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Banks and the Domestic and International Propagation of Macroeconomic and Financial Shocks

Zeno Enders, Robert Kollman and Gernot J. Müller

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Banks and the Domestic and International Propagation of Macroeconomic and Financial Shocks

Zeno Enders
University of Bonn

Robert Kollmann (*)
ECARES, Université Libre de Bruxelles and CEPR

Gernot Müller
University of Bonn and CEPR

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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 fall in both domestic and foreign output.

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(*) Corresponding author. ECARES, CP 114, Université Libre de Bruxelles; 50 Av. Franklin Roosevelt; B-1050 Brussels, Belgium. E-mail addresses:
zenders@uni-bonn.de, robert_kollmann@yahoo.com, gernot.mueller@uni-bonn.de

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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.

We 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. We show that the model can quantitatively account for the world-wide drop in real activity during the current financial crisis. The model also explains key facts about international business cycles during 'normal' times better than conventional multi-country macro models--in particular, it helps to explain the close correlation between US and European business cycles.

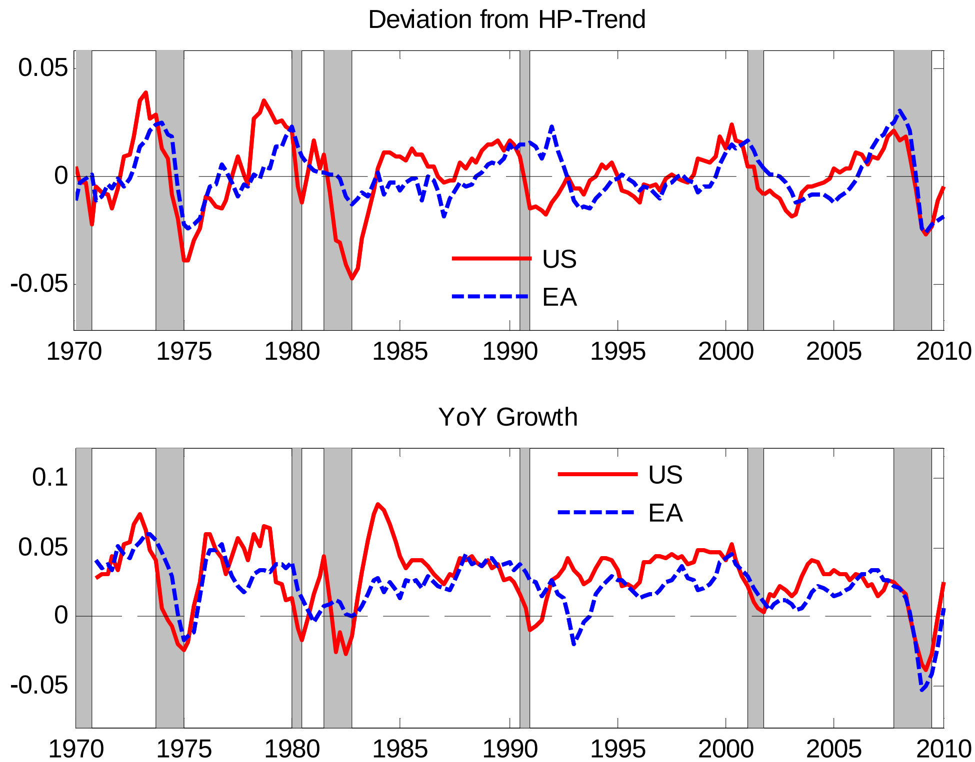
To be added: discussion of related literature. Goodfriend and McCallum (2007); Van den Heuvel (2008). Recent quantitative *closed economy* DSGE models with banks: de Walque, Pierrard and Rouabah (2010); Gerali, Neri, Sessa and Signoretti (2010); Roeger (2009). Value added of paper here: emphasis on transmission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

Section 2 discusses the data that motivate this paper. Section 3 develops a closed economy model to generate basic intuition on the effects of credit losses and TFP shocks, in the presence of banks. Section 4 analyzes the international transmission of shocks, in a two-country model with a global bank. Section 5 concludes.

2. Properties of the data

In this section we highlight some features of the data suggesting that financial factors may play an important role for the (international) transmission of business cycle fluctuations. We focus on data for the US and euro area (EA). To start with, we display in figure 1 the cyclical component of output in both currency areas obtained by applying an HP-filter with a smoothing parameter of 1600 (top panel) and by computing year-on-year growth rates (bottom panel). Our sample covers the period 1970q1—2010q1.

