Global Banks, Financial Shocks and International Business Cycles: Evidence from an Estimated Model

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This paper estimates a two-country model with a global bank, using US and Euro Area (EA) data. Empirically, a model version with a bank capital requirement outperforms a structure without such a constraint. A loan loss originating in one country triggers a global output reduction. Banking shocks matter more for EA macro variables than for US real activity. Banking shocks account for about 2%-5% of the unconditional variance of US GDP and for 3%-14% of the variance of EA GDP. During the 2007-09 recession, banking shocks accounted for about 15% of the fall in US and EA GDP, and for more than a third of the fall in EA investment and employment.

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1. INTRODUCTION
The recent financial crisis began in US financial markets in 2007 and was quickly and strongly transmitted to Europe and other parts of the world. The crisis revealed the fragility of major financial institutions, and led to the worst global recession since the Great Depression. These dramatic events require a rethinking of the role of financial intermediaries for real activity. Before the financial crisis, standard applied macro models abstracted from financial intermediaries (e.g., Christiano, Eichenbaum and Evans 2005). The crisis revealed the stark limitations of those models.

The crisis has stimulated much research that incorporates banks into dynamic stochastic general equilibrium (DSGE) models. Given the global nature of the banking industry, and of the financial crisis, that research has frequently focused on open economy models; see, for example, Devereux and Sutherland (2011), Kamber and Thoenissen (2011), Kollmann, Enders and Müller (2011), Perri and Quadrini (2011) and van Wincoop (2013). Closed economy DSGE models with banks were, i.a., presented by Aikman and Paustian (2006), Van den Heuvel (2008), Gerlai et al. (2010) and Meh and Moran (2010). In this new class of DSGE models, bank capital is a key state variable for the supply of credit, and for real activity; negative shocks to bank capital are predicted to increase the spread between banks’ lending and deposit rates, and to trigger a fall in bank credit and output; with a globalized banking system, a loan loss in one country can thus lead to a worldwide recession.

So far, this new macro-banking literature has mainly used calibrated models—a systematic empirical evaluation, using econometric methods, is necessary, to guide further model building and policy. In order to provide an empirical assessment of the role of banks as a source of shocks and as a transmission channel in the global economy, the paper here estimates (using Bayesian methods) a two-country DSGE model with a global bank. Quarterly US and Euro Area (EA) macro data and banking data (bank loans, bank capital ratio, loan spread) for the period 1990q1-2010q3 are used. Specifically, I take the Kollmann, Enders and Müller (2011) two-country model with a banking sector to the data—that structure is used as it features a ‘bank capital channel’ that is broadly representative of other recent macro-banking models.

The structure builds on the International Real Business Cycle (RBC) literature, but while standard International RBC models assume direct frictionless international borrowing and lending (e.g., Backus, Kehoe and Kydland 1992, Baxter and Crucini 1995, Kollmann 1996), the model here assumes that a global bank intermediates between savers and borrowers in the two countries. Importantly, the bank has to finance a fraction of her assets using equity (own funds). This capital requirement can reflect legal constraints and, more broadly, market pressures. It implies that the loan rate spread (relative to the deposit rate) is a decreasing function of bank capital. To focus on the role of bank capital


2. Some previous papers have estimated open economy DSGE models without banks; e.g., de Walque, Smets and Wouters (2005), Adolfson et al. (2007), Justiniano and Preston (2010), Le et al. (2010), Jacob and Peersman (2013).
for international shock transmission, I adopt an aggregate perspective and assume a representative bank that may be thought of as the global financial system; thus, I abstract from frictions in the interbank market that played an important role in the early stages of the financial crisis (Brunnermeier 2009). The estimated model assumes exogenous demand and supply shocks in home and foreign labor and good markets. In addition, there are exogenous loan losses (defaults) in the two countries, and exogenous fluctuations in the required (target) bank capital ratio—henceforth, I refer to these shocks as ‘banking shocks.’ (Other recent studies on DSGE models with banks discuss too--but do not estimate--exogenous shocks to bank revenue/capital; see, e.g., Gerali et al. 2010, Meh and Moran 2010, and Gertler and Karadi 2011.)

The estimated banking model matches key cyclical properties of US and EA macro and banking variables. For example, it captures the fact that US and EA loans are procyclical, while the loan spread is countercyclical. The estimation results indicate that the bank capital requirement, and the banking shocks, matter for the dynamics of macro and banking variables. A model with these ingredients outperforms a model variant without an operative bank capital requirement (and without banking shocks)--the model with the bank capital requirement generates predicted second moments of key macro and banking variables that are mostly closer to empirical moments; the marginal likelihood of that model is markedly higher.

The model estimates suggest that global banking is a powerful international transmission channel for financial shocks. In the presence of a bank capital requirement, loan losses and shocks to the required bank capital ratio induce sizable common responses of home and foreign real activity. That positive international transmission mechanism is not present in standard International RBC models (without banks). According to the baseline model estimates, a one percentage point fall in the global bank capital ratio raises the loan rate spread by about 20 basis points. An unanticipated US loan loss worth 1% of steady state quarterly GDP lowers US and EA quarterly GDP by about 0.10% and 0.12%, respectively, on impact; a EA loan loss of the same size lowers US and EA GDP by 0.14% and 0.18%, respectively. A US loan loss thus lowers EA real activity more than US real activity. An unanticipated increase in the required bank ratio by one percentage point lowers US and EA GDP by 0.10% and 0.11%, respectively.

Banking shocks account for a non-negligible share of the unconditional variance of real activity. Specifically, banking shocks explain about 2%-5% of the variance of US GDP, and 3%-14% of the variance of EA GDP. These shocks account for higher variance shares of employment and investment--especially of EA investment (above 20%). Thus, banking shocks matter more for EA real activity than for US real activity. US loan losses account for a greater share of the variance of EA real activity than of the variance of US real activity. Exposure to US loan losses (via the global banking system) thus deepened the recent recession in the EA.

However, despite the positive international transmission of banking shocks, the model here cannot account for the high positive (unconditional) cross-country correlation of real activity seen in the data, unless total factor productivity (TFP) is strongly correlated across countries. For TFP shocks (and other nonbanking shocks) are the dominant source of real activity fluctuations, according to the model estimates. Like standard open economy models without banks (e.g., Backus, Kehoe and Kydland 1992), the model here predicts that a positive shock to home TFP raises home GDP, but lowers...
foreign GDP. Conventional models too require shocks that are positively correlated across countries, to explain the empirical cross-country correlation of real activity.

The model estimates suggest that banking shocks contributed noticeably to the ‘Great Recession’ of 2007-09, but were not its dominant cause: banking shocks accounted for about 15% of the fall in US and EA GDP during the recession--but they explained more than a third of the fall in EA investment and employment. During the previous two US recessions in the estimation period (1990-91 and 2001), banking shocks accounted for a roughly similar share of the fall in US output, investment and employment as in the 2007-09 recession.

I consider several empirical measures of credit and lending spreads and find that the key results are robust across the different measures.

This paper is complementary to Gerali et al. (2010) who estimated (using Euro Area data) a closed economy New Keynesian macro model with a banking sector that faces a bank capital requirement. The paper here differs (inter alia) from Gerali et al. by estimating a real (flex-price) two-country world with a global bank that experiences loan loss shocks. By contrast, the empirical analysis of Gerali et al. focuses on the role of shocks to borrowers’ collateral constraints.

Sect. 2 presents the model. Sect. 3 discusses the econometric approach. Sect. 4 describes key data features. Sect. 5 reports the estimation results. Sect. 6 concludes.

2. A TWO-COUNTRY WORLD WITH A GLOBAL FINANCIAL INTERMEDIARY

As mentioned above, this paper takes the theoretical two-country model of Kollmann, Enders and Müller (2011) to US and EA data. In each of the two countries, called ‘Home’ (H) and ‘Foreign’ (F), there is a representative worker, an entrepreneur and a government. A global bank collects deposits from workers, and makes loans to entrepreneurs, in both countries. The bank faces a capital requirement: a fraction of bank assets has to be financed using the bank’s own funds (equity). Entrepreneurs produce a homogenous tradable good that is used for consumption and for capital accumulation. All agents are infinitely-lived. Markets are competitive. Preferences and technologies have the same structure in both countries. The following exposition focuses thus on the Home country. Foreign variables are denoted by an asterisk.

2.1. Preferences, technologies, markets

2.1.1. The Home worker

The Home worker provides labor to the Home entrepreneur and invests her savings in one-period bank deposits. Her date t budget constraint is:

$$C_t^S + D_{t+1} + T_t^S = \omega_t N_t + D_t R_t^D,$$

where $C_t^S$ and $N_t$ are the worker’s consumption and hours worked respectively. $\omega_t$ is the real wage rate. $D_{t+1}$ is the bank deposit held by the saver at the end of period t. $R_t^D$ is

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3. Governments, and a rich set of (banking and non-banking) shocks are added to the Kollmann, Enders and Müller (2011) model, to permit an empirical evaluation of the bank capital channel, and of the contribution of banking shocks to historical data for key macro variables. Also, the present paper allows for asymmetries between countries, to capture differences between the sensitivity of the US and EA economies to banking shocks.
the gross interest rate on deposits, between t-1 and t. \( T_t^S \) is a lump sum tax. The worker’s date t expected life-time utility, \( V_t^s \), is:

\[
V_t^s = u(C_t^s) + \Psi^D u(D_{t+1}) - \Psi^N N_t + E_t \beta_{t+1} V_{t+1}^s,
\]

with \( u(x) = x^{1-\sigma} - 1 \), \( \sigma > 0 \) and \( \Psi^D > 0 \). The worker’s marginal disutility of labor, \( \Psi^N > 0 \), is an exogenous random variable that will be referred to as the Home labor supply shock. Note that deposits provide utility to the worker (liquidity services). This ensures that, in equilibrium, the deposit rate is smaller than the loan rate, and that workers hold deposits while entrepreneurs borrow. The worker’s subjective discount factor is decreasing in her future consumption: \( \beta_{t+1} \equiv \beta^s(C_{t+1}^s) \), with \( 0 < \beta^s(C_{t+1}^s) < 1 \). The subjective discount factors of other agents are likewise decreasing functions of their own consumption (this induces mean-reversion in individual wealth, and thus ensures stationarity, as required for the numerical solution and estimation methods.) Agents treat their subjective discount factors as given, i.e. they do not internalize the effect of consumption on the discount factor—I thus write the argument of the subjective discount factor with an upper-bar. It is assumed that all agents have the same steady state rate of time preference, and the same risk aversion coefficient, \( \sigma \).

