Investigating Excess Reserve Accumulation and Credit Crunch in U.S. Commercial Banks Focusing on the Financial Crisis

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Excess Reserve Accumulation and Credit Crunch in U.S. Commercial Banks during the Global Financial Crisis*

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Abstract

This paper using bank-specific data for the period 1999-2009 investigates the excess reserve accumulation and credit crunch in the US commercial banking industry during the financial crisis of 2007-2008. During the sample period, the lending and reserve behaviors of large banks significantly differ from those of small banks. A large amount of excess reserve builds up in the large banks during the crisis whereas excess reserve of small banks remains stable at low levels. Large banks experience severe credit crunch during the crisis which the small banks are able to avert. Employing a two-stage model of the banking industry that treats large and small banks separately, I demonstrate that among other factors, differences in idiosyncratic uncertainties in the form of volatility of deposits and short-term funding and disparities in investments in risky trading securities can generate similar patterns observed in data. I also address the ongoing debate between two schools of thought, one of which attributes the buildup of excess reserves and reduction in interbank lending to liquidity hoarding due to precautionary motive, while the other ascribes these to an increase in counterparty risk. I demonstrate that counterparty risk plays a greater role over the short run whereas the impact of liquidity hoarding is more prominent over the long run.

KEYWORDS: excess reserves; bank loans; deposit volatility; trading securities; liquidity hoarding; counterparty risk

1. Introduction

Excess reserve holdings in U.S. commercial banks increased dramatically during the financial crisis of 2007-08 (Ashcraft et al., 2009; Keister and McAndrews, 2009; Ennis and Wolman, 2011; Günter, 2012). A large accumulation of excess reserves in the banking system can constitute a variety of serious problems. Myers and Rajan (1998) focusing on the "dark side of liquidity," stress that greater liquidity reduces a financial institution's capacity to raise external finances by reducing its ability to commit to a specific course of action. Several authors argue that in addition to exerting significant inflationary pressure, excess liquidity in the banking system makes the use of monetary policy for stabilizing the economy largely ineffective (e.g., Nissanke and Aryeetey, 1998; Agénor et al., 2004; Saxegaard, 2006; Acharya and Merrouche, 2010). Edlin and Jaffee (2009) identify the high level of excess reserves in the U.S. banks during the financial crisis as either the problem behind the continuing credit crunch or a severe symptom of the problem. As a result of these

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potential negative consequences, several authors recommend drastic regulations to curb excess reserves in the banking system (e.g., Dasgupta, 2009; Mankiw, 2009; Sumner, 2009).

In this paper, I identify that the large accumulation of excess reserves in the U.S. commercial banking industry during the global financial crisis is primarily due to excess reserves buildup in the large banks. Using banking institution–specific data on U.S. commercial banks between 1999 and 2009, I notice that large banks generally hold much larger amounts of excess reserves than small banks, and their reserves increase substantially during the financial crisis with small banks' reserve holdings remaining more or less stable at low levels throughout. In addition, large banks reduce their real sector lending over the years whereas the opposite is true for small banks. These observations give rise to the following interrelated questions: Why do excess reserves of large commercial banks increase so much during the financial crisis whereas excess reserves of small banks remain stable at low levels? Why do large commercial banks' lending activities reduce over the years compared to small banks'?

I demonstrate that overall, large banks hold larger excess reserves and extend a smaller amount of loans compared to small banks, primarily due to the former being exposed to larger idiosyncratic uncertainties in the form of volatility of deposit and short-term funding and investing heavily in risky trading securities. Uncertainties in deposit financing lead to liquidity hoarding due to a precautionary motive whereas increased investments in risky trading securities together with increased macro risk reduce interbank lending and elevate excess reserves by raising counterparty risk. I address the ongoing debate between two schools of thought, one of which attributes the accumulation of excess reserves and drying up of interbank lending to liquidity hoarding due to a precautionary motive, while the other ascribes these to an increase in counterparty risk. I illustrate that in terms of explaining the increase in excess reserves and decrease in loans during the financial crisis, counterparty risk plays a greater role over the short run whereas the impact of liquidity hoarding is more dominant over the long run.

I employ a stochastic two-stage model where large and small banks are treated separately. These banks choose real sector lending in stage 1 and the amount of interbank lending/borrowing and excess reserves in stage 2. Assuming exogenous capital funding (deterministic), deposit financing (stochastic with known distribution) and investments in trading securities, the model endogenously generates predictions for real sector lending, interbank lending/borrowing and excess reserves. Increased dispersion of the distribution of deposits and short-term funding raises excess reserves by increasing uncertainty in availability of funds in an environment where loan commitments must be met. Banks' increased investments in risky trading securities, on the other hand, exert upward pressure on excess reserves by increasing the costs of monitoring these banks in the interbank market.

Calibrating the model to the U.S. banking sector, I perform numerical analysis that generates patterns similar to what is observed in data as to how lending and excess reserves have evolved in large and small commercial banks in the U.S. over the period of 1999 to 2009. Excess reserves received a lot of attention following the financial crisis of 2007-2008 as evident by the comment made by Mankiw (2009) that with banks holding substantial excess reserves, the historical concern about cash hoarding suddenly seems to be very modern. A number of authors attempt to explain this recent proliferation of excess reserves in the U.S. banking system and/or the simultaneous fall in interbank lending and borrowing activities (e.g., Allen et al., 2009; Ashcraft et al., 2009; Keister and McAndrews, 2009; Afonso et al., 2011; Günter, 2012). Keister and McAndrews (2009) explain the phenomena through a hypothetical example, arguing that the increase in excess reserve holdings simply reflects the size of policy initiatives of the central bank. Ashcraft et al. (2009)

present a partial equilibrium model of banking incorporating credit and liquidity frictions in the interbank market. They use daily trading data covering a period from September 2007 to August 2008 and explain the reserve holdings through daily liquidity requirements. Their theoretical results show that banks rationally hold excess reserves intraday and overnight as a precautionary measure against liquidity shocks. Allen et al. (2009) develop a model with incomplete markets with symmetric information, which results in limited hedging opportunities for banks. In their model, in the face of increased aggregate uncertainty banks hold excess reserves to meet potential high aggregate liquidity demand. Afonso et al. (2011) compare the roles of counterparty risk and liquidity hoarding in explaining the drying up of federal fund loans during the recent financial crisis in the U.S. Using daily trading data on 360 borrowing banks and 373 lending banks for the period April 2008 to February 2009, they find that counterparty risk plays a larger role than liquidity hoarding. Günter (2012) extends a small-scale DSGE model with an explicit banking sector and attempts to explain the high excess reserve holdings of U.S. banks and low interbank borrowing and lending activities through uncertainties in net deposit inflows and limited access to the federal funds market. The paper assumes that an exogenous proportion of banks simply cannot access the interbank market. In equilibrium, liquidity rich banks that can access the interbank market lend to liquidity deficient banks, and those that cannot access the market pile up excess reserves.

This study differs from the existing literature in several ways. The existing studies that incorporate banking data in their analyses either use bank-level data on a small subset of banks and study excess reserves and/or interbank lending over a short period of time, or use aggregate banking sector data to study the issues over the long term. In contrast, this paper uses bank-specific data on a comprehensive sample of banks over a long period of time and unlike any other paper identifies that large and small commercial banks differ significantly in their loan and reserve behavior. This paper – also unlike any previous study – identifies the differences in idiosyncratic uncertainties faced by large and small banks and the differences in investments in trading securities between these bank groups and uses these to explain the observed disparities in their lending and reserve behavior. Another novel contribution of this paper is that it combines the roles of liquidity hoarding and counterparty risk together in the same framework and demonstrates that the impact of counterparty risk is more important in the short run whereas liquidity hoarding plays a greater role in the long run in explaining the increase in excess reserves and decrease in lending.

The rest of this paper is organized as follows. Section 2 provides a detailed analysis of the observed data patterns in the U.S. commercial banking industry, focusing on the differences between large and small banks. Section 3 presents the theoretical framework of the study. Section 4 explains the calibration process and provides a summary of the values of calibrated parameters and exogenous variables. Section 5 provides theoretical and numerical analyses of the model, reports all the results, compares the role of counterparty risk to that of liquidity hoarding. Section 6 concludes.

2. Data

I obtain data on U.S. banks from the 2010 version of Bankscope database, a database of banks' financial statements, ratings and intelligence, reported by the Bureau Van Dijk.[1] Although the database contains data on U.S. banks since 1987, its coverage of banks per year till 1998 is very limited. In order to properly represent the U.S. banking industry as well as have consistency in data coverage, I use data for the years 1999 to 2009. The final sample includes a total of 87,336 bank-year observations and 9,297 unique banks. The sample includes 7,940 banks on average per year with a maximum of 8,303 banks in 2003 and a minimum of 7,276 banks in 2009.

In this study, excess reserves (ER) are calculated as:

$$ER = Total\ Reserves - Required\ Reserve = Liquid\ Assets - \theta(NTA)$$

where θ and NTA denote required reserve ratio and net transaction accounts, respectively.[2] Instead of focusing on only cash in vaults and reserves with the Federal Reserve (primary reserves), this measure of excess reserves includes both primary and secondary reserves (treasury bills, interest-earning deposits, dues from other banks, trading securities, etc.) to provide a more comprehensive measure of bank liquidity. While these reserves provide liquidity to the banks, they hinder profitability since they generally earn little or no interest.[3]

Bank size in a given year is determined by the amount of deposits and short-term funding a bank has in that year. I use deposits and short-term funding instead of total assets to measure bank size because deposits and short-term funding are assumed to be exogenous in my model whereas a number of key components of total assets such as lending to the real sector, interbank loans and excess reserves are not. Even if I use total assets to measure bank size, there would be no qualitative change in data patterns given that deposits and short-term funding and total assets are just about perfectly positively correlated (the yearly average correlation coefficient between the two series is 0.996 for my sample period). For each year, I define large banks as the largest 25 banks and small banks as 75% of the smallest banks in the commercial banking industry. I define large and small banks in this way with a view to identifying differences in data patterns between the largest and the smallest banks while accommodating as many banks as possible in the analysis. If I alter the definitions and use different combinations of large and small banks — for example, the largest 5 banks vs. 25% of the smallest banks or the largest 10 banks vs. 50% of the smallest banks — I do not find any qualitative difference in data patterns. Similar to Corbae and D'Erasmo (2010), I find that the commercial banking industry in the U.S. is very concentrated with the market share of deposits and short-term funding of the 25 largest banks ranging between 47.1% and 65.7% and the market share of 75% of the smallest banks ranging between 5.5% and 7.3% for the sample period.

Figure 1 shows that after being quite stable at around 10% to 11% during 1999 to 2006, the ratio of excess reserves to deposits and short-term funding in U.S. commercial banks increases to 15% in 2007 and reaches nearly 20% in 2008 before coming down to pre-crisis level in 2009. This

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[1] Another potential data source would be the Call reports that the U.S. commercial banks file with the Fed. I use Bankscope instead because it contains information on two key variables — net trading income and total liquid assets — which are missing in the Call reports. Some of the components of liquid assets are reported in the Call reports but the sum of these components does not equal total liquid assets reported in Bankscope.

[2] In the U.S., required reserves are computed by applying the required reserve ratio on *NTA*. *NTA* is computed as the difference between a bank's deposits and cash & due from banks. The required reserve ratio varies among 0%, 3% and 10% depending on the amount of *NTA* held by the bank. The *NTA* amounts vary from year to year and are set by the Federal Reserve Board. All the necessary information about the required reserves is obtained from the Fed's website.

[3] In the U.S., primary reserves earned zero interest before October 2008.

ratio in large banks is 18.7% on average for all years except 2007 and 2008; the ratio increases to 22.5% in 2007 and reaches its highest value of 28.6% in 2008. Excess reserves in small banks remain relatively stable at low levels with the ratio of excess reserves to deposits and short-term funding ranging between 1.3% and 4.4%.

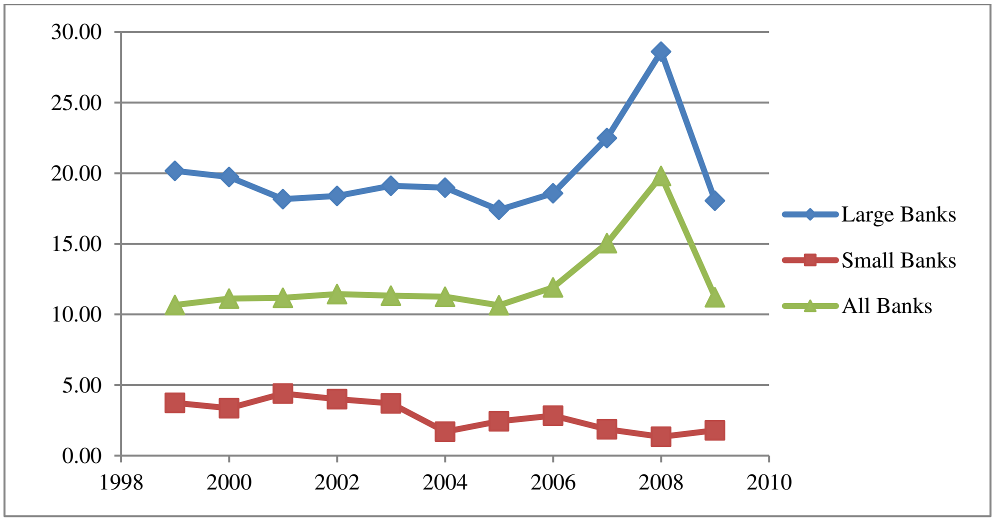

Figure 1: Excess Reserves as a Percentage of Deposits and Short-Term Funding in Large, Small and All Banks

In addition to the difference in excess reserves between large and small banks, I observe substantial disparity in lending behavior between these bank groups. During the sample period, large banks display a decreasing trend in lending activities whereas the opposite is true for small banks. This implies that the ratio of loans relative to deposits and short-term funding of large banks to small banks decreases over time. From being around 1 during 1999-2001, this ratio decreases to 0.77 in 2008. Figure 2 presents loans as a percentage of deposits and short-term funding in large, small and all banks from 1999 to 2009.

One of the factors that plays an important role in explaining the above data patterns is investments in risky trading securities.[4] During the sample period, large banks heavily invested in trading securities whereas small banks' participation in trading activities is virtually nonexistent. Figure 3 presents trading securities as a percentage of deposits and short-term funding in large, small and all banks from 1999 to 2009. As can be observed in Figure 3, large banks hold a significant amount of trading securities whereas small banks hold a negligible amount. Additionally, large banks' investments in these securities are higher during 2007 and 2008 than in any other years.

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[4] According to the Statement of Financial Accounting Standards No. 115 (SFAS 115), issued in 1993, trading securities are defined as "debt and equity securities purchased with the intent to sell in the near term." These trading securities differ from Held-to-maturity (HTM) Securities, which are defined as "debt securities that management has the positive intent and ability to hold to maturity" and Available-for-sale (AFS) securities, which are defined as "Debt and equity securities not classified as either HTM or Trading securities" (Lifschutz, 2010).

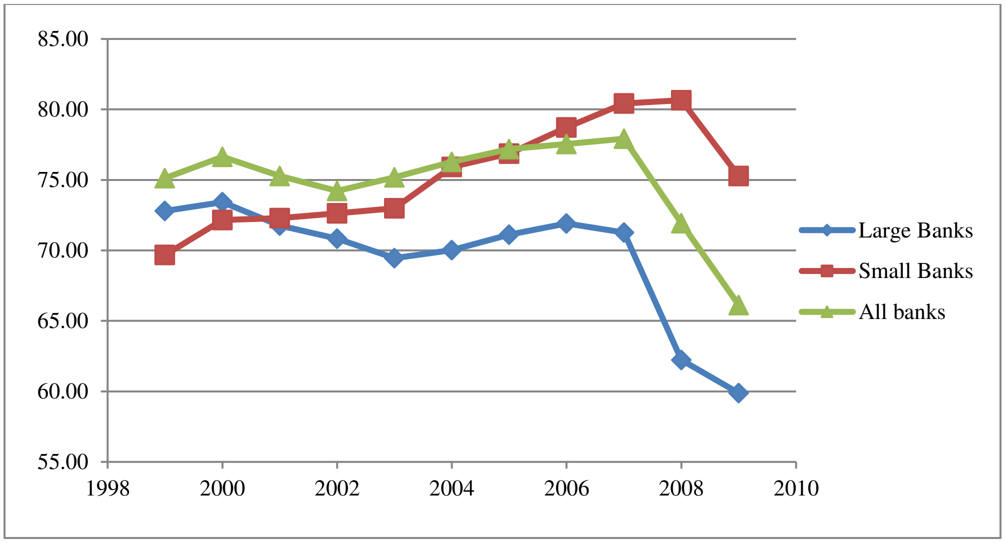

Figure 2: Loans as a Percentage of Deposits and Short-Term Funding in Large, Small and All Banks

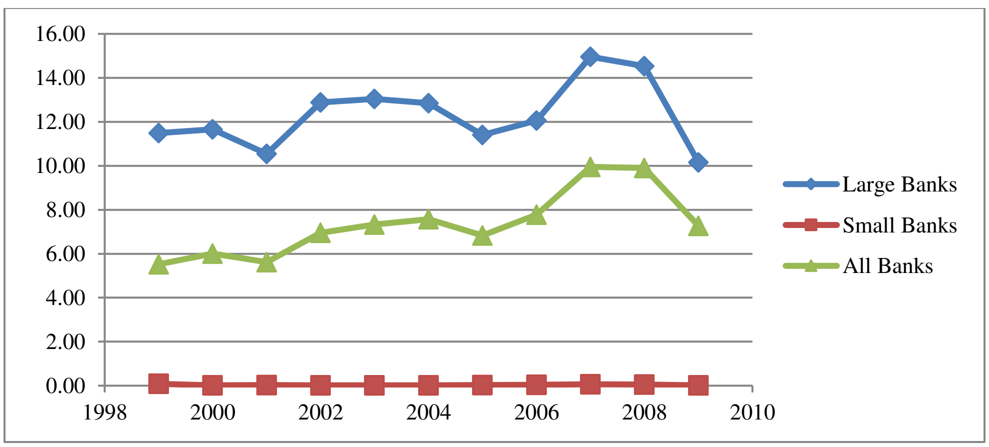

Figure 3: Trading Securities as a Percentage of Deposits and Short-Term Funding in Large, Small and All Banks

Trading activities tend to be much riskier than other forms of banking activity (Kwan, 1998; Orl, 2010). In order to compare the riskiness of different banking activities, I compute standard deviations of the logarithms of yearly net interest revenue, net trading income and other operating income for the U.S. commercial banking industry for the sample period.[5] I find that the volatility of net trading income is 9.8 times higher than that of net interest income and 9.3 times higher than that of other operating income. One interesting question is why large banks put so much money in trading securities despite these being so risky. Ex-ante underestimation of risk may be a potential candidate to explain such behavior. At the individual bank level, trading securities can potentially raise huge amount of profits. For example, in 2007, while Bank of America and Citibank N.A. lost approximately $3.2 billion and $2.8 billion, respectively, on trading securities, J.P. Morgan Chase Bank made a whopping profit of around $7.9 billion in trading activities. So, if the policymakers of a bank underestimate the risks involved and are overconfident that they have a good chance of

[5] These incomes are adjusted for inflation for the sake of comparability across years. CPI data have been computed (base year=2005) using information from the website of the U.S. Bureau of Labor Statistics.

being on the winning side, they may be inclined to invest heavily on trading securities despite their highly risky nature. It is also interesting to observe the large discrepancy between large and small banks in terms of investments in risky trading securities. One reason could be that small banks are worse than large banks at managing the risks associated with these investments.[6] The magnitude of fluctuations in net trading income for small banks lends support to this argument with the coefficient of variation of yearly net trading income for small banks being 8.7 times higher than that of the large banks.[7] Additionally, it may be that because of their size, small banks lack the necessary resources or knowledge to enter the trading market or that the cost of accessing the market or hiring skilled and trained personnel is too high for them. On the basis of the analysis performed in this section, in the theoretical framework of the study I assume for simplicity that small banks do not invest in risky trading securities. Given the very small amount that these small banks as a whole invest in trading securities (ranging from 0.02% to 0.08% of deposits and short-term funding), the conclusions derived in this paper would not change even if I did not make this assumption.

