Research Division
Federal Reserve Bank of St. Louis
Working Paper Series

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Working Paper 2013-029B
http://research.stlouisfed.org/wp/2013/2013-029.pdf

October 2013
Revised October 2013

FEDERAL RESERVE BANK OF ST. LOUIS
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Understanding the Accumulation of Bank and Thrift Reserves during the U.S. Financial Crisis*

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This version: October 28, 2013

Abstract

The level of aggregate excess reserves held by U.S. depository institutions increased significantly at the peak of the financial crisis of 2007-09. Although the amount of aggregate reserves is almost entirely determined by the policy initiatives of the central bank that act on the asset side of its balance sheet, the motivations of individual banks in accumulating reserves differ and respond to the impact of changes in the economic environment on individual institutions. We undertake a systematic analysis of this massive accumulation of excess reserves using bank-level data for more than 7,000 commercial banks and almost 1,000 savings institutions during the U.S. financial crisis. We propose a testable stochastic model of reserves determination when interest is paid on reserves, which we estimate using bank-level data and censored regression methods. We find evidence primarily of a precautionary motive for reserves accumulation with some notable heterogeneity in the response of reserves accumulation to external and internal factors of the largest banks compared with smaller banks. We combine propensity score matching and a difference-in-difference approach to determine whether the beneficiaries of the Capital Purchase Program of the Troubled Assets Relief Program accumulated lower reserves than non-beneficiaries. Contrary to anecdotal evidence, we find that banks that participated in the program accumulated fewer reserves than non-participants in the initial quarters after the capital injection.

*We thank audience members at the EEA Oslo 2011, AMES Seoul 2011, Midwest Macro 2011, CEA 2012, Santa Clara University, University of San Francisco, UC Santa Cruz brown bag lunch, the St. Louis Federal Reserve brown bag and conference participants at the joint ECB-DBC Conference 2013. We would also like to thank George Bulman, Carlos Dobkin, Carl Walsh, Riccardo DiCecio, and David Wheelock for helpful comments. Hoda El-Ghazaly provided excellent assistance with data management. Su-Hsin Chang: Washington University in St. Louis, Division of Public Health Sciences, Washington University School of Medicine, 660 South Euclid Avenue, Campus Box 8100, St. Louis, MO 63110, changsh@wudosis.wustl.edu. Silvio Contessi: Federal Reserve Bank of St. Louis, Research Division, P.O. Box 442, St. Louis, MO 63166-0442, silvio.contessi@stls.frb.org; telephone: 314-444-7410; fax: 314- 444-8731. Johanna Francis: Fordham University, Department of Economics, E-507 Dealy Hall, 441 East Fordham Road, Bronx, NY, 10458, ajofrancis@fordham.edu and University of California, Santa Cruz, Department of Economics, Santa Cruz, CA 95064. The views expressed are those of the authors and do not represent official positions of the Federal Reserve Bank of St. Louis, the Board of Governors, or the Federal Reserve System.

JEL Classification: E44, E51, G21
Keywords: Commercial Banks, Financial Crisis, Excess Reserves, TARP

1 Introduction

The aggregate level of deposits held by U.S. depository institutions (DIs) at the Federal Reserve Banks (Fed) increased massively at the peak of the financial crisis between the end of August 2008 and the end of December 2008, in parallel with the unprecedented expansion of the Fed balance sheet (Figure 1).[1] This huge change in deposits at the Fed, most of which are excess reserves, prompted some commentators to argue that precautionary hoarding of cash and reserves was impeding loan growth and potentially slowing the recovery from the 2007-09 recession. The fear was that the accumulation of reserves would dampen the effect of Fed operations to revive the economy and at the same time potentially generate inflation. Keister and McAndrews (2009) and Martin, McAndrews, and Skeie (2013) explain clearly that the level of aggregate reserves is determined by the policy initiatives of the Federal Reserve and may only marginally affect aggregate lending. Although this is true at an aggregate level, excess reserve holdings are not distributed evenly across banks; individual banks can alter the composition of their balance sheets, changing lending to firms and consumers while hoarding excess reserves and cash.

The biggest question that the massive accumulation of reserves raises is why individual profit-maximizing banks hold excess reserves and cash. Our answer is intuitive: because they were concerned about balance sheet risk and accessing short term liquidity.

