Appendix

For Online Publication

A Data

A.1 Data Sources

Name	Data	Source
Macroeconomic Data		
Output	Real Gross Domestic Product	BEA
Investment	Real Gross Private Domestic Investment	BEA
Consumption	Real Personal Consumption Expenditures	BEA
Hours	Non-farm Business Sector: Hours of All Persons	BLS
BAA-10Y Spread	Moody's Seasoned Baa Corporate Bond Yield Relative to Yield on 10-Year Treasury Constant Maturity	Federal Reserve Bank of St. Louis and Moody's
AAA-10Y Spread	Moody's Seasoned Aaa Corporate Bond Yield Relative to Yield on 10-Year Treasury Constant Maturity	Federal Reserve Bank of St. Louis and Moody's
TED Spread	TED Spread	Federal Reserve Bank of St. Louis
Data from Compustat		
Market Value of Equity	Common Shares Outstanding × Price (Close) – Quarter	Compustat
Short-Term Debt	Debt in Current Liabilities	Compustat
Long-Term Debt	Long-Term Debt – Total	Compustat
Accounts Payable	Accounts Payable	Compustat

Table 4: Data sources.

For the figures, output, investment, consumption, and hours are detrended using CBO potential estimates for output and hours, normalizing the deviations from trend to zero at the start of the figures in 2004Q2. For the tables, we detrend them using a log-quadratic trend estimated using data from 1986Q1 to 2018Q4. We also detrend the market value of equity using a log-quadratic trend for both figures and tables, normalizing it to zero in 2004Q2.

A.2 Definition of Retail and Shadow Banks in Compustat

Table 5 provides an overview of the definition of retail and shadow banks. As there are many definitions of shadow banking in the literature, we discuss our approach below and contrast it with other choices in the literature.

Definition of Retail Banks For the purpose of this paper, retail banks are all institutions that predominantly finance themselves with deposits, while shadow banks are institutions that predominantly finance themselves with wholesale funding. According to this definition, it is quite natural to include depository institutions (2-digit SIC code

60) into the retail banking sector. The relevant 3-digit SIC codes are commercial banks (SIC code 602) and savings institutions (SIC code 603). There are no firms with SIC code 603 (credit unions), SIC code 608 (foreign banking and branches and agencies of) or SIC code 609 (functions related to depository banking) in Compustat. In addition, we include bank holding companies (SIC code 6712) into the retail banking sector, as these are effectively vehicles for owners of banks. The official definition of this industry is *Establishments primarily engaged in holding or owning the securities of banks for the sole purpose of exercising some degree of control over the activities of bank companies whose securities they hold. Companies holding securities of banks, but which are predominantly operating the banks, are classified according to the kind of bank operated.*[24] Our definition of the retail banking sector is in line with Begenau and Landvoigt 2022.

Type	SIC Code	Description
Retail Banks		
	602	Commercial Banks
	603	Savings Institutions
	6712	Holding Offices
Shadow Banks		
	614	Personal Credit Institutions
	615	Business Credit Institutions
	616	Mortgage Bankers & Brokers
	617	Finance Lessors
	6211	Security Brokers & Dealers

Table 5: Definition of retail and shadow banks.

Definition of Shadow Banks There are many different definitions of non-banks or shadow banks in the literature. Pozsar et al. 2012 and Gallin 2013 provide overviews. Our definition of shadow banks comprises non-depository credit institutions (SIC code 61) and security brokers, dealers and flotation companies (SIC code 6211). Security brokers and dealers are often included into the definition of shadow banks (see e.g. Gertler, Kiyotaki, and Prestipino 2016 or Ferrante 2018). Regarding non-depository credit institutions, we exclude firms with SIC code 611 (federal and federally-sponsored credit agencies). As these institutions have very high leverage, our decision to exclude them lowers shadow bank leverage. These firms are, among others, Freddie Mac and Fannie Mae, which are both very large and special in that they are subject to implicit government guarantees, such that our model of shadow banks is not appropriate for these institutions. The other groups are non-depository lenders, e.g. personal credit institutions (SIC code 614), business credit institutions and mortgage lenders. Common to these institutions is that they

24. See here: https://www.osha.gov/sic-manual/6712.

borrow to originate loans. Among these institutions are for example finance companies, which are often included in definitions of shadow banks (see e.g. Pozsar et al. 2012, exhibit 1).

Our definition of shadow banks is similar to Begenau and Landvoigt 2022, but more narrow. They additionally include real estate investment trusts into their definition of shadow banks (SIC code 6798). We chose not to do so, as real estate investment trusts have similar business models as mutual funds and rely on equity financing, not short-term debt. Thus, our model of the shadow banking sector would not be appropriate for these firms. This is a large category in Compustat. Our decision not to include REITs into the shadow banking sector increases shadow bank leverage. Moreover, Begenau and Landvoigt 2022 include miscellaneous investment firms into the shadow banking sector. These are SIC codes 6799 and 6726. We choose to exclude these as well, as they include venture capital firms and closed-end investment funds, which also have different business models compared to the shadow banks in our model.

Internal vs External Shadow Banks Common to many definitions of shadow banks, including ours, is the issue that they only comprise external shadow banks, i.e. institutions that are independent of traditional banks, but perform bank-like activities. An important narrative of the financial crisis is about internal shadow banks, i.e. subsidiaries of traditional banks that were founded for the purpose of regulatory arbitrage. For a description of this process, see Pozsar et al. 2012, exhibit 8. An example of internal shadow banks are special purpose vehicles (SPVs). While it is hard to observe the balance sheets of these shadow banks, the narrative is consistent with the model in this paper: these shadow banks relied on asset-backed commercial paper for funding and used high leverage. Thus, they were strongly affected by the breakdown of the asset-backed commercial paper market (Covitz, Liang, and Suarez 2013), leading to those SPVs being taken back on the balance sheets of commercial banks (He, Khang, and Krishnamurthy 2010, Acharya, Schnabl, and Suarez 2013).

A.3 Data used in Section 4

We use data on all types of financial intermediaries, i.e., with SIC codes as in Table 5. The net worth is defined as the end of period equity price (prccq) times common shares outstanding (cshoq). The return on assets is defined as 400 times income before extraordinary items (ibq) divided by total assets (atq). All other variables are log-transformed and multiplied with 100.

B A Simple Model of Deposit Insurance

This section outlines a simple model with asymmetric information between lenders and borrowers that can explain two critical differences between the market for deposits and wholesale funding in the main text. First, there is deposit insurance in the deposit market but not in the wholesale funding market. Second, wholesale financing allows more leverage than deposit financing.

In a nutshell, the argument goes as follows. Lenders can purchase costly signals about the quality of borrowers, but doing so is only worthwhile in the absence of deposit insurance. Deposit insurance, in turn, is costly for good borrowers, as it reduces their future profits because they must insure lenders against the losses from bad borrowers. As leverage capacity is increasing in profits, deposit insurance reduces the leverage capacity of good borrowers. For lenders with high information acquisition costs, as one would expect of retail investors like households, deposit insurance, and low leverage capacity are optimal. For lenders with low costs of information acquisition, as one would expect of institutional investors, no deposit insurance and high leverage capacity are optimal.

Borrowers There are two periods. The economy consists of a continuum of islands. On each island, there is a continuum of measure 1 of borrowers and lenders. Borrowers choose assets k_1 and debt b_1 to maximize

$$\max_{k_1,b_1} E_1\left[c_2\right] \tag{B.1}$$

subject to

$$c_2 = Z_2 k_1 - b_1 \tag{B.2}$$

$$k_1 = b_1 + n_1 \tag{B.3}$$

$$\psi k_1 = V_1 \tag{B.4}$$

All borrowers on each island are the same, but they differ in their second period asset return across islands. Borrowers, but not lenders, know Z_2 in period 1. For a fraction of islands χ, Z_2 is $\underline{Z} \leq \psi$, while for the remaining fraction $1-\chi$, Z_2 is equal to $\bar{Z}$, which is such that $(1-\chi)\bar{Z} + \chi\underline{Z} > 1$. This assumption ensures that it makes sense for lenders to lend.

Lenders Lenders maximize utility from the second period amount of lending $U(c_2^L)$. Similar to Caballero and Farhi (2017), lenders are infinitely risk averse, i.e., they want a safe return on their lending. Therefore, they choose the value of the collateral constraint V_1 so that the borrower will never divert assets. Lenders can pay a cost κ to observe Z_2.

B.1 First best

Suppose that lenders can perfectly observe the productivity of borrowers Z_2. Then, it is not optimal to lend to low-type banks (i.e., those with $Z_2 = \underline{Z}$), as they will certainly divert assets. To see this, substitute

$$c_2 = (\underline{Z} - 1)k_1 + n_1 \tag{B.5}$$

into the incentive constraint. This yields

$$\phi_1 = \frac{1}{\psi - (\underline{Z} - 1)} \leq 1. \tag{B.6}$$

I.e., any leverage that is above 1 violates the incentive constraint.

For high-type borrowers, the optimal leverage is

$$\phi_1^{FB} = \frac{1}{\psi - (\bar{Z} - 1)} > 1. \tag{B.7}$$

The payoff to the lender on a good island is $c_2^{L,FB} = (\phi_1^{FB} - 1)n_1 > 0$, the payoff to a lender on a bad island is 0.

B.2 No deposit insurance

Case 1: no signal If lenders do not pay to observe the signal, they cannot condition the incentive constraint on the realization of Z_2. To avoid losses, they must set the incentive constraint so that the low-type borrowers will not divert. This restriction implies that there is no lending in equilibrium. The payoff to the lender is, therefore, 0. Borrowers consume their net worth.

Case 2: signal If lenders pay for the signal, they can implement the first best allocation, i.e., they will not lend to the low type borrowers and lend $(\phi_1^{FB} - 1)n_1$ to the high type borrowers. Their payoff is $c_2^L = c_2^{L,FB} - \kappa$, i.e., the loan amount minus the signal cost. Bad borrowers consume their net worth n_1, good borrowers $c_2 = ((\bar{Z}-1)\phi_1^{FB}+1)n_1 > n_1$.

This result implies that it is always optimal for lenders to purchase the signal as long as $c_2^{L,FB} > 0$.