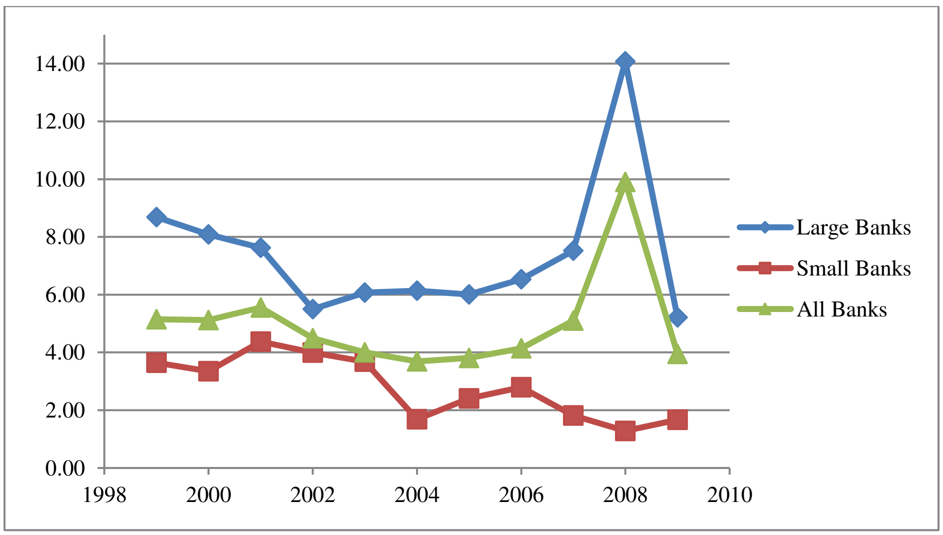

Figure 4: Excess Reserves Net of Trading Securities as a Percentage of Deposits and Short-Term Funding in Large, Small and All Bank

Since banks treat these risky trading securities as liquid assets, to get a real sense of low-earning excess liquidity I compute a measure of "risk free" excess reserves by deducting trading securities from excess reserves. Figure 4 presents excess reserves net of trading securities as a percentage of deposits and short-term funding in large, small and all banks. Although this measure decreases the difference between large and small banks, large banks' holdings of risk-free excess reserves still remain significantly higher than those of their smaller counterparts. Risk-free excess reserves relative to deposits and short-term funding in large banks on average are 2.4 times higher than those in small banks for all years except 2007 and 2008. In 2007, these are 4.2 times higher and in

[6] Although small banks' participation in trading activities is negligible, a very few small banks do participate in trading. An average of 23 small banks out of an average total of 5,955 or 0.4% of the small banks on average report non-zero net trading income each year during 1999 to 2009. In comparison, an average of 23.4 large banks out of 25 or 93.5% of the large banks report non-zero trading income each year during the sample period.

[7] Although a huge discrepancy exists in the percentage of large and small banks that participate in trading activities, this comparison is meaningful given that the average number of large banks and small banks with non-zero net trading income per year during 1999 to 2009 is almost identical.

2008, 11 times higher. In the following theoretical and numerical analyses, the term "excess reserves" implies "excess reserves net of trading securities."

The above analysis of banks' balance sheet data shows that large and small banks have major differences in how they manage loans, excess reserves and risky trading securities.[8] The analysis performed in the subsequent sections of the paper attempts to explain the differences in the first two and uses the difference in the third as part of the explanation.

3. Theoretical Framework

In each period t, mass $N_t^j, j = \{B, S\}$ of banks indexed on the interval $[0, N_t^j], j = \{B, S\}$ exist in the economy where j denotes bank type. Superscripts $'B'$ and $'S'$ identify large/ big and small banks, respectively. D_t^j and $Z_t^j, j = \{B, S\}$, respectively, denote exogenously determined deposits and bank capital. Total deposits in the banking sector are given by: $D_t^B + D_t^S = D_t$, where $D_t^j = \int_0^{N_t^j} d_t^j(i)di$, $j = \{B, S\}$. Here, i and $d_t(i)$ denote individual bank and bank-specific deposits, respectively. Equivalently, total bank capital in the banking sector is given by: $Z_t^B + Z_t^S = Z_t$, where $Z_t^j = \int_0^{N_t^j} z_t^j(i)di$. Here, $z_t(i)$ denotes bank-specific capital. Banks pay rental rate r_t^Z to rent capital and deposit rate r_t^D on deposits.[9] Loans to the real sector are denoted by $l_t^j(i), j = \{B, S\}$.

Banks invest an exogenously determined proportion ψ_t^j, $j = \{B, S\}$ of their deposits in risky trading securities $TS_t^j(i), j = \{B, S\}$ and earn a rate of return r_t^{TS}. I assume that small banks do not invest in trading securities, i.e., $TS_t^S(i) = 0$ and $\psi_t^S = 0$ on the basis of the evidence provided in section 2. Banks maintain a fraction $\theta_t^j, j = \{B, S\}$ of their deposits as statutory required reserves, $RR_t^j(i), j = \{B, S\}$ and spend a proportion $\gamma_t^j, j = \{B, S\}$ of their deposits on other assets.

Similar to Günter (2012), I assume that there is no uncertainty in bank capital inflows but that net deposit inflows are stochastic.[10] Let $f(d_t^j(i))$ and $F(d_t^j(i))$ denote the probability density function (*pdf*) and cumulative distribution function (*cdf*), respectively, of stochastic deposit realization of bank i of type $j = \{B, S\}$. Assume that the deposits come from normal distribution with mean μ_t^j and standard deviation σ_{jt}, i.e., $d_t^j(i) \sim N(\mu_t^j, \sigma_{jt}^2))$, $j = \{B, S\}$. The distribution of deposits is common knowledge, but an individual bank does not initially know its own deposit realization. To address the Basel II accords, similar to Dib (2010) and Günter (2012) I include a minimum capital requirement constraint (the ratio of bank capital to real sector loans must be greater than a minimum level) in the banks' optimization problem. This implies that real sector loans extended by a bank are bounded up by the minimum capital requirement: $l_t^j(i) \leq \kappa z_t^j(i)$, $j = B, S$, where κ denotes the inverse of the minimum capital to loan ratio. The uncertainty in the decision-making process stems from the key assumption that individual bank-specific net deposit

[8] There is not much difference between large and small banks in terms of other forms of assets and capital as explained in Web Appendix A.

[9] r_t^Z is assumed to be greater than r_t^D. The higher interest rate on bank capital together with a minimum capital requirement (discussed later) address the real resource cost of lending underscored by Baltensperger (1980) and justify a higher lending rate r_t^L than deposit rate r_t^D.

[10] Equivalently, bank-specific uncertainty can be thought of in terms of stochastic deposit outflows. However, as suggested by Kaufman and Lombra (1980) and supported by Günter (2012), one bank's outflow is generally another bank's inflow. Therefore, the corresponding probability distribution should be identical.

inflows are not realized until banks obtain bank capital and choose how much loan to extend to the real sector. The loan commitments a bank makes must be met.

Once loans are chosen and deposits are realized, banks can enter the interbank market and engage in interbank lending and borrowing depending on their deposit realizations. Banks with deposit realizations lower than what is required to extend the desired amount of loans would like to be borrowers in the interbank market. Large banks pay an interest rate ρ^B whereas small banks pay an interest rate ρ^S to borrow funds from the interbank market. A difference in interest rates exists due to differences in costs of monitoring large and small banks in the interbank market, which is discussed later. For a large bank with low deposit realization, total interbank borrowing is given by: $b_t^B(i) = b_{Bt}^B(i) + b_{St}^B(i) = l_t^B(i) - (1 - \theta_t^B - \gamma_t^B - \psi_t^B)d_t^B(i) - z_t^B(i)$. Here, $b_t^B(i)$ denotes total federal funds borrowing of large bank i, $b_{Bt}^B(i)$ denotes the amount that large bank i borrows from other large banks and $b_{St}^B(i)$ denotes the amount that large bank i borrows from small banks. For small banks with low deposit realizations, total interbank borrowing is given by: $b_t^S(i) = b_{Bt}^S(i) + b_{St}^S(i) = l_t^S(i) - (1 - \theta_t^S - \gamma_t^S)d_t^S(i) - z_t^S(i)$. $b_t^S(i)$ denotes the total amount that small bank i borrows from the interbank market, $b_{Bt}^S(i)$ the amount borrowed from large banks and $b_{St}^S(i)$ the amount borrowed from other small banks. Banks with deposit realizations higher than that required to extend the desired amount of loans, on the other hand, may become lenders in the interbank market and/or may simply keep the additional available liquidity as excess reserves $x_t^j(i), j = B, S$, and earn interest rate r_t on excess reserves. All banks earn this same rate on required reserves also. The lender banks face costs of monitoring the borrower banks. The costs of monitoring large and small banks are given, respectively, by:

$$C(m_{Bt}^j(i)) = \frac{\Delta_t^j}{2}(m_{Bt}^j(i))^2\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right), j = B, S$$

$$C\left(m_{St}^j(i)\right) = \frac{\Delta_t^j}{2}(m_{St}^j(i))^2\sigma_{t_{(Y/Y_T)}}, j = B, S$$

where, $m_{Bt}^j(i),\ j = \{B, S\}$ denotes the amount large or small bank i lends to large banks and $m_{St}^j(i),\ j = \{B, S\}$ denotes the amount large or small bank i lends to small banks. $\sigma_{t_{(Y/Y_T)}}$ is a measure of the macro risks prevailing at time t, and Δ_t^j is a positive parameter that determines the equilibrium value of monitoring costs. Δ_t^j can be interpreted as an inefficiency cost in the monitoring process. $\Delta_t^B < \Delta_t^S$ assuming large banks have more resources and better access to information and can monitor the borrowing banks more efficiently compared with small banks. The cost functions imply that costs of monitoring both types of bank increase with macro risk. In addition, costs of monitoring large borrower banks vary positively with the proportion of risky trading securities (ψ_t^B) these banks hold. The idea is that given the risky nature of these trading securities, large investments in these raise the overall riskiness of the banks' portfolios and therefore raise the cost of monitoring these banks. The interaction term, $\sigma_{t_{(Y/Y_T)}}\psi_t^B$, in the cost of monitoring large banks implies that in an economic environment with high macro risk, increase in risky investments raises the cost by more and vice versa. Given these costs, banks with high deposit realizations choose how much of their available liquidity to lend to large banks and to small banks and how much to maintain as excess reserves.[11]

[11] I build upon the monitoring cost function employed by Dib (2010) and add more structure to it. In equilibrium, banks with riskier portfolio should pay greater interest rate to borrow from the interbank market compared to banks

The optimization problem is set as a two-stage problem where an individual bank chooses the amount of loans it will extend to the real sector in the first stage and chooses the amount of interbank borrowing, lending and excess reserves in the second stage given the amount of loans it has chosen in the first. The problem is solved by backward induction. The second-stage problem is solved first, and the solutions are incorporated in the first-stage problem.

For ease of understanding, a timeline depicting the sequence of events in both stages is outlined below as Figure 5:

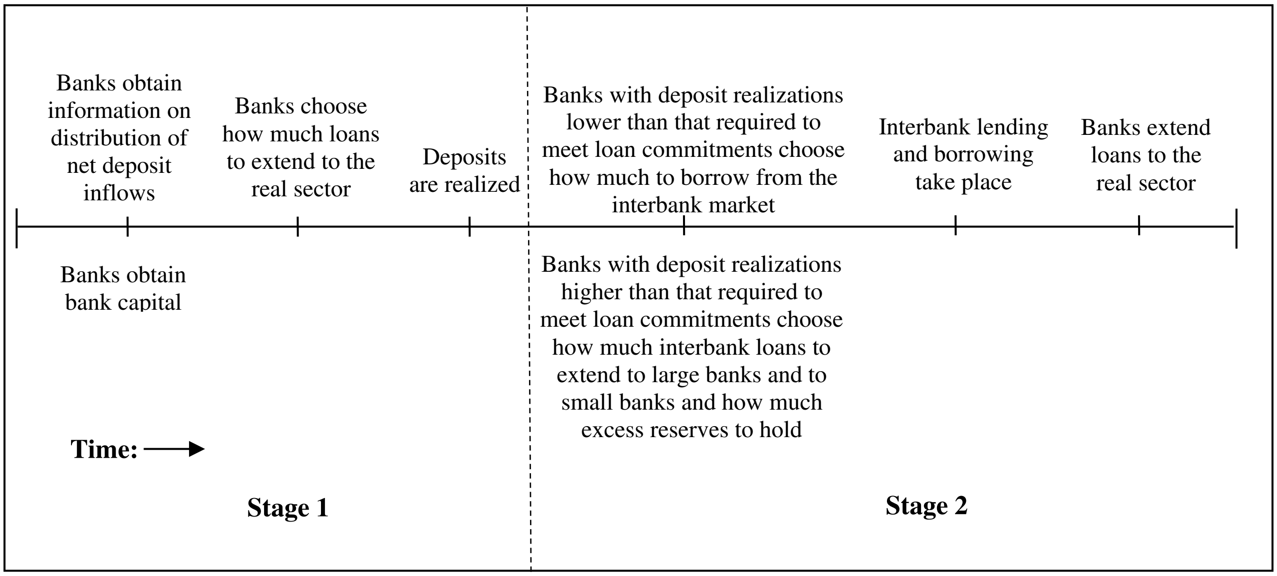

Figure 5: Sequence of Events in the Two-Stage Model

3.1 Banks' Problem

3.1.1 First Stage

Each bank i of type $j \in \{B, S\}$ obtains exogenously determined bank capital $\bar{z}_t^j$ and chooses $l_t^j(i) \leq \kappa \bar{z}_t^j$ before deposits are realized, to maximize expected profit: [12]

$$\max_{l_t^j(i) \leq \kappa \bar{z}_t^j} E_t\left(\Pi_t^j(i)\right) = E_t\Big\{r_t^L l_t^j(i) + r_t^{TS} TS_t^j(i) + r_t RR_t^j(i) - r_t^D E_t d_t^j(i) - r_t^Z \bar{z}_t^j - \rho_t^j E_t\left[\left(b_{Bt}^j(i) + b_{St}^j(i)\right) \middle| d_t^j(i) \leq \Omega_t^j\right] + \rho_t^B E_t\left[m_{Bt}^j(i) \middle| d_t^j(i) > \Omega_t^j\right] + \rho_t^S E_t\left[m_{St}^j(i) \middle| d_t^j(i) > \Omega_t^j\right] - E_t C(m_{Bt}^j(i)) - E_t C\left(m_{St}^j(i)\right) + r_t E_t\left[x_t^j \middle| d_t^j(i) > \Omega_t^j\right]\Big\}$$

Here, $\Omega_t^j = \frac{l_t^j(i) - \bar{z}_t^j}{1 - \theta_t^j - \gamma_t^j - \psi_t^j}$

whose portfolios are less risky. Including monitoring costs in the model is a way to generate interest rate differential in equilibrium and is common in the literature (see, e.g., Goodfriend & McCallum; 2007).

[12] Since there is no uncertainty in bank capital inflows, I assume for simplicity that each type $j \in \{B, S\}$ bank receives the same amount of bank capital $\bar{z}_t^j = Z_t^j / N_t^j$.

3.1.2 Second Stage

Once loans are chosen and deposits are realized, the banks enter the federal funds market.[13] A bank with a deposit realization smaller than that required to extend the desired amount of loans (a liquidity deficient bank) enters the market as a potential borrower. Since loan commitments must be met, the borrower bank chooses to borrow its entire liquidity deficiency — that is, for each bank i of type $j \in \{B, S\}$, if

$$l_t^j - \bar{z}_t^j - \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) \geq 0,$$
$$=> d_t^j(i) \leq \frac{l_t^j - \bar{z}_t^j}{1 - \theta_t^j - \gamma_t^j - \psi_t^j} = \Omega_t^j,$$

then demand for interbank borrowing for bank i of type $j \in \{B, S\}$ is given by:

$$b_{Bt}^j(i) + b_{St}^j(i) = l_t^j - \bar{z}_t^j - \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i)$$

A bank with a deposit realization higher than that required to extend the desired amount of loans (a liquidity rich bank) enters the market as a potential lender. For each bank i of type $j \in \{B, S\}$, if

$$l_t^j - \bar{z}_t^j - \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) < 0,$$
$$=> d_t^j(i) > \frac{l_t^j - \bar{z}_t^j}{1 - \theta_t^j - \gamma_t^j - \psi_t^j} = \Omega_t^j,$$

then, each bank i of type $j \in \{B, S\}$ chooses the amount it lends to large banks $m_{Bt}^j(i)$, the amount it lends to small banks $m_{St}^j(i)$ and the amount it retains as excess reserves $x_t^j(i)$ to maximize profits from the interbank (IB) market:

$$\max_{m_{Bt}^j(i), m_{St}^j(i), x_t^j(i)} \Pi_{IBt}^j(i) = \rho_t^B m_{Bt}^j(i) + \rho_t^S m_{St}^j(i) + r_t x_t^j(i) - C(m_{Bt}^j(i)) - C\left(m_{St}^j(i)\right)$$

subject to:

$$x_t^j(i) + m_{Bt}^j(i) + m_{St}^j(i) = \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) + \bar{z}_t^j - l_t^j$$
$$x_t^j(i) \geq 0$$

[13] Note that banks choose interbank borrowing, lending and excess reserves in the second stage after loans to the real sector have already been chosen in the first. As a result, in the second stage problem loans, $l_t^j, j = \{B, S\}$, are treated as deterministic. Given the expected values of interbank borrowing, lending and excess reserves, each large bank chooses identical l_t^B in the first stage. Each small bank does the same. Therefore, the notation 'i' after $l_t^j, j = \{B, S\}$ is not used in the second stage anymore.

