Online Appendix: Deposit Competition and Financial Fragility

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Appendix A: Model Extensions and Alternative Specifications

A.1 Too Big To Fail

Characterization:

We model too big to fail (TBTF) as a government bailout of uninsured creditors of banks, which prevents a bank from entering bankruptcy. The bailout has to be uncertain, otherwise uninsured depositors would not be responsive to changes in bankruptcy probability, which is what we find in the data. In the event that profits are low enough that the equity holders of the bank would be willing to let the bank fail $R_{k,t} < \bar{R}_k$, the government initiates a bailout with with probability $p_{TBTF} < 1$. The government provides just enough funds to make equity holders indifferent to bank default $M^I s^I_{k,t}\left(R_{k,t} - \bar{R}_k\right) + M^N s^N_{k,t}\left(R_{k,t} - \bar{R}_k\right)$. In this way, the TBTF transfers funds to equity holders of the bank, but does not make them better off. The probability that returns are low and the bank might default is $\rho_{k,t} = Pr\left(R_{k,t} < \bar{R}_k\right) = \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)$. If depositors are not bailed out, with probability $(1 - p_{TBTF})$, they lose utility flow $\gamma_F > 0$. Therefore, they suffer an expected utility loss of $\rho_{k,t}\left(1 - p_{TBTF}\right)\gamma_F$. The total indirect utility derived by an uninsured depositor j from bank k at time t is then as follows:

$$u^N_{j,k,t} = \alpha^N i^N_{k,t} - \rho_{k,t}\left(1 - p_{TBTF}\right)\gamma_F + \delta^N_k + \varepsilon^N_{j,k,t}.$$

The TBTF version of the model implies that the probability of default that matters for uninsured depositors is $\rho_{k,t}\left(1 - p_{TBTF}\right)$, which includes the probability of bailout and which is what we measure in the data. Therefore, including TBTF has no impact on the estimation of demand or depositor behavior. The same is the case for equity holders of the bank: their bankruptcy decision, as well as deposit pricing, only depends on the overall sensitivity of uninsured depositors to default. Because the transfers they obtain are used to pay depositors and bond holders, they realize no net gains, and do not alter their behavior. Hence, the bank's first order conditions for deposit rate setting and bankruptcy remain:

$$\text{Insured Deposits: } \mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right) - \left(c_k + i^I_{k,t}\right) = \frac{1}{\left(\left(1 - s^I \left(i^I_{k,t}, \mathbf{i^I_{-k,t}}\right)\right) \alpha^I\right.},$$

$$\text{Uninsured Deposits: } \mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right) - i^N_{k,t} = \frac{1}{\left(\left(1 - s^N_{k,t} \left(i^I_{k,t}, \mathbf{i^I_{-k,t}}, \rho_{k,t}, \rho_{\mathbf{-k,t}}\right)\right) \alpha^N\right.}.$$

$$\text{Bankruptcy: } b_k - \left(M^I s^I_{k,t}\left(\bar{R}_k - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(\bar{R}_k - i^N_{k,t}\right)\right) = \begin{array}{c} \frac{1}{1+r}\left(M^I s^I_{k,t} + M^N s^N_{k,t}\right)\left(1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \times \\ \times \left(\left(\mu_k - \bar{R}_k\right) + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \end{array}.$$

Calibration:

Although the Too-Big-to-Fail provision described above does not change a bank's interest rate and bankruptcy decision, TBTF does impact the probability a bank defaults and thus changes the calibration of the model. Because the TBTF provision does not impact the bank's first order conditions, we can calibrate the model using the same set of equations for each bank:

$$c_k = \left(i^N_k + \frac{1}{(1 - s^N_k)\alpha^N} \right) - \left(i^I_k + \frac{1}{(1 - s^I_k)\alpha^I} \right)$$

$$\sigma_k = \frac{\frac{(1+r)}{M^I s^I_k + M^N s^N_k}\left(b_k + M^I s^I_k \left(i^N + \frac{1}{\alpha^N(1-s^N_k)} - \frac{1}{\alpha^I(1-s^I_k)}\right) + M^N s^N_k i^N_k\right) - (1+r)\left(\frac{1}{\alpha(1-s^N_k)} + i^N_k\right)}{\phi(\Phi^{-1}(\rho_k)) + \Phi^{-1}(\rho_k)(\rho_k + r) - (1+r)\lambda\left((\Phi^{-1}(\rho_k)\right)}.$$

$$\mu_k = i^N_k - \sigma_k \lambda \left(\Phi^{-1}(\rho_k)\right) + \frac{1}{(1 - s^N_k)\alpha^N}$$

As illustrated in the above equations, calibrating the model requires knowledge of the probability that the bank experiences a return shock below the bankruptcy threshold $\bar{R}_k$, $\rho_k = Pr\left(R_{k,t} < \bar{R}_k\right) = \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)$, which is not directly observed in the data. Rather, in the data we observe the risk-neutral probability of default, which now comprises the probability that a bank's returns are below the threshold value $\bar{R}_k$ and the probability that the government does not bail out the bank,

$$\text{Risk Neutral Probability of Default: } \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\left(1 - p_{TBTF}\right).$$

With knowledge of p_{TBTF}, we can calculate ρ_k from the risk-neutral probability of default and calibrate the model using the above equations for c_k, σ_k and μ_k.

A.2 Capital Requirements: Risky Assets

Characterization:

We implement capital requirements by requiring equity holders to co-invest a κ share of deposits and coupon payments every period, $\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)$, leading to a capital requirement of $\omega = \frac{\kappa}{1+\kappa}$. This additional capital is invested along with deposits and is lost if the firm defaults. Therefore, if the bank wants to raise additional deposits, equity holders have to supply additional capital. Capital requirements also make bankruptcy more costly as equity holders lose their co-invested capital $\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)$ in the event of a default. Through these channels, capital requirements directly impact a bank's deposit rate-setting and optimal bankruptcy decisions. Conversely, the addition of capital requirements does not affect the behavior of consumers, other than through the impact capital requirements have on the behavior of banks.

Under the capital requirements specification, the total net period profits of a bank are equal to the net returns on deposits plus the net return on co-invested capital,

$$\pi_{k,t} = M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right) + \underbrace{\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)}_{\text{Invested Capital}}\underbrace{\left(R_{k,t} - r\right)}_{\text{Net Return}}.$$

The term $\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)$ represents required invested capital, R is the return on both deposits and capital, and r is the cost of capital.

Capital requirements impact a bank's decision to default by impacting the bank's net period profits and cost of default. Recall that after the realization of the profit shock $R_{k,t}$, the bank has to repay depositors and the bond payment b_k. If profits are lower than the required payment, the equity holders have to either provide the funds to make up the shortfall or default. The shortfall that equity holders have to finance comprises the net profits (or losses) of the bank after repaying depositors and bond payments $M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right) + \kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)\left(R_{k,t} - r\right) - b_k$. Equity holders choose to finance the shortfall and remain in business as long as the value of remaining in business (shortfall plus future franchise value E_k) exceeds the cost of default,

$$\underbrace{\begin{array}{c} M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right) \\ +\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)\left(R_{k,t} - r\right) - b_k + \frac{1}{1+r}E_k \end{array}}_{\text{Value of Staying in Business}} > \underbrace{-\kappa\left(b_k + M^I s^I_k + M^N s^N_k\right)}_{\text{Cost of Default}}.$$

Again, the expression implies a cut-off strategy for the firm. If the return the bank earns on deposits $R_{k,t}$ falls below some level $\bar{R}_k$, the equity holders will not inject funds and the bank will default. Otherwise, the equity holders will choose to repay the deposits and the debt coupon. $\bar{R}_k$ is then implicitly defined as the level of bank profitability at which equity holders are indifferent between defaulting and financing the bank. Solving for the optimal cut-off rule as above and in Hortaçsu et al. (2011) we obtain the condition:

$$\begin{array}{c} b_k(1-\kappa) - M^I s^I_{k,t}\left(\bar{R}_k - c_k - i^I_{k,t} - \kappa\right) \\ -M^N s^N_{k,t}\left(\bar{R}_k - i^N_{k,t} - \kappa\right) \\ -\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)\left(\bar{R}_k - r\right) \end{array} = \frac{1}{1+r}\left[\begin{array}{c} -\kappa\left(M^I s^I_k + M^N s^N_k + b\right) \\ +\left[\left(M^I s^I_{k,t} + M^N s^N_{k,t}\right)(1+\kappa) + b\kappa\right] \\ \times\left(1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \\ \times\left(\left(\mu_k - \bar{R}_k\right) + \sigma_k \lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \end{array}\right].$$