B.3 With deposit insurance

With a deposit insurance scheme, non-diverting borrowers must replace the losses from other diverting borrowers. Suppose that lenders lend to both good and bad borrowers. If low-type borrowers divert, they run away with $\psi k_1 = \psi(b_1 + n_1)$. Lenders recover the remainder $(1-\psi)(b_1+n_1)$. To ensure that lenders get their full money back, non-diverting borrowers need to pay $\psi b_1 - (1-\psi)n_1$ for every diverting borrower, of which there is a total mass χ. That implies that the payoff to non-diverting borrowers in period 2 is

$$((\bar{Z}-1)\phi_1 + 1)n_1 - \frac{\chi}{1-\chi}\left[\psi(\phi_1 - 1) - (1-\psi)\right] n_1. \tag{B.8}$$

This payoff implies that the optimal leverage constraint is

$$\psi\phi_1 = ((\bar{Z}-1)\phi_1 + 1) - \frac{\chi}{1-\chi}\left[\psi(\phi_1 - 1) - (1-\psi)\right]. \tag{B.9}$$

Solving this yields

$$\tilde{\phi}_1 = \frac{1 + \frac{\chi}{1-\chi}}{\psi\left(1 + \frac{\chi}{1-\chi}\right) - (\bar{Z}-1)}. \tag{B.10}$$

Taking the derivative with respect to $a \equiv 1 + \frac{\chi}{1-\chi}$, we get that

$$\frac{\partial \phi_1}{\partial a} = \frac{-(\bar{Z}-1)}{\left(\psi a - (\bar{Z}-1)\right)^2} < 0. \tag{B.11}$$

For small levels of χ, a higher level of χ reduces equilibrium leverage. It also implies that leverage with deposit insurance is lower than without it.

The payoff of the lender is $\tilde{b}_1 = (\tilde{\phi}_1 - 1)n_1$.

B.4 Optimality of deposit insurance

From the planner's perspective, whether deposit insurance is optimal in the end depends on the information acquisition cost. The total resources available for consumption in period 2 without deposit insurance is $\bar{Z}_2\phi_1 n_1(1-\chi) - \kappa$, the total resources available with deposit insurance is $\bar{Z}_2\tilde{\phi}_1 n_1(1-\chi)$, with $\tilde{\phi}_1 < \phi_1$. This comparison implies that there is a unique value of κ such that below this value, deposit insurance is not optimal, while above this value, deposit insurance is optimal. Moreover, in the market with deposit insurance, all else equal, leverage will be lower.

In the wholesale funding market, the lenders are institutional investors with low information acquisition costs. There, deposit insurance is not optimal. The small model above further implies that leverage will be high in this market. In contrast, in the deposit funding market, where the lenders are often households or small retail investors, information acquisition is costly, and deposit insurance is optimal. The model further implies that leverage for deposit-financed institutions will be low.

C Standard Part of the Model

C.1 Households

Preferences Households maximize utility from consumption. Their utility function is

$$\mathbb{E}_t \left[\sum_{s=t}^{\infty} \beta^{s-t} \left[U(c_s^H) - G(l_s^H) - \sum_{J \in H,R} \zeta^J(\tilde{A}_{t+1}^J, A_{t+1}) \right] \right], \tag{C.1}$$

where β is the discount factor of the household. c_t^H denotes household consumption, l_t^H labor supply in period t. $U(c)$ is the current utility function of the household from consumption, $G(l)$ is the disutility of labor. $\zeta^J(\tilde{A}^J, A)$ is a utility loss due to the effort of loan servicing of sector J.

The stochastic discount factor of the household between period t and $t+s$ is

$$\Lambda_{t,t+s} = \beta^{s-t} \frac{U'(c_{t+s}^H)}{U'(c_t^H)}.$$

Household Budget Constraint Households consume and make deposits d_{t+1}^H at banks. They supply labor and receive W_t as labor income. They invest a_{t+1}^H into mutual funds at a price Q_t and subject to a fee f_t^H, receiving a return R_t^A on past investments.[25] In addition, they own the banks and firms and receive their profits Π_t.[26] Deposits yield a safe gross return R_t^D. The budget constraint of the household is

$$c_t^H + d_{t+1}^H + (Q_t + f_t^H) a_{t+1}^H = R_t^D d_t^H + W_t l_t^H + \Pi_t. \tag{C.2}$$

The maximization problem of the household is to choose c_t^H, l_t^H, d_{t+1}^H and a_{t+1}^H to maximize C.1 subject to C.2. The first-order conditions of the household are

$$Q_t + f_t^H = \mathbb{E}_t \Lambda_{t,t+1} R_{t+1}^A \tag{C.3}$$

$$1 = \mathbb{E}_t \Lambda_{t,t+1} R_{t+1}^D \tag{C.4}$$

$$G'(l_t^H) = U'(c_t^H) W_t. \tag{C.5}$$

C.2 Production

The production side of the economy is standard and follows GKP2020. Final goods producers repackage inputs from intermediate goods producers, and capital goods producers transform final goods into capital goods.

25. We introduce direct intermediation since, in its absence, deposits would be the only asset households have access to, complicating the equilibrium in the market for deposits.

26. Profits of capital producers are 0 in steady state but may arise outside of the steady state due to the capital adjustment cost.

C.2.1 Final Goods Producers

Competitive final goods producers repackage intermediate goods $y_t(i)$, which they purchase from a continuum of intermediate goods producers i at price $p_t(i)$, to produce output Y_t according to the following production function:

$$Y_t = \int_0^1 \left(y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{C.6}$$

Cost minimization yields a demand for intermediate good i given by

$$y_t(i) = \left(\frac{p_t(i)}{P_t} \right)^{-\varepsilon} Y_t, \tag{C.7}$$

where P_t is a composite price index given by

$$P_t = \left[\int_0^1 p_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}. \tag{C.8}$$

C.2.2 Intermediate Goods Producers

Intermediate goods producers choose labor $l_t(i)$ and capital $k_t(i)$ to produce intermediate goods $y_t(i)$ at the minimal cost. They set a price $p_t(i)$, subject to a quadratic Rotemberg (1982) price adjustment cost with parameter ρ^R, taking the demand function from final goods producers as given. Their production function is

$$y_t(i) = k_t(i)^{\alpha} l_t(i)^{1-\alpha}. \tag{C.9}$$

Cost minimization yields a marginal cost function

$$mc = \frac{1}{\mathcal{M}_t} = \left(\frac{r_t^A}{\alpha} \right)^{\alpha} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha}, \tag{C.10}$$

where $\mathcal{M}_t$ is the markup over marginal cost, $r_t^A = R_t^A - (1-\delta)Q_t$ is the user cost of capital, and W_t is real wage. The intermediary goods producers choose prices $p_t(i)$ to maximize

$$\sum_{s=t}^{\infty} \Lambda_{t,s} \left[p_s(i) y_s(i) - \frac{1}{\mathcal{M}_s} y_s(i) - \frac{\rho^R}{2} \left(\frac{p_s(i)}{p_{s-1}(i)} - 1 \right) Y_s \right], \tag{C.11}$$

subject to the demand for the intermediate good by the final goods producer C.7. All intermediate goods producers choose the same price, such that $p_t(i) = P_t$. The first-order condition of the intermediate goods producers for the optimal price is

$$(\pi_t - 1)\pi_t - \frac{\varepsilon}{\rho^R}\left(\frac{1}{\mathcal{M}_t} - \frac{\varepsilon - 1}{\varepsilon}\right) = \mathbb{E}_t\Lambda_{t,t+1}\frac{Y_{t+1}}{Y_t}(\pi_{t+1} - 1)\pi_{t+1}, \tag{C.12}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation rate.

The intermediate goods producers own the capital stock. Since they are all identical, they all hold the same amount of capital: $k_t(i) = K_t$. The aggregate capital stock follows the law of motion

$$S_{t+1} = (1 - \delta)K_t + X_t, \tag{C.13}$$

$$K_t = Z_t S_t. \tag{C.14}$$

with depreciation rate δ and investment X_t. We distinguish between capital at the end of $t - 1$, S_t, and capital at the beginning of t, K_t. The distinction arises because of Z_t, which is a capital quality shock that creates exogenous variation in the value of capital, following Merton (1973) and Gertler and Karadi (2011). We interpret it as a fraction of the capital stock losing its economic value. It follows the law of motion

$$\ln Z_t = \rho^Z \ln Z_{t-1} + \varepsilon_t^Z,$$

with $\varepsilon_t^Z \sim N(-(\sigma^Z)^2, \sigma^Z)$.

Firms finance capital purchases using state-contingent retail loans. Hence, the balance sheet constraint of the intermediate goods producers is

$$A_{t+1}^H + A_{t+1}^R + A_{t+1}^S = S_{t+1}. \tag{C.15}$$

C.2.3 Capital Goods Producers

Capital goods producers use a technology that transforms I_t units of final goods into X_t units of capital goods. They face a concave production function, which we specify following Jermann (1998) and Boldrin, Christiano, and Fisher (2001):

$$X_t = \left(\frac{\theta_1}{1 - \theta_0}\left(\frac{I_t}{K_t}\right)^{1-\theta_0} + \theta_2\right) K_t. \tag{C.16}$$

The production function is scaled by the aggregate capital stock K_t, which the capital goods producers take as given. The capital goods producers maximize profits with respect to I_t, which are

$$\Pi_t^Q = Q_t X_t - I_t, \tag{C.17}$$

subject to C.16. The first-order condition from the solution of the capital goods producers' problem yields the following expression for the price of capital:

$$Q_t = \frac{1}{\theta_1} \left(\frac{I_t}{K_t} \right)^{\theta_0}. \tag{C.18}$$

θ_0 is the elasticity of the capital price to the investment-capital ratio. Due to the concave production function, the capital goods producers may earn non-zero profits outside the steady state. The households own them. Firms transfer any profits or losses to households in each period.