3.1.3 Interbank Market Clearing Conditions

The following interbank market clearing conditions must be satisfied.

Market Clearing Condition 1:

Total interbank lending to large banks must be equal to the total demand for interbank borrowing by large banks:

$$N_t^B E_t[m_{Bt}^B(i)^* | d_t^B(i) > \Omega_t^B] + N_t^S E_t[m_{Bt}^S(i)^* | d_t^S(i) > \Omega_t^S] = N_t^B E_t[l_t^B - (1 - \theta_t^B - \gamma_t^B - \psi_t^B\ ) d_t^B(i) | d_t^B(i) \leq \Omega_t^B]$$

which implies:

$$N_t^B \int_{\Omega_t^B}^{\infty} m_{Bt}^B(i)^* f\left(d_t^B(i)\right) d\left(d_t^B(i)\right) + N_t^S \int_{\Omega_t^S}^{\infty} m_{Bt}^S(i)^* f\left(d_t^S(i)\right) d\left(d_t^S(i)\right) = N_t^B \int_{-\infty}^{\Omega_t^B} [l_t^B - \bar{z}_t^B - (1 - \theta_t^B - \gamma_t^B - \psi_t^B) d_t^B(i)]\, f\left(d_t^B(i)\right) d\left(d_t^B(i)\right)$$

where, $m_{Bt}^B(i)^*$ denotes the optimal amount of interbank loans large bank i extends to other large banks and $m_{Bt}^S(i)^*$ denotes the optimal amount of interbank loans small bank i extends to large banks.

Market Clearing Condition 2:

Total interbank lending to small banks must be equal to total demand for interbank borrowing by small banks:

$$N_t^B E_t[m_{St}^B(i)^* | d_t^B(i) > \Omega_t^B] + N_t^S E_t[m_{St}^S(i)^* \big| d_t^S(i) > \Omega_t^S] \quad = N_t^S E_t[l_t^S - \bar{z}_t^S - (1 - \theta_t^S - \gamma_t^S) d_t^S(i) | d_t^S(i) \leq \Omega_t^S]$$

which implies:

$$N_t^B \int_{\Omega_t^B}^{\infty} m_{St}^B(i)^* f\left(d_t^B(i)\right) d\left(d_t^B(i)\right) + N_t^S \int_{\Omega_t^S}^{\infty} m_{St}^S(i)^* f\left(d_t^S(i)\right) d\left(d_t^S(i)\right) = N_t^B \int_{-\infty}^{\Omega_t^S} [l_t^S - \bar{z}_t^S - (1 - \theta_t^S - \gamma_t^S) d_t^S(i)]\, f\left(d_t^S(i)\right) d\left(d_t^S(i)\right)$$

where, $m_{St}^B(i)^*$ denotes the optimal amount of interbank loans large bank i extends to small banks and $m_{St}^S(i)^*$ denotes the optimal amount of interbank loans small bank i extends to other small banks.

3.2 Solution to Banks' Problems

3.2.1 Solution to the Second-Stage Problem

Algebraic solutions to liquidity deficient banks have already been provided in section 3.1.2, which suggest that demand for interbank borrowing equals the entire liquidity deficiency the banks face. For liquidity rich banks, which are potential lenders in the interbank market, the solutions are provided below.

First order conditions from banks' second-stage problem with respect to $m^j_{Bt}(i)$, $m^j_{St}(i)$, $x^j_t(i)$ and $\lambda^j_{1t}(i)$ (Lagrange multiplier on the equality constraint) where $j \in \{B, S\}$, yield, respectively:

$$\rho^B_t - \Delta^j_t m^j_{Bt}(i)\left(\sigma_{t_{(Y/Y_T)}} + \psi^B_t + \sigma_{t_{(Y/Y_T)}}\psi^B_t\right) = \lambda^j_{1t}(i) \quad (1)$$

$$\rho^S_t - \Delta^j_t m^j_{St}(i)\sigma_{t_{(Y/Y_T)}} = \lambda^j_{1t}(i) \quad (2)$$

$$r_t - \lambda^j_{1t}(i) + \lambda^j_{2t}(i) = 0 \quad (3)$$

$$x^j_t(i) + m^j_{Bt}(i) + m^j_{St}(i) = \left(1 - \theta^j_t - \gamma^j_t - \psi^j_t\right)d^j_t(i) + \bar{z}^j_t - l^j_t \quad (4)$$

Kuhn-Tucker condition with respect to $\lambda^j_{2t}(i)$ (Lagrange multiplier on the inequality constraint) yields:

$$\lambda^j_2(i)x^j_t(i) = 0 \text{ with complementary slackness} \quad (5)$$

From equations (1) and (2), I obtain:

$$m^j_{Bt}(i) = \frac{\rho^B_t - \rho^S_t + \Delta^j_t m^j_{St}(i)\sigma_{t_{(Y/Y_T)}}}{\Delta^j_t\left(\sigma_{t_{(Y/Y_T)}} + \psi^B_t + \sigma_{t_{(Y/Y_T)}}\psi^B_t\right)} \quad (6)$$

From equations (1) and (3), I obtain:

$$m^j_{Bt}(i) = \frac{\rho^B_t - r_t - \lambda^j_2(i)}{\Delta^j_t\left(\sigma_{t_{(Y/Y_T)}} + \psi^B_t + \sigma_{t_{(Y/Y_T)}}\psi^B_t\right)} \quad (7)$$

From equations (2) and (3), I obtain:

$$m^j_{St}(i) = \frac{\rho^S_t - r_t - \lambda^j_2(i)}{\Delta^B_t \sigma_{t_{(Y/Y_T)}}} \quad (8)$$

The Kuhn-Tucker conditions (equation [5]) imply four possible cases. The cases are summarized in Table 1:

Table 1: Four Possible Cases with Respect to Excess Reserves Stemming from the Kuhn-Tucker Conditions of the Second-Stage Problem

Case 1	**Case 2**	**Case 3**	**Case 4**
$x^B_t(i) = 0, x^S_t(i) = 0$ The inequality constraints on excess reserves of both large and small banks are binding.	$x^B_t(i) = 0, x^S_t(i) \geq 0$ The inequality constraint on large banks' excess reserves is binding; the inequality constraint on excess reserves of small banks is not binding.	$x^B_t(i) \geq 0, x^S_t(i) = 0$ The inequality constraint on large banks' excess reserves is not binding; the inequality constraint on excess reserves of small banks is binding.	$x^B_t(i) \geq 0, x^S_t(i) \geq 0$ Neither of the inequality constraints is binding.

Algebraic expressions of the solutions to the second-stage problem vary with these cases. Given the first order conditions, the algebraic expressions of the solutions to optimal $m_{Bt}^{j}(i), m_{St}^{j}(i)$ and $x_t^j(i)$ are provided below for the different cases.

In cases where $x_t^j = 0$, optimal lending of bank i of type $j \in \{B, S\}$ to large banks is expressed as:

$$m_{Bt}^{j}(i)^{*} = \frac{(\rho_t^B - \rho_t^S) + \Delta_t^j \sigma_{t(Y/Y_T)} \left[\left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) + \bar{z}_t^j - l_t^j \right]}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j \left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)} \psi_t^B \right)} \tag{9}$$

whereas in cases where $x_t^j \geq 0$, it is expressed as:

$$m_{Bt}^{j}(i)^{*} = \frac{\rho_t^B - r_t}{\Delta_t^j \left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)} \psi_t^B \right)} \tag{10}$$

In cases where $x_t^j = 0$, optimal lending of bank i of type $j \in \{B, S\}$ to small banks is expressed as:

$$m_{St}^{j}(i)^{*} = \frac{\Delta_t^j \left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)} \psi_t^B \right) \left[\left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) + \bar{z}_t^j - l_t^j \right] - (\rho_t^B - \rho_t^S)}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j \left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)} \psi_t^B \right)} \tag{11}$$

whereas in cases where $x_t^j \geq 0$, it is expressed as:

$$m_{St}^{j}(i)^{*} = \frac{\rho_t^S - r_t}{\Delta_t^j \sigma_{t(Y/Y_T)}} \tag{12}$$

In cases where $x_t^j = 0$, optimal excess reserves of bank i of type $j \in \{B, S\}$ are expressed as:

$$x_t^j(i)^{*} = 0 \tag{13}$$

whereas, in cases where $x_t^j \geq 0$, optimal excess reserves are expressed as:

$$x_t^j(i)^{*} = \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i) + \bar{z}_t^j - l_t^j - \frac{\rho_t^B - r_t}{\Delta_t^j \left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)} \psi_t^B \right)} - \frac{\rho_t^S - r_t}{\Delta_t^j \sigma_{t(Y/Y_T)}} \tag{14}$$

3.2.2 Computing the Expected Values

For the market clearing conditions as well as the first stage problem, I need to compute the expected values for $b_t^j(i), m_{Bt}^{j}(i), m_{St}^{j}(i)$ and $x_t^j(i)$ under the different cases. The expected values are reported below.[14]

[14] See relevant derivations in Appendix A.

Under all the cases, expected interbank borrowing of bank i of type $j \in \{B, S\}$ is expressed as:

$$E_t\left[b_t^j(i)^* | d_t^j(i) \leq \Omega_t^j\right] = \int_{-\infty}^{\Omega_t^j} [l_t^j - \bar{z}_t^j - \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right) d_t^j(i)]\, f\left(d_t^j(i)\right) d\left(d_t^j(i)\right)$$

which can be solved as:

$$E_t\left[b_t^j(i)^* | d_t^j(i) \leq \Omega_t^j\right] \\ = \left[l_t^j - \bar{z}_t^j - \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right)\mu_t^j\right] F\left(\Omega_t^j\right) + \left(1 - \theta_t^j - \gamma_t^j \psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right) \tag{15}$$

In cases where $x_t^j = 0$, expected value of optimal lending of bank i of type $j \in \{B, S\}$ to large banks is expressed as:

$$E_t[m_{Bt}^j(i)^* | d_t^j(i) > \Omega_t^j] \\ = \frac{(\rho_t^B - \rho_t^S)\left(1 - F\left(\Omega_t^j\right)\right) + \Delta_t^j \sigma_{t(Y/Y_T)} \left\{\left[\left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right)\mu_t^j + \bar{z}_t^j - l_t^j\right]\left(1 - F\left(\Omega_t^j\right)\right) + \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right)\right\}}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} \tag{16}$$

whereas in cases where $x_t^j \geq 0$, it is expressed as:

$$E_t[m_{Bt}^j(i)^* | d_t^j(i) > \Omega_t^j] = \frac{(\rho_t^B - r_t)\left(1 - F\left(\Omega_t^j\right)\right)}{\Delta_t^B\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} \tag{17}$$

In cases where $x_t^j = 0$, expected value of optimal lending of bank i of type $j \in \{B, S\}$ to small banks is expressed as:

$$E_t[m_{St}^j(i)^* | d_t^j(i) > \Omega_t^j] = \\ \frac{\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)\left\{\left[\left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right)\mu_t^j + \bar{z}_t^j - l_t^j\right]\left(1 - F\left(\Omega_t^j\right)\right) + \left(1 - \theta_t^j - \gamma_t^j - \psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right)\right\} - (\rho_t^B - \rho_t^S)\left(1 - F\left(\Omega_t^j\right)\right)}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} \tag{18}$$

whereas in cases where $x_t^j \geq 0$, it is expressed as:

$$E_t[m_{St}^j(i)^* | d_t^j(i) > \Omega_t^j] = \frac{(\rho_t^S - r_t)\left(1 - F\left(\Omega_t^j\right)\right)}{\Delta_t^j \sigma_{t(Y/Y_T)}} \tag{19}$$

In cases where $x_t^j = 0$, expected value of optimal excess reserves of bank i of type $j \in \{B, S\}$ are expressed as:

$$E_t[x_t^j(i)^* | d_t^j(i) > \Omega_t^j] = 0 \tag{20}$$

whereas in cases where $x_t^j \geq 0$, expected value of optimal excess reserves is expressed as:

$$[E_t x_t^j(i)^* | d_t^j(i) > \Omega_t^j] = \left\{ \begin{matrix} \left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j + \bar{z}_t^j - l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right) \\ +\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right) \end{matrix} \right\} - \frac{\left(\rho_t^B - r_t\right)\left(1-F\left(\Omega_t^j\right)\right)}{\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} - \frac{\left(\rho_t^S - r_t\right)\left(1-F\left(\Omega_t^j\right)\right)}{\Delta_t^j \sigma_{t(Y/Y_T)}} \quad (21)$$

3.2.3 Solving the First-Stage Problem

Given the algebraic expressions of the expected values of the solutions to the second-stage problem, I can take first-order conditions with respect to the expected profit functions in the first stage. The algebraic expressions of the first order conditions vary with the cases, of course.

In cases where $x_t^j = 0$, for bank i of type $j \in \{B, S\}$, the first order condition with respect to $l_t^j(i)$ yields (after some algebraic manipulation):

$$\frac{dE_t(\Pi_t^j(i)}{dl_t^j(i)} = r_t^L - \rho_t^j F\left(\Omega_t^j\right) - \frac{(\rho_t^B - \rho_t^S)^2 f\left(\Omega_t^j\right)\Omega_t^{j'}\left(l_t^j\right)F\left(\Omega_t^j\right)}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)}$$
$$-\left(1-F\left(\Omega_t^j\right)\right)\left[\begin{matrix} \frac{\rho_t^B \Delta_t^j \sigma_{t(Y/Y_T)} + \rho_t^S \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} \\ -\frac{\Delta_t^j \sigma_{t(Y/Y_T)}\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)\left\{\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j + \bar{z}_t^j - l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right) + \left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right)\right\}}{\Delta_t^j \sigma_{t(Y/Y_T)} + \Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} \end{matrix}\right] = 0 \quad (22)$$

In cases where $x_t^j \geq 0$ on the other hand, for bank i of type $j \in \{B, S\}$, the first order condition with respect to $l_t^j(i)$ yields (after some algebraic manipulation):

$$\frac{dE_t(\Pi_t^j(i)}{dl_t^j(i)} = r_t^L - \rho_t^j F\left(\Omega_t^j\right) - f\left(\Omega_t^j\right)\Omega_t^{j'}\left(l_t^j\right)\left[\frac{\rho_t^B(\rho_t^B - r_t)}{\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} - \frac{\rho_t^S(\rho_t^S - r_t)}{\Delta_t^j \sigma_{t(Y/Y_T)}}\right]$$
$$+\left(1-F\left(\Omega_t^j\right)\right)f\left(\Omega_t^j\right)\Omega_t^{j'}\left(l_t^j\right)\left[\frac{\left(\rho_t^B - r_t\right)^2}{\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} + \frac{\left(\rho_t^S - r_t\right)^2}{\Delta_t^j \sigma_{t(Y/Y_T)}}\right] +$$
$$r_t\left\{f\left(\Omega_t^j\right)\Omega_t^{j'}\left(l_t^j\right)\left[\frac{\rho_t^B - r_t}{\Delta_t^j\left(\sigma_{t(Y/Y_T)} + \psi_t^B + \sigma_{t(Y/Y_T)}\psi_t^B\right)} + \frac{\rho_t^S - r_t}{\Delta_t^j \sigma_{t(Y/Y_T)}}\right] - \left(1-F\left(\Omega_t^j\right)\right)\right\} = 0 \quad (23)$$

Real sector loan, $l_t^j(i)$, $j \in \{B, S\}$, is solved numerically using equations (22) and (23) and the two market clearing conditions.

4. Data on Exogenous Variables and Calibration of Parameters

The model contains several exogenous variables and parameters. All the values for the exogenous variables and parameters are reported in Table 2. All the parameters are calibrated using yearly U.S. data (except GDP, where quarterly data have been used) for the period 1999 to 2009. All the bank-specific data are obtained from the Bankscope 2010 database. Data on annualized lending rate, r_t^L, annualized federal funds rate, r_t^F, annualized treasury bill (t-bill) rate, r_t, and the ratio of federal funds and security repurchase agreements to deposits are obtained from the Board of

Governor of the Federal Reserve System,[15] whereas quarterly data on GDP (needed to compute a measure of macro risk) are obtained from the U.S. Department of Commerce, Bureau of Economic Analysis.[16]

Table 2: Values of Exogenous Variables and Parameters [a]

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N_t^B	25	25	25	25	25	25	25	25	25	25	25
N_t^S	5,945	6,068	6,150	6,203	6,228	6,094	6,006	5,903	5,809	5,646	5,458
κ	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
μ_t^B	88,116	98,576	106,436	117,524	129,431	149,761	166,705	192,089	218,264	254,089	256,019
μ_t^S	54	58	63	68	72	77	82	85	89	96	104
σ_t^B	99,469	102,968	110,236	125,194	135,343	187,524	228,693	266,880	296,672	355,801	352,010
σ_t^S	35	38	41	45	48	52	57	60	62	65	70
θ_t^B	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
θ_t^S	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
ψ_t	0.11	0.12	0.11	0.13	0.13	0.13	0.11	0.12	0.15	0.15	0.10
γ_t^B	0.29	0.29	0.33	0.33	0.33	0.34	0.33	0.33	0.31	0.31	0.39
γ_t^S	0.36	0.35	0.34	0.34	0.35	0.35	0.34	0.33	0.32	0.32	0.34
r_t^L	0.080	0.092	0.069	0.047	0.041	0.043	0.062	0.080	0.081	0.051	0.033
r_t^F	0.050	0.062	0.039	0.017	0.011	0.014	0.032	0.050	0.050	0.019	0.002
r_t	0.046	0.058	0.035	0.016	0.010	0.012	0.029	0.047	0.043	0.013	0.001
$\sigma_{t(Y/Y_T)}$	0.0071	0.0073	0.0092	0.0050	0.0063	0.0041	0.0048	0.0040	0.0055	0.0205	0.0129
M_t^{AB}	410,873	443,360	403,810	465,269	520,052	551,257	622,062	686,211	634,195	398,164	687,713
Δ_t^B [b]	0.000030	0.000032	0.000029	0.000006	0.000008	0.000010	0.000020	0.000021	0.000038	0.000019	0.000002
Δ_t^S	0.000202	0.000226	0.000197	0.000045	0.000061	0.000077	0.000167	0.000200	0.000396	0.000223	0.000019

[a] μ_t^B, μ_t^S and M_t^{AB} are reported in millions of USD, and all the numbers reported are rounded up or down when required.