Our study consists of two parts, in the first part we undertake a systematic analysis of this massive accumulation of excess reserves using microeconomic data for more than 7,000 commercial banks and almost 1,000 saving institutions to identify motives for accumulation and determine whether these motives differ across depository institutions by size and type. In the second part, we study the effect of the CPP on reserve and cash accumulation.

In the first part of our analysis, we provide some insight into the heterogeneous effects of the 2007-09 financial crisis and to some extent of the fiscal and monetary policy actions in the commercial banking sector. We estimate a log-linearized version of a simple model of stochastic reserve accumulation using bank-level data and censored regression methods.[2]

[1] DIs (commercial banks, savings institutions, credit unions, and foreign banking entities) may hold their required reserves as either vault cash or deposits at their regional Federal Reserve Bank. Deposits at the Federal Reserve are the sum of reserve balances with Federal Reserve Banks and required clearing balances; on August 27, 2008, total deposits at Federal Reserve Banks were $20.394 billion; on December 29, 2010, they were $1020.937 billion.

[2] Excess reserve holdings at the micro level are confidential information. To recover a bank level estimate of excess reserves we subtract estimated required reserves from reported cash including total reserve holdings at the Federal

We find evidence of three motives for reserve and cash accumulation, first, there appears to be a strong precautionary motive due to weak balance sheets, second, evidence of concerns about accessing short term liquidity in the market, particularly for large banks[3], and third, evidence that banks are sensitive to changes in the opportunity cost of holding low-interest bearing assets suggesting that opportunities for low-risk lending were inadequate.

We uncover significant heterogeneity in the responsiveness of reserve accumulation. We find that large banks' cash and excess reserve holdings are much more responsive to the penalty rate than small banks, a different relationship between capital ratios and cash and reserve accumulation for large versus small banks, and that large banks are much more sensitive to distressed loans as a percentage of deposits than small banks. We also find that thrifts behave like small banks in terms of the relationship between capital adequacy and reserve accumulation but like large banks in relation to the penalty rate and sensitivity to distressed loans.

These results likely reflect several important changes in the banking environment during this period. First, the Federal Funds and the Repurchase markets experienced significant volume declines during our sample period. These markets are a significant source of short term funding for banks. Notably, the declines in trading activity were more pronounced for large bank trading than for small banks. Second, increases the CBOE Volatility index (VIX) during this period are suggestive of changes in risk perceptions. Third, there was significant regulatory uncertainty related to new consumer protection laws, changes to capital requirements, and concerns about future litigation.

In the second part of our analysis, we study the relationship between the Capital Purchase Program (CPP) of the Troubled Assets Relief Program (TARP) and cash and reserve accumulation by banks.[4] The ideal way to study the effect of capital injections on the banking system would be to have a counterfactual. Although we cannot observe what would have happened to the balance sheets of banks that received CPP funds had they not received them, we can observe banks that were ex ante similar to the CPP beneficiaries but did not receive the capital injections. Operationally, we use propensity score matching to construct a control group of non-CPP institutions that we compare with the CPP beneficiaries. We then estimate the difference-in-difference between pairs of indicators for the two groups of banks to remove unobservable differences between

Reserve. Therefore our measure of excess reserves also includes cash in addition to excess balances at the Federal Reserve. We discuss the bias this might create in our estimates in section 5.1

[3] Ashcraft, McAndrews, and Skeie (2011) find similar evidence which we discuss in section 5.2.

[4] We use CPP and TARP interchangeably, although the CPP was the part of the TARP related to the banking sector.

them. Although we are able to match a large number of banks that received CPP funds, an important caveat of our study is that, because almost all large banks (as ranked by assets) received CPP funds, finding an opportune control is unfeasible; therefore, we remove the largest 20 banks from our study.

We find that the remaining sample of the beneficiaries of the capital injection of CPP funds accumulated less cash and reserves than non-beneficiaries. Popular opinion at the time of the crisis was that the CPP had failed to improve lending because it increased reserve accumulation. Contessi and Francis (2011) found, on the contrary, that banks receiving CPP funds provided more loans than their counterparts, but since issues of endogeneity and selection were not dealt with formally, these were tentative statements. The banks that did not receive CPP funds may not have received them for various reasons; for example, because they were sufficiently capitalized and therefore had no need for the funds, or alternatively, because they were in such poor financial health that they were ineligible for the program. In this paper, we construct an appropriate control group to address problems of endogeneity and selection for our results. To the best of our knowledge, this is the first study to adopt propensity score matching in the non-experimental setting of applied banking. Black and Hazelwood (2012) study bank risk taking after receiving CPP using an event study methodology that also carefully controls for differences between CPP and non-CPP recipients.