The Home worker maximizes her life-time utility subject to the period-by-period budget constraint (1). That decision problem has these first-order conditions:

\[
\begin{align*}
\frac{u'(C_t^s)}{C_t^s} \alpha_t &= \Psi^N_t, \\
R_t^D E_t \beta_{t+1}^s u'(C_{t+1}^s) u'(C_t^s) + \Psi^D u'(D_{t+1}) u'(C_t^s) &= 1.
\end{align*}
\]

### 2.1.2. The Home entrepreneur

The Home entrepreneur accumulates physical capital and uses capital and local labor to produce output. Her technology is \( Z_t = \Theta_t(K_t)^{\alpha_t}(N_t)^{1-\alpha_t} \), \( 0 < \alpha_t < 1 \), where \( Z_t, K_t \) and \( N_t \) are output, capital and labor, respectively. Total factor productivity (TFP), \( \Theta_t > 0 \), is an exogenous random variable. The law of motion of the capital stock is \( K_{t+1} = (1-\delta)K_t + \Xi_t, I_t \), where \( 0 \leq \delta \leq 1 \) is the capital depreciation rate and \( I_t \) is gross investment. \( \Xi_t > 0 \) is an exogenous random shock to investment efficiency (Fischer 2006, Justiniano, Primiceri and Tambalotti 2008). Gross investment is generated using output. Let \( \xi(I_t, I_t) \) be the amount of output needed to generate \( I_t \), where \( I_t \) is steady state investment, and \( \xi \) an increasing, strictly convex function with \( \xi(I) = \xi'(I) = 1 \). Henceforth, variables without time subscripts denote steady state values. The Home entrepreneur’s period t budget constraint is:

\[
L_t R_t^L - \Delta_t + 1 \xi(I_t, I_t) + \omega_t N_t + d_t^E + T_t^E = L_{t+1} + \Theta_t (K_t)^{\alpha_t}(N_t)^{1-\alpha_t},
\]

where \( L_t \) is a one-period bank loan received by the Home entrepreneur in period t-1. \( R_t^L \) is the gross interest rate on that loan, set at t-1. In period t, the Home entrepreneur defaults by an exogenous random amount \( \Delta_t \) on the amount \( L_t R_t^E \) that she owes the bank. \( T_t^E \) is a lump sum tax. \( d_t^E \) is the entrepreneur’s dividend income at t. The entrepreneur consumes her dividend income. Her expected lifetime utility at t, \( V_t^E \), is:
\[ V^E_t = u(d^E_t) + E_{t+1} \beta^E_t V^E_{t+1}, \quad \text{with} \quad \beta^E_t = \beta(d^E_t) < 1. \]

Utility maximization by the entrepreneur (subject to (2)) yields these first-order conditions:

\[
\begin{align*}
\omega_t &= (1 - \alpha)\theta_t K^\alpha_t N^{-\alpha}_t, \\
R^E_t E_t \beta^E_t u'(d^E_t) u'(d^E_t) &= 1, \\
E_t \beta^E_t (u'(d^E_t) u'(d^E_t)) \{\theta_{t+1} \alpha K^{\alpha}_{t+1} N^{1-\alpha}_{t+1} + q_{t+1} (1-\delta)\} / q_t &= 1, \quad \text{with} \quad q_t = \xi(t/I) / \Xi_t.
\end{align*}
\]

2.1.3. The Home government

At date 0, the Home government makes exogenous random output purchases \( G_t \) that are financed using lump sum taxes: \( G_t = T^W_t + T^E_t + T^B_t \), where \( T^B_t \) is a tax paid by the bank (see below). Each Home agent bears a constant share of the total Home tax burden, equal to her share in Home steady state consumption: \( T^E_t = \lambda^H G_t \) for \( i = S, E, B \) where \( \lambda^H \) is time-invariant. In setting taxes, the Home and Foreign governments assume that 50% of the banker’s consumption takes place in country Home.

2.1.4. The global bank

The paper focuses on the role of bank capital for the transmission of macroeconomic and financial shocks to global real activity. I therefore adopt an aggregate perspective, and assume a representative global bank that may be thought of as the global financial system. At date 0, the global bank receives deposits \( D^*_{t+1} \) and \( D^W_{t+1} \) from the Home and Foreign workers, respectively, and makes loans \( L^*_{t+1} \) and \( L^W_{t+1} \) to Home and Foreign entrepreneurs, respectively. Let \( D^W_{t+1} = D^*_{t+1} + D^E_{t+1} \) and \( L^W_{t+1} = L^*_{t+1} + L^E_{t+1} \) denote worldwide deposits and loans. The bank faces a capital requirement: her date 0 capital \( L^W_{t+1} - D^W_{t+1} \) should not be smaller than a fraction \( \gamma^*_t \) of the bank’s assets \( L^W_{t+1} \). This may reflect a legal requirement (macro-prudential policy) or, more broadly, market pressures. To allow for time-variation in these factors, I assume that \( \gamma^*_t \) is an exogenous random variable. A sensitivity analysis below considers a model variant with a constant bank capital requirement (\( \gamma^*_t = \gamma \)). Bank capital requirements are often justified as limiting moral hazard in the presence of informational frictions and deposit insurance (see Freixas and Rochet 2008). This issue is not modeled here. Instead, I take the capital requirement as given, and focus on its macroeconomic effects.

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4. Thus, the interbank market is not modeled here. Frictions in that market would matter for aggregate activity if they affected the flow of funds from savers to borrowers. The model here captures empirical fluctuations in the loan spread and in the volume of intermediation. To investigate the potential role of an interbank market, I studied a model variant with a global savings bank and a global investment bank. The savings bank gets deposits from households, and lends to the investment bank (interbank market), which lends to firms. Each bank faces a capital requirement. Aggregate dynamics hinges on total bank capital--thus that set-up is observationally equivalent to the representative-bank model.

5. See Meh and Moran (2010) for a closed economy DSGE model in which bank capital mitigates an agency problem between banks and their creditors. The model here could be used to evaluate macro-prudential government policies that set \( \gamma^*_t \) as a function of the state of the economy--this is beyond the scope of the paper. Mendicino and Punzi (2011) and Brzoza-Brzezina, Kolasa and Makarski (2013) show that macro-prudential policy may have important effects on real activity and welfare.
I assume that the bank can hold less capital than the required level, but that this is costly. Let \( x_t = (L_t^W - D_t^W) - \gamma_t \), \( L_t^W = (1 - \gamma_t) (L_{t-1}^W - D_{t-1}^W) \) denote the bank’s ‘excess’ capital at the end of period \( t \). The bank bears a cost (penalty) \( L_t^W \phi(x_t/L_t^W) \) as a function of \( x_t \), where \( L_t^W \) is the steady state stock of loans. \( \phi \) is a smooth, convex function (\( \phi'' \geq 0 \)) for which I assume: \( \phi(x_t/L_t^W) > 0 \) for \( x_t < 0 \); \( \phi(0) = 0 \). Thus, for \( x_t < 0 \) the bank incurs a positive cost; the cost is zero when the bank meets her capital requirement.\(^6\)

At \( t \), the bank also bears an operating cost \( \Gamma(D_t^W + L_t^W) \), where \( \Gamma > 0 \) is the (constant) real marginal cost of taking deposits and making loans. The bank’s period \( t \) budget constraint is:

\[
L_{t+1}^W + D_t^W R_t^D + \Gamma(D_t^W + L_t^W) + L_t^W \phi(x_t/L_t^W) + d_t^B + T_t^B + T_t^{B*} = L_t^W R_t^L - \Delta_t - \Delta_t^* + D_{t+1}^W,
\]

where \( \Delta_t + \Delta_t^* \) is the bank’s total loan loss, and \( T_t^B + T_t^{B*} \) is the total tax paid by the bank (in the two countries). \( d_t^B \) is the dividend generated by the bank at \( t \). As the bank acts competitively, loan rates and deposit rates are equated across countries. (4) implies that bank capital at the end of period \( t \) equals bank capital at the end of \( t-1 \), plus retained bank earnings in \( t \). The banker consumes her dividend income, and selects the path of loans and deposits to maximize her welfare. The banker’s expected life-time utility at \( t \), \( V_t^B \), is:

\[
V_t^B = u(d_t^B) + E_t \beta_t V_{t+1}^B, \text{ with } \beta_t = \beta(d_{t-1}^B) < 1.
\]