Capital requirements also impact a bank's optimal deposit rate decision. Banks set the deposit rate for insured and uninsured deposits to maximize the expected return to equity holders. The corresponding equity value at the beginning of the period is

$$E_k = \max_{i^I_{k,t}, i^N_{k,t}} \int_{\bar{R}_k}^{\infty} \left[\begin{array}{c} M^I s^I_{k,t}\left(i^I_{k,t}, \mathbf{i^I_{-k,t}}\right)\left(R_{k,t} - c_k - i^I_{k,t}\right) \\ +M^N s^N_{k,t}\left(i^N_{k,t}, \mathbf{i^N_{-k,t}}, \rho_{k,t}, \rho_{\mathbf{-k,t}}\right)\left(R_{k,t} - i^N_{k,t}\right) \\ +\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)\left(R_{k,t} - r\right) \\ -b_k + \frac{1}{1+r} E_k \end{array}\right] dF(R_{k,t}) - \int_{-\infty}^{\bar{R}_k} \left[\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)\right] dF(R_{k,t}).$$

By comparing equity value in the baseline model with the capital requirements model, we see how the addition of capital requirements impacts the deposit rate decision through two channels. First, capital requirements impact a bank's net period profits through the term $\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)$. Second, capital requirements make default expensive for equity holders since equity holders lose their invested capital in the event of a default. The cost of default born by equity holders depends directly on the deposit rate offered, because the required capital is tied to the level of deposits. The corresponding first order conditions for setting insured and uninsured deposits are given by:

$$\left[\mu_k(1+\kappa) + \sigma_k\lambda\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)(1+\kappa) - c_k - i^I_k - \kappa r_\kappa - \frac{1}{\alpha^I(1 - s^I_{k,t})}\right]\left[1 - \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)\right] = \kappa\Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)$$

$$\left[\mu_k(1+\kappa) + \sigma_k\lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)(1+\kappa) - i^N_k - \kappa r_\kappa - \frac{1}{\alpha^N(1 - s^N_{k,t})}\right]\left[1 - \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)\right] = \kappa\Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right).$$

Calibration:

In Section **??**, we examine how incorporating existing capital requirements impacts our calibrated supply-side parameters. As in the baseline model, we calibrate the supply-side parameters (c_k, σ_k, and μ_k) using revealed preferences of banks. Specifically, we use the bank's first order conditions for setting insured and uninsured deposit rates along with the bank's bankruptcy cut-off condition to solve for the supply-side parameters. Rearranging the above bank optimality conditions, we solve for closed-form solutions for the bank-specific parameters c_k, σ_k , and μ_k[1]:

$$c_k = \left(i_k^N + \frac{1}{(1-s_k^N)\alpha^N} \right) - \left(i_k^I + \frac{1}{(1-s_k^I)\alpha^I} \right)$$

$$\sigma_k = \frac{(1+r)\left[\begin{array}{c} \frac{1}{(M^I s_k^I + M^N s_k^N) + b_k \frac{\kappa}{(1+\kappa)}} \left(b_k(1-\kappa) + M^I s_k^I (c_k + i_k^I - \kappa) + M^N s_k^N (i_k^N - \kappa) + \kappa (M^I s_k^I + M^N s_k^N + b_k) \left(\frac{1}{1+r} + r \right) \right) \\ - \left(\frac{\kappa \rho_k}{1-\rho_k} \right) + i_k^N + \kappa r + \frac{1}{\alpha^N (1-s_k^N)} \end{array} \right]}{(1+\kappa)\left[\phi\left(\Phi^{-1}(\rho_k)\right) + \Phi^{-1}(\rho_k)\left(\rho_k + r\right) - (1+r)\lambda(\Phi^{-1}(\rho_k))\right]}.$$

$$\mu_k = \frac{\left(\frac{\kappa \Phi}{1-\Phi} \right) + i_k^N + \kappa^N r + \frac{1}{\alpha^N (1-s_k^N)} - \sigma_k \lambda \left(\Phi^{-1}(\rho_k) \right) (1+\kappa)}{1+\kappa}$$

Risk Free Capital Requirements:

The model is easily extended to allow for other implementations of capital requirements. One such implementation we investigate is a policy under which equity holders are required to co-invest a κ share of deposits and coupon payments every period, $\kappa \left(b_k + M^I s_{k,t}^I + M^N s_{k,t}^N \right)$, where the additional capital is invested in the risk-free asset. In the previous implementation of capital requirements we considered, bank capital requirements were invested in the same risky asset as deposits.

Under the risk-free capital requirements version of the model, the net period profits of a bank are identical to the baseline model,

$$\pi_{k,t} = M^I s_{k,t}^I \left(R_{k,t} - c_k - i_{k,t}^I \right) + M^N s_{k,t}^N \left(R_{k,t} - i_{k,t}^N \right).$$

Risk-free capital requirements do not impact the period net profits of the bank because the required capital is invested in the risk-free asset $(\kappa(b_k + M^I s_{k,t}^I + M^N s_{k,t}^N)\,(r - r) = 0)$.

Risk-free capital requirements still make bankruptcy more costly for equity holders. In the event of a default, equity holders must forfeit the required capital. Under the risk-free capital requirement, equity holders choose to finance the shortfall and remain in business as long as the value of remaining in business (shortfall plus future franchise value E_k) exceeds the cost of default,

[1] To avoid cluttered notation we omit the subscript t.

$$\underbrace{M^I s_{k,t}^I \left(R_{k,t} - c_k - i_{k,t}^I\right) + M^N s_{k,t}^N \left(R_{k,t} - i_{k,t}^N\right) - b_k + \frac{1}{1+r} E_k}_{\text{Value of Staying in Business}} > \underbrace{-\kappa \left(b_k + M^I s_k^I + M^N s_k^N\right)}_{\text{Cost of Default}}.$$

The optimal decision remains a cut-off strategy $\bar{R}_k$ for the firm. Solving for the optimal strategy, we obtain

$$\begin{array}{c} b_k(1-\kappa) - M^I s_{k,t}^I \left(\bar{R}_k - c_k - i_{k,t}^I - \kappa\right) \\ -M^N s_{k,t}^N \left(\bar{R}_k - i_{k,t}^N - \kappa\right) \end{array} = \frac{\left(M^I s_{k,t}^I + M^N s_{k,t}^N\right)}{1+r} \left[\begin{array}{c} -\kappa \left(1 + \frac{b}{M^I s_{k,t}^I + M^N s_{k,t}^N}\right) \\ + \left(1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \\ \times \left(\left(\mu_k - \bar{R}_k\right) + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right) \end{array} \right].$$

The addition of risk-free capital requirements also impacts a bank's optimal deposit rate decision through its effect on the cost of default. Banks set the deposit rate for insured and uninsured deposits to maximize the expected return to equity holders which is given by

$$E_k = \max_{i_{k,t}^I, i_{k,t}^N} \int_{\bar{R}_k}^{\infty} \left[\begin{array}{c} M^I s_{k,t}^I \left(i_{k,t}^I, \mathbf{i_{-k,t}^I}\right) \left(R_{k,t} - c_k - i_{k,t}^I\right) \\ +M^N s_{k,t}^N \left(i_{k,t}^N, \mathbf{i_{-k,t}^N}, \rho_{k,t}, \rho_{-\mathbf{k},\mathbf{t}}\right) \left(R_{k,t} - i_{k,t}^N\right) \\ -b_k + \frac{1}{1+r} E_k \end{array} \right] dF(R_{k,t}) - \int_{-\infty}^{\bar{R}_k} \left[\kappa \left(b_k + M^I s_{k,t}^I + M^N s_{k,t}^N\right)\right] dF(R_{k,t}).$$

The corresponding first order conditions for setting insured and uninsured deposits are given by

$$\left[\mu_k + \sigma_k \lambda \left(\frac{\bar{R} - \mu_k}{\sigma_k}\right) - c_k - i_k^I - \frac{1}{\alpha^I (1 - s_{k,t}^I)}\right] \left[1 - \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)\right] = \kappa \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right),$$

$$\left[\mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right) - i_k^N - \frac{1}{\alpha^N (1 - s_{k,t}^N)}\right] \left[1 - \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)\right] = \kappa \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right).$$

A.3 Costly External Finance

Characterization:

In the baseline model, equity holders must inject additional funds in the event of a period shortfall to avoid default. In Section **??**, we relax the assumption that the injection of funds by equity holders is frictionless. As an extension of the model, we include a deadweight cost of external financing, which is proportional to the amount of funds injected, with a constant marginal cost of τ_+. Therefore, if equity holders realize a shortfall of $b_k - M^I s_{k,t}^I \left(R_{k,t} - c_k - i_{k,t}^I\right) - M^N s_{k,t}^N \left(R_{k,t} - i_{k,t}^N\right)$, they have to spend $(1 + \tau_+)$ times the equity shortfall (rather than 1x the shortfall) in order to recapitalize the bank.

With costly external financing, the firm's net period profits on deposits remain the same as in the baseline model,

$$\pi_{k,t} = M^I s^I_{k,t} \left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t} \left(R_{k,t} - i^N_{k,t}\right).$$

If the firm's net per period profits $M^I s^I_{k,t} \left(\bar{R}_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t} \left(\bar{R}_{k,t} - i^N_{k,t}\right)$ are less than its financing costs b_k, its equity holders must either inject additional funds or declare bankruptcy. We let R^*_k denote the return at which the firm's net period profits are equal to its additional financing costs b_k,

$$R^*_k = \frac{b_k + M^I s^I_{k,t} \left(c_k + i^I_{k,t}\right) + M^N s^N i^N_{k,t}}{M^I s^I_{k,t} + M^N s^N_{k,t}}.$$

If the realized return is below the threshold R^*_k, equity holders must inject additional funds or default.