The paper is organized as follows. In Section 2, we present an overview of the existing literature and in Section 3 we discuss the specific case of the United States. In Section 4 we develop the testable model, and Section 5 presents the data and the estimation. Section 6 studies the relationship between the CPP and cash and reserves accumulation. Section 7 concludes.

2 Related Literature

The literature on banking reserves is large and diverse and includes a number of key contributions. The two most significant branches of the literature for our study consider explanations for reserves accumulation by U.S. banks during the 1930s and the substantial buildup in excess reserves in the Japanese banking system during the 1990s. We also briefly review modern contributions on the role of uncertainty and interest on reserve policies on excess reserve accumulation.

In their influential analysis of the monetary history of the Depression era, and particularly the increase in excess reserve holdings, Friedman and Schwartz (1963) argued

that banks desired a higher level of reserves for precautionary purposes after the panic of the early 1930s. On the contrary, Horwich (1963) provided early empirical evidence suggesting banks held excess reserves because of the lack of profitable alternatives to holding cash as a result of low interest rates. Along with these two contributions, many articles in the post-World War II literature tried to rebut the widespread view of reserves accumulation at the time that considered excess reserves to be purely surplus. This view was surprisingly shared by members of the Federal Open Market Committee (FOMC). According to this view, excess reserves served no useful economic purpose, as commercial banks passively accumulated them due to the lack of good loan opportunities (a view sometimes referred to as the "inertia effect" hypothesis; see Frost, 1971). As a consequence, the Federal Reserve was essentially powerless to expand the money supply because the banking system was caught in a liquidity trap, an event we find evidence for in the most recent financial crisis. Bernanke (1983) and Bernanke and Gertler (1990) emphasize the role of high risks and low returns on alternatives during the Depression era, supporting of the view that excess reserve holdings may also reflect an environment with few investment alternatives that have comparable low risks. The theoretical literature on banking reserves dissects the role of uncertainty on bank cash flows and how it differs between periods of crisis and non-crisis (see, e.g. Orr and Mellon, 1961; Poole, 1968; Cooper, 1971; Frost, 1971; Ratti, 1979; Hanes, 2006). As uncertainty plays a role in our analysis, we sketch the main contributions. Technical errors in a paper by Orr and Mellon (1961) spurred a debate on the relationship between stochastic reserve losses and the expansion of bank credit and the conditions under which the introduction of uncertainty into cash flows played a role in reducing lending compared with a deterministic environment (see, e.g., Cooper, 1971; Ratti, 1979).

Frost (1971) models bank demand for excess reserve holdings as an inventory problem, assuming that excess reserves allow banks to reduce the cost of meeting requirements when they face stochastic reserve flows and transaction curves. His model generates kinked demand curves that rationalize excess reserves accumulation during the 1930s. More recently, Hanes (2006) develops a model in which an increase in the reserve supply reduces long-term rates, holding fixed expectations of future overnight rates, and shows that the model is consistent with the relationship between reserve quantities and bond yields over the 1934-39 period.

A series of recent studies discusses the relevance of the constraints exerted by excess liquidity and their role in signaling a bank's own liquidity. Calomiris, Mason, and

Wheelock (2011) use bank-level data to understand whether the doubling of reserve requirements imposed by the Federal Reserve in 1936-37 increased reserve demand and induced a credit contraction, contributing to the deep recession of 1937-38. They find that reserve requirements were not binding on bank reserve demand in 1936 and 1937 and therefore had little impact on credit availability. They thus argue that increases in reserve demand between 1935 and 1937 reflected changes in the fundamental determinants of reserve demand, not changes in reserve requirements. Calomiris and Wilson (2004) argue that increasing reserve demand during periods of financial upheaval may be due to the liquidity signaling effect that high levels of reserves provide to depositors and creditors. Van Horn (2009), examining the years leading up to the Depression era, found that Federal Reserve System non-members, which had no access to the lender of last resort, increased their ratio of excess reserves to assets after the first banking panic much more than member banks, which could access emergency lending through the Fed. Ennis and Wolman (2012) find a similar result for the 2007-2009 crisis.

