

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

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February 15, 2012

This paper takes a two-country model with a global bank to US and Euro Area (EA) data. The estimation results (based on Bayesian methods) suggest that global banking strengthens the positive international transmission of real economic disturbances. Shocks that originate in the banking sector account for roughly 20% of the forecast error variance of investment, and about 5% of the forecast variance of US and EA GDP. Bank shocks explain 5%-20% of the fall in US and EA real activity, during the Great Recession.

Key words: financial crisis, financial intermediaries, real activity, investment, Bayesian econometrics.

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Matthias Paustian contributed to this project in its early stages; I thank him for his advice. I am also grateful to Christoph Thoenissen and Alan Sutherland for useful discussions, and to Scott Davis, Steve Davis, Mick Devereux, Domenico Giannone, Kalin Nikolov, Ken West and Raf Wouters for helpful comments and suggestions. I thank the National Bank of Belgium and the EU Commission for financial support (CEPR project 'Politics, Economics and Global Governance: The European Dimensions' funded by the EU Commission under its 7th Framework Programme for Research, Contract Nr. 217559.)

1. Introduction

In the years before the recent (2007-09) financial crisis, the leverage of many major financial institutions increased steadily. The crisis revealed the fragility of the financial sector, and of many highly indebted non-financial firms and households, and it has triggered the sharpest global recession since the 1930s. Before the crisis, structural macro models largely abstracted from financial intermediaries. The crisis has stimulated much research that includes financial intermediaries in dynamic macro models. Given the global nature of the crisis, that research has largely focused on open economy models; see, e.g., Davis (2011), Gamber and Thoenissen (2011), Devereux and Sutherland (2011), In't Veld et al. (2011), Kollmann et al. (2011), Nguyen (2011), Paustian and Sondergaard (2010), Perri and Quadrini (2011), Perri and Kalemli-Ozcan (2011), Ueda (2011) and van Wincoop (2011) who present open economy models with banks.¹ In this class of models, the presence of banks may affect the transmission of macroeconomic and financial shocks, as the net worth of banks is a key state variable for real activity. A negative shock to bank capital is predicted to raise the spread between banks' lending and deposit rates, and to lower lending and real activity; thus, shocks in one country that lower global banks' capital can trigger a worldwide recession. So far, this new macro-banking literature has focused on relatively stylized, calibrated models.

A key contribution of this paper is to take this new class of models to the data. Specifically, we estimate a two-country DSGE model with a global bank, using US and EA data, by Bayesian econometric methods.² The estimation results suggest that global banking strengthens the positive international transmission of real economic disturbances. Shocks that originate in the banking sector account for roughly 20% of the forecast error variance of investment, and for about 5% of the forecast variance of US and EA GDP. Surprisingly, the contribution of banking shocks account to the Great Recession is relatively model: these shocks account for about 5%-20% of the fall in real activity, during the Recession.

¹ Closed economy macro models with banks were, i.a., presented by Aikman and Paustian (2006), Van den Heuvel (2008), Gertler and Kiyotaki (2009), Dib (2009), Adrian and Shin (2010), de Walque et al. (2010), and Challe et al. (2011).

² Some previous papers have estimated open economy DSGE models, but those studies abstracted from banks; see Adolfson (2009), Justiniano and Preston (2010), de Walque et al. (2005) and Peersman and Jacob (2011).

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

2. A two-country world with a global financial intermediary

We estimate a two-country model that builds on the theoretical set-up of Kollmann et al. (2011).³ There is a representative global bank. In each of the two countries, referred to as ‘Home’ and ‘Foreign’, there is a representative worker, an entrepreneur and a government. All agents are infinitely lived. The bank collects deposits from Home and Foreign workers, and makes loans to Home and Foreign entrepreneurs. The bank faces a collateral constraint that ties the maximum amount of debt that the bank can issue to the bank’s net worth. There is a final good that is produced by Home and Foreign entrepreneurs using local labor and capital. The good can freely be traded. It is used for consumption and for capital accumulation (by entrepreneurs). All markets are competitive. Preferences and technologies have the same structure in both countries. The following exposition thus focuses on the Home country. Foreign variables are denoted by an asterisk.

2.1. Preferences, technologies, markets

The Home worker

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

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

where C_t and W_t are the worker’s consumption and the wage rate, respectively (the final good is used as numéraire). T_t^W is a lump sum tax. N_t are hours worked. D_{t+1} is the bank deposit held by the Home worker at the end of period t . R_t^D is the gross interest rate on deposits, between $t-1$ and t . The worker’s expected life-time utility at date t is:

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

³ The model here is different in that, i.a., governments, and a larger number of shocks are assumed.

$u(x)=(x^{1-\sigma}-1)/(1-\sigma)$ and $\chi(N)=(N^{1+1/\eta})/(1+1/\eta)$, $\sigma > 0$, $\eta > 0$. $\Psi^D > 0$ is a constant.

Ψ_t^N is an exogenous stochastic taste shock that affects the worker's labor supply. $0 < \beta < 1$ is the subjective discount factor. Workers, entrepreneurs and the banker have the same subjective discount factor. We assume that deposits provide utility to the worker (liquidity services). This allows us to calibrate the model in such a way that, in steady state, the deposit rate is smaller than the lending rate, and that workers hold deposits while entrepreneurs borrow.

The Home worker maximizes (2) subject to the period-by-budget constraint (1). That decision problem has these first-order conditions:

$$R_{t+1}^D E_t \beta u'(C_{t+1})/u'(C_t) + \Psi^D u'(D_{t+1})/u'(C_t) = 1, \quad u'(C_t) W_t = \Psi_t^N \chi'(N_t).$$

The Home entrepreneur

The Home entrepreneur accumulates physical capital and uses capital and local labor to produce the final good. Home final good output, denoted Z_t , is produced using the Cobb-Douglas technology $Z_t = \theta_t (K_t)^\alpha (N_t)^{1-\alpha}$, with $0 < \alpha < 1$. K_t is the capital stock used at t . Total factor productivity (TFP), θ_t , is an exogenous random variable that follows an AR(1) process (see below). The law of motion of the Home capital stock is $K_{t+1} = (1-\delta)K_t + \Xi_t I_t$, where $0 \leq \delta \leq 1$ is the depreciation rate of capital and I_t is gross investment. $\Xi_t > 0$ is an exogenous shock to investment efficiency (see Fischer, 2002, 2006; Greenwood et al., 1997; Justiniano et al., 2007). Gross investment is generated using the final good. Let $I\xi(I_t/I)$ be the amount of the final good needed to generate I_t , where I is steady state investment, and ξ is an increasing, strictly convex function with $\xi'(1)=1$. The Home entrepreneur's period t budget constraint is:

$$L_t R_t^L - \Delta_t + T_t^E + I\xi(I_t/I) + W_t N_t + d_t^E = L_{t+1} + \theta_t (K_t)^\alpha (N_t)^{1-\alpha}, \quad (3)$$

where L_t is a one-period bank loan received by the Home entrepreneur in period $t-1$. R_t^L is the gross rate on that loan, set at $t-1$. We assume that in period t , the Home entrepreneur defaults by an exogenous amount Δ_t on the contracted amount $L_t R_t^L$ that she owes the bank. T_t^E is a lump sum tax paid by the entrepreneur. d_t^E is the

entrepreneur's dividend income at t . The entrepreneur consumes her dividend income. Her expected lifetime utility at t is $E_t \sum_{s=0}^{\infty} \beta^s u(d_{t+s}^E)$, Maximization of that life-time utility subject to (3) yields these first-order conditions:

$$\begin{aligned} W_t &= (1-\alpha)\theta_t K_t^\alpha N_t^{1-\alpha}, \\ R_{t+1}^L E_t \beta u'(d_{t+1}^E) / u'(d_t^E) &= 1, \\ E_t \beta (u'(d_{t+1}^E) / u'(d_t^E)) \{ \theta_{t+1} \alpha K_{t+1}^{\alpha-1} N_{t+1}^{1-\alpha} + q_{t+1} (1-\delta) \} / q_t &= 1, \end{aligned} \quad (4)$$

where $q_t \equiv \xi'(I_t/I) / \Xi_t$ is the marginal cost of gross investment at date t .