Figure 1

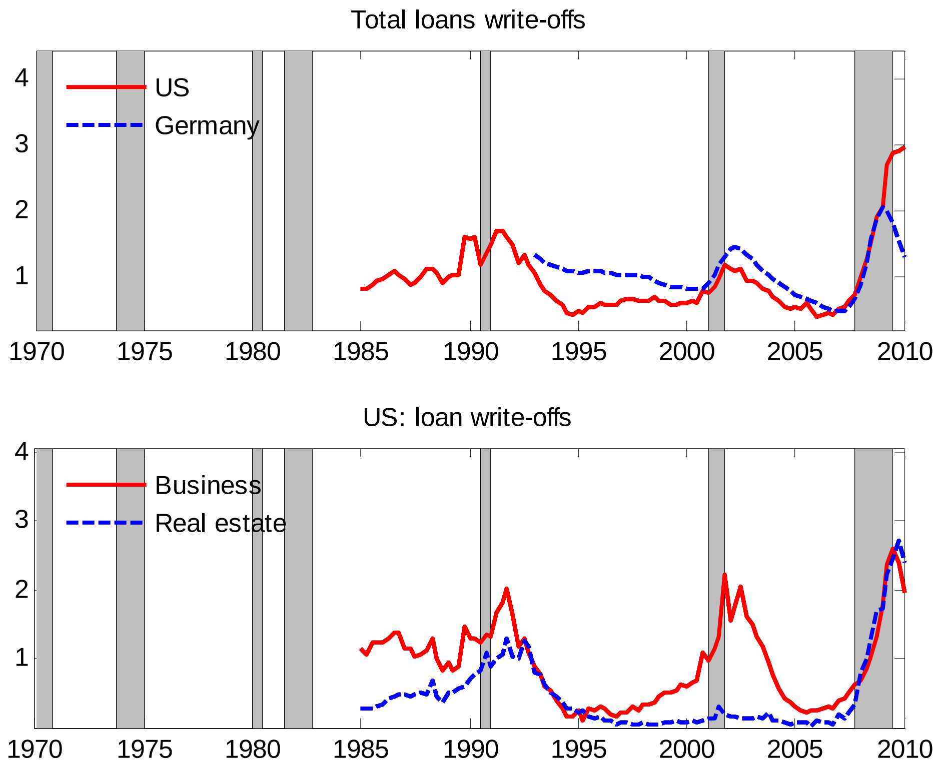


In each instance, the solid (dashed) line shows data for the US (EA) and the shaded areas indicate NBER recessions.

Casual inspection of the graphs suggests that the US cycle tends to lead the European cycle by a few quarters, with the exception the recession triggered by the global financial crisis, which the NBER business cycle committee dates to have started in 2007q4 (and which we assume has come to an end by 2009q3 in line with the St. Louis Fed). Regarding this recession, it seems noteworthy that it appears to be less deep and protracted than earlier recessions in the US if the cyclical component is isolated through the HP-filter. This however is likely to be the result of an end-of-sample problem, as the growth rates in the bottom panel illustrate. Also, in the EA, the latest recession clearly outperforms earlier episodes in size and length. Yet it seems that the output implications of the latest recession are not on an altogether different scale relative to earlier episodes.

There is nevertheless a widespread perception that there is something special about this latest episode, notably the extent to which financial factors played a crucial role in triggering and propagating the economic downturn.