As in the baseline and the other alternative model specifications, a bank's optimal bankruptcy decision follows a cut-off rule. Equity holders choose to finance the shortfall as long as the franchise value next period (evaluated today) exceeds the size of the shortfall they would have to finance, including the deadweight cost of financing,

$$(1 + \tau_+) \left[M^I s^I_{k,t} \left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t} \left(R_{k,t} - i^N_{k,t}\right) - b_k\right] + \frac{1}{1+r} E_k > 0.$$

Following Hortaçsu et al. (2011) we solve for the optimal threshold $\bar{R}_k$ such that the equity holder is indifferent between defaulting and not defaulting:

$$(1+\tau_+) \left[\begin{array}{c} b_k - M^I s^I_{k,t} \left(\bar{R}_k - c_k - i^I_{k,t}\right) \\ -M^N s^N_{k,t} \left(\bar{R}_k - i^N_{k,t}\right) \end{array} \right] = \frac{M^I s^I_{k,t} + M^N s^N_{k,t}}{1+r} \left[\begin{array}{c} (1+\tau_+) \left[\mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right) - \bar{R}_k\right] \left[1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right] \\ -\tau_+ \left[\mu_k + \sigma_k \lambda \left(\frac{R^*_k - \mu_k}{\sigma_k}\right) - \bar{R}_k\right] \left[1 - \Phi\left(\frac{R^*_k - \mu_k}{\sigma_k}\right)\right] \end{array} \right].$$

Accounting for potentially costly external financing also changes the bank's optimal behavior on the deposit side. Costly external financing makes adverse return shocks more costly as equity holders have to cover $(1 + \tau_+)$ of the equity shortfall rather than just shortfall. Banks set deposit rates to maximize equity value where equity value is given by

$$E_k = \max_{i^I_{k,t}, i^N_{k,t}} \underbrace{(1+\tau_+)\int_{\bar{R}_k}^{R^*_k} \begin{bmatrix} M^I s^I_{k,t}\left(i^I_{k,t}, \mathbf{i^I_{-k,t}}\right)\left(R_{k,t} - c_k - i^I_{k,t}\right) \\ +M^N s^N_{k,t}\left(i^N_{k,t}, \mathbf{i^N_{-k,t}}, \rho_{k,t}, \rho_{-\mathbf{k,t}}\right)\left(R_{k,t} - i^N_{k,t}\right) \\ +\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)(R_{k,t} - r) \\ -b_k + \frac{1}{1+r}E_k \end{bmatrix} dF(R_{k,t})}_{\text{Shortfall}}$$

$$+ \underbrace{\int_{R^*_k}^{\infty} \begin{bmatrix} M^I s^I_{k,t}\left(i^I_{k,t}, \mathbf{i^I_{-k,t}}\right)\left(R_{k,t} - c_k - i^I_{k,t}\right) \\ +M^N s^N_{k,t}\left(i^N_{k,t}, \mathbf{i^N_{-k,t}}, \rho_{k,t}, \rho_{-\mathbf{k,t}}\right)\left(R_{k,t} - i^N_{k,t}\right) \\ +\kappa\left(b_k + M^I s^I_{k,t} + M^N s^N_{k,t}\right)(R_{k,t} - r) \\ -b_k + \frac{1}{1+r}E_k \end{bmatrix} dF(R_{k,t})}_{\text{No Shortfall}}.$$

The difference between equity value in the baseline model and when we account for costly external financing is that it changes the return on deposits if $R < R^*_k$. The corresponding first order conditions for setting insured and uninsured deposit rates are given by

$$\begin{aligned} 0 &= -\tau_+\alpha^I(1 - s^I_{k,t})\left[\mu_k + \sigma_k\lambda\left(\frac{R^*_k - \mu_k}{\sigma_k}\right) - c_k - i^I_{k,t}\right]\left[1 - \Phi\left(\frac{R^*_k - \mu_k}{\sigma_k}\right)\right] \\ &\quad +(1+\tau_+)\alpha^I(1 - s^I_{k,t})\left[\mu_k + \sigma_k\lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right) - c_k - i^I_{k,t}\right]\left[1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right] \\ &\quad -(1+\tau_+)\left[\Phi\left(\frac{R^*_k - \mu_k}{\sigma_k}\right) - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right], \end{aligned}$$

$$\begin{aligned} 0 &= -\tau_+\alpha^N(1 - s^N_{k,t})\left[\mu_k + \sigma_k\lambda\left(\frac{R^*_k - \mu_k}{\sigma_k}\right) - i^N_{k,t}\right]\left[1 - \Phi\left(\frac{R^*_k - \mu_k}{\sigma_k}\right)\right] \\ &\quad +(1+\tau_+)\alpha^N(1 - s^N_{k,t})\left[\mu_k + \sigma_k\lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right) - i^N_{k,t}\right]\left[1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right] \\ &\quad -(1+\tau_+)\left[\Phi\left(\frac{R^* - \mu_k}{\sigma_k}\right) - \Phi\left(\frac{\bar{R} - \mu_k}{\sigma_k}\right)\right]. \end{aligned}$$

Calibration:

In Section **??**, we recalibrate the model where we assume banks currently face a deadweight cost of external financing. As in the baseline version of the model, we used revealed preferences of the bank to calibrate the supply side parameters c_k, σ_k, and μ_k for each bank. Specifically, we use the bank's first order conditions for each bank's two deposit rates, and the bankruptcy decision to solve for the supply-side parameters. Unlike the baseline version of the model, we no longer have a closed-form solution for the supply-side parameters. We numerically solve the system of equations, three equations for each bank, using a non-linear equation solver.[2]

Appendix B: Calculating Multiple Equilibria and Welfare

B.1 Multiple Equilibria

We search for multiple equilibria in the banking sector, given our parameter estimates. In equilibrium, depositors are fully rational and select the utility maximizing bank such that optimal depositor behavior results in the market shares characterized by

$$s^I_{k,t}\left(i^I_{k,t},\mathbf{i^I_{-k,t}}\right)=\frac{exp(\alpha^I i^I_{k,t}+\delta^I_k)}{\sum_{l=1}^K exp(\alpha i^I_{l,t}+\delta^I_l)},$$

$$s^N_{k,t}\left(i^N_{k,t},\mathbf{i^N_{-k,t}},\rho_{k,t},\rho_{-k,t}\right)=\frac{exp(\alpha^N i^N_k-\rho_k\gamma+\delta^N_k)}{\sum_{l=1}^K exp(\alpha^N i^N_l-\rho_l\gamma+\delta^N_l)}.$$

Similarly, banks optimally set deposit rates and optimally default. Each equilibrium consists of a set of bank default probabilities and insured/uninsured deposit rates that satisfy each bank's first-order conditions

$$\text{Bankruptcy: } b_k-\left(M^I s^I_{k,t}\left(\bar{R}_k-c_k-i^I_{k,t}\right)+M^N s^N_{k,t}\left(\bar{R}_k-i^N_{k,t}\right)\right)=\begin{array}{c}\frac{1}{1+r}\left(M^I s^I_{k,t}+M^N s^N_{k,t}\right)\left(1-\Phi\left(\frac{\bar{R}_k-\mu_k}{\sigma_k}\right)\right)\times\\ \times\left(\left(\mu_k-\bar{R}_k\right)+\sigma_k\lambda\left(\frac{\bar{R}_k-\mu_k}{\sigma_k}\right)\right)\end{array},$$

$$\text{Insured Deposits: } \underbrace{\underbrace{\mu_k}_{mean\,return}+\underbrace{\sigma_k\lambda\left(\frac{\bar{R}_k-\mu_k}{\sigma_k}\right)}_{limited\,liabillity}}_{mb}-\underbrace{\left(c_k+i^I_{k,t}\right)}_{mc}=\underbrace{\frac{1}{\left(\left(1-s^I\left(i^I_{k,t},\mathbf{i^I_{-k,t}}\right)\right)\alpha^I\right.}}_{mark-up},$$

$$\text{Uninsured Deposits: } \mu_k+\sigma_k\lambda\left(\frac{\bar{R}_k-\mu_k}{\sigma_k}\right)-i^N_{k,t}=\frac{1}{\left(\left(1-s^N_{k,t}\left(i^I_{k,t},\mathbf{i^I_{-k,t}},\rho_{k,t},\rho_{\mathbf{-k,t}}\right)\right)\alpha^N\right.}.$$

Our equilibrium analysis focuses on the five largest banks, thus we search for multiple equilibria by finding solutions to the system of fifteen nonlinear equations given by each bank's first-order conditions. We search for solutions to the system of equations using a non-linear equation solver initiated at a set of 1,953,125 different starting points. Each starting point consists of a set of default probabilities and insured/uninsured deposit rates. Specifically, we initiate a non-linear equation solver[3] where we set each bank's default probability to either 0.0001%, 1%, 5%, 10%, 20%, 30%, 50%, 65%, or 90% (and all of the 5^9 possible combinations among

[2] Specifically we use the R package NLEQSLV and use Broyden's Method with a tolerance of 10e-12.
[3] Specifically we use the R package NLEQSLV with Broyden's method.

banks) and set each bank's offered insured/uninsured deposit rate to 1%. The tolerance for accepting a solution to the fifteen nonlinear equations is 10e-10.

