Financial Business Cycles*

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Abstract

Using Bayesian methods, I estimate a DSGE model where a recession is initiated by losses suffered by financial intermediaries and exacerbated by their inability to extend credit to the real economy. The event that triggers the recession is similar to a redistribution shock: a small sector of the economy – borrowers who use their home as collateral – defaults on their loans (that is, they pay back less than contractually agreed). When banks hold little equity in excess of regulatory requirements, their losses require them to react immediately, either by recapitalizing or by deleveraging. By deleveraging, banks transform the initial shock into a credit crunch, and, to the extent that some firms depend on bank credit, amplify and propagate the financial shocks to the real economy. I find that this shock – combined with other financial shocks that affect leveraged sectors of the economy – accounts for more than one half of the decline in output during the Great Recession.

KEYWORDS: Banks, DSGE Models, Collateral Constraints, Housing, Bayesian estimation.

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1 Introduction

In this paper I estimate, using Bayesian methods, a model with banks and financially constrained households and firms. I present a basic model which conveys the main ideas. I then take a richer version of this model to the data, estimate it using Bayesian methods, and use it to provide an accounting of the role played by different financial shocks and frictions during the financial crisis.

The main questions that I ask are: (1) How much can redistributions of wealth – such as those that take place when borrowers default on their debts — disrupt the credit intermediation process? (2) Can changes in credit standards affect business cycles? (3) How important are shocks to asset prices for business fluctuations? To answer these questions, I add to an otherwise standard RBC model financial frictions on banks, on households, and on firms, and conduct a horse race between familiar shocks (a shock to the consumption/leisure margin, shocks to technology) and not-so-familiar ones. The not-so-familiar ones are redistribution shocks[1] (transfers of wealth from savers to borrowers that take place in the event of default); credit squeezes (changes in maximum loan-to-value ratios) and asset price shocks (changes in the value of collateral): these "financial shocks" were arguably at the core of the last recession. More generally, financial factors were at the core of at least two of the last three recessions in the United States (the 1990-91 one and the Great Recession of 2007-2009): yet a large class of estimated dynamic equilibrium models either ignore financial frictions, or consider one set of financial frictions independently from others. While this approach might be useful for building intuition, it eludes a proper quantification of the role of financial factors in business fluctuations, especially when several sets of financial frictions reinforce and amplify each other.

The estimation of the model parameters and structural shocks gives large prominence to financial business cycles. I find that financial shocks account for more than one half of the decline in private GDP during the 2007-2009 recession, and they also play an important, although less sizeable, role during other recessions. As with any estimated model, my approach has the natural interpretation of an accounting exercise. This happens because some of the key shocks are directly used as observables at the estimation stage, so that their filtering is decoupled from the estimation of the rest of the model's structural parameters.[2]

At the core of the paper is the idea that business cycles are financial rather than real. That is,

[1] Throughout the paper, I use the terms "redistribution shocks", "repayment shocks" and "default shocks" interchangeably.

[2] My approach is inspired by a large body of literature, including the recent work by Jermann and Quadrini (2012) who construct time series for financial and technology shocks using a Solow-residual-style approach and show that the series constructed using this approach are highly correlated with those obtained through a Bayesian estimation exercise.

rather than originated and propagated by changes in technology, business cycles are mostly caused by disruptions in the flow of resources between different groups of agents. In the model economy of this paper, these disruptions take place when a group of agents defaults on its obligations, therefore paying back less than contractually agreed. Or when credit limits are relaxed or tightened either in response to changes in asset prices or for some other exogenous reason. Of course, many of the stories told here resemble familiar accounts of the Great Recession: the bursting of the housing bubble merely changed the value of houses in units of consumption, yet it lead to a wave of defaults and to a severe crisis in the financial sector. The ensuing problems of the financial institutions that owned mortgages lead to a reduction in the supply of credit to all sectors of the economy. Many of these ideas are all familiar. The novel elements are the financial shocks, and the estimation.[3]

Several of the ideas and modeling devices in this paper build on an important tradition in macroeconomic modeling that treats banks as intermediaries between savers and borrowers. Recent contributions include Brunnermeier and Sannikov (2010), Angeloni and Faia (2009), Gerali, Neri, Sessa, and Signoretti (2010), Kiley and Sim (2011), Kollmann, Enders, and Muller (2011), Meh and Moran (2010), Williamson (2012), and Van den Heuvel (2008). The reason why banks exist in my model is purely technological: without banks, the world would be autarchic and agents would be unable to transfer resources across each other and over time. As in the recent work by Gertler and Karadi (2011) and Gertler and Kiyotaki (2010), I give a prominent role to banks by assuming that intermediaries face a balance sheet constraint when obtaining deposits. In these papers however, the shock that causes a financial business cycle is a shock to the quality of bank capital that is, by design, calibrated to produce a downturn as big as in the data. Instead, I either calibrate – in the basic model – the size of the shock by using information on losses suffered by financial intermediaries during the Great Recession, or estimate – in the extended model – all the shocks using Bayesian techniques. The advantage of the estimation strategy is obvious, and opens the avenue for a richer treatment of many of the questions that are left unanswered in the paper. Another important difference is that I layer two sets of financial frictions in the model: on the one hand, banks face frictions in obtaining funds from households; on the other, entrepreneurs face frictions in obtaining funds from banks.

[3] Regarding the focus on estimation, closely related to my work are the papers of Jermann and Quadrini (2012) and Christiano, Motto, and Rostagno (2012), but these models do not have an explicit modeling of the banking sector.

2 The Basic Model and the Impact of a Financial Shock

2.1 Markets, Technology and Preferences

I consider a discrete-time economy. The economy features three agents: households, bankers, and entrepreneurs. Each agent has a unit mass.[4] Households work, consume and buy real estate, and make one-period deposits into a bank. The household sector in the aggregate is net saver. Entrepreneurs accumulate real estate, hire households, and borrow from banks. In between the households and the entrepreneurs, bankers intermediate funds. The nature of the banking activity implies that bankers are borrowers when it comes to their relationship with households, and are lenders when it comes to their relationship with the credit-dependent sector – entrepreneurs – of the economy. I design preferences in a way that two frictions coexist and interact in the model's equilbrium: first, bankers' are credit constrained in how much they can borrow from the patient savers; second, entrepreneurs are credit constrained in how much they can borrow from bankers.

Households. The representative household chooses consumption C_t, housing H_t, and time spent working $N_{H,t}$ to solve the following intertemporal problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta_H^t \left(\log C_{H,t} + j \log H_{H,t} + \tau \log \left(1 - N_{H,t}\right)\right),$$

where β_H is the discount factor, subject to the following flow-of-funds constraint:

$$C_{H,t} + D_t + q_t \left(H_{H,t} - H_{H,t-1}\right) = R_{H,t-1} D_{t-1} + W_{H,t} N_{H,t} + \varepsilon_t, \tag{1}$$

where D_t denotes bank deposits (earning a predetermined, gross return $R_{H,t}$), q_t is the price of housing in units of consumption, and $W_{H,t}$ is the wage rate. Housing does not depreciate. The term ε_t denotes a redistribution/repayment shock that transfers wealth from the bank to the household (the same shock, with opposite sign, appears in the banker's budget constraint too). Here, it captures losses on banks which are gains from the households and, absent equilibrium effects, should wash out in the aggregate (they do not in this model). The optimality conditions yield standard first-order conditions for consumption/deposits, housing demand, and labor supply:

[4] Except for the introduction of the banking sector, the model structure closely follows a flexible price version of the basic model in Iacoviello (2005), where credit-constrained entrepreneurs borrow from households directly. Here, banks intermediate between households and entrepreneurs.

$$\frac{1}{C_{H,t}} = \beta_H E_t \left(\frac{1}{C_{H,t+1}} R_{H,t} \right), \tag{2}$$

$$\frac{q_t}{C_{H,t}} = \frac{j}{H_{H,t}} + \beta_H E_t \left(\frac{q_{t+1}}{C_{H,t+1}} \right), \tag{3}$$

$$\frac{W_{H,t}}{C_{H,t}} = \frac{\tau}{1 - N_{H,t}}. \tag{4}$$

Entrepreneurs. A continuum of unit measure entrepreneurs solve the following problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta_E^t \log C_{E,t}$$

subject to:

$$C_{E,t} + q_t \left(H_{E,t} - H_{E,t-1} \right) + R_{E,t} L_{E,t-1} + W_{H,t} N_{H,t} + ac_{EE,t} = Y_t + L_{E,t}, \tag{5}$$

$$Y_t = H_{E,t-1}^{\nu} N_{H,t}^{1-\nu}, \tag{6}$$

$$L_{E,t} \leq m_H E_t \left(\frac{q_{t+1}}{R_{E,t+1}} H_{E,t} \right) - m_N W_{H,t} N_{H,t}. \tag{7}$$

Here, $L_{E,t}$ are loans that banks extend to entrepreneurs (yielding a gross return $R_{E,t}$). Entrepreneurs own housing (commercial real estate) which, combined with household labor, produce the final output Y_t.

To motivate entrepreneurial borrowing, I assume that entrepreneurs discount the future more heavily than households and bankers. Formally, their discount factor satisfies the restriction that $\beta_E < \frac{1}{\gamma_E \frac{1}{\beta_H} + (1-\gamma_E) \frac{1}{\beta_B}}$. Entrepreneurs cannot borrow more than a fraction m_H of the expected value of their real estate stock. In addition, the borrowing constraint stipulates that a fraction m_N of the wage bill must be paid in advance, as in Neumeyer and Perri (2005). The term $ac_{EE,t} = \frac{\phi_{EE}}{2} \frac{\left(L_{E,t} - L_{E,t-1} \right)^2}{L_E}$ is a quadratic loan portfolio adjustment cost, assumed to be external to the entrepreneur. This cost penalizes entrepreneurs for changing their loan balances too quickly between one period and the next: it captures the idea that the volume of lending changes slowly over time.[5]

Denoting with $\lambda_{E,t}$ the Lagrange multiplier on the borrowing constraint, the first order condi-

[5] Aliaga-Daz and Olivero (2010) present a DSGE model of hold-up effects where switching banks is costly for entrepreneurs. Curdia and Woodford (2010) and Goodfriend and McCallum (2007) develop models of financial intermediation with convex portfolio adjustment costs which mimic the functional form adopted here.

tions for optimization for loans, real estate and labor are respectively:

$$\left(1-\lambda_{E,t}-\frac{\partial ac_{LE,t}}{\partial L_{E,t}}\right)\frac{1}{c_{E,t}}=\beta_E E_t\left(R_{E,t+1}\frac{1}{c_{E,t+1}}\right), \tag{8}$$

$$\left(q_t-\lambda_{E,t}m_H E_t\left(\frac{q_{t+1}}{R_{E,t+1}}\right)\right)\frac{1}{c_{E,t}}=\beta_E E_t\left(\left(q_{t+1}+\frac{\nu Y_{t+1}}{H_{E,t}}\right)\frac{1}{c_{E,t+1}}\right), \tag{9}$$

$$\frac{(1-\nu)\,Y_t}{1+m_N\lambda_{E,t}}=W_{H,t}N_{H,t}. \tag{10}$$

As the first–order conditions show, credit constraints (as proxied by the Lagrange multiplier $\lambda_{E,t}$) introduce a wedge between the cost of factors and their marginal product, thus acting as a tax on the demand for credit and for the factors of production. The wedge is intertemporal in the consumption Euler equation (8) and in real estate demand equation (9); and intratemporal in the case of the labor demand equation (10).

Bankers. A continuum of unit measure bankers solve the following problem:

$$\max E_0\sum_{t=0}^{\infty}\beta_B^t\log C_{B,t}$$

where $\beta_B<\beta_H$, subject to

$$C_{B,t}+R_{H,t-1}D_{t-1}+L_{E,t}+ac_{EB,t}=D_t+R_{E,t}L_{E,t-1}-\varepsilon_t, \tag{11}$$

where the D are household deposits, L_E are loans to entrepreneurs, and C_B is banker's private consumption. Note that this formulation is analogous to a formulation where bankers maximize a convex function of dividends (discounted at rate β_B), once C_B is reinterpreted as the residual income of the banker after depositors have been repaid and loans have been issued. As for the entrepreneurial problem, the term $ac_{EB,t}=\frac{\phi_{EB}}{2}\frac{\left(L_{E,t}-L_{E,t-1}\right)^2}{L_E}$ is a quadratic portfolio loan adjustment cost, assumed to be external to the banker. The term ε_t is the redistribution shock that transfers resources from the bank to the household.

Adjustment cost aside, the flow of funds constraint of the banker implicitly assumes that deposits can be costlessly converted into loans. To make matters more interesting, I assume that the bank is constrained in its ability to issue liabilities by the amount of equity capital (assets less liabilities) in its portfolio. This constraint can be motivated by regulatory concerns or by standard limited commitment problems: for instance, typical regulatory requirements (such as those agreed by the Basel Committee on Banking Supervision) posit that banks hold a capital to assets ratio greater than or equal to some predetermined ratio. Letting $K_{B,t}=L_{E,t}-D_t-E_t\varepsilon_{t+1}$ define bank capital at the beginning of the period (before loan losses caused by redistribution shocks have been realized), a capital requirement constraint can be reinterpreted as a standard borrowing constraint, such as:

$$D_t \leq \gamma_E \left(L_{E,t} - E_t \varepsilon_{t+1} \right). \tag{12}$$

Above, the left-hand side denotes banks liabilities D_t, while the right-hand side denotes which fraction of each of the banks' assets can be used as collateral, once one takes into account losses that banks may suffer as a result of expected future repayment shocks, $E_t \varepsilon_{t+1}$.