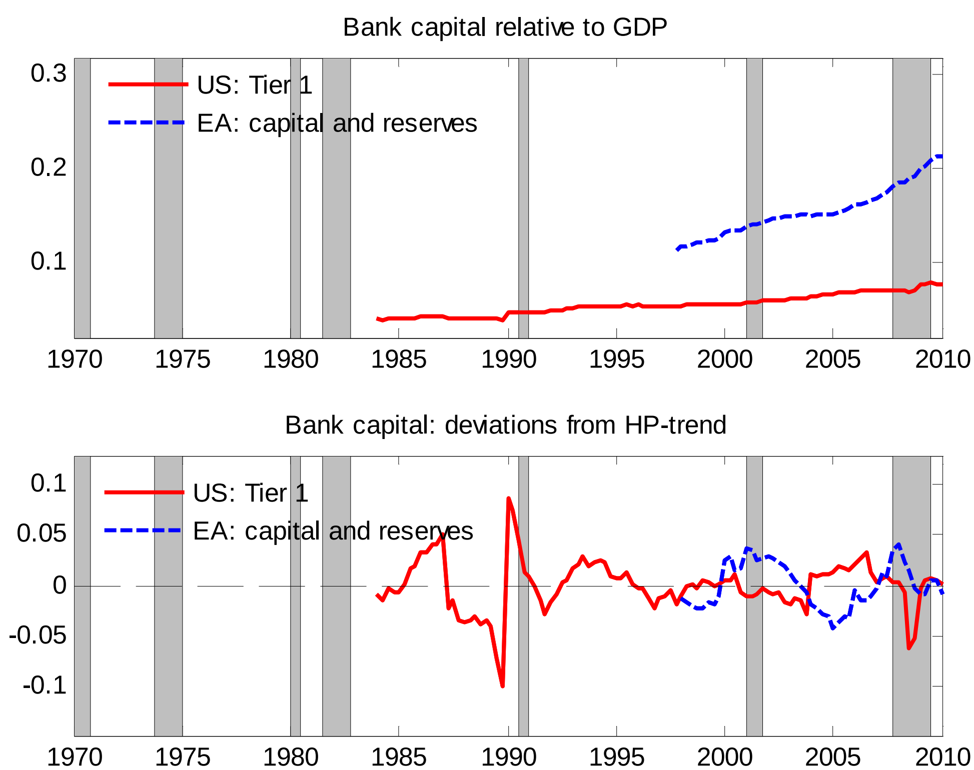
Figure 2



We therefore plot, in the top panel of figure 2, the write-off rates on loans in the US and Germany (as aggregated data for the EA is not available), measured in percent of the total amount of outstanding loans (annualized). For the US, the data is obtained from the Federal Reserve Board (charge-off and delinquency rates on loans and leases at all insured U.S.-chartered commercial banks, representing the value of loans removed from the books and charged against loss reserves, measured net of recoveries). For Germany the data are obtained from the Global Financial Stability Report (IMF, April 2010) at an annual frequency and interpolated to obtain quarterly observations. These time series illustrate that loan write-offs---in line with widely held notions on the origins of the global financial crisis---have indeed reached unprecedented levels during the 2007—2009 period. In the bottom panel, we provide a more disaggregated perspective for the US, displaying charge-off rates for business loans and loans secured by real estate.

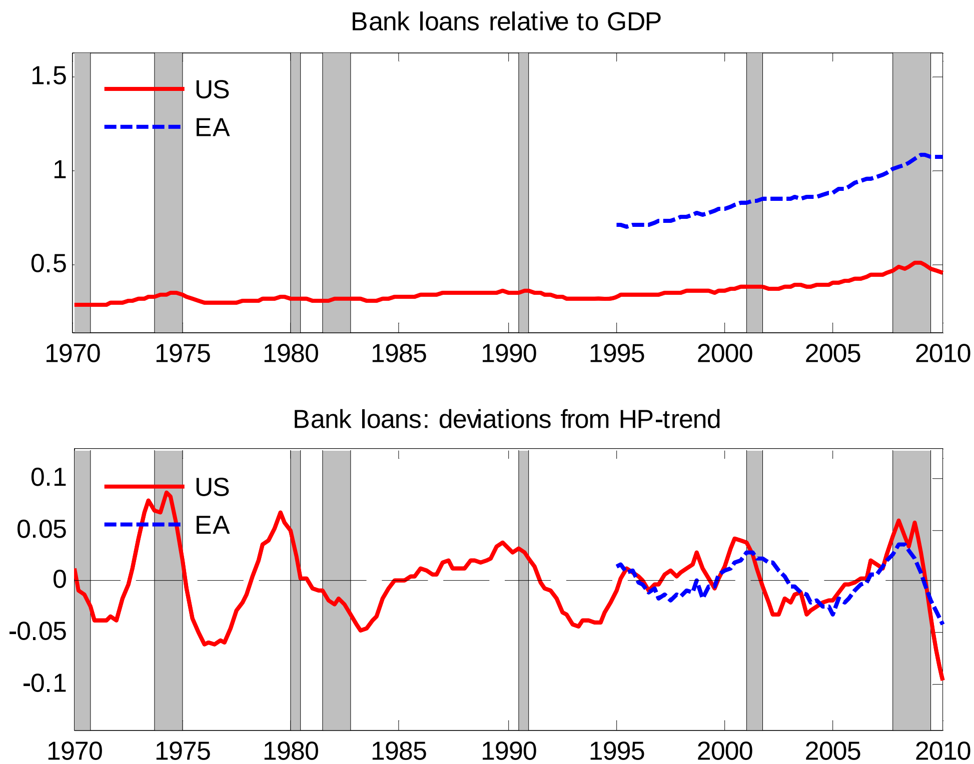
These developments have left their mark on banks' balance sheets. To illustrate this point we display, in figure 3, bank capital as a fraction of GDP (top panel) and the deviation of the log of bank capital (in real terms) from an HP-trend (source US: FDIC, Tier 1 leverage capital; source EA: ECB, MFIs excluding Eurosystem: capital and reserves). For the US we find a sizable decline in bank capital relative to trend during the latest recession. Also in the EA, bank capital declined strongly after 2008q1. It seems noteworthy, however, that the late 1980s also saw sharp swing s in US bank capital (likely a result of the S&L crisis).

Figure 3



It is also instructive to investigate the behavior of bank loans, which we display in figure 4. Data for US (EA) loans and leases in bank credit (loans of MFIs to non-financial corporations and households) are obtained from the Federal Reserve Board (ECB) and plotted, as a fraction of annual GDP in the top panel of figure 4. In the bottom panel we display the percentage deviations from an HP-trend of the corresponding series measured in real terms.

