Deposit Competition and Financial Fragility: Evidence from the U.S. Banking Sector

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Abstract

We develop a structural empirical model of the U.S. banking sector. Insured depositors and run-prone uninsured depositors choose between differentiated banks. Banks compete for deposits and endogenously default. The estimated demand for uninsured deposits declines with banks' financial distress, which is not the case for insured deposits. We calibrate the supply side of the model. The calibrated model possesses multiple equilibria with bank-run features, suggesting that banks can be very fragile. We use our model to analyze proposed bank regulations. For example, our results suggest that a capital requirement below 18% can lead to significant instability in the banking system.

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1 Introduction

The recent financial crisis has brought renewed attention to the stability of the banking sector. An extensive theoretical literature allows us to understand the mechanisms underlying banking (in)stability (Diamond and Dybvig 1983, Goldstein and Pauzner 2005).[1] These models have also provided a rich environment to study the qualitative consequences of policy interventions. These qualitative models, however, were not designed to address quantitative questions. For example, Diamond-Dybvig (1983) style models imply that equilibria in which banks are unstable might exist, but do not tell us how bad these equilibria would be given the fundamentals of the U.S. banking sector. We fill this gap by developing a quantitative model of the U.S. banking sector. As in Diamond and Dybvig (1983) and Goldstein and Pauzner (2005), uninsured depositors are run prone and are the main source of instability in the banking sector. Differentiated banks compete for uninsured and insured depositors, and endogenously default. We estimate and calibrate the model on a new data set covering the largest U.S. banks over the period 2002-2013. We find that the uninsured deposit elasticity to bank default is large enough to introduce the possibility of alternative equilibria in which banks are substantially more likely to default. We study how competition for deposits among banks affects the feedback between bank distress and deposits, and transmits shocks from one bank to the system. Last, we use our model to analyze the proposed bank regulatory changes and find that some regulations could exacerbate the instability of the system. Our results suggest that the capital requirements below 18% allow for equilibria with substantial probabilities of bank default and large welfare losses.[2]

Deposits represent over three-quarters of funding of U.S. commercial banks (Hanson et al. 2015). Moreover, in the largest commercial banks, approximately half of deposits are uninsured. Uninsured deposits are frequently impaired in cases of bank default,[3] and are therefore potentially prone to runs. Figure 1 suggests that financial distress of banks affects their ability to attract uninsured deposits. We plot the relationship between the uninsured-deposit market shares and financial distress for Citi Bank and JPMorgan Chase from 2005 through 2010. As distress[4] of Citi Bank increases relative to JPMorgan, Citi's market share of uninsured deposits decreases and JPMorgan's market share increases (Panel A). Note that the market shares of insured deposits, which should be insensitive to distress, show no such relationship (Panel B). The existing literature suggests that uninsured deposits can lead to bank instability and be subject to self-reinforcing runs. (Diamond and Dybvig 1983, Goldstein and Pauzner 2005). Such feedback mechanisms can even result

[1] See also, Postlewaite and Vives (1987); Cooper and Ross (1998); Peck and Shell (2003); Allen and Gale (2004); Rochet and Vives (2004); Fahri, Golosov, and Tsyvinski (2009); Gertler and Kiyotaki (2015); and Kashyap, Tsomocos, and Vardoulakis (2014).

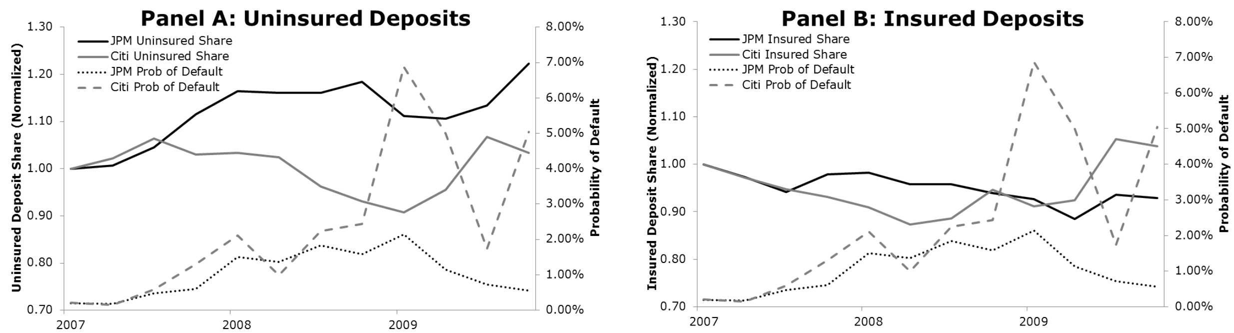
[2] The Financial Stability Board, a group of international regulators, has proposed total loss-absorbing capacity of large banks, which is the equivalent of our capital requirements, of $16-20\%$ of assets.

[3] The FDIC reports that only approximately 25% of transactions transfer all deposits, including the uninsured, to a new institution. (https://www.fdic.gov/bank/individual/failed/wamu_q_and_a.html [Accessed on 12/28/2014]

[4] We measure distress using Credit Default Swap Spreads (CDS)

in multiple equilibria.

Figure 1: Deposit Rates vs Financial Distress - Citi Bank and JPMorgan Chase



Whether such feedback mechanisms can lead to multiple equilibria depends on the sensitivity of uninsured depositors to bank distress, on which there is little systematic evidence. In principle, uninsured depositors should be very sensitive to potential bank default. In Diamond and Dybvig (1983), as soon as depositors think their deposits could be impaired, they withdraw, thereby triggering bank default. Alternatively, the Basel Committee on Banking Supervision (2013) considers uninsured deposits as the second most stable source of funding after insured depositors. If uninsured deposits are not very responsive to bank distress, because this bank provides payroll services or manages receivables for the depositor, then the danger of a panic run would be diminished. Even if the estimates were available, the literature provides little guidance on whether the elasticity is large enough to result in self-reinforcing runs or multiple equilibria.[5] The strength of the feedback between deposits and financial distress also depends on how costly deposit withdrawals are for a bank, and how a bank responds to a raised probability of withdrawals (for example, by raising interest rates). To quantify these forces, we develop a model of retail banking, which we calibrate using data for large U.S. banks.

Demand for deposits in our model is driven by several forces. First, as is standard in bank run models, the demand for uninsured deposits depends on the financial health of the bank, because these deposits may be impaired in case of bank default. Casual observation suggests that U.S. commercial banks are differentiated. For example, Citi offers a somewhat larger ATM network than Fifth Third Bank and has had substantially fewer complaints against it filed by customers at the Consumer Financial Protection Bureau on a per customer basis. Large and persistent differences in banks' market shares suggest that product differentiation plays an important role in U.S. commercial banking. We therefore depart from the current literature by adding product differentiation between banks. The properties of the demand function, especially the elasticity of uninsured-deposit demand with respect to financial distress, provide substantial discipline on the magnitude

[5] A notable exception is Hortaçsu et al. (2011) who evaluate the possibility of runs in the auto industry, and find that despite feedback effects, the elasticity is too small.

of self-fulfilling runs that the model can generate.

The second force, which determines the strength of the feedback, is the behavior of banks. Banks compete for insured and uninsured deposits by setting interest rates in a standard Bertrand-Nash differentiated products setting (Matutes and Vives 1996). Banks earn stochastic returns on deposits net of other operational costs. We model banks' endogenous default decisions in a simple framework based on Leland (1994). Each period, equity holders decide whether to continue operations by repaying deposits and the long-term debt coupon. Alternatively, banks can declare bankruptcy, which is anticipated by rational depositors. Because consumers are sensitive to financial distress, a bank in financial distress has to offer higher interest rates on its deposits, which decreases its profitability. We take this model to the data by first estimating demand for deposits and then calibrating the supply side of the model.

We estimate demand using variation in banks' financial distress, interest rates on deposits, and bank market shares using a standard model of demand (Berry 1994; Berry, Levinsohn, and Pakes 1995). To illustrate the effect of financial distress on demand for uninsured deposits, we first estimate a triple-difference specification with bank and time fixed effects. We find that as a bank's financial distress increases, the market share of its uninsured deposits declines relative to its share of insured deposits, suggesting that demand for uninsured deposits declines with a bank's financial distress. We provide complementary evidence exploiting variation in banks' financial distress resulting from changes in banks' portfolio holdings and performance, and find similar results. Contrary to uninsured deposits, we find no evidence that insured deposits are sensitive to banks' financial distress. Jointly, several sources of variation paint the same picture that uninsured depositors are run prone: as a bank's default probability increases, the demand for uninsured deposits decreases. The effect is substantial: a 100 basis point increase in the risk-neutral probability of bankruptcy results in a 12% market share decline.

To obtain supply-side parameters, which govern banks' behavior, we calibrate the model using revealed preferences of banks. Banks optimally set interest rates on insured and uninsured deposits, and choose when to default. With the addition of demand estimates, banks' optimality conditions allow us to calibrate the quantities we do not observe, the mean and variance of returns on deposits for each bank, as well as the additional non-interest costs of servicing insured deposits that reconcile the behavior of banks with observed quantities. We solve for the parameters in closed form and show that the parameters are exactly and uniquely identified. For any observed equilibrium of the game, there is a unique set of parameters that rationalizes the data. Even though the baseline model is fairly simple and sparse, the calibration yields reasonable results on quantities, which were not used to calibrate the model. For example, the implied bank profitability is approximately 2.3% to 3.75%, which is similar to balance sheet measures of profitability in Hanson et al. (2015) and Hirtle et al. (2015) of 2%-2.5%.

At the estimated parameter values, our model has multiple equilibria across which banks' survival probabilities and interest rates differ significantly. For example, Wachovia's market-implied, risk-neutral probability of default as of March 2008 was 3.3%. Our model indicates an additional equilibrium exists in which Wachovia's risk-neutral default probability is 52%. The multiple equilibria results can be interpreted as follows. Consumers rationally believed that there was a 3.3% chance that Wachovia would default in March 2008. However, the same fundamentals supported an equilibrium in which Wachovia would default with a risk-neutral probability of 52% in March 2008. In this equilibrium, depositors would correctly believe that Wachovia was more likely to default and would withdraw their deposits, which would in turn lower the profitability of Wachovia and increase its probability of default. Our estimates suggest that if the equilibrium changes, then seemingly stable banks can quickly become unstable with no change in their fundamentals.

Several broad facts emerge from our analysis of multiple equilibria. First, the banking system was in the best equilibrium for much of the period we study and close to the best in the rest of it. Second, substantially worse equilibria with large welfare losses, in which each bank has a higher default probability and some banks are highly unstable, also exist. This instability of one bank can spill over to other banks even without direct linkages between banks. A bank with a high probability of default is willing to offer high insured deposit rates, because FDIC insurance bears their cost with a high probability. To compete for these deposits, other banks increase rates as well, which decreases their margins and increases their distress. This argument was used by the FDIC when it successfully pressured Ally Bank to lower its deposit rates in 2009 (Leiber 2009).

Last, in all equilibria, several banks remain active, and provide depositor services to a large part of the market. Depositors value banking services, and as more banks are distressed, the demand for deposits shifts to relatively healthier banks. These results suggest that a mechanism that could destabilize the whole banking system would have to involve direct linkages across banks, which would overcome the force for stability we describe above.

Overall, we provide a workhorse model that allows us to evaluate the stability of the banking system in the presence of run-prone uninsured deposits. We use the model to show that the large amounts of uninsured deposits in the U.S. commercial banking system can lead to severely unstable banks, given the elasticity of uninsured deposits to financial distress. We then use our calibrated model to assess some recent and proposed bank regulatory changes. We analyze the effect of interest caps on insured deposits,[6] and find that they limit the worst possible losses to the FDIC. We also find that increasing FDIC insurance mostly transfers rents to newly insured depositors without large improvements to banking stability, but that the results of this seemingly simple policy critically depend on the preferences of newly insured depositors. Conversely,

[6]Such caps had been put in place under Regulation Q, which allowed the Federal Reserve to set interest rate ceilings on banking deposits.

we find evidence suggesting that imposing bank risk limits may be counterproductive and could actually decrease stability in the banking sector.

We use our model to quantitatively study the effect of capital requirements. Increasing capital requirements decreases the severity of the largest possible instability in the banking sector, but also eliminates some equilibria in which the banking system is very stable. We find that banking stability and welfare do not necessarily go hand in hand. Increasing capital requirements past a certain point decreases welfare even if it increases banking stability. Last, we show that capital requirements above 18% eliminate the possibility of equilibria with large welfare losses.

To allow for a rich and more realistic analysis of policy, we explore several extensions of the model. Because our analysis focuses on large U.S. banks, we allow the government to save banks from bankruptcy through recapitalization, capturing some features of too-big-to-fail policies. We also incorporate costly equity issuance and bankruptcy costs. These extensions have little impact on parameter estimates. Perhaps more surprisingly, while these extensions significantly alter the welfare cost of default, the basic consequences of capital requirements remain largely unchanged. Similar to the baseline model, capital requirements above 18% eliminate the possibility of equilibria with large welfare losses. Under a max-min welfare criterion,[7] these capital requirements are optimal, exceed the 8% requirements proposed under Basel III accords, and are quite close to the $16-20\%$ total loss-absorbing capacity proposed by the Financial Stability Board.

Our policy conclusions are clearly limited to the specific setting we examine. One can consider situations in which depositors, even if they are insured, are sensitive to default. For example, if there are delays in accessing payouts from deposit insurance, such as in India, then insured depositors suffer in bank default even if they eventually recover their deposits (Iyer and Puri 2012). Alternatively, if depositors believe that the banking system is likely subject to capital controls or haircuts if banks are close to defaulting, as has been recently the case in Greece and Cyprus, they may want to withdraw insured deposits prior to bankruptcy as well.

Our empirical and theoretical analysis relates to several strands in the banking and industrial organization literature. Our banking model builds on the automaker model from Hortaçsu et al. (2011). Our model is also in the spirit of the existing literature on bank runs, financial stability, and financial regulation, including the seminal work of Diamond and Dybvig (1983), and more recently Postlewaite and Vives (1987); Cooper and Ross (1998); Peck and Shell (2003); Allen and Gale (2004); Rochet and Vives (2004); Goldstein and Pauzner (2005); Fahri, Golosov, and Tsyvinski (2009); Gertler and Kiyotaki (2015); and Kashyap, Tsomocos, and Vardoulakis (2014).[8] Similar to Matutes and Vives (1996), our model emphasizes the strategic interaction

[7] An uncertainty averse planer would choose such a criterion (Gilboa and Schmeidler, 1989).

[8] For purely information based models of bank runs, see Chari and Jagannathan (1988), Jacklin and Bhattacharya (1988), Allen and Gale (1998), and Uhlig (2010).

among banks through competition.[9]

Our paper follows the precedent of recent papers that estimate structural models of imperfect competition in the banking sector. Our BLP-style demand model is closely related to the work of Dick (2008), who estimates demand for deposits using FDIC data. Unfortunately, the FDIC branch-level data does not break deposits down by insured vs. uninsured categories, hence we cannot utilize this level of disaggregation in our estimation exercise. Our supply-side model focuses on the deposit rate-setting and (endogenous) bankruptcy decisions of banks. Aguirregabiria, Clark, and Wang (2013) estimate a model in which the branch networks of banks are determined endogenously, and use their model to estimate banks' revealed preference for geographical risk diversification. Corbae and D'Erasmo (2013) and (2014) provide dynamic equilibrium models of the banking sector with imperfect competition, and use their models to evaluate the counterfactual effects of banking regulations, such as capital requirements. Our model and empirical analysis focuses on (imperfect) competition in the market for deposits, with special attention to insured vs. uninsured deposits, and pays particular attention to the presence of multiple equilibria and the possibility of bank runs or run-type equilibria.

The empirical results of our paper correspond to the existing literature on empirical bank runs and deposit insurance (for an overview, see Goldstein 2013). Iyer and Puri (2012) use unique event study data to examine how depositors responded to financial distress and a subsequent bank run for a large Indian bank. Kelly and Ó Gráda (2000) and Ó Gráda and White (2003) examine depositor runs using depositor-level data in a New York bank during 19^{th} century banking panics. Our paper also relates to Gorton (1988), who examines the relationship between economic fundamentals and banking crises between 1863 and 1914, and Calomiris and Mason (2003), who study the role bank fundamentals played in bank runs occurring during the Great Depression. The empirical findings from our demand estimates closely relate to the findings from Schumacher (2000) and Martinez Peria and Schmukler (2001), who examine how depositors respond to bank financial distress during the banking crises that occurred in Argentina, Chile, and Mexico during the 1980s and 1990s. Lastly, our empirical results relate to Hortaçsu et. al (2013), who measure the cost of financial distress in the automaker industry.

Our paper is also broadly linked to the literature which studies runs in other financial markets, such as money market funds and the asset-backed commercial paper market (Jank and Wedow 2010; Acharya, Schnabl, and Suarez 2013; Covitz, Liang, and Suarez 2013; Kacperczyk and Schnabl 2013; Strahan and Tanyeri 2015; Schroth, Suarez, and Taylor 2014; and Schmidt, Timmermann, and Wermers 2014). The

[9] There exists a long literature on the connection between competition and stability in the banking sector such as Keeley (1990), Hellman et al. (2000), and Boyd and De Nicolo (2005). In general, the results are mixed as to whether competition leads to increased or decreased stability in the banking sector. We analyze a different mechanism. We analyze how the change in the financial stability of one bank impacts the stability of its competitors through the deposit competition channel.

run-prone behavior of uninsured depositors is similar to strategic complementarities in withdrawal behavior of mutual fund investors in Chen, Goldstein, and Jiang (2010).