The Home government

At date t , the Home government makes exogenous final good purchases G_t . These purchases are financed using the lump sum taxes levied on the Home household, the Home entrepreneur, and by a lump sum tax levied on the global banker (see below): $G_t = T_t^W + T_t^E + T_t^B$, where T_t^B is the tax paid by the bank to the Home government. The total tax burden is divided between these agents, according to their shares in steady state consumption, i.e. $T_t^i = \lambda^i G_t$ for $i=W, E, B$ where λ^i is a time-invariant factor that equals agent i 's consumption share in total country H consumption.⁴

The global bank

In period t , the global bank receives deposits D_{t+1} and D_{t+1}^* from the Home and Foreign workers, respectively, and makes loans L_{t+1} and L_{t+1}^* to the Home and Foreign entrepreneurs. Let $D_{t+1}^W \equiv D_{t+1} + D_{t+1}^*$ and $L_{t+1}^W \equiv L_{t+1} + L_{t+1}^*$ be worldwide stocks of deposits and loans at the end of period t . The bank faces a capital requirement: her date t capital $L_{t+1}^W - D_{t+1}^W$ should not be smaller than a fraction γ_t of the bank's assets L_{t+1}^W . One may view this as an implicit requirement reflecting market pressures, or as a legal requirement. γ_t is an exogenous random variable. The bank can hold less capital than the required level, but this is costly. Let $x_t \equiv (L_{t+1}^W - D_{t+1}^W) - \gamma_t L_{t+1}^W = (1-\gamma_t)L_{t+1}^W - D_{t+1}^W$ denote the

⁴ E.g. $\lambda^H = C / (C + d^E + d^B / 2)$, where d^S is the banker's steady state consumption (of which 50% is assumed to occur in country H).

bank's 'excess' capital at the end of period t . The bank bears a cost $L^W \phi(x_t/L^W)$ as a function of x_t , where L^W is the steady state stock of loans. ϕ is a convex function ($\phi'' \geq 0$) for which we assume: $\phi(x_t) > 0$ 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 its capital requirement. (Note that the above assumptions imply $\phi'(0) \leq 0$.) At t , the bank also bears an operating cost $\Gamma \cdot (D_{t+1}^W + L_{t+1}^W)$, where $\Gamma > 0$ is the (constant) real marginal cost of taking deposits and making loans. The bank's period t budget constraint is:

$$L_{t+1}^W + D_t^W R_t^D + \Gamma \cdot (D_{t+1}^W + L_{t+1}^W) + L^W \phi(\{L_{t+1}^W(1-\gamma_t) - D_{t+1}^W\}/L^W) + d_t^B = L_t^W R_t^L + D_{t+1}^W - T_t^B - T_t^{B*} - \Delta_t - \Delta_t^*, \quad (5)$$

where d_t^B is the profit (dividend) generated by the bank at t . $T_t^B + T_t^{B*}$ is the total tax paid by the bank (while $\Delta_t + \Delta_t^*$ is the bank's total loan loss).

The global bank acts competitively, and thus loan rates and deposit rates are equated across countries. 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 (5). Ruling out Ponzi schemes, that problem has these first-order conditions:

$$R_{t+1}^D E_t \beta u'(d_{t+1}^B) / u'(d_t^B) = 1 - \Gamma + \phi'_t, \quad R_{t+1}^L E_t \beta u'(d_{t+1}^B) / u'(d_t^B) = 1 + \Gamma + (1-\gamma)\phi'_t,$$

with $\phi'_t \equiv \phi'(\{(1-\gamma_t)L_{t+1}^W - D_{t+1}^W\}/L^W)$.

These equations imply $R_{t+1}^L/R_{t+1}^D = (1 + \Gamma + (1-\gamma_t)\phi'_t) / (1 - \Gamma + \phi'_t)$. Hence, the loan rate spread is a function of the required capital ratio and of the bank's excess capital, x_t . A linear approximation of the bank's Euler equations around $x=0$ yields:

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

Assume that the bank raises deposits *and* loans by one unit. This raises the bank's operating cost by 2Γ units; it also lowers the bank's excess capital by γ_t , which raises the penalty $L^W \phi(x_t/L^W)$ by $-\gamma_t \phi'(x_t/L^W)$. The bank's first order conditions imply that the loan rate spread $R_{t+1}^L - R_{t+1}^D$ covers the marginal cost $2\Gamma - \gamma_t \phi'(x_t/L^W)$. Under strict

convexity of the ‘penalty’ function, $\phi'' > 0$, the marginal value of excess capital is decreasing in excess capital, and hence the spread is an increasing function of excess bank capital. Let $cr_t \equiv (L_{t+1}^W - D_{t+1}^W)/L_{t+1}^W$ be the bank’s capital ratio at t . Note that $x_t/L^W \equiv cr_t - \gamma_t$. Hence,

$$R_{t+1}^L - R_{t+1}^D \cong 2\Gamma + [\gamma\phi''(0) - \phi'(0)]\gamma_t - \gamma\phi''(0) \cdot cr_t.$$

When $\phi''(0) > 0$, the loan rate spread $R_{t+1}^L - R_{t+1}^D$ is hence a *decreasing* function of the actual capital ratio cr_t , and an *increasing* function of the required capital ratio γ_t . The curvature of the bank’s penalty function $\phi''(0)$ governs thus the sensitivity of the loan spread to change in the bank’s capital ratio. A 1 percentage point increase in the capital ratio lowers the loan spread by $4\gamma\phi''(0)$ percentage points per annum.

Forcing variables

There are 11 exogenous forcing variables: Home and Foreign TFP (θ_t, θ_t^*), investment efficiency (Ξ_t, Ξ_t^*), government purchases (G_t, G_t^*), labor supply shocks (Ψ_t^N, Ψ_t^{N*}), loan defaults (Δ_t, Δ_t^*) and the required bank capital ratio (γ_t). We allow for a large number of non-bank related shocks, to give the model the chance to explain the data, in the absence of banking shocks. The recent empirical estimates of DSGE models suggest that many shocks are needed to adequately explain macro time data (Smets and Wouters (2007)).

Following the empirical DSGE literature, we assume that TFP, investment efficiency, government purchases and labor supply shocks follow univariate AR(1) processes (we refer to these shocks as ‘non-bank’ shocks): $\ln(x_t/z) = \rho^x \ln(z_{t-1}/z) + \varepsilon_t^z$ for non-bank shock z_t , where ε_t^z is a normally distributed innovation. We allow for correlation between all non-bank innovations.

We assume that loan default in each country depends on lagged default, and on GDP in the same country, while the required bank capital ratio depends on world GDP:

$$\Delta_t/Y = \rho^\Delta \Delta_{t-1}/Y + \vartheta^\Delta \ln(Y_t/Y) + \varepsilon_t^\Delta, \quad \Delta_t^*/Y^* = \rho^{\Delta^*} \Delta_{t-1}^*/Y^* + \vartheta^{\Delta^*} \ln(Y_t^*/Y^*) + \varepsilon_t^{\Delta^*},$$

$$\ln(\gamma_t/\gamma) = \rho^\gamma \ln(\gamma_{t-1}/\gamma) + \mathcal{G}^\gamma \ln(Y_t^W/Y^W) + \varepsilon_t^\gamma,$$

where ε_t^Δ , ε_t^Δ and ε_t^γ are normal white noises. Y_t , Y_t^* and $Y_t^W \equiv Y_t + Y_t^*$ are Home and Foreign GDP and world GDP respectively. The default innovations ε_t^Δ and ε_t^Δ are correlated with each other, but uncorrelated with the innovations to the non-bank forcing variables. The innovation to the required bank capital ratio ε_t^γ is independent of all other innovations. We assume that default and the required capital ratio are correlated with non-bank forcing, via the dependence of default on GDP. Allowing for a more general pattern of correlation (e.g. allowing the three banking innovations to be correlated with each of the non-banking innovations) would be computationally much more burdensome. As discussed below, we directly estimate the laws of motion of the non-bank forcing variables, using empirical measures of these variables; by contrast, the laws of motion of the banking shocks are estimated through the lens of the DSGE model.

Market clearing

Market clearing for the final good requires:

$$Z_t + Z_t^* = C_t + C_t^* + d_t^E + d_t^{E*} + d_t^B + I\xi(I_t/I) + I^*\xi(I_t^*/I^*) + G_t + G_t^* + L^W \phi(\{L_{t+1}^W(1-\gamma_t) - D_{t+1}^W\}/L^W) + \Gamma \cdot (L_{t+1}^W + D_{t+1}^W).$$

2.2 Model solution

We take a linear approximation of the model equations around a deterministic steady state. The solution of the linearized model is given by $s_t = \Lambda_1 s_{t-1} + \Lambda_2 \varepsilon_t$, where s_t is a vector consisting of states, controls and forcing variables chosen (or realized) in period t , expressed as in deviation from the deterministic steady state. ε_t is the vector of date t innovations to the forcing variables. Λ_1 and Λ_2 are matrices whose elements are functions of the structural parameters.⁵

⁵ We use Chris Sims' MATLAB proc gensys.m to solve the linearized model (Sims (2000)).

3. Econometric approach

The estimation uses empirical information on a subset of the variables included in the vector s_t . Let $\tilde{z}_t$ be the vector of variables used for the estimation: $\tilde{z}_t = \Lambda_3 s_t$, where Λ_3 is a ‘selection matrix’. The econometrician is assumed to observe the vector z_t $z_t = \tilde{z}_t + \omega_t$, where ω_t is a vector of Gaussian i.i.d. measurement errors that has mean zero (measurement error is independent across variables and independent of the forcing variables).

Given the assumption that structural innovations and measurement errors are Gaussian, the likelihood function of the data $Z_T \equiv \{z_t\}_{t=1,\dots,T}$ can easily be derived. See Hamilton (1994, ch.13) and Schmitt-Grohé and Uribe (2011). Let $L(Z_T | \Theta)$ denote the likelihood function, where Θ is the vector of model parameters.