Figure 4

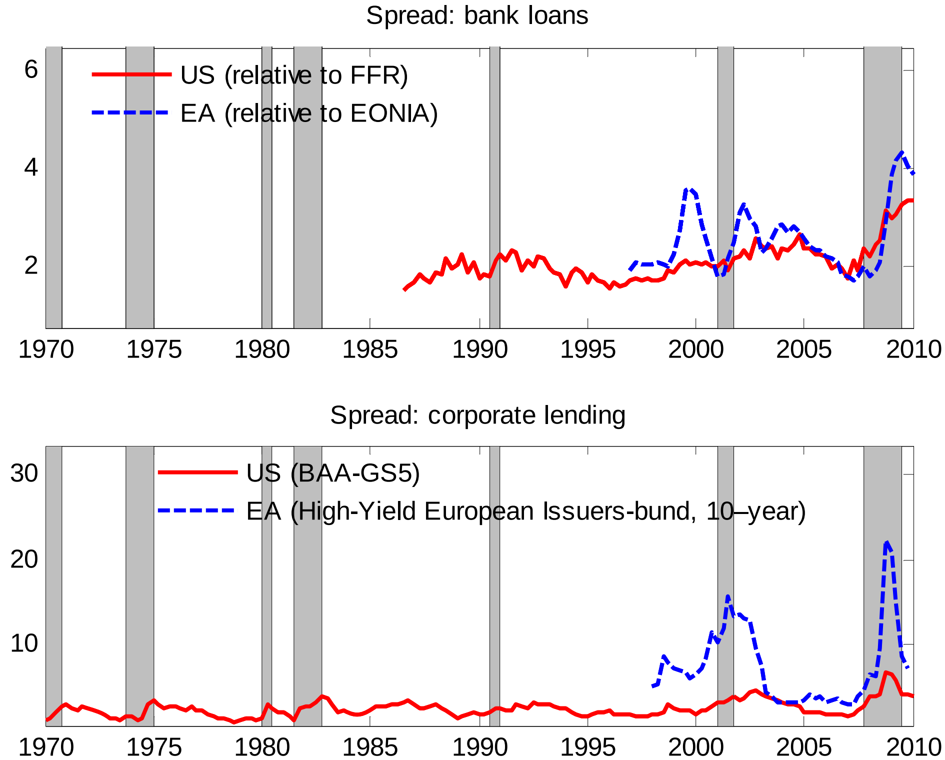


We find a sizeable decline in bank loans. In particular for the US, one observes a drop relative to trend which exceeds those observed during earlier episodes. It is also noteworthy however that bank loans appear to lag output somewhat over the cycle.

We finally turn to interest rate spreads, some of which are well-known to have risen sharply during the 2007—09 crisis. As our particular focus is on the role of banks, we display, in the top panel of figure 5, the spread between the loan rate and the money market rate (we view these spreads as proxies for the spread between bank's lending rates and deposit rates; consistent time series deposit rates do not seem to be available for the US). [1]

[1] US: Commercial and Industrial Loan Rates Spreads over intended federal funds rate; source: Survey of terms of business lending, Federal Reserve Board; EA: rate on loans over 1 and up to 5 years, up to and including EUR 1 million, from July 2003, series backdated with corresponding data from Bundesbank relative to EONIA.

Figure 5



In the bottom panel of figure 5 we also display spreads for corporate lending, which appear to have peaked earlier than the spread which characterizing bank lending.

Below we will conduct quantitative experiments within a business cycle framework to explore the international transmission of shocks. With respect to the 2007-2009 recession, our interest centers on the fact that this crisis is characterized strong *simultaneous* reduction in US and EA output, whereas typically US recessions leads EA recessions (Giannone, Lenza and Reichlin (2010)). We will argue that this distinguishing feature of the 2007-09 recession reflects the globalization of the banking sector.

We will also assess to what extent the predictions of the model match key cyclical features of the data as summarized in tables 1 and 2. Table 1 reports standard deviations for output, consumption, investment, deposits, loans and the spread characterizing bank lending, both for the US and the EA. Except for output, all standard deviations are normalized by the standard deviation of output. Table 2 reports the correlation of various variables with output within each currency area, as well as the correlation of variables across currency areas. We find that investment and consumption are highly procyclical and sizable cross-country correlations. Interestingly, we find the highest cross-country correlation for consumption. Similarly, deposits, loans and spreads are positively correlated across countries as well.

Table 1: Standard deviations

	US (1973–2010)	US (1995–2010)	EA (1995–2010)
Output (Y)	1.55	1.12	1.25
Consumption (C)	0.81	0.82	0.59
Investment (I)	4.87	4.18	2.50
Deposits (D)	0.93	0.68	1.37
Loans (L)	1.94	2.43	1.44
Spread	0.34	0.37	0.51

Notes: statistics are computed for time series after applying HP-filter (except for spread); baseline sample: 1995Q1–2010Q1, except for statistics involving deposits in EA (sample starts in 1997Q4 only); long sample for US starts in 1973Q1 (except for spread measures: starting data is 1987). US-investment includes residential investment and changes in inventories in the long sample.

Table 2: Correlations

	$\rho(X_{US,long}, Y_{US,long})$	$\rho(X_{US}, Y_{US})$	$\rho(X_{EA}, Y_{EA})$	$\rho(X_{US}, X_{EA})$
Y	1.00	1.00	1.00	0.76
C	0.86	0.85	0.87	0.85
I	0.92	0.94	0.94	0.79
D	0.37	-0.28	0.20	0.32
L	0.50	0.51	0.78	0.72
Spread	-0.27	-0.35	-0.62	0.71

Notes: statistics are computed for time series after applying HP-filter (except for spread); baseline sample: 1995Q1–2010Q1, except for statistics involving deposits in EA (sample starts in 1997Q4 only); long sample for US starts in 1973Q1.

3. 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.

3.1. Agents and Markets

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:

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

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:

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

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

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).