[b] Note that all numerical solutions reported in this paper correspond to either case 1 or case 3. Since Δ_t^B and Δ_t^S for both these cases are calibrated using expressions for interbank loans under case 3, I report only the case 3 values for Δ_t^B and Δ_t^S in this table.

Given my definitions of large and small banks, N_t^B equals 25 whereas N_t^S corresponds to the 75% of the smallest commercial banks each year. Similar to Dib (2010) and Günter (2012), κ is set to 12.5. This implies a minimum capital requirement of 8%, which corresponds to Basel Accord II. θ_t^B and θ_t^S are computed as the ratio of the sum of required reserves to the sum of net transaction accounts for the large and small banks, respectively. γ_t^B and γ_t^S are calculated as the ratio of the sum of "other assets" to the sum of deposits and short-term funding of the large and small banks, respectively. Other assets are computed by deducting the sum of loans and liquid assets from total assets. ψ_t^B is calculated as the ratio of the sum of trading securities to the sum of deposits and short-term funding of the large banks.

For each year, μ_t^j and σ_t^j are the average and standard deviation, respectively, of total deposits and short-term funding of bank type $j \in \{B, S\}$. Figure 6 presents the coefficients of variation of deposits and short-term funding of large and small banks, $CV_{d_t^B}$ and $CV_{d_t^S}$, respectively. The figure

[15] For all the data obtained from the Board of Governors of the Federal Reserve System reported in this paper, see [1] *Flow of Funds Accounts of the United States - Annual Flows and Outstandings: 1995-2004.* Washington D.C. 20551: Board of Governors of the Federal Reserve System, June 7, 2012. [2] *Flow of Funds Accounts of the United States - Annual Flows and Outstandings: 2005-2011.* Washington D.C. 20551: Board of Governors of the Federal Reserve System, June 7, 2012.

[16] Since he Bankscope database does not report data on detailed components of liquid assets or reserves, an average proxy rate needs to be used as the rate of return on reserves. I use the t-bill rate for that purpose since t-bills are significant components of bank reserves and the t-bill rate is an important benchmark interest rate together with the federal funds rate. In addition, the t-bill rate satisfies the model's assumption of $r_t^F > r_t$ for all years. I use the t-bill rate with the lowest available maturity for each year since I am comparing bank decisions between interbank lending and holding reserves, and interbank loans usually act to curb liquidity deficiency on a very short-term basis. For 1999 to 2001, the rates are three months' t-bill rates whereas for 2002 to 2009, the rates are four weeks' t-bill rates.

demonstrates that large banks are exposed to much larger idiosyncratic uncertainties than small banks. For small banks, idiosyncratic uncertainty remains fairly steady throughout my sample period whereas for large banks, this measure of uncertainty remains more or less stable till 2003 and then starts to increase, peaking in 2008.[17] A measure of macro risk, $\sigma_{t_{(Y/Y_T)}}$, is computed utilizing quarterly data on GDP. The trend GDP (Y_T) is separated using the Hodrick-Prescott (HP) Filter. I measure the cyclical component of GDP as $\log(Y/Y_T)$ and compute standard deviation of the cyclical component of GDP for three leads and three lags centered on the current period. The average of the four quarterly values is used as $\sigma_{t_{(Y/Y_T)}}$ for each year. Figure 7 exhibits standard deviation of the cyclical component of quarterly GDP ($\sigma_{t_{(Y/Y_T)}}$) from 1998 to 2012. The figure reveals that macro risk in the U.S. is substantially higher during the financial crisis, namely in 2008, compared with other years.

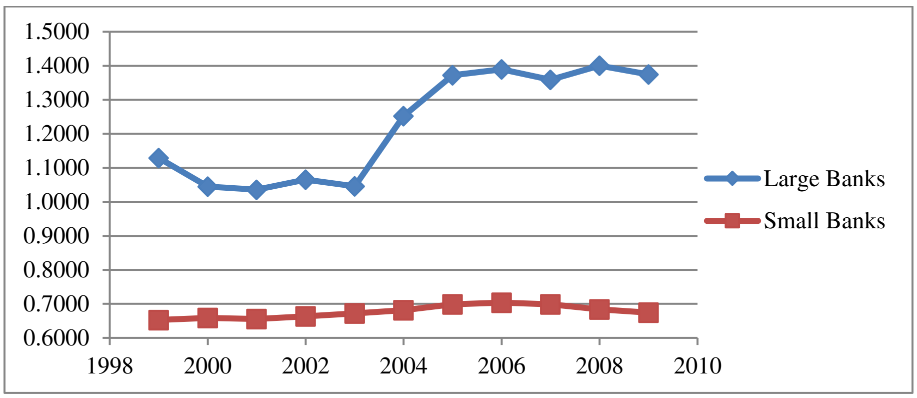

Figure 6: Coefficient of Variation of Deposits and Short-Term Funding of Large and Small Banks

Δ_t^B and Δ_t^S are calibrated utilizing the left hand sides of the interbank market clearing conditions together with data on the ratio of federal funds and security repurchase agreements to deposits,[18] effective federal funds rate, r_t^F, t-bill rate, r_t and other exogenous variables and parameters in the following way. I multiply the ratio of federal funds and security repurchase agreements to deposits by the sum of deposits and short-term funding for all the banks in my sample to obtain a measure of model-equivalent total interbank lending, M_t^{AB}. The sum of the left-hand side expressions from the two interbank market clearing conditions are equated to M_t^{AB}:

$$N_t^B E_t[m_{Bt}^B(i)^*|d_t^B(i) > \Omega_t^B] + N_t^S E_t[m_{Bt}^S(i)^*|d_t^S(i) > \Omega_t^S] + N_t^B E_t[m_{St}^B(i)^*|d_t^B(i) > \Omega_t^B] + N_t^S E_t[m_{St}^S(i)^*\big|d_t^S(i) > \Omega_t^S] = M_t^{AB}$$

Since the algebraic expressions of the solutions to the interbank loans vary with the cases, the calibration of Δ_t^B and Δ_t^S also varies with the cases. For each case, I utilize the expected values of the interbank loans reported in section 3.2.2. I use the average federal funds rate, r_t^F, in place of

[17] One potential explanation for larger $CV_{d_t^B}$ compared with $CV_{d_t^S}$ could be that large banks hold a relatively larger share of short-term wholesale funding than small banks, and short-term debt in general is considered to be more unstable than retail deposits (e.g., Ivashina and Scharfstein, 2010). However, this does not explain the rise in risk since 2004 within large banks as there is no systematic rise in large banks' holdings of short-term funding since 2004. These observed patterns concerning the idiosyncratic uncertainties seem very interesting and provide scope for further research. Although a full-fledged enquiry of this issue is beyond the scope of this study, I provide two possible explanations in web appendix B.

[18] The ratio is computed using data on U.S.-chartered depository institutions and foreign banking offices in the U.S.

both ρ_t^B and ρ_t^S (since data on bank-specific interbank borrowing/lending rates are unavailable) and a common Δ_t in place of Δ_t^B and Δ_t^S. Given all relevant parameter values and data on relevant variables, I solve for a common Δ_t for the banking industry as a whole utilizing the above equation.[19] Finally, I divide Δ_t by the deposit and short-term funding shares (measure of bank size) of large banks and small banks to obtain Δ_t^B and Δ_t^S, respectively. Since large banks' deposit and short-term funding share is larger than that of their smaller counterparts, $\Delta_t^B < \Delta_t^S$ as per the assumption made in section 3 of this paper.[20]

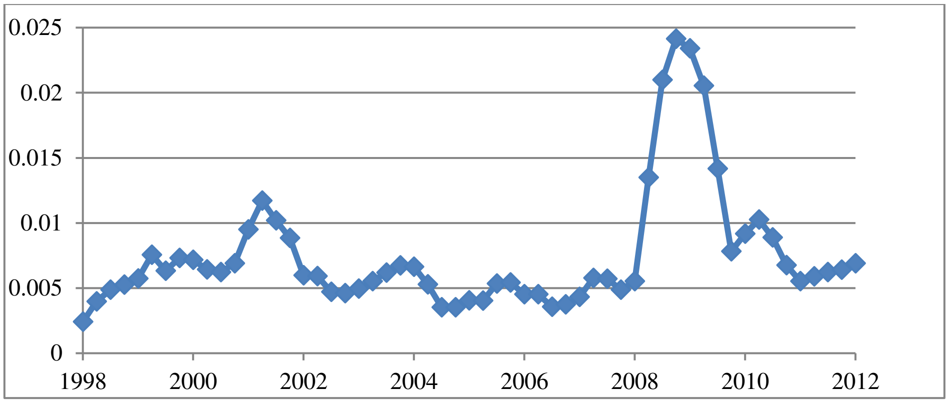

Figure 7: Standard Deviation of Cyclical Component of GDP

As can be observed from the data and calibration sections, both measures of risk are at their highest (idiosyncratic risk for large banks and macro risk affecting both types of banks) during the financial crisis. Large banks' investments in risky trading securities are also at their peak during the crisis. These three factors play a pivotal role in driving the results of the paper.

5. Results

5.1 Analytical Results

This section reports how expected excess reserves move with idiosyncratic risk, macro risk and risky trading securities.[21] For large banks, when excess reserves are positive — that is, in case (3) and case (4), everything else remaining constant, expected excess reserves increase at an increasing rate with idiosyncratic risk (σ_{Bt}) and increase at a decreasing rate with macro risk ($\sigma_{t(Y/Y_T)}$). The impact of ψ_t^B on $E_t x_t^B$ is more complex. Intuitively, two broad effects are at play — a balance sheet effect and a cost effect. The balance sheet effect creates downward pressure on expected excess reserves since increased investments in trading securities reduce expected available funds

[19] Note that case 1 expressions for interbank loans cannot be used to calibrate Δ_t. This is because given the expected values of interbank loans under case 1, Δ_t gets cancelled out. As the best possible alternative for solving the second-stage problem under case 1, I use the value of Δ_t calibrated using expressions under case 3. Remember that case 1 implies $x_t^B = 0$ and $x_t^S = 0$ whereas case 3 implies $x_t^B \geq 0$ and $x_t^S = 0$. This means that even if I obtain $x_t^B = 0$ as a final solution, it does not contradict the conditions under case 3.

[20] Regardless of which case or which expressions of interbank lending I use to calibrate Δ_t, I find that case 2 ($x_t^B(i) = 0, x_t^S(i) \geq 0$) or case 4 ($x_t^B(i) \geq 0, x_t^S(i) \geq 0$) cannot be sustained as solutions to the banks' problems. Numerical solutions for all years correspond to either case 1 ($x_t^B(i) = 0, x_t^S(i) = 0$) or case 3 ($x_t^B(i) \geq 0, x_t^S(i) = 0$). Since Δ_t for both these cases is calibrated using expressions for interbank lending under case 3, calibrated values of Δ_t used for all the numerical analyses in this paper are based on case 3 expressions.

[21] The relevant differentiation results are reported in Appendix B.

(funds in excess of the loan commitments). The cost effect, on the other hand, creates upward pressure on expected excess reserves because higher ψ_t^B increases the expected cost of monitoring large borrowing banks, reducing expected interbank lending, which means large banks can get rid of less of their expected available liquidity. Overall, when ψ_t^B is relatively small, an increase in ψ_t^B increases expected excess reserves. As ψ_t^B keeps increasing, $E_t x_t^B$ continues to increase at a decreasing rate and eventually after ψ_t^B reaches a certain value, the negative effects take over and further increase in ψ_t^B decreases $E_t x_t^B$.

For small banks on the other hand, when excess reserves are positive, i.e., in case (2) and case (4), everything else remaining constant, $E_t x_t^S$ increases with σ_{St} at an increasing rate and increase with $\sigma_{t_{(Y/Y_T)}}$ and ψ_t^B at a decreasing rate.[22]

5.2 Numerical Results

For each year, I solve the banks' problems in the following way. I consider each case from the second-stage problem separately. Note that for each case, the market clearing conditions are functions of $l_t^B, l_t^S, \rho_t^B, \rho_t^S$, exogenous variables and parameters. Also for each case from the first-stage problem, the first order condition for large banks is a function of $l_t^B, \rho_t^B, \rho_t^S$, exogenous variables and parameters whereas the first order condition for small banks is a function of $l_t^S, \rho_t^B, \rho_t^S$, exogenous variables and parameters.

Thus, for each case I obtain four equations (two first order conditions and two market clearing conditions) with four unknowns ($l_t^B, l_t^S, \rho_t^B, \rho_t^S$), which can be numerically solved simultaneously. If the solutions yield $l_t^{B^*} \leq \kappa \bar{z}_t^B$ and $l_t^{S^*} \leq \kappa \bar{z}_t^S$ and meet the non-negativity constraints on the excess reserves, then these are the final solutions. However, if either $l_t^{B^*} > \kappa \bar{z}_t^B$ or $l_t^{S^*} > \kappa \bar{z}_t^S$ then these cannot be the solutions since the minimum capital requirements must be met. Based on my numerical calculations, $l_t^{B^*}$ is always less than $\kappa \bar{z}_t^B$ whereas $l_t^{S^*}$ is always greater than $\kappa \bar{z}_t^S$. In this scenario, since unconstrained $l_t^{S^*}$ is greater than $\kappa \bar{z}_t^S$, I set $l_t^{S^*} = \kappa \bar{z}_t^S$ and use the first order condition for large banks from the first stage and the two market clearing conditions to solve for optimal l_t^B, ρ_t^B and ρ_t^S given $l_t^{S^*} = \kappa \bar{z}_t^S$. If the new $l_t^{B^*} \leq \kappa \bar{z}_t^B$ and the non-negativity constraints on excess reserves from the second stage are met, then I treat these as the final solutions.[23]

According to the model, each year large banks lend less than the maximum allowable loans as sanctioned by the minimum capital requirement whereas small banks extend the maximum allowable amount. For large banks, the model predicts zero excess reserves for the years 1999 to 2004 and 2009, and positive excess reserves for the years 2005 to 2008. The model always predicts zero excess reserves for small banks. In terms of interbank lending and borrowing, the quantitative analysis reveals the following pattern. After the deposits are realized, large banks with high deposit draws lend to large banks with low draws. They find it optimal to lend heavily to the small banks as well. The total available funds of the small banks in the forms of deposits and bank capital plus the amount these banks receive from large banks in the interbank market exceed the maximum

[22] Numerical analysis isolating the impacts of idiosyncratic volatility and risky investments on expected excess reserves of large banks in web appendix C confirms the analytical results derived in this section. Web appendix C also demonstrates that the level of idiosyncratic uncertainty determines whether banks hold excess reserves or not. Once that is decided, the amounts of real sector lending and excess reserves are effectively determined by a combination of σ_{Bt} and ψ_t^B.

[23] Since optimal l_t^B, ρ_t^B and ρ_t^S change from the unconstrained solution, given these values, I solve for $l_t^{S^*}$ from small banks' first order condition to check whether unconstrained $l_t^{S^*}$ still remains greater than $\kappa \bar{z}_t^S$ and find that it does in every year.

amount of loans the small banks can extend. The small banks find it optimal to lend this additional available amount (after extending the maximum allowable loans to the real sector) to large banks with low deposit draws, which allows these large banks to increase their loans to the real sector.[24]

Figure 8 and Figure 9 compare the model's predictions with data for loans and excess reserves, respectively, together with the trends and equation of the trends for each graph. As can be observed in Figure 8, similar to the data the model predicts a decreasing trend in lending activities by large banks, and an increasing trend in lending activities by small banks. Figure 9 demonstrates that similar to data the model predicts that the ratio of excess reserves to deposits and short-term funding for small banks remains stable at low levels (at zero for the model) throughout the sample period whereas for large banks, the ratio initially remains relatively low, then increases, peaks during the financial crisis and comes down to pre-crisis level.

The model's predictions are largely driven by two factors: idiosyncratic uncertainty and risky investments. A higher coefficient of variation of deposit distribution raises the probability of obtaining a lower deposit draw and leads to banks choosing a smaller amount of loans since loan commitments must be met — implying a precautionary motive of not having enough funds to meet loan commitments. Once deposits are realized, banks with high deposit draws end up with a large amount of funds in excess of the loan commitments they made. These banks enter the interbank market as potential lenders while banks with low draws enter as potential borrowers. The large amount of trading securities held by borrowing banks raises the cost of monitoring these banks and thereby reduces interbank lending, as a result of which banks with high deposit draws cannot lend out all of their excess available funds through the interbank market and end up with excess reserves. The increase in monitoring cost due to the higher amount of risky investments and the higher macro risk can be interpreted as a higher cost due to increased counterparty risk. Together, the choice of small loan commitments due to a precautionary motive (liquidity hoarding) and not being able to lend out additional available funds due to the high monitoring cost (counterparty risk) result in low real sector lending and high excess reserves.

Small banks face considerably lower idiosyncratic uncertainty compared with large banks. Therefore, even without interbank borrowing their choice of loans is relatively higher than that of large banks. This implies that once deposits are realized, these small banks do not face large liquidity deficiencies, nor do they end up with a large amount of excess liquidity. In addition, given the vast difference in scale of operation between large and small banks even a small supply of interbank loans from large banks is sufficient to meet small banks' liquidity deficiency. Likewise, a small borrowing demand by large banks provides ample opportunity for small banks to get rid of their excess liquidity. Also, since small banks do not invest in risky trading securities, the cost of monitoring these banks is low in the interbank market. Given these conditions, small banks always can borrow any liquidity deficiencies they may face and lend out any amount of excess liquidity they may have after deposits are realized. Hence, the model predicts $l_t^{S^*} = \kappa \bar{z}_t^S$ and $E_t x_t^{S^*} = 0$ in every year.