The remainder of the paper is laid out as follows. Section 2 develops our theoretical model of the banking sector. Section 3 describes the data used to estimate the deposit demand system and calibrate our theoretical model. Section 4 estimates the demand system for both insured and uninsured deposits. Section 5 calibrates the banking side of the model. Section 6 studies the structure of multiple equilibria in the banking sector. Section 7 assesses the stability of the banking sector and evaluates several proposed bank regulations. Section 8, extends the model to incorporate several other features of the banking sector, including "Too Big To Fail," bankruptcy costs, costly external finance, and run-prone insured depositors. Last, Section 9 concludes the paper.

2 Model

In this section, we present the baseline quantitative model. We emphasize two main features of depositors' preferences. The first are potentially run-prone, uninsured depositors who are the source of banking instability: their demand for deposits depends on the financial health of the bank. Second, depositors derive utility from services provided by differentiated banks. The latter feature captures persistent and large differences in banks' market share of deposits identified in Section 3. The last feature we build into the model is endogenous bankruptcy of banks. If returns are low, and fall short of required payments, equity holders can choose whether they want to fund the shortfall in the spirit of Leland (1994), or let the bank default. An alternative institutional interpretation of default in the model is that equity holders are allowed to recapitalize the bank at the end of each period. Regulators then inspect whether the bank can repay all deposits and the debt that has come due. If not, the bank is taken into receivership. For example, investors led by the Texas Pacific Group, a private equity firm, injected $7 billion into Washington Mutual after regulators warned that it was inadequately capitalized. They chose not to recapitalize again five months later, allowing the bank to be taken into FDIC receivership.[10]

The basic model contains three features we require to quantitatively approach the U.S. banking sector: run-prone depositors, bank differentiation, and endogenous default. On the other hand, we try to keep the model stripped down enough to convey the intuition behind the forces driving the model, and its estimation. We incorporate additional features of banking and default in Section 8 to allow for a richer and more realistic analysis of policy.

[10]The Washington Mutual case is not an exception. While there is limited data on equity issuance of private banks, SNL Financial data reports at least forty failed banks had obtained equity injections in the two years prior to failure, and 124 distinct banks that had later failed had 689 capital offerings from 2008 to 2015.

We proceed by first setting up the model, describing depositors' preferences, banks' technology, and funding. We then solve for deposit demand within a period, given interest rates set by banks and banks' expected default rates. Last, we characterize the equilibrium deposit rates and default decisions of a bank, given depositors' rational expectations of default decisions.

2.1 Model Framework

The model is in discrete time. Every period, a mass of M^I consumers are choosing among K banks to deposit insured deposits, and a mass of M^N consumers are choosing among the same banks to deposit uninsured deposits, taking interest rates and the probabilities of default as given. Banks are indexed by k and compete for insured and uninsured deposits from consumers indexed by j. Within the period, the timing is as follows:

- Banks set interest rates for insured and uninsured deposits $i^I_{k,t}$, and $i^N_{k,t}$;
- Consumers choose where to deposit funds;
- Banks invest deposits, and banks' profit shock is realized;
- Banks choose whether to repay deposits and the coupon on long-term debt, or default.

The model is specified under the risk neutral measure.[11]

2.1.1 Depositor Preferences

Demand for deposits at bank k at time t depends on the interest rate the bank offers, the services it provides the depositor, and, for uninsured depositors, the probability that the bank will default. The uninsured depositor is promised an interest rate $i^N_{k,t}$, from which she derives utility $\alpha^N i^N_{k,t}$, in which α^N measures depositors' sensitivity to interest rates. In the event of a bankruptcy, uninsured depositors lose utility flow $\gamma > 0$ with a risk-neutral probability $\rho_{k,t}$, suffering an expected utility loss of $\rho_{k,t}\gamma$.

Depositors also derive utility from banking services: $\delta^N_k + \varepsilon^N_{j,k,t}$. Bank-specific fixed effects, δ^N_k, reflect bank quality differences: all else equal, some banks offer better services than others. In addition, depositors' preferences for banks also differ; some consumers prefer Bank of America, and others Wells Fargo, for example, because of the proximity of ATMs to their home. These differences are captured in the i.i.d utility shock $\varepsilon^N_{j,k,t}$. The total indirect utility derived by an uninsured depositor j from bank k at time t is then as follows:

$$u^N_{j,k,t} = \alpha^N i^N_{k,t} - \rho_{k,t}\gamma + \delta^N_k + \varepsilon^N_{j,k,t}. \tag{1}$$

[11] This does not imply that either depositors or shareholders are risk neutral. Instead, the risk-neutral probability is a transformation, which adjusts the probability measure of events by giving greater weight to probability of events with higher marginal utility, adjusting for risk aversion. Our model is specified under the risk-neutral measure because CDS spreads, which we use to estimate our model, reflect risk-neutral default probability, rather then the objective probability of default.

The preferences of insured and uninsured depositors might differ. The indirect utility of insured depositors closely mirrors that of uninsured depositors, but insured depositors do not lose utility in case of bankruptcy, obtain potentially different banking services, and differ in interest rate sensitivity (indexed by I):

$$u^I_{j,k,t} = \alpha^I i^I_{k,t} + \delta^I_k + \varepsilon^I_{j,k,t}. \tag{2}$$

In Section 8.5 we relax this assumption, and allow insured depositors to be sensitive to bankruptcy as well. This modification will address the situation in which insured depositors succumb to panics, or they correctly believe that their deposits will be impaired with bankruptcy because deposit insurance will be violated, or capital controls will be imposed on the banking system.

2.1.2 Banks

Banks compete for depositors, each seeking to maximize equity value. A bank's profit maximization problem involves a three-part decision process: setting its insured deposit rate, setting its uninsured deposit rate, and ultimately deciding to continue its operations or declare bankruptcy.

Banks earn profits by lending out deposits. Bank k earns a period t return on deposits net of other (non-interest) costs $R_{k,t}$. These returns already account for all non-interest costs, such as costs of loan defaults, the costs of screening loans, providing services to depositors, etc. These returns are stochastic, distributed under the risk-neutral measure as $R_{k,t} \sim N(\mu_k, \sigma_k)$, and are i.i.d across time, but can be arbitrarily correlated among banks.[12] Note that these per-period returns can be negative if the bank invests in bad projects. Because we index the process with k, some banks are, on average, better at using deposits than others, and these differences are persistent. Differences arise because some banks invest these deposits better or because they have lower costs of servicing loans and deposits.

Servicing insured depositors can be more expensive than the uninsured depositors, because of FDIC deposit insurance premiums and other additional costs banks incur with insured, typically smaller accounts. Banks therefore incur an additional cost of servicing insured depositors, c_k, relative to uninsured depositors. A bank whose market share of insured deposits is $s^I_{k,t}$ and whose market share of uninsured deposits is $s^N_{k,t}$ earns a gross return on deposits of $M^I s^I_{k,t}(1 + R_{k,t} - c_k) + M^N s^N_{k,t}(1 + R_{k,t})$.

Banks' profits are reduced by interest payments on deposits. They have to repay deposits, including the interest rate, at a cost of $M^I s^I_{k,t}\left(1 + i^I_{k,t}\right) + M^N s^N_{k,t}\left(1 + i^N_{k,t}\right)$. The total net period profit of a bank is then:

$$\pi_{k,t} = M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right). \tag{3}$$

[12] The correlation in returns introduces correlation in ex post bank default, but does not otherwise affect the ex ante probabilities of default, which are the object of interest in our model.

If $\pi_{k,t}$ is negative, the bank is suffering operating losses in a given period.

Banks use three different types of financing. They are financed through deposits, which have to be repaid at the end of each period. Banks are also financed with a consol bond, which promises an infinite stream of period coupons b_k. The residual financiers of the firm are deep-pocket equity holders (Leland, 1994). Each period, the bank disburses profits to their equity holders after paying depositors and the bond coupon. Conversely, if there is a shortfall, $M^I s^I_{k,t}\left(\bar{R}_k - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(\bar{R}_k - i^N_{k,t}\right) - b_k < 0$, equity holders can decide whether to inject enough funds to repay deposits and the bond coupon, or to default. In case of default, equity holders are protected by limited liability.

In the baseline model, the injection of funds is frictionless, as is the disbursement of dividends to equity holders. We relax this assumption in Section 8.2.2. An alternative institutional interpretation of default in the model is that equity holders are allowed to recapitalize the bank at the end of each period. Regulators then inspect whether the bank can repay all deposits and the debt that has come due. If not, the bank is taken into receivership. Both interpretations are consistent with the setting of the model.

At bankruptcy, the bank is sold and the proceeds are used to repay the depositors and bondholders. To focus on the interaction between deposit demand and the bank's bankruptcy decision, we assume that bankruptcy does not affect the bank's productivity, and that the bank retains the same form of financing it had before bankruptcy. This implies that unlike in Leland (1994) style models, there are no direct costs of bankruptcy. In Section 8.2.1, we allow for direct bankruptcy costs.

2.2 Equilibrium

We study pure strategy Bayesian Nash equilibria. The equilibrium is characterized by the optimal behavior of banks and depositors. Banks choose to default optimally given the ex post profitability of deposits. Depositors are fully rational, anticipate the probability of default, and incorporate these beliefs when choosing deposits. Banks choose optimal interest rates, given demand for deposits.

The equilibrium of this game is stationary. Bank returns shocks are i.i.d. and market parameters are constant; in the event of bankruptcy, the bank is placed under new ownership with the same capital structure. In the stationary equilibrium, banks compete with each other for deposits within periods, but not across periods.[13] Stationarity has two advantages. First, it allows us to focus on the feedback between deposit decisions and banks' bankruptcy, abstracting from the dynamics of interest rate setting across periods. Second, stationarity greatly simplifies the analysis of default, allowing the problem to be tractable: a bank's decision to default *ex post* is independent of default decisions of other banks, even if ex ante banking decisions

[13] We abstract from switching costs for deposits.

are linked. Hence, banks use the same interest rate-setting and bankruptcy decision policies from period to period.

2.2.1 Demand for Deposits

Consumers choose among banks, taking the offered interest rates and beliefs of default probabilities as given. To aggregate consumer preferences, we employ a standard assumption in discrete choice demand models (Berry, Levinsohn, and Pakes 1995), that the utility shocks $\varepsilon^I_{j,k,t}$ and $\varepsilon^N_{j,k,t}$ are distributed i.i.d. Type 1 Extreme Value, leading to standard logit market shares. Let $\mathbf{i^I_{-k,t}}$, $\mathbf{i^N_{-k,t}}$, and $\rho_{\mathbf{-k,t}}$ denote the vectors of deposit rates offered by banks other than k and their expected default probabilities. Let $s^I_{k,t}$ and $s^N_{k,t}$ denote the share of consumers choosing to deposit insured and uninsured deposits with bank k. Given the distribution of $\varepsilon^I_{j,k,t}$and $\varepsilon^N_{j,k,t}$, consumers' optimal choices result in the following demand function:

$$s^I_{k,t}\left(i^I_{k,t}, \mathbf{i^I_{-k,t}}\right) = \frac{exp(\alpha^I i^I_{k,t} + \delta^I_k)}{\sum_{l=1}^K exp(\alpha i^I_{l,t} + \delta^I_l)}, \tag{4}$$

$$s^N_{k,t}\left(i^N_{k,t}, \mathbf{i^N_{-k,t}}, \rho_{k,t}, \rho_{-k,t}\right) = \frac{exp(\alpha^N i^N_k - \rho_k \gamma + \delta^N_k)}{\sum_{l=1}^K exp(\alpha^N i^N_l - \rho_l \gamma + \delta^N_l)}. \tag{5}$$

Because consumers have rational expectations, their expectations of default probabilities are correct in equilibrium.

2.2.2 Bank's Default Choice

Default is an endogenous choice of equity holders. The bank does not default simply because it runs out of funds to repay depositors and bondholders following a bad profit realization. Even after a bad shock, equity holders can inject funds into the bank to save it if the franchise value of a continuing bank is valuable enough. The bank defaults when equity holders' value of keeping the bank alive is smaller than the funds they have to inject in the bank.

More formally, 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 provide the funds to make up the shortfall. The shortfall that equity holders have to finance comprises the net profits (or losses) of the bank after repaying depositors and bond payments $M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right) - b_k$.

Because they are protected by limited liability, the equity holders can always decide not to finance the shortfall, and let the bank default. If the bank defaults, the equity holders lose the bank franchise and, therefore, the claim to cash flows of the bank from the next period onward. Let E_k[14] denote the franchise value of the bank. 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:

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

This 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 is indifferent between defaulting and financing the bank:

$$M^I s^I_{k,t}\left(\bar{R}_{k,t} - c_k - i^I_{k,t}\right) + M^N s^N_{k,t}\left(\bar{R}_k - i^N_{k,t}\right) - b_k + \frac{1}{1+r}E_k = 0.$$

Note that $\bar{R}_k$ is unique for a given interest rate choice of bank k, consumer's deposit choices, and the continuation value of the bank to equity holders, E_k. On the other hand, these quantities are determined in equilibrium by the expectation of the bank's expected default rule, $\bar{R}_k$. The optimal cut-off rule, $\bar{R}_k$, corresponds directly to the risk-neutral probability of default $\rho_{k,t} = \Phi\left(\frac{\bar{R}-\mu_R}{\sigma_R}\right)$. Solving for the optimal cut-off rule as in Hortaçsu et al. (2011) we obtain[15]:

$$\underbrace{b_k - \left(\underbrace{M^I s^I_{k,t}\left(\bar{R}_k - c_k - i^I_{k,t}\right)}_{\pi\, insured\, dep} + \underbrace{M^N s^N_{k,t}\left(\bar{R}_k - i^N_{k,t}\right)}_{\pi\, uninsured\, dep}\right)}_{shortfall\, at\, threshold} = \begin{array}{c} \frac{1}{1+r}\underbrace{\left(M^I s^I_{k,t} + M^N s^N_{k,t}\right)}_{total\, deposits}\underbrace{\left(1 - \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\right)}_{survival\, prob.} \times \\ \times \underbrace{\left(\left(\mu_k - \bar{R}_k\right) + \sigma_k \underbrace{\lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)}_{limited\, liability}\right)}_{expected\, return\, on\, deposits} \end{array}, \tag{6}$$

where $\lambda(\cdot) \equiv \frac{\phi(\cdot)}{1-\Phi(\cdot)}$ is the inverse Mills ratio.

The left-hand side of this expression is the amount of funds equity holders have to inject at the default threshold. The right-hand side represents the future value of the bank in equilibrium, which depends on how many deposits it can raise in equilibrium, the equilibrium survival probability, and the expected return on deposits. The last term illustrates that a part of the value equity holders obtain from the bank arises from the limited liability of equity, the ability to default in the future.

[14] Because of stationarity, we do not index by t.

[15] As in Hortaçsu et al. (2011), it can be shown that the continuation value of the bank to equity holders can be written as $E_k = (M^I s^I_k + M^N s^N_{k,})\mathrm{E}[R - \bar{R}_k | R > \bar{R}_k]\,\Pr(R > \bar{R}_k)$

A critical result arising from the bankruptcy cut-off condition (eq. 6) is that the cut-off rule, and consequently the probability of default, need not be unique. Since consumer utility for uninsured deposits depends on bank survival and bank survival depends on consumer demand, the model generates potential feedback loops. A key consequence of such feedback loops is that the perceived default risk can be self-fulfilling: a decrease in demand for deposits raises the probability a bank defaults and vice versa. We analyze the possibility of multiple equilibria arising from the bankruptcy condition in detail in Section 6.

2.2.3 Setting Deposit Rates

Banks compete for deposits by playing a differentiated product Bertrand-Nash interest rate setting game for both types of deposits. Prior to the start of each period, banks set the deposit rate for insured and uninsured deposits to maximize the expected return to equity holders. Because of limited liability, equity holders only internalize the payoffs if the profit shock $R_{k,t}$ is above the optimal default boundary $\bar{R}_k$. The corresponding equity value at the beginning of the period is

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

Applying the normal distribution of $R_{k,t}$, we obtain:

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

The choice of deposit rates can affect the value of equity through its influence on both current-period operating profits and the bankruptcy boundary $\bar{R}$ in eq. (6). Because equity holders choose to default optimally, we can apply the envelope theorem, which implies that we can ignore the effect that changing deposit rates have on probability of default, i.e. $\frac{d\bar{R}_k}{di^I_{k,t}} = \frac{d\bar{R}_k}{di^N_{k,t}} = 0$. Deposit rates are therefore chosen to maximize current period profits, accounting for equity holders' limited liability $\sigma_k \lambda\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)$.

The converse is not true; the probability of default (which is a direct function of $\bar{R}_k$) directly influences the rate setting through its effect on consumer demand for uninsured deposits, $s^N\left(i^I_{k,t}, \mathbf{i^I_{-k,t}}, \rho_{k,t}, \rho_{\mathbf{-k,t}}\right)$. The probability of default also has an indirect effect on the the pricing decision for insured deposits rates. The bank only pays the interest rate payments on deposits if it does not default, otherwise the cost is born by the uninsured depositors and, for insured depositors, the FDIC. Therefore, even though insured depositors are not subject to default risk, the bank takes it into account when setting insured rates.