B.2 Welfare Calculations

We use the model to compare consumer surplus, annualized equity value, and FDIC insurance costs across different equilibria. Each component of surplus is calculated as follows. From the logit demand system, consumer welfare is given by:

$$CS = \frac{M^I}{\alpha^I}\left(\ln\sum_{l=1}^{K}\exp(\alpha^I i_k^I + \delta_k^I + \xi_k^I) + C\right) + \frac{M^N}{\alpha^N}\left(\ln\sum_{l=1}^{K}\exp(\alpha^N i_k^N - \rho_k\gamma + \delta_k^N + \xi_k^N) + C\right),$$

where we have omitted the time subscripts and C is the Euler-Mascheroni constant. We compute the value of bank equity from the bank's default condition:

$$E_k = (1+r)\left[b - \kappa(b + M^I s_k^I + M^N s_k^N)(\bar{R}_k - r_k) - M^I s_k^I(\bar{R}_k - c_k - i_k^I + \kappa) - M^N s_k^N(\bar{R}_k - i_k^N + \kappa)\right],$$

where κ reflects capital requirements ($\kappa = 0$ in the baseline case). The annualized equity value of all banks is then given by:

$$AEV = \sum_{l=1}^{K} rE_l.$$

The expected payout of the the FDIC is equal to the weighted sum of insured deposits weighted by the default probability, assuming a 40% recovery rate:

$$EC = 0.6\sum_{l=1}^{K}\rho_l M^I s_l^I.$$

Last, we compute the change in welfare between counterfactual and the observed equilibrium as the change in consumer surplus, annualized equity value, and FDIC insurance cost

$$\Delta W = \Delta CS + \Delta AEV - \Delta EC.$$

B.3 Optimal Capital Requirements

In Sections 7 and 8, we examine the effect of capital requirements on the space of potential equilibria and calculate the optimal capital requirement under the max-min welfare criterion. Calculating the optimal capital requirement under the max-min welfare criterion requires investigating the entire space of equilibria under each potential capital requirement. To calculate the optimal capital requirement, we compute the space of equilibria for each level of capital requirements κ, where we let κ range from 0 to 50% in increments of 2%.[4] For each level of κ, we search for all potential equilibria by finding solutions to the set of fifteen first-order conditions, as described in Appendix B1. Mechanically, we search for multiple equilibria for each level of capital requirements using an iterative procedure as follows. First, for each level of κ, we initiate a non-linear equation solver[5] where we set each bank's default probability to either 0.0001%, , 20%, 70%, or 90% (and all of the 5^5 possible combinations among banks) and set each bank's offered insured/uninsured deposit rate to 1%. This gives a set of equilibria for each level of κ. Second, for each level of κ, we again use a non-linear equation solver[6] where we initiate the solver using the entire set of equilibria (across all κ) that we recovered in the first step. Given the full space of equilibria, we then compute welfare for each equilibrium outcome and determine the optimal capital requirement under the max-min welfare criterion.

Appendix C: Risk Limits Counterfactual

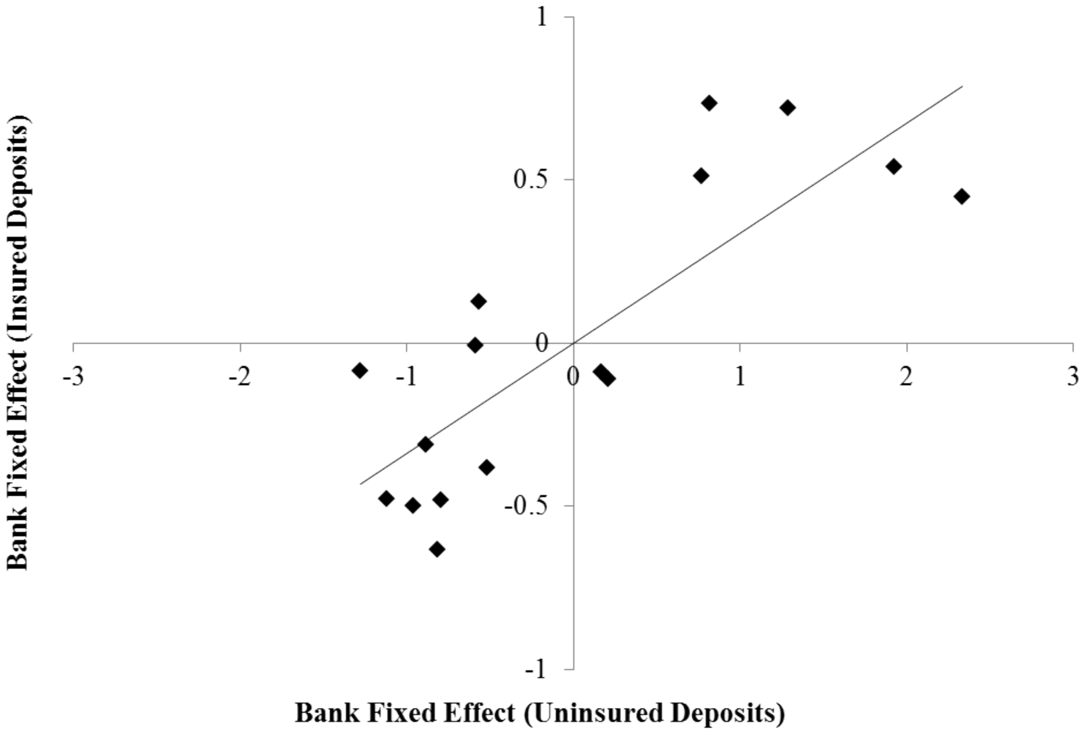
The recent financial crises prompted regulators to examine putting risk limits on financial institutions. We use our model to consider the effect of limiting the risk that banks are eligible to undertake. Specifically, we impose a counterfactual policy in which banks are forced to hold securities/investments that cap the standard deviation of income/returns σ_R at 12.00%. For simplicity, we assume that all banks in excess of the risk limit reduce σ_R to 12.00% exactly. All five banks studied would be forced to reduce the volatility of their returns.

Placing risk limits on banks produces two offsetting effects on the financial stability of banks. On one hand, risk limits lower the probability that a bank experiences an adverse income shock; negative income shocks are less common. On the other hand, risk limits lower the future value of the equity, which makes default less costly.

Table A3 illustrates the equilibrium effect of the hypothetical risk-limit policy. We compute the new equilibrium using a non-linear equation solver initiated at the observed equilibrium. The risk limit increases the probability that each bank defaults. Overall, the calibration results suggest that imposing risk limits of this form could be counterproductive. On average, the risk limit increases the probability that each bank defaults by over 2.00% points. Although risk limits lower the volatility of bank returns, they also lower the profitability of banks, which could potentially destabilize the banking sector.

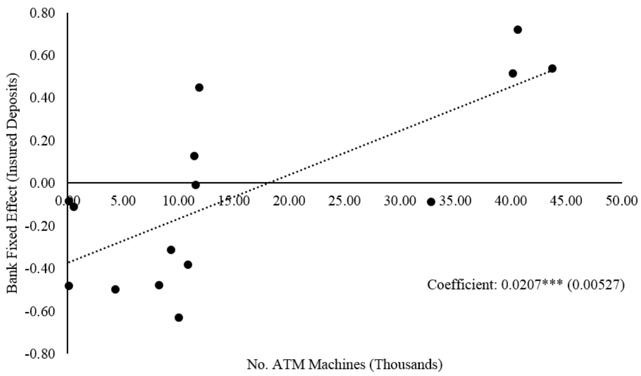
[4] In the baseline model we let κ range from 0 to 50% in increments of 1%.
[5] Specifically we use the R package NLEQSLV with Broyden's method.
[6] Specifically we use the R package NLEQSLV with Broyden's method.

Figure A1: Demand Estimates - Bank Brand/Fixed Effects

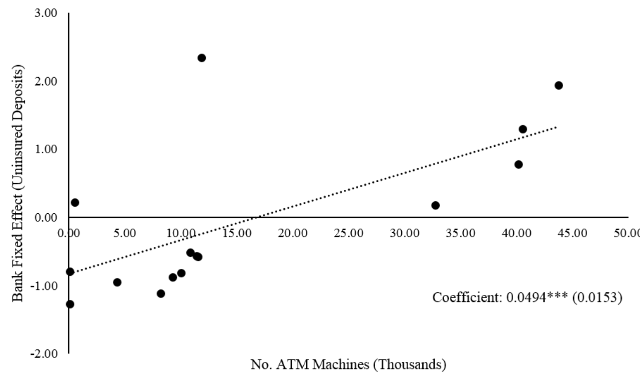


Notes: Figure A1 displays the estimated bank fixed effects corresponding to column (1) and (3) in Table 3.