Large banks face substantially larger idiosyncratic uncertainties compared with small banks throughout 1999 to 2009. They also invest heavily in risky trading securities. For large banks, these factors together result in a significantly lower amount of loans in all years and larger excess reserves during 2005 to 2008. The idiosyncratic uncertainty faced by large banks remains reasonably stable at a relatively low value till 2003 and then increases, reaching its highest value in 2008. Risky investments in trading securities, on the other hand, are the highest in 2007,

[24] Appendix C reports the balance sheets (average values) computed based on the model's predictions.

followed by 2008. These two factors play crucial roles as the model predicts the lowest loans and highest expected excess reserves for large banks during the financial crisis of 2007–2008.[25]

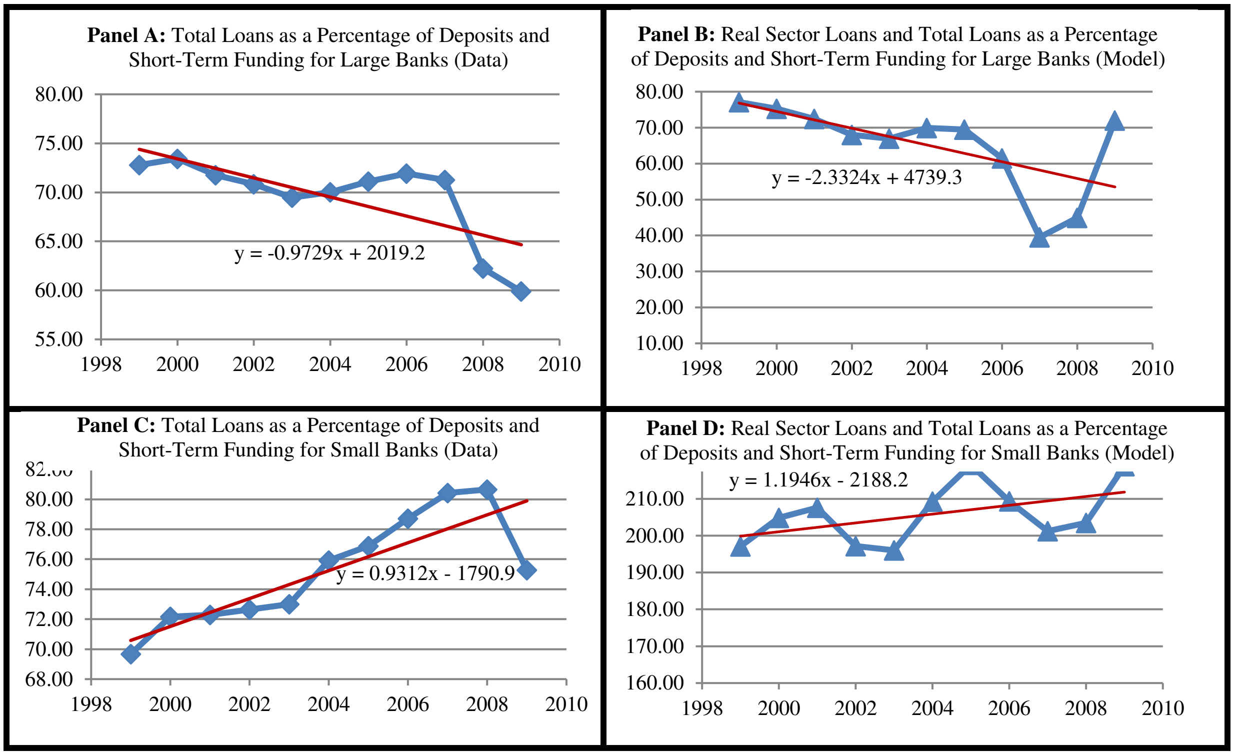

Figure 8: Loans as a Percentage of Deposits and Short-Term Funding in Large and Small Banks: Data vs. Model (numbers in panels A, B, C and D are expressed as %). The straight red lines are the linear trend lines and the corresponding equations are the equations for the trend lines. In panels B and D, for both large and small banks the model's predictions for loans to the real sector as well as total loans are presented. The difference between the two represents interbank lending. In panels A and C, only total loans are reported because Bankscope does not contain bank-specific information on interbank lending.

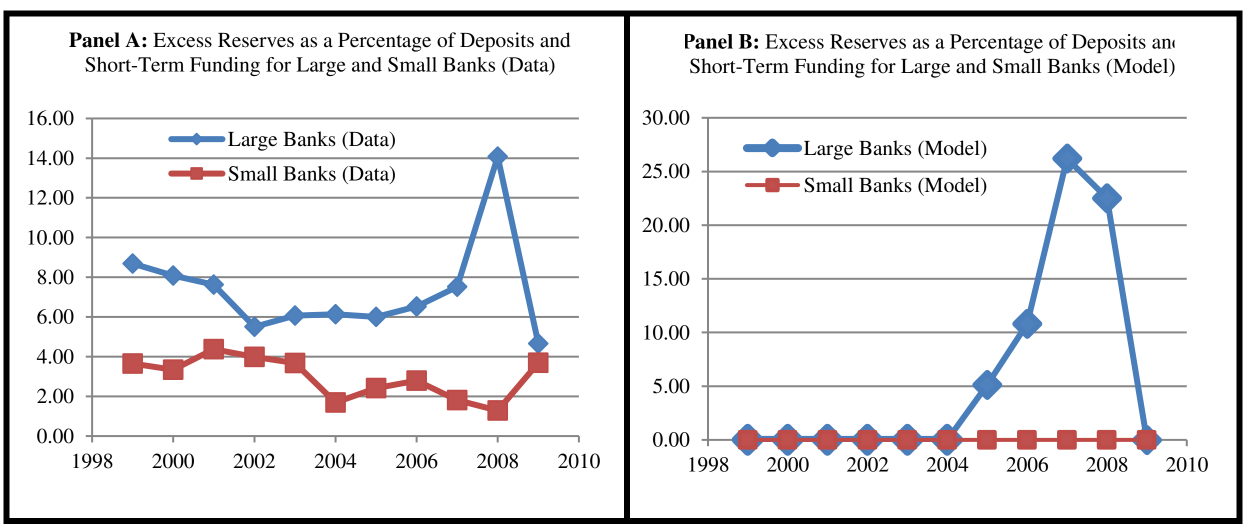

Figure 9: Excess Reserves as a Percentage of Deposits and Short-Term Funding in Large and Small Banks: Data vs. Model (all numbers are expressed as %)

[25] Another factor that might have played a role is discount window (DW) borrowing. Web appendix D explains the role of discount window borrowing and demonstrates that it has notable effect on model outcomes only in 2008.

5.3 Counterparty Risk vs. Liquidity Hoarding: Short Run vs. Long Run

This section focuses on the debate between two schools of thought that can potentially explain increase in excess reserves, reduction in interbank loans and subsequent reduction in loans to the real sector. Some researchers argue that increase in counterparty risk prevents banks from making loans in the interbank market (e.g., Flannery, 1996; Flannery and Sorescu, 1996; Furfine, 2001; Freixas and Jorge, 2008; Heider, Hoerova and Holthausen, 2009; Keister and McAndrews, 2009; Bruche and Suárez, 2010; Afonso et al., 2011) whereas others assert the importance of liquidity hoarding due to precautionary motive (e.g., Caballero and Krishnamurthy, 2008; Allen et al., 2009; Ashcraft et al., 2009; Diamond and Rajan, 2009; Günter, 2012).

Afonso et al. (2011) address this debate by comparing the roles of counterparty risk and liquidity hoarding in explaining the drying up of federal fund loans during the financial crisis in the U.S. and find that counterparty risk plays a larger role. Running a couple of experiments using my model, I find similar results when considering the short run. Over the long run, however, I find that the impact of liquidity hoarding is greater.

In order to identify the relative impacts of counterparty risk and liquidity hoarding over the short run, I fix the relevant parts of costs of monitoring borrower banks (capture counterparty risk)[26] and coefficients of variation of deposits and short-term funding (capture liquidity hoarding) of large and small banks at 2006 levels (i.e., at levels just before the crisis began) and generate predictions for 2006 to 2008. I keep all other variables and parameters at their original values. For computing these impacts over the long run, the relevant parameters are fixed at 1999 levels (i.e., at levels in the beginning of my sample period) and predictions are generated for 1999 to 2009. For isolating the roles of counterparty risk and liquidity hoarding, variations in relevant parts of monitoring costs and coefficients of variation of deposits are added one by one to the model, and predictions are generated for the above-mentioned years. Figure 10 and Figure 11 illustrate the short-term and long-term impacts, respectively, of counterparty risk and liquidity hoarding on real sector loans and excess reserves of large banks.[27]

In both the figures, the green line corresponds to predictions with fixed parameter values, the red line indicates predictions with variations in monitoring costs whereas the blue line corresponds to predictions with variations in monitoring costs as well as coefficients of variation of deposits and short-term funding. Note that decrease in predicted loans and increase in predicted reserves due to introduction of variation in the parameter of interest implies greater impact. Figure 10 clearly depicts that counterparty risk plays a greater role than does liquidity hoarding in the short run. When variation in monitoring costs is added, predicted loans decrease and excess reserves increase by much larger amounts (shift from green to red line) than when variation in volatility of deposits and short-term funding is introduced (shift from red to blue line). Figure 11, on the other hand, demonstrates that over the long run, liquidity hoarding plays a greater role than does counterparty risk. Variation in volatility of deposits and short-term funding reduces predicted loans

[26] The relevant parts are the coefficients of $\Delta_t^j m_{Bt}^j$ and $\Delta_t^j m_{St}^j, j \in \{B, S\}$ of the marginal costs of monitoring large and small banks, respectively — that is, the parts of monitoring costs that depend on risky trading securities and macro risk.

[27] These effects are reported for only large banks because for small banks, under all these cases predicted real sector loans and reserves remain unchanged.

and raises predicted reserves by a significantly greater amount (shift from red to blue line) compared with variation in monitoring costs (shift from green to red line). [28]

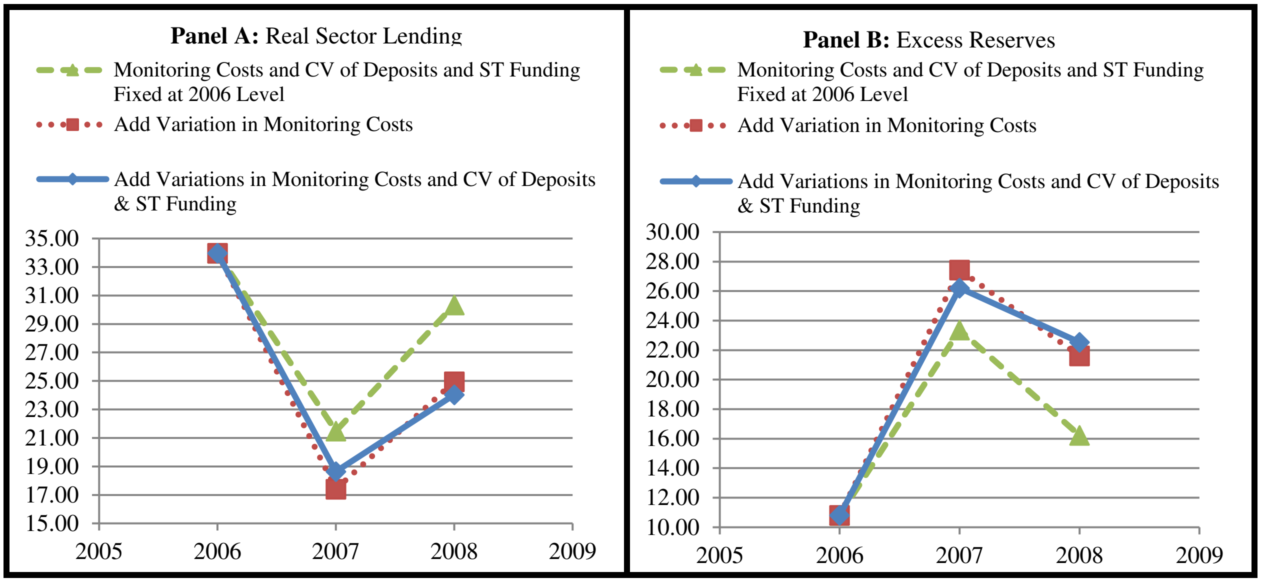

Figure 40: Short-Term Effects of Counterparty Risk and Liquidity Hoarding on Real Sector Loans and Excess Reserves of Large Banks. Numbers in Panels A and B are expressed as a % of deposits and short-term funding.

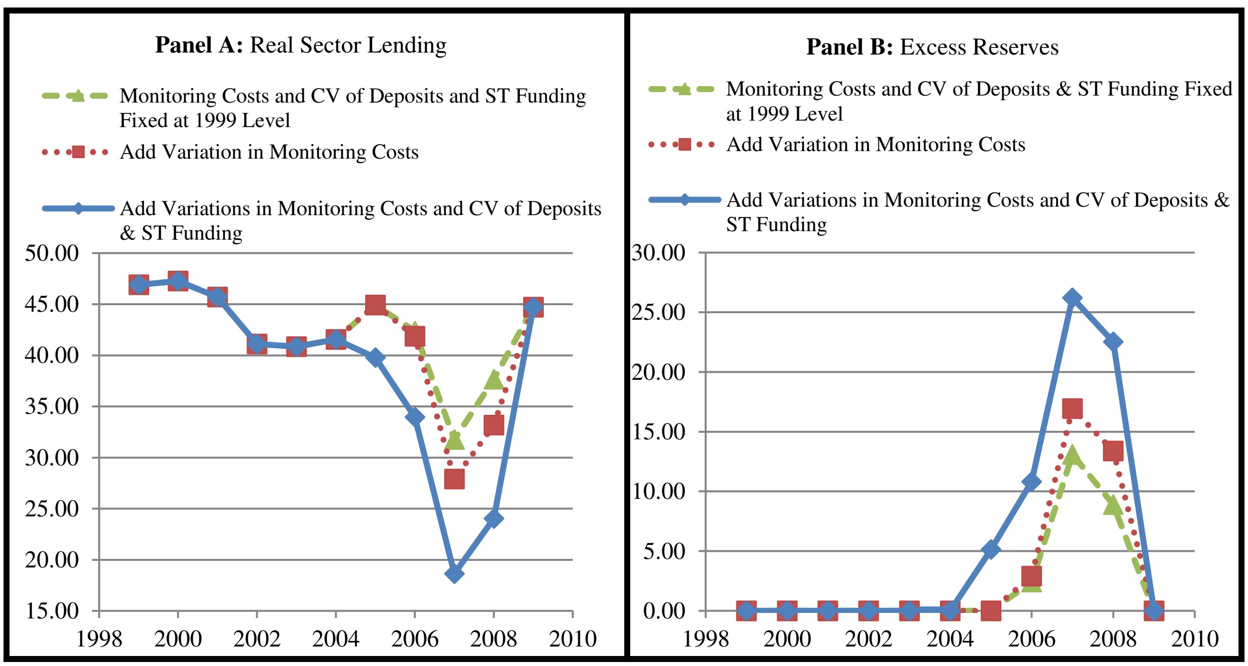

Figure 51: Long-Term Effects of Counterparty Risk and Liquidity Hoarding on Real Sector Loans and Excess Reserves of Large Banks. Numbers in Panels A and B are expressed as a % of deposits and short-term funding.

[28] Note that for some of the years, predictions of all the versions are identical. This is because under case 1 solutions ($x_t^B = x_t^S = 0$) with binding $l_t^S \leq \kappa \bar{z}_t^S$ constraint, $l_t^{B^*}$ and $E_t x_t^{B^*}$ do not vary with coefficient of variation of deposits and short-term funding or monitoring costs. Only the interbank interest rates adjust.

6. Conclusion

This paper employs a two-stage model to explain the excess reserve buildup and credit crunch in the US commercial banking industry during the financial crisis of 2007-2008 and demonstrates that idiosyncratic uncertainties and investments in risky trading securities play important roles in explaining the observed data patterns. The paper also analyzes the relative importance of the roles of counterparty risk and liquidity hoarding and shows that the former's impact is larger over the short run whereas the latter's effect is larger over the long run.

Like any study the paper has some limitations because of which some discrepancies exist between the data and the model's predictions. This is expected since the model makes some simplifying assumptions for the sake of tractability as it is not possible for a model to capture all the aspects of reality encompassing an extremely complicated system such as the commercial banking industry. According to the model, lending activities of large banks revive in 2009 after bottoming out during the financial crisis while data suggest a further fall in large banks' lending activities in 2009. Data suggest a further fall in lending activities in 2009 largely because of the large increase in impaired loans, an aspect not captured by the model.[29] The model's predictions of total loans and excess reserves for large banks during the financial crisis are lower and higher, respectively. One potential explanation is that during the crisis, in addition to the DW loans, the Federal Reserve secretly injected a huge amount of funds to the largest financial corporations including the large commercial banks to help them meet their emergency liquidity shortfalls, which is not captured by the model.[30] The model's predicted lending activities for small banks during the entire sample period are higher than those observed in data. This is because the model assumes ample demand for real sector loans and does not consider cost of monitoring real sector borrowers. It is very likely that given their limited size and resources, small banks would face lower demand for real sector loans and incur greater cost of monitoring real sector borrowers compared with large banks. These factors would result in a smaller amount of real sector lending by small banks compared with the model's predictions. Finally, the model predicts zero excess reserves for small banks in all years and for large banks in some years whereas data show small positive excess reserves in those years. Certain factors concerning interbank lending and borrowing — such as information distortions, transaction costs and holdup problems — that are present in reality but absent in the model can explain the existence of some positive amount of excess reserves in years for which the model's prediction of excess reserves is zero. Large banks additionally may be exposed more to factors such as exchange rate risk than are small banks, which may lead to some additional excess reserves.[31] Such factors can explain why excess reserves of large banks are slightly higher than those of small banks in years when the model predicts zero excess reserves for both large and small banks.

These limitations provide scope for future research. Future research can try to incorporate some of the factors missing in this analysis and gauge their effects on reserve and loan behaviors of commercial banks. The model in this paper treats idiosyncratic uncertainty exogenously. Future

[29] Impaired loans relative to total equity for large banks increased to 20.5% in 2009 from 9.8% in 2008. Between 1999 and 2007, on average the ratio was 5.7%.

[30] The Federal Reserve used several emergency funding programs in addition to its traditional DW facility and the TAF designed to augment the DW. These additional programs are Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF), Commercial Paper Funding Facility (CPFF), Primary Dealer Credit Facility (PDCF), Term Securities Lending Facility (TSLF) and Single-tranche open market operations (ST OMO). See Keoun and Kuntz (2011a, 2011b) and Kuntz and Ivry (2011) for details.

[31] As suggested by Agénor et al. (2004), if a bank has liabilities in foreign currency and the exchange rate of domestic currency is expected to depreciate then the bank would need to keep some reserves to account for that risk.

research can construct a model endogenizing it and analyze what factors cause idiosyncratic uncertainty to change.

The findings have important managerial and policy implications. Bank owners and management should devote more resources and time to better understand and better manage the risks associated with trading activities and activities such as excessive use of credit derivatives that may give rise to high volatility in deposit flows. Policy makers should closely monitor these activities as well as design and implement regulations to curb unwarranted risk-taking.