The corresponding first order condition, which characterizes the optimal rate for insured deposits $i^I_{k,t}$, is:

$$\text{Insured Deposits:} \quad \underbrace{\underbrace{\mu_k}_{mean\,return} + \underbrace{\sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right)}_{limited\,liabillity}}_{mb} - \underbrace{\left(c_k + i^I_{k,t}\right)}_{mc} = \underbrace{\frac{1}{\left(\left(1 - s^I \left(i^I_{k,t}, \mathbf{i^I_{-k,t}} \right) \right) \alpha^I \right.}}_{mark-up}. \tag{7}$$

This condition resembles oligopoly Bertrand-Nash pricing conditions.[16] For insured deposits, the modification arises in the marginal benefit of deposits, which includes the benefit of limited liability $\sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right)$ in addition to the expected net return μ_k earned on deposits. The marginal cost of the insured loan is the interest payment on the loan, as well as the non-interest cost of the loan. The right-hand side is the standard mark-up from a logit demand model.

Similarly, the optimal rate for uninsured deposits is characterized by:

$$\text{Uninsured Deposits:} \quad \mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right) - i^N_{k,t} = \frac{1}{\left(\left(1 - s^N_{k,t} \left(i^I_{k,t}, \mathbf{i^I_{-k,t}}, \rho_{k,t}, \rho_{\mathbf{-k,t}} \right) \right) \alpha^N \right.}. \tag{8}$$

Note that the marginal benefit of insured and uninsured deposits is the same, because they are used to finance the same projects on the margin. The difference in pricing arises because of different marginal costs of insured loans c_k, different price elasticities of depositors reflected in α^I and α^N, and differences in bank's attractiveness across deposits, reflected in equilibrium market shares $s^I \left(i^I_{k,t}, \mathbf{i^I_{-k,t}} \right)$ and $s^N \left(i^I_{k,t}, \mathbf{i^I_{-k,t}}, \rho_{k,t}, \rho_{\mathbf{-k,t}} \right)$. Moreover, the demand for uninsured deposits depends on the endogenous probability of default. The optimal deposit rate is increasing in a bank's probability of default for both uninsured and insured deposits.[17]

The mark-ups banks earn on deposits have important consequences for bank stability. First, a positive mark-up on insured and uninsured deposits illustrates why losing deposits is costly to a bank. Because banks are oligopolists, they earn positive rents and price deposits above marginal costs. A drop in deposits therefore lowers the value of the bank. In fact, a marginal decrease in deposits for one period[18] lowers the value of the bank by exactly the value of the mark-up.

[16] Note, the standard conditions in a Bertrand-Nash oligopoly, suggesting that a firm should never price on the inelastic portion of the residual demand curve, do not apply in our model. We can rewrite the FOC for insured deposits as:

$$\mu_k + \sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right) - c_k = i^I_{k,t} \left(1 + \frac{1}{e^I_{k,t}} \right),$$

where e^I_k is the elasticity of demand for insured deposits. The marginal benefit of deposits exceeds the marginal cost as long as the elasticity of demand is positive, $e^I_{k,t} > 0$.

[17] This is roughly consistent with the empirical findings in Acharya and Mora (2015).

[18] Holding interest rates offered fixed.

Second, the insured deposits pricing equation illustrates the comparative advantage of distressed banks in supplying insured deposits. This comparative advantage incentivizes risky banks to increase insured deposit rates. To see the intuition, note that the benefit of limited liability is increasing in the probability of bankruptcy, i.e., $\sigma_k \lambda \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right)$ is increasing in $\bar{R}_k$. As the default probability increases, insured deposits become more profitable, because the probability that they will be repaid decreases (LHS of 7). Insured depositors do not internalize this cost: the probability of bankruptcy does not enter the elasticity of demand for insured deposits (RHS of 7). Holding other banks' interest rates fixed, as distress increases, the bank wants to increase its insured deposit rate to again equalize the marginal benefit and marginal cost of deposits, increasing its market share at the expense of other banks. Thereby, risk shifting of the distressed bank decreases the value of its competitors, potentially increasing their distress. For uninsured deposits, on the other hand, this risk-shifting motive is dampened. While distress increases the marginal benefit of uninsured deposits (LHS of 8), it also decreases deposit demand (RHS of 8), decreasing incentives of the bank to change interest rates. Moreover, this decreased demand for uninsured deposits increases competitors market shares and profitability, lowering distress.

2.2.4 Equilibrium

The pure strategy Bayesian Nash equilibria are characterized by $5K$ conditions[19] that capture the optimal behavior of banks and depositors. Demand for deposits is characterized by insured- and uninsured-depositor choice of banks in the market share equation (4) and eq. (5) for each of the K banks. Depositors anticipate the probability of default, and incorporate these beliefs when choosing deposits. Supply is characterized by banks' maximization: banks choose to default optimally given the ex post profitability of deposits, so (6) holds for each of the K banks. Each bank also sets interest rates on insured and uninsured deposits to maximize profits, so (7), and (8) hold for each of the K bank. Last, depositors have rational expectations, so their beliefs are correct in equilibrium.

Formally, an equilibrium is a set of default probabilities, $\rho_{1,t}$,...$\rho_{K,t}$, and interest rates on insured and uninsured deposits, $i^I_{1,t}, ...i^I_{K,t}$ and $i^N_{1,t}, ...i^N_{K,t}$, for all banks such that:

1. Given interest rates on insured deposits $i^I_{1,t}, ...i^I_{K,t}$ insured deposits' market shares satisfy (4) for each bank.

2. Given interest rates on uninsured deposits $i^N_{1,t}, ...i^N_{K,t}$, and consumers' beliefs about banks' bankruptcy probabilities $\rho_{1,t}$,...$\rho_{K,t}$, uninsured deposits' market shares satisfy (5) for each bank.

[19] Recall that K is the number of banks in the industry.

3. Interest rates on insured and uninsured deposits $i^I_{1,t}, ...i^I_{K,t}$ and $i^N_{1,t}, ...i^N_{K,t}$ satisfy (7), and (8) respectively for each bank.

4. The optimal default condition is satisfied for each bank, (6) holds.

5. Consumers' beliefs about banks' bankruptcy probabilities are correct in equilibrium.

If there are are multiple equilibria, then there exist several vectors of interest rates and default probabilities, which satisfy these $5K$ conditions. These equilibrium conditions form the basis for our estimation and calibration when we take the model to the data. In Sections 6 we explore the structure of the equilibria of the game for the estimated parameters.

2.3 Model Discussion

Despite its simple set-up, the model features substantial heterogeneity among banks, as well as rich strategic interactions among depositors and banks, preventing analytical comparative statics. We numerically explore the structure of the equilibria of the game in Section 6, and in Section 7 we evaluate the consequences of different policies. In this section, we illustrate some of the economic forces that drive the model by focusing on partial relationships between endogenous choices of depositors and banks. Specifically, we focus on the source of panic runs in our model, and the role that competition plays in transmission of shocks across banks.

2.3.1 Panic, Fundamentals, and Bank Runs

One of the main features of our model is that uninsured depositor utility depends on bank survival, and bank survival depends on demand for deposits. This interaction leads to potential multiple equilibria, in which different levels of default are possible for the same fundamentals of banks in the industry. The mechanism driving the self-fulfilling equilibria is closely related to panic-based runs explored in the literature (Diamond and Dybvig 1983, Goldstein and Pauzner 2005). In these models, uninsured depositor withdrawals decrease banks' funds, increasing the likelihood of bank failure, providing uninsured depositors further incentives to withdraw. A similar panic-run mechanism arises in our model: if some depositors choose not to deposit with a bank, this decreases the value of the bank, making it more likely that equity holders will allow the bank to slide into bankruptcy. This decreases other depositor's incentives to invest with a bank. The primary difference is that in Diamond and Dybvig (1983) and Goldstein and Pauzner (2005) the bank fails because it does not have enough funds to repay deposits. In our model, equity holders have the opportunity to recapitalize the bank, should a shortfall occur.

Panic runs in which strategic complementarities drive bank instability can broadly manifest in two ways. In Diamond and Dybvig (1983) and related models, banking instability manifests in multiple equilibria, which are driven by differences in beliefs. If uninsured depositors believe that the bank will fail, they withdraw deposits, increasing the probability of default. Frequently, these equilibria are degenerate–either the bank fails for sure or it is completely stable. The selection of which equilibrium is played is not determined within the model. Instead, non-fundamental sunspots coordinate the beliefs of depositors. In global games models, such as Goldstein and Pauzner (2005), on the other hand, the equilibrium is unique and banking instability arises because shocks to fundamentals are amplified by the strategic complementary (coordination failure) between uninsured depositors. Instability, in our model, is to a large extent driven by multiplicity of equilibria, but with several important differences from Diamond and Dybvig (1983) and related models. First, in any given equilibrium, actual bank default is triggered by a realization of fundamentals, whether the return on a bank's investment $R_{k,t}$ exceeds the default threshold $\bar{R}_k$. Second, the equilibria are not degenerate: equilibria are characterized by banks' default probabilities, which are generally bounded away from 0 and 1. Third, equilibria are not only driven by beliefs; fundamentals and policy pin down the range of these equilibria.

The latter is the case because fundamentals directly affect the probability of bank failure. The literature on banking crises distinguishes coordination failures, panics, from fundamental runs, in which depositors withdraw funds because banks' fundamentals are weak, independent of the actions of other depositors (see Goldstein and Pauzner 2005). There is also a force related to fundamental runs in our model.

To see the intuition, consider the behavior of uninsured depositor i, and assume that banking fundamentals unexpectedly change while other depositors', $-i$, decisions remain unchanged. To isolate the effect of fundamentals, consider a one period unexpected decrease in the mean expected return $\mu_{k,t}$, which occurs after interest rates are set but before depositors have made their deposit decisions. Since depositors' decisions (aside from depositor i) are unchanged, as are the interest rates and the continuation value of equity, the bankruptcy threshold $\bar{R}_k$ remains unchanged. The probability that the firm's returns fall under the threshold this period, however, increases, since $\rho_{k,t} = \Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)$. A decrease in the bank's profitability increases the probability of bankruptcy for a given threshold: $\frac{\partial \rho_k}{\partial(-\mu_{k,t})} > 0$, decreasing the probability that depositor i deposits with bank k. Therefore, firm fundamentals and coordination failures between depositors jointly determine banking stability.

3 Data

Our data set covers sixteen of the largest U.S. retail banks over the period 2002-2013.[20] A primary objective of our study is to empirically measure how both uninsured and insured depositors respond to financial distress in the retail banking sector. We measure a bank's level of financial distress using its credit default swap (CDS) spread and measure the response of depositors using insured and uninsured deposit levels, while conditioning on deposit rates and other bank characteristics. Table 1 summarizes our deposit and CDS data.

CDS gives us a direct and daily market measure of the financial solvency of each banking institution. CDS is a liquid financial derivatives contract in which the seller of the CDS contract agrees to compensate the buyer of the contract in the event a third party defaults.[21] Our CDS data comes from the Markit Database. We measure financial distress at the monthly level using the average daily CDS spread for the five-year CDS contract. The average CDS spread in our data set is 0.87%, which corresponds to a modest risk-neutral 1.43% annual probability of default.[22] The advantage of measuring default risk using the CDS spread over other ad hoc balance sheet measures is that it is a public, tradable, market rate that directly measures the default risk of a bank.

We examine the relationship between deposit levels and CDS to determine how depositors respond to financial distress. Our deposit-level data comes from the FDIC's Statistics on Depository Institutions. The FDIC provides quarterly estimates of uninsured and insured deposit levels for all FDIC insured banks. During the financial crisis in October 2008, the FDIC increased the deposit insurance limit threshold from \$100k to \$250k. The Call Reports data reflects the regulatory changes in the deposit limit threshold. The level of uninsured deposits across banks ranges from \$4.10 billion to \$939.0 billion in our sample. On average, uninsured deposits account for just over half (53.36%) of total deposits, while total deposits account for 77% of liabilities for the banks in our sample.

We use a new and novel deposit rate data set from RateWatch, which includes daily branch-level deposit rate data for several different types of accounts. Specifically, we measure deposit rates using one-year certificate of deposit (CD) rates. We do not separately observe deposit rates for insured and uninsured deposits. However, certificates of deposit have different minimum deposit requirements. We use heterogeneity in the minimum deposit levels to help pinpoint the effect of deposit insurance on deposit rates. Since deposits

[20] As of 12/31/2009, fifteen (all) of the banks studied were among the twenty (thirty) largest U.S. banks in terms of deposits. Our data set excludes five of the largest twenty banks. Of those five banks, four were excluded (ING, State Street Bank and Trust Company, Bank of New York Mellon and Fia Card Services) because they had fewer than ten domestic branch locations. The other excluded large bank, Capital One, was excluded due to data availability.

[21] For example, the five-year CDS spread for Bank of America in March 2009 was 3.19%. The CDS buyer agrees to pay 3.19% to the contract seller over a five year period or until Bank of America defaults. If Bank of America defaults, the CDS seller compensates the buyer of the CDS contract for the losses of the underlying Bank of America, as determined by an auction.

[22] We calculate the probability of default under a risk neutral model with a constant hazard rate under the assumption that LIBOR is 3% and the recovery rate is 40%. See Hull (2012) for further details.

in excess of $100k ($250k after October 2008) are not covered by FDIC insurance, we interpret CDs with minimum deposits of $10k to be more likely to be fully insured than CDs with minimum deposits of $100k. We calculate deposit rates for each bank and account type (minimum deposit and maturity) using the median deposit rate offered at the monthly level.

To assess the effect of default risk on deposit rates we decompose deposit rates into two components, the prevailing risk-free rate and the corresponding spread/premium. We define the deposit spread as the difference between the certificate of deposit rate and the corresponding one-year treasury rate. Table 1 summarizes the deposit rate spread for one year CDs with minimum deposit levels of $10k and $100k. As expected, the average deposit rate is higher for the CDs with the $100k minimum deposit threshold than for CDs with a $10k minimum deposit threshold.

A key feature of the banking sector, and our model, is heterogeneity in the quality of banking services offered by banks. One critical dimension of bank quality we control for is the number of bank branches and ATM locations. The FDIC's Statistics on Depository Institution provides panel data on the number of branch locations for each bank over the period 2002-2013. We supplement the FDIC branch location data with a new data set that includes the ATM locations for all major banks as of 2015. We manually collected the ATM data from a popular website that locates MasterCard ATMs.[23] As a potentially more direct measure of the quality of banking services, we use the Consumer Financial Protection Bureau's (CFPB) newly available Consumer Complaint Database. The CFPB's Consumer Complaint database is a collection of nearly 500,000 complaints regarding financial products and services. We measure the quality of a bank's services as the number of complaints each bank received per account[24] over the period July 2011-2015.

4 Demand for Deposits

4.1 Motivating Evidence: Uninsured Deposits and Financial Distress

The generic problem with estimating the effect of financial distress on demand for goods is that a decline in demand for a product decreases the profits of a firm, increasing its financial distress. If the quality of the product is not observed by the researcher, then this introduces a bias into the relationship between financial distress and demand (Hortaçsu et al. 2013). Before estimating the parameters of the demand system, we illustrate that uninsured deposits are indeed run prone: an increase in a bank's financial distress leads to a decrease in uninsured deposits.

We approach the reverse causality problem by studying how responsive uninsured and insured deposits

[23] https://www.mastercard.us/en-us/consumers/get-support/locate-an-atm.html
[24] We use data on the number of accounts at each bank as of March 2015 from the FDIC's Statistics on Depository Institutions.

are to banks' financial distress. The idea behind our approach is illustrated in a simple cut of the data in Figure 1. In Panel A, we plot the relationship between the uninsured deposit market shares and financial distress for Citi Bank and JPMorgan Chase over the period 2005 through 2010. In Panel B, we plot the same relationship for the market share of insured deposits. As Citi Bank's distress increases relative to JPMorgan, Citi's market share of uninsured deposits decreases and JP Morgan's increases. Citi's insured deposits, on the other hand, are not responsive to the increase in distress relative to JPMorgan. The lack of a response from the insured depositors suggests that the change in financial distress is driving the relationship between distress and uninsured deposits, rather than changes in how attractive a bank is to depositors on dimensions other than financial distress.

To capture the same intuition in a regression, we estimate the following differences in differences specification:

$$\ln s^N_{k,t} = \gamma \rho_{k,t} + \mu_k + \mu_t + \Gamma X_{k,t} + \varepsilon_{k,t},$$

in which μ_k and μ_t are bank and quarter effects respectively, and $X_{k,t}$ measures observable bank characteristics. The main coefficient of interest is γ, measuring how responsive demand for uninsured deposits is to financial distress of the bank. As we can see in the figure, there is aggregate variation both in deposit levels and financial distress of banks. Time fixed effects absorb such aggregate variation, ensuring we identify the effect from relative changes of deposits and distress of banks, i.e., that we compare Citi to JPMorgan. The inclusion of bank fixed effects ensures that banks which offer on average worse services, and are therefore in financial distress, do not confound our estimates. We present the estimate in column 2 of Table 2. The coefficient is negative, suggesting that as a bank's CDS increases relative to other banks, it's relative market share of uninsured deposits declines, i.e. uninsured depositors leave banks in financial distress.