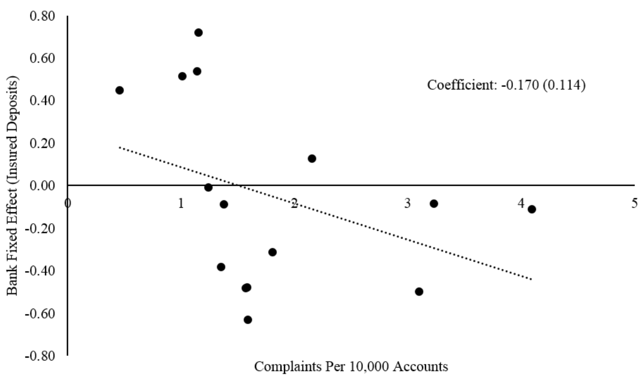
Figure A2: Bank Brand/Fixed Effects vs. Bank Quality



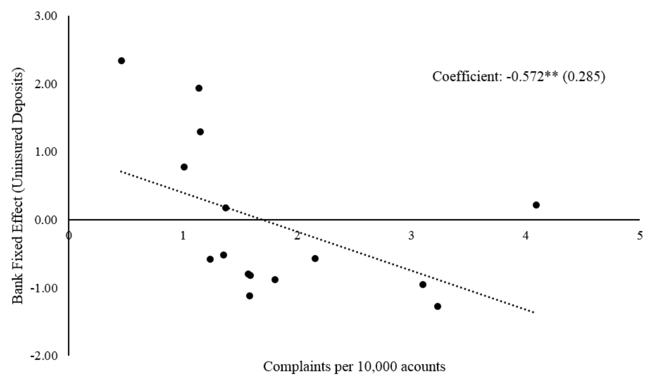
(a) Bank Brand Effects (Ins) vs. No. of ATM Machines



(b) Bank Brand Effects (Unins) vs. No. of ATM Machines



(c) Bank Brand Effects (Ins) vs. Complaints Per Account



(d) Bank Brand Effects (Unins) vs. Complaints Per Account

Note: Figure A2 Panels (a)-(d) displays the regression of the estimated bank fixed effects on the number of ATM machines operated by each bank and the number of customer complaints per customer filed with the Consumer Finance Protection Bureau (CFPB). The estimated fixed effects correspond to the preferred demand specifications which are reported in column (1) and (3) in Table 3. We calculate the number of ATM machines operated by each bank using a new data set that includes the ATM locations for all major banks as of 2015. We manually collected the ATM location data from a popular website that locates Mastercard ATMs. We measure the number of complaints using the Consumer Financial Protection Bureau's (CFPB) newly available Consumer Complaint Database. We measure the quality of a bank's services as the number of complaints each bank received per bank account over the period July 2011-2015. We calculate the number of bank accounts as of March 2015 from the FDIC's Statistics on Depository Institutions.

Table A1 - Panel A: Multiple Equilibria 2007

	Obs	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Insured Interest Rate													
JPMorgan Chase	3.68%	4.04%	81.87%	76.65%	76.62%	4.63%	75.02%	4.67%	4.42%	4.61%	4.42%	4.88%	11.93%
Bank of America	3.59%	4.08%	80.05%	4.43%	4.45%	71.29%	72.96%	71.26%	4.42%	9.44%	4.40%	4.81%	4.71%
Wells Fargo	4.17%	4.81%	7.29%	7.73%	7.76%	7.92%	7.93%	7.95%	12.44%	6.03%	6.03%	6.72%	6.34%
Citi Bank	4.21%	5.19%	5.64%	4.09%	6.71%	4.07%	7.07%	7.10%	6.36%	6.46%	6.27%	14.26%	6.79%
Wachovia	3.78%	4.23%	82.05%	76.25%	76.22%	72.90%	5.11%	72.87%	4.77%	4.86%	11.21%	5.18%	5.04%
Uninsured Interest Rate													
JPMorgan Chase	3.68%	4.07%	82.05%	78.46%	78.42%	4.59%	77.13%	4.62%	4.40%	4.58%	4.40%	4.82%	18.65%
Bank of America	3.92%	4.50%	80.86%	4.63%	4.65%	73.44%	74.91%	73.41%	4.65%	14.74%	4.65%	5.01%	4.93%
Wells Fargo	3.83%	4.50%	6.98%	7.40%	7.42%	7.58%	7.59%	7.60%	19.64%	5.68%	5.69%	6.34%	5.97%
Citi Bank	4.21%	5.20%	5.75%	3.99%	6.66%	3.88%	6.95%	6.98%	6.29%	6.33%	6.20%	26.12%	6.61%
Wachovia	3.83%	4.31%	82.98%	77.89%	77.86%	74.82%	5.11%	74.79%	4.79%	4.88%	16.52%	5.18%	5.05%
Probability of Default													
JPMorgan Chase	0.20%	1.10%	100.00%	100.00%	100.00%	2.61%	100.00%	2.73%	2.03%	2.64%	2.04%	3.44%	55.70%
Bank of America	0.11%	1.63%	100.00%	2.05%	2.13%	100.00%	100.00%	100.00%	2.17%	45.19%	2.17%	3.49%	3.20%
Wells Fargo	0.15%	1.30%	6.70%	7.83%	7.89%	8.31%	8.34%	8.38%	43.04%	3.80%	3.79%	5.37%	4.50%
Citi Bank	0.21%	1.57%	2.15%	0.04%	3.90%	0.02%	4.52%	4.57%	3.35%	3.53%	3.21%	43.56%	4.09%
Wachovia	0.18%	1.37%	100.00%	100.00%	100.00%	100.00%	3.76%	100.00%	2.76%	3.06%	49.57%	4.03%	3.61%
Insured Deposit Share													
JPMorgan Chase	3.44%	3.90%	30.01%	51.30%	51.29%	0.00%	53.64%	0.00%	0.88%	1.47%	1.15%	0.72%	77.46%
Bank of America	9.45%	11.55%	29.86%	0.00%	0.00%	48.37%	46.36%	48.36%	2.55%	72.61%	3.30%	2.00%	3.21%
Wells Fargo	3.79%	5.08%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	81.23%	2.80%	2.45%	1.76%	2.39%
Citi Bank	2.28%	3.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.33%	2.11%	1.66%	86.55%	1.83%
Wachovia	4.38%	5.25%	40.12%	48.70%	48.71%	51.63%	0.00%	51.64%	1.30%	2.04%	74.84%	1.03%	1.62%
Cumulative Share	23.34%	29.51%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	87.30%	81.04%	83.41%	92.06%	86.50%
Uninsured Deposit Share													
JPMorgan Chase	13.61%	13.25%	19.27%	12.69%	12.72%	13.34%	11.06%	13.38%	13.26%	13.53%	13.29%	13.73%	0.19%
Bank of America	9.84%	9.15%	10.85%	9.16%	9.18%	4.09%	5.26%	4.12%	9.33%	0.24%	9.36%	9.67%	9.68%
Wells Fargo	4.18%	4.13%	2.73%	3.04%	3.05%	3.19%	3.20%	3.21%	0.28%	4.17%	3.93%	4.13%	4.23%
Citi Bank	16.24%	16.48%	14.48%	16.89%	16.34%	17.97%	17.11%	17.17%	16.83%	17.68%	16.92%	3.32%	18.21%
Wachovia	4.40%	4.19%	7.08%	3.63%	3.64%	2.36%	3.98%	2.37%	4.06%	4.24%	0.08%	4.25%	4.29%
Cumulative Share	48.28%	47.19%	54.42%	45.42%	44.94%	40.95%	40.61%	40.25%	43.76%	39.86%	43.58%	35.11%	36.59%
FDIC Ins. Cost	$1bn	$11bn	$2,547bn	$2,547bn	$2,547bn	$2,547bn	$2,547bn	$2,547bn	$894bn	$843bn	$951bn	$966bn	$1,108bn
Change in Welfare	-	-$19bn	-$410bn	-$576bn	-$602bn	-$685bn	-$715bn	-$718bn	-$1,038bn	-$1,048bn	-$1,144bn	-$1,194bn	-$1,408bn

Notes: Column (1) displays the observed equilibrium as of 3/31/07. Columns (3)-(14) display other potential equilibria. Equilibria are ordered by welfare. As detailed in the Appendix, welfare is reported relative to its respective values in the observed equilibrium, assuming a bankruptcy cost of 20%. We do not report all potential equilibria. For ease of exposition, we omit equilibria where the cumulative difference in default probabilities is within 10% of a reported equilibrium. Cells highlighted in red indicate that the probability of default is greater than 40%. FDIC insurance cost reflects the total expected insurance payout for the five major banks. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate.