The model is estimated using quarterly data for the US and the EA, for the period 1990q1-2010q3. The following 12 empirical series are used for estimation: US and EA GDP, private consumption, investment, employment, the stock of US and EA commercial bank loans (deflated using the GDP deflator), the loan spread of US commercial banks, and the capital ratio of US commercial banks (based on Flow of Funds data). EA loan spreads are only available for the period since 2003q1; as predicted by the model, the EA loan spread closely tracks the US loan spread (see below). We use the US loan spread as a measure of the global loan spread, and take the US bank capital ratio as a proxy for the capital ratio of the global bank. For estimation, the loan spread and the capital ratio are demeaned, while the other empirical variables are linearly detrended in log-form. (EA data are taken from the ECB’s Euro-Area-Wide-Model data base, and from the ECB Monthly Statistical Bulletin. See the Data Appendix for a more detailed description of the data.) As we use our model features 11 shocks, we need to assume that *at least* one of the 12 empirical series used for estimation is measured with error (in order to ensure that the model is non-singular). We estimate the model under the assumption that *all* observables contain measurement error (assuming that only banking variables contain measurement error does not affect the main results.)

We calibrate parameters whose values are uncontroversial and/or pinned down by (banking) regulations and/or average long run features of bank balance sheets. Following

much of the recent literature on the estimation of DSGE models, we follow a Bayesian approach to estimate the remaining parameters (e.g., Otrok (2000), Smets and Wouters (2007)). Let $p(\Theta)$ be a prior density of Θ . According to Bayes' law, the posterior density of Θ is $p(\Theta|Z_T)=L(Z_T|\Theta)p(\Theta)/L(Z_T)$, where $L(Z_T)\equiv\int L(Z_T|\Theta)p(\Theta)d\Theta$ is the marginal data likelihood of the model. For each model variant discussed below, we report the mode and standard deviation of the posterior parameter density, and the marginal likelihood (a measure of model fit).

3.1. Calibrated parameters

Calibrated technology, preferences and government purchases parameters

The elasticity of final good output with respect to capital is set at $\alpha=0.3$, which implies a 30% labor share, consistent with US and EA data. As is standard in the DSGE literature, the (quarterly) depreciation rate of physical capital is set at $\delta=0.025$ (consistent with the estimates of, e.g., Christiano and Eichenbaum (1992)). We consider a baseline specification in which all agents have log utility, $\sigma=1$, and labor supply is infinitely elastic, $\eta=\infty$; the same values of σ, η have widely been used in macro model (Hansen and Rogerson (1995)), and they are especially useful in the model here as they imply that $\Psi_t^N=W_t/C_t$ holds (from worker first order conditions), which allows direct estimation of the labor supply shock Ψ_t^N . Our empirical measure of Home exogenous demand G_t is the sum of US government consumption and US to countries other than the EA. Foreign exogenous demand is defined analogously, using EA government consumption and net exports (to third countries). During 1990-2010, these measure of exogenous demand represented 14.2% of US GDP and 21.2% of EA GDP, respectively. We set the steady state GDP ratio in both countries at the average of those shares, 17.8%.

Calibrated banking parameters

The mean value of the required bank capital ratio is set at $\gamma=11.17\%$; this corresponds to the average capital ratio of US commercial banks during the sample period 1990-2010 (based on Flow of Funds data). We take as our measure of the US lending rate spread the series 'Commercial and Industrial Loan Rates Spreads over intended federal funds rate'

published by the FRB (Survey of Terms of Business Lending, table E.2). The average real loan rate and the Federal Fund rate (taken as a measure of banks' marginal funding cost) were 3.440% and 1.279% p.a., respectively (real rates are computed using CPI inflation). Hence, the mean loan rate spread was 2.161% p.a.. We set the steady state deposit and loan rates in the model at these average sample rates. (We use US rate information to calibrate the interest rates, as EA rates are only available for 2003-2010. During that period, the mean EA lending spread (2.01%) was close to the value assumed in the calibration. The EA spread closely tracked the US spread, in 2003-2010; correlation: 0.90).⁶ Using the interest rate on short term Certificates of Deposit as a measure of banks' marginal funding cost yields a spread series that has a mean of 1.929% p.a. and a 0.75 correlation with the spread used in the subsequent analysis. Our baseline spread measure tracks information on lending spreads provided by the US Senior Loan Officer Opinion Survey (SLOOS) on Bank Lending Practices—the correlations between our spread measure and the SLOOS 'Net percentage of banks increasing spreads of loan rates over banks' cost of funds to large and middle-market firms' is 0.39; the correlation with the 'Net percentage of banks increasing spreads of loan rates over banks' cost of funds to small firms' is 0.46.

Given our calibration of steady state interest rates, we thus set the quarterly subjective discount factor at $\beta=0.99156$ (as $\beta R^L=1$, from the entrepreneur's Euler equation). The bank's Euler equations imply $R^D\beta=1-\Gamma+\phi'$ and $R^L\beta=1+\Gamma+(1-\gamma)\phi'$. These two conditions pin down the marginal operating cost Γ and the steady state slope of the bank's 'penalty' function ϕ' ($\Gamma=0.25\%$, $\phi'=-0.28\%$).

As the calibrated bank capital ratio matches the average empirical ratio, we assume that excess bank capital is zero in steady state, $L^W(1-\gamma)=D^W$. We set the steady state ratio of the stock of loans to annual GDP at 70% (which corresponds to the mean ratio across the US and EA in 1990-2010).⁷ This calibration pins down the worker's

⁶ Our measure of the EA spread is the MFI loan rate minus the EONIA rate.

⁷ Mean ratio of stock of total bank credit by US Commercial banks to annual GDP: 53%. Mean ratio of EA MFI loans to private sector to annual GDP: 87%.

preference parameter $\Psi^D=0.024$ (that affects the demand for deposits), and the steady state value of the labor supply parameter $\Psi^N=3.25$.⁸

Calibrated shock processes.

As the non-bank forcing variables can be measured directly, we fit (by OLS) AR(1) equations to the forcing variables (instead of estimating their laws of motion through the lens of the DSGE model), and we use the estimated autoregressive parameters and innovation standard deviations to calibrate the non-bank shock processes in the model. Empirically, the non-bank forcing variables are highly correlated. It thus seems important to allow for correlation between the non-bank shocks, in the calibration. To ensure that the cross-correlations of the non-bank forcing variables in the model match empirical correlations, we set the correlations of the non-bank shock *innovations* equal to the empirical (unconditional) correlations of the forcing variables. (In contrast to the approach here, the empirical DSGE literature assumes that all shocks are uncorrelated, and it estimates all shock processes via the full DSGE model; applying that conventional estimation strategy approach to the model here leaves the key empirical results unaffected.)

The estimated time series parameters of the non-bank forcing variables are reported in Table 1 (where a description of the empirical measures used in estimation can also be found). TFP, investment efficiency (measured as the ratio of the CPI to the investment price index), the labor supply shock (measured as the ratio of wage earnings to consumption) and ‘exogenous demand’ (G) are all highly persistent (AR coefficients in the range 0.8-0.98). US innovations to investment efficiency, the labor supply shock and exogenous demand are more volatile than the corresponding EA innovations. ‘Exogenous demand’ is negatively correlated across the US and EA (-0.13), the other forcing variable are positively correlated across the US and EA.

By contrast, we estimate the laws of motion of the loan default and of the required bank capital ratio, through the lens of the DSGE model. The motivation for this is that

⁸ In steady state, the ratio of the capital stock to annual GDP is 2.27, while the consumptions of the worker, the banker and the entrepreneur represent 55.3%, 0.1% and 4.1% of GDP, respectively.

data on EA bank losses are only available for a short time span (2003-); also, it is not clear how to directly measure the implicit capital requirement reflecting market pressures.

4. Data plots and business cycle statistics.

Figure 1-4 plot key macro/financial series. Figure 1 shows linearly detrended log bank loans, loan spreads (% p.a. not demeaned or detrended) and loan loss rates (write-downs, as annualized fractions of the stock of loans), for US commercial banks and EA Monetary and Financial Institutions (MFIs). (EA loan losses and loan spreads are only available for 2003q1-2010q3). Loans grew strongly in the years before 2008, and then collapsed sharply, in the US and EA. Loan loss rates in the US have likewise increased strongly since 2007, especially in the US (the EA loan loss rate series exhibits sizable short-term movements). US and EA loan rate spreads have risen sharply since the start of the crisis; the EA lending spread closely tracks the US spread.

Panel (a) of Figure 2 plots the capital ratio of US commercial banks (CB), computed from Flow of Funds (FoF) data. The capital ratio exhibits relatively mild fluctuations, and mostly stays in the range between 9.5% and 12.5%. Panel (b) of the Figure plots the CB-FoF capital ratio, together with the loan spread (both series are standardized). Except for the period of the financial crisis (when the capital ratio and the spread were above their mean values), the two series are negatively correlated, as predicted by the model. While the loan rate spread rose sharply during the crisis (as mentioned above), the bank capital ratio has had a flat trend since about 2005. It has been argued that this may partly reflect accounting discretion, which has allowed banks to overstate the value of their assets in the crisis (e.g., Huizinga and Laeven, 2009). The correlation between the CB-FoF capital ratio and the lending spread was -0.46 during the period 1990-2007, but close to zero (-0.06) over the whole sample period (1990-2010). Panel (b) of the Figure also plots the (standardized) ‘net percentage of banks increasing spreads of loan rates over cost of funds to large and middle market firms’ (from Senior Loan Officers Opinion Survey, SLOOS). That series closely tracks our loan spread series (correlation 0.39, during 1990-2010). The SLOOS series is negatively correlated with the CB-FoF bank capital ratio (-0.47 for 1990-2007; -0.21 for 1990-2010).