Let $m_{B,t} \equiv \beta_B E_t \left(\frac{C_{B,t}}{C_{B,t+1}} \right)$ denote the banker's stochastic discount factor. The optimality conditions for deposits and loans are respectively:

$$1 - \lambda_{B,t} = E_t \left(m_{B,t} R_{H,t} \right), \tag{13}$$

$$1 - \gamma_E \lambda_{B,t} + \frac{\partial ac_{EB,t}}{\partial L_{E,t}} = E_t \left(m_{B,t} R_{E,t+1} \right). \tag{14}$$

The interpretation of the two first-order condition is straightforward. It also illustrates why the different classes of assets pay different returns in equilibrium. Consider the ways a bank can increase its consumption by one extra unit today.

1. The banker can borrow from the household, increasing deposits D_t by one unit today: in doing so, the bank reduces its equity by one unit, thus tightening its borrowing constraint one–for–one and reducing the utility value of an extra deposit by $\lambda_{B,t}$. Overall, today's payoff from the deposit is $1 - \lambda_{B,t}$. The next-period cost is given by the stochastic discount factor times the interest rate R_H.

2. The banker can consume more today by reducing loans by one unit. By lending less, the bank tightens its borrowing constraint, since it reduces its equity. The utility cost of tightening the borrowing constraint through lower loans is equal to $\gamma_E \lambda_{B,t}$. Intuitively, the more loans are useful as collateral for the bank activity (the higher γ_E is), the larger the utility cost of not making loans.

For the bank to be indifferent between collecting deposits (borrowing) and making loans (saving), the returns across assets must be equalized. Given that R_H is determined from the household problem, the banker will be borrowing constrained, and λ_B will be positive, so long as $m_{B,t}$ is sufficiently lower than the inverse of R_H. In turn, if λ_B is positive, the required returns on loans R_E will be higher, the lower γ_E is. Intuitively, the lower γ_E is, the lower is the liquidity value of loans for the bank in relaxing its borrowing constraint, and the higher the compensation required by the bank to be indifferent between lending and borrowing. Moreover, loans will pay a return that is (near the steady state) higher than the cost of deposits, since, so long as γ_E is lower than one, they are less liquid than the deposits.

Market Clearing. I normalize the total supply of housing to unity. The market clearing conditions for goods and houses are respectively:

$$Y_t = C_{H,t} + C_{B,t} + C_{E,t}, \tag{15}$$

$$H_{E,t} + H_{H,t} = 1. \tag{16}$$

Steady State Properties of the Model. In the non-stochastic steady state of the model, the interest rate on deposits equals the inverse of the household discount factor. This can be seen immediately from equation (2) evaluated at steady state. That is:

$$R_H = \frac{1}{\beta_H}. \tag{17}$$

In addition, when evaluated at their non-stochastic steady state, equations (13) and (14) imply that: (1) so long as $\beta_B < \beta_H$ (bankers are impatient), the bankers will be credit constrained and; (2) so long as γ_E is smaller than one, there will be a positive spread between the return on loans and the cost of deposits. The spread will be larger the tighter the capital requirement constraint for the bank. Formally:

$$\lambda_B = 1 - \beta_B R_H = 1 - \frac{\beta_B}{\beta_H} > 0, \tag{18}$$

$$R_E = \frac{1}{\beta_B} - \gamma_E \left(\frac{1}{\beta_B} - \frac{1}{\beta_H} \right) > R_H. \tag{19}$$

I turn now to entrepreneurs. Given the interest rates on loans R_E, a necessary condition for entrepreneur to be constrained is that their discount factor is lower than the inverse of the return on loans above. When this condition is satisfied (that is, $\beta_E R_E < 1$), entrepreneurs will be constrained in a neighborhood of the steady state. Alternatively, this condition requires that entrepreneurs' discount rate is higher than a weighted average of the discount factors of households and banks.

$$\frac{1}{\beta_E} > \gamma_E \frac{1}{\beta_H} + (1 - \gamma_E) \frac{1}{\beta_B}. \tag{20}$$

Both the bankers' credit constraint and the entrepreneurs' credit constraint create a positive wedge between the steady state output in absence of financial frictions and the output when financial frictions are present. The credit constraint on banks limits the amount of savings that banks can transform into loans. Likewise, the credit constraint on entrepreneurs limits the amount of loans that can be invested for production. Both forces lower steady state output. The same forces are also at work for shocks that move the economy away from the steady state, to the extent that these shocks tighten or loosen the severity of the borrowing constraints.

2.2 Calibration

To illustrate the main workings of the model, I study the macroeconomic consequences of a shock that persistently reduces bank equity. In the full estimated model, I also look at other shocks, and estimate using Bayesian methods the model's structural parameters. The parameters chosen here are in line estimates and calibration of the full model.

The time period is a quarter. The discount factor of households, entrepreneurs and banker are set respectively at $\beta_H = 0.9925$, $\beta_E = 0.94$ and $\beta_B = 0.945$. Together with the choice of the leverage parameters (described below), these numbers imply an annualized steady-state deposit rate R_H of 3 percent, and a steady-state lending rate R_E of 5 percent.

The weight on leisure in the household utility function is set at 2, implying a share of active time spent working close to one half, and a Frisch labor supply elasticity around 1.

The share of real estate in production ν is set at 0.05. Together with $j = 0.075$, the preference parameter for housing in the utility function, these choices imply a ratio of real estate wealth to output of 3.1 (annualized), of which 0.8 is commercial real estate and 2.3 is residential real estate.

I next choose the parameters controlling leverage. I set $m_N = 1$, so that all labor costs must be paid in advance. I set m_H, the entrepreneurial loan-to-value ratio, to 0.9. The leverage parameter for the bank is set at $\gamma_E = 0.9$: this number is consistent with aggregate data on bank balance sheets that show capital–asset ratios for banks close to 0.1.

Finally, I set the adjustment cost parameters for loans, ϕ_{EE} and ϕ_{EB}, equal to 0.25.

2.3 The Dynamics of a Financial Shock

To gain intuition into the workings of the model, it is useful to consider how time-variation in the tightness of the bankers' borrowing constraint can affect equilibrium dynamics.

I begin with the price side. Abstracting from adjustment costs, the expression for the spread between the return on loans and the cost of deposits can be written as:

$$E_t \left(R_{E.t+1} \right) - R_{H,t} = \frac{\lambda_{B,t}}{m_{B,t}} \left(1 - \gamma_E \right). \tag{21}$$

According to this expression, the spread between the return on entrepreneurial loans and the cost of deposits gets larger whenever the banker's multiplier on the borrowing constraint $\lambda_{B,t}$ gets higher. When the capital becomes tighter, for instance because bank net worth is lower, the bank requires a larger return on its loans in order to be indifferent between extending loans and issuing deposits. This occurs because loans are intrinsically more illiquid than deposits: when the constraint is binding, a decline in deposits of 1 dollar requires a decline in loans by $\frac{1}{\gamma_E}$ dollars. All else equal, a rise in the spread will act as a drag on economic activity during periods of lower bank net worth.

Now I move to the quantity side: whenever a shock causes a reduction in bank capital, the logic of the balance sheet requires the bank to contract its assets by a multiple of its capital, in order for the bank to restore its leverage ratio. The bank could avoid this by raising new capital (reducing bankers' consumption), but the bankers' impatience motive make this route impractical as well as insufficient. As a consequence, the bank reduces its lending. If the productive sector of the economy depends on bank credit to run its activities, the contraction in bank credit causes in turn a recession.

How do financial shocks affect the economy? Here I consider the effect of a redistribution shock ε_t. An interpretation of this shock is that it captures losses for the banking system caused, for instance, by a wave of loan defaults. Granted, loan defaults are not exogenous events, and they have broader consequences than just hitting the balance sheet of lenders, especially given the large legal and social costs associated with defaults. The reason why I measure redistribution shocks by looking at the data on loan losses – caused directly or indirectly by defaults – is that I can use the discipline of the data in sizing them up.

Figure 1 plots a dynamic simulation for the model economy. I assume that the stochastic process for ε_t follows

$$\varepsilon_t = 0.9\varepsilon_{t-1} + \iota_t. \tag{22}$$

I feed in the model a sequence of unexpected shocks to ι_t, each quarter equal to 0.36 percent of annual GDP, which lasts 3 years and causes losses for the banking system to rise from zero to 3 percent of GDP after 3 years, before loan losses gradually return to zero.[6] Note that the losses for the banking system are equal to the gains of household sector. As such, the shock is a pure redistribution shock. From the standpoint of the bank, the loan losses closely mimic the losses of financial system during the Great Recession. Between 2007Q1 and 2009Q4, annualized loan charge-off rates on residential mortgages rose from 0.1 percent to 2.8 percent, and charge-off rates

[6] In the experiment reported here, the cumulative loan losses for banks are about 9 percent of annual GDP after 5 years. These numbers are in the ballpark of the IMF estimates of total writedowns by banks and other financial institutions which were made during the financial crisis. See for instance Table 1.3 in IMF (2009).

on consumer loans rose from 2.7 percent to 6.6 percent. Given a ratio of total household debt to GDP close to 1, the shock here mimics the increase in loan charge-offs of the Great Recession. Note also that throughout the paper, my maintained assumption is that banks cannot react to the shock by charging higher interest rates (to make up for the losses or for the higher risk).

The shock impairs the bank's balance sheet, by reducing the value of the banks' assets (total loans minus loan losses) relative to the liabilities (household deposits): at that point, in absence of any further adjustment to either loans or deposits, the bank would have a capital asset ratio that is below target. The bank could restore its capital-asset ratio either by deleveraging (reducing its deposits from households), or reducing consumption in order to restore its equity cushion. If reducing consumption is costly, the bank cuts back on its loans, and begins a vicious, dynamic circle of simultaneous reduction both in loans and deposits, thus propagating the credit crunch. In particular, the decline in loans to the credit-dependent sector of the economy (entrepreneurs) acts a drag on both consumption and productive investment. It drags investment down because credit–constrained entrepreneurs reduce their real estate holdings and labor demand as credit supply is reduced. And it drags consumption down because the decline in labor demand and the reduction in entrepreneurial investment induce a decline in total output.[7]

3 Extended Model and Structural Estimation

The basic model of the previous section assumes that real estate is the only input in production, that there is no heterogeneity across households, and that all the productive assets in the economy are held by firms that are credit constrained. In addition, the model lacks a horse race between "financial" shocks and other shocks that could be potentially important for explaining business fluctuations. In this section, I extend the model of the previous section by relaxing the assumptions above. I then take the model to the data using likelihood based techniques. An advantage of this approach is that the estimation provides an in-sample historical decomposition of all the forces driving recent U.S. business cycles in general, and the Great Recession in particular.

Relative to the model of the previous section, I split the household sector into two types. Alongside the patient households of the previous section, there is a group of impatient households that earns a fraction σ of the total wage income in the economy and borrows against their houses. Patient households also accumulate a share $1 - \mu$ of variable capital, while entrepreneurs accumulate real estate (as before) and the remaining fraction μ of variable capital. Banks collect deposit and

[7] An additional force that reduces output in the wake of a redistribution shock is a negative wealth effect on labor supply for the households who receive funds from the bank. This effect contributes to less than one quarter of the decline in output.

make loans to either impatient households or entrepreneurs. To enable the model to potentially capture the slow dynamics of many macroeconomic variables, I allow for – but do not impose – quadratic adjustment costs for all assets that can be accumulated over time, for habits in consumption, and for inertia in the borrowing constraints of households and entrepreneurs and in the capital adequacy constraint of the bank. With appropriate choices of the parameters, the model of the next section nests either the basic model of the previous section or the standard RBC model as special cases. Finally, as in virtually every model that is estimated using likelihood–based techniques, I allow for a rich array of shocks to explain the variation in the data.

3.1 The Full Model

Patient Households. The patient households objective is given by

$$\max E_0 \sum_{t=0}^{\infty} \beta_H^t \left(A_{p,t}\left(1-\eta\right)\log\left(C_{H,t}-\eta C_{H,t-1}\right)+jA_{j,t}A_{p,t}\log H_{H,t}+\tau\log\left(1-N_{H,t}\right)\right)$$

subject to the following budget constraint:

$$\begin{aligned} & C_{H,t}+\frac{K_{H,t}}{A_{K,t}}+D_t+q_t\left(H_{H,t}-H_{H,t-1}\right)+ac_{KH,t}+ac_{DH,t} \\ = & \left(R_{M,t}z_{KH,t}+\frac{1-\delta_{KH,t}}{A_{K,t}}\right)K_{H,t-1}+R_{H,t-1}D_{t-1}+W_{H,t}N_{H,t}. \end{aligned} \tag{23}$$

In the utility function above, the term $A_{p,t}$ denotes a shock to preferences for consumption and housing jointly (aggregate spending shock), the $A_{j,t}$ term denotes a housing demand shock, and η measures external habits in consumption. Households own physical capital K_H and rent capital services $z_H K_H$ to entrepreneurs at the rental rate R_M (the utilization rate is $z_{H,t}$). The term $A_{K,t}$ denotes an investment–specific shock. The terms $ac_{KH,t}$ and $ac_{DH,t}$ denote convex, external adjustment costs for deposits and capital. The parameter $\delta_{KH,t}$ denotes the depreciation function for physical capital, which assumes that depreciation is convex in the utilization rate of capital. The functional forms for the adjustment costs and the depreciation function and the complete derivations of the model are available in Appendix B.