The banker’s utility maximization problem has these first-order conditions:

\[
R_{t+1}^D E_t \beta_t u'(d_{t+1}^B) u'(d_t^B) = 1 - \Gamma + \phi_t'(x_t/L_t^W),
\]

\[
R_{t+1}^L E_t \beta_t u'(d_{t+1}^B) u'(d_t^B) = 1 + \Gamma + (1 - \gamma_t) \phi_t'(x_t/L_t^W).
\]

A linear approximation of these Euler equations (around \( x = 0 \)) gives:

\[
R_{t+1}^L - R_{t+1}^D \cong 2 \Gamma - \gamma_t \phi_t'(x_t/L_t^W) \cong 2 \Gamma - \gamma_t \phi_t'(0) - \gamma_t \phi''(0) \cdot \phi_t'(0) \cdot x_t/L_t^W.
\]

Hence, the loan rate spread \( R_{t+1}^L - R_{t+1}^D \) is a function of the required capital ratio \( \gamma_t \) and of the bank’s excess capital, \( x_t \).\(^7\) Note that if the bank raises deposits and loans by one unit, then her operating cost rises by \( 2 \Gamma \) units; excess bank capital falls by \( \gamma_t \), which raises the penalty \( L_t^W \phi(x_t/L_t^W) \) by \( -\gamma_t \phi_t'(x_t/L_t^W) \). The bank’s Euler equations imply that the spread between the loan rate and the deposit rate \( R_{t+1}^L - R_{t+1}^D \) covers the marginal cost

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6. Gerali et al. (2010) assume a quadratic function \( \phi \cong \chi(x_t)^2, \chi > 0 \), under which the bank also bears a positive cost for \( x_t > 0 \). That function satisfies my assumptions. My setup is more general: it allows for the possibility that positive excess capital generates a convenience yield (\( \phi < 0 \) for \( x_t > 0 \)). Up to a linear approximation (around \( x = 0 \)), both specifications yield identical predictions; importantly, the loan spread is decreasing in \( x_t \), and only if \( \phi'' > 0 \) (see below); the key (uncontroversial) assumption is, thus, the convexity of \( \phi \). Benes and Kumhof (2011) assume \( \phi < 0 \) for \( x_t < 0 \), and \( \phi = 0 \) for \( x_t > 0 \); that cost function is not differentiable at \( x = 0 \); the numerical solution method (linearization) used here cannot be applied to a model with that function.

7. Gerali et al. (2010) assume a constant target bank capital ratio, but postulate exogenous changes in bank markups (market power) that likewise impact the spread; see also Kannan, Rabanal and Scott (2012).
2Γ−γ_iφ'(x_i/L^W_i). Under strict convexity of Φ (i.e. Φ''>0), the marginal benefit of excess capital −φ' is a decreasing function of (excess) bank capital, which implies that the loan rate spread is likewise a decreasing function of excess bank capital.

The sensitivity of the loan rate spread to changes in bank capital is governed by Φ''. Note that \( x_i/L^W_i \approx cr_i - γ_i \), where \( cr_i = (L^W_{t+1} - D^W_{t+1})/L^W_{t+1} \) is the bank’s capital ratio, i.e. the ratio of bank equity to bank assets. A one percentage point rise in the capital ratio lowers the loan rate spread by 4γΦ'' percentage points per annum (p.a.), while a one percentage point increase in the required bank capital ratio (holding constant \( cr_i \)) raises the spread by 4[γΦ'' −φ'] percentage points p.a.

2.1.5. Market clearing
Market clearing for the output good requires:
\[
S_i + Z_i = C_i + x_i + d_i^E + d_i^H + I_i(x_i/L^W_i) + G_i + G^*_i + L^W_i \Phi (x_i/L^W_i) + \Gamma (L^W_{t+1} + D^W_{t+1}).
\]

2.1.6. Forcing variables
Steady state TFP and investment efficiency are normalized to unity (\( \theta = \theta^* = \Xi = \Xi^* = 1 \)).

There are 11 forcing variables: Home and Foreign TFP (\( \theta_i, \theta_{i}^* \)), investment efficiency (\( \Xi_i, \Xi_{i}^* \)), government purchases (\( G_i, G^*_{i} \)), labor supply shocks (\( \Psi^N_i, \Psi^{N*}_{i} \)), loan losses (\( \Delta_i, \Delta_{i}^* \)) and the required bank capital ratio (\( \gamma_i \)). I refer to the first 8 shocks as ‘non-banking’ shocks, and to the last three shocks as ‘banking shocks’. A large number of non-banking shocks is assumed so that the model has the potential to capture important features of macro data, even in the absence of banking shocks. Other recent estimated DSGE models likewise assume many shocks (e.g., Smets and Wouters 2007).

Following the empirical DSGE literature, I consider a baseline specification in which all 11 forcing variables are independent univariate AR(1) processes:
\[
\ln(z_i/t) = \rho \ln(z_{i-1}/z) + \epsilon_i^z,
\]
for variable \( z_i \), with 0<\( \rho \)<1, where \( \epsilon_i^z \) is a normally distributed white noise.

2.2 Model solution
A linear approximation (around the deterministic steady state) is used to solve the model. The solution can be expressed as
\[
s_t = \Lambda_1 s_{t-1} + \Lambda_2 \epsilon_t,
\]
where \( s_t \) is a vector consisting of states and controls chosen (or realized) at date \( t \), expressed as deviations from steady state values. \( \epsilon_t \) is the vector of innovations to forcing variables. \( \Lambda_1, \Lambda_2 \) are matrices whose elements are functions of model parameters.

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8. The bank operating cost and cost of excess bank capital represent inputs used by the bank and have thus to be subtracted from entrepreneurs’ output when computing GDP. I assume the bank purchases the resources \( \Gamma (L^W_{t+1} + D^W_{t+1}) \), and a fraction \( L/L^W \) of the resource cost \( L^W \Phi (x_i/L^W_i) \) from the Home entrepreneur. Thus, Home GDP is: \( Y_i = Z_i - \Gamma (L^W_{t+1} + D^W_{t+1}) - L \Phi (x_i/L^W_i) \), and \( Y_i + Y^*_i = C_i + x_i + d_i^E + d_i^H + I_i(x_i/L^W_i) + G_i + G^*_{i} \).
3. ECONOMETRIC APPROACH

The model is estimated using quarterly time series for 12 macro and banking variables, in 1990q1-2010q3: US and EA GDP, total private consumption, investment, employment, commercial bank credit (deflated using the GDP deflator); the loan rate spread of US commercial banks, and the capital ratio of US commercial banks. US (EA) data are taken as empirical counterparts of Home (Foreign) variables in the model. The baseline estimates use data on total bank credit (to all sectors) by US Commercial banks and by EA Monetary financial institutions (MFI). Below, I also report estimation results that use data on credit to the business sector. (I use total credit for the baseline estimates, as that variable accounts for a greater share of bank assets.) The baseline measure of the US loan rate spread is the ‘commercial and industrial loan rates spread over intended federal funds rate,’ from the Federal Reserve Board’s (FRB) Survey of Terms of Business Lending (Table E.2). Data on the EA loan rate spread are only available for the period since 2003q1; as shown in Figure 1, the available EA loan spread closely tracks the US loan spread (correlation: 0.90). (The EA spread plotted in Figure 1 is the difference between the EA MFI loan rate and the EONIA rate.) I thus use the US loan rate spread as a measure of the global loan spread. The US Commercial bank capital ratio is taken as a proxy for the capital ratio of the global bank. Following Kollmann and Zeugner (2012), the empirical bank capital ratio measure is constructed as (total financial assets – total liabilities)/total financial assets, using Flow of Funds (FRB) data. In estimation, the loan spread and the capital ratio are demeaned; the other empirical variables are linearly detrended in log-form. See the Appendix for further information on empirical variables.

The number of data series used for estimation (12) exceeds the number of shocks (11). To avoid stochastic singularity of the model, I assume that all observed variables contain measurement error. Allowing for measurement error also seems important because (especially) the empirical banking series might be imperfect measures of the theoretical concepts.9 The period t data used in estimation, \( y_{t}^{obs} \), are a subset of the states and controls included in the vector \( s_{t} \) (see (6)):

\[
y_{t}^{obs} = \Gamma s_{t} + \mu_{t},
\]

where \( \Gamma \) is a matrix, and \( \mu_{t} \) is a vector of Gaussian i.i.d. measurement errors that are independent of the true state variables at all leads and lags. I use a Bayesian approach to estimate a subset of the parameters, while the remaining parameters are calibrated.

3.1.1. Estimated parameters

I estimate the (scaled) curvature of the bank capital penalty function \( 4\gamma \phi'' \), the curvature of the investment cost function \( \xi'' \), and the risk aversion coefficient \( \sigma \). The first two parameters do not affect the steady state, but are key for the dynamic properties of the model. In particular, \( 4\gamma \phi'' \) (sensitivity of the loan rate spread to changes in the bank capital ratio) is crucial for the transmission of banking shocks to real activity.