Table A1 - Panel B: Multiple Equilibria 2009

	Obs	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Insured Interest Rate															
JPMorgan Chase	0.20%	-0.83%	80.99%	-0.36%	77.30%	76.93%	77.01%	1.17%	1.18%	1.24%	0.86%	1.21%	0.91%	7.86%	1.49%
Bank of America	1.49%	1.45%	0.91%	76.37%	1.59%	1.62%	76.33%	69.21%	68.71%	2.45%	2.05%	7.49%	2.08%	2.50%	2.48%
Wells Fargo	1.09%	1.05%	80.93%	77.72%	77.75%	0.90%	0.69%	70.08%	1.77%	66.12%	1.53%	1.75%	8.47%	1.96%	1.94%
Citi Bank	2.47%	2.42%	1.34%	-0.72%	2.17%	2.22%	2.02%	3.21%	3.22%	3.27%	2.99%	3.29%	3.03%	3.55%	12.13%
Wachovia	0.90%	0.87%	79.98%	76.92%	1.14%	76.62%	1.03%	1.89%	68.80%	65.36%	7.65%	1.64%	1.48%	1.87%	1.87%
Uninsured Interest Rate															
JPMorgan Chase	0.20%	-0.96%	81.19%	-0.31%	78.93%	78.72%	78.93%	1.09%	1.10%	1.15%	0.79%	1.09%	0.83%	16.69%	1.33%
Bank of America	1.14%	1.11%	0.58%	76.19%	1.20%	1.24%	76.39%	70.79%	70.38%	1.99%	1.61%	13.21%	1.64%	2.00%	2.00%
Wells Fargo	1.29%	1.26%	81.33%	78.64%	78.69%	1.07%	0.86%	71.82%	1.91%	68.16%	1.68%	1.90%	13.87%	2.10%	2.08%
Citi Bank	2.47%	2.43%	1.57%	-0.90%	2.30%	2.35%	2.17%	3.19%	3.20%	3.24%	2.96%	3.20%	3.00%	3.43%	21.77%
Wachovia	1.09%	1.06%	80.30%	77.76%	1.28%	77.52%	1.17%	2.02%	70.46%	67.26%	12.83%	1.77%	1.62%	1.98%	1.98%
Probability of Default															
JPMorgan Chase	2.14%	0.04%	99.99%	0.76%	99.98%	99.98%	99.98%	4.20%	4.23%	4.38%	3.53%	4.42%	3.64%	48.72%	5.08%
Bank of America	5.11%	4.99%	2.66%	100.00%	4.82%	4.95%	100.00%	100.00%	100.00%	7.85%	6.63%	51.19%	6.74%	8.22%	8.14%
Wells Fargo	2.74%	2.62%	100.00%	100.00%	100.00%	1.92%	1.28%	100.00%	4.80%	100.00%	4.03%	4.82%	54.81%	5.57%	5.46%
Citi Bank	6.87%	6.75%	4.06%	0.00%	6.04%	6.16%	5.67%	8.68%	8.71%	8.84%	8.14%	8.91%	8.23%	9.61%	58.97%
Wachovia	3.80%	3.70%	100.00%	100.00%	4.29%	100.00%	3.90%	7.05%	100.00%	100.00%	53.11%	6.22%	5.63%	7.04%	7.02%
Insured Deposit Share															
JPMorgan Chase	5.61%	3.15%	56.27%	0.00%	64.08%	64.69%	65.06%	0.00%	0.00%	0.00%	2.09%	2.38%	2.03%	82.02%	1.65%
Bank of America	9.58%	9.67%	0.00%	30.18%	0.00%	0.00%	34.94%	52.85%	53.56%	0.00%	3.36%	76.29%	3.25%	2.81%	2.37%
Wells Fargo	4.06%	4.09%	23.30%	35.65%	35.92%	0.00%	0.00%	47.15%	0.00%	50.56%	1.32%	1.40%	74.63%	1.10%	0.92%
Citi Bank	2.07%	2.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.71%	0.78%	0.69%	0.63%	83.61%
Wachovia	5.55%	5.61%	20.43%	34.17%	0.00%	35.31%	0.00%	0.00%	46.44%	49.44%	74.09%	2.01%	1.87%	1.59%	1.35%
Cumulative Share	26.86%	24.60%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	81.56%	82.87%	82.48%	88.14%	89.91%
Uninsured Deposit Share															
JPMorgan Chase	17.08%	18.06%	34.23%	15.29%	29.70%	29.10%	28.41%	16.87%	16.89%	16.99%	17.14%	17.86%	17.19%	0.98%	18.08%
Bank of America	11.66%	11.60%	9.12%	16.37%	9.73%	9.77%	15.74%	8.98%	8.42%	10.70%	11.27%	0.31%	11.28%	11.83%	11.64%
Wells Fargo	4.24%	4.21%	7.81%	6.47%	6.36%	3.66%	3.61%	2.80%	4.02%	1.56%	4.16%	4.34%	0.05%	4.42%	4.35%
Citi Bank	14.75%	14.65%	11.42%	16.37%	12.68%	12.76%	12.43%	14.59%	14.61%	14.71%	14.77%	15.47%	14.83%	15.92%	0.66%
Wachovia	3.69%	3.66%	6.77%	5.75%	2.85%	5.46%	2.81%	3.16%	2.31%	1.38%	0.06%	3.66%	3.50%	3.70%	3.62%
Cumulative Share	51.42%	52.17%	69.34%	60.25%	61.31%	60.74%	63.00%	46.40%	46.24%	45.33%	47.40%	41.64%	46.86%	36.84%	38.35%
FDIC Ins. Cost	$31bn	$27bn	$2,899bn	$2,899bn	$2,899bn	$2,899bn	$2,899bn	$2,899bn	$2,899bn	$2,899bn	$1,153bn	$1,143bn	$1,199bn	$1,172bn	$1,442bn
Change in Welfare	-	$18bn	-$247bn	-$328bn	-$422bn	-$433bn	-$485bn	-$765bn	-$782bn	-$901bn	-$1,345bn	-$1,386bn	-$1,409bn	-$1,449bn	-$1,772bn

Notes: Column (1) displays the observed equilibrium as of 3/31/09. Column (2) displays the best potential equilibrium in terms of welfare. Columns (3)-(15) display potential bank-run equilibria. Equilibria are ordered by welfare. As detailed in the Appendix, welfare is reported relative to its respective values in the observed equilibrium, assuming a bankruptcy cost of 20%. We do not report all potential equilibria. For ease of exposition, we omit equilibria where the cumulative difference in default probabilities is within 10% of a reported equilibrium. Cells highlighted in red indicate that the probability of default is greater than 40%. FDIC insurance cost reflects the total expected insurance payout for the five major banks. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate.