Impatient Households. The objective of impatient households is given by

$$\max E_0 \sum_{t=0}^{\infty} \beta_S^t \left(A_{p,t}\left(1-\eta\right)\log\left(C_{S,t}-\eta C_{S,t-1}\right)+jA_{j,t}A_{p,t}\log H_{S,t}+\tau\log\left(1-N_{S,t}\right)\right)$$

where β_S denotes their discount factor.[8] Their budget constraint is given by

$$C_{S,t} + q_t \left(H_{S,t} - H_{S,t-1} \right) + R_{S,t-1} L_{S,t-1} - \varepsilon_{H,t} + ac_{SS,t} = L_{S,t} + W_{S,t} N_{S,t} \tag{24}$$

where L_S denotes loans made by bank to impatient households, paying a gross interest rate R_S, and the term $ac_{SS,t}$ denotes a convex cost of adjusting loans from one period to the next. The term $\varepsilon_{H,t}$ in the budget constraint is an exogenous shock, similar to the redistribution shock of the previous section, that transfers wealth from banks to households: I assume that impatient households can pay back less (more) than agreed on their contractual obligations when ε is greater (smaller) than zero; from their point of view, this "redistribution" shock represents – all else equal – a positive shock to wealth, since it allows them to spend more than previously anticipated. When I take the model to the data, I measure this shock by looking at data on loan losses (net charge-offs) on residential mortgages suffered by financial intermediaries.

Impatient households are also subject to a borrowing constraint that limits their liabilities to a fraction of the value of their house:

$$L_{S,t} \leq \rho_S L_{S,t-1} + (1 - \rho_S) \, m_S A_{MH,t} E_t \left(\frac{q_{t+1}}{R_{S,t}} H_{S,t} \right). \tag{25}$$

The term ρ_S allows for slow adjustment over time of the borrowing constraint, to capture the idea that in practice lenders do not readjust the borrowing limit every quarter. The term $A_{MH,t}$ denotes an exogenous shock to the borrowing capacity of the household, due to, for instance, looser screening practices of the banks that allow them to supply more loans for given amount of collateral. The constraint binds in a neighborhood of the non-stochastic steady state if β_S is lower than a weighted average of the discount factors of patient households and bankers.

Note that one could endogenize the default/repayment shock in other ways: for instance, one could assume that if house prices fall below some value, borrowers could find it optimal to default rather than roll their debt over: defaulting would be equivalent to choosing a value for $R_{S,t} L_{S,t-1}$ lower than previously agreed.

Bankers. Bankers solve

$$\max E_0 \sum_{t=0}^{\infty} \beta_B^t \left(1 - \eta \right) \log \left(C_{B,t} - \eta C_{B,t-1} \right)$$

[8] For impatient households to borrow and to be credit constrained in equilibrium, one needs to assume that their discount factor is lower than a weighted average of the discount factors of households and banks. See Appendix B for details. An analogous restriction applies to entrepreneurs.

subject to the following budget constraint:

$$\begin{aligned} & C_{B,t} + R_{H,t-1}D_{t-1} + L_{E,t} + L_{S,t} + ac_{DB,t} + ac_{EB,t} + ac_{SB,t} \\ = \; & D_t + R_{E,t}L_{E,t-1} + R_{S,t}L_{S,t-1} - \varepsilon_{E,t} - \varepsilon_{S,t}. \end{aligned} \tag{26}$$

The last two terms denote repayment shocks. As before, the terms $ac_{DB,t}$, $ac_{EB,t}$ and $ac_{SB,t}$ denote adjustment costs paid by the bank for adjusting deposits, loans to entrepreneurs L_E, and loans to impatient households L_S. The bank is subject to a capital adequacy constraint of the form

$$L_t - D_t - E_t\varepsilon_{t+1} \geq \rho_D \left(L_{t-1} - D_{t-1} - E_{t-1}\varepsilon_t\right) + (1-\gamma)(1-\rho_D)\left(L_t - E_t\varepsilon_{t+1}\right), \tag{27}$$

where $L = L_E + L_S$ are bank assets and $\varepsilon_t = \varepsilon_{E,t} + \varepsilon_{S,t}$ are loan losses. This constraint posits that bank equity (after expected losses) must exceed a fraction of bank assets, allowing for partial adjustment in bank capital given by ρ_D. In this formulation, the capital–asset ratio of the bank can temporarily deviate from its long-run target, γ, so long as ρ_D is not equal to zero. Such a formulation allows the bank to take corrective action to restore its capital–asset ratio beyond one period.

Entrepreneurs. The last group of agents are the entrepreneurs. They hire workers and combine them with capital (both produced by them and supplied by patient households) in order to produce the final good Y. Their utility function is

$$\max E_0 \sum_{t=0}^{\infty} \beta_E^t (1-\eta) \log\left(C_{E,t} - \eta C_{E,t-1}\right)$$

and they are subject to the following budget constraint

$$\begin{aligned} C_{E,t} + \frac{K_{E,t}}{A_{K,t}} + q_t H_{E,t} + R_{E,t}L_{E,t-1} + W_{H,t}N_{H,t} + W_{S,t}N_{S,t} + R_{M,t}z_{KH,t}K_{H,t-1} + ac_{KE,t} + ac_{EE,t} \\ = Y_t + \frac{1-\delta_{KE,t}}{A_{K,t}}K_{E,t-1} + q_t H_{E,t-1} + L_{E,t} + \varepsilon_{E,t}, \end{aligned} \tag{28}$$

where ε_E denotes default/repayment shocks and $ac_{KE,t}$ and $ac_{EE,t}$ denotes adjustment costs for capital and loans. The production function is given by

$$Y_t = A_{Z,t}\left(z_{KH,t}K_{H,t-1}\right)^{\alpha(1-\mu)}\left(z_{KE,t}K_{E,t-1}\right)^{\alpha\mu} H_{E,t-1}^{\nu} N_{H,t}^{(1-\alpha-\nu)(1-\sigma)} N_{S,t}^{(1-\alpha-\nu)\sigma}, \tag{29}$$

where $A_{Z,t}$ is a shock to total factor productivity. Finally, entrepreneurs are subject to a borrowing constraint that acts as a wedge on the capital and labor demand. The constraint is given by:

$$L_{E,t} \leq \rho_E L_{E,t-1} + (1-\rho_E) A_{ME,t} \left(m_H E_t \left(\frac{q_{t+1}}{R_{E,t+1}} H_{E,t} \right) + m_K K_{E,t} - m_N \left(W_{H,t} N_{H,t} + W_{S,t} N_{S,t} \right) \right). \tag{30}$$

In a manner similar to the impatient households problem, the term $A_{ME,t}$ denotes a shock to the borrowing capacity of the entrepreneur.

Market Clearing and Equilibrium. Market clearing is implied by Walras's law by aggregating all the budget constraints. For housing, we have the following market clearing condition

$$H_{H,t} + H_{S,t} + H_{E,t} = 1. \tag{31}$$

An equilibrium can be defined in the usual way. To compute the model dynamics, I solve a linearized version of the system of equations describing the equilibrium of the model under the maintained assumption that the constraints given by equations (25), (27) and (30) are always binding. I verify that, given the size of the estimated shocks, the Lagrange multipliers are always positive throughout a given simulation.

3.2 Data

My emphasis on financial factors leads me to consider for estimation several quantities which are important to distinguish the various shocks in the data. I estimate the model using US quarterly data from 1985Q1 to 2010Q4.[9] I use eight time series as observables: real consumption, real nonresidential fixed investment, losses on loans to businesses, losses on loans to households, loans to businesses, loans to households, real house prices, and total factor productivity. Appendix C describes the data construction. Except for loan losses, I detrend the logarithm of each variable independently using a quadratic trend.[10] The detrended and demeaned data are plotted in Figure 2. I then use Bayesian methods as described in An and Schorfheide (2007) to estimate the remaining model parameters.

[9] The sample begins in 1985Q1, but the first 20 observations are used as a training sample for the Kalman filter, so that the estimation is effectively based on the observations from 1990Q1 to 2010Q4.

[10] Although several recent estimated DSGE models allow for deterministic or stochastic trends, incorporating such features into a model with financial variables such as loans is nontrivial. Several financial variables appear to have trends of their own which would require specific modeling assumptions to guarantee balanced growth: for instance, the ratio of household debt to GDP has been rising throughout the sample in question. I leave exploration of this topic for future research.

3.3 Calibration and Priors

Table 1 summarizes the calibrated parameters (which can be viewed as strict priors). These values are kept fixed because the dataset is demeaned and cannot pin down the steady state values in the estimation procedure. I set the variable capital share in production α at 0.35 and capital depreciation rate at 0.035. I choose a number for the depreciation rate which is slightly larger than the typical number in the literature – 0.025 – since my model also includes real estate as a factor of production which does not depreciate altogether. These numbers imply an investment to output ratio of 0.26 and a variable capital to output ratio of 2. All the leverage parameters are set at 0.9, and I assume labor must be fully paid in advance, so that $m_N = 1$. Together with the discount factors, the leverage parameters imply an annualized steady-state return on deposits of 3 percent, a steady-state return on loans of 4 percent, and a spread of lending over borrowing rates of 1 percent.

Tables 2.a and 2.b show the prior distributions for the model's remaining parameters. I assume that all parameters are independent *a priori*. The domain of most parameters, whenever possible, covers a wide range of outcomes. I choose to be conservative about the a priori importance of financial shocks. In particular, my assumptions about the relative importance of the various shocks implies that, at the prior mean, the three financial shocks (that is, the combination of housing price shocks, default/repayment shocks, and loan-to-value ratio shocks) account for about 15 percent of the total variance of output, consumption and investment at business cycle frequencies (as implied by an HP-filter with a smoothing parameter of 1,600).

3.4 Estimation Findings and the Model's Transmission Mechanism

The last three columns of Tables 2.a and 2.b report the means and 5% and 95% of the posterior distribution for the estimated model parameters. All shocks are estimated to be quite persistent, with autocorrelation coefficients ranging from 0.84 to 0.994. The share of constrained entrepreneurs, μ, is found to be 0.46, slightly lower than its 0.5 prior. The wage share of constrained households, σ, is found to be 0.33, slightly higher than its 0.3 prior.

There is substantially more inertia in the household and entrepreneurs' borrowing constraints than in the capital adequacy constraint of the bank. Interestingly, the inertia in the borrowing constraint lines up with the well-known observation that various indicators of the quantity of credit tend to lag the business cycle, rather than to lead it.

All shocks are found to be quite persistent. The estimated standard deviation of the household default shock is only 0.13 percentage points. Seen through the lenses of the model, the experience of the financial crisis, when charge-offs rates on loans to households rose by more than 2 percentage points (see Figure 2), appears a remarkably rare event.

An important question that one can ask of the estimated model is: how important were financial shocks in shaping the recent US macroeconomic experience? Figure 3 provides an answer to this question by providing historical decompositions of output, total loans, house prices and investment over the estimation sample. In the data – consistent with the model – output is defined at the sum of total consumption and nonresidential fixed investment, thus excluding the foreign and the government sector. As the figure shows, movements in output and investment do not appear to be driven much by financial shocks until 2007, but the Great recession offers a remarkably different picture, as also shown in Table 3. More than half of the decline in output growth and investment is driven by the combined effect of default shocks, housing demand shocks, and LTV shocks. The timing of the shocks, in particular, is of independent interest. Early during the Great Recession in 2007 and 2008, the decline in output and investment is mostly driven by negative housing demand shocks, which lower collateral values, borrowing capacity of entrepreneurs, and with them investment and output. Default shocks account for 1.2 percentage points of the 3.6 percent decline in output in 2008, and for 1.4 percentage points of the 9 percent decline in output in 2009. In 2010, with output growth nearly recovering, tighter credit in the form of negative LTV shocks subtracts 1.5 percent from output growth. All told, the three financial shocks combined can explain about three quarters (9 percentage points out a 13 percent decline) of the output decline from 2007 to the end of 2010.

Figure 4 conducts an external validation exercise to assess the reliability of the model in fitting time series that were not used as inputs in the estimation exercise. Such an exercise is of particular interest since it addresses the critique that DSGE models can do a good job at fitting data in sample, but have poor performance otherwise. In particular, given the estimated shocks, I contrast the model's simulated time series for interest rate spreads, capacity utilization and bankers' consumption against their data counterparts. The top panel plots the two-year ahead interest rate spread against the C&I Loan Rate Spread over Intended Fed Funds Rate for all loans from the Fed Survey of Terms of Business Lending.[11] Both in the model and in the data, the interest-rate spread rises markedly during the 2007-2009 period, although the increase – in percentage terms – is slightly larger in the data than in the model.[12] In the middle panel, the behavior of capital utilization in the model mimics its data analogue,[13] with both the model and the data pointing to a large and

[11] The series name in the data is *FCIRS@USECON*. I construct the model interest spread as the difference between lending rate for entrepreneurs (R_E) and deposit rate (R_H). I construct a model-consistent two-year spread using the expectation hypothesis to match the average duration of C&I Loans in the Survey of Terms of Business Lending.

[12] In the model, spreads rise when banks' financial conditions worsens, since they signal the unwillingness of banks to lend funds. In the data, the rise in spreads reflects default risk that is not priced in the model.

[13] There is no satisfactory counterpart to model's capital utilization in the data. Existing data refer only to manufacturing, and are calculated by comparing actual production with a measure of full-capacity production. The proxy I use is the total industry capacity utilization is the Board of Governors of the Federal Reserve System

persistent decline in utilization around the financial crisis. The bottom panel compares bankers' consumption with a measure of the health of the banking system in the data, namely corporate profits of the financial sector.[14] Both measures tank during the Great Recession.

Figure 5 illustrates the model's transmission mechanism for the three key markets in the model, at the model's parameter estimates. I focus on how resources get transferred from the savers (the patient households) to ultimate users of them (the final good firms), and on how a given size financial shock affect the functioning of these markets. For the purposes of the figure, I choose a default/redistribution shock that leads to a rise in charge-off rates for household loans from 0 to 2 percent, a magnitude somewhat comparable to the magnitudes of the Great Recession. In the market for deposits D, household–savers set aside resources, and supply them to the bank. The bank demands deposits from the household. The slope of demand and supply curves are a function of the estimated parameters ϕ_{DB} and $\phi_{DH,}$ which measures the convex adjustment cost of changing deposits both for banks and for households. The linearized demand and supply schedules are plotted in the figure. The negative financial shock hits the financial position of the bank and – holding everything else the same – reduces the bank's ability to borrow from the household at a given deposit rate. The deposits demand curve shifts to the left, thus reducing equilibrium deposits and the deposit interest rate.[15]

In the market for loans L_E, the dynamics reflect two forces. On the supply side, as bankers are forced to deleverage, they reduce the supply of loans, which shifts inwards. On the demand side, at the going interest rate, entrepreneurs would like to borrow more: given their high discount factor and their binding borrowing constraint, the drop in consumption growth increases their loan demand. At the model's estimates, the inward shift in loan supply is far larger than the increase in loan demand, the equilibrium lending rate rises, and total loans drop.

In the market for capital K_E, as equilibrium borrowing drops, entrepreneurs are less able to supply funds to final good firms, and the supply of capital drops. Capital demand also drops because wealthier borrowers decide to work less, and because factor complementarities reduce the marginal product of capital as real estate demand and utilization rates fall, even as total factor productivity remains unchanged. In turn, the decline in the demand for other factors lowers the marginal product of capital, thus further exacerbating the decline of output.

(Industrial Production and Capacity Utilization Summary Table, *CUT@USECON*).

[14] The data source for corporate profits is the BEA GDP release. The series name is *YCPDF@USECON.*

[15] As general equilibrium repercussions affect wages and consumption for all agents, the household's supply of deposits moves too. In particular, as expected consumption growth drops, the supply of deposits temporarily shifts to the right, thus further lowering the interest rate.

4 Robustness Analysis

Figure 6 offers a summary picture of the model dynamics in response to the estimated shocks, at the mean of estimated parameter values. As a comparison benchmark, I illustrate the model responses by comparing them to those of a model with financial frictions on households and firms but without banks. The top two rows, showing the impulse response to default shocks of entrepreneurs and impatient households respectively, show how the presence of constrained banks works to amplify given financial shocks. In particular, the second row shows how a one standard deviation household repayment shock (corresponding to a persistent rise in charge-off rates for the banks of 0.13 percentage points) leads to a protracted decline in output and investment, whereas the effects would be much more muted in a frictionless model without banks. As for the other shocks, the dynamics in a model with banks (compared to those of a model without) are not dramatically different. This implies that financial frictions on banks work mostly to amplify shocks originating in the banking sector.

Figure 7 illustrates the strength of the various channels in shaping output dynamics in response to an estimated one standard deviation household default shock. I compare three models: the RBC model; a model with traditional financial frictions on both firms and households; and the model with financial and banking frictions together.

The RBC model has only two household types, all investment is done by the patient households, and the entrepreneurial sector is shut off (by setting μ and ν to zero). The only friction here pertains to the fact that households who borrow are financially constrained: if this friction was missing, there would be no heterogeneity, and no way to even think about repayment shocks (the shock would wash out in the aggregate, both in an accounting sense and in a behaviorial sense). In the RBC version of the model, the repayment shock transfers wealth away from the savers towards the borrowers. On the one hand, borrowers consume more. On the other hand, patient households consume less, but also save less in order to smooth their consumption, so that the decline in their consumption does not fully offset the rise in borrowers' consumption, and aggregate consumption rises. In turn, the decline in saving of the patient households leads to a decline in investment that more than offsets the rise in consumption, so that aggregate output falls, although the total effects are very small. A one-standard deviation shock leads to a 0.02 percent decline in output after one year.

In the model with financial frictions both for households and for entrepreneurs, but without banks, the decline in saving of the households following the repayment shock reduces the supply of available funds for the entrepreneurs, and causes a knock-on effect on borrowing and investment that further magnifies the output decline. The decline in output after one year is about 0.05 percent, twice as large than in the RBC case.

The largest negative effects on economic activity from the repayment shock occur when both the banking channel and the collateral channel are at work, thus restoring the baseline model. By putting direct pressure on the bank's balance sheet, the repayment shock further strengthens the drop in output. At the trough, the output decline is 0.15 percent, almost one order of magnitude larger than in the model without financial frictions.

5 Concluding Remarks

In this paper I have presented and estimated a DSGE model where losses sustained by banks can produced sizeable, pronounced and long-lasting effects on business activity. The key ingredients of the model are regulatory constraints on the leverage of the banks and a business sector that is bank–dependent for its operations. In an estimated version of the model, financial shocks account for more than one half of the decline in output during the Great Recession.

Despite its complexity, my model precludes an examination of certain aspects that may be important to understand the role of banks and leveraged agents in business fluctuations. First, banks offer the important benefit of maturity transformation by intermediating across needs and projects with different termination dates. However, while the simple model of this paper features loans and deposits with different adjustment costs, it abstract from a richer examination of the liquidity role provided of banks through this function. Second, because of the illiquid nature of many of the bank's assets, banks can be subject to runs, especially in periods when their balance sheets are weak or perceived as such. Third, default episodes are obviously the consequence of some negative shocks hitting elsewhere in the economy, and one would love to have a parsimonious macro framework that explains defaults without losing the tractability of a stylized model that can be taken to the data. The recent papers by Andreasen, Ferman, and Zabczyk (2013), Forlati and Lambertini (2011) and Gertler and Kiyotaki (2013) contain interesting examples of models that have begun to address these issues.

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Table 1: Calibration

Parameter		Value
Household-saver (HS) discount factor	β_H	0.9925
Household-borrower (HB) discount factor	β_S	0.94
Banker discount factor	β_B	0.945
Entrepreneur (E) discount factor	β_E	0.94
total capital share in production	α	0.35
Loan-to-value ratio on housing, HB	m_S	0.9
Loan-to-value ratio on housing, E	m_H	0.9
Loan-to-value ratio on capital, E	m_K	0.9
Wage bill paid in advance	m_N	1
Liabilities to assets ratio for Banker	γ_E, γ_S	0.9
Housing preference share	j	0.075
Capital depreciation rate	δ_{KE}, δ_{KH}	0.035
Labor Supply parameter	τ	2

Table 2.a: Estimation, Structural Parameters

Parameter		Prior distribution			Posterior Distribution		
		Density	Mean	St.dev.	5%	Mean	95%
Habit in Consumption	η	beta	**0.5**	0.15	0.36	**0.46**	0.56
D adj cost, Banks	ϕ_{DB}	gamm	**0.25**	0.125	0.05	**0.14**	0.26
D adj cost, Household Saver (HS)	ϕ_{DH}	gamm	**0.25**	0.125	0.04	**0.10**	0.20
K adj. cost, Entrepreneurs (E)	ϕ_{KE}	gamm	**1**	0.5	0.23	**0.59**	1.41
K adj. cost, Household Saver (HS)	ϕ_{KH}	gamm	**1**	0.5	0.88	**1.73**	2.95
Loan to E adj cost, Banks	ϕ_{EB}	gamm	**0.25**	0.125	0.03	**0.07**	0.13
Loan to E adj cost, E	ϕ_{EE}	gamm	**0.25**	0.125	0.02	**0.06**	0.11
Loan to HB adj cost, Banks	ϕ_{SB}	gamm	**0.25**	0.125	0.24	**0.47**	0.72
Loan to HB adj cost, HH Borrower HB	ϕ_{SS}	gamm	**0.25**	0.125	0.14	**0.37**	0.66
Capital share of E	μ	beta	**0.5**	0.1	0.34	**0.46**	0.58
Housing share of E	ν	beta	**0.04**	0.01	0.03	**0.04**	0.05
Inertia in capital adequacy constraint	ρ_D	beta	**0.25**	0.1	0.10	**0.24**	0.41
Inertia in E borrowing constraint	ρ_E	beta	**0.25**	0.1	0.53	**0.65**	0.79
Inertia in HB borrowing constraint	ρ_S	beta	**0.25**	0.1	0.64	**0.70**	0.76
Wage share HB	σ	beta	**0.3**	0.1	0.22	**0.33**	0.45
Curvature for utilization function E	ζ_E	beta	**0.2**	0.1	0.20	**0.42**	0.63
Curvature for utilization function HS	ζ_H	beta	**0.2**	0.1	0.18	**0.38**	0.58

Table 2.b: Estimation, Shock Processes

Parameter		Prior distribution			Posterior Distribution		
		Density	Mean	St.dev.	5%	Mean	95%
Autocor. E default shock	ρ_{be}	beta	**0.8**	0.1	0.886	**0.932**	0.971
Autocor. HB default shock	ρ_{bh}	beta	**0.8**	0.1	0.944	**0.969**	0.988
Autocor. housing demand shock	ρ_j	beta	**0.8**	0.1	0.986	**0.992**	0.997
Autocor. investment shock	ρ_k	beta	**0.8**	0.1	0.840	**0.916**	0.973
Autocor. loan-to-value shock, E	ρ_{me}	beta	**0.8**	0.1	0.750	**0.839**	0.917
Autocor. loan-to-value shock, HB	ρ_{mh}	beta	**0.8**	0.1	0.781	**0.873**	0.948
Autocor. preference shock	ρ_p	beta	**0.8**	0.1	0.989	**0.994**	0.998
Autocor. technology shock	ρ_z	beta	**0.8**	0.1	0.973	**0.988**	0.997
St.dev., Default shock, E	σ_{be}	invg	**0.0025**	0.025	0.0009	**0.0011**	0.0012
St.dev., Default shock, HB	σ_{bh}	invg	**0.0025**	0.025	0.0012	**0.0013**	0.0015
St.dev., housing demand shock	σ_j	invg	**0.05**	0.05	0.0248	**0.0346**	0.0473
St.dev., investment shock	σ_k	invg	**0.005**	0.025	0.0049	**0.0081**	0.0161
St.dev., loan-to-value shock, E	σ_{me}	invg	**0.0025**	0.025	0.0129	**0.0204**	0.0366
St.dev., loan-to-value shock, HB	σ_{mh}	invg	**0.0025**	0.025	0.0090	**0.0115**	0.0150
St.dev., preference shock	σ_p	invg	**0.005**	0.025	0.0179	**0.0205**	0.0237
St.dev., technology shock	σ_z	invg	**0.005**	0.025	0.0062	**0.0070**	0.0080

Table 3: Historical Decomposition

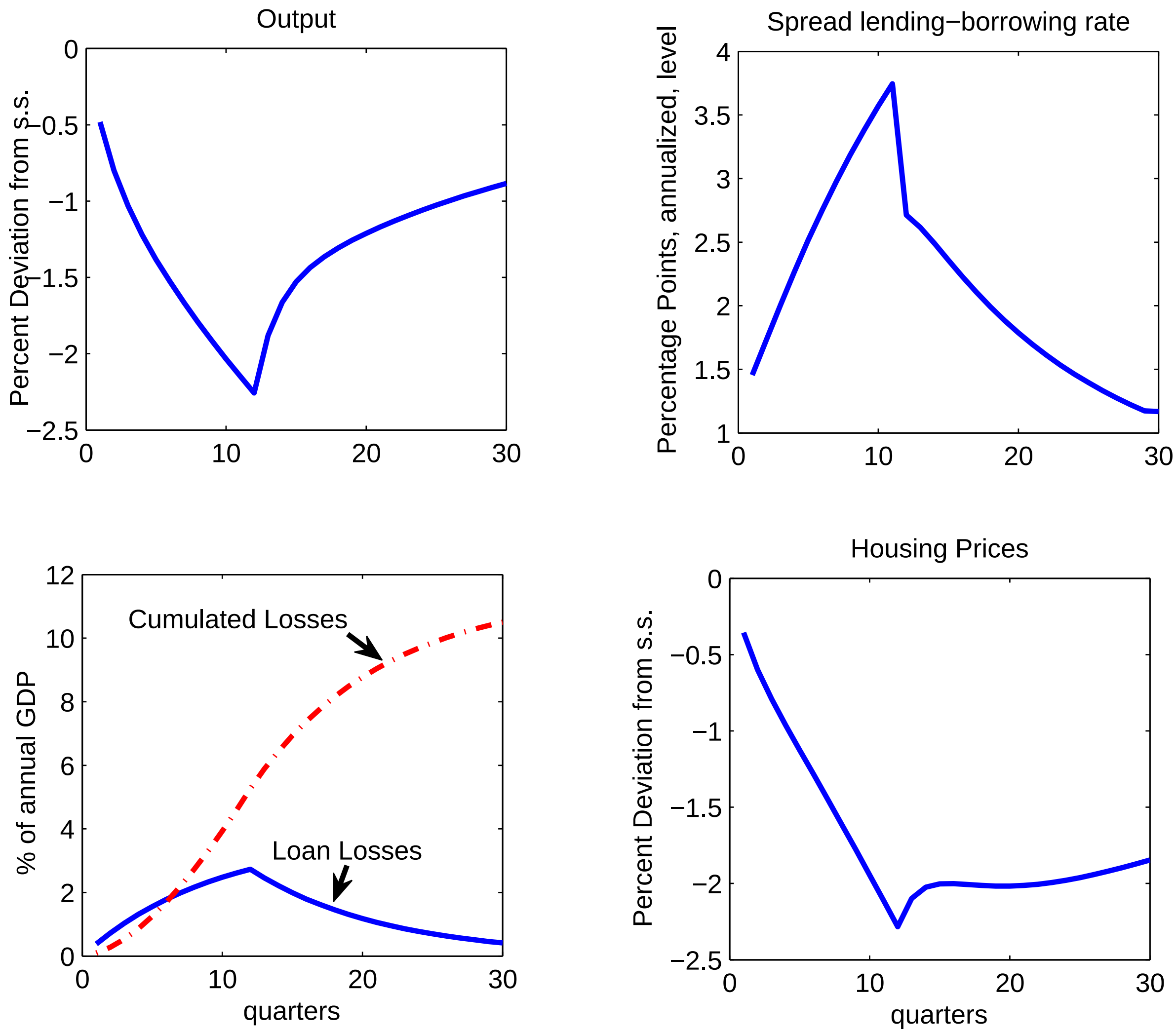
Contribution to Output	**2007**	**2008**	**2009**	**2010**	**2007-2010**
Default shocks	-0.2	-1.2	-1.4	0.1	-2.7
Housing Demand shock	-1.3	-1.7	-1.0	0.0	-4.1
LTV shocks	1.1	0.2	-2.2	-1.5	-2.4
Preference shock	2.9	-0.1	-4.9	2.6	0.5
TFP shocks	-2.2	-0.8	0.3	-1.3	-4.0
All shocks (data)	**0.3**	**-3.6**	**-9.3**	**-0.1**	**-12.6**

Contribution to Investment	**2007**	**2008**	**2009**	**2010**	**2007-2010**
Default shocks	-0.5	-2.7	-3.0	0.7	-5.5
Housing Demand shock	-2.1	-3.4	-2.8	-0.9	-9.1
LTV shocks	3.5	1.7	-6.8	-5.7	-7.3
Preference shock	2.5	-0.9	-5.7	5.1	1.0
TFP shocks	-0.5	1.1	-4.9	2.2	-2.1
All shocks (data)	3.0	-4.2	-23.3	1.4	-23.1

Contribution to Consumption	**2007**	**2008**	**2009**	**2010**	**2007-2010**
Default shocks	-0.1	-0.7	-0.9	-0.1	-1.7
Housing Demand shock	-1.1	-1.1	-0.4	0.3	-2.3
LTV shocks	0.2	-0.3	-0.6	-0.1	-0.7
Preference shock	3.1	0.1	-4.6	1.8	0.4
TFP shocks	-2.7	-1.4	2.0	-2.5	-4.7
All shocks (data)	-0.6	-3.4	-4.5	-0.6	-9.1

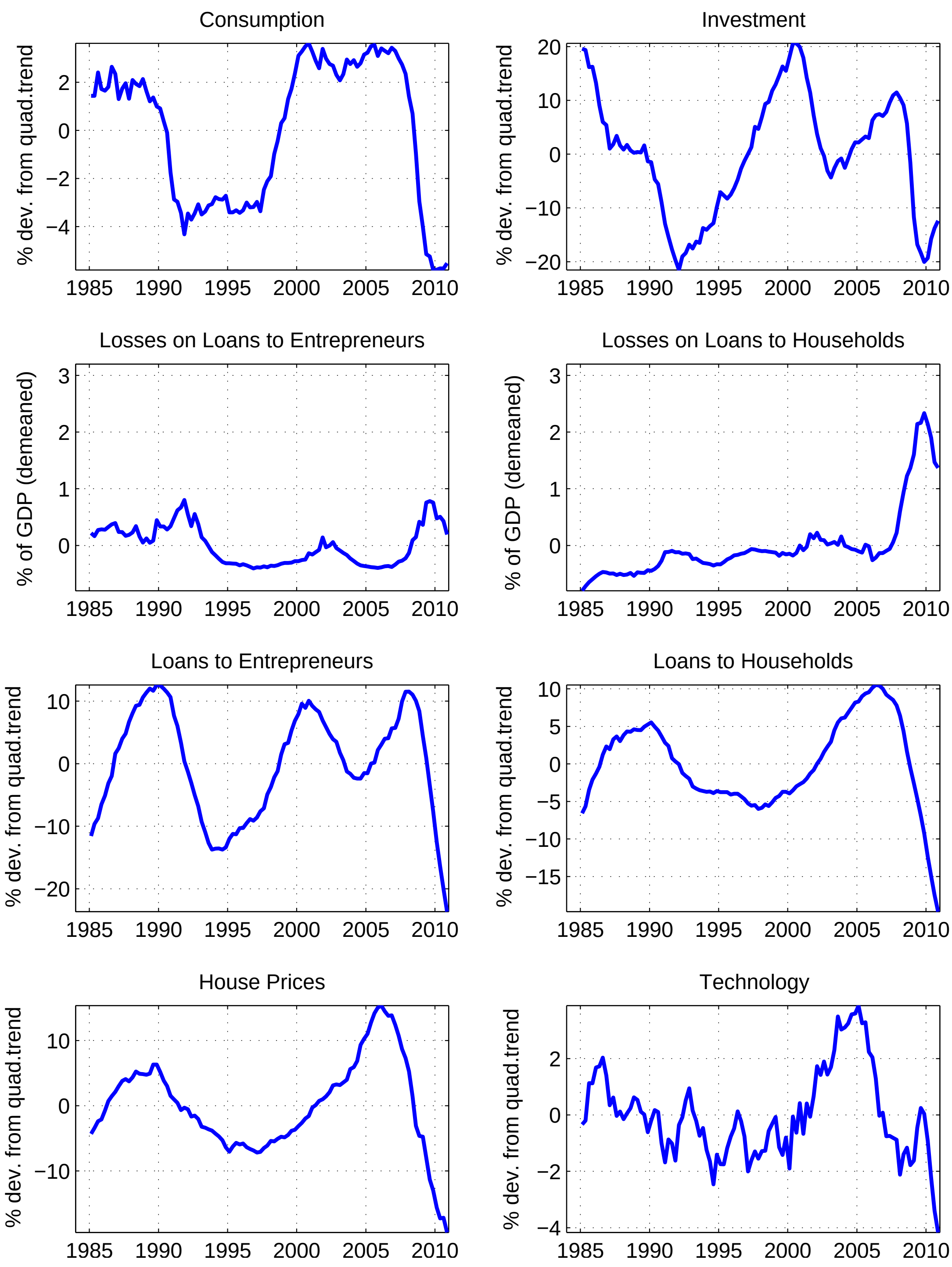
Contribution of each estimated shock to year-on-year growth in Annual Output (sum of consumption and non-residential fixed investment), Annual Investment and Annual Consumption.

Figure 1: Dynamics of the Basic Model after Default Shock



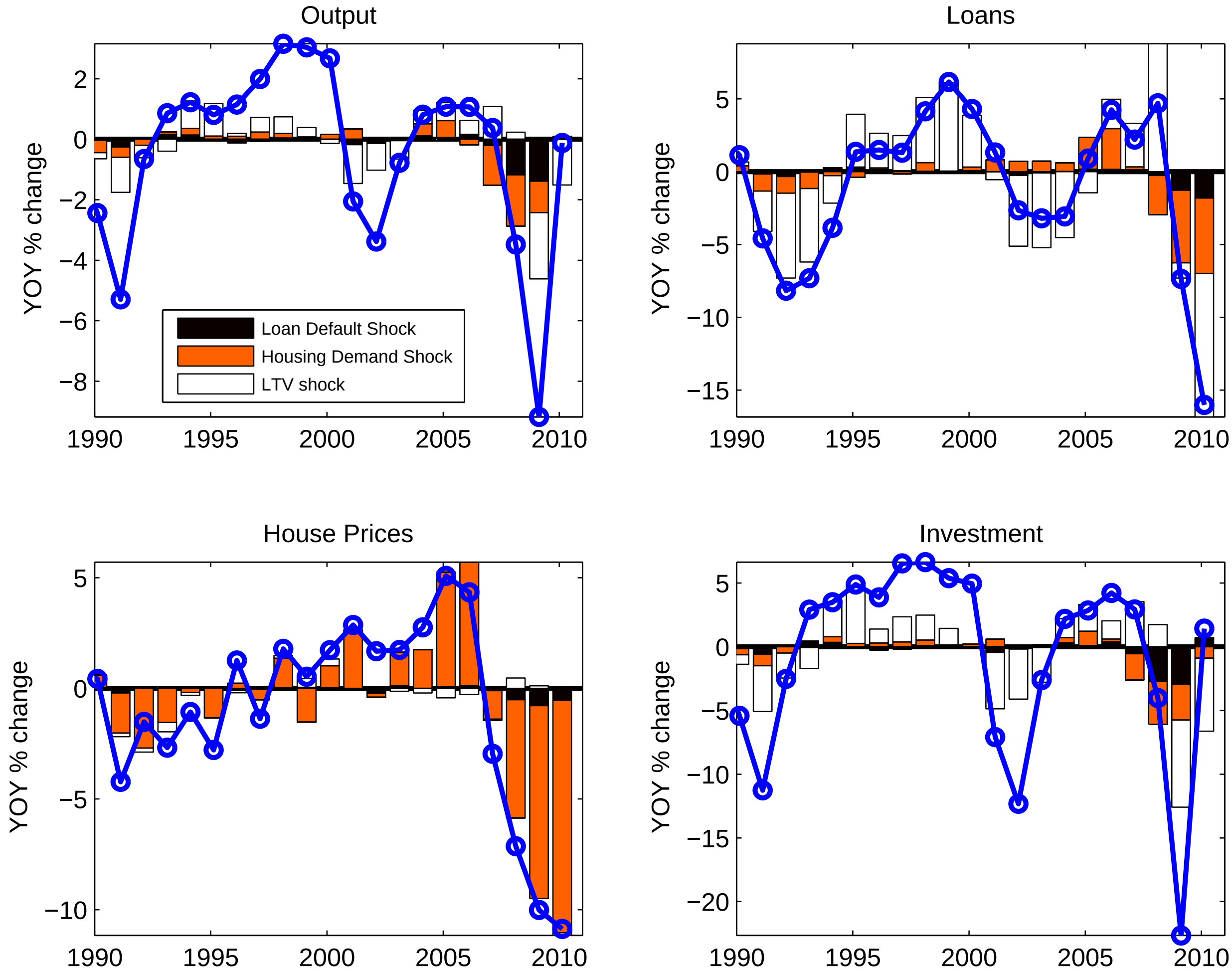
Note: The plots show the responses of macroeconomic variables to a shock that leads after 3 years to (flow) loan losses for banks equal to 2.8 percent of GDP. The cumulated losses are the cumulative sum of the flow loan losses, divided by 4 to express as a fraction of annual GDP.

Figure 2: Data Used in Estimation



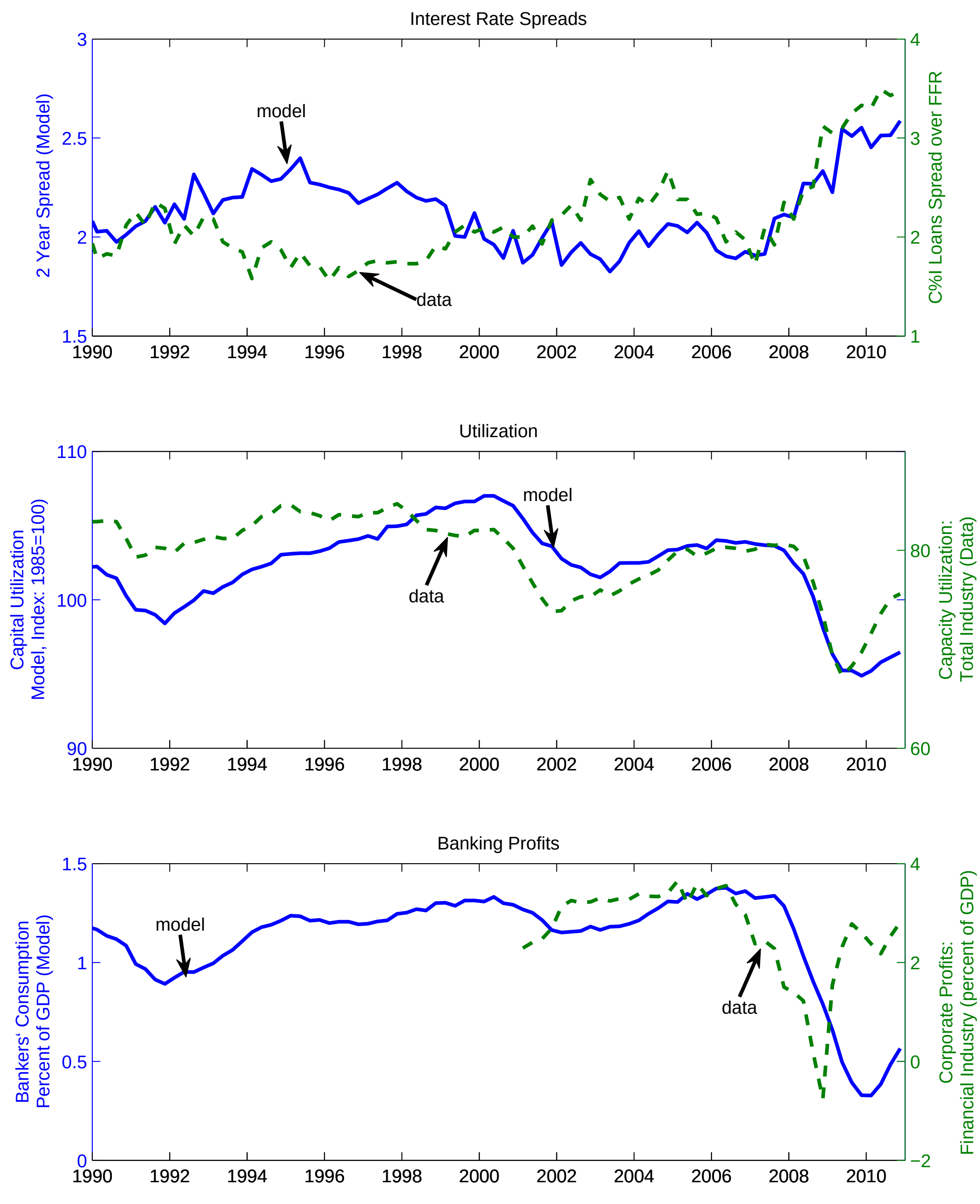
Note: The model parameters are estimated using data from 1990Q1 to 2010Q4. The 1985-1989 period is used to initialize the Kalman filter.

Figure 3: Historical Decomposition of the Estimated Model



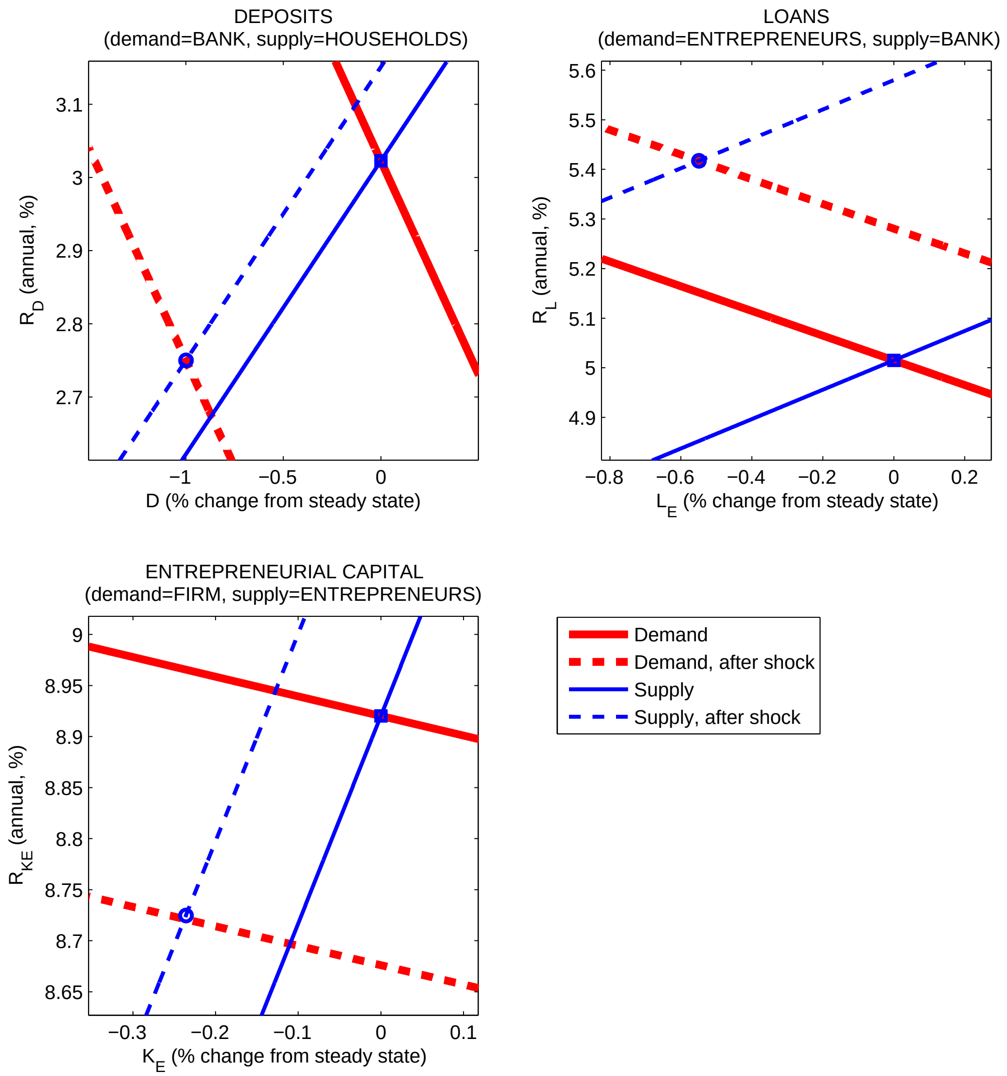
Note: The solid lines plot actual data. The bars show the contributions of the estimated financial shocks. Data are expressed in deviation from their mean.

Figure 4: External Validation: Historical Decomposition of Model Series



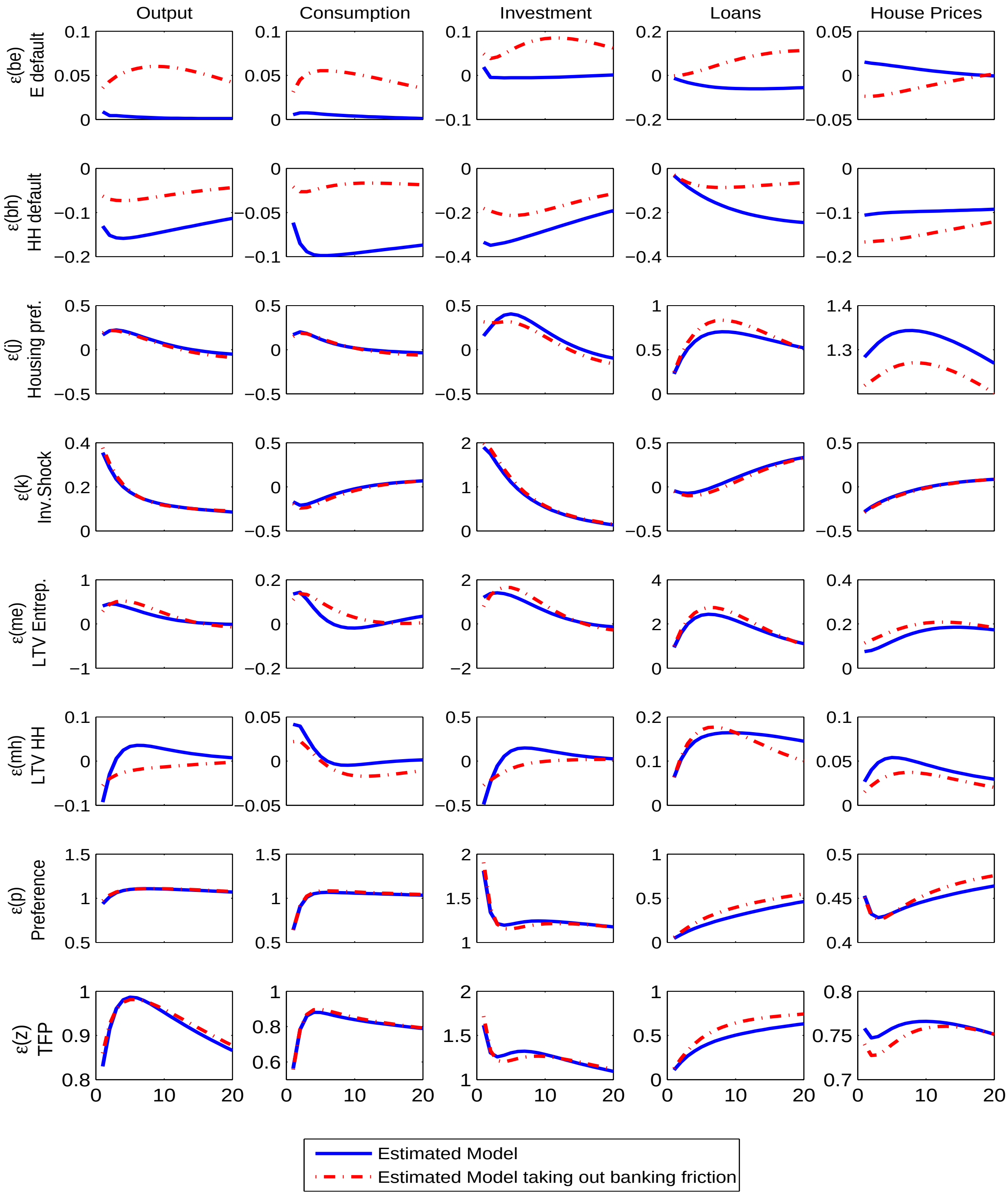
Note: The solid lines plot model simulated (smoothed estimates) series. The dashed lines plot similar objects from actual data.

Figure 5: Transmission Mechanism of Default Shock



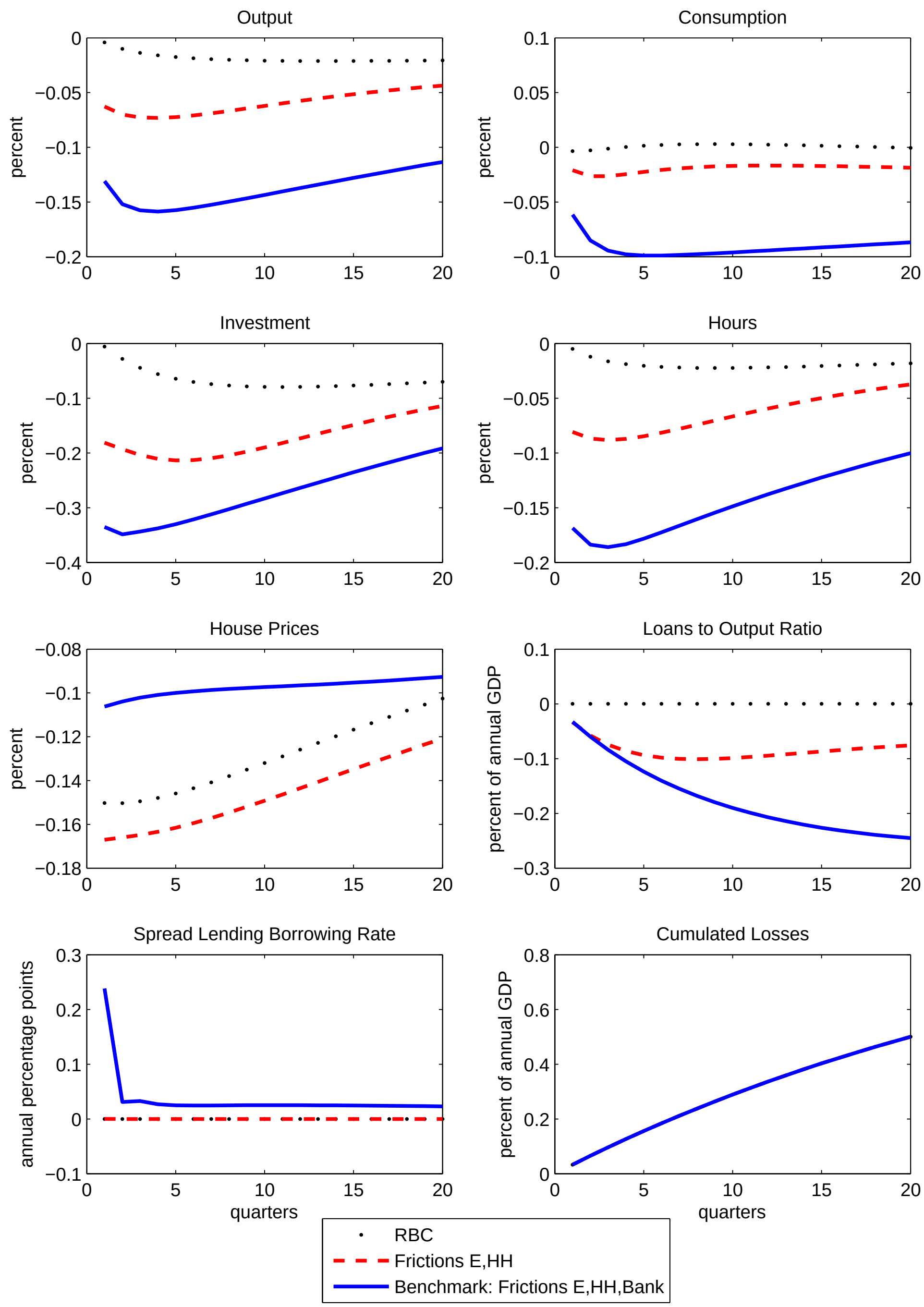
Note: Each panel plots the linearized demand and supply curves for deposits, loans to entrepreneurs, and entrepreneurial capital in steady state and away from it, in the first period when a redistribution shock (that transfers 2 percent of GDP from banks to impatient households) hits.

Figure 6: Impulse Responses to all Shocks, Estimated Banking Model and Counterfactual Model without Banks



Note: horizontal axis: quarters from the shock; vertical axis: percent deviation from the steady state. The solid lines plot, for each row, the responses to a each estimated shock, one standard deviation in side. The dashed lines plot the same model shutting off the banking sector.

Figure 7: Impulse Responses to Estimated Household Default Shock



Note: horizontal axis: quarters from the shock; vertical axis: percentage deviation from the steady state. Loans and loan losses are percentages of annualized output. The Spread between the Loan and Deposit Rate is expressed in annualized percentage points. The shock is one (estimated) standard deviation.

Appendix

Appendix A Complete Set of Equations of the Basic Model

The basic model is described by the following set of equations. I denote with u_{ij} the marginal utility of good i for agent j.

$$C_{H,t} + D_t + q_t \left(H_{H,t} - H_{H,t-1}\right) = R_{H,t-1} D_{t-1} + W_{H,t} N_{H,t} + \varepsilon_{S,t}, \tag{A.1}$$

$$u_{CH,t} = \beta_H E_t \left(R_{H,t} u_{CH,t+1}\right), \tag{A.2}$$

$$W_{H,t} u_{CH,t} = \frac{\tau_H}{1 - N_{H,t}}, \tag{A.3}$$

$$q_t u_{CH,t} = u_{HH,t} + \beta_H E_t \left(q_{t+1} u_{CH,t+1}\right), \tag{A.4}$$

$$C_{B,t} + R_{H,t-1} D_{t-1} + L_{E,t} + ac_{EB,t} = D_t + R_{E,t} L_{E,t-1} - \varepsilon_{S,t}, \tag{A.5}$$

$$D_t = \gamma \left(L_{Et} - E_t \varepsilon_{S,t+1}\right), \tag{A.6}$$

$$\left(1 - \gamma + \frac{\partial ac_{EB,t}}{\partial L_{E,t}}\right) u_{CB,t} = \beta_B E_t \left(\left(R_{E,t+1} - \gamma R_{H,t}\right) u_{CB,t+1}\right), \tag{A.7}$$

$$C_{E,t} + q_t \left(H_{E,t} - H_{E,t-1}\right) + R_{E,t} L_{E,t-1} + W_{H,t} N_{H,t} = Y_t + L_{E,t} + ac_{EE,t}, \tag{A.8}$$

$$Y_t = H_{E,t-1}^{\nu} N_{H,t}^{1-\nu}, \tag{A.9}$$

$$L_{E,t} = m_H E_t \left(\frac{q_{t+1}}{R_{E,t+1}} H_{E,t}\right) - m_N W_{H,t} N_{H,t}, \tag{A.10}$$

$$\left(q_t - E_t \left(1 - \frac{\partial ac_{EE,t}}{\partial L_{E,t}}\right) \frac{m_H q_{t+1}}{R_{E,t+1}}\right) u_{CE,t} = \beta_E E_t \left(\left(q_{t+1} \left(1 - m_H\right) + \nu \frac{Y_{t+1}}{H_{E,t}}\right) u_{CE,t+1}\right), \tag{A.11}$$

$$\left(1 - \nu\right) Y_t = W_{H,t} N_{H,t} E_t \left(1 + m_N \left(1 - \frac{\partial ac_{EE,t}}{\partial L_{E,t}} - \beta_E R_{E,t+1} \frac{u_{CE,t+1}}{u_{CE,t}}\right)\right), \tag{A.12}$$

$$H_{H,t} + H_{E,t} = 1. \tag{A.13}$$

The model endogenous variables are Y, H_E, H_H, N_H, C_B, C_E, C_H, L_E, D, q, W_H, R_E, and R_H. The exogenous repayment shock is $\varepsilon_{S,t}$.

Appendix B Complete Set of Equations of the Extended Model

Patient/Saver Households

Patient households solve:

$$\max E_0 \sum_{t=0}^{\infty} \beta_H^t \left(A_{p,t}\left(1-\eta\right)\log\left(C_{H,t}-\eta C_{H,t-1}\right)+jA_{j,t}A_{p,t}\log H_{H,t}+\tau\log\left(1-N_{H,t}\right)\right)$$

subject to:

$$\begin{aligned} & C_{H,t}+\frac{K_{H,t}}{A_{K,t}}+D_t+q_t\left(H_{H,t}-H_{H,t-1}\right)+ac_{KH,t}+ac_{DH,t}, \\ = & \left(R_{M,t}z_{KH,t}+\frac{1-\delta_{KH,t}}{A_{K,t}}\right)K_{H,t-1}+R_{H,t-1}D_{t-1}+W_{H,t}N_{H,t}, \end{aligned} \tag{B.1}$$

where the adjustment costs take the following form

$$\begin{aligned} ac_{KH,t} &= \frac{\phi_{KH}}{2}\frac{\left(K_{H,t}-K_{H,t-1}\right)^2}{K_H}, \\ ac_{DH,t} &= \frac{\phi_{DH}}{2}\frac{\left(D_t-D_{t-1}\right)^2}{D}, \end{aligned}$$

and the depreciation function is

$$\delta_{KH,t}=\delta_{KH}+b_{KH}\left(0.5\zeta_H' z_{KH,t}^2+\left(1-\zeta_H'\right)z_{KH,t}+\left(0.5\zeta_H'-1\right)\right),$$

where $\zeta_H' = \frac{\zeta_H}{1-\zeta_H}$ is a parameter measuring the curvature of the utilization rate function. $\zeta_H = 0$ implies $\zeta_H' = 0$; ζ_H approaching 1 implies ζ_H' approaches infinity and $\delta_{KH,t}$ stays constant. $b_{KH} = \frac{1}{\beta_H}+1-\delta_{KH}$ and implies a unitary steady state utilization rate. ac measures a quadratic adjustment cost for changing the quantity i between time $t-1$ and time t. Both habits and adjustment costs are assumed to be external.

Denote with $u_{CH,t} = \frac{A_{p,t}(1-\eta)}{C_{H,t}-\eta C_{H,t-1}}$ and $u_{HH,t} = \frac{jA_{j,t}A_{p,t}}{H_{H,t}}$ the marginal utilities of consumption and housing. The optimality conditions yield a deposit supply equation; labor supply; an equation for the supply of capital; housing demand; and an equation for the optimal utilization rate.

$$u_{CH,t}\left(1+\frac{\partial ac_{DH,t}}{\partial D_t}\right)=\beta_H E_t\left(R_{H,t}u_{CH,t+1}\right), \tag{B.2}$$

$$W_{H,t}u_{CH,t}=\frac{\tau_H}{1-N_{H,t}}, \tag{B.3}$$

$$\frac{1}{A_{K,t}}u_{CH,t}\left(1+\frac{\partial ac_{KH,t}}{\partial K_{H,t}}\right)=\beta_H E_t\left(\left(R_{M,t+1}z_{KH,t+1}+\frac{1-\delta_{KH,t+1}}{A_{K,t+1}}\right)u_{CH,t+1}\right), \tag{B.4}$$

$$q_t u_{CH,t}=u_{HH,t}+\beta_H E_t\left(q_{t+1}u_{CH,t+1}\right), \tag{B.5}$$

$$R_{M,t}=\frac{\partial\delta_{KH,t}}{\partial z_{KH,t}}, \tag{B.6}$$

where $A_{K,t}$ is an investment shock, $A_{p,t}$ is a consumption preference shock, $A_{j,t}$ is a housing demand shock.

Impatient / Borrower Households

Impatient households solve:

$$\max E_0 \sum_{t=0}^{\infty} \beta_S^t \left(A_{p,t}\left(1-\eta\right)\log\left(C_{S,t}-\eta C_{S,t-1}\right)+jA_{j,t}A_{p,t}\log H_{S,t}+\tau\log\left(1-N_{S,t}\right)\right),$$

where

$$\beta_S < \left(1-\left(\left(1-\beta_B\right)\rho_D+\left(1-\rho_D\right)\gamma_S\right)\frac{1-\beta_B R_H}{1-\beta_B\rho_D}\right)\beta_B,$$

subject to

$$C_{S,t}+q_t\left(H_{S,t}-H_{S,t-1}\right)+R_{S,t-1}L_{S,t-1}-\varepsilon_{H,t}+ac_{SS,t}=L_{S,t}+W_{S,t}N_{S,t}, \tag{B.7}$$

and to

$$L_{S,t}\leq\rho_S L_{S,t-1}+\left(1-\rho_S\right)m_S A_{MH,t}E_t\left(\frac{q_{t+1}}{R_{S,t}}H_{S,t}\right), \tag{B.8}$$

where $\varepsilon_{H,t}$ is the borrower repayment shock, $A_{MH,t}$ is a loan-to-value ratio shock. The adjustment cost is:

$$ac_{SS,t}=\frac{\phi_{SS}}{2}\frac{\left(L_{S,t}-L_{S,t-1}\right)^2}{L_S}.$$

The first order conditions are, denoting with $u_{CS,t}=\frac{A_{p,t}(1-\eta)}{C_{S,t}-\eta C_{S,t-1}}$ and $u_{HS,t}=\frac{jA_{j,t}A_{p,t}}{H_{S,t}}$ the marginal utilities of consumption and housing; and with $\lambda_{S,t}u_{CS,t}$ the (normalized) multiplier on the borrowing constraint:

$$\left(1-\frac{\partial ac_{SS,t}}{\partial L_{S,t}}-\lambda_{S,t}\right)u_{CS,t}=\beta_S E_t\left(\left(R_{S,t}-\rho_S\lambda_{S,t+1}\right)u_{CS,t+1}\right), \tag{B.9}$$

$$W_{S,t}u_{CS,t}=\frac{\tau_S}{1-N_{S,t}}, \tag{B.10}$$

$$\left(q_t-\lambda_{S,t}\left(1-\rho_S\right)m_S A_{MH,t}E_t\frac{q_{t+1}}{R_{S,t}}\right)u_{CS,t}=u_{HS,t}+\beta_S E_t\left(q_{t+1}u_{CS,t+1}\right). \tag{B.11}$$

Bankers

Bankers solve:

$$\max E_0 \sum_{t=0}^{\infty} \beta_B^t\left(1-\eta\right)\log\left(C_{B,t}-\eta C_{B,t-1}\right)$$

where

$$\beta_B < \beta_H,$$

subject to

$$C_{B,t}+R_{H,t-1}D_{t-1}+L_{E,t}+L_{S,t}+ac_{DB,t}+ac_{EB,t}+ac_{SB,t}=D_t+R_{E,t}L_{E,t-1}+R_{S,t}L_{S,t-1}-\varepsilon_{E,t}-\varepsilon_{S,t}, \tag{B.12}$$

where $\varepsilon_{E,t}$ is the entrepreneur repayment shock. The adjustment costs are:

$$\begin{aligned} ac_{DB,t} &= \frac{\phi_{DB}}{2}\frac{\left(D_t - D_{t-1}\right)^2}{D}, \\ ac_{EB,t} &= \frac{\phi_{EB}}{2}\frac{\left(L_{E,t} - L_{E,t-1}\right)^2}{L_E}, \\ ac_{SB,t} &= \frac{\phi_{SB}}{2}\frac{\left(L_{S,t} - L_{S,t-1}\right)^2}{L_S}. \end{aligned}$$

Denote $\varepsilon_t = \varepsilon_{E,t} + \varepsilon_{S,t}$. Let $L_t = L_{E,t} + L_{S,t}$. The banker's constraint is a capital adequacy constraint of the form:

$$\underbrace{(L_t - D_t - E_t\varepsilon_{t-1})}_{\text{bank equity}} \geq \rho_D \left(L_{t-1} - D_{t-1} - E_{t-1}\varepsilon_t\right) + (1-\gamma)(1-\rho_D)\underbrace{(L_t - E_t\varepsilon_{t+1})}_{\text{bank assets}},$$

stating that bank equity (after expected losses) must exceed a fraction of bank assets, allowing for a partial adjustment in bank capital given by ρ_D. Such constraint can be rewritten as a leverage constraint of the form

$$\begin{aligned} &D_t \leq \rho_D \left(D_{t-1} - \left(L_{E,t-1} + L_{S,t-1} - E_{t-1}\left(\varepsilon_{E,t} + \varepsilon_{S,t}\right)\right)\right) + \\ &(1 - (1-\gamma)(1-\rho_D))\left(L_{Et} + L_{S,t} - E_t\left(\varepsilon_{E,t+1} + \varepsilon_{S,t+1}\right)\right). \end{aligned} \tag{B.13}$$

The first order conditions to the banker's problem imply, choosing D, L_E, L_S and letting $\lambda_{B,t}u_{CB,t}$ be the normalized multiplier on the borrowing constraint (where $u_{CB,t}$ is the banker's marginal utility of consumption):

$$\left(1 - \lambda_{B,t} - \frac{\partial ac_{DB,t}}{\partial D_t}\right) u_{CB,t} = \beta_B E_t\left(\left(R_{H,t} - \rho_D\lambda_{B,t+1}\right)u_{CB,t+1}\right), \tag{B.14}$$

$$\left(1 - \left(\gamma_E\left(1-\rho_D\right) + \rho_D\right)\lambda_{B,t} + \frac{\partial ac_{EB,t}}{\partial L_{E,t}}\right) u_{CB,t} = \beta_B E_t\left(\left(R_{E,t+1} - \rho_D\lambda_{B,t+1}\right)u_{CB,t+1}\right), \tag{B.15}$$

$$\left(1 - \left(\gamma_S\left(1-\rho_D\right) + \rho_D\right)\lambda_{B,t} + \frac{\partial ac_{SB,t}}{\partial L_{S,t}}\right) u_{CB,t} = \beta_B E_t\left(\left(R_{S,t} - \rho_D\lambda_{B,t+1}\right)u_{CB,t+1}\right). \tag{B.16}$$

Entrepreneurs

Entrepreneurs obtain loans and produce goods (including capital). Entrepreneurs hire workers and demand capital supplied by the household sector.

$$\max E_0 \sum_{t=0}^{\infty} \beta_E^t (1-\eta)\log\left(C_{E,t} - \eta C_{E,t-1}\right)$$

where

$$\beta_E\left(1 - \left(\left(1-\beta_B\right)\rho_D + \left(1-\rho_D\right)\gamma_E\right)\frac{1-\beta_B R_H}{1-\beta_B\rho_D}\right) < \beta_B,$$

subject to:

$$C_{E,t}+\frac{K_{E,t}}{A_{K,t}}+q_tH_{E,t}+R_{E,t}L_{E,t-1}+W_{H,t}N_{H,t}+W_{S,t}N_{S,t}+R_{M,t}z_{KH,t}K_{H,t-1}+ac_{KE,t}+ac_{EE,t},$$
$$=Y_t+\frac{1-\delta_{KE,t}}{A_{K,t}}K_{E,t-1}+q_tH_{E,t-1}+L_{E,t}+\varepsilon_{E,t}, \tag{B.17}$$

and to

$$Y_t=A_{Z,t}\left(z_{KH,t}K_{H,t-1}\right)^{\alpha(1-\mu)}\left(z_{KE,t}K_{E,t-1}\right)^{\alpha\mu}H_{E,t-1}^{\nu}N_{H,t}^{(1-\alpha-\nu)(1-\sigma)}N_{S,t}^{(1-\alpha-\nu)\sigma}, \tag{B.18}$$

where $A_{Z,t}$ is a shock to total factor productivity. The adjustment costs are

$$\begin{aligned} ac_{KE,t} &= \frac{\phi_{KE}}{2}\frac{\left(K_{E,t}-K_{E,t-1}\right)^2}{K_E}, \\ ac_{EE,t} &= \frac{\phi_{EE}}{2}\frac{\left(L_{E,t}-L_{E,t-1}\right)^2}{L_E}. \end{aligned}$$

Note that symmetrically to the household problem entrepreneurs are subject to an investment shock, can adjust the capital utilization rate, and pay a quadratic capital adjustment cost. The depreciation rate is governed by

$$\delta_{KE,t}=\delta_{KE}+b_{KE}\left(0.5\zeta_E' z_{KE,t}^2+\left(1-\zeta_E'\right)z_{KE,t}+\left(0.5\zeta_E'-1\right)\right),$$

where setting $b_{KE}=\frac{1}{\beta_E}+1-\delta_{KE}$ implies a unitary steady state utilization rate.