C.3 Policy, Aggregation and Market Clearing

C.3.1 Monetary Policy

The central bank sets the nominal interest rate R^N_{t+1} according to a rule which responds to inflation π_t with elasticity κ^π and a measure of the output gap with elasticity κ^y:

$$R^N_{t+1} = \frac{1}{\beta} \pi_t^{\kappa^\pi} \left(\frac{\mathcal{M}_t}{\mathcal{M}^n_t} \right)^{\kappa^y}. \tag{C.19}$$

$\mathcal{M}^n_t = \frac{\varepsilon}{\varepsilon - 1}$ is the optimal markup of the intermediate goods producers absent price rigidities. We use this measure instead of the actual output gap since we have a closed-form expression for optimal markup absent price rigidities, but not for the natural output rate Y^n_t. This markup measures the labor market wedge due to nominal rigidities.

After the financial crisis, the US economy remained at the zero lower bound of the nominal interest rate for an extended period. The model is already highly complex. Therefore, modeling the effects of the zero lower bound, while interesting, is unfortunately beyond the scope of this paper.

C.3.2 Aggregation

There is no idiosyncratic uncertainty for households, so that we can consider the problem of a representative household. Moreover, since the policy functions of an individual bank are linear in net worth, we will characterize the equilibrium in terms of the aggregate decisions of the banking sectors. The aggregate net worth of the retail and shadow banking sectors is the sum of the net worth of incumbent and newly entering banks:

$$N_t^R = \max\left\{R_t^A A_t^R + R_t^B B_t^R - R_t^D D_t^R, 0\right\}(1-\sigma^R) + \upsilon K_t \tag{C.20}$$

$$N_t^S = \begin{cases} \max\left\{R_t^A A_t^S + R_t^B B_t^S, 0\right\}(1-\sigma^S) + \upsilon K_t & \text{if no panic occurs} \\ 0 & \text{if a panic occurs} \\ \upsilon K_t + (1-\sigma^S)\upsilon K_{t-1} & \text{in the period after a panic.} \end{cases} \tag{C.21}$$

Aggregate profits are profits of screening firms $\Pi_t^{L,H} + \Pi_t^{L,R}$, intermediate goods producers Π_t^F, and capital goods producers Π_t^Q, plus the sum of the net worth of exiting retail banks and shadow banks minus the net worth of entering banks:

$$\Pi_t = \Pi_t^Q + \Pi_t^F + \sigma^R n_t^R + \sigma^S n_t^S + \Pi_t^{L,H} + \Pi_t^{L,R} - 2\upsilon K_t \tag{C.22}$$

The production function gives the aggregate output:

$$Y_t = K_t^\alpha L_t^{1-\alpha}. \tag{C.23}$$

C.3.3 Market Clearing

The markets for retail loans,

$$S_{t+1} = A_{t+1}^H + A_{t+1}^R + A_{t+1}^S \tag{C.24}$$

labor,

$$L_t^H = L_t \tag{C.25}$$

deposits,

$$D_{t+1}^H = D_{t+1}^R \tag{C.26}$$

wholesale loans,

$$0 = B_{t+1}^R + B_{t+1}^S \tag{C.27}$$

investment

$$X_t = S_{t+1} - (1-\delta)K_t \tag{C.28}$$

and loan services

$$A_{t+1}^J = \tilde{A}_{t+1}^J, \quad J \in \{H, R\} \tag{C.29}$$

have to clear. Since there is a representative household, the individual consumption and aggregate consumption are equal, $c_t^H = C_t^H$. We infer household consumption from the aggregate resource constraint:

$$C_t^H = Y_t - I_t - G - \frac{\rho^R}{2}(\pi_t - 1)^2 Y_t, \tag{C.30}$$

where G denotes government consumption.

D Full Statement of the Equilibrium Conditions

Denote variables in the no-run equilibrium by X_t and variables in the run equilibrium by X_t^*. We introduce the following notation to denote state-contingent variables:

$$\mathbf{X}_{t+1} = \begin{cases} X_{t+1}^* & \text{if } x_{t+1}^* \leq 1 \text{ and sunspot observed} \\ X_{t+1} & \text{if } x_{t+1}^* \leq 1 \text{ and no sunspot observed or } x_{t+1}^* > 1 \end{cases}$$

D.1 No Run Equilibrium

- Household:
  - Capital:

$$\left(Q_t + f_t^H\right) = \mathbb{E}_t\left(\mathbf{\Lambda}_{t,t+1}^H \mathbf{R}_{t+1}^A\right) \tag{D.1}$$

  - Deposits:

$$1 = \mathbb{E}_t\left(\mathbf{\Lambda}_{t,t+1}^H R_{t+1}^D\right) \tag{D.2}$$

  - Labor

$$\mu L_t^\phi = (C_t^H)^{-\sigma} W_t \tag{D.3}$$

  - Stochastic Discount Factor

$$\mathbf{\Lambda}_{t,t+1}^H = \beta\left(\frac{\mathbf{C}_{t+1}^H}{C_t^H}\right)^{-\sigma} \tag{D.4}$$

- Shadow Bank:
  - Value Function

$$\Omega_t^S n_t^S = \mathbb{E}_t \tilde{\mathbf{\Omega}}_{t+1}^S \mathbf{n}_{t+1}^S \tag{D.5}$$

  - Shadow Bank Stochastic Discount Factor

$$\tilde{\mathbf{\Omega}}_{t+1}^S = \mathbf{\Lambda}_{t,t+1}^H\left[\sigma^S + (1-\sigma^S)\mathbf{\Omega}_{t+1}^S\right] \tag{D.6}$$

  - Balance Sheet Constraint

$$b_{t+1}^S + Q_t a_{t+1}^S = n_t^S \tag{D.7}$$

- Incentive Constraint

$$\psi\left[Q_t a^S_{t+1} + (1-\omega) b^S_{t+1}\right] = \Omega^S_t n^S_t \tag{D.8}$$

- Net Worth Law of Motion

$$\mathbf{n}^S_{t+1} = \max\left\{\mathbf{R}^A_{t+1}(a^S_{t+1} + R^B_{t+1} b^S_{t+1}, 0\right\} \tag{D.9}$$

- Retail Bank:
  - Value Function

$$\Omega^R_t n^R_t = \mathbb{E}_t \tilde{\mathbf{\Omega}}^R_{t+1} \mathbf{n}^R_{t+1} \tag{D.10}$$

  - Retail Bank Stochastic Discount Factor

$$\tilde{\mathbf{\Omega}}^R_{t+1} = \mathbf{\Lambda}^H_{t,t+1}\left[\sigma^R + (1-\sigma^R)\mathbf{\Omega}^R_{t+1}\right] \tag{D.11}$$

  - Balance Sheet Constraint

$$Q_t a^R_{t+1} + b^R_{t+1} = n^R_t + d^R_{t+1} \tag{D.12}$$

  - Net Worth Law of Motion

$$\mathbf{n}^R_{t+1} = \max\left\{\mathbf{R}^A_{t+1} a^R_{t+1} + \min\{\mathbf{x}_{t+1}, 1\} R^B_{t+1} b^R_{t+1} - R^D_{t+1} d^R_{t+1}, 0\right\} \tag{D.13}$$

  - For the remaining two equations, there are two cases:
    - Case 1: Binding Incentive Constraint
      - Incentive Constraint

$$\psi\left[\left(Q_t + f^R_t\right) a^R_{t+1} + \gamma b^R_{t+1}\right] = \Omega^R_t n^R_t \tag{D.14}$$

      - Wholesale Lending FOC

$$\gamma \mathbb{E}_t \tilde{\mathbf{\Omega}}^R_{t+1}\left[\frac{\mathbf{R}^A_{t+1}}{Q_t + f^R_t} - R^D_{t+1}\right] = \mathbb{E}_t \tilde{\mathbf{\Omega}}^R_{t+1}\left[\min\{\mathbf{x}_{t+1}, 1\} R^B_{t+1} - R^D_{t+1}\right] \tag{D.15}$$

    - Case 2: Non-binding Incentive Constraint
      - Retail Lending FOC

$$\mathbb{E}_t \tilde{\mathbf{\Omega}}^R_{t+1}\left[\frac{\mathbf{R}^A_{t+1}}{Q_t + f^R_t} - R^D_{t+1}\right] = 0 \tag{D.16}$$

· Wholesale Lending FOC

$$\mathbb{E}_t \tilde{\mathbf{\Omega}}^R_{t+1} \left[\min\{\mathbf{x}_{t+1}, 1\} R^B_{t+1} - R^D_{t+1} \right] = 0 \tag{D.17}$$

- Capital Goods Producers:

  – Production Function

$$X_t = \left[\frac{\theta_1}{1-\theta_0} \left(\frac{I_t}{K_t} \right)^{1-\theta_0} + \theta_2 \right] K_t \tag{D.18}$$

  – FOC

$$Q_t = \frac{1}{\theta_1} \left(\frac{I_t}{K_t} \right)^{\theta_0} \tag{D.19}$$

- Intermediate Goods Producers:

  – Production Function

$$Y_t = K_t^{\alpha} L_t^{1-\alpha} \tag{D.20}$$

  – Phillips Curve

$$(\Pi_t - 1)\Pi_t - \frac{\varepsilon}{\rho^R} \left(\frac{1}{\mathcal{M}_t} - \frac{\varepsilon - 1}{\varepsilon} \right) = \mathbb{E}_t \mathbf{\Lambda}^H_{t,t+1} \frac{\mathbf{Y_{t+1}}}{Y_t} (\mathbf{\Pi}_{t+1} - 1) \mathbf{\Pi}_{t+1} \tag{D.21}$$

  – Marginal Cost

$$\frac{1}{\mathcal{M}_t} = \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r^K_t}{\alpha} \right)^{\alpha} \tag{D.22}$$

  – Factor Prices

$$r^K_t = \frac{1}{\mathcal{M}_t} \alpha K_t^{\alpha-1} L_t^{1-\alpha} \tag{D.23}$$

$$W_t = \frac{1}{\mathcal{M}_t} (1-\alpha) K_t^{\alpha} L_t^{-\alpha} \tag{D.24}$$

- Loan Servicing Firms:

  – Household fee:

$$f^H_t = \frac{\eta^H}{(C^H_t)^{-\sigma}} \max\left\{ \frac{A^H_{t+1}}{A_{t+1}} - \zeta^H, 0 \right\} \tag{D.25}$$

  – Retail bank fee:

$$f^R_t = \frac{\eta^R}{(C^H_t)^{-\sigma}} \max\left\{ \frac{A^R_{t+1}}{A_{t+1}} - \zeta^R, 0 \right\} \tag{D.26}$$