Figure 3 plots the market value of equity to assets (at book values), for financial corporations included in the Dow Jones stock prices index ‘US-Banks’, as reported by

Datastream.⁹ That series exhibits a steady fall since about 2000. The market-based capital ratio fell during the first year of the financial crisis, 2008 (from 10.8% in 2008q1 to 3.8% in 2009q1), but recovered after that (to 7.8% in 2010q3). Its correlation with the loan spread is -0.51, during the sample period.

Figure 4 plots linearly detrended (log) GPD, private consumption, investment and employment. In the second half of 2008, these variables contracted sharply, in the US and EA. The fall in US and EA output was similar (-6%) between 2007q4 and 2009q4. Consumption and investment fell much more sharply in the US than in the EA; e.g. US investment was 34% below trend in 2009q2, while EA investment was ‘merely’ 8% below trend, in the same quarter.

Table 2 reports moments of HP filtered key macro and banking variables, for the US and the EA (1990q1-2010q3). Output volatility 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. US investment is almost twice as volatile as EA investment. In both countries, loans are more volatile than output, while the loan spread is countercyclical. The variables considered in the Table are positively correlated across the US and EA.

5. Model estimates

5.1. Estimated parameters

We estimate the following behavioral parameters, using the Bayesian approach: (i) sensitivity of the (annualized) loan rate spread to the bank capital ratio, $4\gamma\phi$; (ii) curvature of the cost of investment, ξ ; (iii) parameters of the laws of motion of loan defaults and the required bank capital ratio; (iv) standard deviations of measurement errors of the 12 empirical variables used for estimation.

⁹ The ‘US-Banks’ index only include the major financial institutions, while Flow of Funds data cover all firms in a given sector. The average ‘market-value’ based capital ratio was 21.7% during 1990-2010. This greater ratio reflects the fact that the market value of equity is generally greater than its book value. Leverage measures based on book-value equity (also available from Datastream) are much closer to FoF-based leverage measures, 7% (see Kollmann and Zeugner (2011) for further comparisons between FoF and market-value based capital ratios).

Prior distributions

The priors on the estimated are shown in column (1). We set the mean of the prior distribution at $4\gamma\phi$ at 0.2, which implies that a 1 percentage point increase in the bank capital ratio lowers the loan spread by 20 basis points p.a. This corresponds of the estimate of the sensitivity of the loan spread (w.r.t. bank capital) based on aggregate spreads and bank capital data provided by Kollmann et al. (2011), and is also in the range of estimates based on micro-banking data (e.g., Hubbard et al. (2002), Santos and Winton (2009)). The mean of the prior distribution of the curvature of the investment cost is set at 1, which implies that a 1% increase in investment raises the price of investment by 1% [add: references]. The standard deviations of the prior distributions of these parameters are set at half of the mean of the distribution, which (for the gamma prior distribution assumed here) implies that a wide range of parameter values around the mean has non-negligible mass.

The prior distributions of the standard deviations of innovations to Home and Foreign loan default (normalized by steady state GDP) and to the benchmark (required) bank capital ratio have a mean of 0.5% and a standard deviation of 0.1%.¹⁰ The prior distributions of the AR(1) correlation coefficients of the banking shocks, and of the cross-country correlations of default have a mean 0.5 and standard deviation 0.1. The response coefficients of loan defaults and the required capital ratio has a zero prior mean. The prior distribution of the standard deviation of measurement error has mean equal to 1/4 of the standard deviation of the corresponding empirical series, and a standard deviation that is set at 1/5 of the mean.

Posterior estimates

Columns (2) and (3) of Table 3 report the mode of the posterior parameter distribution, and the standard deviation of the posterior.¹¹ The data are informative about the estimated parameters: in almost all cases, the posteriors have lower standard deviations than the

¹⁰ The prior distribution of the standard deviations of shock innovations is inverted gamma (IG). The IG has fatter tails than the normal distribution. Hence, a 0.1% standard deviation of the prior is not very restrictive. The empirical results are not very sensitive to the choice of priors.

¹¹ The mode of the posterior distribution is the parameter vector Θ that maximizes the posterior distribution; the standard deviations of the posterior reported here are based on a Normal approximation of the posterior distribution; see, e.g., Canova (2007), p.340.

priors, and the posterior estimates (modes) differ noticeably from the priors. The posterior estimate suggest that a 1percentage increase in the bank capital ratio is accompanied by a 0.45 basis point in the annualized loan rate spread. The posterior estimates suggest that US loan default innovation are less volatile than EA loan default innovations (posterior std. 0.59% and 1.15%, respectively). The required bank capital ratio undergoes sizable fluctuations (posterior std.: 0.54%). US and EA loan default shocks are positively correlated (0.44). Surprisingly, the responses coefficients of loan default and of the required bank capital ratio to GDP are slightly positive. The posterior estimates of the standard deviation of measurement error are mostly markedly smaller than the priors.

Business cycle moments implied by posterior estimates

Table 4 implies business cycle statistics (of HP filtered theoretical variables) implied by the posterior parameter estimates. The reported moments pertain to country 1, which we take as the theoretical counterpart of the US (the predicted moments for the EA are similar). Column (1) allows for all 11 structural shocks, and measurement error. In Columns (2)-(7), only one type of shocks is considered, without measurement error (the model is not re-estimated). Column (8) reports empirical moments (from Table 1). The model with all shocks generates moments that are broadly in the range of the empirical moments. The predicted standard deviation of GDP, 1.16% is larger than the empirical standard deviation, 1.12%

The model (with all shocks) captures the fact that investment and loans are more volatile than GDP, but it over-predicts the volatility of consumption (predicted relative standard deviation: 1.21). The model also captures the cross-correlations of the variables with domestic GDP—it correctly predicts that the loan spread is countercyclical. Finally, the model correctly predicts that the variables considered in the Table are *positively* correlated across the US and the EA—the predicted cross-country correlation of GDP is 0.44, which is close to the empirical correlation (0.56).

The model variants with just one type of shock show that TFP shocks and Labour supply shocks are the main drivers of GDP fluctuations (predicted std. of GDP with just these shocks: 0.87% and 0.80%, respectively). The other shocks induce much smaller

fluctuations in GDP (default shocks and shocks to the required bank capital ratio induce GDP standard deviations of 0.28% and 0.13%, respectively).

With just TFP shocks, just investment efficiency shocks, and just labor supply shocks GDP is negatively correlated across countries. By contrast, government purchases shocks and the banking shocks induce positive cross-country output correlations. With just default shocks, GDP, investment and employment that are (almost) *perfectly* correlated across the two countries. This is due to the fact that a default by Home entrepreneurs (say) lowers the bank's capital, which triggers a rise in the world-wide loan spread and, in response to this, loans, investment and GDP fall in both countries.

Forecast variance decomposition

Table x [to be added] decomposes the forecast error variance of GDP, consumption, investment, employment, loans, and spreads. 'Banking shocks' (i.e. the default shocks and the shocks to the required bank capital ratio) account for about 5% of the forecast error variance of country 1 and country 2 GDP, and for about 20% of the forecast error variance of investment, at horizons ranging between 1 and 100 quarters. Slightly less than half of each country's GDP forecast variance is accounted for by foreign default shocks. The 'banking shocks' account for 99% of the forecast error variance of the loan spread and of country 2 loans, and for 65% of the forecast error variance of country 1 loans (at all horizons).

Decomposing historical time series

A decomposition of the historical time series into contributions of the different shocks yields a picture that is consistent with the forecast error variance decompositions. Banking shocks account for a small component of the historical time series on GDP and investment. Figure 5 shows decomposes the historical series into the contributions of the banking shocks and of US and EA non-bank shocks. The banking shocks account for about 10%-20% of the fall in GDP during the financial crisis. The contribution of banking shocks to the decline in EA investment is more sizable—close to 50%.

Does global banking matter for the (international) transmission of shocks?

While bank-specific *shocks* only play a relatively modest role for fluctuations in GDP, the existence of (global) banks matters for the transmission of shocks to GDP. Hence, banks do not matter primarily as a source of disturbance, but because they affect the transmission mechanism. When we (essentially) eliminate the bank, by eliminating the bank-specific shocks, by setting the steady state loan spread at a very small number, and by setting the curvature of the bank's penalty function ϕ'' very close to zero, so that the loan spread is (essentially) constant (and close to zero), then the model here behaves like a standard international RBC model with a 'bonds-only-structure' (Kollmann (1996)). The cross-country correlation of GDP and investment drop to -0.08 and -0.17 (compared to 0.32 and 0.59 in the baseline model with banks). These predicted correlations are obtained by 'switching off' the bank, in the baseline mode, without re-estimating the non-banking parameters. Re-estimating a model variant in which the bank is a 'veil' yields much lower predicted cross-country output correlations (-0.40). The marginal likelihood of the baseline model (with banking friction) is 2122.42, while the marginal likelihood of the model without a bank is -92488.¹² Thus, the model with a global bank is overwhelmingly preferred to the model without bank.