Japan's Lost Decade also offers an important modern episode of steep reserve accumulation. Japanese banks began a sustained increase in excess reserve accumulation in mid-2001, which peaked in 2003:Q3 when the ratio of actual to required reserves reached 5.9. In Figure 2 we offer a comparison between the sharp increase in the ratio of actual to required reserves within the Japanese banking system between 2001 and 2006 and the increase in excess reserves during the Great Depressions and during the recent U.S. Great Financial Crisis (GFC). The recent reserves accumulation of Japan and the United States are much more pronounced, they clearly dwarf the accumulation of reserves (in terms of the ratio of excess to required reserves) during the U.S. Great Depression. Ogawa (2007) studies the determinants of bank-level reserve accumulation in Japan during the 1998-2002 period. His results suggest that a strong precautionary motive induced banks with large numbers of bad loans to accumulate relatively more reserves.[5] He attributed Japanese banks' precautionary behavior to the general instability in the Japanese banking system and the poor health of the individual bank's balance sheets. He found that banks with better capitalization and a sounder portfolio of loans did not have as much incentive to overaccumulate reserves compared with banks that had poorer-quality portfolios and shakier balance sheets. Figures 3, 4, and 5 offer a comparison of the three historical episodes in which the excess-to-required reserve ratio (ERR) is plotted against a short-term rate that represents potential al-

[5] Other work (see, e.g. Uesugi, 2002; Hamilton, 1997; Thornton, 2001) considers the liquidity effect: the proposition that monetary expansion lowers short-term nominal interest rates.

ternative investment opportunities to holding cash. Along with these two series, the graphs plots the 24-month rolling correlations between the two, which is predominantly negative, indicating that times of increases in the ERR are times in which this rough measure of the opportunity cost of holding reserves decreases. It is clear that the sign of the correlation observed by Ogawa (2007) is the same for the two historical episodes of reserves accumulation in the United states.

To conclude our review, there is a growing literature that discusses excess reserves in the context of contemporary monetary policy when the monetary authority pays a positive IOR, as practiced, for example, in Canada, the United States (since October, 2008), New Zealand, the euro area, as well as other countries. Goodfriend (2002) discusses the benefits of the additional policy instrument provided by paying IOR. Keister, Martin, and McAndrews (2008) explain how the payment of IOR can generate a floor that "divorces" money from monetary policy, as the supply of reserves is then not necessarily tied to the target interest rate, thereby allowing central banks to increase the supply of reserves without driving market rates below target. Hornstein (2010) develops a stylized monetary model to explain the mechanics of monetary policy when the central bank pays IOR and finds that, although the responses of inflation and output to innovations in the target interest rate are slightly different from models in which reserves yield zero interest, such differences are small. In the context of the U.S. financial crisis, Bech and Klee (2011) use a market micro-structure approach to study a theoretical model in which bargaining power among traders explains why the federal funds rate remained below the target rate and the rate paid on reserves during the U.S. financial crisis. Ashcraft, McAndrews, and Skeie (2011) use data on intraday account balances held by banks at the Fed combined with Fedwire interbank transactions to identify precautionary hoarding of reserves and reluctance to lend during the first phases of the U.S. financial crisis. They then use these results to develop a model with credit and liquidity frictions in the interbank market consistent with their evidence on precautionary motives. Martin, McAndrews, and Skeie (2013) derive a simple model to show that aggregate bank lending and aggregate reserves are disconnected when interest is paid on reserves. Ennis and Wolman (2012) study a cross-section of banking reserves during the financial crisis, focusing on larger banks, and explain the mechanics of their accumulation in detail.

3 Reserve Accumulation: The U.S. Experience (2007-10)

3.1 Institutional Details

In this subsection, we discuss the institutional structure of the U.S. banking system, which provides a basis for our model in Section 4 and the estimation in Section 5.2.