- Monetary Policy

$$R^N_{t+1} = \frac{1}{\beta}\pi_t^{\kappa^\pi}\left(\frac{\mathcal{M}_t}{\mathcal{M}_t^n}\right)^{\kappa^y}. \tag{D.27}$$

- Fisher Equation

$$R^D_{t+1} = \frac{R^N_{t+1}}{\Pi_t}. \tag{D.28}$$

- Aggregate Laws of Motion:
  - Aggregate Retail Bank Net Worth

$$\mathbf{N}^R_{t+1} = \max\left\{\left(\mathbf{R}^A_{t+1}\frac{a^R_{t+1}}{n^R_t} + \tilde{\mathbf{R}}^B_{t+1}\frac{b^R_{t+1}}{n^R_t} - R^D_{t+1}\frac{d^R_{t+1}}{n^R_t}\right)N^R_t, 0\right\} + \nu^R\mathbf{K}_{t+1} \tag{D.29}$$

  - Aggregate Shadow Bank Net Worth

$$\mathbf{N}^S_{t+1} = \begin{cases} \max\left\{\left(\mathbf{R}^A_{t+1}\frac{a^S_{t+1}}{n^S_t} - R^B_{t+1}\frac{b^S_{t+1}}{n^S_t}\right)N^S_t, 0\right\} + \nu^S\mathbf{K}_{t+1} & \text{if no run in } t+1 \\ 0 & \text{if run in } t+1 \end{cases} \tag{D.30}$$

  - Shadow Bank Recovery Value

$$\mathbf{x}_{t+1} = \frac{\mathbf{R}^A_{t+1}a^S_{t+1}}{R^B_{t+1}b^S_{t+1}} \tag{D.31}$$

  - End-of-period Capital

$$S_{t+1} = (1-\delta)K_t + X_t \tag{D.32}$$

  - Beginning-of-period Capital

$$K_t = Z_t S_t \tag{D.33}$$

  - Capital Quality

$$\ln(Z_t) = \rho_Z \ln(Z_{t-1}) + \epsilon_t \tag{D.34}$$

  - Sunspot

$$\Xi_t = \begin{cases} 1 & \text{with prob. } \pi \\ 0 & \text{with prob. } 1-\pi \end{cases} \tag{D.35}$$

- Aggregate Resource Constraint

$$C^H_t = Y_t\left(1 - \frac{\rho^R}{2}(\Pi_t - 1)^2\right) - I_t - G \tag{D.36}$$

D.2 Run Equilibrium

We do not repeat the equilibrium conditions which do not change relative to the no-run equilibrium.

- Retail Bank:
  - Value Function

$$\Omega_t^R n_t^R = \mathbb{E}_t \tilde{\boldsymbol{\Omega}}_{t+1}^R \mathbf{n}_{t+1}^R \tag{D.37}$$

  - Retail Bank Stochastic Discount Factor

$$\tilde{\boldsymbol{\Omega}}_{t+1}^R = \boldsymbol{\Lambda}_{t,t+1}^H \left[\sigma^R + (1-\sigma^R)\boldsymbol{\Omega}_{t+1}^R\right] \tag{D.38}$$

  - Balance Sheet Constraint

$$Q_t a_{t+1}^R = n_t^R + d_{t+1}^R \tag{D.39}$$

  - Net Worth Law of Motion

$$\mathbf{n}_{t+1}^R = \max\left\{\mathbf{R}_{t+1}^A a_{t+1}^R - R_{t+1}^D d_{t+1}^R, 0\right\} \tag{D.40}$$

  - For the remaining equation, there are two cases:
    * Case 1: Binding Incentive Constraint
      · Incentive Constraint

$$\psi\left[\left(Q_t + f_t^R\right) a_{t+1}^R\right] = \Omega_t^R n_t^R \tag{D.41}$$

    * Case 2: Non-binding Incentive Constraint
      · Retail Lending FOC

$$\mathbb{E}_t \tilde{\boldsymbol{\Omega}}_{t+1}^R \left[\frac{\mathbf{R}_{t+1}^A}{Q_t + f_t^R} - R_{t+1}^D\right] = 0 \tag{D.42}$$

- Aggregate Laws of Motion:
  - Aggregate Retail Bank Net Worth

$$\mathbf{N}_{t+1}^R = \max\left\{\left(\mathbf{R}_{t+1}^A \frac{a_{t+1}^R}{n_t^R} - R_{t+1}^D \frac{d_{t+1}^R}{n_t^R}\right) N_t^R, 0\right\} + \nu^R \mathbf{K}_{t+1} \tag{D.43}$$

  - Aggregate Shadow Bank Net Worth

$$\mathbf{N}_{t+1}^S = \nu^S \left[(1-\sigma^S)K_t + \mathbf{K}_{t+1}\right] \tag{D.44}$$

- Aggregate Resource Constraint

$$C_t^H = Y_t\left(1 - \frac{\rho^R}{2}(\Pi_t - 1)^2\right) - I_t - G - \nu^S K_t \tag{D.45}$$

E Additional Analytic Results

E.1 Co-movement Between Credit Spreads

There are three important credit spreads in the model, namely the credit spreads for retail loans $\Delta^{A,R}_{t+1}$ and $\Delta^{A,S}_{t+1}$ and the return on wholesale loans Δ^{B}_{t+1}. First, we can express the relationship between the two credit spreads on retail loans as

$$\Delta^{A,S}_{t+1} = \mathbb{E}_t \frac{R^A_{t+1}}{Q_t} \frac{f^R_t}{Q_t + f^R_t} + \Delta^{A,R}_{t+1}, \tag{E.1}$$

showing that they are closely related, with the wedge between them increasing in the fraction of retail loans intermediated by the retail banking sector.

The relationship between the spreads on retail loans and the spread on wholesale loans depends on whether the leverage constraint in the retail banking sector is binding or not. In particular, in the case of a non-binding retail bank leverage constraint, we can see from equations 3.15 and 3.16 that there will be no co-movement between the spreads if the recovery value on wholesale loans is above one. If the recovery value on wholesale loans is below one, there can be some co-movement between the spreads, to the extent that the recovery value on wholesale loans and the return on retail loans co-move. Quantitatively, this co-movement is very limited.

In contrast, there is a direct link between the credit spreads on retail loans and wholesale loans, if the constraint of the retail banking sector binds: In that case, we can rewrite equation 3.19 as

$$\begin{aligned}\Delta^B_{t+1} = &\left(\frac{1}{\mathbb{E}_t \underline{x}_{t+1}} - 1\right) R^D_{t+1} + \gamma \frac{1}{\mathbb{E}_t \underline{x}_{t+1}} \Delta^{A,R}_{t+1} \\ &- \frac{cov\left(\tilde{\Omega}^R_{t+1}, \underline{x}_{t+1} R^B_{t+1}\right)}{\mathbb{E}_t \tilde{\Omega}^R_{t+1} \mathbb{E}_t \underline{x}_{t+1}} + \gamma \frac{cov\left(\tilde{\Omega}^R_{t+1}, \frac{R^A_{t+1}}{Q_t + f^R_t}\right)}{\mathbb{E}_t \tilde{\Omega}^R_{t+1} \mathbb{E}_t \underline{x}_{t+1}}.\end{aligned}$$

The second term shows that there is direct co-movement between the credit spreads. This implication of the model is consistent with the observation that credit spreads on the money markets, like the TED spread, were unrelated to corporate bond spreads during normal times, but became highly correlated during the financial crisis of 2007-09.

F Additional Quantitative Results

F.1 Model Fit

Table 6 shows how well the baseline model matches the targeted moments. The first column shows the data, the second column the corresponding moments for the baseline model. For comparison, the last column reports the results of an alternative model in which retail banks do not face financial frictions. This latter model is qualitatively very similar to the model of Gertler, Kiyotaki, and Prestipino (2020a). We recalibrate the alternative model to ensure that it is observationally equivalent in terms of the targeted moments that it shares with the baseline model. The recalibrated parameters are $\psi = 0.2496$, $\pi = 0.0222$, $\zeta^H = 0.1756$, $\eta^H = 1.3797$, $\sigma^S = 0.0958$ and $\upsilon = 0.0007$.

Overall, both the baseline model and the alternative model match the targeted moments well. This is not obvious, given that it is a complicated nonlinear model with multiple equilibria and occasionally binding constraints. The model without financial frictions of retail banks can by construction not match the AAA-10Y spread, the TED spread, retail bank leverage, and the fall in bank net worth. Moreover, the frequency of banking panics in the alternative model is somewhat lower, despite shadow bank leverage being similar. Both models struggle to explain the full increase in the BAA spread. This may be due to default risk of non-corporate borrowers, which we abstract from in this paper. Taken together, these results nevertheless give a first indication that modelling retail banks explicitly is important for the propagation of banking panics.

	Data	Baseline	No R-Constraint
St. Dev., Output	2.450	2.481	1.930
Autocorrelation, Output	0.973	0.882	0.870
Mean, AAA-10Y Spread	1.354	1.638	0.038
Mean, BAA-10Y Spread	2.330	2.561	2.317
Mean, Retail Bank Asset Share	0.450	0.447	0.462
Mean, Shadow Bank Asset Share	0.350	0.352	0.359
Mean, Retail Bank Leverage	10.000	8.290	1.000
Mean, Shadow Bank Leverage	15.000	12.878	11.875
Frequency of Banking Panics	4.089	4.512	2.835
TED Spread Increase in Run	1.842	2.876	0.000
BAA Spread Increase in Run	3.251	1.173	1.026
Fall in Retail Net Worth in Run	-68.545	-67.071	-4.583
Fall in Investment in Run	-32.307	-29.511	-28.331

Table 6: Model fit: targeted moments.

Note: The model moments come from a simulation of the baseline model of 1000 economies for 2000 periods, discarding the first 1000 periods as burn-in. The data for output, consumption, investment, hours, and net worth are detrended with a quadratic trend estimated using data from 1986Q1 to 2018Q4. The model and the data for the AAA-10Y spread, the BAA-10Y spread and the TED spread are annualized.