Table A2: Counterfactual Analysis - Interest Rate Limits on Insured Deposits

	Obs	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Insured Interest Rate															
JPMorgan Chase	1.73%	0.98%	2.13%	2.55%	6.54%	2.22%	6.54%	2.50%	2.97%	6.54%	0.86%	2.56%	3.23%	6.54%	2.80%
Bank of America	1.98%	1.53%	2.08%	2.32%	2.34%	2.11%	2.45%	2.22%	2.47%	2.47%	2.53%	6.54%	2.59%	2.58%	6.54%
Wells Fargo	2.13%	2.05%	6.54%	2.66%	2.79%	2.62%	6.54%	6.54%	3.07%	3.13%	6.54%	2.90%	6.54%	6.54%	6.54%
Citi Bank	2.23%	2.11%	2.64%	6.54%	3.21%	2.74%	3.52%	3.04%	6.54%	3.60%	6.54%	3.11%	6.54%	3.86%	3.38%
Wachovia	2.08%	2.04%	2.29%	2.45%	2.52%	6.54%	2.70%	6.54%	6.54%	6.54%	6.54%	2.54%	6.54%	6.54%	2.67%
Uninsured Interest Rate															
JPMorgan Chase	1.73%	0.94%	2.09%	2.43%	16.40%	2.18%	17.10%	2.42%	2.80%	17.45%	0.40%	2.47%	3.01%	18.10%	2.68%
Bank of America	1.97%	1.40%	2.00%	2.26%	2.24%	2.00%	2.31%	2.08%	2.34%	2.32%	2.38%	10.62%	2.43%	2.41%	10.83%
Wells Fargo	2.32%	2.25%	12.85%	2.82%	2.95%	2.79%	13.02%	13.06%	3.20%	3.27%	13.12%	3.05%	13.14%	13.22%	13.21%
Citi Bank	2.23%	2.13%	2.59%	19.96%	3.03%	2.68%	3.29%	2.94%	22.27%	3.36%	23.42%	2.99%	23.64%	3.57%	3.21%
Wachovia	2.23%	2.19%	2.41%	2.57%	2.63%	11.43%	2.78%	11.55%	11.50%	11.57%	11.60%	2.63%	11.62%	11.69%	2.76%
Probability of Default															
JPMorgan Chase	1.50%	0.19%	2.24%	3.16%	37.70%	2.42%	39.64%	2.98%	4.03%	40.61%	0.00%	3.11%	4.59%	42.38%	3.61%
Bank of America	1.82%	0.03%	2.02%	3.25%	3.19%	2.06%	3.59%	2.45%	3.73%	3.66%	3.94%	48.77%	4.19%	4.10%	49.97%
Wells Fargo	1.50%	1.34%	32.19%	2.69%	2.98%	2.55%	32.74%	32.88%	3.62%	3.77%	33.10%	3.19%	33.16%	33.42%	33.37%
Citi Bank	2.11%	1.92%	2.77%	38.59%	3.76%	2.94%	4.31%	3.45%	43.73%	4.46%	46.24%	3.57%	46.71%	4.93%	4.04%
Wachovia	3.28%	3.14%	3.88%	4.52%	4.72%	41.05%	5.29%	41.58%	41.37%	41.68%	41.81%	4.67%	41.88%	42.18%	5.14%
Insured Deposit Share															
JPMorgan Chase	3.38%	2.26%	2.80%	4.18%	35.46%	2.53%	27.09%	2.33%	3.37%	24.13%	0.81%	2.36%	3.19%	20.08%	2.24%
Bank of America	9.26%	7.39%	6.47%	8.62%	7.08%	5.61%	5.78%	4.67%	5.95%	5.22%	5.14%	57.89%	5.16%	4.63%	47.83%
Wells Fargo	3.99%	3.96%	35.04%	4.16%	3.66%	2.99%	25.27%	23.37%	3.33%	3.04%	21.34%	2.68%	20.80%	18.73%	18.86%
Citi Bank	2.07%	2.00%	1.73%	19.89%	2.28%	1.57%	2.09%	1.46%	12.54%	1.95%	10.44%	1.49%	10.17%	1.90%	1.44%
Wachovia	5.81%	5.89%	4.32%	5.52%	4.68%	44.92%	3.96%	35.08%	38.49%	33.78%	32.04%	3.26%	31.22%	28.12%	2.92%
Cumulative Share	24.51%	21.50%	50.37%	42.38%	53.16%	57.62%	64.20%	66.90%	63.68%	68.12%	69.77%	67.67%	70.54%	73.46%	73.29%
Uninsured Deposit Share															
JPMorgan Chase	15.86%	16.06%	16.16%	17.39%	2.30%	16.20%	2.14%	16.56%	17.87%	2.03%	20.49%	16.67%	18.32%	1.91%	17.04%
Bank of America	9.23%	10.32%	9.53%	9.73%	9.81%	9.60%	9.99%	9.75%	10.02%	10.03%	10.11%	0.12%	10.18%	10.17%	0.11%
Wells Fargo	4.30%	4.25%	0.55%	4.84%	4.78%	4.34%	0.64%	0.55%	4.95%	4.88%	0.65%	4.47%	0.67%	0.65%	0.57%
Citi Bank	16.80%	16.58%	17.29%	3.90%	18.81%	17.38%	19.39%	17.90%	3.24%	19.48%	2.95%	18.05%	2.97%	20.07%	18.58%
Wachovia	4.74%	4.70%	4.77%	5.15%	5.09%	0.20%	5.15%	0.20%	0.24%	0.23%	0.23%	4.84%	0.24%	0.23%	4.90%
Cumulative Share	50.93%	51.91%	48.29%	41.01%	40.80%	47.72%	37.32%	44.96%	36.32%	36.66%	34.43%	44.16%	32.38%	33.03%	41.21%
FDIC Ins. Cost	$14bn	$8bn	$311bn	$225bn	$373bn	$499bn	$520bn	$599bn	$583bn	$646bn	$679bn	$761bn	$668bn	$717bn	$812bn
Change in Welfare	-	$20bn	-$343bn	-$352bn	-$511bn	-$579bn	-$714bn	-$716bn	-$819bn	-$877bn	-$919bn	-$941bn	-$958bn	-$997bn	-$1,022bn

Notes: Column (1) displays the observed equilibrium as of 3/31/08. Column (2) displays the best potential equilibrium in terms of welfare. Columns (3)-(15) display potential bank-run equilibria if regulators were to impose a maximum allowable deposit rate of the one-year treasury rate, plus 5.00% on insured deposits. Equilibria are ordered by welfare. As detailed in the Appendix, welfare is reported relative to its respective values in the observed equilibrium, assuming a bankruptcy cost of 20%. We do not report all potential equilibria. For ease of exposition, we omit equilibria where the cumulative difference in default probabilities is within 10% of a reported equilibrium. Cells highlighted in red indicate that the probability of default is greater than 40%. FDIC insurance cost reflects the total expected insurance payout for the five major banks. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate.

Table A2 (Continued): Counterfactual Analysis - Interest Rate Limits on Insured Deposits

	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
Insured Interest Rate														
JPMorgan Chase	6.54%	2.86%	0.86%	3.07%	6.54%	3.49%	6.54%	6.54%	6.54%	6.54%	6.54%	6.54%	6.54%	6.54%
Bank of America	2.79%	6.54%	6.54%	6.54%	6.54%	6.54%	6.54%	2.92%	6.54%	6.54%	6.54%	6.54%	6.54%	6.54%
Wells Fargo	6.54%	3.16%	3.25%	6.54%	3.36%	6.54%	6.54%	6.54%	3.58%	6.54%	3.74%	6.54%	3.95%	6.54%
Citi Bank	6.54%	3.44%	6.54%	3.68%	3.90%	6.54%	4.14%	6.54%	4.20%	4.42%	6.54%	6.54%	6.54%	6.54%
Wachovia	3.05%	6.54%	2.84%	6.54%	2.91%	3.04%	3.04%	6.54%	6.54%	6.54%	3.25%	3.39%	6.54%	6.54%
Uninsured Interest Rate														
JPMorgan Chase	17.50%	2.73%	0.38%	2.91%	18.18%	3.23%	18.80%	18.47%	19.13%	19.70%	18.57%	19.15%	19.48%	20.02%
Bank of America	2.63%	10.94%	10.71%	11.14%	10.86%	10.94%	11.06%	2.73%	11.17%	11.35%	10.96%	11.15%	11.26%	11.43%
Wells Fargo	13.09%	3.30%	3.37%	13.42%	3.48%	13.30%	13.37%	13.30%	3.69%	13.57%	3.81%	13.45%	4.01%	13.64%
Citi Bank	23.34%	3.26%	23.59%	3.45%	3.59%	25.08%	3.78%	25.28%	3.83%	3.99%	25.47%	26.64%	27.26%	28.33%
Wachovia	3.11%	11.75%	2.91%	11.86%	2.98%	3.10%	3.10%	11.74%	11.88%	11.99%	3.30%	3.42%	11.93%	12.03%
Probability of Default														
JPMorgan Chase	40.80%	3.73%	0.00%	4.19%	42.62%	5.18%	44.29%	43.44%	45.18%	46.71%	43.71%	45.29%	46.16%	47.60%
Bank of America	5.28%	50.60%	49.31%	51.72%	50.17%	50.62%	51.28%	5.86%	51.89%	52.93%	50.76%	51.79%	52.39%	53.35%
Wells Fargo	33.02%	3.81%	4.05%	34.04%	4.32%	33.66%	33.91%	33.68%	4.88%	34.56%	5.31%	34.17%	5.87%	34.81%
Citi Bank	46.12%	4.15%	46.59%	4.58%	5.01%	49.79%	5.45%	50.28%	5.55%	5.98%	50.67%	53.11%	54.36%	56.51%
Wachovia	6.59%	42.44%	5.77%	42.93%	6.02%	6.48%	6.49%	42.43%	43.01%	43.48%	7.33%	7.81%	43.24%	43.67%
Insured Deposit Share														
JPMorgan Chase	24.09%	2.12%	0.79%	2.09%	19.64%	3.08%	16.92%	18.54%	15.71%	13.98%	18.10%	15.89%	14.82%	13.38%
Bank of America	6.28%	43.78%	52.90%	37.94%	46.45%	43.64%	40.02%	5.23%	37.16%	33.08%	42.81%	37.58%	35.06%	31.64%
Wells Fargo	22.47%	2.36%	3.01%	14.96%	2.82%	17.21%	15.78%	17.30%	2.58%	13.04%	3.25%	14.82%	3.02%	12.48%
Citi Bank	10.99%	1.36%	10.20%	1.36%	1.90%	8.41%	1.89%	8.46%	1.81%	1.83%	8.26%	7.25%	6.76%	6.10%
Wachovia	4.33%	25.91%	3.55%	22.46%	3.26%	3.29%	3.03%	25.97%	21.99%	19.58%	3.67%	3.48%	20.75%	18.73%
Cumulative Share	68.17%	75.55%	70.46%	78.81%	74.06%	75.63%	77.65%	75.50%	79.25%	81.52%	76.09%	79.01%	80.42%	82.33%
Uninsured Deposit Share														
JPMorgan Chase	2.44%	17.10%	20.62%	17.48%	1.90%	18.84%	1.80%	2.21%	1.72%	1.64%	2.17%	2.08%	1.99%	1.92%
Bank of America	10.48%	0.11%	0.13%	0.10%	0.13%	0.13%	0.12%	10.66%	0.11%	0.11%	0.15%	0.14%	0.13%	0.13%
Wells Fargo	0.77%	4.58%	5.01%	0.58%	5.03%	0.69%	0.66%	0.79%	5.17%	0.67%	5.78%	0.80%	5.96%	0.82%
Citi Bank	3.47%	18.67%	2.92%	19.20%	20.16%	2.73%	20.75%	3.06%	20.82%	21.42%	3.01%	2.85%	2.72%	2.63%
Wachovia	5.68%	0.20%	5.22%	0.20%	5.23%	5.38%	5.32%	0.28%	0.23%	0.24%	5.76%	5.86%	0.28%	0.29%
Cumulative Share	22.83%	40.65%	33.90%	37.56%	32.46%	27.76%	28.66%	16.99%	28.06%	24.08%	16.87%	11.75%	11.08%	5.78%
FDIC Ins. Cost	$611bn	$889bn	$830bn	$919bn	$854bn	$864bn	$897bn	$784bn	$960bn	$990bn	$912bn	$954bn	$,1013bn	$1,044bn
Change in Welfare	-$1,027bn	-$1,121bn	-$1,125bn	-$1,184bn	-$1,185bn	-$1,260bn	-$1,276bn	-$1,326bn	-$1,359bn	-$1,443bn	-$1,496bn	-$1,648bn	-$1,733bn	-$1,945bn