To be added:

Results are robust to estimating the time series parameters of all forcing variables and also other behavioral parameters (risk aversion, labor supply elasticity etc.).

6. Conclusion

Shocks originating in the banking system were not a major source of fluctuations in US and EA GDP (but these shocks matter more for investment). However banking has a noticeable effect on the transmission of other macro shocks. Global banking leads to more synchronized national business cycles.

¹² We compute the marginal likelihood using a Laplace approximation.

DATA APPENDIX

To be added

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Figure 1. Bank loans, loan spreads, loan loss rates

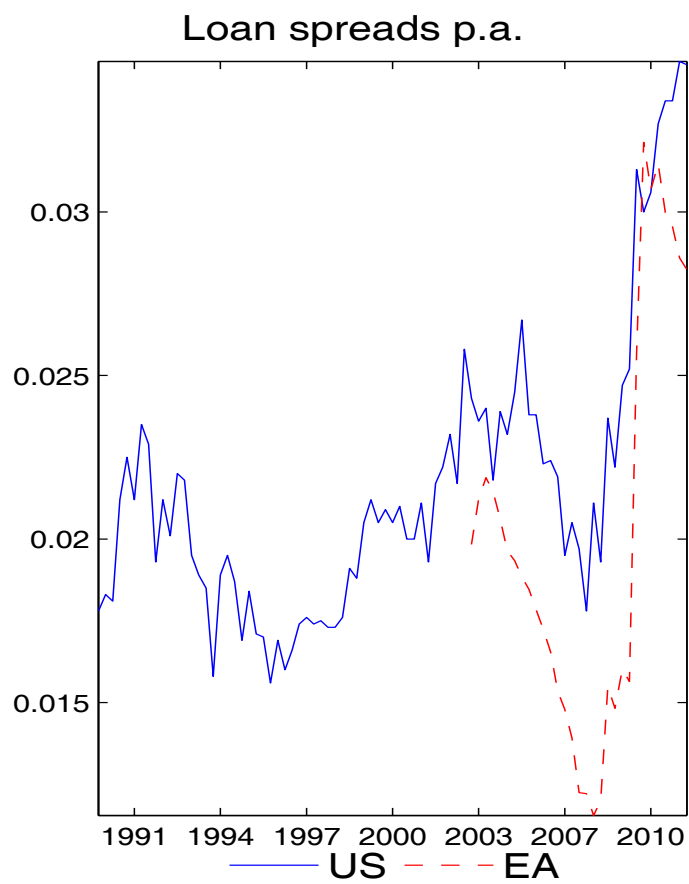
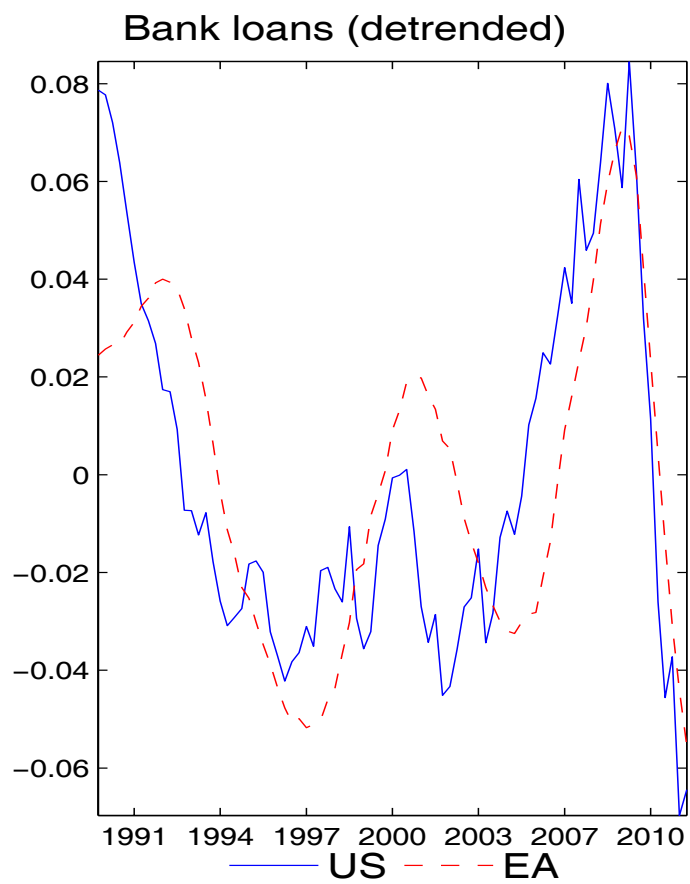
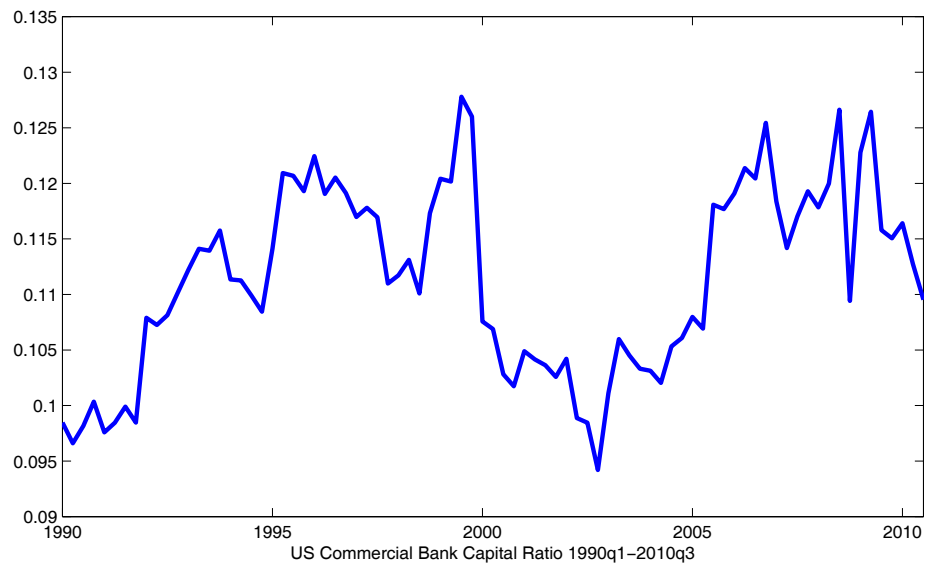


Fig. 2 US Commercial Bank Capital Ratios and Loan Rate Spreads
(a) Capital Ratio



(b) Capital Ratio, Loan Rate Spread

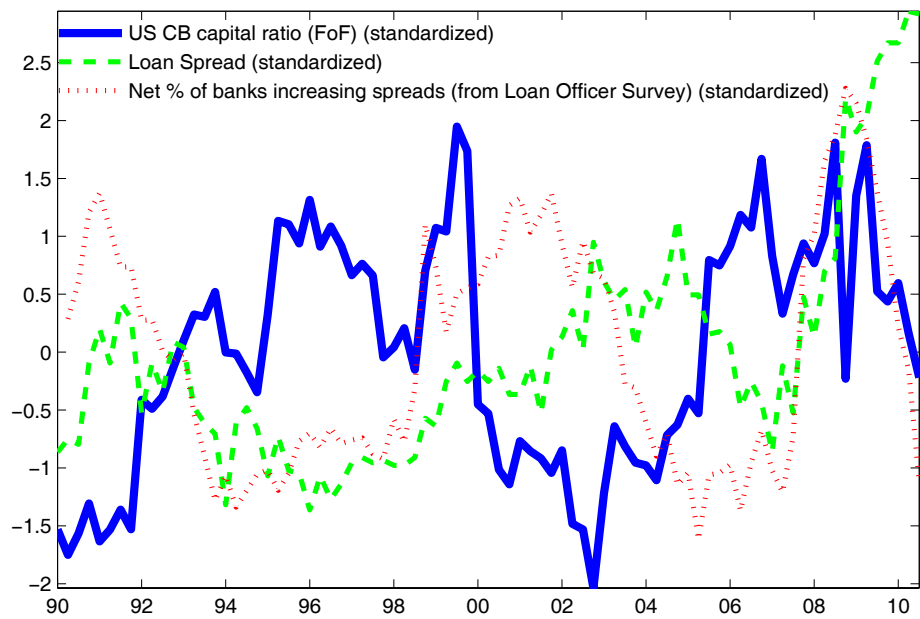
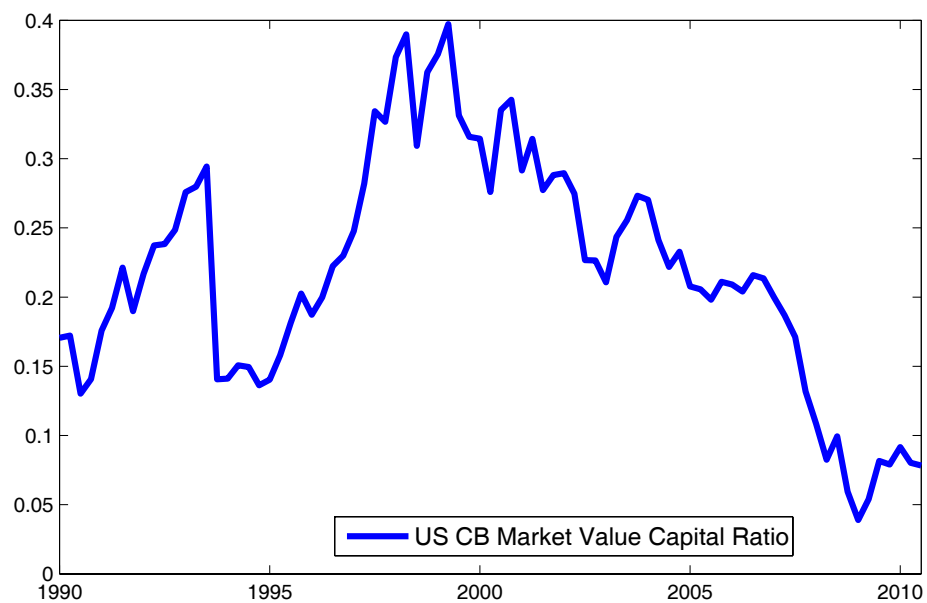