F.2 Business Cycles Dynamics

As an important test of the plausibility of the model, Table 7 displays untargeted business cycle moments. Again, we compare the baseline model to the data and an alternative model in which retail banks do not face financial frictions. We can see that the baseline model produces plausible volatilities and business cycle correlations and autocorrelations of macroeconomic aggregates, asset prices and financial sector variables, despite relying only on a single shock. In particular, the model matches the fact that bank net worth is pro-cyclical and that credit spreads are counter-cyclical. It also matches the volatilities of these variables well.

The TED spread in the data is pro-cyclical, which is counter-intuitive. The reason is that it did not increase during the 1990 and 2001 recessions, which were not accompanied by financial crises. As we are primarily interested in providing a model of the 2008 financial crisis, this is not a big concern.

Hours in the model are weakly counter-cyclical, and even more so in the model without retail bank financial constraints. As we show below, they are pro-cyclical on impact, but then overshoot after a few periods. Introducing wage stickiness or using Greenwood et al. (1988)-preferences would help to overcome this issue, albeit at the price of complicating the model somewhat. It is, however, not central for the main results.

F.3 Impulse Response to a Capital Quality Shock

Figure 7 shows that financial constraints of retail banks amplify the endogenous response to exogenous shocks substantially. The blue line with circles shows the impulse responses to a one standard deviation negative capital quality shock in the baseline model, and the red line with crosses shows the alternative model in which retail banks are never financially constrained.

The response to a shock of the same size of all variables is substantially amplified in the baseline model compared to the alternative model. For example, the impact effect of a one standard deviation shock on output is around a drop of 1 percent in the baseline model, but only of 0.75 in the model without retail bank financial constraints. The mechanism is as follows: In the baseline model, the negative capital quality shock leads to a fall in the net worth of both retail and shadow banks. As a result, both sectors cut lending to the non-financial sector. Moreover, retail banks also cut lending on the wholesale funding market, which drives up the funding cost of shadow banks, forcing them to cut lending even further. In that sense, financial constraints of retail banks have a both a direct effect and an indirect wholesale credit supply effect working through the wholesale funding market on lending to the non-financial sector. Note also that the panic probability in the alternative model is on average much lower and is also substantially less responsive to the shock than in the baseline model.

a) Standard deviations

	Data	Baseline	No R-Constraint
Output (Y)	2.450	2.481	1.930
Consumption (C_H)	2.881	2.597	2.406
Investment (I)	10.858	8.344	5.876
Hours (L)	3.805	3.273	2.881
Retail Bank Net Worth (N_R)	22.827	23.680	7.166
Shadow Bank Net Worth (N_S)	42.939	47.525	33.439
AAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q} - R^D$)	0.459	0.191	0.005
BAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q+f_R} - R^D$)	0.712	0.275	0.163
TED Spread ($R^B - R^D$)	0.403	0.680	0.000

b) Correlations with GDP

	Data	Baseline	No R-Constraint
Output (Y)	1.000	1.000	1.000
Consumption (C_H)	0.952	0.765	0.800
Investment (I)	0.820	0.793	0.669
Hours (L)	0.629	0.002	-0.164
Retail Bank Net Worth (N_R)	0.475	0.984	0.213
Shadow Bank Net Worth (N_S)	0.778	0.955	0.958
AAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q} - R^D$)	-0.206	-0.910	0.900
BAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q+f_R} - R^D$)	-0.137	-0.787	-0.547
TED Spread ($R^B - R^D$)	0.328	-0.815	-0.134

c) Autocorrelations

	Data	Baseline	No R-Constraint
Output (Y)	0.973	0.882	0.870
Consumption (C_H)	0.985	0.995	0.993
Investment (I)	0.962	0.750	0.699
Hours (L)	0.984	0.854	0.879
Retail Bank Net Worth (N_R)	0.779	0.881	0.467
Shadow Bank Net Worth (N_S)	0.918	0.859	0.846
AAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q} - R^D$)	0.910	0.831	0.970
BAA-10Y Spread ($\mathbb{E}\frac{R^A}{Q+f_R} - R^D$)	0.891	0.774	0.704
TED Spread ($R^B - R^D$)	0.805	0.804	0.017

Table 7: Model fit: business cycle statistics.

Note: The model moments come from a simulation of the baseline model of 1000 economies for 2000 periods, discarding the first 1000 periods as burn-in. The data for output, consumption, investment, hours, and net worth are detrended with a quadratic trend estimated using data from 1986Q1 to 2018Q4. The model and the data for the AAA-10Y spread, the BAA-10Y spread and the TED spread are annualized.

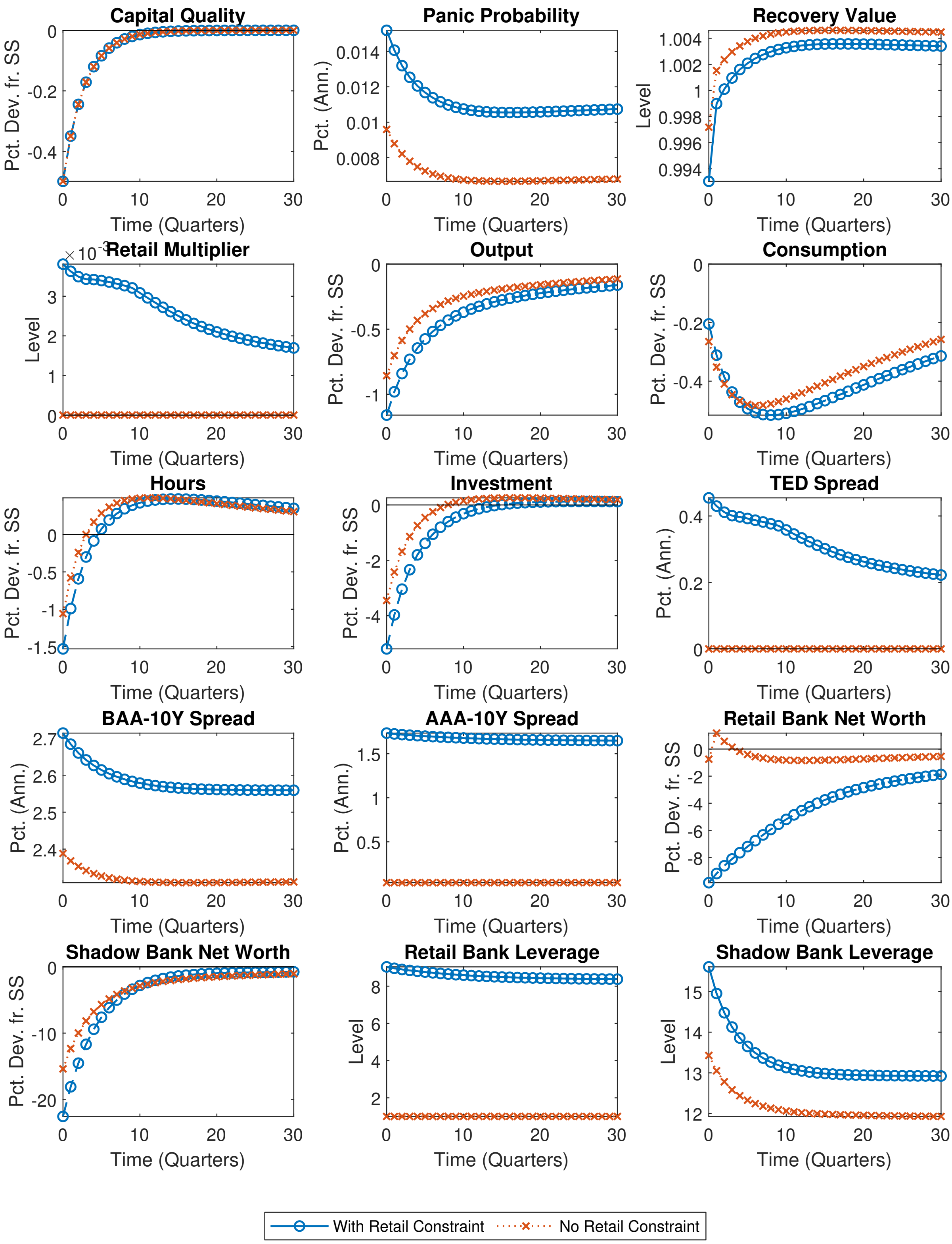

Figure 7: Amplification due to financial constraints of retail banks.

F.4 Panic vs No Panic Case

Figure 8 compares the dynamics in the main experiment in Figure 3 to the case where no sunspot realizes. Once the panic happens, we see that there is substantial amplification of the shock due to the panic in the sense that output, investment, consumption, and hours in the model simulation with the banking panic fall more than in the model simulation without the banking panic. In that way, the model can reproduce the fall in these variables quantitatively without relying on exceptionally large shocks.

F.5 Event Study vs Run Experiment

Figure 9 compares the banking panic event study shown in Figure 4 to the run experiment shown in Figure 3. While the event study is preceded by longer-lasting booms, the dynamics are remarkably similar, given that shocks in the event study are not targeted.

F.6 Banking Panic Event Study in the Baseline and the No R-IC Models

Figure 10 compares the event studies of banking panics in the baseline model and in the model without financial constraints of retail banks. Due to retail bank constraints, the boom-bust cycle around banking panics is substantially amplified, confirming the results in Figure 3.

F.7 The Long-Run Effects of a Permanent Liquidity Facility

Table 8 compares statistics from simulations of the baseline model to those from a model where the central bank intervenes whenever there is stress in the wholesale funding market.

Unconditionally, switching to a regime with a permanent liquidity facility that becomes active whenever there is stress on the wholesale funding markets can reduce output volatility by about 5 percent or 0.1 percentage points. Consumption volatility decreases less, but investment volatility decreases markedly by about 9.5 percent or 0.5 percentage points. The frequency of banking panics decreases by about 12.6 percent or 0.6 percentage points per year. Note that this reduction of volatility occurs despite an increased leverage in both the retail banking sector and the shadow banking sector. Finally, the lower probability of banking panics leads to a small increase in the level of consumption, output and investment.