Notes: Columns (16)-(29) display potential bank-run equilibria if regulators were to impose a maximum allowable deposit rate of the one-year treasury rate, plus 5.00% on insured deposits as of 3/31/2008. Equilibria are ordered by welfare. As detailed in the Appendix, welfare is reported relative to its respective values in the observed equilibrium, assuming a bankruptcy cost of 20%. We do not report all potential equilibria. For ease of exposition, we omit equilibria where the cumulative difference in default probabilities is within 10% of a reported equilibrium. Cells highlighted in red indicate that the probability of default is greater than 40%. FDIC insurance cost reflects the total expected insurance payout for the five major banks. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate.

Table A3: Counterfactual Analysis - Risk Limits

Bank	Prob. of Default.	Prob. of Default (12% Cap)
JPMorgan Chase	1.50%	6.36%
Citi Bank	2.11%	8.32%
Bank of America	1.82%	3.46%
Wells Fargo	1.50%	6.84%
Wachovia	3.28%	6.09%

Notes: Column (1) displays the realized equilibrium probability of default as of 03/31/2008. Column (2) displays an equilibrium probability of default if regulators were to impose a counterfactual policy in which banks are forced to hold securities/investments that cap the standard deviation of income/returns σ_R at 12.00%. We calculate and select the reported new equilibrium using8 a non-linear equation solver (we use the R package NLEQSLV with Broyden's Method) initiated at the observed equilibrium.

Table A4 - Panel A: Too Big To Fail

Calibration/Model	Mean Return (μ)	Std. Dev. of Returns (σ)	Non-Interest Cost (c)
Baseline Model	7.80%	15.94%	4.67%
Alternative Specifications:			
TBTF (10%)	7.76%	15.82%	4.67%
TBTF (50%)	7.40%	14.72%	4.67%
TBTF (75%)	6.88%	12.61%	4.67%
Capital Rq., Adj. & TBTF (10%)	7.96%	13.12%	4.67%
Capital Rq., Adj. & TBTF (50%)	7.68%	13.38%	4.67%
Capital Rq., Adj. & TBTF (75%)	7.17%	13.44%	4.67%

Table A4 Panel B: Too Big To Fail

Calibration/Model	Optimal Capital Req. κ
Baseline Model	39%
Alternative Specifications:	
TBTF (10%)	36%
TBTF (50%)	24%
TBTF (75%)	12%
Capital Rq., Adj. & TBTF (10%)	30 %
Capital Rq., Adj. & TBTF (50%)	24%
Capital Rq., Adj. & TBTF (75%)	14%
Capital Rq., Adj., TBTF (10%) & Bankruptcy Costs (20%)	30%
Capital Rq., Adj., TBTF (50%) & Bankruptcy Costs (20%)	24%
Capital Rq., Adj., TBTF (75%) & Bankruptcy Costs (20%)	14%

Notes: Table A3 Panels A and B display the calibrated parameters and optimal capital requirements under the alternative too-big-to-fail model specifications as of 3/31/2008. Panel A displays the average of the calibrated parameters (μ, σ, c) under each specification. Panel B displays the optimal capital requirement. The optimal capital requirement maximizes welfare, given that the worst equilibrium outcome (in terms of welfare) is realized. The alternative model specifications reported in Panel A are as follows. We calibrate the model where investors anticipate a too-big-to-fail (TBTF) policy where the government bails out uninsured depositors with 10%, 50%, and 75% probability. We also calibrate the model to existing capital requirements, under the TBTF policy and with capital adjustment costs. The details of each alternative specification are discussed in Section 8 and the Appendix.

Table A5: Robustness Checks - Risk Free Rate

Panel A: Calibrated Parameters and Optimal Capital Requirement

Calibration/Model	Mean Return (μ)	Std. Dev. of Returns (σ)	Non-Interest Cost (c)	Optimal Capital Req. ω
Baseline Model	7.80%	15.94%	4.67%	39%
Alt. Risk Free Rate (30YCMT)	7.74%	17.76%	4.67%	43%

Panel B: Multiple Equilibria

	Obs	(2)	(3)	(4)	(5)	(6)	(7)
Insured Interest Rate							
JPMorgan Chase	1.73%	0.87%	2.49%	2.47%	2.69%	10.65%	3.17%
Bank of America	1.98%	1.47%	2.11%	2.12%	7.51%	2.44%	2.44%
Wells Fargo	2.13%	2.01%	10.22%	3.07%	3.10%	3.62%	3.70%
Citi Bank	2.23%	0.69%	3.01%	2.99%	3.23%	3.71%	12.41%
Wachovia	2.08%	0.88%	2.61%	8.90%	2.64%	2.95%	2.98%
Uninsured Interest Rate							
JPMorgan Chase	1.73%	0.85%	2.42%	2.40%	2.58%	21.37%	3.00%
Bank of America	1.97%	1.36%	1.92%	1.94%	12.00%	2.22%	2.22%
Wells Fargo	2.32%	2.21%	18.31%	3.23%	3.24%	3.74%	3.83%
Citi Bank	2.23%	0.71%	2.93%	2.91%	3.09%	3.49%	25.49%
Wachovia	2.23%	0.92%	2.69%	14.64%	2.72%	3.01%	3.04%
Probability of Default							
JPMorgan Chase	1.50%	0.17%	2.75%	2.73%	3.16%	46.12%	4.06%
Bank of America	1.82%	0.02%	1.78%	1.87%	51.44%	3.05%	3.03%
Wells Fargo	1.50%	1.27%	44.48%	3.35%	3.42%	4.54%	4.72%
Citi Bank	2.11%	0.11%	3.24%	3.22%	3.60%	4.38%	46.37%
Wachovia	3.28%	0.00%	4.68%	50.60%	4.85%	5.80%	5.89%
Insured Deposit Share							
JPMorgan Chase	3.38%	2.22%	0.93%	1.24%	1.75%	85.15%	0.84%
Bank of America	9.26%	7.48%	1.77%	2.39%	70.49%	1.61%	1.29%
Wells Fargo	3.99%	4.05%	81.95%	1.65%	2.08%	1.27%	1.07%
Citi Bank	2.07%	0.91%	0.58%	0.77%	1.09%	0.66%	87.70%
Wachovia	5.81%	3.12%	1.40%	76.05%	2.38%	1.29%	1.05%
Cumulative Share	24.51%	17.78%	86.63%	82.09%	77.78%	89.97%	91.96%
Uninsured Deposit Share							
JPMorgan Chase	15.86%	15.80%	16.09%	16.19%	16.80%	1.84%	17.28%
Bank of America	9.23%	10.19%	9.75%	9.75%	0.11%	10.05%	10.05%
Wells Fargo	4.30%	4.23%	0.29%	4.23%	4.47%	4.53%	4.48%
Citi Bank	16.80%	16.36%	17.35%	17.44%	18.20%	18.99%	3.72%
Wachovia	4.74%	5.61%	4.54%	0.10%	4.79%	4.79%	4.75%
Cumulative Share	50.93%	52.19%	48.02%	47.70%	44.37%	40.21%	40.29%
FDIC Ins. Cost	\$14bn	\$2bn	\$974bn	\$1,029bn	\$973bn	\$1,051bn	\$1,088bn
Change in Welfare	\$0bn	\$29bn	-\$1,093bn	-\$1,199bn	-\$1,183bn	-\$1,267bn	-\$1,302bn

Notes: Panel A displays the calibrated parameters and optimal capital requirement as of 3/31/08 under the baseline specification and the alternative specification, where we set the discount rate r equal to the 30-Year Constant Maturity Treasury Rate (30YCMT) as of 3/31/08 (4.30%). The optimal capital requirement maximizes welfare given that the worst equilibrium outcome (in terms of welfare) is realized.

Panel B displays the model equilibria under the alternative specification where we set the risk free rate equal to 30YCMT. Column (1) displays the observed equilibrium as of 3/31/08. Columns (2)-(7) display other potential equilibria. Equilibria are ordered by welfare. As detailed in the Appendix, welfare is reported relative to its respective values in the observed equilibrium, assuming a bankruptcy cost of 20%. We do not report all potential equilibria. For ease of exposition, we omit equilibria where the cumulative difference in default probabilities is within 10% of a reported equilibrium. Cells highlighted in red indicate that the probability of default is greater than 40%. FDIC insurance cost reflects the total expected insurance payout for the five major banks. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate.