20	0.95	0.20	0.95	0.00	---
r^L	5.03	0.03	0.20	0.95	5.07	---
C	0.66	0.89	0.66	0.89	0.00	---
d^E	0.38	0.24	0.20	0.47	0.32	---
d^B	12.47	0.02	0.16	0.15	12.47	---
I	5.91	0.98	5.91	0.98	0.00	---
GDP	1.69	1.00	1.69	1.00	0.00	---
(c) NO BANK (DIRECT HOUSEHOLD LENDING TO ENTREPRENEUR)						
x	---	---	---	---	---	---
D	---	---	---	---	---	---
L	4.14	0.25	3.49	0.31	2.22	-1.00
r^D	---	---	---	---	---	---
r^L	0.22	0.94	0.22	0.94	0.00	0.97
r^L	5.08	0.05	0.22	0.94	5.08	0.97
C	0.60	0.88	0.60	0.88	0.01	-0.97
d^E	0.40	0.29	0.23	0.49	0.32	1.00
d^B	---	---	---	---	---	---
I	6.88	0.98	6.88	0.98	0.09	0.98
GDP	1.85	1.00	1.85	1.00	0.03	1.00

Notes: The Table shows predicted model statistics. % Std: standard deviation in %. CorrY: correlation with GDP. Statistics for bank capital (x), deposits (*D*) and loans (*L*) pertain to series that were normalized by steady state GDP (responses of deposits and loans pertain to end-of-period stocks). Statistics for household consumption (C), entrepreneur's dividend (d^E), bank dividend (d^B), investment (*I*), hours worked (*N*), the wager rate (*W*) and GDP pertain to series that were expressed as relative deviations from steady state values. Deposit rate (r^D), expected effective loan rate net of default (r^L), and loan rate before default (r^L) are expressed in % per annum terms. **% Std: standard deviation (in %); CorrY: correlation with GDP.**

Table 3. Two-country model: % impulse responses (t periods after shock)

t	*x*	r^D	r^L ‖	*D1*	*L1*	*C1*	*I1*	*GDP1* ‖	*D2*	*L2*	*C2*	*I2*	*GDP2*
(a) BASELINE CALIBRATION													
					1% shock to country 1 TFP								
0	-0.02	-0.02	-0.00	0.53	0.30	0.77	3.35	1.31	-0.18	0.05	0.08	-0.03	0.05
1	-0.03	-0.02	0.00	1.01	0.54	0.76	2.97	1.23	-0.37	0.10	0.07	0.03	0.06
4	-0.03	-0.03	-0.00	2.17	1.01	0.74	2.08	1.02	-0.87	0.35	0.06	0.20	0.09
					1% credit loss shock in country 1								
0	-0.75	-0.31	4.21	-0.34	-2.09	0.14	-1.99	-0.37	-0.35	-0.34	0.15	-1.99	-0.35
1	-0.48	-0.20	3.99	-0.67	-2.16	0.07	-1.19	-0.20	-0.67	-0.41	0.07	-1.19	-0.22
4	-0.13	-0.05	3.23	-1.04	-2.18	-0.02	-0.15	-0.04	-1.04	-0.43	-0.02	-0.15	-0.05

Note*: Di, Li, Ci, Ii, GDPi*: deposits, loans, household consumption, investment and GDP in country I (i=1,2)

Table 4. Two country model: predicted moments (HP filtered)

	TFP & default shock		**Just TFP shock**		**Just default shock**	
	% Std.	**Corr1&2**	**% Std.**	**Corr1&2**	**% Std.**	**Corr1&2**
(a) BASELINE CALIBRATION WITH BANK						
D	2.54	0.04	1.89	-0.72	1.69	1.00
L	3.12	0.38	1.01	0.10	2.95	0.41
I	4.38	0.49	3.04	-0.05	3.15	1.00
GDP	1.30	0.23	1.18	0.07	0.54	0.99

Note: %Std: standard deviation (in %), Corr1&2: cross-country correlation

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