An alternative explanation of this result would be that a bank's attractiveness has declined, and this is not captured by the bank fixed effect μ_k or its observable characteristics $X_{k,t}$. We address this alternative by estimating a triple-differences specification. Insured depositors are insulated from a bank's bankruptcy, so they should not react to an increase in its probability of default. So if we see a bank's market share of insured deposits decline with a rise in financial distress, we should conclude that it is the decline in unobserved banking quality which is driving the relationship. A large decline in uninsured deposits relative to insured deposits, on the other hand, suggests that financial distress is driving the decision of uninsured depositors, and not a substantial decline in services, which would likely affect both types of depositors. We implement the idea by estimating how the difference between the market share of uninsured and insured deposits within a bank, $\ln s^N_{k,t} - \ln s^I_{k,t}$, responds to financial distress of a bank:

$$\ln s_{k,t}^N - \ln s_{k,t}^I = \gamma \rho_{k,t} + \mu_k + \mu_t + \Gamma X_{k,t} + \varepsilon_{k,t}.$$

Bank fixed effects again absorb time invariant differences between banks in insured and uninsured deposits. Quarter fixed effects control for aggregate shifts in relative preferences of insured to uninsured deposits. The negative coefficient in column 1 of Table 2 shows that as financial distress of a bank increases, the market share of its uninsured deposits declines relative to its share of insured deposits.

Last, we present a placebo test using insured deposits. Insured depositors are insulated from a bank's bankruptcy, so they should not react to an increase in its probability of default. However, if the alternative is driving our results, then changes in financial distress arise because the bank has become less attractive to uninsured depositors independent of its probability of default. Such a decline in quality should also be at least partially reflected in a decline of insured depositors. Instead, results in column 3 of Table 2 show that a bank's market share of insured depositors, if anything, is increasing in its probability of default. This suggests that changes in the financial distress of a bank are not caused by unobserved changes in services the bank offered to depositors. Jointly, the differences in differences specification, the placebo, and the triple differences specification all point to the same idea: that demand for uninsured deposits declines with a bank's financial distress.

4.2 Demand Estimation

Next, using banks' characteristics and market share data described in Section 2, we estimate the utility parameters from equations (4) and (5). We consider the sixteen largest banks, and designate all other banks outside of the sixteen in our data set as the outside good, which we index by 0. Because we estimate the demand system from within-bank variation, we allow for the quality of the bank to change over time. We denote the time varying component of bank quality for uninsured and insured deposits as $\xi_{k,t}^N$ and $\xi_{k,t}^I$, resulting in total bank quality of $\delta_k^N + \xi_{k,t}^N$ and $\delta_k^N + \xi_{k,t}^N$. We normalize the benefits consumers derive from the outside good by setting $\delta_0^N + \xi_{0,t}^N = \delta_0^I + \xi_{0,t}^I = 0$.

The logit demand system in eq. 5 then results in the following linear regression specification:

$$\ln s_{k,t}^N - \ln s_{0,t}^N = \alpha(i_{k,t}^N - i_{0,t}^N) - \gamma(\rho_{k,t} - \rho_{0,t}) + \delta_k^N + \xi_{k,t}^N. \tag{9}$$

Because we do not observe the characteristics and the price of the outside good, $\rho_{0,t}$ and $i_{0,t}^N$, we include quarter fixed effects ζ_t^N, which absorb the outside good, resulting in a differences in differences specification:

$$\ln s_{k,t}^N = \alpha i_{k,t}^N - \gamma \rho_{k,t} + \zeta_t^N + \delta_k^N + \xi_{k,t}^N. \tag{10}$$

The corresponding specification for insured deposits does not depend on financial distress:

$$\ln s_{k,t}^I = \delta_k^I + \alpha i_{k,t}^I + \zeta_t^I + \xi_{k,t}^I.$$

Even within the differences in differences setting, *changes* in the utility that depositors derive from a given bank, $\xi_{j,t}^N$, are a potential source of bias, as we discuss in Section 4.1. To circumvent the simultaneity problem, we use an instrumental variables strategy, which we discuss in more detail in Section 4.2.1.

In addition to the interest rate and default sensitivity parameters α^I, α^N, and γ, we are also able to recover the unobservable bank specific utility shocks $\xi_{j,t}^I$ and $\xi_{j,t}^N$ from our regression specification estimates as:

$$\begin{aligned} \widehat{\xi_{j,t}^N} &= \ln s_{k,t} - \left(\widehat{\delta_k^N} - \widehat{\gamma}\rho_{k,t} + \widehat{\alpha} i_{k,t}^N + \widehat{\zeta_t^N}\right), \\ \widehat{\xi_{j,t}^I} &= \ln s_{k,t} - \left(\widehat{\delta_k^I} + \widehat{\alpha} i_{k,t}^I + \widehat{\zeta_t^I}\right). \end{aligned} \tag{11}$$

Intuitively, we use the residuals from specification (10) and calculate $\xi_{j,t}^I$ and $\xi_{j,t}^N$ such that estimated market shares at each time period for each bank are equal to the observed market shares.

4.2.1 Elasticity of Deposits to Financial Distress

An alternative to the triple differences approach which we present above is to obtain variation in financial distress of a bank, which is orthogonal to how depositors value banking services. We start with the differences in differences specification in eq. (10) in which we instrument the probability of default of a bank. We base the instruments on the idea that the performance of a bank's loan portfolio affects the financial condition of a bank, but has little to do with the services depositors can obtain from this bank.

The first instruments we use are based on the net amount of charged-off loans by a bank. Loan charge-offs measure the net value of loans and leases that were removed from the bank's balance sheet because of uncollectibility, and are one measure of the performance of a bank's loan portfolio. We include bank fixed effects in the specification, so our results are not driven by the fact that banks which give bad loans also offer poor services that make them unattractive to depositors. Instead, our instrument is identified from changes in loan charge-offs within a bank over time. We use two types of charge-offs: those for all loans, and charge-offs for real estate secured loans. Quarter fixed effects absorb any aggregate activity, which would affect loan performance, and would also change depositors' preferences. Moreover, loans that are written off in a given period have been made in the past, so we exploit the variation in the quality of the loans the bank has made in the past to generate variation in financial distress in the present. Therefore, the possibility is small that changes in loan charge-offs within a bank over time would measure the services that depositors obtain from a bank.

The second instrument we use exploits a similar source of variation, the share of collateralized mortgage obligations (CMOs) held by the bank as a share of its securities. The idea is that changes in the value of structured products held in a bank's portfolio have little to do with the changes in the quality of deposit services the bank offers. We use both the share of privately issued CMOs as a share of total securities, as well as the share of government issued CMOs as a share of total securities. The former performed poorly, increasing a bank's financial distress, while the latter performed well, being government insured. Again, because of bank fixed effects, we exploit within-bank changes in banks' portfolio structure over time, and quarter fixed effects absorb the aggregate changes in the performance of these securities and depositor behavior.

Table 3 displays the demand estimates for uninsured deposits with both choices of instruments. Consistent with the results in the previous section, we estimate that an increase in the probability of default for a bank decreases demand for uninsured deposits. Interestingly, we find very similar coefficients for both instruments, even though one is estimated with variation in within-bank changes of loans given in the past, and the other using within-bank changes in the current performance of structured securities. Moreover, as before, we estimate a placebo and allow the demand for insured deposits to depend on the instrumented values of default probabilities using the same instruments. The coefficients for insured deposits are small and insignificant. The instrumental variables results, jointly with the results from the previous section, support the hypothesis that uninsured depositors are run prone. As a bank's default probability increases, the demand for uninsured deposits decreases.

We estimate $-\gamma$ to be negative in all three specifications (Table 3, columns 1-3). The results from column 3 can be interpreted as a 1 percentage point increase in the risk-neutral probability of default is associated with a 12% decrease in the market share of uninsured deposits, implying an elasticity of -0.60.[25]

4.2.2 Interest Rate Elasticity and Differentiation of Banks

Recall from Section 4.2 that the demand for deposits depends on the interest rates $i^N_{k,t}$, $i^I_{k,t}$ and the accompanying parameters α^N, α^I, which measure depositors' sensitivity to interest rates. Deposit rates can be correlated with time-varying bank quality. We use the variation in input prices to instrument for the

[25]The marginal effect and elasticity are computed using a 5% probability of default and a 5% market share.

rates in the spirit of Villas-Boas (2007). We construct the instrument from the bank-specific pass-through of treasury rates to insured and uninsured deposits. As expected, we estimate a positive and statistically significant relationship between demand for deposits and the offered interest rate in each specification for both insured and uninsured deposits. Both insured and uninsured deposits are quite price insensitive: with a demand elasticity of 0.56 for insured deposits and 0.16 for uninsured deposits.[26]

Bank fixed effects measure how much depositors value the services of a bank, holding deposit rates and financial distress fixed. We report the estimated bank fixed effects for the preferred specifications (columns 3 and 4 in Table 3) for both uninsured and insured deposits in Figure A1. Figure A1 illustrates that bank fixed effects are positively correlated across uninsured and insured deposit markets. Intuitively, this suggests that, on average, banks which offer attractive services to insured depositors also offer attractive services to uninsured depositors, which one would expect. The largest five banks by deposit size (Bank of America, Citi Bank, JP Morgan Chase, Wachovia, and Wells Fargo) have the largest insured and uninsured fixed effects. Our demand specifications control for the number of branches, so this finding is not mechanical. Conditional on the number of branches, depositors value the services of the five largest banks more than the services of other banks. The heterogeneity among banks is substantial: the average insured depositor is indifferent between depositing at Bank of America or depositing at Citi Bank with a 0.46% point higher deposit rate. Although the value of services offered to depositors is correlated across deposit types, they are not perfectly correlated. For example, Santander has the lowest (16th) ranked brand effect for uninsured deposits while it has the 8th highest brand effect for insured deposits. This heterogeneity suggests that some banks have a comparative advantage in attracting one type of deposits relative to others.

To further assess whether our estimates of bank fixed effects are plausibly related to the quality of bank services, we examine the relationship between our estimated fixed effects and observable dimensions of bank quality. Depositors frequently obtain banking services, such as withdrawals or deposits, from ATMs. Therefore one would expect that banks with a larger and denser ATM network would provide more services to depositors. Figure A2 Panels (a) and (b) confirm this intuition: banks with a larger ATM network have larger estimates of service quality as measured by bank fixed effects. A perhaps more direct way we measure if consumers are satisfied with banking service quality is the frequency of complaints against the bank. We would expect banks with fewer complaints to provide a higher level of service. The Consumer Financial Protection Bureau allows consumers to file complaints against the bank, which we merge with our data.[27] Results in Figure A2 Panels (c) and (d) confirm that banks with fewer complaints per customer have larger

[26] Uninsured and insured elasticities are computed using the demand estimates from columns (3) and (4) in Table 3 and under the assumption that the offered deposit rate is 1% and market share is 5%.

[27] We obtained the data from the Consumer Financial Protection Bureau's Consumer Complaint Database http://www.consumer finance.gov/complaintdatabase/.

estimates of service quality as measured by bank fixed effects.

Overall, our demand deposit specifications yield three results. First, uninsured deposits are run prone. As the probability of default of a bank increases, the demand for deposits from that bank decreases. Second, the demand for both insured and uninsured deposits is relatively inelastic. Lastly, we find that the services of the five major U.S. banks are valued highest by depositors (controlling for the number of branches), and that there exists a fair amount of heterogeneity in the strength of these services across banks and deposit types.

5 Supply of Deposit Services

5.1 Calibration of Supply Parameters

To estimate the demand for deposits we rely on revealed preferences of depositors, without imposing model restrictions resulting from banks' behavior. To obtain supply-side parameters, which govern the behavior of banks, we calibrate the model using revealed preferences of banks. Banks optimally set interest rates on insured and uninsured deposits, and choose when to default. Given data and demand estimates, we calibrate the model such that bank-specific parameters c_k, σ_k , and μ_k are consistent with banks' optimal pricing and default behavior. For every bank, we have three parameters to calibrate, and three equations, which characterize the bank's optimal behavior. We solve for the parameters in closed form and show that the solution is unique so the model is exactly identified. In other words, for any observed equilibrium of the game, there is a unique set of parameters that rationalizes the data.

We obtain the inputs from the data or from balance sheet information as follows. From the data, we directly measure deposit rates, $i^I_{k,t}$, $i^N_{k,t}$, market shares of deposits $s^I_{k,t}$, $s^N_{k,t}$, and total deposits in a market M^I,M^N. We compute the debt service rate, b_k, for each bank as the product of the bank's unsecured funding rate and all non-deposit liabilities. We calculate a bank's unsecured funding rate as the ten-year treasury rate plus the CDS spread.[28] The CDS spread measures the bank's credit spread, while the treasury rate measures the risk-free market interest rate. We calibrate the model using a discount rate r of 5% for each bank.[29] Last, we obtain the utility parameters α^I and α^N from demand estimation corresponding to the IV demand estimates in columns (3) and (4) of Table 3 as discussed in Section 4.2.

Because we calibrate the model for a given observed equilibrium, we drop the subscript t from the notation for ease of exposition. The first parameter we calibrate for each bank is the non-interest cost of

[28] We use CDS spreads as of March 31, 2008. When calculating the unsecured funding rate for different time periods we use the corresponding treasury rate. We calibrate the model keeping the CDS spread fixed across time periods for ease of comparison.

[29] As a robustness check, in Appendix Table A5 we recalibrate the model using the corresponding 30 Year Treasury Rate as the discount rate r.

insured deposits, c_k, which we obtain from the pricing decisions of the bank. Inspecting the first order conditions between insured (eq. 7) and uninsured deposits (eq. 8), we can write the cost as the difference in margins the bank earns on these two types of deposits:

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

Intuitively, larger marginal costs of insured deposits c_k are passed-through to consumers with a mark-up. Because the marginal benefit of deposits is the same for insured and uninsured deposits, we can difference it out. Knowing demand elasticity and quantities, we can invert the marginal costs from the pricing equations.

Next, we calibrate the risk-neutral variance of bank profits σ_k. We derive a closed form solution for the variance in terms of the demand parameters, and other observable variables. To obtain the intuition for the mapping between observable quantities and the variance, we present the main steps in the derivation of the analytical solution. The main insight we use is that the limited liability benefits that equity holders earn can be expressed in terms of the observable probability of bankruptcy and σ_k. First note that, assuming informationally efficient CDS markets, we can observe the risk-neutral probability of bankruptcy in the data. Its equivalent in the model is

$$\rho_k = \Phi \left(\frac{\bar{R}_k - \mu_k}{\sigma_k} \right). \tag{12}$$

We invert this expression to obtain the normalized endogenous bankruptcy cut-off:

$$\frac{\bar{R}_k - \mu_k}{\sigma_k} = \Phi^{-1} \left(\rho_k \right). \tag{13}$$

We start with the bankruptcy condition (6) at which the bank is indifferent between defaulting and staying in business. First, we show that the bank's payoff from not defaulting (RHS of 6) is a function of observable quantities and the probability of default, by substituting for (12) and (13):

$$b_k - M^I s_k^I \left(\bar{R}_k - c_k - i_k^I \right) - M^N s_k^N \left(\bar{R}_k - i_l^N \right) = \sigma_k \left(\begin{array}{c} \frac{1}{1+r} \left(M^I s_k^I + M^N s_k^N \right) (1 - \rho_k) \\ \left(-\Phi^{-1} \left(\rho_k \right) + \lambda \left(\Phi^{-1} \left(\rho_k \right) \right) \right) \end{array} \right).$$

The unobservable quantities in the LHS are the margins on deposits earned by the bank, $\left(\bar{R}_k - c_k - i_k^I \right)$ and $\left(\bar{R}_k - i_l^N \right)$. We can express margins in terms of demand parameters and the probability of bankruptcy, by substituting in for optimal pricing from (7) and (8), and then substituting from (12) and (13):

$$\left(\bar{R}_k - c_k - i_k^I \right) = \frac{1}{\left(1 - s_k^I \right) \alpha^I} + \sigma_k \left(\Phi^{-1} \left(\rho_k \right) - \lambda \left(\Phi^{-1} \left(\rho_k \right) \right) \right).$$

Therefore, the margin on deposits is a function of the price elasticity of demand $\frac{1}{(1-s_k^I)\alpha^I}$ and limited liability benefits $\sigma_k \left(\Phi^{-1}(\rho_k) - \lambda\left(\Phi^{-1}(\rho_k)\right)\right)$.

The financial shortfall at bankruptcy (LHS), as well as the benefit of continuing the enterprise (RHS) are a linear function of the variance, σ_k. Therefore, there is a unique value of the variance that makes the bank's indifference condition consistent with the data. Substituting the margins into the bankruptcy condition, we obtain a closed form solution for the variance of profits of bank k:

$$\sigma_k = \frac{\frac{(1+r)}{M^I s_k^I + M^N s_k^N}\left(b_k - \frac{M^I s_k^I}{\alpha^I(1-s_k^I)} - \frac{M^N s_k^N}{\alpha(1-s_k^N)}\right)}{(\rho_k + r)\left[\Phi^{-1}(\rho_k) - \lambda\left((\Phi^{-1}(\rho_k)\right)\right]}.$$

Last, we compute the expected return on deposits from the optimal pricing of deposits:

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

Intuitively, for a given level of default rates, volatility, and demand elasticity, if a firm is willing to offer depositors higher interest rates, it is because it expects to earn large returns on these deposits, implying a large μ_k.