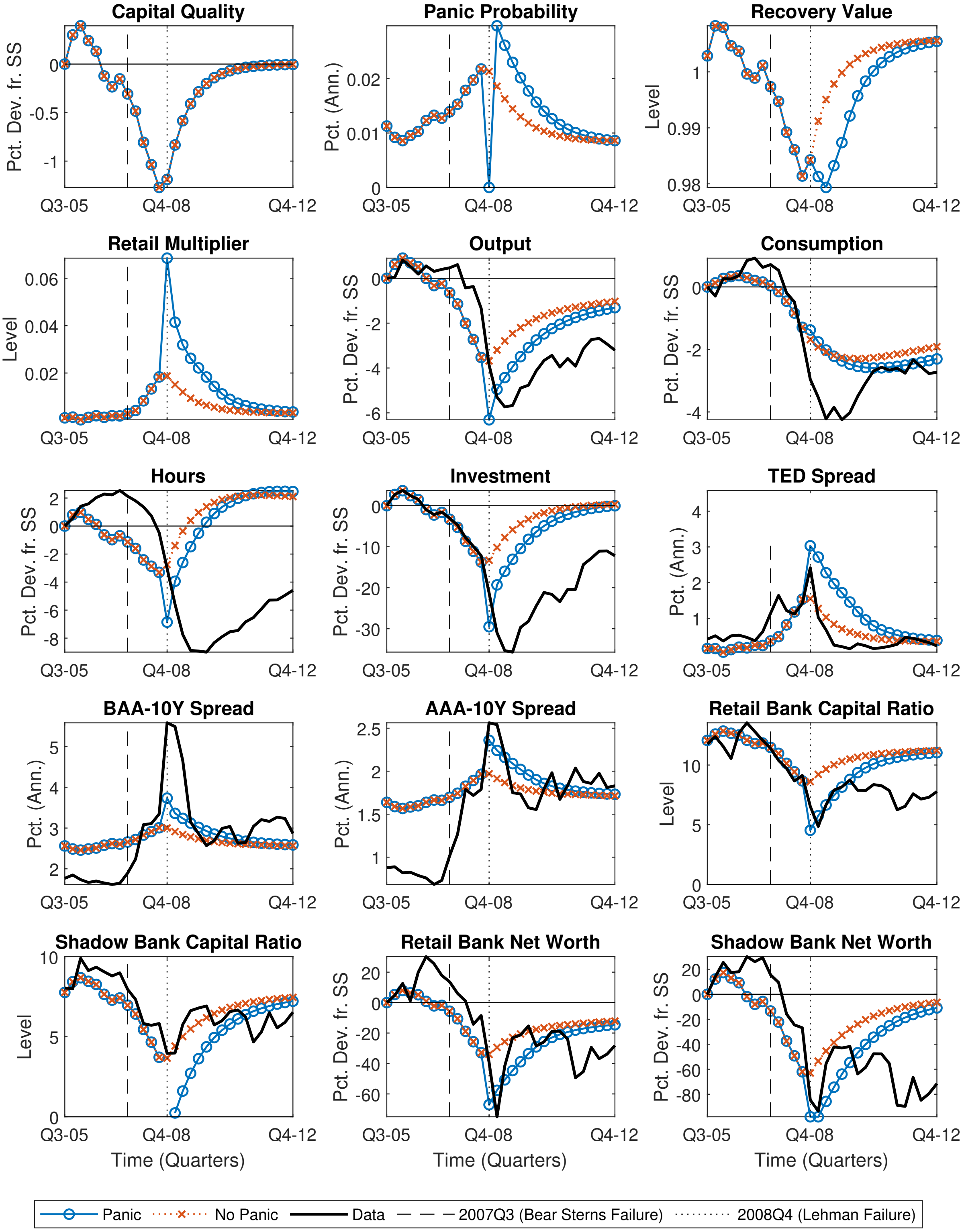

Figure 8: A banking panic in the model and in the data - the no panic case.

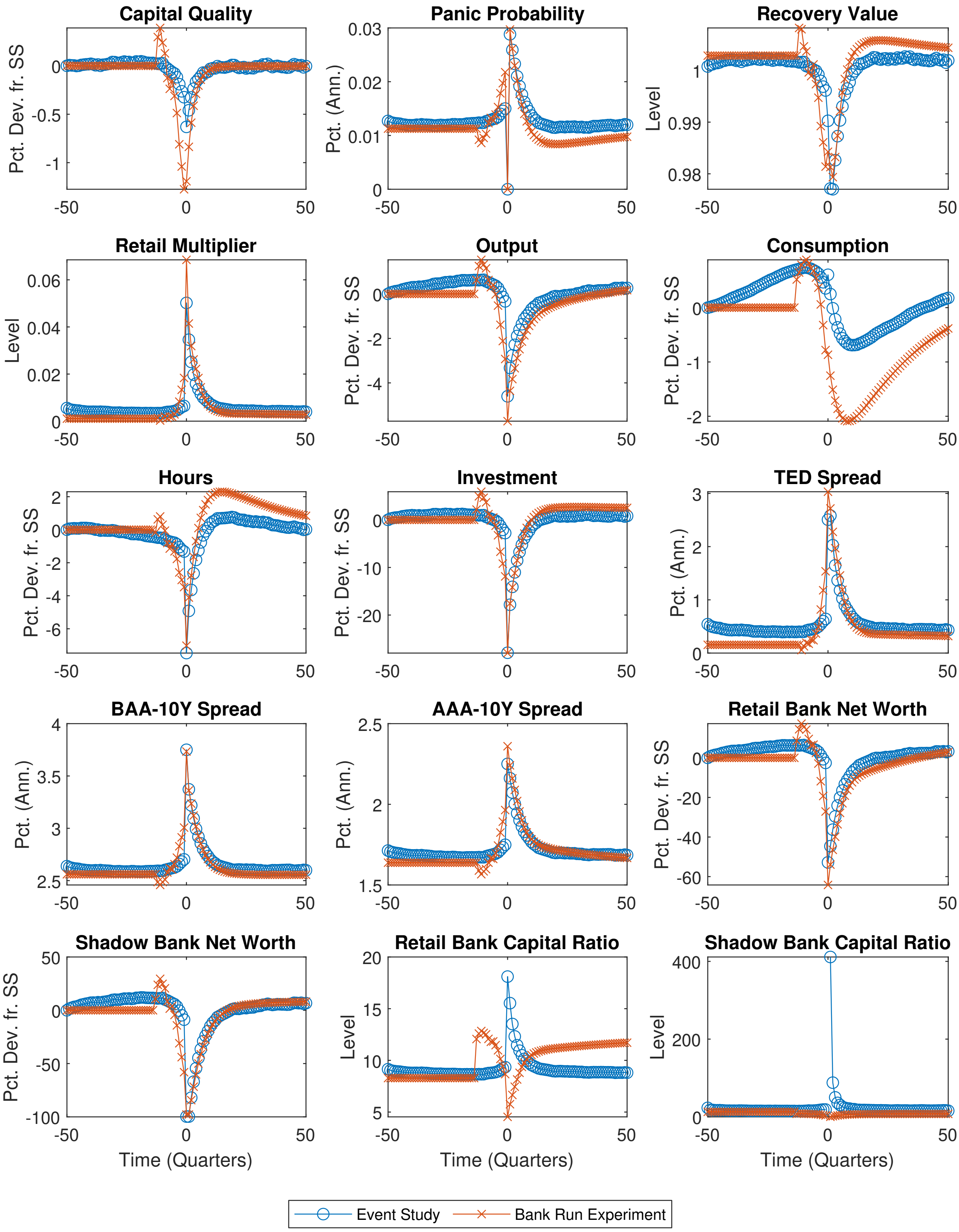

Figure 9: Comparing the event study and the run experiment in the paper

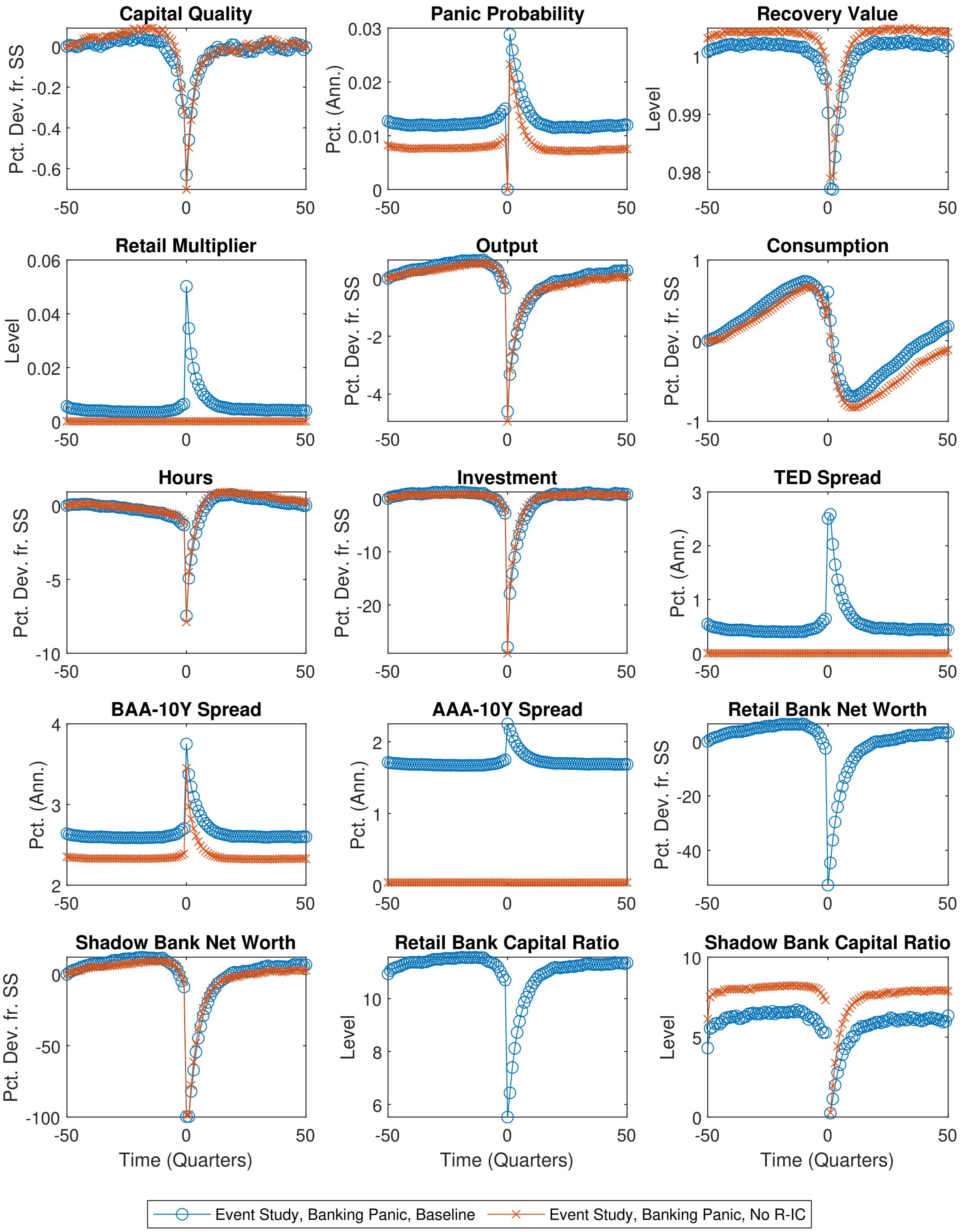

Figure 10: Comparing the event study in the baseline model and in the model without retail bank financial constraints

	Baseline	Policy	% Change
Mean, Output	1.227	1.228	0.075
Mean, Consumption	0.735	0.735	0.050
Mean, Investment	0.243	0.244	0.250
St. Dev., Output	2.481	2.358	-4.951
St. Dev. Consumption	2.597	2.557	-1.519
St. Dev. Investment	8.344	7.555	-9.458
Mean, Retail Bank Leverage	8.290	8.329	0.471
Mean, Shadow Bank Leverage	12.878	13.237	2.795
Frequency of Banking Panics	4.512	3.942	-12.625

Table 8: The Long-Run Effects of a Permanent Liquidity Facility.

Note: The moments come from a simulation of the baseline model of 1000 economies for 2000 periods, discarding the first 1000 periods as burn-in.

G Computation

G.1 Solving the Model

Households Using the stochastic discount factor D.4 in D.2, the deposit rate is

$$R^D_{t+1} = \left[\beta \mathbb{E}_t \left(\frac{\mathbf{C}^H_{t+1}}{C^H_t}\right)^{-\sigma}\right]^{-1}. \tag{G.1}$$

Households' labor supply is D.3:

$$L_t = \left[\frac{1}{\mu}(C^H_t)^{-\sigma} W_t\right]^{\frac{1}{\phi}}. \tag{G.2}$$

Consumption is D.36

$$C^H_t = Y_t(1 - \frac{\rho^R}{2}(\Pi_t - 1)^2) - I_t - G. \tag{G.3}$$

Household capital holdings are D.1:

$$
\begin{aligned}
Q_t + f_t^H &= \mathbb{E}_t\left(\mathbf{\Lambda}_{t,t+1}^H \mathbf{R}_{t+1}^A\right) \\
&= \beta \mathbb{E}_t\left(\left(\frac{\mathbf{C}_{t+1}^H}{C_t^H}\right)^{-\sigma} \mathbf{R}_{t+1}^A\right) \\
f_t^H &= \beta \mathbb{E}_t\left(\left(\frac{\mathbf{C}_{t+1}^H}{C_t^H}\right)^{-\sigma} \mathbf{R}_{t+1}^A\right) - Q_t \\
\frac{\eta^H}{(C_t^H)^{-\sigma}} \max\left\{\frac{A_{t+1}^H}{A_{t+1}} - \zeta^H, 0\right\} &= \beta \mathbb{E}_t\left(\left(\frac{\mathbf{C}_{t+1}^H}{C_t^H}\right)^{-\sigma} \mathbf{R}_{t+1}^A\right) - Q_t \qquad \text{(G.4)}
\end{aligned}
$$

Assuming that $A_{t+1}^H > \zeta^H A_{t+1}$ at all times yields

$$
A_{t+1}^H = \left[\frac{(C_t^H)^{-\sigma}}{\eta^H}\left[\beta \mathbb{E}_t\left(\left(\frac{\mathbf{C}_{t+1}^H}{C_t^H}\right)^{-\sigma} \mathbf{R}_{t+1}^A\right) - Q_t\right] + \zeta^H\right] A_{t+1}. \qquad \text{(G.5)}
$$

Retail Banks Retail bank borrowing is D.12

$$
d_{t+1}^R = Q_t a_{t+1}^R + b_{t+1}^R - n_t^R. \qquad \text{(G.6)}
$$

Retail bank lending on the wholesale funding market is given by market clearing:

$$
b_{t+1}^R = -b_{t+1}^S. \qquad \text{(G.7)}
$$

In the case of a binding incentive constraint, retail bank lending on the retail funding market is D.14

$$
\begin{aligned}
\left(Q_t + f_t^R\right) a_{t+1}^R + \gamma b_{t+1}^R &= \frac{1}{\psi}\Omega_t^R n_t^R \\
\left(Q_t + \frac{\eta^R}{(C_t^H)^{-\sigma}} \max\left\{\frac{A_{t+1}^R}{A_{t+1}} - \zeta^R, 0\right\}\right) a_{t+1}^R &= \frac{1}{\psi}\Omega_t^R n_t^R - \gamma b_{t+1}^R. \qquad \text{(G.8)}
\end{aligned}
$$

Noting that $a_{t+1}^R = A_{t+1}^R$, this is a quadratic equation. As long as $A_{t+1}^R > \zeta^R A_{t+1}$ at all times, its solution is

$$
\frac{\eta^R}{(C_t^H)^{-\sigma}} \frac{1}{A_{t+1}} (A_{t+1}^R)^2 + \left(Q_t - \frac{\eta^R}{(C_t^H)^{-\sigma}}\zeta^R\right) A_{t+1}^R - \left(\frac{1}{\psi}\Omega_t^R n_t^R - \gamma b_{t+1}^R\right) = 0
$$

$$
A_{t+1}^R = \frac{-\left(Q_t - \frac{\eta^R}{(C_t^H)^{-\sigma}}\zeta^R\right) + \sqrt{\left(Q_t - \frac{\eta^R}{(C_t^H)^{-\sigma}}\zeta^R\right)^2 + 4\frac{\eta^R}{(C_t^H)^{-\sigma}}\frac{1}{A_{t+1}}\left(\frac{1}{\psi}\Omega_t^R n_t^R - \gamma b_{t+1}^R\right)}}{2\frac{\eta^R}{(C_t^H)^{-\sigma}}} A_{t+1}. \qquad \text{(G.9)}
$$

In the case of a non-binding incentive constraint, retail bank lending is D.16:

$$Q_t + f_t^R = \frac{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R \mathbf{R}_{t+1}^A\right]}{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R R_{t+1}^D\right]} \tag{G.10}$$

$$\frac{\eta^R}{(C_t^H)^{-\sigma}} \max\left\{\frac{A_{t+1}^R}{A_{t+1}} - \zeta^R, 0\right\} = \frac{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R \mathbf{R}_{t+1}^A\right]}{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R\right] R_{t+1}^D} - Q_t. \tag{G.11}$$

Assuming $A_{t+1}^R > \zeta^R A_{t+1}$ at all times yields

$$\frac{A_{t+1}^R}{A_{t+1}} - \zeta^R = \frac{(C_t^H)^{-\sigma}}{\eta^R}\left[\frac{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R \mathbf{R}_{t+1}^A\right]}{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R\right] R_{t+1}^D} - Q_t\right]$$

$$A_{t+1}^R = \left[\frac{(C_t^H)^{-\sigma}}{\eta^R}\left[\frac{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R \mathbf{R}_{t+1}^A\right]}{\mathbb{E}_t\left[\tilde{\mathbf{\Omega}}_{t+1}^R\right] R_{t+1}^D} - Q_t\right] + \zeta^R\right] A_{t+1}. \tag{G.12}$$

Shadow Banks Shadow bank borrowing is given by D.7

$$-b_{t+1}^S = Q_t a_{t+1}^S - n_t^S. \tag{G.13}$$

Plugging this expression into D.8 yields shadow bank lending

$$\psi\left[Q_t a_{t+1}^S - (1-\omega)(Q_t a_{t+1}^S - n_t^S)\right] = \Omega_t^S n_t^S$$

$$Q_t a_{t+1}^S - (1-\omega)(Q_t a_{t+1}^S - n_t^S) = \frac{1}{\psi}\Omega_t^S n_t^S$$

$$\omega Q_t a_{t+1}^S + (1-\omega) n_t^S = \frac{1}{\psi}\Omega_t^S n_t^S$$

$$a_{t+1}^S = \frac{\frac{1}{\psi}\Omega_t^S - (1-\omega)}{\omega Q_t} n_t^S \tag{G.14}$$

Production and Policy The first order condition of capital producers D.19 yields the capital price:

$$Q_t = \frac{1}{\theta_1}\left(\frac{S_{t+1} - (1-\delta)K_t}{K_t}\right)^{\theta_0}. \tag{G.15}$$

Plugging inflation and the retal rate into the Fisher equation yields the nominal rate.

Plugging this into the Taylor rule then yields the optimal markup:

$$
\begin{aligned}
R^N_{t+1} &= \frac{1}{\beta}\Pi_t^{\kappa^\pi}\left(\frac{\mathcal{M}_t}{\mathcal{M}^n_t}\right)^{\kappa^y} \\
\left(\frac{\mathcal{M}_t}{\mathcal{M}^n_t}\right)^{\kappa^y} &= \beta R^N_{t+1}\Pi_t^{-\kappa^\pi} \\
\mathcal{M}_t &= \left[\beta R^N_{t+1}\Pi_t^{-\kappa^\pi}\right]^{\frac{1}{\kappa^y}}\mathcal{M}^n_t \\
&= \left[\beta R^D_{t+1}\Pi_t^{1-\kappa^\pi}\right]^{\frac{1}{\kappa^y}}\mathcal{M}^n_t
\end{aligned} \tag{G.16}
$$

Plugging this into D.24 and combining it with D.3 yields labor:

$$
\begin{aligned}
L_t &= \left[\frac{1}{\mu}(C^H_t)^{-\sigma}\frac{1}{\mathcal{M}_t}(1-\alpha)K_t^\alpha\right]^{\frac{1}{\phi}} L_t^{\frac{-\alpha}{\phi}} \\
L_t^{1+\frac{\alpha}{\phi}} &= \left[\frac{1}{\mu}(C^H_t)^{-\sigma}\frac{1}{\mathcal{M}_t}(1-\alpha)K_t^\alpha\right]^{\frac{1}{\phi}} \\
L_t &= \left[\frac{1}{\mu}(C^H_t)^{-\sigma}\frac{1}{\mathcal{M}_t}(1-\alpha)K_t^\alpha\right]^{\frac{1}{\phi+\alpha}}.
\end{aligned} \tag{G.17}
$$

From the production function, we get output. The Phillips curve D.21 yields the optimal inflation, the resource constraint optimal consumption. As these are nonlinear functions, inflation and consumption need to be found numerically.