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9. To break the singularity, measurement error in just one observable is sufficient. To determine the presence of measurement error empirically, I allow for it in all series. Assuming measurement error just in banking variables gives similar results. For recent estimated DSGE models with measurement error see Ireland (2004), Boivin and Giannoni (2006), Galí, Smets and Wouters (2011) and de Antonio Liedo (2011). Sizable estimated measurement error may suggest model misspecification (Canova 2007).
The means and standard deviations of the prior distributions of these parameters are shown in Columns (1)-(2) of Table 1. I set the mean of the prior distribution of $4\gamma\phi''$ at 0.2, a value consistent with time series regressions of the loan rate spread on aggregate bank capital reported by Kollmann, Enders and Müller (2011). (As discussed below, I set the steady state required bank capital ratio at $\gamma=11.17\%$.) Investment is excessively volatile when the capital accumulation technology is linear ($\xi''=0$), as then international capital flows respond very strongly to country-specific shocks. I set the mean of the prior distribution of $\xi''$ at 1; for that value, the ratio of the standard deviation of investment divided by the standard deviation of GDP is about 3 in the model variants discussed below (when the other parameters are set at prior mean values), and thus roughly in the range of the relative volatility of EA investment. The mean of the prior distribution of $\sigma$ is set at 2. (The prior distributions of $\sigma, 4\gamma\phi''$ and $\xi''$ are Gamma distributions with standard deviations set at half the prior means. Thus a reasonably wide range of parameter values around the mean has non-negligible mass.)

I also estimate the autocorrelations of the 11 forcing variables, and the standard deviations of the 11 shock innovations, as well as the standard deviation of measurement errors. The prior distributions of autocorrelations [standard deviations of innovations] of forcing variables have mean 0.5 [0.5\%] and a standard deviation of 0.1 [0.1\%]. The prior means and prior standard deviations of the standard deviations of measurement errors are 1/4 and 1/20, respectively, of standard deviations of corresponding (demeaned/detrended) empirical series. Using more diffuse priors leaves the results unchanged.

### 3.1.2. Calibrated parameters

I calibrate the remaining structural parameters so that the steady state matches long run properties of the data. It would be difficult to estimate the calibrated parameters through the lens of the model, using the (detrended) empirical time series used for estimation (see Smets and Wouters 2007). One period in the model represents one quarter in calendar time. As is standard in the macro literature, the (quarterly) depreciation rate of physical capital is set at $\delta=0.025$. The elasticity of output with respect to capital is set at $\alpha=0.3$, consistent with long run average historical US and EA labor shares of about 70\%.

The two-country model here abstracts from US and EA trade with third countries; I thus use the sum of US government consumption and of US net exports to countries other than the EA as an empirical measure of US ‘autonomous’ spending, $G_t$; EA autonomous spending is constructed analogously. During 1990q1-2010q3, US [EA] autonomous spending represented 14.2\% of US GDP [21.2\% of EA GDP], on average. I thus set $GY=14.2\%$, $G^*Y^*=21.2\%$.

Most DSGE studies calibrate the subjective discount factor to match average historical returns. I use the same approach. As mentioned above, it is assumed that all agents have the same steady state subjective discount factor, here denoted by $\beta$. $\beta$ is set so that the steady state loan rate matches the mean 1990q1-2010q3 US real loan rate. I use the interest rate on ‘commercial and industrial loans made by all commercial banks’ from the FRB Survey of Terms of Business Lending as a measure of the nominal loan rate, from which I subtract the quarterly growth rate of the US GDP deflator to construct the real loan rate. The average US real loan rate 1990q1-2010q3 was 3.440\% p.a.
Accordingly, I set the (quarterly) steady state subjective discount factor at $\beta=0.9918$ (as $\beta R^t=1$, from the entrepreneur’s Euler equation (3)).

I assume that all agents’ subjective discount factors have the same elasticity with respect to consumption, denoted by $\epsilon_\beta$. I set $\epsilon_\beta$ at a small absolute value, $\epsilon_\beta=-0.001$, that yields a stationary equilibrium, while generating (essentially) the same short run dynamics as a model with a constant subjective discount factor. (Impulse responses over the first 100 periods are very similar across model variants with $\epsilon_\beta=0$ and $\epsilon_\beta=-0.001$.)

The sample mean (1990q1-2010q3) of the US loan rate spread was 2.161% p.a.. I set the steady state deposit rates in the model at 1.279% p.a., so that the steady state loan spread matches the mean historical spread. The mean EA loan spread was 2.01% in 2003-10 (see above), which is close to the steady state spread used in the calibration.

I set the steady state actual and required bank capital ratios at 11.17%, which corresponds to the average capital ratio of US commercial banks during the sample period (from Flow of Funds data). The bank’s Euler equations imply $R^D \beta=1-\Gamma+\phi'$ and $R^L \beta=1+\Gamma+(1-\gamma)\phi'$. Given $R^D$ and $R^L$, these conditions pin down the bank’s marginal operating cost $\Gamma$ and the steady state slope of the bank’s penalty function, $\phi'$: $\Gamma=0.25\%$, $\phi'=-0.28\%$, $cr=\gamma$ implies that steady state excess bank capital is zero, $x=0$, i.e. $L^w (1-\gamma)=D^w$. (Setting $x\neq0$ generates the same behavior, provided the calibration matches the same steady state deposit and loan rates, as the baseline calibration with $x=0$.) I set $L(1-\gamma)=D$ and $L(1-\gamma)=D^*$, i.e. the steady state ratio of deposits to loans is the same in both countries (consistent with the data). The mean ratios of outstanding US and EA bank loans to annual domestic GDP were 53% and 87% respectively, in 1990q1-2010q3. Thus, the US has a noticeably lower loans/GDP ratio than the EA. I assume that the steady state ratios of loans to annual GDP are 53% in country ‘Home’, and 87% in ‘Foreign’. Finally, I assume that both countries have the same steady state GDP, normalized at unity: $Y=Y^*=1$. These steady state targets pin down the remaining preference parameters (weights of deposits in Home and Foreign workers’ utility functions, $\Psi^D,\Psi^{D*}$, and steady state marginal disutilities of labor, $\Psi^N,\Psi^{N*}$). In steady state, consumption by the Home [Foreign] worker and the entrepreneur represent respectively 58.2% and 4.8% [52.3% and 3.5%] of domestic GDP, and the banker’s consumption is 0.21% of world GDP.

4. DATA PLOTS AND BUSINESS CYCLES

Figure 2 plots the (demeaned/detrended) 12 empirical quarterly time series (1990q1-2010q3) used in estimation. Macro aggregates co-move closely across the US and the EA—the synchronicity was especially high during the ‘Great Recession’ of 2007q4-2009q2 (as dated by the NBER). (Shaded areas in Figures indicate NBER recessions.) Relative to trend, US output fell by 8.5%, during the recession, while EA output fell by 7.5%; US consumption (-7.3%) and investment (-35.1%) fell more sharply than EA consumption (-4.0%) and investment (-15.9%). US and EA bank lending grew strongly in the years before 2008, and then decreased sharply. The loan rate spread fell during the three years prior to the crisis, but rose sharply during the Great Recession. The empirical bank capital ratio exhibits relatively mild fluctuations—throughout the sample period it
stays in a ±2% range around the sample mean of 11.17%. Interestingly, the bank capital ratio has had a flat trend since about 2005. This pattern is in line with the finding of Kalemli-Ozcan, Sorensen and Yesiltas (2012) (based on micro-level bank data for 68 countries), that there was no visible increase in commercial bank leverage, prior to the crisis; the authors argue that ‘excessive risk taking before the crisis was not easily detectable because the risk involved the quality rather than the quantity of assets’ (p.1). It has been argued that the stability of the observed capital ratio during the crisis may partly reflect accounting discretion, which has allowed banks to overstate the value of their assets in the crisis (Huizinga and Laeven 2009).

Figure 3 plots the bank capital ratio, together with the baseline loan spread series and two other spread measures that are used for robustness checks below (all series in Figure 3 are demeaned). Except for the period of the financial crisis, the bank capital ratio and the baseline loan rate spread comove negatively. The correlation between the bank capital ratio and the baseline lending spread was -0.46 during the period 1990-2007, and -0.06 over the whole sample period.

Figure 3 also plots the US series ‘net percentage of banks increasing spreads of loan rates over cost of funds,’ from the FRB Senior Loan Officer Opinion Survey on Bank Lending Practices, SLOOS. (The series represents the percentage of banks increasing spreads minus the percentage of banks lowering spreads; the plotted series is scaled so that its standard deviation equals that of the baseline loan spread.) That series is positively correlated with the baseline loan spread (correlation 0.39 for 1990-2010), and negatively correlated with the bank capital ratio (-0.47 for 1990-2007; -0.21 for 1990-2010). Also plotted in Figure 3 (see right Panel) is Gilchrist and Zakrajšek’s (2011a) excess US commercial bond premium, constructed by subtracting expected bond default probabilities from the spread between the yield on US commercial bonds and the yield on US Treasury bonds. As commercial banks are key players in the commercial bond market, the commercial bond premium might be informative about credit spreads/market conditions. (Gilchrist and Zakrajšek 2011a argue that ‘an increase in the excess bond premium reflects [...] a contraction of the supply of credit with significant adverse consequences for the macroeconomy’, p.31.) The excess bond premium too is negatively correlated with the bank capital ratio (correlation: -0.49 for 1990-2007; -0.15 for 1990-2010). The bond premium is positively correlated with the baseline loan rate spread (0.29) and with the SLOOS ‘net percentage of banks increasing spreads’ (0.79).

Overall, the data are thus consistent with the model’s key prediction that the spread is inversely related to the bank capital ratio (see (5)). The absence of a pronounced inverse relation during the crisis might be due to the fact that the measured bank capital ratio overstates the true capital ratio during the crisis (see discussion above), or that the required bank capital ratio rose during the crisis (this could rationalize the observed increase in the loan rate spread, during the crisis, without a fall in the bank capital ratio).