5.2 Calibration Results

The average profitability of banks is driven by two parameters: the mean return on deposits, μ_k, and the additional costs of servicing insured deposits, c_k. Figure 3 displays estimated mean return on deposits across the banks in our sample as of March 2008. We find that banks earn mean returns on deposits between 7.50% to 8.50%.[30] Figure 2 displays estimated cost of servicing insured depositors across the banks in our sample as of March 2008. Our estimates suggest these additional costs amount to approximately 4% to 5.5%.[31] These calibrations rationalize the interest rates charged on insured and uninsured deposits with demand estimates, CDS spreads, and deposit amounts across banks. To evaluate these estimates, we compare them against balance sheet estimates of banking profitability, which we did not use in our calibration, as well as industry estimates of the costs of small bank accounts to banks.

It is difficult to directly measure expected returns on deposits under the risk-neutral measure in the data in general, but this task is even more difficult during the crisis, because ex post realized returns during the crisis were substantially below the expectation. Hirtle et al. (2015) report the historical net interest margin of U.S. commercial banks at approximately 3.5%. This estimate is on the lower end of our calibrated values:

[30] To put these estimates in perspective, the 10 year Treasury yield as of March 2008 was 3.45%.

[31] Because we have a continuum of depositors, the marginal and average cost of servicing an account are the same. The interpretation of c_k as a fixed cost per depositor is probably more sensible, so $c_k$should be evaluated as such.

the mean returns banks earn on deposits exceed the interest payment by 3.5% - 6.5%. Since insured deposits are approximately half of all deposits for the banks in our sample, the overall average profitability of deposits is approximately 2.9% to 3.75%. Hanson et al. (2015) and Hirtle et al. (2015) use balance sheet data to compute that banks earn approximately 2-2.5%. Even though our calibrations do not use the balance sheet items from these studies, our estimates lie in the ballpark of the estimates from those studies.

Industry estimates suggest that small bank accounts are substantially less profitable than large bank accounts. In fact, the American Banker's Association estimates that approximately half of checking accounts are unprofitable. Our calibration results are consistent with the idea that the costs of small, insured accounts are substantially larger than the cost of uninsured accounts. For a $2,500 account, our estimates of c_k imply an additional cost of $100 to $137.5 per year. Banks frequently charge fees for depositors with small accounts, smaller than $500-$1,500, with fees between $5 to $10 per month.[32] We also estimate the perceived volatility of returns banks earn on deposits, which range from 8% to 22% as displayed in Figure 4.

6 Multiple equilibria

We use our model to study whether other equilibria can be supported in a market with the calibrated fundamentals. Recall that the fundamentals of the model are consumer preferences for deposits, the distribution of returns on deposits, and long-term debt burdens of banks. An alternative equilibrium is one in which consumers with the same preferences rationally believe that banks' probabilities of bankruptcy differ from the realized probability. Given these beliefs, the banks' optimal choices of interest rates and default decisions are such that the probability of bankruptcy equals depositors' beliefs. We rank these equilibria in terms of the best and worst equilibria based on total welfare, as described in Appendix B. For ease of exposition, we limit the market to the five largest banks, rather than the full set in the analysis.

A worse equilibrium can potentially exist because a decline in depositors' beliefs about a bank's survival probability decreases demand for deposits, lowering the bank's profitability and increasing its probability of default. If the feedback is strong enough, a new equilibrium could exist that supports such pessimistic beliefs. More precisely, because banks compete, an equilibrium is determined by consumer beliefs about default probabilities of all banks. These have to be consistent with the optimal interest-setting and default behavior of all banks, which compete for deposits. Therefore, a shift in one bank's level of financial distress can spread to other banks through equilibrium deposit competition effects.

We first illustrate how the banking system with the same fundamentals[33] can result in significantly worse

[32] http://abcnews.go.com/blogs/business/2012/09/basic-checking-account-fees-at-10-largest-banks/, downloaded on 9/19/2014

[33] By fundamentals we refer to the estimated utility parameters, calibrated supply parameters (μ_k, σ_k, c_k) and debt service

equilibria with lower welfare. We then classify the alternative equilibria, and study how contagion of financial distress can occur without direct linkages across banks.

6.1 Results

We find several equilibria consistent with the calibrated fundamentals. For example, Wachovia's market-implied risk-neutral probability of default as of March 2008 was 3.3%. Our model indicates an additional equilibrium exists in which Wachovia defaults with a risk-neutral probability of 52% (Table 4, equilibrium 5). The multiple equilibria results can be interpreted as follows. Consumers rationally believed that there was a 3.3% chance that Wachovia would default in March 2008. However, if consumers suddenly believed that there was a 52% chance that Wachovia would default in March 2008, those beliefs would also be rational, even though the underlying fundamentals of the banking system would be the same. If depositors believed that Wachovia was more likely to default, they would have started to withdraw their deposits, which would have in turn lowered the profitability of Wachovia and increased its probability of default.

Three broad facts emerge from the analysis of multiple equilibria. First, the banking system was in the best equilibrium for much of the period we study, and close to the best one in the rest of the period. Second, each bank individually is subject to instability, which can spill over to other banks. Last, even in the worst equilibria, several banks remain active and provide depositor services to a large part of the market. We next discuss these facts in more detail.

6.1.1 Banking System and the Good Equilibria

For the most part, the banking system was close to the best equilibrium of our model in terms of the total associated welfare. For 2008 and 2009, we can find equilibria which have slightly lower default probabilities for all banks and higher associated welfare (equilibrium 2 in Table 4 and Panel B of Table A1). Conversely, in 2007 there are no equilibria that strictly dominate the observed equilibrium in the data. We do find an equilibrium in 2007, which is slightly worse than the realized equilibrium for each bank in terms of default probabilities (Table A1 Panel A, equilibrium 2). These close equilibria suggest that the realized market default rates, as measured by CDS, are not necessarily a monotonic transformation of underlying fundamentals, even in equilibria in which banking is stable. Rather, some banks are better off because consumers' beliefs in their stability are high. On the other hand, the realized equilibrium, as well as other proximate equilibria, are substantially better than the bad equilibria we discuss below.

b_k which are assumed to be constant.

6.2 Asymmetric Equilibria and Contagion of Financial Distress

One set of possible alternative equilibria we find are ones in which one bank's probability of default is substantially higher than that of the other banks, in the range of 40% to 60%. We find such equilibria are possible for every bank, suggesting that each bank individually is subject to instability (Table 4, equilibria 3-7; Table A1 Panel A, equilibria 9-13; Table A1 Panel B, equilibria 11-15).

These equilibria provide a window into the propagation of adverse shocks in the banking system, without direct linkages between banks. To illustrate the link, consider the alternative equilibrium in March of 2008 in which Bank of America's probability of defaulting is 53% (Table 4, equilibrium 4). Bank of America's market share of uninsured deposits in March of 2008 was 9%, but it is 0.1% in this equilibrium. Financial distress decreases demand for Bank of America's uninsured deposits and increases demand for competitors, all else equal. On the other hand, Bank of America also offers higher deposit rates. To compete, Bank of America's competitors raise their interest rates, on average by approximately 1%.

Competition for insured deposits propagates financial distress across banks. The distressed bank suffers no direct decrease in demand for insured deposits. Instead, because it is likely to default, the FDIC guarantee becomes very valuable: in the high default probability equilibrium, Bank of America's equity holders only pay for these deposits half the time. Providing high interest rates on insured deposits is therefore quite cheap. This gives the distressed bank a comparative advantage in attracting insured deposits, and its market share of insured deposits actually increases. For example, one month before Washington Mutual failed, a Wall Street Journal blog titled "Return on Investment" reported the following "Washington Mutual is offering a remarkable 4.9% interest rate on one-year CDs ... the minimum deposit is just $1,000. And unlike stockholders and bondholders, your money is guaranteed by the federal government."[34]

While the distressed bank attracts insured deposits, the competitor banks suffer a decline in insured-deposits market share and pay a higher interest rate on these deposits. This lowers profits of non-distressed banks in the system, increasing their distress. When Bank of America experiences financial distress, the probability that each one of its competitors defaults increases by over 1.5 percentage points (Table 4, equilibrium 4). The example of Ally Bank illustrates such spillovers. In 2009, Ally Bank offered among the highest interest rates in the country, while its parent company GMAC was receiving FDIC assistance. The American Bankers Association, in a letter to the FDIC, complained that these rates were taking advantage of government guarantees and hurting other banks in the system. Limiting interest rates that undercapitalized banks can offer would "protect healthy bank competitors from having to pay unsustainably high and above market rates for deposits to compete against an institution taking advantage of FDIC insurance in an unsafe

[34]http //blogs.wsj.com/roi/2008/08/29/banks-offer-higher-cd-rates-to-offset-credit-crunch-losses [accessed on 12/17/2014]

manner." The FDIC responded by tying a part of its assistance to GMAC to the deposit rates of Ally Bank. Ally Bank lowered its rates afterward (Yingling 2009, Leiber 2009).

The distressed bank's comparative advantage in attracting insured deposits is particularly strong in our model, because we allow banks to offer arbitrarily high interest rates on insured deposits. This is reflected in exorbitant interest rates offered by unstable banks in bad equilibria. For example, Bank of America's insured deposit rate is 7.33% (Table 4, equilibrium 4). We can interpret the high interest rate as the rate Bank of America would be willing to offer without regulatory constraints, i.e., as a shadow price of uninsured deposits for Bank of America in the equilibrium in which it is unstable. We analyze how imposing interest rates limits on insured deposits would affect spillovers and the possibility for multiple equilibria in Section 7.1.

6.2.1 Provision of Banking Services in High Default Probability Equilibria

We also find equilibria in which multiple banks face extreme distress. In 2007 and 2009, we find several equilibria in which two or three banks are unstable, with risk-neutral default probabilities over 50% (Appendix Table A1 Panels A and B).[35] Equally interesting, however, is that we find no equilibria in which four or five of the largest banks are unstable in any of the periods studied. Intuitively, as more banks are distressed, the demand for uninsured deposits shifts to relatively healthier banks. This effect is too weak to prevent spillovers across banks in asymmetric equilibria in which few banks default. However, it is strong enough to prevent all banks from being simultaneously unstable. One can see that by tracking the total market share of uninsured deposits for the banks we consider. For example, their market share is 51% in the observed equilibrium in 2008, and does not decline below 38% in any alternative equilibrium.[36] Because depositors value services they obtain from banks, an equilibrium in which all banks are unstable is not achievable for the calibrated values of the parameters we obtain. These results suggest that a mechanism that could destabilize the entire banking system would have to involve direct linkages across banks, which would overcome the force for stability we describe above.

[35] Note that in the equilibria in which multiple banks experience financial distress, total welfare is generally higher than in the equilibria in which only one bank experiences financial distress. This is because the multiple distressed banks compete for depositors by offering higher and higher deposit rates which makes consumers better off.

[36] We fix the utility of the outside good at the estimated level for the time period of the counterfactual.

7 Policy Analysis

7.1 Interest Rate Limits on Insured Deposits

As we show in Section 6.2, the instability of one bank can propagate to other banks through competition. The negative spillover is substantially stronger for insured deposits, because unstable banks value the FDIC guarantee more. Interest rate limits, such as the one imposed on Ally Bank, might prevent banks from taking advantage of the guarantee and possibly limit the effect of spillovers on other banks. In fact, Regulation Q, which had allowed the Federal Reserve to set interest rate ceilings on banking deposits in the past, was put in place in 1933 partly to "prevent 'excessive' rate competition that...lead to bank failures" (Cook 1978).

We analyze this intuition by imposing limits on the insured interest rates that banks are allowed to offer. We compute alternative equilibria in the calibrated model under this policy and present the results in Table A2. The policy is effective at curbing FDIC costs. For example, in 2008, one of the worst equilibrium without limits on insured rates results in expected FDIC costs of approximately \$1.1 trillion (Table 4, equilibrium 7). In this equilibrium, the unstable bank, Citi, takes extreme advantage of FDIC insurance and attracts most insured deposits—the market share of Citi rises to 87%. We impose a very loose limit on insured deposit rates, at 5 percentage points above the treasury rate. The interest rate cap prevents unstable banks from attracting all insured deposits, limiting their market share to 83%. If we compare the equilibrium in which Citi experiences substantial distress with (Table A2, equilibrium 4) and without the interest rate cap (Table 4, equilibrium 7), we see that the policy is effective at curbing the expected FDIC costs, decreasing them by over three-fourths: \$0.225 trillion. The costs are also lower because the expected default outcomes are less severe under the alternative policy. As suggested by the American Bankers Association in their letter to the FDIC, the policy also seems to limit spillovers between banks. The stable banks manage to hold on to some insured deposits, and because interest rates are lower, they are also more profitable, increasing their stability.

The policy does have one surprising aspect. While the banking system is more stable from the perspective of default rates, it provides fewer services to *uninsured* depositors. Without *insured* interest rate limits, the lowest market share of uninsured deposits obtained by the five major banks we analyze is 38% (Table A2, equilibrium 7). Conversely, limits on insured deposit rates lead to several equilibria in which uninsured deposits leave the system even if banks are more stable. The lowest market share of uninsured deposits is below 5% (Table 5, equilibrium 29), or roughly 85% smaller than without limits. Therefore, while the policy can result in increased stability of the banking system and smaller costs to the FDIC, it can have an adverse effect on the level of uninsured deposit services provided by the banking system. These results caution that even simple and seemingly reasonable policies may have distributional consequences which have to be considered.

7.2 FDIC Insurance Limit Change

During the financial crisis, the FDIC raised the limit on deposit insurance, first in October 2008 and then as part of the Dodd-Frank Act in 2010. We use our calibrated model to estimate the effect such a policy would have had prior to the peak of the financial crisis in March 2008.

We mirror the actual policy change by increasing the total number of insured deposits available, M^I, by 1.00% of uninsured deposits, and decreasing uninsured deposits, M^N, by 1.00%. In our baseline specification, the newly insured depositors have the same preferences as the uninsured depositors, but are insensitive to bank default. We present the results in Table 5, Panel A. Most banks' default probabilities do not change significantly, so the policy does not stabilize the system, since most of the rents accrue to the newly insured depositors. We calculate the expected FDIC insurance payout under the two policy regimes. The consequence of the policy is to increase the expected cost to the FDIC by roughly $265 million, but the results differ among banks. The results have differential effects, because banks differ in the quality of services for insured and uninsured depositors. Therefore, a shift in the composition of demand affects them to a different extent. Furthermore, the cost of servicing insured depositors (c_k) differs across banks, affecting their pricing of deposits. Overall, our counterfactual suggests that the primary consequence of the policy is to transfer rents from the FDIC to the newly insured depositors.

To illustrate the importance of modeling realistic aspects of depositors' preferences, consider the counterfactual below. We change the preferences of newly insured depositors to coincide with those of the insured depositors. Under this counterfactual, the FDIC limit increase would have lowered the probability of default for all banks we consider (Table 5, Panel B). It would also lower the expected costs of FDIC insurance by $500 million. This change in depositors' preferences radically changes the policy implications.

Why do these two counterfactual have such different impacts on banking stability? The policy change transfers rents from the FDIC to banks and depositors. Broadly, if, in equilibrium, these rents go to the depositor, banks' incentives to default do not change much. Conversely, if the rents accrue to the banks, there is an offsetting effect, which potentially lowers the probability that each bank defaults. These two forces help explain part of the asymmetric effect of increased FDIC insurance. Overall, our results suggest that a quantitative model can be useful in analyzing even seemingly simple policies. Our model is silent about the risk-taking decision of bank managers. The moral hazard problem will temper the conclusions of our counterfactual analysis, introducing additional costs of FDIC insurance.

7.3 Capital Requirements

The last policy we consider is the introduction of capital requirements. In the Appendix, we also use our model to consider an additional policy that limits the risk that banks are eligible to undertake. In the baseline model, limited liability protects equity holders. If the bank defaults, equity holders only lose the franchise value of the bank, which is the expected value of the future cash flows from the bank. Capital requirements have been at the center of proposed policy solutions to combat banking instability.[37] We implement capital requirements by requiring equity holders to post 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.

The addition of capital requirements changes the characterization of the optimal default threshold, as well as the optimal pricing of deposits. We characterize how capital requirements affect both the default and interest rate-setting behavior of banks in the Appendix. We consider two variants of capital requirements. In the first version, additional capital is invested along with deposits. In the second, which we investigate in Section 8.4, capital is invested at the risk-free rate.

We compute equilibria in the calibrated model for different levels of capital requirements ω as of March 2008. Because there are multiple equilibria for each ω, we streamline the analysis by focusing on the best and worst equilibrium from the perspective of bank stability and welfare for each capital requirement ω. Last, we propose a welfare criterion that allows us to choose an optimal policy in the presence of multiple equilibria. Using this criterion, we solve for optimal capital requirements.

We first analyze the consequences of increasing capital requirements for the stability of the banking sector. We measure bank stability as the average risk-neutral probability of default across the analyzed banks for each equilibrium. We rank equilibria according to this measure, and plot the best and the worst equilibrium for each capital requirement in Panel A of Figure 5. Increasing capital requirements increases banking sector stability in the worst equilibrium. The average probability of bankruptcy in the worst equilibrium declines precipitously as we increase ω from 0 to 23%. The decline slows as we increase capital requirements past $\omega = 23\%$. Intuitively, increasing capital requirements increases the stability of banks by decreasing the limited liability of equity holders, making them less prone to gamble. Therefore, capital requirements decrease the severity of the largest possible instability in the banking sector.

The intuition that capital requirements uniformly increase the stability of the banking sector does not hold. As capital requirements increase from $\omega = 0$ to $\omega = 20\%$, banking sector stability in the best

[37] For example, the Dodd-Frank act, the Financial Stability Board total loss-absorbing capacity proposal for large banks, the Basel III accords.

equilibrium declines slightly. The driving force for this result is that in good equilibria the banking system is already stable: consumers believe that banks are stable so demand for deposits is high, making banks profitable and decreasing the probability of default. Capital requirements decrease the profitability of equity and decrease banking stability. Overall, capital requirements decrease the severity of the largest possible instability in the banking sector, but at the cost of eliminating some equilibria in which the banking system is very stable.

From the perspective of policy makers, banking stability is an intermediate goal towards a broader objective of fostering overall welfare. Consumers earn interest rates on their deposits and obtain banking services, which they value.[38] Equity holders earn rents from the intermediation of deposits, because they offer differentiated goods and the market is not perfectly competitive.[39][40] Because insured depositors and equity holders partially obtain surplus from the expected FDIC insurance, we have to account for expected FDIC costs in the welfare calculation as well. While increasing capital requirements can increase banking stability, it may depress valuable banking activity. We therefore study how capital requirements affect the surplus generated by the banking system. We first describe how the set of equilibria changes as we increase capital requirements, and then propose the optimal capital requirement.

Figure 5, Panel B presents the welfare in the best (highest welfare) and worst (lowest welfare) equilibria for different levels of ω. The welfare in the best equilibrium does not vary much and remains relatively stable as capital requirements change from 0 to 50%.

The welfare in the worst equilibrium improves drastically as capital requirements increase from no capital requirements, $\omega = 0$, towards $\omega = 18\%$, with a welfare gain of approximately \$2.5 trillion. After that point, welfare increases slowly and as we increase capital requirements further, past $\omega = 39\%$, the welfare of the worst equilibrium begins to decline.

These results show that banking stability and welfare do not necessarily go hand in hand. For example, in the worst equilibrium, banking stability increases with capital requirements, but welfare starts to decrease after capital requirements exceed approximately 39%. The source of this wedge between banking stability and welfare is consumer surplus. In Panels C, D, and E, we separately plot how different components of surplus change with capital requirements. Both equity value and the costs to the FDIC decline with capital requirements in the worst equilibrium, as one would expect. Consumer surplus in the worst equilibrium, on the other hand, reaches its global peak at approximately $\omega = 35\%$, and is monotonically declining thereafter.

[38] The utility function of uninsured depositors already accounts for expected utility loss due to default, and the consumer surplus can therefore be interpreted as the expected surplus.

[39] Depositor surplus and FDIC costs are measured as annual flows. Equity values, however, are measured as the present value of expected discounted cash flows to equity holders. We compute the expected flow benefits to equity holders as rE_k.

[40] We do not include the surplus borrowers earn from their bank loans. Insofar as increasing capital requirements decreases banking activity, this surplus loss increases the cost of capital requirements further.

Our model suggests that there are multiple equilibria for each level of capital requirements and that the welfare consequences of policies differ based on which equilibrium is played by the agents in a model. How should a planner choose the optimal capital requirement in the face of multiple equilibria? This choice is especially difficult because it is plausible that the planner does not know which equilibrium will be chosen after the policy has changed. If the planner is uncertainty averse and her priors over which equilibria will be chosen are unrestricted, then she will maximize the welfare of the worst possible equilibrium (Gilboa and Schmeidler 1989). Under this criterion, the optimal capital requirement is 39%.

More broadly, our results suggest that a planner may want to err on the side of capital requirements which are too high rather than too low because the welfare losses from suboptimal requirements are very asymmetric. Welfare losses in bad equilibria are substantial for capital requirements below 18%, relative to any losses a planner might incur by choosing requirements that are too strict. These estimates are substantially higher than the 8% requirements proposed under Basel III accords, and closer to the $16-20\%$ total loss-absorbing capacity proposed by the Financial Stability Board. When we examine model extensions in Section 8.3.2, we find large welfare losses for capital requirements below 15-18% across a wide set of model perturbations. The increase in welfare for capital requirements above 18%, however, is not robust. In other words, it seems that the optimal capital requirement of $\omega = 39\%$ is not robust to model perturbations. A more robust recommendation of our model is closer to 18%.

8 Robustness and Sensitivity Analysis

8.1 Too Big to Fail

We model "too big to fail" (TBTF) as a bailout of uninsured creditors of banks, which keeps the bank outside of 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:

$$u_{j,k,t}^{N} = \alpha^{N} i_{k,t}^{N} - \rho_{k,t} \left(1 - p_{TBTF}\right) \gamma_{F} + \delta_{k}^{N} + \varepsilon_{j,k,t}^{N}.$$

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 is what we measure in the data. In other words, the CDS-implied probability of default reflects the probability that a bank defaults and is not bailed out, which is the relevant probability for uninsured depositors. 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.

The calibration of the model does change, however. The risk neutral probability of default in the data $\rho_{k,t}\left(1 - p_{TBTF}\right)$ now comprises the probability that returns are below the cut-off value $\Phi\left(\frac{\bar{R}_k - \mu_k}{\sigma_k}\right)\left(1 - p_{TBTF}\right)$, which we have to account for in the calibration. In our calibrations, we assume that the bailout probability ranges from 0 to 75%. For detail, see Appendix A. Moreover, we now have to account for the cost of government bailouts when computing welfare consequences of policies.

8.2 Bankruptcy Cost and Costly External Finance

Here we examine the sensitivity of the model to bankruptcy costs and costly equity issuance. We start with the baseline model with capital requirements, and introduce both features simultaneously. We relegate all technical details, including the optimality conditions and calibration equations to the Appendix.

8.2.1 Bankruptcy Cost

In the baseline model, we assume that the process of bankruptcy is costless. Here we explore the consequences of a one-time reorganization deadweight cost in bankruptcy. Such costs can arise if the bank has to fire-sell some of its assets during the reorganization process, or if the process distracts management and labor from profit maximizing tasks. We model bankruptcy costs as a one-time deadweight cost realized at bankruptcy, which is proportional to the size of the invested funds $\chi\left(M^{I} s_{k,t}^{I} + M^{N} s_{k,t}^{N}\right)$. We experiment with two different values of χ. We choose $\chi = 10\%$, which is twice the bankruptcy costs obtained in Hortaçsu et al. (2013), and $\chi = 20\%$, which is approximately 2/3 of the estimated cost of bank failures to the FDIC

(Granja, Matvos, and Seru 2015).[41][42]

Bankruptcy costs do not alter the estimation of the model. The insured depositors are insulated from bankruptcy, so their incentives remain unaltered. If uninsured depositors internalize the bankruptcy cost, then this is reflected in their sensitivity to default, γ, which we estimate from the data. Last, equity holders do not directly internalize the bankruptcy cost, since they are wiped out in bankruptcy. They only internalize these costs indirectly to compensate the uninsured depositors for bearing them by compensating them for their sensitivity to default γ, which remains unchanged. Increasing the social cost of default bankruptcy cost plays a potentially important role in assessing the welfare consequences of alternative policies, which we study in Section 8.3.2

8.2.2 Costly External Finance

We also relax the assumption that injection of funds by equity holders is frictionless. A variety of theories suggests that injecting external funds into the firm is costly due to frictions such as adverse selection, moral hazard, and related agency problems. We capture these frictions as 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 $b_k - M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) - M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right)$ they have to spend $(1+\tau_{+})\left(b_k - M^I s^I_{k,t}\left(R_{k,t} - c_k - i^I_{k,t}\right) - M^N s^N_{k,t}\left(R_{k,t} - i^N_{k,t}\right)\right)$ to recapitalize the bank. We set $\tau_{+} = 5\%$, consistent with the estimates the literature on financing costs of large firms (Hennessy and Whited 2005, Matvos and Seru 2014).

Costly external finance has no effect on depositor demand. Intuitively, these costs increase the benefits to bankruptcy through two channels. First, they increase the costs of recapitalizing the bank directly. Second, because recapitalization is more expensive, the present value of the bank, all else equal, is smaller, further decreasing the benefits of recapitalization.

8.3 Results

8.3.1 Calibration

We explore how changing the model to allow for TBTF, equity issuance costs, and an 8% capital requirement[43] affects the estimates of the supply side parameters μ_k, σ_k, c_k (the other two extensions we consider, bankruptcy costs and run-prone insured depositors, do not affect the calibration). We first present the

[41] The total costs of bank failures to the FDIC include repayment of depositors, as well as any deadweight costs which arise in bankruptcy.

[42] The two values of χ produce quantitatively similar results. Hence, we report the values for the larger value of χ, $\chi = 20\%$.

[43] In Section 7.3 we investigate the consequences that different capital requirements would have on bank stability and welfare, keeping the estimates from the baseline model. Here, we instead explore how the 8% capital requirement, which was in place during the estimation period, would affect the estimates of model parameters.

model with all extensions simultaneously. Then, to better understand how these extensions affect parameter estimates, we study how adding each one of them individually to the baseline model affects the estimates. We derive the equations for each calibration in the Appendix.

Table 6 Panel A presents the average calibrated parameters across banks. The first thing to notice is that the extensions have no effect on the additional costs of servicing insured deposits, c_k, which we more formally show in Appendix A. Intuitively, what drives the calibrated parameters is the difference in deposit pricing across insured and uninsured depositors. Within the pricing equations, our extensions mainly affect the marginal benefits of deposits, which is differenced out when we calibrate c_k.

The extensions have a small effect on the mean and standard deviation of returns on deposits, μ_k, and σ_k. Introducing all extensions simultaneously has only minor consequences on the parameter estimates. The mean returns on deposits are 7.8% in the baseline model, and decrease to 7.7% in the model with TBTF (50% bailout probability)[44], equity issuance, and an 8% capital requirement. Similarly, the volatility of the returns is 15.9% in the baseline model, and is 13.4% in the extension. The costs of servicing insured deposits, c_k, stays the same.

One reason why the extensions have a very small effect on the estimates is because they have offsetting effects. First, adding TBTF has the smallest consequences. The mean and standard deviation of 7.4% and 14.7% are slightly lower than in the baseline model of 7.8% and 15.9%. Capital requirements and costs of equity issuance have more pronounced effects on the estimates, but have offsetting effects. Introducing capital requirements lowers the estimate of the return mean to 7.6%, but increases volatility to 18.4%. Conversely, introducing capital requirements increases the mean to 8.2%, but decreases the volatility to 11.4%. Overall, adding these extensions has little effect on the estimates from the model.

8.3.2 Capital Requirements

The second way we explore the consequences of various model extensions is to examine their effects on policy counterfactuals. Specifically, we study how model perturbations alter the consequences of different capital requirements. For each perturbation of the model, we use the corresponding calibrated parameters from Table 6 Panel B. We compute all equilibria for each level of capital requirements ω. The full extension incorporates TBTF, equity issuance costs, and bankruptcy costs. We also impose an 8% capital requirement when we calibrate the parameters. Then, to understand individual extensions better, we add each one of them individually to the baseline model.

We plot the best and worst welfare equilibrium across capital requirements for each model perturbation

[44] In Table 6 we report the results assuming 50% bailout probability. In appendix Table A4 we report the corresponding results where we examine bailout probabilities ranging from 0-75%.

in Figure 6 Panels (a)-(e). From the figures, it is clear that adding all extensions to the model does little to change our inference of the consequences of capital requirements. Even with 20% bankruptcy costs, 5% issuance costs, and a 50% probability of bailouts, the main qualitative and quantitative predictions are intact. As in the baseline model, capital requirements have a large effect on the welfare and default probabilities in the worst equilibrium, but affect the best equilibrium little. Second, across model perturbations, there is a large drop in the welfare of the worst equilibrium below capital requirements of 15-18%. Last, the optimal capital requirement in the baseline model of 39% seems to not be robust, but is instead a local optimum relative to model perturbations. When we add costly equity issuance or TBTF to the baseline model, the slight increase in welfare for capital requirements is instead a slight decline, leading to a global capital requirement optimum of 24%.

8.4 Risk Free Capital Requirements

One key reform of the Basel III accords is to require that banks hold sufficient high-quality liquid assets resembling cash (the liquidity coverage ratio). In Section 7.3 capital requirements are invested in the same asset as deposits. To approximate the liquidity coverage ratio requirement in our setting, we study the consequences of investing capital requirements into a risk-free asset earning r. Broadly, risk-free capital requirements decrease the attractiveness of capital requirements for equity holders because banks' investments are, on average, profitable. This implementation of capital requirements also decreases the FDIC default costs. Because banks default when their investments have low returns, the assets invested by equity holders can only repay a small share of depositors' claims if they are co-invested with other assets. This is not the case if capital requirements are held in safe assets. We present the best and worst welfare equilibrium for each capital requirement in Figure 7.

Qualitatively, investment of capital requirements in the safe asset has two consequences. First, the best and worst equilibrium with risk-free capital requirements are bounded by the corresponding equilibria with risky asset capital requirements. Second, there is a large drop in the welfare of the worst equilibrium below capital requirements of 14%, similar to the baseline model, and other model perturbations we have explored. Similar to other extensions, the welfare of the worst equilibrium peaks at this capital requirement. This extension suggests that the implementation of capital requirements can have interesting and important consequences for the stability of the banking sector.

8.5 Run-prone Insured Depositors

Our baseline model is motivated in large part by the U.S. banking system to which we apply the model. Insured depositors trust the FDIC and are not sensitive to default, i.e., run prone. This assumption is consistent with the anecdotal behavior of insured depositors in the last crisis. The "silent run" on Wachovia, in which depositors withdrew almost $5 billion in a day was primarily driven by uninsured depositors, rather than insured ones.[45] Moreover, consistent with anecdotal evidence, we find that insured depositors are not sensitive to bank distress.

However, one can consider situations in which depositors, even if they are insured, are sensitive to default. For example, if there are delays in accessing payouts from deposit insurance, such as in India, then insured depositors suffer in bank default even if they eventually recover their deposits (Iyer and Puri 2012). Alternatively, if depositors believe that the banking system is likely subject to capital controls if banks are close to defaulting, as has been recently the case in Greece, they may want to withdraw insured deposits prior to bankruptcy as well. Or, insured depositors, being poorly informed, may believe that bankruptcy will impair their access to deposits, even if that is not the case ex post. To broaden the scope of the model and account for such phenomena, we modify the utility function of insured depositors, and allow them to be sensitive to default as well:

$$u^I_{j,k,t} = \alpha^I i^I_{k,t} + \gamma^I \rho_{k,t} + \delta^I_k + \varepsilon^I_{j,k,t}.$$

In settings in which insured depositors are indeed run prone, one can estimate demand for insured deposits using the same approach as we do for estimating demand for uninsured deposits. This modification of the model does not affect the calibration of the supply side of the model.

While insured depositors in the U.S. are insensitive to distress in the data, we can still examine the consequences of run-prone insured depositors on the stability of the U.S. banking sector. We recompute equilibria using our calibrated values, but assume that insured depositors' sensitivity to default is 50% of that of the uninsured depositors, $\gamma^I = .5\gamma$. We choose a lower sensitivity of insured depositors to reflect the idea that insured depositors generally do better in bankruptcy, even outside the U.S. We keep other parameters of the model equal to the baseline.

We present the best and worst welfare equilibrium for each capital requirement in Figure 6 Panel (f). As one would expect, the potential costs of instability are worse when the population of depositors is more run prone. The worst possible equilibrium that can be obtained features welfare losses that are almost $1.2 trillion larger than in the baseline model. Because runs are costlier in this setting, the largest possible gains from

[45] Rothacker, Rick (October 11, 2008). "$5 billion withdrawn in one day in silent run," Charlotte Observer. Retrieved July 8, 2014.

capital requirements in the worst equilibrium exceed those from the baseline model. Therefore, one might conjecture that larger capital requirements could be required to eliminate bad equilibria. Instead, the benefits from capital requirements are realized slightly faster, and peak for a capital requirement around 15-22%. The driver seems to be increased complementarities between depositors. Because insured depositors behave more like the uninsured depositors, the strategic complementarities between them are larger. The larger complementarities lead to more extreme equilibria, both good and bad, as well as more abrupt transitions between them.

9 Conclusion

Our paper develops a new empirical model of the banking sector, which emphasizes the feedback relationship between the demand for uninsured deposits, demand for insured deposits, financial health of banks, and bank competition. One advantage of our model is that we are able to take it to the data and quantify the forces that determine the strength of the feedback between deposits and financial distress. Our central finding is that the large amounts of uninsured deposits in the U.S. commercial banking system can lead to unstable banks, given the elasticity of deposits to financial distress.

We then use our calibrated model to assess some recent and proposed bank regulatory changes. The results suggest that accounting for heterogeneity in banks and in depositors' preferences is important, because policies produce asymmetric effects across banks (both positive and negative). For example, limits on insured deposit interest rates eliminate the possibility of the worst equilibria in terms of default rates, but also allow for equilibria with a significantly contracted amount of banking services provisions. We evaluate bank stability and welfare under different capital requirements, and find that banking stability and welfare do not necessarily go hand in hand. Increasing capital requirements past a certain point decreases welfare even if it increases banking stability. Last, we show how to use the model to evaluate optimal capital requirements. Overall, we provide a workhorse model that allows us to evaluate the stability of the banking system in the presence of run-prone uninsured deposits.

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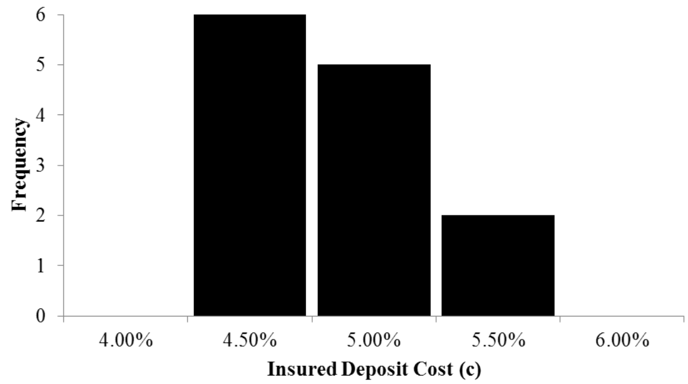
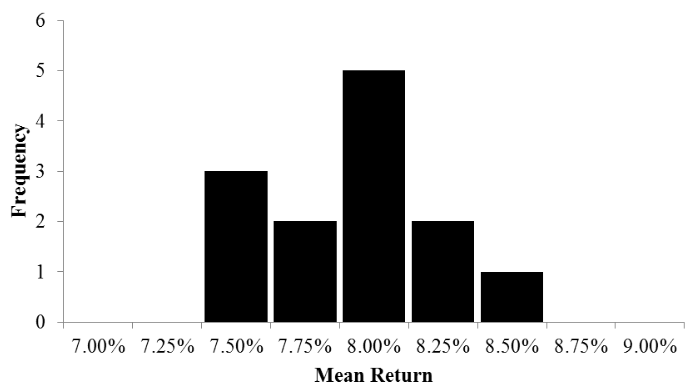
Figure 2: Calibrated Non-Interest Cost of Insured Deposits



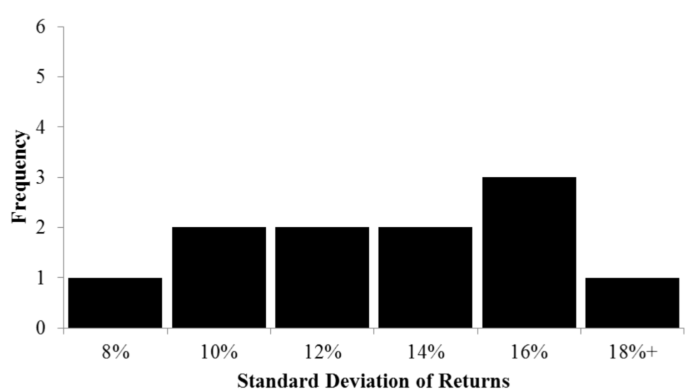
Notes: Figure 2 plots the calibrated non-interest cost of insured deposits as of 03/31/2008.

Figure 3: Calibrated Mean Return on Deposits



Notes: Figure 3 plots the calibrated mean return on deposits as of 03/31/2008.

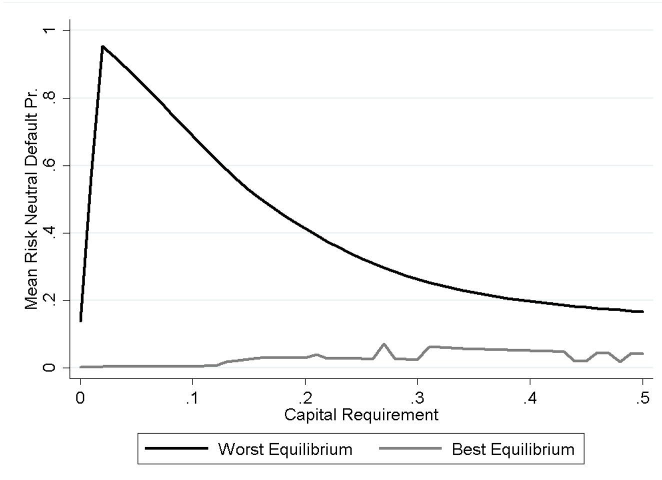
Figure 4: Calibrated Standard Deviation of Return on Deposits



Notes: Figure 4 plots the calibrated standard deviation of the return on deposits as of 03/31/2008.

Figure 5: Capital Requirements

Panel A: Banking Stability and Capital Requirements



Panel B: Welfare and Capital Requirements

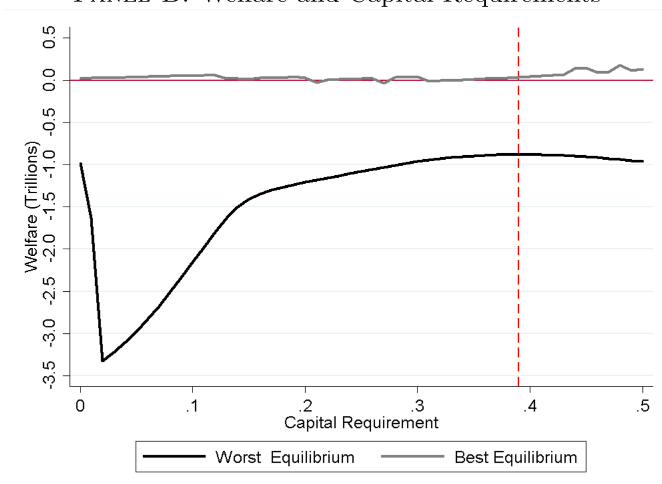
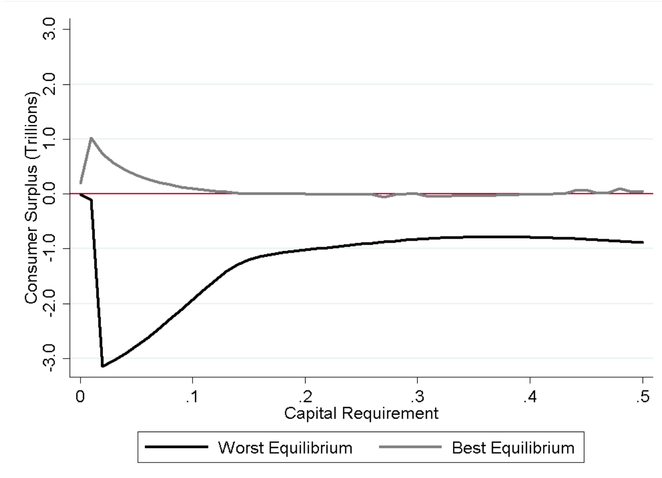
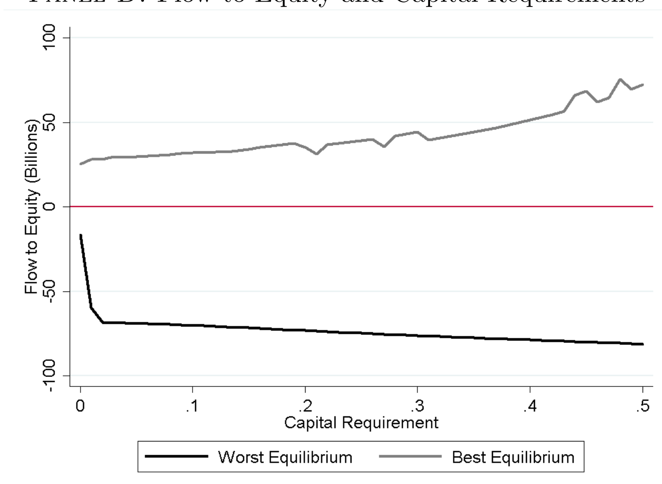


Figure 5: Capital Requirements

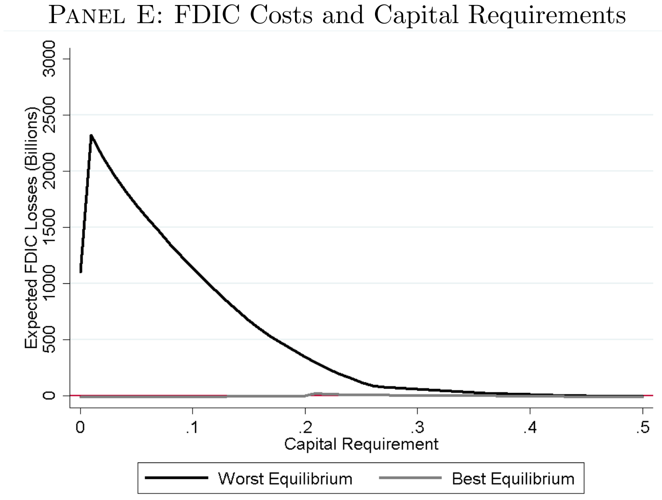
Panel C: Consumer Surplus and Capital Requirements



Panel D: Flow to Equity and Capital Requirements

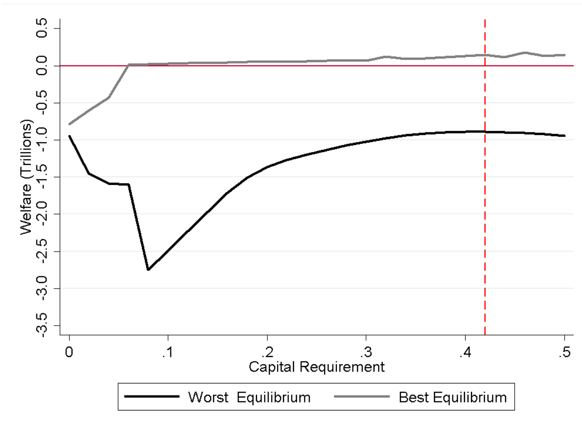


Panel E: FDIC Costs and Capital Requirements

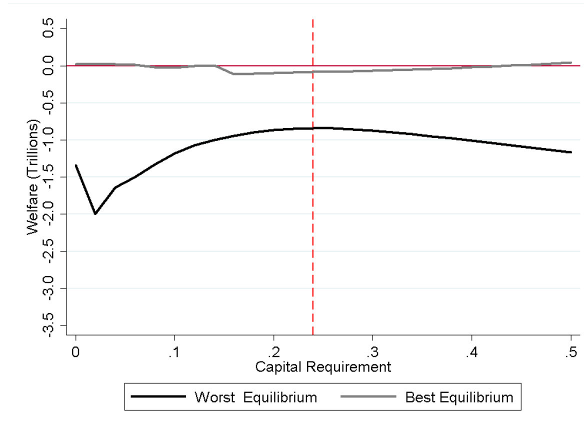


Notes: Figure 5 plots the probability of default (averaged across banks), welfare, consumer surplus, annualized equity value, and expected FDIC losses in the worst and best equilibria as of 03/31/2008. The best/worst equilibria are defined in terms of the relevant measure (probability of default, welfare, etc.). As detailed in the Appendix, welfare, consumer surplus, annualized equity value, and expected FDIC losses are reported relative to their respective values in the observed equilibrium.

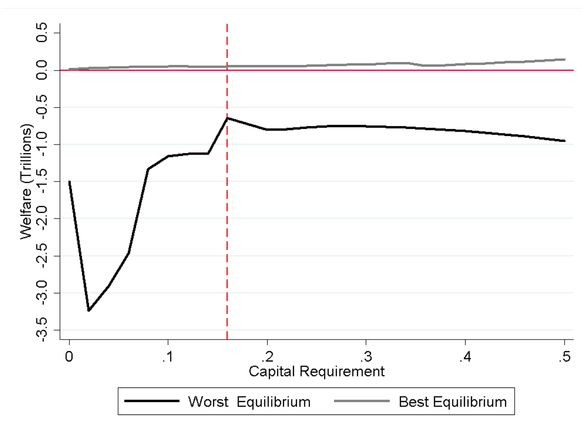
Figure 6: Capital Requirements Under Alternative Specifications



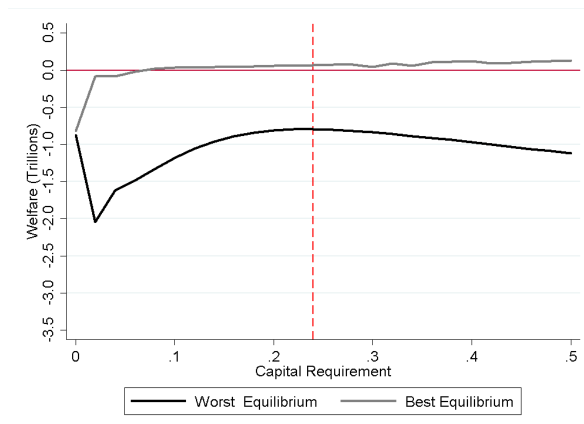
(a) Capital Req.(8%)



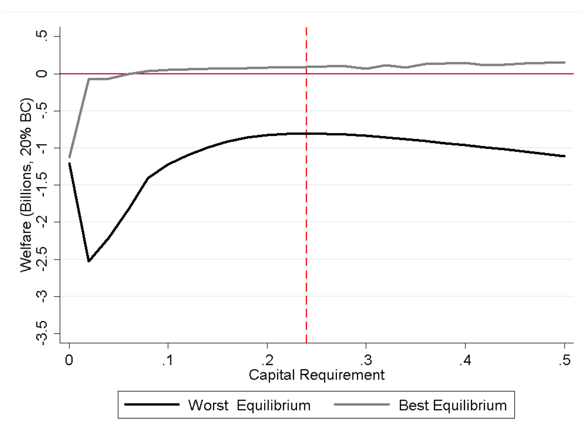
(b) Too Big To Fail



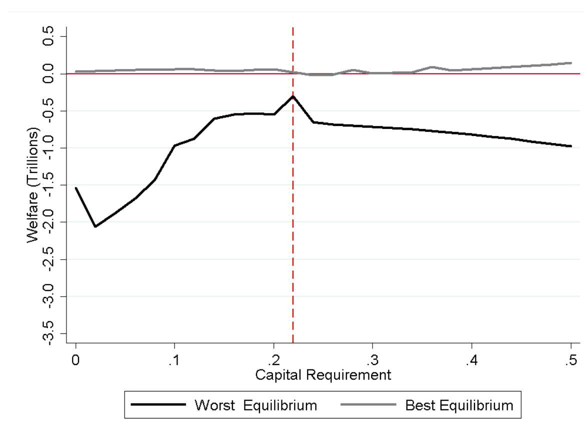
(c) Capital Adj Costs (5%)



(d) Capital Req, Adj Costs and TBTF



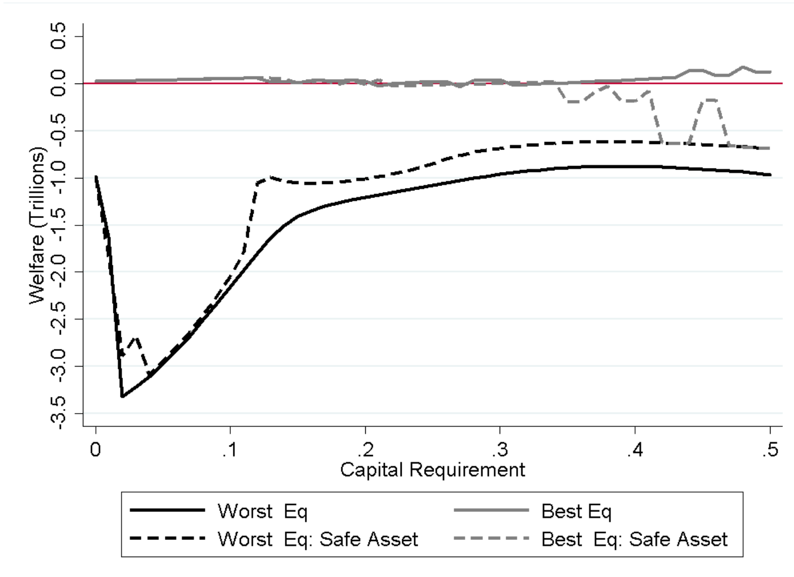
(e) Capital Req, Adj Costs, TBTF, and Bankruptcy Costs



(f) Insured Depositor Run

Notes: Figure 6 Panels (a)-(f) plots the welfare in the worst and best equilibria as of 03/31/2008 as a function of capital requirements for each model perturbation. The best/worst equilibria are defined in terms of welfare. As detailed in the Appendix, welfare, consumer surplus, annualized equity value, and expected FDIC losses are reported relative to their respective values in the observed equilibrium. The model pertubations reported in Panels (a)-(f) are as follows. In Panels (a), (d), and (e), we calibrate to existing capital requirements of 8%. In Panels (b), (d), and (e), we allow for investors to anticipate a too-big-to-fail policy where the government bails out uninsured depositors with 50% probability. In Panels (c), (d), and (e), we calibrate the model with the deadweight cost of external financing, which is proportional to the amount of funds injected, with a constant marginal cost of 5%. In Panel (e) we report the welfare corresponding to a bankruptcy cost of 20%. Last, in Panel (f) we report the results if insured depositors were also sensitive to bank default risk, with sensitivity $\gamma^I = .5\gamma$. Full details for each model perturbation are reported in Section 8 and the Appendix.

Figure 7: Risk Free Capital Requirements



Notes: Figure 7 plots the welfare in the worst and best equilibria as of 03/31/2008 as a function of capital requirements. The best/worst equilibria are defined in terms of welfare. The black and gray solid lines plot welfare in the worst/best equilibria in our baseline specification, where banks are allowed to co-invest the required capital along with the bank's deposits in the risky asset. The black and gray dashed lines plot welfare in the worst/best equilibria if banks are required to co-invest the required capital in safe assets. Full details for the alternative risk-free capital requirements model are discussed in Section 8.4 and the Appendix.