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Appendix

A. Derivation of Relevant Expected Values

The following results have been used in computing the expected values in section 3.2.2

For bank i of type $j \in \{B, S\}$, expected interbank borrowing can be computed as:

$$E_t\left[b_{Bt}^j(i) + b_{St}^j(i) | d_t^j(i) \leq \Omega_t^j\right] = \int_{-\infty}^{\Omega_t^j} [l_t^j - \bar{z}_t^j - (1 - \theta_t^j - \gamma_t^j - \psi_t^j) d_t^j(i)]\, f\left(d_t^j(i)\right) d\left(d_t^j(i)\right)$$

$$= \left\{[l_t^j - \bar{z}_t^j] F(\Omega_t^j) - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\left[\int_{-\infty}^{\Omega_t^j} (d_t^j(i) - \mu_t^j + \mu_t^j) f\left(d_t^j(i)\right) d\left(d_t^j(i)\right)\right]\right\}$$

$$= \left\{[l_t^j - \bar{z}_t^j - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\mu_t^j] F(\Omega_t^j) - (1 - \theta_t^j - \gamma_t^j - \psi_t^j) \int_{-\infty}^{\Omega_t^j} (d_t^j(i) - \mu_t^j) f\left(d_t^j(i)\right) d\left(d_t^j(i)\right)\right\}$$

$$= \left\{[l_t^j - \bar{z}_t^j - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\mu_t^j] F(\Omega_t^j) - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\left(\frac{1}{\sigma_{jt}\sqrt{2\pi}}\right) \int_{-\infty}^{\Omega_t^j} (d_t^j(i) - \mu_t^j)\, e^{-\frac{\left(d_t^j(i) - \mu_t^j\right)^2}{2\sigma_{jt}^2}} d(d_t^j(i))\right\}$$

$$= \left\{[l_t^j - \bar{z}_t^j - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\mu_t^j] F(\Omega_t^j) - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\left(\frac{1}{\sigma_{jt}\sqrt{2\pi}}\right)(-\sigma_{jt}^2)\left[e^{-\frac{\left(d_t^j(i) - \mu_t^j\right)^2}{2\sigma_{jt}^2}}\right]_{-\infty}^{\Omega_t^j}\right\}$$

Finally, I obtain the expression for expected interbank borrowing for bank i of type $j \in \{B, S\}$ in equation (15):

$$E_t\left[b_t^j(i)^* | d_t^j(i) \leq \Omega_t^j\right] = E_t\left[b_{Bt}^j(i)^* + b_{St}^j(i)^* | d_t^B(i) \leq \Omega_t^B\right] =$$

$$\left[l_t^j - \bar{z}_t^j - (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\mu_t^j\right] F(\Omega_t^j) + (1 - \theta_t^j - \gamma_t^j - \psi_t^j)\sigma_{jt}^2 f(\Omega_t^j)$$

For bank i of type $j \in \{B, S\}$, the following expected value has been used in computation of equation (16), equation (18) and equation (21):

$$E_t\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)d_t^j(i)+\bar{z}_t^j-l_t^j \middle| d_t^j(i)>\Omega_t^j\right]$$

$$=\int_{\Omega_t^j}^{\infty}\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)d_t^j(i)+\bar{z}_t^j-l_t^j\right]f(d_t^j(i))d(d_t^j(i))$$

$$=\left\{\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\left[\int_{\Omega_t^j}^{\infty}(d_t^j(i)-\mu_t^j+\mu_t^j)f\left(d_t^j(i)\right)d\left(d_t^j(i)\right)\right]+[\bar{z}_t^j-l_t^j]\left(1-F\left(\Omega_t^j\right)\right)\right\}$$

$$=\left\{\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j+\bar{z}_t^j-l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right)+\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\int_{\Omega_t^j}^{\infty}(d_t^j(i)-\mu_t^j)\, f\left(d_t^j(i)\right)d\left(d_t^j(i)\right)\right\}$$

$$=\left\{\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j+\bar{z}_t^j-l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right)+\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\left(\frac{1}{\sigma_{jt}\sqrt{2\pi}}\right)\int_{\Omega_t^j}^{\infty}(d_t^j(i)-\mu_t^j)\, e^{-\frac{\left(d_t^j(i)-\mu_t^j\right)^2}{2\sigma_{jt}^2}}\, d\left(d_t^j(i)\right)\right\}$$

$$=\left\{\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j+\bar{z}_t^j-l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right)+\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\left(\frac{1}{\sigma_{jt}\sqrt{2\pi}}\right)\left(-\sigma_{jt}^2\right)\left[e^{-\frac{\left(d_t^j(i)-\mu_t^j\right)^2}{2\sigma_{jt}^2}}\right]_{\Omega_t^j}^{\infty}\right\}$$

Finally, I obtain the following expression used in equation (16), equation (18) and equation (21):

$$E_t\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)d_t^j(i)+\bar{z}_t^j-l_t^j \middle| d_t^j(i)>\Omega_t^j\right]$$

$$=\left\{\left[\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\mu_t^j+\bar{z}_t^j-l_t^j\right]\left(1-F\left(\Omega_t^j\right)\right)+\left(1-\theta_t^j-\gamma_t^j-\psi_t^j\right)\sigma_{jt}^2 f\left(\Omega_t^j\right)\right\}$$

B. How Excess Reserves Vary with Idiosyncratic Risk, Macro Risk and Trading securities

Differentiating $E_t x_t^B(i)$ with respect to σ_{Bt}, I obtain:

$$\frac{\partial E_t x_t^B(i)}{\partial \sigma_{Bt}} = 2\sigma_{Bt}(1 - \theta_t^B - \gamma_t^B - \psi_t^B) f(\Omega_t^B) > 0$$

Differentiating again with respect to σ_{Bt} gives us:

$$\frac{\partial}{\partial \sigma_{Bt}}\left(\frac{\partial E_t x_t^B(i)}{\partial \sigma_{Bt}}\right) = 2(1 - \theta_t^B - \gamma_t^B - \psi_t^B) f(\Omega_t^B) > 0$$

since $\theta_t^B + \gamma_t^B + \psi_t^B < 1$.

Differentiating $E_t x_t^B(i)$ with respect to $\sigma_{t_{(Y/Y_T)}}$, I obtain:

$$\frac{\partial E_t x_t^B(i)}{\partial \sigma_{t_{(Y/Y_T)}}} = \frac{\Delta_t^B(1+\psi_t^B)(\rho_t^B - r_t)\left(1 - F(\Omega_t^B)\right)}{\left\{\Delta_t^B\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right)\right\}^2} + \frac{\Delta_t^B(\rho_t^S - r_t)\left(1 - F(\Omega_t^B)\right)}{\left(\Delta_t^B \sigma_{t_{(Y/Y_T)}}\right)^2} > 0$$

since $\rho_t^B > r_t$ and $\rho_t^S > r_t$.

Differentiating again with respect to $\sigma_{t_{(Y/Y_T)}}$ gives us:

$$\frac{\partial}{\partial \sigma_{t_{(Y/Y_T)}}}\left(\frac{\partial E_t x_t^B(i)}{\partial \sigma_{t_{(Y/Y_T)}}}\right) = -\frac{2\left(1 - F(\Omega_t^B)\right)}{\Delta_t^B}\left[\frac{(1+\psi_t^B)^2(\rho_t^B - r_t)}{\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right)^3} + \frac{(\rho_t^S - r_t)}{\left(\sigma_{t_{(Y/Y_T)}}\right)^3}\right] < 0$$

Differentiating $E_t x_t^B(i)$ with respect to σ_{Bt}, I obtain:

$$\frac{\partial E_t x_t^B(i)}{\partial \psi_t^B} = \overbrace{-\left\{\mu_t^B\left(1 - F(\Omega_t^B)\right) + \sigma_{Bt}^2 f(\Omega_t^B) + [(1 - \theta_t^B - \gamma_t^B - \psi_t^B)\mu_t^B + \bar{z}_t^B - l_t^B] f(\Omega_t^B)\Omega_{\psi_t^B}^{B'}\right\}}^{-}$$

$$\overbrace{+\frac{\Delta_t^B\left(1 + \sigma_{t_{(Y/Y_T)}}\right)(\rho_t^B - r_t)\left(1 - F(\Omega_t^B)\right)}{\left\{\Delta_t^B\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right)\right\}^2} + \left[\frac{(\rho_t^B - r_t)}{\Delta_t^B\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right)} + \frac{(\rho_t^S - r_t)}{\Delta_t^B \sigma_{t_{(Y/Y_T)}}}\right] f(\Omega_t^B)\Omega_{\psi_t^B}^{B'}}^{+}$$

‘+’ when ψ_t^B is small and ‘-’ when ψ_t^B is large

$$\overbrace{+(1 - \theta_t^B - \gamma_t^B - \psi_t^B)\sigma_{Bt}^2 f'_{\psi_t}(\Omega_t^B)\Omega_{\psi_t}^{B'}}$$

The impact of ψ_t^B on $E_t x_t^B$ can be divided into three separate parts. Mathematically, the first effect is negative since $\theta_t^B + \gamma_t^B + \psi_t^B < 1$ and $f(\Omega_t^B)\Omega_{\psi_t^B}^{B'} > 0$, whereas the second is positive since $\rho_t^B > r_t$ and $\rho_t^S > r_t$. Therefore, whether $E_t x_t^B$ increases or decreases with ψ_t^B depends on which effect is stronger. Given that ψ_t^B appears a number of times in the denominator of the expression for the second effect, the effect is large when ψ_t^B is small and small when ψ_t^B is large. As a result, for small ψ_t^B the positive effect dominates and for large ψ_t^B, the negative effect dominates.[32] In addition, the third effect is positive for a relatively small value of ψ_t^B and negative for a relatively large value of ψ_t^B because of the following. In the third part, $(1-\theta_t^B-\gamma_t^B-\psi_t^B)\sigma_{Bt}^2 \Omega_{\psi_t^B}^{B'} > 0$. The ambiguity for this effect lies with the sign of $f'_{\psi_t^B}(\Omega_t^B)$. Numerical analysis reveals that $f'_{\psi_t^B}(\Omega_t^B)$ is a small positive number for a relatively small value of ψ_t^B and a small negative number for a relatively large value of ψ_t^B.

Differentiating $E_t x_t^S(i)$ with respect to σ_{St}, I obtain:

$$\frac{\partial E_t x_t^S(i)}{\partial \sigma_{St}} = 2\sigma_{St}(1-\theta_t^S-\gamma_t^S)f(\Omega_t^S) > 0$$

since $\theta_t^S+\gamma_t^S < 1$.

Differentiating again with respect to σ_{St} gives us:

$$\frac{\partial}{\partial \sigma_{St}}\left(\frac{\partial E_t x_t^S(i)}{\partial \sigma_{St}}\right) = 2(1-\theta_t^S-\gamma_t^S)f(\Omega_t^S) > 0$$

Differentiating $E_t x_t^S(i)$ with respect to $\sigma_{t(Y/Y_T)}$, I obtain:

$$\frac{\partial E_t x_t^S(i)}{\partial \sigma_{t(Y/Y_T)}} = \frac{\Delta_t^S(1+\psi_t^B)(\rho_t^B-r_t)\left(1-F(\Omega_t^S)\right)}{\left\{\Delta_t^S\left(\sigma_{t(Y/Y_T)}+\psi_t^B+\sigma_{t(Y/Y_T)}\psi_t^B\right)\right\}^2} + \frac{\Delta_t^S(\rho_t^S-r_t)\left(1-F(\Omega_t^S)\right)}{\left(\Delta_t^S\sigma_{t(Y/Y_T)}\right)^2} > 0$$

since $\rho_t^B > r_t$ and $\rho_t^S > r_t$.

Differentiating again with respect to $\sigma_{t(Y/Y_T)}$ gives us:

$$\frac{\partial}{\partial \sigma_{t(Y/Y_T)}}\left(\frac{\partial E_t x_t^S(i)}{\partial \sigma_{t(Y/Y_T)}}\right) = -\frac{2\left(1-F(\Omega_t^S)\right)}{\Delta_t^S}\left[\frac{(1+\psi_t^B)^2(\rho_t^B-r_t)}{\left(\sigma_{t(Y/Y_T)}+\psi_t^B+\sigma_{t(Y/Y_T)}\psi_t^B\right)^3} + \frac{(\rho_t^S-r_t)}{\left(\sigma_{t(Y/Y_T)}\right)^3}\right] < 0$$

And finally, differentiating $E_t x_t^S(i)$ with respect to ψ_t^B I obtain:

$$\frac{\partial E_t x_t^S(i)}{\partial \psi_t^B} = \frac{\Delta_t^S(1+\sigma_{t(Y/Y_T)})(\rho_t^B-r_t)\left(1-F(\Omega_t^S)\right)}{\left\{\Delta_t^S\left(\sigma_{t(Y/Y_T)}+\psi_t^B+\sigma_{t(Y/Y_T)}\psi_t^B\right)\right\}^2} > 0$$

since $\rho_t^B > r_t$.

Differentiating again with respect to ψ_t^B gives us:

$$\frac{\partial}{\partial \psi_t}\left(\frac{\partial E_t x_t^S(i)}{\partial \psi_t^B}\right) = -\frac{2\left(1+\sigma_{t(Y/Y_T)}\right)^2(\rho_t^B-r_t)\left(1-F(\Omega_t^S)\right)}{\Delta_t^S\left(\sigma_{t(Y/Y_T)}+\psi_t^B+\sigma_{t(Y/Y_T)}\psi_t^B\right)^3} < 0$$

[32] Numerical exercise reveals that the negative effect also gets smaller as ψ_t^B increases but the decrease in this effect is smaller than the decrease in the positive effect.

C. Balance Sheets Predicted by the Model

The balance sheets derived utilizing the model for large and small banks for the years 1999 to 2009 are provided below.[33]

Large Banks: Balance Sheet, 1999			
Assets		**Liabilities**	
Real Sector Loans	41,341.51	Deposits & ST Funding	88,115.76
Required Reserves	8,811.58	Interbank Borrowing	13,782.09
Excess Reserves	0.00	Bank Capital	10,802.17
Trading Securities	10,123.00		
Interbank Lending	26,589.49		
Other Assets	25,834.44		
Total	**112,700.03**	**Total**	**112,700.03**

Small Banks: Balance Sheet, 1999			
Assets		**Liabilities**	
Real Sector Loans	91.33	Deposits & ST Funding	54.35
Required Reserves	4.39	Interbank Borrowing	69.68
Excess Reserves	0.00	Bank Capital	7.31
Trading Securities	0.00		
Interbank Lending	15.82		
Other Assets	19.80		
Total	**131.34**	**Total**	**131.34**

Large Banks: Balance Sheet, 2000			
Assets		**Liabilities**	
Real Sector Loans	46,587.54	Deposits & ST Funding	98,575.58
Required Reserves	9,944.59	Interbank Borrowing	13,980.93
Excess Reserves	0.00	Bank Capital	12,071.08
Trading Securities	11,487.20		
Interbank Lending	27,611.05		
Other Assets	28,997.20		
Total	**124,627.58**	**Total**	**124,627.58**

Small Banks: Balance Sheet, 2000			
Assets		**Liabilities**	
Real Sector Loans	96.72	Deposits & ST Funding	57.74
Required Reserves	4.87	Interbank Borrowing	77.72
Excess Reserves	0.00	Bank Capital	7.74
Trading Securities	0.00		
Interbank Lending	21.57		
Other Assets	20.04		
Total	**143.19**	**Total**	**143.19**

Large Banks: Balance Sheet, 2001			
Assets		**Liabilities**	
Real Sector Loans	48,650.47	Deposits & ST Funding	106,436.36
Required Reserves	10,643.64	Interbank Borrowing	13,980.55
Excess Reserves	0.00	Bank Capital	13,737.07
Trading Securities	11,221.93		
Interbank Lending	28,448.37		
Other Assets	35,189.58		
Total	**134,153.99**	**Total**	**134,153.99**

Small Banks: Balance Sheet, 2001			
Assets		**Liabilities**	
Real Sector Loans	103.40	Deposits & ST Funding	62.96
Required Reserves	5.51	Interbank Borrowing	86.13
Excess Reserves	0.00	Bank Capital	8.27
Trading Securities	0.00		
Interbank Lending	27.31		
Other Assets	21.13		
Total	**157.35**	**Total**	**157.35**

[33] The balance sheet entries are average values for large and small banks and are in millions of US Dollars; the numbers in the balance sheets are rounded up or down to two decimal points.