Fig. 3 US Banks, *Market Value* Based Capital Ratio (Dow Jones US Banks Index) and Loan Rate Spreads

(a) Capital Ratio



(b) Capital Ratio, Loan Rate Spread (standardized)

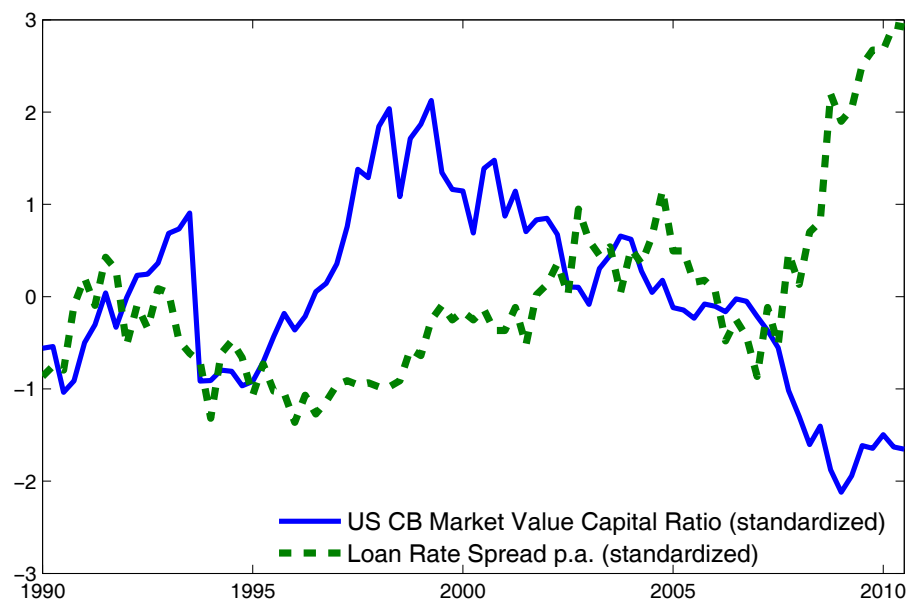


Figure 4. Macro data

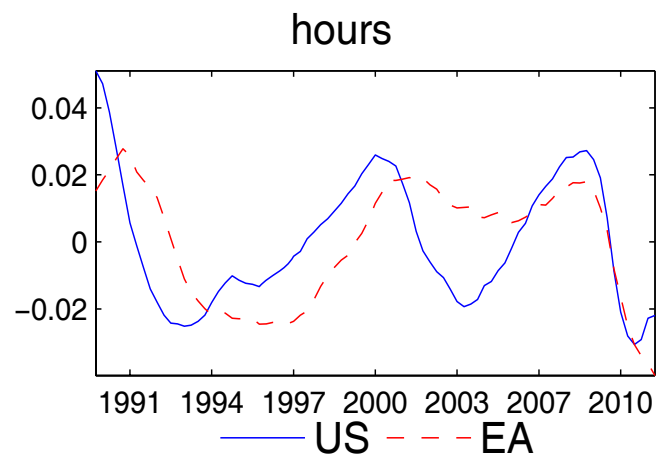
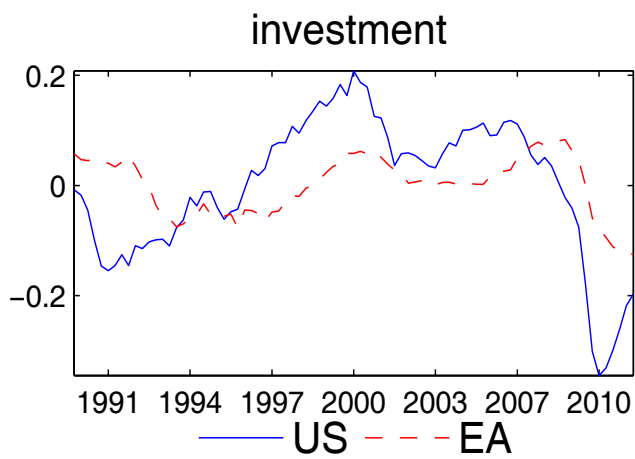
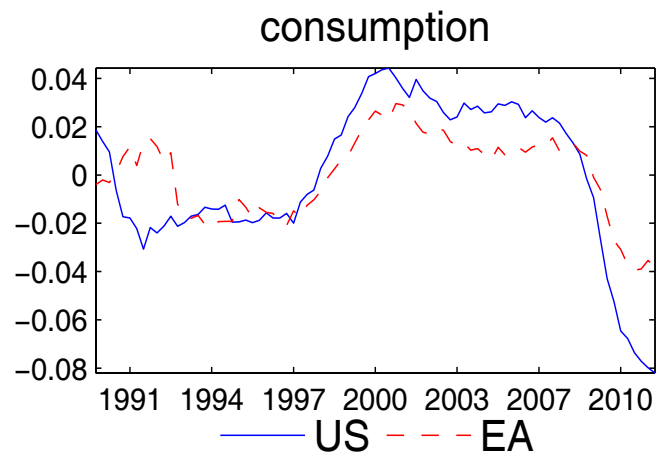
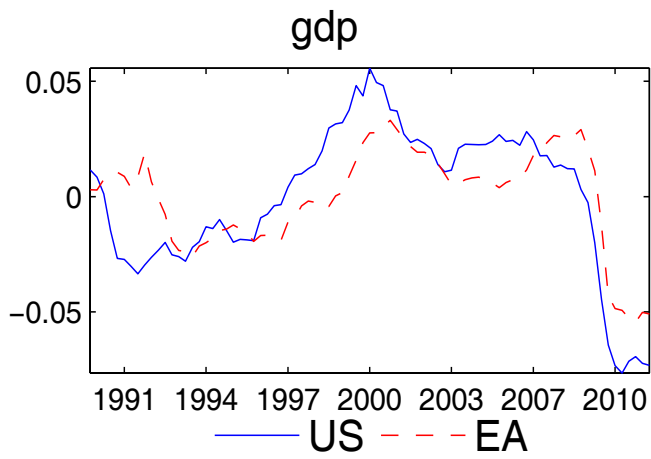