Finally, the rental rate of capital is given by D.23. Moreover, market clearing in the market for capital must hold: $A_{t+1} = S_{t+1}$. Plugging in the demand schedules for households, retail banks and shadow banks into this market clearing condition yields another nonlinear equation. Solving for the general equilibrium therefore boils down to solving a nonlinear equation system in three variables: inflation Π_t, consumption C^H_t and the optimal capital stock S_{t+1}. With the optimal allocation, it is then possible to compute the law of motions for the endogenous states and update the value function, as explained below.

G.2 Solution Algorithm

We solve the model nonlinearly using projection methods. Solving the model nonlinearly is important, because bank runs can lead to large deviations from steady state, where perturbation algorithms are inaccurate.

The state space of the model is $\mathcal{S} = (n^R, n^S, K, Z)$ in the no bank run equilibrium and $\mathcal{S}^* = (n^{R,*}, K, Z)$ in the bank run equilibrium. n^R is the net worth of incumbent retail bankers, n^S the net worth of incumbent shadow bankers. We use Smolyak grids $\mathcal{S}_i, i = 1, \ldots, N$ and $\mathcal{S}^*_i, i = 1, \ldots, N^*$ of order $\mu = 5$ for the endogenous and exogenous states. We compute the Smolyak grid and polynomials using the toolbox by Judd, Maliar,

Maliar, and Valero (2014).

We need to find the following policy functions for the no-run equilibrium: $\mathbf{C^H}(\mathcal{S})$, $\mathbf{V^R}(\mathcal{S})$, $\mathbf{V^S}(\mathcal{S})$, $\mathbf{Q}(\mathcal{S})$, $\mathbf{L}(\mathcal{S})$ and $\mathbf{\Pi}(\mathcal{S})$. Denote those functions as $\mathbf{V}(\mathcal{S})$. For the run equilibrium, we need to find policy functions $\mathbf{C^{H,*}}(\mathcal{S}^*)$, $\mathbf{V^{R,*}}(\mathcal{S}^*)$, $\mathbf{Q}^*(\mathcal{S}^*)$ and $\mathbf{L}^*(\mathcal{S}^*)$. Denote those functions as $\mathbf{V}^*(\mathcal{S})$. We compute one set of functions for both the case of the binding and the non-binding incentive constraints of retail banks. Between grid points, we approximate these functions using polynomial basis functions $\mathcal{P}(\mathcal{S})$. We compute the polynomial coefficients by imposing that the polynomial approximations must be equal to the original functions on the grid. Specifically, denoting the polynomial coefficients by α, we impose

$$\mathcal{P}(\mathcal{S}_i)\alpha_V \equiv \mathbf{V}(\mathcal{S}_i) = V(\mathcal{S}_i) \quad i = 1, \ldots, N. \tag{G.18}$$

for all N grid points. We use an anisotropic grid with 5th-order Smolyak polynomials for the net worth of retail and shadow banks and 5th-order polynomials for capital and the capital quality shock.

We also need to find laws of motion for the future endogenous state variables, $\mathbf{n^R}'(\mathcal{S}, \varepsilon^{Z'}, \Xi')$, $\mathbf{n^S}'(\mathcal{S}, \varepsilon^{Z'}, \Xi')$, $\mathbf{K}'(\mathcal{S}, \varepsilon^{Z'}, \Xi')$, the probability of a banking panic $\mathbf{p}'(\mathcal{S}, \varepsilon^{Z'}, \Xi')$, and the recovery rates $\mathbf{x}'(\mathcal{S}, \varepsilon^{Z'}, \Xi')$ and $\mathbf{x}^{*\prime}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$. Collect those laws of motion as $\mathbf{T}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$, and the corresponding laws of motion for the bank run equilibrium as $\mathbf{T}^*(\mathcal{S}^*, \varepsilon^{Z'}, \Xi')$ The laws of motion depend on both the realization of the next period capital quality shock $\varepsilon^{Z'}$ and the sunspot Ξ'.

With this in mind, we will now outline our solution algorithm. Suppose we are in iteration k and have initial guesses for the policy functions $\mathbf{V_{(k)}}(\mathcal{S})$ and $\mathbf{V^*_{(k)}}(\mathcal{S})$, as well as laws of motion $\mathbf{T_{(k)}}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$ and $\mathbf{T^*_{(k)}}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$.

1. Given the value functions and the future net worth, compute the future value functions and capital prices as

$$V'_{(k)} = \mathbf{V}_{(k)}(\mathbf{T}_{(k)}(\mathcal{S}, \varepsilon^{Z'}, \Xi'))$$

2. Compute the expected value functions for the forward-looking equations D.1, D.2, D.5, D.10, D.15, D.16, D.17, and D.21.

3. Find the new policy functions and equilibrium prices as described in section G.1.

4. Using the new policy functions and equilibrium prics, find the new value functions and laws of motion $\tilde{\mathbf{V}}_{\mathbf{(k+1)}}(\mathcal{S})$ and $\tilde{\mathbf{T}}_{\mathbf{(k+1)}}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$.

5. Repeat steps 1 to 4 for the run equilibrium to find $\tilde{\mathbf{V}}^*_{\mathbf{(k+1)}}(\mathcal{S})$ and $\tilde{\mathbf{T}}^*_{\mathbf{(k+1)}}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$.

6. Compute errors as

$$\varepsilon^V = \max |\tilde{\mathbf{V}}_{(\mathbf{k+1})}(\mathcal{S}) - \mathbf{V}_{(\mathbf{k})}(\mathcal{S})|$$
$$\varepsilon^T = \max \mathbb{E}|\tilde{\mathbf{T}}_{(\mathbf{k+1})}(\mathcal{S}, \varepsilon^{Z'}, \Xi') - \mathbf{T}_{(\mathbf{k})}(\mathcal{S}, \varepsilon^{Z'}, \Xi')|$$

7. Update the value functions and laws of motion with some attenuation:

$$\mathbf{V}_{(\mathbf{k+1})}(\mathcal{S}) = \iota \mathbf{V}_{(\mathbf{k})}(\mathcal{S}) + (1-\iota)\tilde{\mathbf{V}}_{(\mathbf{k+1})}(\mathcal{S})$$
$$\mathbf{T}_{(\mathbf{k+1})}(\mathcal{S}, \varepsilon^{Z'}, \Xi') = \iota \mathbf{T}_{(\mathbf{k})}(\mathcal{S}, \varepsilon^{Z'}, \Xi') + (1-\iota)\tilde{\mathbf{T}}_{(\mathbf{k+1})}(\mathcal{S}, \varepsilon^{Z'}, \Xi')$$

8. Repeat until the errors ε^V and ε^T are less than 1e-3. The errors in the consumption policy function of the household and the capital price function are much smaller, around 1e-5.

G.3 Precision of the Solution

To gauge the precision of the solution, we compute Euler errors as proposed in Judd (1992) for equations D.1 and D.2. We can see that the Errors are typically small, with means between -4 and -5 in log10-scale.

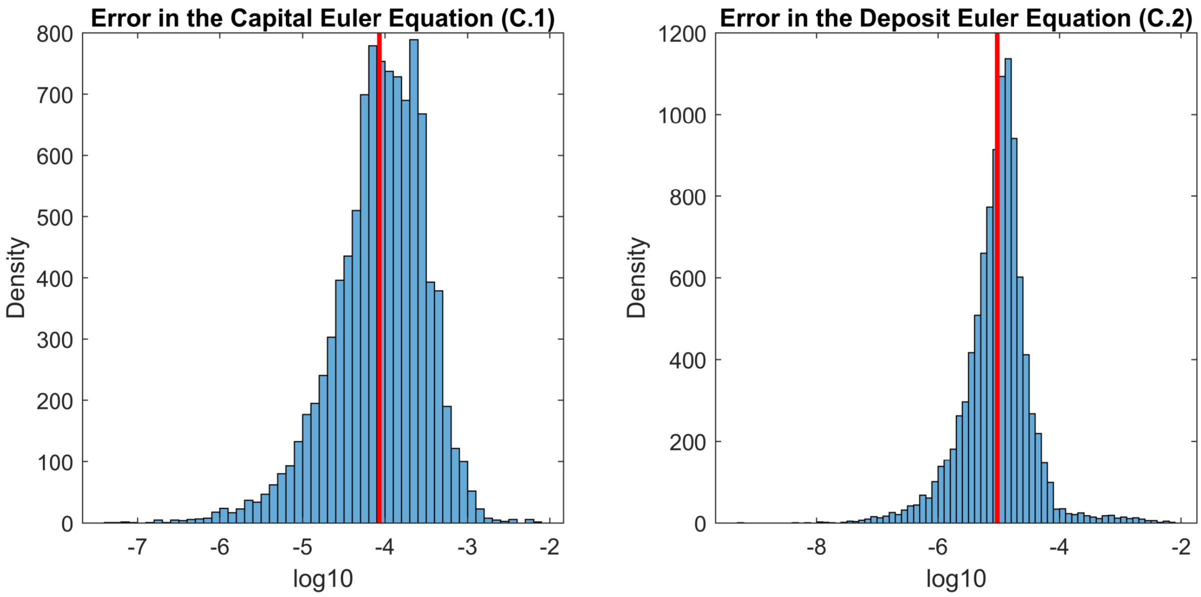

Figure 11: Errors in the Euler equations D.1 and D.2.

Note: Based on a simulation of 1000 economies for 2000 periods, discarding the first 1000 periods as burn-in. The red line denotes the average Euler error.