In the United States, depository institutions must hold an amount of funds in reserve (reserves requirement) against specified deposit liabilities in the form of vault cash or deposits with the regional Federal Reserve Banks. The Federal Reserve Board's Regulation D specifies the dollar amount of a DI's reserve requirement through a reserve ratio applied to reservable liabilities (Table 1). Although reservable liabilities consist of net transaction accounts, non-personal time deposits, and eurocurrency liabilities, since December 27, 1990, only net transaction accounts carry a nonzero reserve requirement.[6]

The reserve ratio depends on the amount of net transaction accounts at the DI. The Garn-St Germain Act of 1982 imposed a zero percent reserve requirement on the first $2 million of reservable liabilities. The amount of net transaction accounts subject to a reserve requirement ratio of 3 percent was set at $25 million under the Monetary Control Act of 1980.[7] Net transaction accounts over the low-reserve tranche are subject to a 10 percent reserve (see Table 1 for current requirements).

To ensure that DIs can meet their funding needs, eligible DIs can borrow under the primary credit program of the discount window. For example, if a DI experiences operational difficulties with its funds management systems, it is at risk of an overnight overdraft, which it can receive through the discount window or the interbank market. Funding needs at an individual institution can also arise from circumstances in which aggregate reserves in the banking system are significantly lower than what the Open Market Desk was anticipating in its management of the federal funds rate target. During the recent financial crisis, the significant strains in interbank funding markets prompted changes in the terms of discount window borrowing: (i) On August 17, 2007, the Fed extended the maximum term for borrowing to 30 days, renewable at the request of the borrower, and reduced the spread on the federal funds rate target from 100 to 50 basis points. (ii) On March 16, 2008, the Fed further extended the term for borrowing to 90 days and reduced the spread on the federal funds rate target to 25 basis points (see Gilbert, Kliesen, Meyer, and Wheelock, 2012).

[6] The Board of Governors has sole authority over changes in reserve requirements within limits specified by law. See http://www.federalreserve.gov/monetarypolicy/reservereq.htm.

[7] The exemption amount is adjusted each year according to a formula specified by the act. The "low-reserve tranche" is also adjusted each year.

3.2 The IOR after October 2008

DIs prefer to minimize the amount of excess reserves they hold because neither vault cash nor reserves at the Federal Reserve normally yield interest income. However, on October 9, 2008, the Federal Reserve Banks started paying interest on required reserve balances and excess balances. Excess reserves jumped, likely in response to both this policy change and the intensification of the crisis as well as due to the fact that the Fed stopped sterilizing its open market purchases (see Figure 1). In Figure 1, the deep green section shows the increase in bank deposits, representing required and excess reserves, in the Federal Reserve System. The large increase in reserve holdings began in 2008:Q4, reached its peak in 2009 and then remained at a new higher level through 2010:Q4.

In the first three months of non negative IOR payments, a distinction arose between balances held to fulfill reserve requirements ("required reserve balances") and balances held in excess of required reserve balances and contractual clearing balances ("excess reserve balances"). The rate paid on required reserve balances was 10 basis points below the average federal funds rate target, while the rate paid on excess balances was 75 basis points below the lowest target. The reference window was the maintenance-period federal funds rate. The spreads were subsequently reduced twice before the end of 2008.[8] These intra quarter changes do not affect our discussion as we study quarterly data.

3.3 IOR and Monetary Policy

Ceteris paribus, whether banks have an incentive to lend reserves depends on the relationship between the return on alternative investments and the floor rate. As explained in Keister, Martin, and McAndrews (2008), the use of the IOR as a floor rate for the relevant policy rate can "divorce" the quantity of reserves from the interest rate target by removing the opportunity cost of holding reserves at the the central bank. The addition of the IOR as another monetary policy tool has been advocated by Woodford (2000), Goodfriend (2002), and others and has been adopted by many central banks (Bowman, Gagnon, and Leahy, 2010). The Fed was granted explicit authorization to pay IOR by the Financial Services Regulatory Act of 2006. The

[8] The first reduction reduced the spread to zero for required balances and 35 basis points for excess balances and both were reduced to zero by the maintenance period ending on November 19, 2008. However, after the December 2008 FOMC meeting, the interest rates on required reserve balances and excess balances were both set at 25 basis points, the upper bound of the newly established target range for the federal funds rate of 0 to 25 basis points. See Bech and Klee (2011) for an excellent discussion.

implementation date was originally established as October 1, 2011, but was brought forward to October 2008 to provide the Fed with an additional monetary policy tool during the U.S. financial crisis.