Figure 5. Historical Decompositions

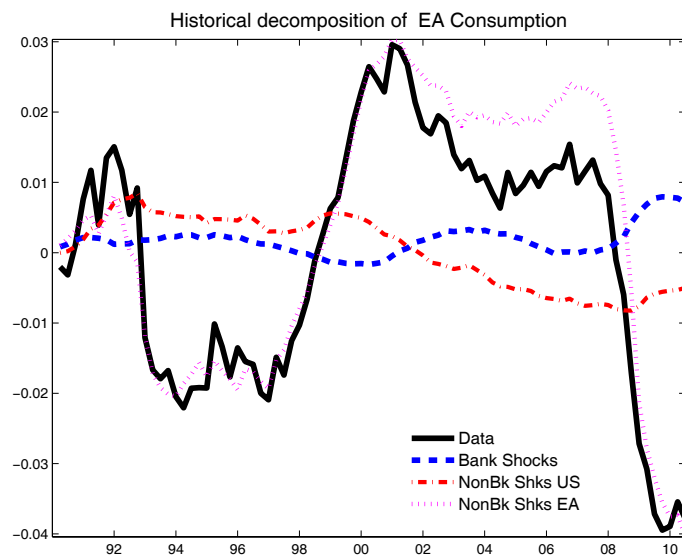
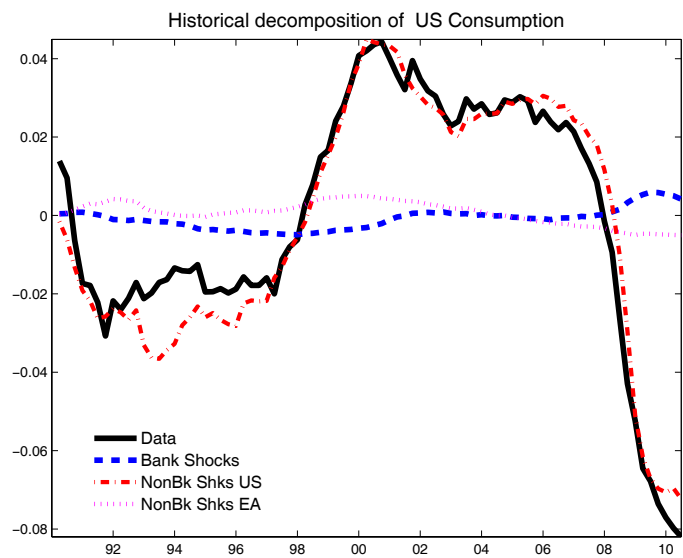
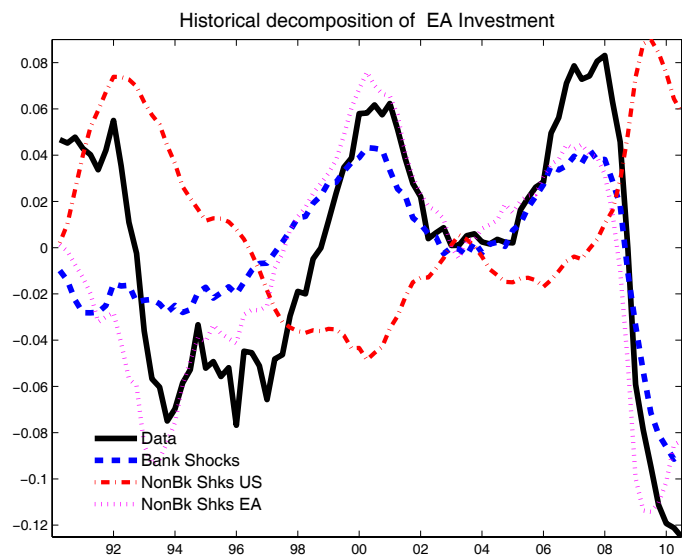
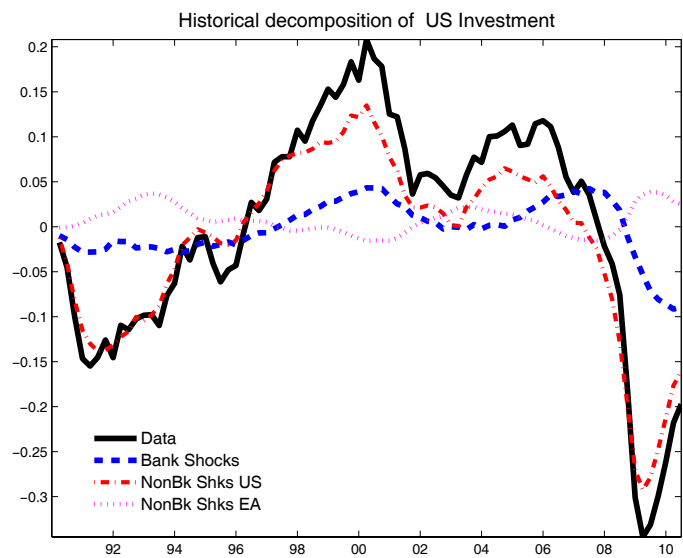
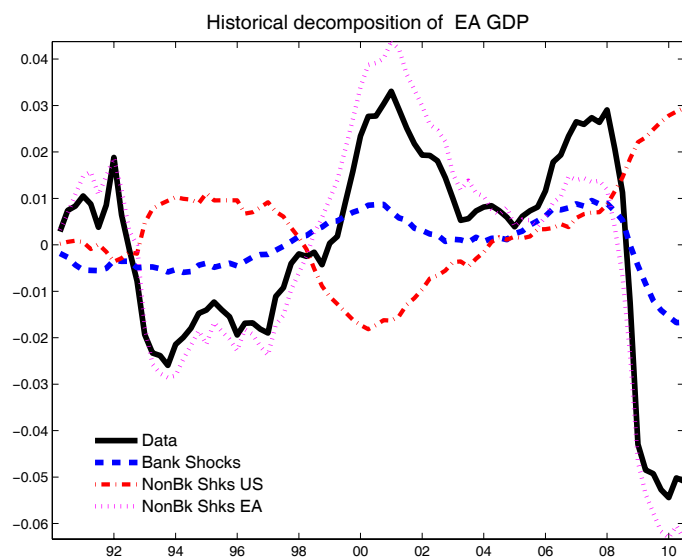
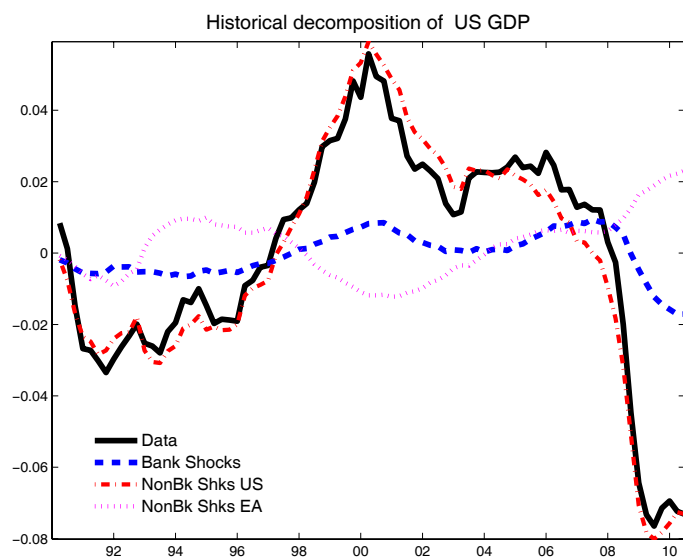


Table 5—ctd.

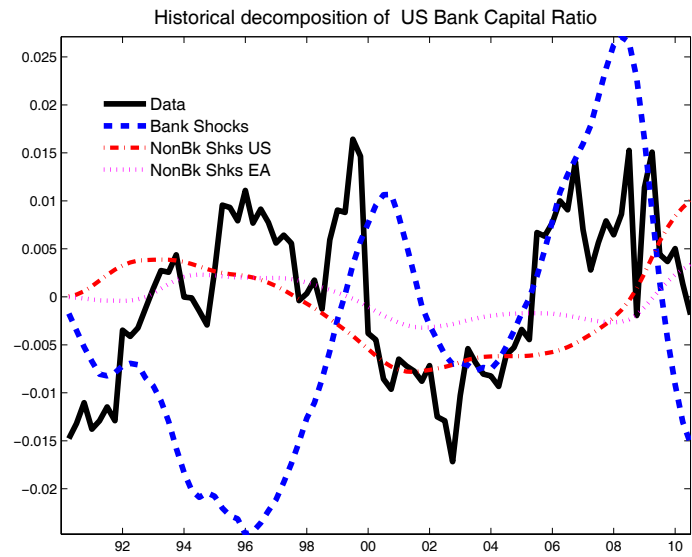
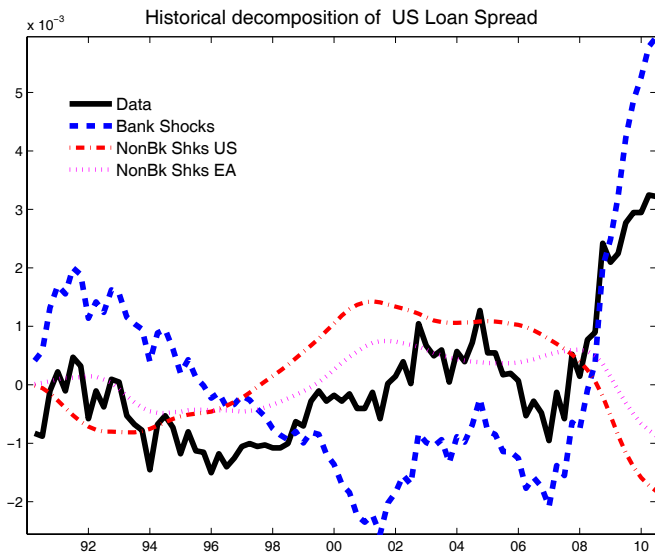
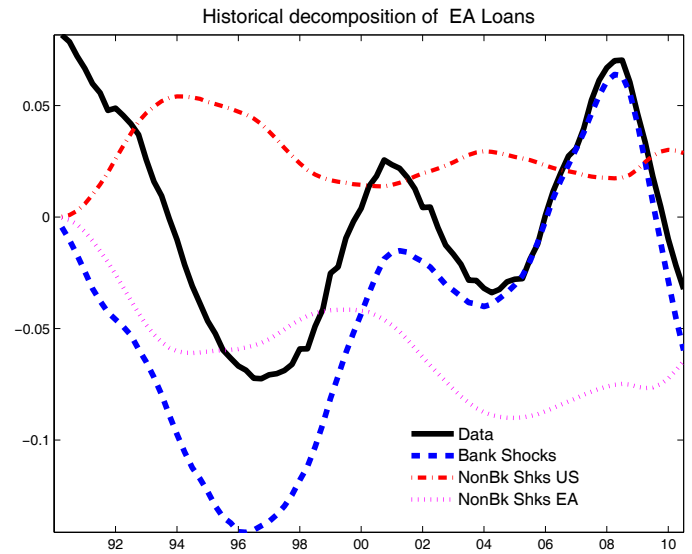
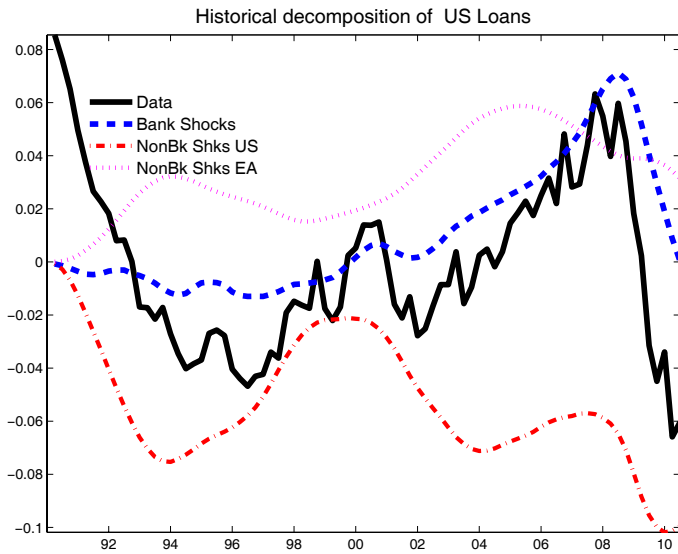