We 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:

$$L_{t+1} + D_t R_t^D + \Gamma(D_{t+1}, L_{t+1}) + \phi(L_{t+1}(1-\gamma) - D_{t+1}) + d_t^B = L_t R_t^L (1-\delta_t^L) + D_{t+1}, \qquad (5)$$

where d_t^E is the profit (dividend) generated by the bank at t. R_t^L is the gross loan interest rate between t-1 and t. $0 \le \delta_t^L \le 1$ 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:

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

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

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:

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

where K_t is the capital stock used in production at t; $0\le\delta\le1$ 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:

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

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

The entrepreneur's period t budget constraint is:

$$L_tR_t^L(1-\delta_t^L)+K_{t+1}+W_tN_t+d_t^E=L_{t+1}+\theta_t(K_t)^\alpha(N_t)^{1-\alpha}+(1-\delta)K_t, \qquad (10)$$

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:

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

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

$$W_t=(1-\alpha)\theta_tK_t^\alpha N_t^{-\alpha}. \qquad (13)$$

Market clearing

Market clearing for the final good requires:

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

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 $\widetilde{R^L_{t+1}} \equiv R^L_{t+1} E_{t+1}(1-\delta^L_{t+1})$ 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 $\widetilde{R^L_{t+1}} E_{t+1} \beta u'(d^B_{t+1})/u'(d^B_t) \cong 1 + \Gamma_{L,t} + (1-\gamma)\phi_t'$. Thus (using (6)), $\widetilde{R^L_{t+1}}/R^D_{t+1} \cong \{1+\Gamma_{L,t} + (1-\gamma)\phi_t'\}/\{1-\Gamma_{D,t} + \phi_t'\}$, and hence:

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

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 $\widetilde{R^L_{t+1}} - R^D_{t+1}$ (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 $\widetilde{R^L_{t+1}}$ observed in equilibrium, and hence no effect on consumption, output, loans or deposits; such a shock only affects the contractual loan rate R_{t+1}^{L} (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, we now analyze in greater detail the optimizing behavior of the bank. We 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:

$$d_t^B = (1-\beta)\{L_t R_t^L (1-\delta_t^L) - D_t R_t^D\}\,; \tag{16}$$

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

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

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

$$A_{t+1} \equiv L_{t+1} - D_{t+1}\beta R^D = \beta^2\{L_t R_t^L (1-\delta_t^L) - D_t R_t^D\}, \tag{17}$$

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:

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

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

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

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

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.

3.2. Calibration

We assume 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, we set the depreciation rate of physical capital at $\delta=0.025$ (a standard value used in quarterly models). We normalize steady state TFP as $\theta=1$.

The required bank capital ratio is set at $\gamma=8\%$ (as under Basel II). The calibration assumes that the deposit rate and the expected effective loan rate (net of default) are 1% and 4% per annum, consistent with an average loan/deposit rate spread of about 3% p.a. seen in the US and the Euro Area (EA). The annual loan default rate is set at 0.95%, so that the observed loan rate is 4.99% per annum. (The steady state default rate does not affect real activity.) On a quarterly basis, the steady state interest rates are thus: $r^d=0.249\%$, $\widetilde{r^L}=0.985\%$ and $r^L=0.987\%$, respectively (where $r^d=R^d-1$, $\widetilde{r^L}=\widetilde{R^L}-1$, $r^L=R^L-1$).

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

We set the steady state excess bank capital at zero, and assume that loans (to the entrepreneur) represents 1/3 of the physical capital stock, i.e. $L/K=1/3.$. This entails that the ratio of loans to annual GDP is 73% in steady state (the mean ratio of bank loans to non-financial businesses divided by annual GDP is about 45% in the US, and 90% in the EA; the value used in the calibration lies between these empirical values).[2] The preference parameters Ψ^D, Ψ^N are set in a manner that delivers $L(1-\gamma)=D$ and $L/K=1/3.$[3] The calibration implies that, in steady state, the consumptions of the banker and of the entrepreneur represent 0.18% and 6.86% of GDP, respectively, and that deposits represent 55% of annual household consumption.

The simulations below are based on a linearization of the model around a deterministic steady state. We 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 16 basis points ($= \gamma \cdot 2 \cdot 0.01 = 0.0016$), as can be seen from (15). Equivalently, a fall in excess bank capital by 1% of annual GDP raises the interest rate spread by 2.56% per annum $(= 0.0016 \cdot 16)$.

2 In the model, fate 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 $\Gamma_t+\phi_t$.

3 Namely, I set $\Psi^D=0.0160$ and $\Psi^N=2.473/Y^{GDP}$. Note that the calibrated Ψ^N (that delivers the targeted ratio of loans to capital) 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.

We assume that TFP and the credit loss rate follow univariate AR(1) processes: $\ln\theta_t = \rho_\theta \ln\theta_{t-1} + \varepsilon_{\theta,t}$ and $\delta_t^L = (1-\rho_\delta)\delta^L + \rho_\delta \delta_{t-1}^L + \varepsilon_{\delta,t}$, where $\varepsilon_{\theta,t}$ and $\varepsilon_{\delta,t}$ are correlated white noises. We fit those processes to TFP and credit loss series for the US and the EA (sample period 1993Q1-2010Q1; this is the longest period for which we could find credit losses are available for the US and the EA; see Section 2). The autocorrelation of linearly detrended US and EA log TFP is 0.95. We thus set $\rho_\theta = 0.95$. The standard deviation of linearly detrended US [EA] log TFP is 1.73% [1.67%]. To match that unconditional standard deviation, we set $E(\varepsilon_{\theta,t})^2 = (0.0053)^2$. (These or very similar parameters of the law of motion of TFP are widely used in the RBC literature; see e.g. King and Rebelo (1999).)