Large Banks: Balance Sheet, 2002			
Assets		Liabilities	
Real Sector Loans	48,320.95	Deposits & ST Funding	117,524.15
Required Reserves	11,752.42	Interbank Borrowing	14,395.93
Excess Reserves	0.00	Bank Capital	13,915.60
Trading Securities	15,140.20		
Interbank Lending	31,595.50		
Other Assets	39,026.61		
Total	**145,835.68**	**Total**	**145,835.68**

Small Banks: Balance Sheet, 2002			
Assets		Liabilities	
Real Sector Loans	117.11	Deposits & ST Funding	67.85
Required Reserves	6.11	Interbank Borrowing	86.02
Excess Reserves	0.00	Bank Capital	9.37
Trading Securities	0.00		
Interbank Lending	16.70		
Other Assets	23.32		
Total	**163.24**	**Total**	**163.24**

Large Banks: Balance Sheet, 2003			
Assets		Liabilities	
Real Sector Loans	52,863.92	Deposits & ST Funding	129,431.47
Required Reserves	12,943.15	Interbank Borrowing	15,501.41
Excess Reserves	0.00	Bank Capital	14,762.91
Trading Securities	16,877.43		
Interbank Lending	33,766.78		
Other Assets	43,244.51		
Total	**159,695.79**	**Total**	**159,695.79**

Small Banks: Balance Sheet, 2003			
Assets		Liabilities	
Real Sector Loans	123.53	Deposits & ST Funding	72.17
Required Reserves	6.57	Interbank Borrowing	91.26
Excess Reserves	0.00	Bank Capital	9.88
Trading Securities	0.00		
Interbank Lending	17.94		
Other Assets	25.27		
Total	**173.31**	**Total**	**173.31**

Large Banks: Balance Sheet, 2004			
Assets		Liabilities	
Real Sector Loans	62,230.66	Deposits & ST Funding	149,761.37
Required Reserves	14,976.14	Interbank Borrowing	23,419.52
Excess Reserves	0.00	Bank Capital	17,120.03
Trading Securities	19,242.25		
Interbank Lending	42,433.98		
Other Assets	51,417.90		
Total	**190,300.92**	**Total**	**190,300.92**

Small Banks: Balance Sheet, 2004			
Assets		Liabilities	
Real Sector Loans	131.30	Deposits & ST Funding	76.74
Required Reserves	6.97	Interbank Borrowing	107.30
Excess Reserves	0.00	Bank Capital	10.50
Trading Securities	0.00		
Interbank Lending	29.29		
Other Assets	26.98		
Total	**194.55**	**Total**	**194.55**

Large Banks: Balance Sheet, 2005			
Assets		**Liabilities**	
Real Sector Loans	66,309.41	Deposits & ST Funding	166,704.99
Required Reserves	16,670.50	Interbank Borrowing	28,772.04
Excess Reserves	8,567.34	Bank Capital	19,220.72
Trading Securities	19,002.46		
Interbank Lending	49,445.75		
Other Assets	54,702.30		
Total	**214,697.75**	**Total**	**214,697.75**

Small Banks: Balance Sheet, 2005			
Assets		**Liabilities**	
Real Sector Loans	144.02	Deposits & ST Funding	81.59
Required Reserves	7.42	Interbank Borrowing	120.92
Excess Reserves	0.00	Bank Capital	11.52
Trading Securities	0.00		
Interbank Lending	34.86		
Other Assets	27.72		
Total	**214.03**	**Total**	**214.03**

Large Banks: Balance Sheet, 2006			
Assets		**Liabilities**	
Real Sector Loans	65,240.12	Deposits & ST Funding	192,089.11
Required Reserves	19,208.91	Interbank Borrowing	29,257.13
Excess Reserves	20,760.60	Bank Capital	22,583.36
Trading Securities	23,155.20		
Interbank Lending	52,827.39		
Other Assets	62,737.38		
Total	**243,929.60**	**Total**	**243,929.60**

Small Banks: Balance Sheet, 2006			
Assets		**Liabilities**	
Real Sector Loans	162.12	Deposits & ST Funding	85.50
Required Reserves	7.82	Interbank Borrowing	116.65
Excess Reserves	0.00	Bank Capital	12.97
Trading Securities	0.00		
Interbank Lending	16.83		
Other Assets	28.34		
Total	**215.12**	**Total**	**215.12**

Large Banks: Balance Sheet, 2007			
Assets		**Liabilities**	
Real Sector Loans	40,679.56	Deposits & ST Funding	218,263.60
Required Reserves	21,826.36	Interbank Borrowing	21,269.30
Excess Reserves	57,204.46	Bank Capital	25,878.58
Trading Securities	32,649.62		
Interbank Lending	45,520.63		
Other Assets	67,530.85		
Total	**265,411.48**	**Total**	**265,411.48**

Small Banks: Balance Sheet, 2007			
Assets		**Liabilities**	
Real Sector Loans	169.78	Deposits & ST Funding	89.04
Required Reserves	8.28	Interbank Borrowing	113.80
Excess Reserves	0.00	Bank Capital	13.58
Trading Securities	0.00		
Interbank Lending	9.43		
Other Assets	28.94		
Total	**216.42**	**Total**	**216.42**

Large Banks: Balance Sheet, 2008

Assets		Liabilities	
Real Sector Loans	61,080.05	Deposits & ST Funding	254,089.19
Required Reserves	25,633.25	Interbank Borrowing	30,414.73
Excess Reserves	57,238.03	Bank Capital	29,258.05
Trading Securities	37,161.28		
Interbank Lending	52,996.71		
Other Assets	79,652.67		
Total	**313,761.98**	**Total**	**313,761.98**

Small Banks: Balance Sheet, 2008

Assets		Liabilities	
Real Sector Loans	169.87	Deposits & ST Funding	95.76
Required Reserves	8.98	Interbank Borrowing	124.97
Excess Reserves	0.00	Bank Capital	13.59
Trading Securities	0.00		
Interbank Lending	24.98		
Other Assets	30.48		
Total	**234.32**	**Total**	**234.32**

Large Banks: Balance Sheet, 2009

Assets		Liabilities	
Real Sector Loans	114,483.05	Deposits & ST Funding	256,018.64
Required Reserves	25,827.90	Interbank Borrowing	47,012.67
Excess Reserves	0.00	Bank Capital	32,083.31
Trading Securities	26,012.79		
Interbank Lending	69,744.68		
Other Assets	99,046.20		
Total	**335,114.62**	**Total**	**335,114.62**

Small Banks: Balance Sheet, 2009

Assets		Liabilities	
Real Sector Loans	177.72	Deposits & ST Funding	104.46
Required Reserves	9.91	Interbank Borrowing	155.01
Excess Reserves	0.00	Bank Capital	14.22
Trading Securities	0.00		
Interbank Lending	50.89		
Other Assets	35.17		
Total	**273.68**	**Total**	**273.68**

Excess Reserve Accumulation and Credit Crunch in U.S. Commercial Banks during the Global Financial Crisis

Asad Karim Khan Priyo

Web Appendix: Not for Publication

A. Additional Balance Sheet Information

Figure A.1 presents the percentage of deposits and short term funding that large, small and all banks spend on assets other than loans and liquid assets (‘other assets’ are computed by deducting the sum of loans and liquid assets from total assets). These include assets such as land & building, plant & equipment, intangible assets, supplies, other non-earning assets etc. As can be observed in the figure, there is not much difference between large and small banks. In addition, for both large and small banks, these remain fairly stable throughout the entire sample period.

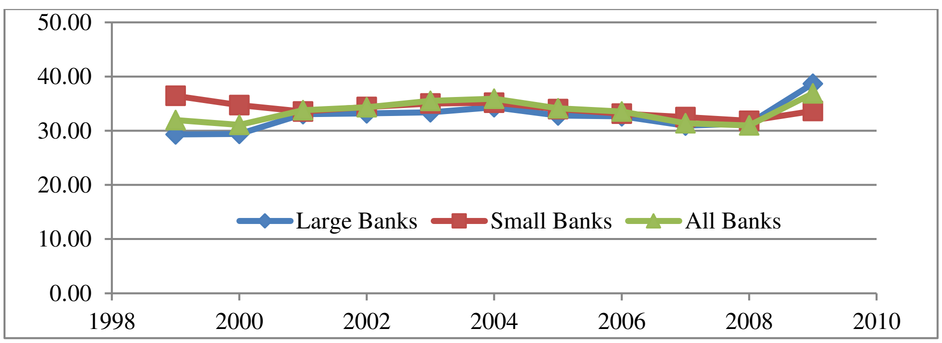

Figure A.1: Other Assets (Assets except Loans and Liquid Assets) as a Percentage of Deposits and Short-Term Funding in Large, Small and All Banks

Figure A.2 and Figure A.3, respectively, present tier 1 capital ratio and total capital ratio in large, small and all banks from 1999 to 2009. The figures show no significant change in these ratios over the entire period. The only interesting observation that I can make is that the small banks always have had greater capital ratios compared to large banks.

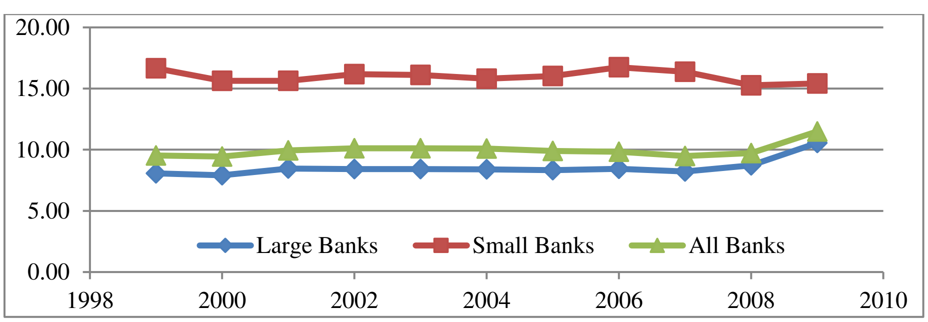

Figure A.2: Tier 1 Capital Ratio in Large, Small and All Banks

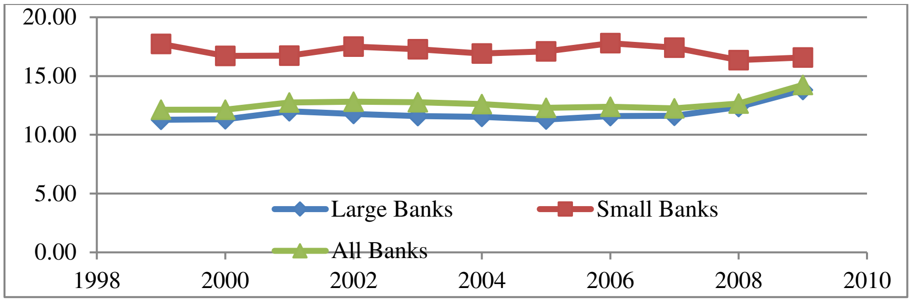

Figure A.3: Total Capital Ratio in Large, Small and All Banks

B. Increase in Idiosyncratic Uncertainties in Large Banks – Possible Explanations

My preliminary investigations reveal two possible explanations. The first has to do with the sub-prime mortgage crisis, and the second involves the substantial increase in the use of financial derivatives, namely credit derivatives by large commercial banks. As reported by Choudhry et al. (2009), interest rates in the U.S. remained exceptionally low during 2001 to 2004, which led to the initiation of a lot of mortgages to a segment of the population who could not have otherwise afforded a home. The Federal Reserve started to raise interest rates from 2004, and as a result, many of these home buyers found their monthly mortgage payments triple and even quadruple. Many defaulted on their mortgage payments and faced foreclosure of their properties. This marked the beginning of the sub-prime mortgage crisis. The beginning of the sub-prime mortgage crisis together with the large amount of mortgage-backed securities that commercial banks (large banks in particular) held during this time may provide one potential explanation for the increase in the volatility of deposits and short-term funding that large banks have faced since 2004.

Considerable increase in the use of financial derivatives — credit derivatives in particular — by large commercial banks may provide another explanation for the increasing idiosyncratic uncertainties faced by large banks. The hypothesis is that given the risky nature of financial derivatives, their increased use would create a lot of movement of funds among the banks that extensively use these risky instruments. This potentially can translate into increased volatility in deposits and short-term funding among these banks. To investigate this, I obtain data on financial derivatives as well as credit derivatives from the Office of the Comptroller of the Currency and find that commercial banks' use of financial derivatives increases more or less at an exponential rate between 1999 and 2008. [34] The use of derivatives has been highly concentrated within the large commercial banks — for example, in 2008 in the U.S. 96% of all outstanding Over the Counter (OTC) derivatives are accounted for by only five large banks and 44% appear in the book of the largest bank, JP Morgan Chase. I find a strong positive correlation (correlation coefficient of 0.86) between total financial derivatives and $CV_{d_t^B}$ during the period 1999 to 2009. An even stronger relationship exists between commercial banks' use of credit derivatives (most of which are credit default swaps; e.g., in 2008, 98.29% of all credit derivatives are credit default swaps) and $CV_{d_t^B}$. Similar to $CV_{d_t^B}$, credit derivatives are fairly stable between 1999 and 2003, start to increase from 2004 and reach the highest point in 2008. The correlation coefficient between credit derivatives and $CV_{d_t^B}$ is 0.88 during the period 1999 to 2009.

Figures B.1 and B.2 report total financial derivatives and credit derivatives, respectively, of all insured U.S. commercial banks and trust companies for the period 1999 to 2009. Figure B.1 depicts

[34] http://www.occ.gov/topics/capital-markets/financial-markets/trading/derivatives/derivatives-quarterly-report.html

that the use of financial derivatives by the U.S. commercial banks as a whole increase roughly at an exponential rate between 1999 and 2009. Credit derivatives – most of which are credit default swaps – on the other hand remain quite stable between 1999 and 2003, and then rapidly increase from 2004 reaching the peak in 2008.[35]

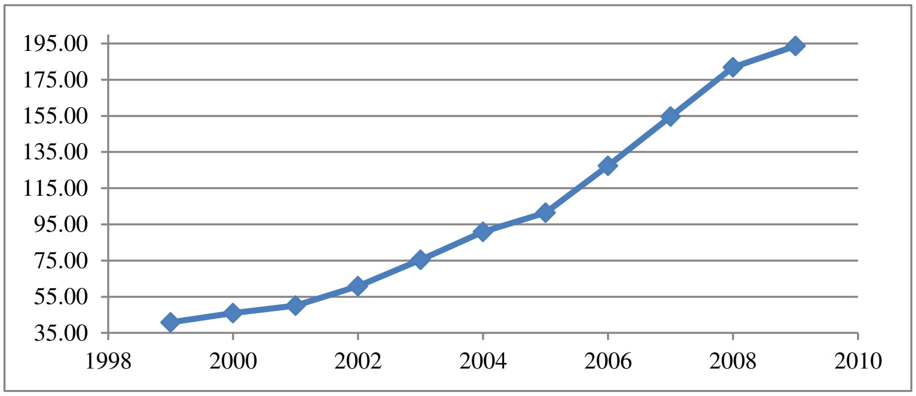

Figure B.1: Total Financial Derivatives in All Insured U.S. Commercial Banks and Trust Companies (In Trillions of 2005 USD)

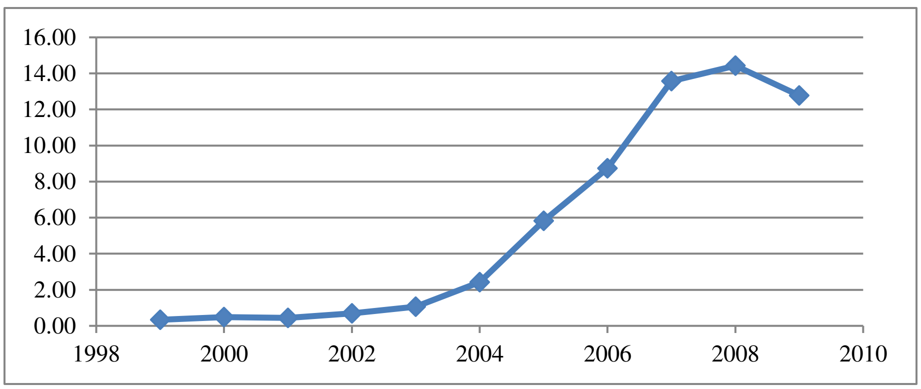

Figure B.2: Total Credit Derivatives in All Insured U.S. Commercial Banks and Trust Companies (In Trillions of 2005 USD)

C. Numerical Exercise: Impacts of Idiosyncratic Uncertainty and Risky Investments on Lending and Reserves

To identify the roles of idiosyncratic uncertainty and risky investments separately on large banks' lending and reserve behavior, I perform the following experiments.[36] To trace the effects of idiosyncratic uncertainty, I fix the values of all variables and parameters except $CV_{d_t^B}$ at 1999 levels. I choose 1999 because it is a typical year with relatively low idiosyncratic uncertainty, low macro risk and low risky investments. Remember that the model predicts relatively high $l_t^{B^*}/d_t^B$ and zero $E_t x_t^{B^*}$ for this year. I vary $CV_{d_t^B}$ starting from a low value of 0.60 to a high value of 2.0, increasing its value incrementally by 0.10 (the original value of $CV_{d_t^B}$ in 1999 is 1.13). To do this,

[35] The numbers presented in Figure B.1 and Figure B.2 are adjusted for inflation for the sake of comparability across years. I use CPI with base year 2005 to adjust the values.
[36] For this section of the study, Δ_t has been recalibrated for the different values of $CV_{d_t^B}$ and ψ_t^B.

I keep μ_t^B fixed and alter σ_{Bt}. For each value of $CV_{d_t^B}$, I numerically solve the model and compute equilibrium $l_t^{B^*}$ and $E_t x_t^{B^*}$. Figure C.1 summarizes how $l_t^{B^*}/d_t^B$ (Panel A) and $E_t x_t^{B^*}/d_t^B$ (Panel B) vary with $CV_{d_t^B}$.

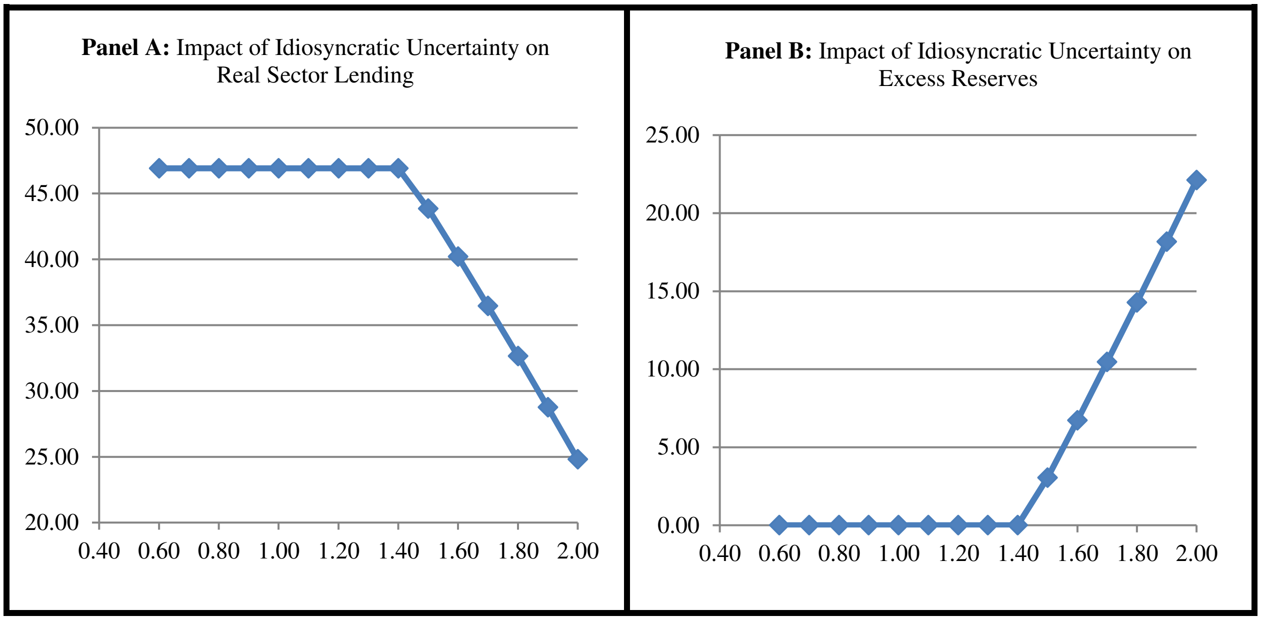

Figure C.1: Impact of Idiosyncratic Uncertainty on Lending and Reserve Behavior of Large Banks. All values except $CV_{d_t^B}$ are fixed at 1999 levels. All numbers in the Y-axis of each panel are expressed as a % of deposits and short-term funding.

For relatively low values of $CV_{d_t^B}$ — that is, between 0.60 and 1.40 — with increase in $CV_{d_t^B}$, $l_t^{B^*}$ remains constant at some positive value whereas $E_t x_t^{B^*}$ remains unchanged at zero. Once $CV_{d_t^B}$ surpasses 1.40, as idiosyncratic uncertainty rises $l_t^{B^*}$ falls rapidly at an increasing rate while $E_t x_t^{B^*}$ becomes positive and increases at an increasing rate as the theoretical analysis predicts in section 5.1.