Table 1. Estimated parameters of exogenous processes (1990q1-2010q3)

(a) Autocorrelations								
	US TFP	EA TFP	US Ieff	EA Ieff	US G	EA G	US LS	EA LS
	0.93	0.96	0.97	0.98	0.92	0.81	0.96	0.93
(b) Standard deviations of innovations (diagonal) and cross-correlations (off-diagonal elements)								
	US TFP	EA TFP	US Ieff	EA Ieff	US G	EA G	US LS	EA LS
US TFP	0.48%	0.51	0.27	0.20	-0.71	-0.24	-0.48	-0.64
EA TFP		0.48%	0.53	0.63	-0.75	0.41	-0.90	-0.48
US Ieff			0.64%	0.84	-0.12	0.16	-0.54	0.05
EA Ieff				0.31%	-0.27	0.37	-0.70	0.14
US G					2.61%	-0.13	0.73	0.65
EA G						1.43%	-0.35	0.19
US LS							0.80%	0.47
EA LS								0.65%

Note: The Table reports the time series parameters if of linearly detrended logged forcing variables.

TFP: total factor productivity; Ieff: investment efficiency; G: government consumption plus net exports to third countries; LS: Labor supply shock

Log TFP is estimated as $\ln(Y_t) - 0.7\ln(N_t)$ where Y_t and N_t are GDP and employment, respectively. Our estimate of investment efficiency is the ratio of the CPI to the investment deflator. Our estimate of the labor supply shock is $\Psi_t^N = W_t/C_t$, where W_t is wage earnings per employee, while C_t is per capita consumption. US G is the sum of government consumption and of US net exports to countries other than the EA (EA G is defined analogously).

Table 2. Historical business cycle statistics, 1990q1-2010q3

	US	EA
Standard deviation (in%)		
GDP (Y)	1.12	1.14
Relative standard deviations (std(x)/std(GDP))		
Consumption	0.82	0.68
Investment	4.54	2.52
Employment	1.03	0.62
Loans	1.68	1.83
Loan spread (p.a.)	0.17	0.33
Correlation with domestic GDP		
Consumption	0.89	0.83
Investment	0.92	0.93
Employment	0.79	0.83
Loans	0.48	0.62
Loan spread (p.a.)	-0.52	-0.91
Cross-country correlations		
GDP	0.56	
Consumption	0.39	
Investment	0.45	
Employment	0.53	
Loans	0.64	
Loan spread (p.a.)	0.79	

Note: moments of HP filtered series are shown (GDP, consumption, investment, employment and loans were logged before applying the filter). Sample period: 1990q1-2010q3 (except for EA loan spread: 1997q3-2010q3).

Table 3. Prior and posterior distribution of parameters—baseline specification

Parameter	Prior distribution			Posterior distribution	
	Mean	Std	Distrib	Mode	Std
	(1)	(2)	(3)	(4)	(5)
Behavioral parameters					
$4\gamma\phi''$	0.20	0.10	G	0.45	0.01
ξ''	1.00	0.50	G	0.12	0.00
Banking shocks					
<i>Standard deviatitions (%) and cross-correlations</i>					
σ^Δ	0.50	0.10	IG	0.59	0.00
$\sigma^{\Delta*}$	0.50	0.10	IG	1.15	0.01
σ^γ	0.50	0.10	IG	0.54	0.01
$Corr(\varepsilon^\Delta, \varepsilon^{\Delta*})$	0.50	0.10	B	0.44	0.01
<i>AR coefficients</i>					
ρ^Δ	0.50	0.10	B	0.63	0.01
$\rho^{\Delta*}$	0.50	0.10	B	0.54	0.01
ρ^γ	0.50	0.10	B	0.79	0.01
<i>Responses to GDP</i>					
g^Δ	0.00	0.10	N	0.12	0.00
g^γ	0.00	0.10	N	0.06	0.00
Standard deviations (%) of measurement errors					
GDP US	0.79	0.16	IG	0.39	0.04
GDP EA	0.54	0.11	IG	0.35	0.04
I US	3.15	0.63	IG	2.62	0.27
I EA	1.33	0.26	IG	0.89	0.12
C US	0.78	0.16	IG	0.68	0.08
C EA	0.44	0.09	IG	0.37	0.05
N US	0.47	0.09	IG	0.29	0.04
N EA	0.45	0.09	IG	0.28	0.04
Loan rate spread	0.03	0.01	IG	0.02	0.00
Loans US	0.85	0.17	IG	0.83	0.07
Loans EA	1.10	0.22	IG	0.44	0.05
Bank cap. ratio	0.21	0.04	IG	1.34	0.11

Notes: Columns (1) and (2) shows the mean and standard deviations of the prior distribution for model parameters. In Column (3), B,G,IG,N indicate the distribution of the prior (B: Beta; G: Gamma; IG: Inverted Gamma; N: Normal). Column (4) reports the mode of the posterior distribution (i.e. the parameter vector Θ that maximizes the posterior distribution); Column (5) reports standard deviations of the posterior distribution (based on a Normal approximation of the posterior distribution; see Canova (2007, p.340)).

Table 4. Country 1 ('US') business cycle statistics implied by posterior mode of model parameters—baseline estimation

	Just shocks to:							DATA
	All shocks	TFP	Inv.Eff.	G	LabS	Default	Reqd.BkCap	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Standard deviation (in%)								
GDP (Y)	1.16	0.87	0.11	0.30	0.80	0.28	0.13	1.12
Relative standard deviations (std(x)/std(GDP))								
Consumption	1.21	0.65	0.76	0.32	0.96	0.35	0.34	0.82
Investment	3.82	1.39	16.35	0.99	1.76	5.29	5.24	4.54
Employment	0.91	0.49	0.96	1.40	1.40	1.41	1.38	1.03
Loans	1.05	0.41	5.08	0.45	0.35	2.50	0.96	1.68
Loan spread	0.38	0.08	0.19	0.07	0.08	0.73	2.20	0.17
Correlation with domestic GDP								
Consumption	0.68	0.91	0.10	-0.98	0.90	-0.85	-0.92	0.89
Investment	0.67	0.95	0.03	0.13	0.94	0.99	0.99	0.92
Employment	0.75	0.81	0.82	0.99	0.99	0.99	0.99	0.79
Loans	0.29	0.36	0.76	0.19	0.56	0.54	0.82	0.48
Loan spread	-0.06	0.31	0.65	0.58	0.36	-0.93	-0.89	-0.52
Cross-country correlations								
GDP	0.44	-0.15	-0.19	0.46	-0.14	1.00	1.00	0.56
Consumption	0.76	0.70	0.79	0.88	0.62	0.89	1.00	0.39
Investment	0.43	0.05	-0.51	-0.14	-0.15	1.00	1.00	0.45
Employment	0.12	-0.88	0.07	0.50	-0.14	1.00	1.00	0.53
Loans	0.24	-0.52	-0.84	0.53	-0.44	0.64	1.00	0.64

Note: The Table shows moments of HP filtered model variables, for the mode posterior estimate of the model parameters. The moments pertain to country 1, which we take as the theoretical counterpart of the US. Column (1) allows for all 11 structural shocks, and measurement error. In Columns (2)-(7), only one type of shocks is considered, without measurement error (the model is not re-estimated). Column (8) reports US empirical moments (from Table 1). Col. (2): just TFP shocks (θ_t, θ_t^*) ; Col. (3): just shocks to investment efficiency (Ξ_t, Ξ_t^*) ; Col. (4): just shocks to government purchases (G_t, G_t^*) ; Col.(5): just labor supply shocks (Ψ_t^N, Ψ_t^{N*}) ; Col.(6): just loan default shocks (Δ_t, Δ_t^*) ; Col. (7): just shock to benchmark bank capital ratio (γ_t) .