The last Column of Table 2 reports moments of Hodrick-Prescott (HP) filtered quarterly macro and banking variables, for the US and the EA (1990q1-2010q3). (The smoothing parameter is set at 1600.) The standard deviation of GDP is very similar in the US (1.12%) and the EA (1.14%). Consumption is less volatile than GDP, while investment is markedly more volatile than GDP. US investment is almost twice as volatile as EA investment. In both ‘countries’, loans are more volatile than output and procyclical, while the loan spread is countercyclical. Real activity and loans are positively correlated across the US and EA.
5. ESTIMATION RESULTS

5.1. Posterior parameter estimates (Table 1)

Cols. (4)-(5) of Table 1 report the mean and standard deviation of the posterior parameter distribution, for the baseline model. (The posterior distribution was obtained using the Random Walk Metropolis algorithm; see An and Schorfheide 2007.)

The data are informative about the estimated parameters: in almost all cases, the posterior parameter distribution has lower standard deviation than the prior distribution; the posterior means often differ noticeably from the prior means (posterior means and modes are very close). The posterior mean of \( \gamma_7 \) indicates that a 1 percentage point increase in the bank capital ratio leads to a 21 basis point reduction in the annualized loan rate spread, and that a 1 percentage point rise in the required bank capital ratio \( \gamma_t \) increases the loan rate spread by 19 basis points p.a.\(^{10}\)

The posterior estimates indicate that EA loan loss shocks are roughly as volatile as US loan loss shocks—the posterior means of the standard deviations of innovations to US and EA loan losses (normalized by steady state GDP) are 0.71% and 0.79%, respectively. The required bank capital ratio undergoes sizable fluctuations (posterior mean of std. of innovation to \( \gamma_t \): 0.61%). The posterior means of the standard deviations of measurement errors are mostly smaller than the prior means (an exception is the measurement error for the bank capital ratio).

All model-predicted moments and other model properties discussed in what follows are computed at the posterior mode of the estimated parameters.

5.2. Business cycle moments implied by posterior parameter estimates (Table 2)

Cols. (1)-(9) of Table 2 report model-predicted moments of HP filtered US and EA variables. Col. (1) ['All'] assumes all 11 structural shocks, and measurement error. Cols. (2)-(9) show moments generated by different subsets of the structural shocks, in isolation, without measurement error. Specifically, Col. (2) ['NonBk'] assumes just the 8 non-banking shocks, and Col. (3) ['Bnk'] assumes just the 3 exogenous banking shocks. Cols. (4)-(9) assume just a single type of shock (Col.(4): just TFP shocks; Col. (5): just investment efficiency shocks; etc.).

The model with all shocks and measurement error generates predicted standard deviations that are mostly in the range of the empirical statistics. The predicted standard deviations of US GDP (1.14%) and of EA GDP (1.22%) are close to the empirical standard deviations (1.12%, 1.14%); see Cols. (1) and (12). The model (with all shocks) captures the fact that investment is more volatile than GDP. The model also captures the high volatility of US loans, but it underpredicts the volatility of EA loans. It matches the procyclical behavior of the macro aggregates, employment and loans, and correctly predicts that the loan spread is countercyclical. However, the baseline model with all (independent) shocks predicts cross-country correlations of GDP (-0.26), investment (-0.02) and employment (-0.24) that are negative, and thus markedly below the empirical

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10. The posterior mean of the spread sensitivity \( 4\gamma_7 \) is close to the prior mean. I experimented with smaller and larger prior means for that parameter---the posterior mean remains close to the posterior mean reported in Table 1, which indicates that the data are informative about \( 4\gamma_7 \).
(positive) correlations. But note that the predicted cross-country consumption correlation (0.24) is positive, and thus much closer to the empirical correlation (0.39).\textsuperscript{11}

Standard open economy macro models without banks (Backus, Kehoe and Kydland 1992, Baxter and Crucini 1995, Kollmann 1996) too generate cross-country correlations of output and investment that are lower than the empirical cross-country correlations, unless TFP (and other non-bank) shocks are highly correlated across countries—the same also holds for a variant of the present model without an operative bank capital requirement ($\phi''=0$). (A model variant with correlated shocks is discussed below.)

Taken in isolation, TFP shocks and labor supply shocks induce by far the largest fluctuations in real activity (predicted standard deviations of US GDP with just these shocks: 0.78% and 0.62%, respectively). The predicted standard deviations of US GDP with just loan loss shocks (0.18%) and with just shocks to the required bank capital ratio (0.08%) are noticeably lower. With just TFP shocks, and just labor supply shocks, GDP is negatively correlated across countries. This is due to the fact that these shocks are negatively transmitted internationally—e.g. a positive shock to Home TFP raises Home GDP, but lowers Foreign GDP; see below. By contrast, banking shocks induce fluctuations in output, investment and employment that are (almost) perfectly positively correlated across countries, in the estimated banking model. Nevertheless, the model with all simultaneous (independent) shocks cannot account for the high empirical unconditional cross-correlation of business cycles, as TFP shocks (and labor supply shocks) are the dominant source of output fluctuations, according to the model estimates. Notice also that banking shocks induce a strong negative correlation between the loan rate spread and GDP.

5.3. Variance shares accounted for by banking shocks (Table 3)

Panel (a) of Table 3 reports the % shares of the predicted variances of HP filtered endogenous variables (with measurement error) that are accounted for by the 8 non-banking shocks (see rows labeled ‘NonBk’), and by the 3 banking shocks (rows labeled ‘Bank’), respectively; the remainder represents the contribution of measurement error to the predicted variance.

According to the baseline model, the banking shocks account for a 3.1% share of US GDP variance, but explain larger shares of the variances of US investment: 6.1%; employment: 6.3%; loans: 41.0%. Banking shocks account for greater variance shares of EA variables--GDP: 4.0%; investment: 22.6%; employment: 7.8%; loans: 72.0%. Thus, roughly one-fifth of the variance of EA investment is due to banking shocks, according to the baseline model. The differences between EA and US variance shares (explained by banking shocks) are highly statistically significant.\textsuperscript{12} The greater role of banking shocks

\textsuperscript{11}. In open-economy DSGE models, the predicted cross-country consumption correlation exceeds the cross-country output correlation, if internationally traded assets allow residents of different countries to share their consumption risk (Kollmann 1996, 2012a). Consumption would be perfectly correlated across countries, if financial markets were complete.

\textsuperscript{12}. I randomly picked 10,000 of the parameter vectors generated by the Metropolis algorithm, and computed variance decompositions for each parameter draw; for more than 97.4% of the draws, the three joint banking shocks--and US and EA loan losses individually--explain greater shares of the variances of EA GDP, investment and employment than of the corresponding US variables.
for EA real activity is due to the fact that (calibrated) steady state loans/GDP and deposits/GDP ratios are higher in the EA than in the US.\footnote{A given deposit rate change, due to a banking shock, has a greater effect on the EA worker’s consumption and hours worked, than on the US worker’s decisions; thus, EA output and investment respond more.}

Note also that banking shocks account for 59.7% of the variance of the bank capital ratio, and for 84.7% of the variance of the loan rate spread (the bank capital ratio is mainly driven by US and EA loan losses, while the loan rate spread is mostly driven by shocks to the required bank capital ratio).\footnote{Non-banking shocks explain negligible shares of the variances of the bank capital ratio and the loan spread. Thus, a sizable share of the bank capital ratio variance (40.1%) is accounted for by measurement error.}

Table 3 shows furthermore that loan loss shocks are more important drivers of \textit{real activity} than shocks to the required bank capital ratio; the latter explain merely 0.5% of the variances of US and EA GDP (see rows labeled \(\Delta^{US}\), \(\Delta^{EA}\) and \(\gamma\) in Panel (a)). Interestingly, US loan losses account for a greater share of the variance of EA GDP, investment and employment than of the variances of the corresponding US variables. This finding is in line with Helbling et al. (2011) who argue, based on vector autoregressions, that US credit supply shocks account for a greater share of fluctuations in global real activity than of US real activity.\footnote{See Eickmeier and Ng (2012) for related VAR evidence on the international transmission of credit supply shifts.}

A robustness analysis below confirms the findings discussed in this Section.\footnote{Nolan and Thoenissen (2009) and Jermann and Quadrini (2012) use closed economy models with collateral-constrained \textit{firms} (no banks) to estimate shocks to firms’ funding, and argue that those shocks explain up to half of US GDP variance. In the model here, only the bank faces a capital requirement. The estimates here suggest a more important role for banking shocks than illustrative calibrations in Kollmann, Enders and Müller (2011), according to which banking shocks account for less than 0.2% of the variance of real activity. This greater role is due to the fact that the \textit{estimated} sensitivity of the loan spread to bank capital here, and the \textit{estimated} variance of loan losses, are larger than in those calibrations.}

\subsection*{5.4. Impulse responses (Table 4)}

Impulse responses (reported in Table 4) help to understand the model’s mechanics, and the predicted business cycle moments. Each impulse response focuses on an isolated innovation, assuming that all other exogenous innovations are zero. (To save space, Table 4 does not show responses to EA ‘non-banking’ shocks—those responses are qualitatively similar to the responses to US ‘non-banking’ shocks.)

A positive innovation to Home TFP raises Home GDP and investment, but leads to a fall in Foreign GDP. The shock raises the income of the Home worker; thus that worker saves more, and her holdings of bank deposits increase—i.e. the bank’s debt rises, which lowers the bank capital ratio. The deposit rate falls (due to the greater supply of deposits), and so does the loan rate—however, the loan rate spread rises. The Foreign worker responds to the fall in the deposit rate by consuming more, and working less, and hence Foreign GDP falls. (Foreign investment rises slightly, due to the fall in the loan rate.) Country-specific labor supply shocks likewise drive Home and Foreign GDP in opposite directions.
By contrast, global banking is a powerful international transmission channel for financial shocks. Loan losses and shocks to the required bank capital ratio induce sizable common responses of Home and Foreign real activity (and loans). For example, a loan loss in one country lowers the global bank’s capital ratio, which triggers a rise in the loan rate spread—the deposit rate falls, while the loan rate rises. In response to this, loans, investment and GDP fall in both countries. A rise in the required capital ratio \( \gamma_t \) likewise raises the loan rate spread; on impact, this too lowers loans, investment and real activity in both countries. Note also that banking shocks drive the loan spread and output in opposite directions. According to the baseline model, an unanticipated US loan loss worth 1% of steady state quarterly US GDP reduces the bank capital ratio by 14.9 basis points, on impact, and it lowers US and EA quarterly GDP by, respectively, 0.10% and 0.12%, on impact. An unanticipated EA loan loss of the same size lowers US and EA GDP by 0.14% and 0.18%, respectively. Thus, EA GDP is more sensitive to domestic and foreign loss shock than US GDP. A US loan loss lowers EA GDP more than US GDP. An unanticipated increase in the required bank capital ratio by one percentage point lowers US and EA GDP by 0.10% and 0.11%, respectively, on impact.\(^{17}\)

5.5. Decomposing historical time series (Figure 4)

Figure 4 plots the estimated contributions of the banking shocks and of US and EA non-banking shocks to the historical time series. Thick continuous lines show the historical data; the thin continuous lines indicate the contribution of banking shocks, while the dashed-dotted and dashed lines represent the contributions of US and EA non-banking shocks, respectively. The historical decomposition yields a picture that is consistent with the variance decompositions. Fluctuations in the bank capital ratio and in the loan rate spread were mainly driven by banking shocks. Banking shocks matter more for EA GDP than for US GDP. During the ‘Great Recession’ of 2007q4-2009q2, banking shocks account for a 1.0 percentage point [1.2 ppt.] fall in US [EA] GDP—i.e. the banking shocks capture 12% [16%] of the 8.5 ppt. [7.5 ppt.] fall in US [EA] GDP, relative to trend. Banking shocks also capture 15% [35%] of the fall in US [EA] investment, and 19% [56%] of the fall in US [EA] employment, during the recession. Thus, more than 1/3 of the fall in EA investment and employment is accounted for by the banking shocks.

In the previous US recession (2001q1-2001q4), banking shocks accounted for 11% of the fall in US output and investment, and for 21% [29%] of the fall in EA output [investment]. During the 1990q3-1991q1 US recession, banking shocks accounted for 6%, 10% and 16%, respectively, of the fall in US GDP, investment and employment (the EA did not experience a recession in 1990-91).

Figure 4 shows that the output components accounted for by the domestic non-banking shocks track historical US and EA GDP very closely. This result parallels the finding by de Walque, Smets and Wouters (2005) and Le et al. (2010) that domestic macro shocks are the main drivers of US and EA GDP. Foreign non-banking shocks had a stabilizing effect on domestic real activity; eg, during the 2007-09 recession, EA non-banking shocks had a positive influence on US GDP, and thus mitigated the US

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17. The (almost) perfect international synchronization of responses to banking shocks reflects the assumption that loan and deposit rates are equated across countries (due to competitive banking)—national segmentation of banking markets would lower the international synchronization of responses to banking shocks. Analysis of models with (partially) segmented banking markets is left for future research.
recession. This reflects the fact that, in the model here, TFP shocks and labor supply shocks are negatively transmitted internationally (see above).

5.6. The role of the bank capital requirement and of banking shocks

The presence of an operative bank capital requirement $\phi'' > 0$ is key for the transmission of banking shocks to domestic and foreign real activity. Banking shocks have a negligible effect on real activity, but remain important drivers of loans and the bank capital ratio, when $\phi''=0$. (An estimated model variant with $\phi''=0$ predicts that banking shocks explain merely 0.002% of the variance of HP filtered GDP and investment, but between 1/3 and 2/3 of the variances of loans and the bank capital ratio.)

Columns (6)-(7) of Table 1 reports posterior parameter estimates for a model variant without an operative bank capital requirement ($\phi''=0$), and without banking shocks. (The priors for the remaining (non-banking) parameters are the same as in the baseline model; the posterior estimates of most parameters are similar to the estimates in the baseline model.) That model variant resembles standard International RBC models with incomplete financial markets in which just an unconditional bond can be traded internationally (see, e.g., Baxter and Crucini 1995, Kollmann 1996). Columns (10)-(11) of Table 2 report the implied business cycle moments.

Table 2 shows that the baseline banking model (with $\phi''>0$ and banking shocks) generates business cycles moments that are mostly closer to the empirical moments than the moments predicted by the variant without the operative bank capital requirement (and no banking shocks); see Columns (1) and (10) of Table 2. (Of the 32 moments considered in the Table, 21 are more closely matched by the baseline model.) For example, predicted standard deviations of US and EA GDP in the baseline model (1.14% and 1.22%, respectively) are larger than in the structure without the operative bank capital requirement (1.01%, 0.95%), and closer to the empirical standard deviations (1.12%, 1.14%). Note that the model variant with $\phi''=0$ too generates predicted cross-country correlations of GDP (-0.16), investment (-0.10) and employment (-0.10) that are markedly below the empirical cross-country correlations (like the baseline structure).18

Model fit can be evaluated using the marginal likelihood (that statistic measures the out-of-sample predictive ability of the model; see Geweke 2001). The log marginal likelihood (LML) of the baseline model is 3300.06, while the LML of the model variant without the operative bank capital requirement and without banking shocks is 3104.02.19

18. Surprisingly, predicted cross-country correlations of GDP and employment with $\phi''=0$ are slightly higher than in the baseline model ($\phi''>0$). This is i.a. due to the fact that estimated standard deviations of TFP shocks (inducing negative cross-country GDP correlations) are slightly lower in the $\phi''=0$ model variant. Setting $\phi''=0$ and eliminating banking shocks, while holding constant all other parameters at estimates for the baseline model, lowers predicted cross-country correlations of GDP, investment and employment to -0.30, -0.14 and -0.32, respectively (compared to -0.26, -0.02, -0.24, in the baseline model). Similarly, when non-banking parameters are held fixed at estimated values from the model variant with $\phi''=0$ (and no banking shocks), then setting $\phi''>0$ and introducing banking shocks raises the cross-country correlations.

19. The LMLs reported here were computed using a Laplace approximation. Geweke’s (1999) harmonic mean estimator, based on parameter draws from the Metropolis algorithm, yields very similar LMLs.
This implies a Bayes factor (ratio of posterior odds to prior odds) of $e^{196.04}$ that massively favors the baseline model. The model variant with an operative bank capital requirement, but without banking shocks has a LML of 3105.36; a model variant without an operative bank capital requirement but with banking shocks has a LML of 3212.29. This suggests that both the operative bank capital requirement and the banking shocks help the model capture the joint dynamics of the macro and banking variables used in estimation. The presence of these model ingredients also helps to better explain the 8 US and EA macro variables used in estimation. For these 8 macro variables, the baseline model has a LML of 2041.23, while the model variant without an operative bank capital requirement and without banking shocks has a LML of 2036.88.

5.7. Robustness checks

The key findings about the role of the bank capital requirement and of banking shocks continue to hold in model variants with correlated shocks, and they are also robust to using alternative measures of banking variables.

The working paper version of this paper (Kollmann 2012b) estimates a variant of the banking model in which the covariance matrix of the 8 non-banking shocks is set equal to the sample covariance matrix of empirical measures of US and EA non-banking shocks. The empirical cross-country correlations of TFP (0.51) and investment efficiency (0.84) are sizable. The model variant with correlated non-banking shocks generates positive cross-country correlations of output (0.45) and investment (0.31) that are close to empirical correlations, but the predicted cross-country consumption correlation (0.75) exceeds the empirical correlation. Panel (b) of Table 3 reports variance decompositions, for the correlated-shocks model variant. In that variant, the banking shocks account for slightly higher variance shares of real activity than in the baseline model, namely for 5.5% [14.2%] of the variance of US [EA] GDP, and 10.6% [53%] of the variance of US [EA] investment.

Panel (c) of Table 3 reports variance shares for a variant of the banking model (independent shocks), in which the required bank capital ratio is constant, $\gamma_1 = \gamma_2$, so that loan losses are the only banking shocks. In that variant too, banking shocks explain somewhat greater shares of the variance of real activity than in the baseline model.

As a further robustness check, I re-estimated the baseline model using other empirical measures of the loan rate spread and of bank loans. Panel (d) of Table 3 reports the resulting variance shares accounted for by banking shocks. Those variance shares are broadly in the same range as the baseline shares discussed above (Panel (a)). (Posterior parameter estimates obtained from the alternative data sets are in the same range as the baseline estimates, and are thus not reported.)