To identify the role of risky investments, I first fix the values of all variables and parameters except ψ_t^B at 1999 levels. I vary ψ_t^B starting from a low value of 2% to a high value of 20%, incrementally raising it by 2% (the original value of ψ_t^B in 1999 is 11.49%). For each value of ψ_t^B, I numerically solve the model and compute equilibrium $l_t^{B^*}$ and $E_t x_t^{B^*}$. Panel A and Panel B in Figure E.2 summarize the results. In this case, $l_t^{B^*}/d_t^B$ falls at a constant rate of 2% — that is, large banks simply substitute trading securities for loans while $E_t x_t^{B^*}$ remains unchanged at zero with increases in ψ_t^B. Note that originally for 1999, the model predicts zero expected excess reserves for large banks. This experiment suggests that if $E_t x_t^{B^*} = 0$ to begin with, raising ψ_t^B in general does not make $E_t x_t^{B^*} > 0$ and only reduces $l_t^{B^*}$.

To investigate and confirm the analytical results for the case when excess reserves are positive — that is, to observe how $l_t^{B^*}$ and $E_t x_t^{B^*}$ vary with ψ_t^B when $E_t x_t^{B^*} > 0$ — I repeat the experiment using 2008 values. Panel C and Panel D in Figure C.2 summarize the results. In this scenario, as ψ_t^B increases $l_t^{B^*}$ decreases at a decreasing rate whereas consistent with the theoretical analysis presented in section 5.1, $E_t x_t^{B^*}$ increases at a decreasing rate for relatively smaller values of ψ_t^B (between 2% and 10% for 2008) and decreases at an increasing rate for relatively larger values of ψ_t^B (between 10% and 20% for 2008). As ψ_t^B increases from a low value, $E_t x_t^{B^*}$ initially increases by a large amount as the cost effect dominates the balance sheet effect. As ψ_t^B keeps increasing, the increase in $E_t x_t^{B^*}$ slows down and eventually for relatively high values of ψ_t^B, $E_t x_t^{B^*}$ starts to decrease as the balance sheet effect dominates the cost effect.

The numerical analysis in this section demonstrates that whether banks have positive or zero excess reserves in equilibrium depends on the level of idiosyncratic uncertainty they face given all other variables and parameters. Everything else remaining constant, the larger the idiosyncratic risk that banks face — that is, the larger the coefficient of variation of net deposit inflows — the higher the amount of liquidity deficiency (amount of funds required to meet loan commitments) and the higher the amount of excess liquidity (amount of funds available in excess of loan commitments) that a bank may potentially face once deposits realize. After deposits are realized, a bank can access the interbank market as a borrower or lender depending on the amount of deposits it receives. Banks with low deposit draws borrow from banks with high draws in the interbank market. A greater amount of borrowing demand with everything else remaining constant raises the cost of borrowing. It turns out that for values of idiosyncratic uncertainty below a certain threshold, as idiosyncratic uncertainty increases banks with low deposit draws find it optimal to raise interbank borrowing by enough to keep real sector loans unchanged. In this scenario, there is enough demand for interbank borrowing that enables banks with high deposit draws to get rid of their excess liquidity by lending in the interbank market. Once idiosyncratic uncertainty is greater than the threshold level, as idiosyncratic uncertainty increases banks with low deposit draws find it too costly to raise interbank borrowing by enough to keep real sector loans unchanged and as a result, real sector loans start falling. In this scenario, banks with good draws cannot lend out all of their excess liquidity since they do not face enough demand, and this in turn results in positive excess reserves.[37]

Once idiosyncratic uncertainty determines whether banks have zero or positive excess reserves, the most important factors that determine the level of loans to the real sector and excess reserves in equilibrium are the level of idiosyncratic uncertainty and the amount of investments in risky trading securities. As long as idiosyncratic uncertainty remains lower than the threshold level, excess reserves remain zero regardless of the level of idiosyncratic uncertainty and risky investments. Loans to the real sector remain constant with increase in idiosyncratic uncertainty and decrease at a constant rate with risky investments.[38] Once idiosyncratic uncertainty exceeds the threshold level — that is, once excess reserves become positive — loans fall rapidly at an increasing rate with idiosyncratic uncertainty and decrease at a decreasing rate with risky investments.[39] Excess reserves, on the other hand, increase at an increasing rate with idiosyncratic

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[37] Numerical analysis reveals that the threshold value for idiosyncratic uncertainty differs by year depending on other factors such as the cost of monitoring large borrower banks (namely, the coefficients of m_{Bt}^B and m_{Bt}^S of the marginal monitoring costs, i.e., $\Delta_t^j\left(\sigma_{t_{(Y/Y_T)}} + \psi_t^B + \sigma_{t_{(Y/Y_T)}}\psi_t^B\right), j \in \{B, S\}$, etc.). Take, for example, 2001 and 2007. Between these two years, monitoring costs are substantially higher in 2007. The threshold $CV_{d_t^B}$ required to result in positive x_t^B is 1.6 in 2001 whereas the same is 0.8 in 2007.

[38] For values of idiosyncratic uncertainty smaller than the threshold level and with binding $l_t^S \leq \kappa \bar{z}_t^S$ constraint, as idiosyncratic uncertainty increases banks with low deposit draws can increase their interbank borrowing sufficiently to keep loans to the real sector unchanged. Only the interbank interest rates adjust. In this scenario, as ψ_t^B increases banks simply substitute trading securities for loans. and loans fall by the exact amount by which trading securities rise. This implies that the interbank rates adjust to offset the cost effect entirely. and we only observe the balance sheet effect.

[39] Loans decrease at a decreasing rate with ψ_t^B because of the following reason. As ψ_t^B increases, the cost of monitoring borrowing large banks increases, which everything else remaining constant reduces expected interbank lending to large banks. As can be observed from equation (10), this cost effect tends to become smaller and smaller as ψ_t^B rises.

uncertainty and initially increase at a decreasing rate and then decrease at an increasing rate with risky investments.[40]

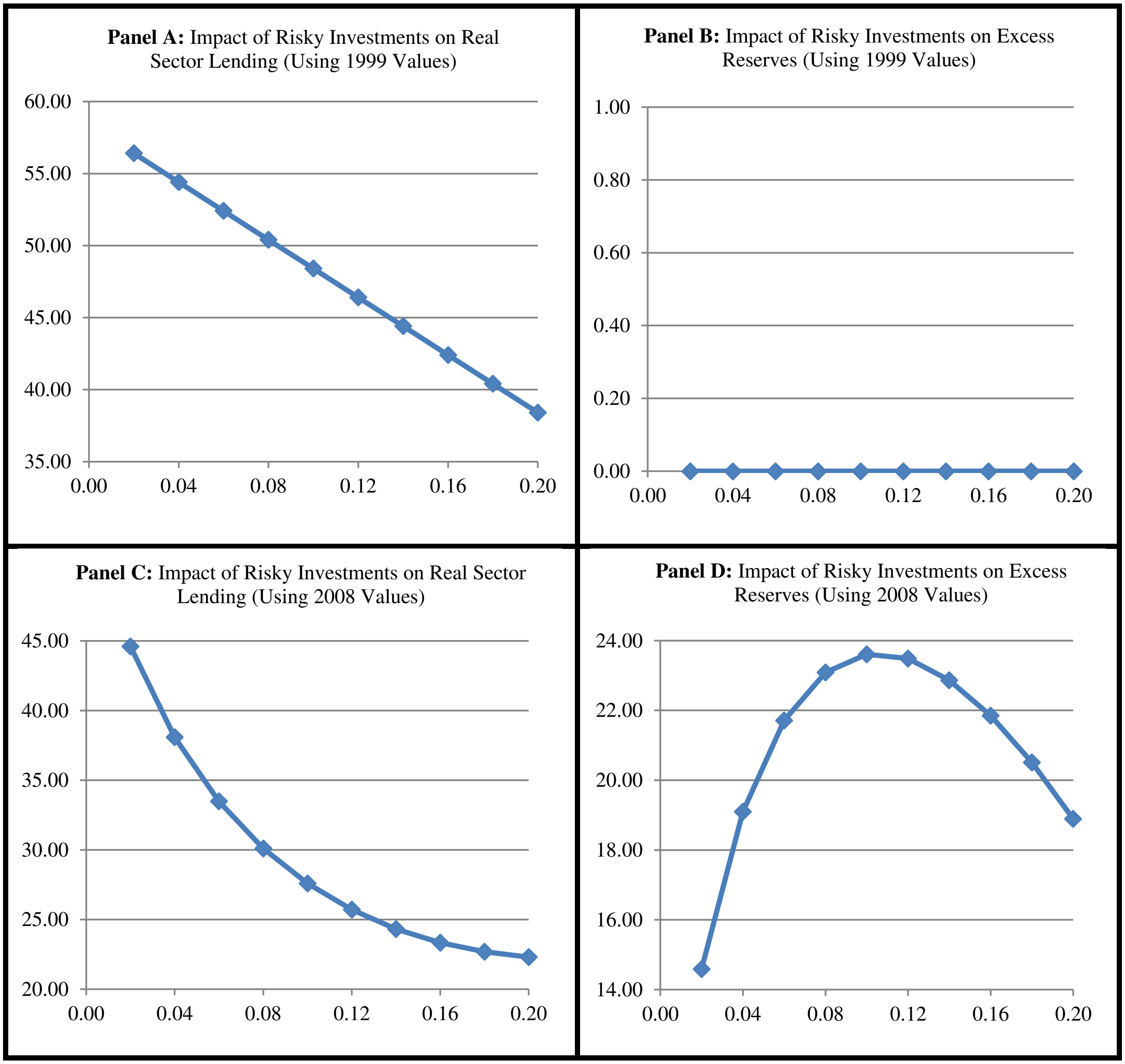

Figure C.21: Impact of Risky Investments on Lending and Reserve Behavior of Large Banks. All values except ψ_t^B are fixed at 1999 levels in Panel A and Panel B and at 2008 levels in Panel C and Panel D. All numbers in the Y-axis of each panel are expressed as a % of deposits and short-term funding.

Therefore, expected interbank lending to large banks reduces as ψ_t^B increases but at a decreasing rate. Finally, as large banks expect to obtain a smaller volume of interbank borrowing, their overall real sector lending decreases at a decreasing rate with ψ_t^B.

[40] It should be noted that the range of values of ψ_t for which excess reserves become significantly small due to balance sheet effect is considerably higher than the values of ψ_t we observe during the sample period of 1999 to 2009. For my sample period, as section 5.2 demonstrates, higher ψ_t is associated with greater amount of excess reserves (when idiosyncratic uncertainty is larger than the threshold level).

D. The Role of Discount Window Borrowing

When commercial banks face a liquidity crisis that cannot be met through the interbank market, they can borrow from the Central Bank, an important role of which is to act as the Lender of Last Resort (e.g., McMahon, 1977; Wallich, 1977; Flannery, 1996; Freixas et al., 1999; Berger et al., 2000; Rochet and Vives, 2004; Armantier et al., 2011; Nakaso, 2013). In the U.S., the Federal Reserve conventionally uses the discount window (DW) facility to provide loans to banks that need emergency liquidity.

Since bank-specific data on DW borrowing are unavailable, I obtain data on aggregate annual DW lending from the Board of Governors of the Federal Reserve System for the period 1999 to 2009 and use the available information to compute the ratio of DW lending to total deposits.[41] The ratio for my sample period is reported in Figure D.1.

It is not surprising to observe that financial institutions borrowed a negligible amount of funds from the DW except during the financial crisis. In general, banks are unwilling to borrow from the DW because DW borrowing is interpreted as a signal of financial weakness — a phenomenon which has come to be known as the DW stigma. Several authors over the years discuss and provide evidence for stigma associated with DW borrowing (e.g., Saunders and Urich, 1988; Peristiani, 1998; Furfine, 2003; Ennis and Weinberg, 2009). Armantier et al. (2011) provide robust empirical evidence of the existence of DW stigma during the financial crisis and refer to the following quotation by Bernanke (2009), which makes the presence of the stigma during the crisis pretty apparent:

> *"In August 2007, ... banks were reluctant to rely on discount window credit to address their funding needs. The banks' concern was that their recourse to the discount window, if it became known, might lead market participants to infer weakness—the so-called stigma problem."*

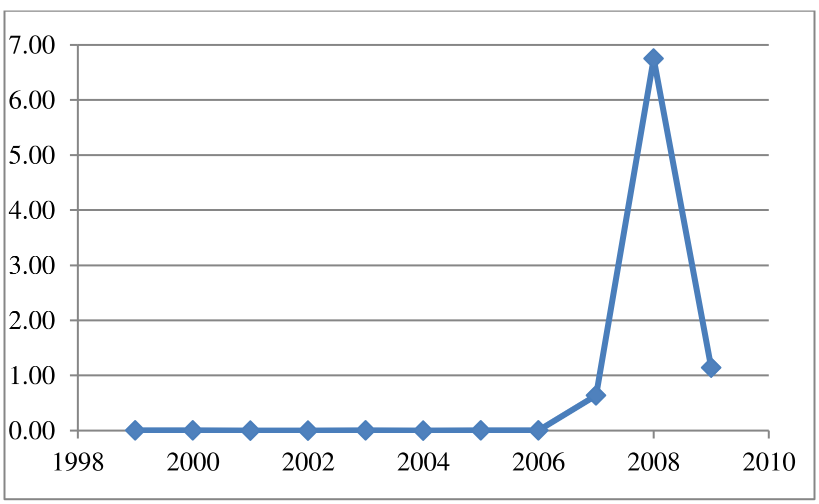

Figure D.1: Discount Window Borrowing as a Percentage of Deposits

[41] Under DW loans, the Board of Governors of the Federal Reserve System reports Federal Reserve loans extended to U.S. banks through term auction credit, primary credit, secondary credit and seasonal credit.

I include DW borrowing in the model as an exogenous variable and utilize the ratio of DW borrowing to total deposits to allocate these funds to large and small banks. I multiply the above-mentioned ratio by deposits and short-term funding held by large and small banks, respectively, to compute model-equivalent measures of DW borrowing by these banks.[42] Predictions of the model with and without DW borrowing on large banks' real sector loans and excess reserves are presented in Figure D.2.[43]

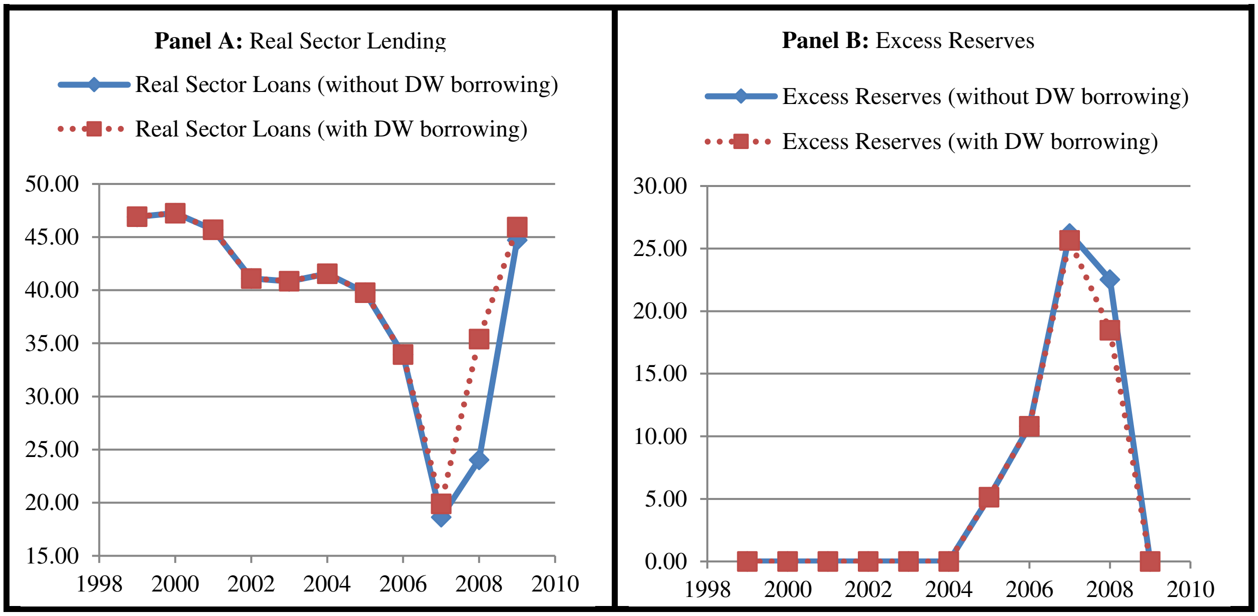

Figure D.2: Effects of Discount Window Borrowing on Real Sector Loans and Excess Reserves of Large Banks. Numbers in Panels A and B are expressed as a % of deposits and short-term funding.

The predictions of the two versions of the model are almost identical in every year except 2007, 2008 and 2009. In 2007 and 2009, the addition of DW borrowing in the model slightly raises predicted real sector loans whereas in 2007 it marginally reduces predicted excess reserves. We observe a larger increase and decrease, respectively, in real sector loans and excess reserves in 2008 given that the quantity of DW borrowing is significantly larger in 2008.[44] The introduction of the DW in the model acts as a positive shock to the supply of funds to liquidity deficient banks in the second stage and allows all banks to choose a higher amount of real sector lending in the first stage — hence the increase in predicted loans. The impact on excess reserves is a bit more ambiguous. Because banks choose a higher amount of loans in the first stage, they are left with a smaller quantity of available liquidity after deposits realize, which creates downward pressure on excess reserves. On the other hand, because the Federal Reserve meets some of the liquidity requirements of liquidity deficient banks, liquidity rich banks can lend out less of their available

[42] Banks with liquidity shortfalls can now borrow from the DW in addition to the federal funds market. These borrowings affect the market clearing conditions and are added to both equations — that is, DW lending to large banks is added to the left hand side of market clearing condition 1 and DW lending to small banks is added to the left hand side of market clearing condition 2.

[43] These effects are reported for only large banks because for small banks under both cases, predicted real sector loans and reserves remain unchanged.

[44] One of the reasons the data suggest a greater amount of DW loans in 2008 may be the introduction of Term Auction Facility (TAF) in December 2007, a lending program created to augment the DW. As suggested by Armantier et al. (2011), one of the Federal Reserve's goals in developing the TAF was to eradicate the stigma associated with the DW.

liquidity, which creates upward pressure on excess reserves. In the end, as Figure D.2 demonstrates DW borrowing reduces predicted excess reserves, but the magnitude of the change is smaller than predicted loans.

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