Entrepreneurs are subject to a borrowing/pay in advance constraint that acts as a wedge on the capital and labor demand. The constraint is

$$L_{E,t}=\rho_E L_{E,t-1}+\left(1-\rho_E\right)A_{ME,t}E_t\left(m_H\frac{q_{t+1}}{R_{E,t+1}}H_{E,t}+m_K K_{E,t}-m_N\left(W_{H,t}N_{H,t}+W_{S,t}N_{S,t}\right)\right). \tag{B.19}$$

Letting $u_{CE,t}$ be the marginal utility of consumption and $\lambda_{E,t}u_{CE,t}$ the normalized borrowing constraint, the first order conditions for L_E, K_E and H_E are:

$$\left(1-\lambda_{E,t}-\frac{\partial ac_{LE,t}}{\partial L_{E,t}}\right)u_{CE,t}=\beta_E E_t\left(\left(R_{E,t+1}-\rho_E\lambda_{E,t+1}\right)u_{CE,t+1}\right), \tag{B.20}$$

$$\left(1+\frac{\partial ac_{KE,t}}{\partial K_{E,t}}-\lambda_{E,t}\left(1-\rho_E\right)m_K A_{ME,t}\right)u_{CE,t}=\beta_E E_t\left(\left(1-\delta_{KE,t+1}+R_{K,t+1}z_{KE,t+1}\right)u_{CE,t+1}\right), \tag{B.21}$$

$$\left(q_t-\lambda_{E,t}\left(1-\rho_E\right)m_H A_{ME,t}E_t\left(\frac{q_{t+1}}{R_{E,t+1}}\right)\right)u_{CE,t}=\beta_E E_t\left(q_{t+1}\left(1+R_{V,t+1}\right)u_{CE,t+1}\right). \tag{B.22}$$

Additionally, these conditions can be combined with those of the production arm of the firm, giving:

$$\alpha\mu Y_t = R_{K,t} z_{KE,t} K_{E,t-1}, \tag{B.23}$$
$$\alpha(1-\mu) Y_t = R_{M,t} z_{KH,t} K_{H,t-1} X_t, \tag{B.24}$$
$$\nu Y_t = R_{V,t} q_t H_{E,t-1}, \tag{B.25}$$
$$(1-\alpha-\nu)(1-\sigma) Y_t = W_{H,t} N_{H,t} (1 + m_N A_{ME,t} \lambda_{E,t}), \tag{B.26}$$
$$(1-\alpha-\nu)\sigma Y_t = W_{S,t} N_{S,t} (1 + m_N A_{ME,t} \lambda_{E,t}), \tag{B.27}$$
$$R_{K,t} = \frac{\partial \delta_{KE,t}}{\partial z_{KE,t}}. \tag{B.28}$$

Equilibrium

Market clearing is implied by Walras's law by aggregating all the budget constraints. For housing, we have the following market clearing condition

$$H_{H,t} + H_{S,t} + H_{E,t} = 1. \tag{B.29}$$

The model endogenous variables are Y, H_E, H_H, H_S, K_E, K_H, N_H, N_S, C_B, C_E, C_H, z_{KH}, z_{KE}, L_E, L_S, D, q, W_H, W_S, R_K, R_M, R_V, R_E, R_S, R_H, λ_E, λ_S, λ_B, together with the definition of the depreciation rate functions and the adjustment cost functions given in the text above.

Shocks

The following zero-mean, AR(1) shocks are present in the estimated version of the model: ε_E, ε_H, A_j, A_K, A_{ME}, A_{MH}, A_p, A_z. The shocks follow the processes given by:

$$\begin{aligned}
\varepsilon_{E,t} &= \rho_{be}\varepsilon_{E,t-1} + \upsilon_{E,t}, \quad \upsilon_E \sim N(0,\sigma_{be}), \\
\varepsilon_{H,t} &= \rho_{bh}\varepsilon_{H,t-1} + \upsilon_{H,t}, \quad \upsilon_H \sim N(0,\sigma_{bh}), \\
\log A_{j,t} &= \rho_j \log A_{j,t-1} + \upsilon_{j,t}, \quad \upsilon_j \sim N(0,\sigma_j), \\
\log A_{K,t} &= \rho_K \log A_{K,t-1} + \upsilon_{K,t}, \quad \upsilon_K \sim N(0,\sigma_k), \\
\log A_{ME,t} &= \rho_{me} \log A_{ME,t-1} + \upsilon_{ME,t}, \quad \upsilon_{ME} \sim N(0,\sigma_{me}), \\
\log A_{MH,t} &= \rho_{mh} \log A_{MH,t-1} + \upsilon_{MH,t}, \quad \upsilon_{MH} \sim N(0,\sigma_{mh}) \\
\log A_{p,t} &= \rho_p \log A_{p,t-1} + \upsilon_{p,t}, \quad \upsilon_p \sim N(0,\sigma_p), \\
\log A_{Z,t} &= \rho_z \log A_{Z,t-1} + \upsilon_{z,t}, \quad \upsilon_z \sim N(0,\sigma_z).
\end{aligned}$$

Appendix C Estimation: Data Construction

The model is estimated with US quarterly data.

I use the following time series as observables. Series mnemonics are from Haver Analytics. Consumption and Investment data are from NIPA. Loan data are from the Flow of Funds Accounts. Loan charge-offs data are from the Federal Reserve Board.

1. **Consumption**

   Model Variable: C_t.

   Data: *CH@USECON:* Real Personal Consumption Expenditures (SAAR, Bil.Chn.2005$, Source: BEA). The series is log transformed, and detrended with a quadratic trend.

2. **Investment**

   Model Variable: $I_t = \frac{K_{E,t}-\left(1-\delta_{KE,t}\right)K_{E,t-1}+K_{H,t}-\left(1-\delta_{KH,t}\right)K_{H,t-1}}{A_{K,t}}$.

   Data: *FNH@USECON*: Real Private Nonresidential Fixed Investment (SAAR, Bil.Chn.2005$, Source: BEA). The series is log transformed, and detrended with a quadratic trend.

3. **Losses on Loans to Entrepreneurs**

   Model Variable: $\varepsilon_{E,t}$.

   Data: $\varepsilon_{Et} = DYRM \times OL14MOR5 + DYI \times (OL14OTL5 + OL14BLN5)$,

   where: *DYRM@USECON*: Loan Charge-Off Rate: Commercial Real Estate Loans: All Comml Banks (SAAR,%) (Source: H8 Release, Federal Reserve Board);

   OL14BLN5@FFUNDS: Nonfinancial business; total mortgages; liability (Source: Table L.101, Flow of Funds Accounts);

   DYI@USECON: Loan Charge-Off Rate: C&I Loans: All Insured Comml Banks (SAAR,%) (Source: H8 Release, Federal Reserve Board);

   OL14OTL5@FFUNDS: Nonfinancial business; other loans and advances; liability (Source: Table L.101, Flow of Funds Accounts);

   OL14BLN5@FFUNDS: Nonfinancial business; depository institution loans n.e.c.; liability (Source: Table L.101, Flow of Funds Accounts).

   The data series is constructed multiplying commercial bank charge-off rates by the volume of loans (C&I loans, mortgages and loans not elsewhere classified) held by nonfinancial businesses.

   Both in the model and in the data, charge-offs rates are scaled by steady–state GDP. In the data, liabilities are in dollars and steady-state GDP is measured by a cubic trend in the sum of nominal consumption and investment.

   Notes: When a bank loan is securitized and sold to another bank or GSE, it shows as a loan in the liability side of the nonfinancial business sector balance sheet, while it shows as a security in the asset side of the bank balance sheet. Charge-offs are measured in the data by looking at reported losses of banks on loans on the asset side of the balance sheet. By multiplying charge-off rates by the total amount of liabilities of the business sector in the form of loans, one is implicitly allocating losses to all loans and securities held by banks or institutions who purchased securities whose underlying asset are these loans (alternatively, one is consolidating GSE, commercial banks and ABS issuers into one single, big, financial institution). More detail is provided in Appendix D.

Charge-offs for commercial mortgages ($DYRM$) are available starting in 1991Q1, whereas charge-offs for C&I Loans (DYI) begin in 1985Q1. I use the regression coefficients of a regression of $DYRM$ on a constant and DYI for the 1991-2010 period and data on DYI in order to backcast the missing data for $DYRM$ for the 1986-1990 period.

4. **Losses on Loans to Households**

   Model Variable: $\varepsilon_{H,t}$.

   Data: $\varepsilon_{Ht} = DYRR \times XL15HOM5 + DYU \times HCCSDODNS$,

   where *DYRR@USECON*: Loan Charge-Off Rate: Residential Real Estate Loans: All Comml Banks (SAAR,%); (Source: H8 Release, Federal Reserve Board);

   XL15HOM5@FFUNDS: Households and nonprofit organizations; home mortgages; liability (Source: Table L.100, Flow of Funds Accounts);

   DYU@USECON Loan Charge-Off Rate: Consumer Loans: All Insured Comml Banks (SA,%) (Source: H8 Release, Federal Reserve Board);

   HCCSDODNS@FFUNDS: Households and nonprofit organizations; consumer credit; liability (Source: Table L.100, Flow of Funds Accounts).

   Both in the model and in the data, charge-offs rates are scaled by steady–state GDP. In the data, liabilities are in dollars and steady-state GDP is measured by a cubic trend in the sum of nominal consumption and investment.

   Notes: Charge-offs for mortgages ($DYRR$) are available starting in 1991Q1, whereas charge-offs for Consumer Loans (DQU) begin in 1985Q1. I use the regression coefficients of a regression of $DYRR$ on a constant and DQU for the 1991-2010 period and data on DYI in order to backcast the missing data for $DYRR$ for the 1986-1990 period.

5. **Loans to Entrepreneurs**

   Model Variable: $L_{E,t}$.

   Data: $L_{E,t} = OL14MOR5 + OL14OTL5 + OL14BLN5$. The series is converted in real terms using the GDP deflator, log transformed and detrended with a quadratic trend.

6. **Loans to Households**

   Model Variable: $L_{H,t}$.

   Data: $L_{H,t} = XL15HOM5 + HCCSDODNS$. The series is converted in real terms using the GDP deflator, log transformed and detrended with a quadratic trend.

7. **House Prices**

   Model Variable: q_t.

   Data: *USHPI@USECON*: FHFA House Price Index, United States (NSA). The series is converted in real terms using the GDP deflator, log transformed and detrended with a quadratic trend (Source: FHFA).

8. **Technology (TFP)**

   Model Variable: $A_{Z,t}$.

Data: Utilization–adjusted quarterly growth rate of TFP (*DTFP_UTIL@SFFED*) constructed by Fernald (2012). The series is integrated back to levels, log transformed, and detrended with a quadratic trend.

Notes: Fernald corrects the Solow residual (a measure of TFP) by utilization (and other adjustments) to arrive at a measure of the growth rate of technology. The utilization-adjusted quarterly series is an improvement over more "naïve" measures of TFP as a high-frequency indicator of technological change". As shown in the bottom right panel of Figure 2, it is hard to characterize the behavior of TFP during the financial crisis is simple terms: TFP is weak around the 2005-2008 period, rises in 2009 in the midst of the financial crisis, and drops again around 2010 (by contrast, TFP without the utilization adjustment does not rise in 2009, as utilization drops substantially at the peak of the financial crisis).

Appendix D Additional Notes on Charge-offs

Charge-off rates are the flow of a bank's net charge-offs (gross charge-offs minus recoveries) during a quarter divided by the average level of its loan outstanding over that quarter multiplied by 400 to express the ratio as an annual percentage rate. Charged-off loans are reported on schedule RI-B and the average levels of loans on schedule RC-K of a bank's quarterly Consolidated Report of Condition and Income (generally referred to as the call report). Charge-off rates on loans are then computed dividing bank's net charge-offs by average outstanding loans of banks.

For the purpose of computing total losses of all financial intermediaries, I apply bank charge-off rates to the entire stock of mortgage debt held by households and businesses in the U.S. Note, in fact, that bank loans are only a fraction of total loan payables of households and businesses, since many loans are sold after origination to GSE and secondary market investors. For instance, as shown in Table $L.217$ of the Flow of Funds data, the total stock of mortgage debt (held by households and businesses) in the U.S. at the end of 2010 was \$13.7 tn. Out of this amount, \$4.2tn is held by banks (largely, U.S. chartered depository institutions) which file the call reports, whereas the rest is held by GSEs and Agency- and GSE-backed mortgage pools (\$6.2tn), by ABS issuers (\$2tn), and a smaller fraction by REITs, Finance Companies, Credit Unions. By allocating all losses to banks, I am effectively consolidating GSE, commercial banks and ABS issuers into one single, big, financial institution. Note also that GSEs may issue liabilities to finance issuance of ABS, and some of their liabilities are in turn owned by banks.

How big were the charge-offs during the financial crisis? If one considers charge-offs at all insured commercial banks, net charge-offs were \$150bn above baseline per year for about 3 years, for a total cumulative loss of around \$450bn. Charge-offs of \$176bn in 2009 against a loan volume of \$6,647bn in the same year (broken down into \$966bn of consumer loans, \$2,099bn of residential real estate loans, and \$1,344bn of commercial real estate loans) indicate a charge-off rate of 2.5 percent, and a ratio of charge-offs to GDP of around 1.5 percent. If one now takes the same charge-off rate but applies it to all debt instruments of households and businesses in the United States, cumulative loan losses in dollars become much larger, since they now apply to a stock of household debt of \$13,394 bn in 2009, and a stock of nonfinancial business debt of \$6,416 bn. Hence the resulting losses are about \$1.2tn (three times larger).