Table 1: Deposit Level, Interest Rate and CDS Summary Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
Ins. Deposits ($bn)	566	141.0	162.0	11.27	845.6
Unins. Deposits ($bn)	566	160.8	205.2	4.083	939.0
CDS Spread	566	0.83%	0.88%	0.05%	5.47%
Deposit Spread (Min. Dep.=$10k)	566	-0.31%	0.71%	-2.66%	2.03%
Deposit Spread (Min. Dep.=$100k)	564	-0.22%	0.70%	-3.67%	2.03%

Notes: Table 1 displays the summary statics corresponding to our retail bank data set, which consists of an unbalanced panel of sixteen of the largest U.S. banks over the period 2002-2013. Observations are bank by quarter. We measure the level of insured and uninsured deposits as per the FDIC's Statistics on Depository Instutitions. We measure CDS at the monthly level using the average daily CDS spread for the five-year CDS contract as reported by Markit. We measure the deposit rate offered by each bank using the median one-year CD rate offered by each bank across all of its branches in a given month as reported by RateWatch. We separately examine the certificate of deposit rates offered for accounts with minimum deposit amounts of $10k and $100k. We report the deposit rate spread, which reflects the one-year certificate of deposit rate relative to the corresponding one-year treasury rate.

Table 2: Deposits and Financial Distress

	Unins. Deposits	Unins Deposits	Ins. Deposits
Prob of Default	-1.98**	-2.13*	-0.16
	(0.96)	(1.14)	(1.04)
Share Difference (Unins.-Ins.)	X		
Quarter Fixed Effects	X	X	X
Bank Fixed Effects	X	X	X
Observations	566	566	566
R-squared	0.949	0.970	0.948

Notes: Table 2 displays the regression of a bank's logged deposit share on its probability of default. Each regression is estimated using an unbalanced panel of sixteen of the largest U.S. banks with quarterly observations over the period 2002-2013. All specifications control for the number of bank branches. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 3: Demand Estimates

	Demand Estimates				Placebo for Default Prob		
	Unins. Deposits			Ins. Deposits	Ins. Deposits		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Deposit Rate	12.62*	18.21***	16.64***	58.79***	59.70***	54.96***	55.35***
	(7.49)	(6.08)	(5.80)	(8.16)	(8.63)	(8.14)	(8.18)
Prob of Default	-18.61***	-10.66*	-12.60**		4.01	-2.86	-1.79
	(7.21)	(5.83)	(5.29)		(5.66)	(5.33)	(4.33)
IV-0 (Pass-Through)	X	X	X	X	X	X	X
IV-1 (CMOs)	X		X		X		X
IV-2 (Loans)		X	X			X	X
Observations	564	564	564	566	566	566	566
R-squared	0.958	0.966	0.964	0.917	0.915	0.921	0.921

Notes: Table 3 displays the demand estimates for uninsured and insured deposits. The dependent variable in each specification is the log of a bank's market share. Each demand specification is estimated using an unbalanced panel of sixteen of the largest U.S. banks with quarterly observations over the period 2002-2013. Each observation is weighted by the square root of the market size. All specifications include bank and quarter fixed effects and control for the number of bank branches. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table 4: Multiple Equilibria 2008

	Obs	(2)	(3)	(4)	(5)	(6)	(7)
Insured Interest Rate							
JPMorgan Chase	1.73%	0.98%	2.46%	2.65%	2.44%	10.48%	3.17%
Bank of America	1.98%	1.53%	2.13%	7.33%	2.14%	2.44%	2.46%
Wells Fargo	2.13%	2.05%	10.04%	3.06%	3.04%	3.58%	3.68%
Citi Bank	2.23%	2.11%	3.01%	3.21%	2.98%	3.72%	12.26%
Wachovia	2.08%	2.04%	2.59%	2.62%	8.75%	2.93%	2.98%
Uninsured Interest Rate							
JPMorgan Chase	1.73%	0.94%	2.41%	2.56%	2.39%	20.35%	3.02%
Bank of America	1.97%	1.40%	1.94%	11.43%	1.96%	2.23%	2.24%
Wells Fargo	2.32%	2.25%	17.41%	3.21%	3.20%	3.71%	3.81%
Citi Bank	2.23%	2.13%	2.94%	3.09%	2.92%	3.52%	24.35%
Wachovia	2.23%	2.19%	2.67%	2.71%	14.06%	3.00%	3.04%
Probability of Default							
JPMorgan Chase	1.50%	0.19%	2.86%	3.29%	2.83%	48.35%	4.37%
Bank of America	1.82%	0.03%	1.85%	53.34%	1.94%	3.21%	3.27%
Wells Fargo	1.50%	1.34%	46.61%	3.56%	3.49%	4.81%	5.06%
Citi Bank	2.11%	1.92%	3.36%	3.74%	3.33%	4.63%	48.20%
Wachovia	3.28%	3.14%	4.74%	4.92%	52.08%	5.96%	6.12%
Insured Deposit Share							
JPMorgan Chase	3.38%	2.26%	1.00%	1.84%	1.30%	83.89%	0.91%
Bank of America	9.26%	7.39%	1.94%	68.34%	2.57%	1.75%	1.42%
Wells Fargo	3.99%	3.96%	80.41%	2.19%	1.73%	1.35%	1.14%
Citi Bank	2.07%	2.00%	0.63%	1.17%	0.82%	0.72%	86.68%
Wachovia	5.81%	5.89%	1.51%	2.53%	74.47%	1.38%	1.14%
Cumulative Share	24.51%	21.50%	85.49%	76.08%	80.88%	89.09%	91.29%
Uninsured Deposit Share							
JPMorgan Chase	15.86%	16.06%	15.96%	16.62%	16.06%	1.19%	17.09%
Bank of America	9.23%	10.32%	9.76%	0.08%	9.75%	10.03%	10.04%
Wells Fargo	4.30%	4.25%	0.19%	4.40%	4.16%	4.43%	4.39%
Citi Bank	16.80%	16.58%	17.23%	18.04%	17.33%	18.79%	2.51%
Wachovia	4.74%	4.70%	4.52%	4.77%	0.08%	4.76%	4.73%
Cumulative Share	50.93%	51.91%	47.67%	43.91%	47.36%	39.19%	38.77%
FDIC Ins. Cost	$14bn	$8bn	$1,002bn	$979bn	$1,037bn	$1,086bn	$1,118bn
Change in Welfare	-	$20bn	-$1,143bn	-$1,205bn	-$1,221bn	-$1,332bn	-$1,365bn

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)-(7) 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 5 - Panel A: Counterfactual Analysis - FDIC Insurance

Bank	Prob. of Default.	Counterfactual	Δ Ins. Cost
JPMorgan Chase	1.50%	1.51%	\$50m
Citi Bank	2.11%	2.13%	\$76m
Bank of America	1.82%	1.84%	\$56m
Wells Fargo	1.50%	1.51%	\$17m
Wachovia	3.28%	3.30%	\$67m

Notes: Column (1) displays the realized equilibrium probability of default as of 03/31/2008. Column (2) displays an equilibrium probability of default if the FDIC were to insure an additional 1% of uninsured deposits. The additional insured deposits are assumed to be treated as a new type of deposit that is valued by consumers similarly to uninsured deposits, except that depositors are insensitive to default risk (i.e., $\gamma = 0$). We calculate and select the reported new equilibrium using a non-linear equation solver (we use the R package NLEQSLV with Broyden's Method) initiated at the observed equilibrium. Column (3) displays the change in the hypothetical equilibrium cost of the FDIC policy change relative to the old policy. We calculate the cost change as the difference in expected insurance payout. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate. Negative values represent a surplus to the FDIC.

Table 5 - Panel B: Counterfactual Analysis - FDIC Insurance

Bank	Prob. of Default.	Counterfactual	Δ Ins. Cost
JPMorgan Chase	1.50%	1.37%	-\$95m
Citi Bank	2.11%	2.02%	-\$51m
Bank of America	1.82%	1.72%	-\$174m
Wells Fargo	1.50%	1.42%	-\$67m
Wachovia	3.28%	3.20%	-\$82m

Notes: Column (1) displays the realized equilibrium probability of default as of 03/31/2008. Column (2) displays an equilibrium probability of default if the FDIC were to insure an additional 1% of uninsured deposits. The additional insured deposits are assumed to be treated identically to existing insured deposits. We calculate and select the reported new equilibrium using a non-linear equation solver (we use the R package NLEQSLV with Broyden's Method) initiated at the observed equilibrium. Column (3) displays the change in the hypothetical equilibrium cost of the FDIC policy change relative to the old policy. We calculate the cost change as the difference in expected insurance payout. We calculate the expected insurance payout as the weighted sum of insured deposits weighted by the probability of default, assuming a 40% recovery rate. Negative values represent a surplus to the FDIC.

TABLE 6 - PANEL A: ALTERNATIVE SPECIFICATIONS, CALIBRATED PARAMETERS

Calibration/Model	Mean Return (μ)	Std. Dev. of Returns (σ)	Non-Interest Cost (c)
Baseline Model	7.80%	15.94%	4.67%
Alternative Specifications:			
Capital Req.(8%)	7.56%	18.38%	4.67%
Capital Adj. Costs (5%)	8.19%	11.35%	4.67%
TBTF (50%)	7.40%	14.72%	4.67%
Capital Rq., Adj. & TBTF (50%)	7.68%	13.38%	4.67%

TABLE 6 - PANEL B: ALTERNATIVE SPECIFICATIONS, OPTIMAL CAPITAL REQUIREMENT

Calibration/Model	Optimal Capital Req. κ
Baseline Model	39%
Alternative Specifications:	
Insured Depositor Run	22%
Capital Req.(8%)	42%
Capital Adj. Costs (5%)	16%
TBTF (50%)	24%
Capital Rq., Adj. & TBTF (50%)	24%
Capital Rq., Adj., TBTF (50%) & Bankruptcy Costs (20%)	24%

Notes: Table 6 Panels A and B display the calibrated parameters and optimal capital requirements under the alternative 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. First, we calibrate the model to existing capital requirements of 8%. Second, we calibrate the model where investors anticipate a "Too Big To Fail" (TBTF) policy where the government bails out uninsured depositors with 50% probability. Third, we calibrate the model with capital adjustment costs (deadweight cost of external financing), which is proportional to the amount of funds injected, with a constant marginal cost of 5%. And last, we calibrate the model to existing capital requirements, under the TBTF policy and with capital adjustment costs. We examine the optimal capital requirements if insured depositors are run prone (sensitivity $\gamma^I = 0.5\gamma$) and with bankruptcy costs of 20%. The addition of bankruptcy costs and/or run-prone insured depositors does not impact the calibration of the model. The details of each alternative specification are discussed in Section 8 and the Appendix.

Appendix For Online Publication

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:

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

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

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 8, 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[46]:

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

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

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

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,

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

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

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

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

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

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

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

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

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

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 8, 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 $b_k - M^I s^I_{k,t}\left(R_{k,t}-c_k-i^I_{k,t}\right) - M^N s^N_{k,t}\left(R_{k,t}-i^N_{k,t}\right)$, 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

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

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

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

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

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

Calibration:

In Section 8, 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.[47]

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

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

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

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

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[48] 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

[47] Specifically we use the R package NLEQSLV and use Broyden's Method with a tolerance of 10e-12.
[48] 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%.[49] 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[50] 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[51] 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

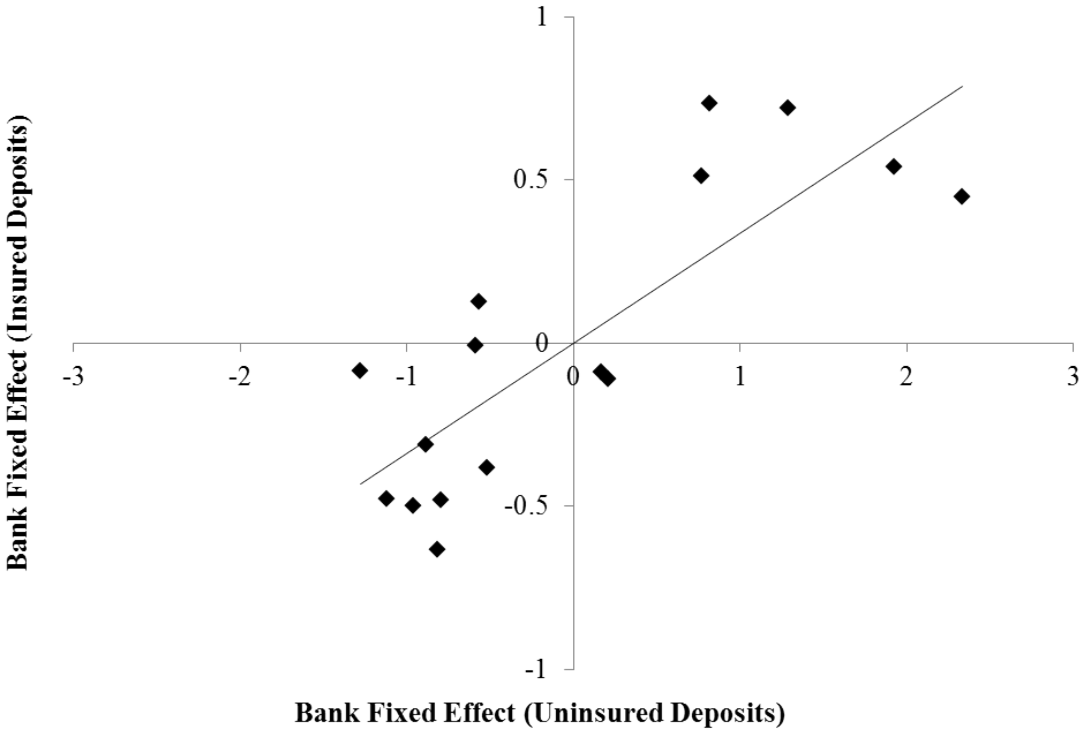
The recent financial crises prompted regulators to examine putting risk limits on financial institutions. We use our model to consider the effect of limiting the risk that banks are eligible to undertake. Specifically, we impose a counterfactual policy in which banks are forced to hold securities/investments 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.

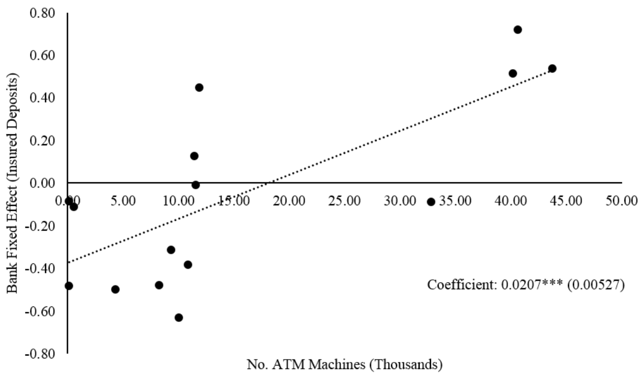
[49] In the baseline model we let κ range from 0 to 50% in increments of 1%.
[50] Specifically we use the R package NLEQSLV with Broyden's method.
[51] Specifically we use the R package NLEQSLV with Broyden's method.

Figure A1: Demand Estimates - Bank Brand/Fixed Effects

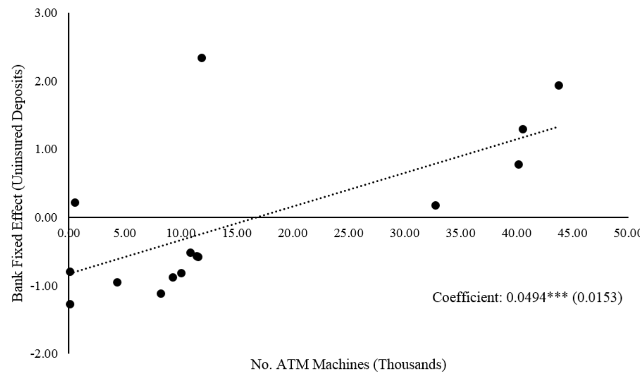


Notes: Figure A1 displays the estimated bank fixed effects corresponding to column (1) and (3) in Table 3.

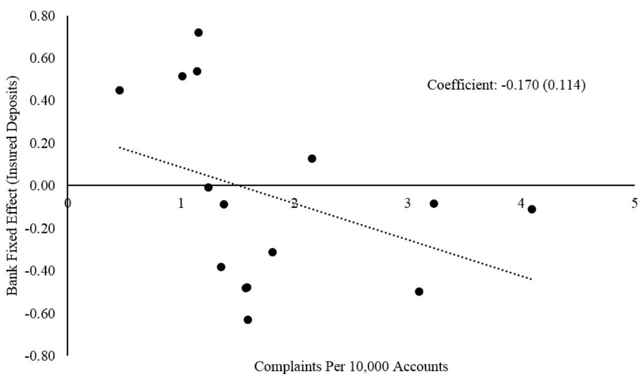
Figure A2: Bank Brand/Fixed Effects vs. Bank Quality



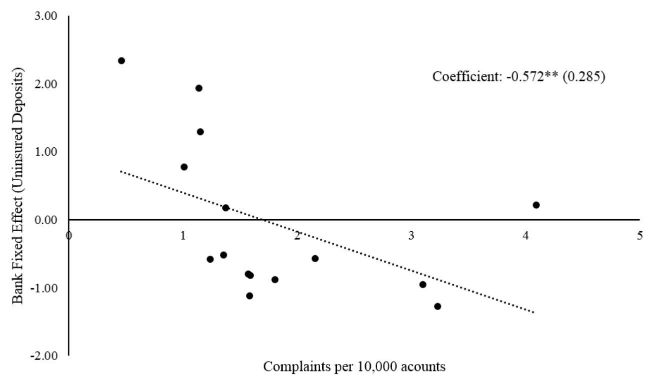
(a) Bank Brand Effects (Ins) vs. No. of ATM Machines



(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.