The autocorrelations of credit loss rates are 0.98 (US) and 0.96 (EA). The standard deviations of these rates are 0.14% (US) and 0.085% (EA). We set $\rho_\delta = 0.97$ and $E(\varepsilon_{\delta,t})^2 = (0.000282)^2$. That calibration implies an unconditional standard deviation of the default rate (in the model) of 0.116%, which is half-way between the empirical standard deviations of US and EA default rates. Empirically, TFP and the loan default rate are negatively correlated (about -0.6 in US, and in EA). We thus set the correlation between the innovations $\varepsilon_{\theta,t}$ and $\varepsilon_{\delta,t}$ at -0.6.

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 $\widetilde{R_{t+1}^L} = R_{t+1}^L E_t(1-\delta_{t+1})$ and for real activity).

3.3. Quantitative results

3.3.1. 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 quarterly GDP; the responses of total consumption, investment 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 20 basis points (bp), while the deposit rate increases by 16 bp.

Panel (a) also shows that (in the baseline model) a 1 percentage point positive innovation to the loan default rate has a sizable, but transient, effect on GDP. On impact GDP falls by 1.53%; GDP 4 quarters after the shock rises by 0.05%. Within the first year, annual GDP falls by 0.63%.; in the second year, annual GDP *rises* by 0.10%. The expected effective loan rate $(\widetilde{r^L})$ falls in response to the credit loss, -6% bp p.a., but the deposit rate falls more strongly, -184 bp. The loan/interest rate spread increases thus by 190 bp. (The loan rate that is not corrected for expected default, r^L, rises by 387 bp).

A 1% credit loss corresponds to 0.74% of annual GDP. 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 6%-7%, in the first year, which is broadly consistent with the actual fall in US and EA GDP during the crisis.

Note also that, in the baseline model, the 1 percentage point innovation to the loan default rate lowers bank equity by 2.92% of steady state (quarterly) GDP, in the period of the shock (loans fall by 4.47% of GDP, while deposits fall by 1.55% of GDP). In steady state, bank equity represents 23.4% of steady state GDP. Hence, bank equity falls by 12.48% (=-2.92/23.4). The Dow Jones index of banking stocks fell by about 60%

during the year 2007 (Federal Reserve Bulletin, May 2010, p.A3). The benchmark model predicts that a 60% fall in bank equity (triggered by credit losses) induces a 7.35% fall in GDP.

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, we 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 only a negligible effect on GDP (+0.01%), investment and aggregate consumption. Without a bank capital constraint, shocks to bank capital cannot rationalize the severity of the 2007-2009 recession.

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, GDP rises by 1.95% on impact (compared to 1.78% 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, we set the weight of deposits in the household's utility function to zero, $\Psi^D=0$, as otherwise no steady state exists, given our 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 2.04% in response to a 1% TFP shock). But now a 1% credit loss shock has a very small (positive) effect on GDP (+0.04%). [4]

3.3.2. Does bank capital matters for business cycles in 'normal' times?

The preceding results suggest that bank capital shocks may be key to understanding the 2007-2009 recession. However, we argue next that bank capital does not matter greatly for conventional business cycle statistics. Table 2 shows the results of stochastic simulations based on the estimated time series processes for TFP and the credit loss rate, during the period 1993-2010. Note that the estimated standard deviation of the innovations to the quarterly credit loss rate is 0.028%, which is much smaller than the huge credit loss rates observed during the 2007-2009 recession.

Table 2 reports predicted moments generated by the model (standard deviations of HP filtered variables, and their correlation with GDP). In line with the impulse responses discussed above, we find that the presence of a bank with a capital constraint dampens the fluctuations of real activity under TFP shocks, and that it generates wider fluctuations in real activity in response to default shocks. However, in terms of the 'business cycle statistics' reported in Table 2, this effect is small. E.g., the predicted standard deviation of GDP under simultaneous TFP and default shocks is 1.24% under the baseline calibration, compared to 1.33% in the model variant in which there is no binding bank capital constraint $(\phi''=0)$. Interestingly, both model variants correctly predict that deposits and loans are more volatile than GDP, and pro-cyclical. Both model variants capture the fact that the credit spread is negatively correlated with GDP (-0.44). This result is largely driven by the assumed negative correlation between TFP and the default rate.

4. A two-country world

We now assume a world with two countries, indexed i=1,2. Both countries produce and consume an identical final good that can costlessly be traded internationally. As before, we 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

[4] This *positive* effect 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 and employment).

entrepreneurs in both countries). The bank acts competitively, and thus the deposit rate and the expected effective loan rates are identical across countries. In terms of the specification of preferences and technologies, the only difference compared to the closed economy model is that we now assume that there are decreasing returns to producing the investment good. [5] Specifically, the production of I_t units of gross investment now requires $I_t\{1+.5\xi(I_t/I)^2\}$ final good units; the curvature parameter ξ is set at a value for which the model generates a realistic ratio between the standard deviations of investment and GDP (a small value of ξ is sufficient for that purpose); without this assumption, investment would be excessively volatile (due to the possibility of importing capital from the other country, in response to a country-specific technology improvement).

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 1.65% and 7.23%, respectively, on impact), and it lowers foreign GDP and investment (-0.047%, -2.42%). By contrast, the 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 0.6% and 3.5%, respectively, in both countries. A credit loss lowers the bank's excess capital, which raises the expected effective 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 0.74% 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 1.3%, in *both* countries, during the first year after the shock. In the second year after the shock, annual world GDP stays below its pre-shock level by 0.31. Hence, the

[5] 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 $\phi''=2/(world\ GDP)$.

effect on GDP is non-negligible, but short-lived. These results seem interesting, in view of the fact that, arguably, the 2007-2009 recession was triggered by an asymmetric financial shock (losses on US estate loans). Relative to US GDP, US credit losses (6%) were only slightly higher than EA losses (5.3%). In the model here, the effect on real activity hinges on credit losses relative to *bank capita*l. Yet, as discussed above, the ratio of bank loans to GDP is roughly twice as high in the EA than in the US. This suggests that, US credit losses, were 100% higher, in the relevant dimension, than EA credit losses [to be confirmed by further empirical analysis].

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 correlations are 0.23 and 0.49, respectively.

[To be completed]

5. 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	$\widetilde{r^L}$	r^L	$r^L - r^D$	C^{total}	I	GDP
(a) BASELINE CALIBRATION WITH BANK										
					1% TFP shock					
0	-0.06	0.76	0.76	0.16	0.20	0.20	0.04	0.63	5.90	1.78
1	-0.09	1.53	1.56	0.11	0.17	0.17	0.06	0.67	5.16	1.66
4	-0.09	3.17	3.35	0.04	0.10	0.10	0.06	0.74	3.62	1.37
8	-0.05	4.42	4.74	0.00	0.04	0.04	0.04	0.75	2.27	1.08
					1% credit loss shock					
0	-2.56	-1.55	-4.47	-1.84	-0.06	3.87	5.71	0.59	-9.14	-1.53
1	-1.31	-3.44	-5.17	-0.90	0.00	3.82	4.72	0.19	-3.84	-0.68
4	-0.20	-4.58	-5.20	-0.09	0.05	3.53	3.62	-0.11	0.64	0.05
8	-0.04	-4.00	-4.40	0.01	0.04	3.12	3.11	-0.10	0.99	0.14
(b) BANK WITHOUT BINDING CAPITAL REQUIREMENT $(\phi''=0)$										
					1% TFP shock					
0	-0.08	0.93	0.92	0.22	0.22	0.22	0.00	0.56	6.86	1.95
1	-0.15	1.88	1.88	0.18	0.18	0.18	0.00	0.62	6.02	1.81
4	-0.30	3.95	3.96	0.10	0.10	0.10	0.00	0.73	4.01	1.45
8	-0.40	5.37	5.39	0.03	0.03	0.03	0.00	0.78	2.20	1.09
					1% credit loss shock					
0	-2.69	-0.00	-2.93	-0.00	-0.00	3.93	3.93	0.00	-0.00	0.01
1	-2.69	-0.00	-2.93	-0.00	-0.00	3.81	3.81	0.00	-0.00	0.01
4	-2.69	-0.00	-2.93	-0.00	-0.00	3.48	3.48	0.00	-0.00	0.01
8	-2.69	-0.00	-2.93	-0.00	0.00	3.08	3.08	-0.00	-0.00	0.01
(c) NO BANK (DIRECT HOUSEHOLD LENDING TO ENTREPRENEUR)										
					1% TFP shock					
0	---	---	1.02	---	0.24	0.24	---	0.52	7.59	2.04
1	---	---	2.11	---	0.20	0.20	---	0.58	6.83	1.92
4	---	---	4.63	---	0.11	0.11	---	0.70	4.92	1.61
8	---	---	6.67	---	0.03	0.03	---	0.78	3.09	1.27
					1% credit loss shock					
0	---	---	-2.86	---	0.00	3.94	---	0.02	0.11	0.04
1	---	---	-2.84	---	0.00	3.82	---	0.02	0.10	0.04
4	---	---	-2.81	---	0.00	3.48	---	0.02	0.09	0.04
8	---	---	-2.77	---	0.00	3.08	---	0.03	0.07	0.04