In Panel (d.1) of Table 3, the baseline loan rate spread is replaced by the series ‘net percentage of banks increasing spreads of loan rates over cost of funds’ from the Senior Loan Officer Opinion Survey (SLOOS), while Panel (d.2) uses the Gilchrist-Zakrajšek (2011a) excess bond premium series in lieu of the baseline loan rate spread.

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20. That variant also assumes that loan losses and the required capital ratio are partly endogenous, as these variables are modeled as linear functions of GDP, and of exogenous disturbances that are independent of the non-banking shocks. The variance shares explained by banking shocks discussed below pertain to the exogenous disturbances. The (partial) endogeneity of loan losses and of the required capital ratio does not affect the key estimation results (the estimated feedback to GDP is weak).
The importance of banking shocks in explaining real activity fluctuations rises somewhat when those alternative spread measures are used to estimate the model. (The same result holds when the SLOOS series ‘net percentage of banks tightening lending standards’ is used instead of the baseline lending spread.) For example, when the Gilchrist-Zakrajšek excess bond premium is used, about 5% of the variance of US and EA GDP is attributed to banking shocks.\(^{21}\)

In Panel (d.3) of Table 3, US and total bank credit are replaced by bank loans to the non-financial business sector. Panel (d.4) replaces total US bank credit by Gilchrist and Zakrajšek’s (2011b) measure of US ‘business lending capacity’ (sum of loans outstanding and of unused credit lines), while EA total credit is replaced by bank loans to the non-financial business sector. The motivation for using the US lending capacity measure is that many US business loans are offered under prior commitment (credit lines); Gilchrist and Zakrajšek (2011b) argue that ‘lending capacity’ is, hence, more informative than loans outstanding for identifying loan supply shifts (no comparable measure exists for the EA). Figures 5 and 6 plot the business loans, and loan capacity, series. Business loans are highly positively correlated with total loans, but more volatile, especially in the US. US lending capacity fell earlier and much more sharply than total lending, during the 2007-09 recession. Panels (d.3)-(d.4) of Table 3 show that the business lending measure yields smaller variance shares due to banking shocks than the baseline total bank credit measure, while the US lending capacity measure yields roughly similar variance shares as the baseline measure.\(^{22}\)

Table 3 suggests that banking shocks account for about 2%-5% of the unconditional variance of GDP and for 3%-14% of the variance of EA GDP. The variance shares of employment and (especially) of investment accounted for by banking shocks are higher; in most specifications, these shocks explain more than 20% of the variance of EA investment.

6. CONCLUSION
This paper has estimated a two-country model with a global banking system, using US and Euro Area (EA) data (1990q1-2010q3), and Bayesian methods. The estimated model matches key US and EA business cycle statistics. Empirically, a model version with an operative bank capital requirement outperforms a structure without such a constraint. Banking shocks account for a non-negligible share of the unconditional variance of real activity. EA real activity depends more on banking shocks than US real activity. US loan losses account for a greater share of the variance of EA real activity than of the variance of US real activity. During the Great Recession (2007-09), banking shocks explained about 15% of the fall in US and EA GDP, and more than a third of the fall in EA investment and employment.

\(^{21}\) The empirical lending rate spread may be affected by factors that are not captured by the model, such as liquidity tensions and banking competition. The fact that the SLOOS index and the Gilchrist-Zakrajšek bond premium explain a slightly greater share of the variance of real activity might indicate that these spread measures capture better those other determinants of credit supply.

\(^{22}\) I also estimated the model using alternative measures of the US bank capital ratio, namely the ratios of Tier 1 capital, and of Tier 1+2 capital, to risk-weighted bank assets (Federal Reserve Bank of New York, 2013). The key estimation results are robust to using those measures.
APPENDIX: DATA

A.1 BASELINE DATA SET USED FOR ESTIMATION

- US GDP, private consumption (total), investment (all at constant prices): from US National Income and Product Accounts (Bureau of Economic Analysis, BEA); the investment series include private and government investment.
- US bank loans: outstanding ‘total bank credit’ by Commercial Banks (Flow of Funds, Table L109), deflated using GDP deflator.
- US bank capital ratio: (total financial assets-total liabilities)/(total financial assets) for Commercial Banks (Flow of Funds, Table L109). The raw capital ratio series has a permanent level shift in 2000q1 (mean ratio in 1990-99: 3.7%; mean in 2000-10: 11.2%). To correct for the break, I regressed the capital ratio on a constant and a dummy that equals 1 for dates before 2000q1; I then adjusted the raw ratio before 2000q1 for the dummy coefficient. A break correction based on a regression that also includes a linear time trend (and the product of the trend and the dummy) gives similar results.
- US loan rate spread: ‘Commercial and industrial loan rates spread over intended federal funds rate’ (‘All loans’ series, Survey of Terms of Business Lending, Table E.2, Federal Reserve Board).
- EA GDP, private consumption (total), investment (all at constant prices): from ECB Area-Wide Model (AWM) database (10th update, September 2010).
- EA employment: from AWM database.
- EA bank loans: MFI loans to private sector (from ECB monthly bulletin), deflated using the GDP deflator.

A.2 VARIABLES USED FOR ESTIMATION OF MODEL VARIANTS

- Excess bond premium: spread between the yield on US commercial bonds and the yield on Treasury bonds, minus expected bond default probabilities, as constructed by Gilchrist and Zakrajšek (2011a) using data for a panel of individual bonds.
- ‘Net percentage of banks increasing spreads of loan rates over cost of funds’: percentage of banks increasing spreads minus the percentage of banks lowering spreads, from the Senior Loan Officer Opinion Survey on Bank Lending Practices, SLOOS (Federal Reserve Board). SLOOS reports a series (net percentages of banks raising spreads) for loans to ‘large and middle-market firms’ and one for loans to ‘small firms’. The two series are very similar (correlation: 0.95). I use the average of the two series.
- EA business loans: MFI loans to non-financial corporations (NFC), from ECB monthly bulletin, deflated using the GDP deflator.
- US business lending capacity: outstanding commercial bank loans plus unused commercial bank lending commitments (credit lines) to the non-financial business sector, constructed by Gilchrist and Zakrajšek (2011b).

A.3. OTHER VARIABLES (USED FOR MODEL CALIBRATION)


All series are quarterly and seasonally adjusted (when relevant).
REFERENCES


## Table 1. Parameters: prior and posterior distributions for two model variants

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior distribution</th>
<th>Posterior distributions</th>
<th>Posterior distributions</th>
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25
Notes: Cols. (1) and (2) shows the mean and standard deviation of the prior distribution for model parameters listed in the left-most Column. Col. (3): the distribution function of the prior (B: Beta; G: Gamma; IG: Inverted Gamma; N: Normal).

Cols. (4)-(7): statistics of posterior parameter distribution (mean, standard deviation), for two model variants.
Cols. (4)-(5): baseline model with operative bank capital requirement ($\phi^0>0$) and banking shocks.
Cols. (6)-(7): model variant without operative bank capital requirement ($\phi^0=0$), no banking shocks.
Entries ‘---’ in Cols. (6)-(7) represent parameters that are set at zero.

Posterior distributions were obtained using the Random Walk Metropolis algorithm (250,000 draws of which the first 50,000 were discarded).

Parameter definitions:
$\frac{\gamma}{\phi}$: sensitivity of loan rate spread to bank capital ratio; a 1 percentage point increase in the bank capital ratio lowers the lending rate spread by $\frac{\gamma}{\phi}$ percentage points ($\phi$: steady state bank capital requirement).
$\xi$: curvature of investment cost function.
$\sigma$: coefficient of relative risk aversion
$\sigma^2, \rho^2$: standard deviation of innovation to forcing variable ‘z’, and autocorrelation of ‘z’, with z representing the following (US/EA) variables—$\theta, \theta'$: TFP; $\Xi, \Xi'$: investment efficiency; $G, G'$: government purchases;
$\Psi, \Psi'$: labor supply shock; $\Delta, \Delta'$: loan loss; $\gamma$: required bank capital ratio.

The estimation uses quarterly time series on 12 time series: US and EA GDP, consumption, investment, employment and real loans; the US commercial bank loan rate spread and the US commercial bank capital ratio. The loan spread and the bank capital ratio are demeaned; other empirical variables are linearly detrended in log form. See Figure 1 for data plots and Data Appendix for data sources. Sample period: 1990q1-2010q3 (83 periods).
Table 2. Business cycle statistics generated by two model variants

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<th>Shocks:</th>
<th>All</th>
<th>NonBk</th>
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<th>G</th>
<th>LabS</th>
<th>Loss</th>
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<td>0.99</td>
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<td>0.51</td>
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<td>0.01</td>
<td>0.19</td>
<td>0.00</td>
<td>0.01</td>
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<td>(c) Cross-country correlations</td>
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<td>-0.39</td>
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</table>

Note: Moments of HP filtered model variables (computed at the posterior mode of model parameters) are shown for two model variants. Cols. (1)-(9): baseline model with operative bank capital requirement ($\phi^\neq 0$) and banking shocks. Col. (1) ["All"] assumes all 11 joint shocks and measurement error. In Cols. (2)-(9), subsets of shocks used, without measurement error (model not re-estimated). Col. (2) ["NonBk"]: just 8 ‘non-banking’ shocks; Col. (3) ["Bnk"]: just 3 banking shocks. Col. (4) ["TFP"]; just US and EA TFP shocks; Col. (5) ["Invest.Eff"]; just investment efficiency shocks; Col. (6) ["G"]; just government purchases shocks; Col. (7) ["LabS"]; just labor supply shocks; Col. (8) ["Loan Loss"]; just loan loss shocks; Col. (9) ["γ"]; just shocks to required bank capital ratio.

Cols. (10)-(11): model variant without operative bank capital requirement ($\phi^\neq 0$), no banking shocks. Col. (10) ["All"]: all non-banking shocks and measurement error; Col. (11) ["NonBk"]: just non-banking shocks, no measurement error. The bank capital ratio is expressed in fractional units. The loan rate spread is in fractional units per annum. Other variables are normalized by steady state values.

Col. (12): empirical moments of HP filtered data. (GDP, consumption, investment, employment and loans are logged before filtering). Statistics for the EA bank capital ratio use the US capital ratio as a proxy. Sample: 1990q1-2010q3 (EA loan spread: 2003q1-10q3).
Table 3. Share (%) of variance of HP filtered variables due to non-banking shocks and to banking shocks

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<td>(3)</td>
<td>(4)</td>
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<td>(6)</td>
<td>(7)</td>
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<td>(a) Baseline model ($\phi$&quot;\text{&quot;}&gt;0, banking shocks) [4\phi&quot;=0.21; LML=3300.06]</td>
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<tr>
<td>(b) Model variant with correlated non-banking shocks [4\phi&quot;=0.48; LML=3323.88]</td>
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<td>(c) Model variant with constant required bank capital ratio, $\gamma=\gamma$ [4\phi&quot;=0.69; LML=3229.48]</td>
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<td>87.09</td>
<td>58.21</td>
<td>82.75</td>
<td>46.36</td>
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<tr>
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<td>2.52</td>
<td>8.83</td>
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(d) Estimates of baseline model based on alternative loan rate spread and bank loans data

(d.1) Loan spread replaced by loan officer survey (SLOOS) spread measure [4\phi"=0.21; LML=3275.21] |       |                |               |               |         |                |             |
| NonBk          | 81.26 | 90.16          | 62.14         | 80.49         | 54.78   | 69.82          | 81.38       |
| Bank           | 3.45  | 4.37           | 0.72          | 2.40          | 6.19    | 21.11          | 6.98        |

(d.2) Loan spread replaced by Gilchrist-Zakrajsek excess bond premium [4\phi"=0.30; LML=3329.21] |       |                |               |               |         |                |             |
| NonBk          | 80.57 | 88.93          | 61.59         | 80.56         | 52.92   | 64.09          | 79.46       |
| Bank           | 4.72  | 5.74           | 0.89          | 2.76          | 8.43    | 27.02          | 9.32        |

(d.3) Total bank loans replaced by business loans [4\phi"=0.18; LML=3080.35] |       |                |               |               |         |                |             |
| NonBk          | 71.98 | 88.15          | 62.13         | 80.98         | 30.52   | 77.89          | 81.37       |
| Bank           | 1.62  | 2.62           | 0.41          | 0.62          | 2.56    | 12.14          | 4.21        |

(d.4) US business lending capacity; EA business loans [4\phi"=0.10; LML=3090.46] |       |                |               |               |         |                |             |
| NonBk          | 84.99 | 91.03          | 50.02         | 82.70         | 48.72   | 61.36          | 84.23       |
| Bank           | 2.65  | 3.82           | 0.87          | 2.73          | 9.59    | 27.60          | 5.26        |

Note: This Table reports shares of the variances of endogenous variables (HP-filtered) that are accounted for by different types of shocks (variance shares are computed at the posterior mode of the estimated parameters).

Panel (a): Baseline banking model ($\phi">0$, banking shocks)

Panel (b): Model variant with correlated non-banking shocks (Kollmann (2012b)).

Panel (c): Model variant with constant required bank capital ratio.

Panel (d): Estimates of the baseline model based on alternative measures of spreads and loans. (d.1): Baseline loan rate spread replaced by 'net percentage of banks increasing spreads of loan rates over cost of funds' from the US senior loan officer opinion survey. (d.2): Baseline loan rate spread replaced by the Gilchrist and Zakrajsek (2011a) excess bond premium series. (d.3): Baseline US and EA loan series replaced by loans to the non-financial business sector. (d.4): Baseline US loan series replaced by US 'business lending capacity' measure of Gilchrist and Zakrajsek (2011b); baseline EA loan series replaced by EA bank lending to the non-financial business sector.

Rows labeled ‘NonBk’ show variance shares accounted for by the 8 ‘non-banking’ shocks.

Rows labeled ‘Bank’: variances shares accounted by the 3 banking shocks.

Rows labeled ‘$\Delta^U$’, ‘$\Delta^E$’ and ‘$\gamma$’: variance shares accounted for by shocks to US loan losses, to EA loan losses and to the required bank capital ratio, respectively.

Variance shares are shown for variables listed above Cols. (1)-(12): US and EA GDP (Cols. (1)-(2)); consumption (Cols. (3)-(4)); investment (Cols. (5)-(6)); employment (Cols. (7)-(8)); loans (Cols. (9)-(10)); bank capital ratio (Col. (11)); Loan spread (Col. (12)). $4\phi"$: a 1 percentage point increase in the bank capital ratio lowers the lending rate spread by $4\phi"$ percentage points per annum.

LML: log marginal likelihood
### Table 4. Baseline model ($\phi^r>0$, banking shocks): dynamic responses to innovations

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<td>(b) US investment efficiency shock (1%)</td>
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<td>(c) US government purchases shock (1%)</td>
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<td>(d) US labor supply shock (1%)</td>
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<td>(e) US loan loss shock (1% of steady state quarterly GDP)</td>
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<td>(f) EA loan loss shock (1% of steady state quarterly GDP)</td>
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<td>(g) Shock to required bank capital ratio (1 percentage point)</td>
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Note: The Table shows dynamic responses to exogenous shocks, after 0, 4 and 20 quarters (see left-most Column labeled ‘Horizon’), of the variables listed at the top of the Table. The responses are computed at the posterior modes of the estimated parameters. In each case, an isolated innovation is considered, assuming that all other exogenous innovations are zero. Panel (a): 1% innovation to US TFP ($\theta$); Panel (b): 1% innovation to US investment efficiency ($\Xi$); Panel (c): 1% innovation to US government purchases ($G$); Panel (d): 1% innovation to US labor supply preference parameter ($\psi^\nu$); Panel (e): innovation to US loan loss ($\Delta$) worth 1% of steady state quarterly GDP; Panel (f): innovation to EA loan loss ($\Delta'$) worth 1% of steady state quarterly GDP; Panel (g): innovation that raises required bank capital ratio ($\gamma'$) by 1 percentage point. Cols. (1)-(2): Responses of US and EA GDP; Cols. (3)-(4): US and EA consumption; Cols. (5)-(6): US and EA investment; Cols. (7)-(8): US and EA employment; Cols. (9)-(10): US and EA loans; Col. (11): bank capital ratio; Col. (12): Loan rate spread. Responses of the bank capital ratio are in basis points. Responses of the loan spread are in basis points per annum. Other responses are in percentage points of steady state values.
Fig. 1. US and Euro Area (EA) loan rate spreads
Note: Loan spreads (p.a.) are not demeaned.
Sample period for US (EA) loan spread:
1990q1-2010q3 (2003q1-2010q3)
Shaded areas: US recessions (NBER dates).

Fig. 2. Time series used in estimation
Note: The Figure shows the US and Euro Area (EA) time series (1990q1-2010q3) used in estimation. ‘Loans’ represent total credit by US commercial banks and EA Monetary Financial Institutions (MFI). The ‘US bank capital ratio’ is the capital ratio of US commercial banks. Bank capital ratio and loan spread (p.a.) are demeaned. Other variables are logged and detrended. Shaded areas indicate US recessions (NBER dates).

Fig. 3. US bank capital, US loan spreads and US excess bond premium
Note: In both panels, the solid line shows the demeaned US bank capital ratio (1990q1-2010q3). The left panel also plots the demeaned baseline US loan spread (dashed line) and the demeaned net percentage of US banks increasing spread, from Survey of Senior Loan Officers Opinion Survey (dotted line). (The SLOOS series is scaled so that its standard deviation equals that of the baseline loan spread.) The right panel plots the demeaned US excess commercial bond premium of Gilchrist and Zakrjasek, 2011a (dashed line). Shaded areas: US recessions (NBER dates).
Figure 4. Historical decompositions, baseline model ($\phi>0$, banking shocks)
Using the baseline model (at posterior mode of estimated parameters), the Figure shows the historical contributions of banking shocks (thin black lines with crosses, $\times$), US non-banking shocks (thin grey lines with triangles, $\▲$), and Euro Area (EA) non-banking shocks (thin grey lines with circles $\bullet$) to historical series, 1990q2-2010q3 (thick black lines: $\rule{2cm}{2mm}$). The historical bank capital ratio and loan rate spread series (p.a.) are demeaned, the other historical series are linearly detrended in log form. Shaded areas: US recessions (NBER dates).
Fig. 5. US commercial banks: total loans, business loans and business lending capacity
Note: The solid line shows total US bank credit (baseline measure); dashed line: business lending; dashed-dotted line: US business lending capacity (Gilchrist and Zakrajsek (2011b). All series are linearly detrended in log form. Sample period: 1990q1-2010q3. Shaded areas: US recessions (NBER dates).

Figure 6. EA banks: total loans and business loans
Note: The solid line shows total EA bank credit (baseline measure); dashed line: loans to non-financial corporations. Both series are linearly detrended in log form. Sample period: 1990q1-2010q3. Shaded areas: US recessions (NBER dates).