Notes: The Table shows % responses to 1% TFP and credit loss shocks (after t=0,1,4,8 quarters). C^{total} is total consumption by the three agents (household, banker, entrepreneur). 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 C^{total}, investment (*I*) and *GDP* are normalized by steady state values. Deposit rate (r^D), expected effective loan rate net of default $(\widetilde{r^L})$, 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		Data	
	Std.	**CorrY**	**Std.**	**CorrY**	**Std.**	**CorrY**	**Std.**	**CorrY**
(a) BASELINE CALIBRATION WITH BANK								
GDP	1.24	1.00	1.21	1.00	0.05	1.00	1.40	1.00
Consumption	0.39	0.92	0.39	0.93	0.41	-0.97	0.70	0.86
Investment	3.31	0.98	3.26	0.98	6.01	0.99	3.68	0.93
Deposits	1.61	0.36	1.57	0.35	3.45	0.03	1.15	0.28
Loans	1.71	0.35	1.68	0.32	4.39	0.42	1.69	0.64
Credit spread	0.12	-0.42	0.04	0.94	3.99	-0.73	0.42	-0.44
(b) BANK WITHOUT BINDING CAPITAL REQUIREMENT $(\phi"=0)$								
GDP	1.33	1.00	1.33	1.00	0.00	1.00	1.40	1.00
Consumption	0.34	0.87	0.34	0.87	0.00	---	0.70	0.86
Investment	3.51	0.98	3.51	0.98	0.02	-0.94	3.68	0.93
Deposits	1.84	0.34	1.84	0.34	0.01	-0.36	1.15	0.28
Loans	1.88	0.36	1.85	0.34	287.29	-1.00	1.69	0.64
Credit spread	0.10	-0.61	0.00	0.95	389.24	0.99	0.42	-0.44
(c) NO BANK (DIRECT HOUSEHOLD LENDING TO ENTREPRENEUR)								
GDP	1.40	1.00	1.40	1.00	0.01	1.00	1.40	1.00
Consumption	0.30	0.87	0.30	0.87	0.53	0.97	0.70	0.86
Investment	3.71	0.98	3.71	0.98	2.78	0.98	3.68	0.93
Deposits	---	---	---	---	---	---	---	---
Loans	2.02	0.32	1.99	0.30	71.55	-1.00	1.69	0.64
Credit spread	---	---	---	---	---	---	---	---

Note.—The Columns labeled ‘Std.’: show % standard deviation of GDP, and relative standard deviations, for the remaining variables (i.e. standard deviations normalized by the standard deviation of GDP). GDP, consumption (all agents) and investment are expressed as relative deviations from steady state values; deposits and loans series are normalized by steady state GDP; the ‘credit spread’ is the difference between the loan rate (not net of expected default) and the deposit rate ($r^L - r^D$), expressed in % per annum terms. All statistics pertain to variables that have been HP filtered. Columns labeled ‘TFP & default shock’, ‘Just TFP shock’ and ‘Just default shock’ show model generated predicted statistics (with both shocks, and just one type of shock, respectively). The Columns labeled ‘Data’ show average empirical statistics for the US (1973-2010) and the EA (1995-2010).

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

t	*x*	r^D	|| r_1^L	*D1*	*L1*	*C1*	*I1*	*GDP1* ||	*D2*	*L2*	*C2*	*I2*	*GDP2*
					1% shock to country 1 TFP								
0	-0.03	0.03	0.05	0.63	1.10	0.70	7.23	1.65	-0.08	-0.51	0.01	-2.42	-0.05
1	-0.04	0.01	0.05	1.28	2.05	0.71	6.25	1.64	-0.13	-0.87	0.02	-1.94	-0.12
4	-0.04	-0.00	0.03	3.06	3.91	0.72	3.93	1.54	-0.67	-1.32	0.03	-0.69	-0.25
					1% credit loss shock in country 1								
0	-1.24	-0.78	4.19	-0.61	-3.52	0.24	-3.62	-0.60	-0.61	-0.61	0.20	-3.62	-0.61
1	-0.54	-0.33	3.94	-1.36	-3.56	0.08	-1.34	-0.23	-0.24	-0.65	0.04	-1.34	-0.24
4	-0.05	-0.02	3.51	-1.72	-3.43	-0.02	-0.19	0.01	-1.72	-0.52	-0.06	0.19	0.01

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

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

	Standard deviation	Correlation with domestic GDP	Cross-country correlation
(a) TFP & credit loss shocks			
GDP	1.14	1.00	0.73
Consumption	0.45	0.96	0.83
Investment	3.33	0.93	0.42
Deposits	1.43	0.31	0.48
Loans	1.70	0.43	0.24
Credit spread	0.10	-0.44	0.79
(b) Just TFP shocks			
GDP	1.12	1.00	0.73
Consumption	0.45	0.97	0.83
Investment	3.30	0.93	0.39
Deposits	1.41	0.29	0.45
Loans	1.69	0.40	0.21
Credit spread	0.04	0.89	1.00
(c) Just credit loss shocks			
GDP	0.03	1.00	1.00
Consumption	0.39	0.39	0.99
Investment	5.99	5.99	1.00
Deposits	3.33	3.33	1.00
Loans	4.65	4.65	0.88
Credit spread	5.52	5.52	0.84

Note.—Standard deviation: for GDP, the % standard deviation is shown; for other variables, relative standard deviations are reported (normalized by the standard deviation of GDP). All statistics pertain to variables that have been HP filtered (GDP, consumption and investment series are expressed as relative deviations from steady state values; deposits and loans series are normalized by steady state GDP).

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