The advantages of the IOR are not controversial and have been discussed widely in the literature. In theory, the short-term interest rate target (for example, the federal funds rate) should be larger than the IOR to allow the central bank to alter the supply of reserves without moving the effective short-term interest rate away from its target. In practice, discrepancies may occur both in normal and in crisis times. For example, during most of the U.S. financial crisis and continuing into the next few years, the IOR and the effective federal funds rate differed. Bech and Klee (2011) explain the conditions under which such a discrepancy may emerge for example, when some traders (e.g., Fannie Mae and Freddy Mac) that cannot be paid IOR by law are willing to trade federal funds below the federal funds target rate.

4 A Simple Model of Excess Reserve Accumulation

In this section we develop a simple model of reserve determination that allows us to focus on the factors impacting reserve accumulation that can also be identified empirically using available bank-level data.

Consider a bank i that faces the problem of allocating a given level of deposits D_i between an interest-bearing asset and cash or reserves at the Federal Reserve.[9]

When r_{IOR} is zero, any positive differential between the returns on the asset (r_A, for example, the yield on 3-month or 1-year Treasury bonds on the secondary market) and the zero-yield reserves induces a profit-maximizing bank to maintain reserves (R_i) at the minimum required level (δD_i, a share δ of deposits). When r_{IOR} is positive, banks may have an incentive to hold excess reserves depending on the relationship between the return on the interest-bearing asset and the IOR (among other factors).

Since deposits can be withdrawn at any time, the bank also faces the risk of large unanticipated withdrawals and, in some cases, of a bank run, if the funds for such withdrawals are not available. Although in classical models such as Diamond and Dybvig (1983) bank runs are due to customers' withdrawals, the same logic applies in the shadow banking market system and the interbank market. If this happens, the bank can only obtain funds by paying a penalty rate of $r_p > r_A$.

[9] We abstract from the effect of information acquisition on deposit behavior; see Baltensperger and Milde (1976) for an analysis including this feature.

A bank facing these scenarios is effectively maximizing expected interest income subject to a resource constraint based on required reserves:

$$\max_{R_i} \; r_A(D_i - R_i) + r_{IOR}R_i - r_p E\left[Max\left(0, L_i - R_i\right)\right] \tag{1}$$

$$s.t.\ \delta D_i \leq R_i, \tag{2}$$

where δ is the reserve requirement and L_i is the (stochastic) deposit withdrawal rate, or reserve losses. The last term of equation 1 is a convex function of R_i and is differentiable if the random variable and L_i have a continuous density $f(x)$. Since the objective function is concave, using the first-order condition, the optimal amount of reserves is determined by the following equation:

$$r_p \Pr\left[L_i \geq R_i\right] = (r_A - r_{IOR}) - \lambda, \tag{3}$$

where $\lambda \geq 0$ is the Lagrange multiplier associated with the required reserves constraint.[10] The key trade-off for a bank is therefore between the expected cost of a liquidity shortage on the left-hand side of equation 3 versus the opportunity cost of holding reserves on the right-hand side.

The larger the stock of reserves, the lower the probability that withdrawals will be larger than reserves and that the bank will have to pay the penalty rate r_p on borrowed funds. On the right-hand side of equation 3, the marginal cost of increasing reserves is determined by the forgone revenues of investing at larger-than-r_{IOR} returns on alternative assets net of the benefit of relaxing the constraint, λ. When the optimal reserve holding R_i^* exceeds the required reserves, then $\lambda = 0$ and the constraint is not binding. The constrained solution, in which $\lambda > 0$, identifies situations in which the bank accumulates only the required reserves δD_i.

Intuitively, the demand for reserves increases when the ratio between the interest rate differential $r_A - r_{IOR}$ and the penalty rate r_p rises. Ogawa (2007) uses a version of this model (due to Freixas and Rochet, 1997) to interpret the increase of excess reserve holdings in the Japanese experience during the Lost Decade. The situation in which banks in poorer financial health hold larger reserves for example, to prevent the

[10] If we consider this cost, $C(R_i)$, the expected cost of a liquidity shortage, to be a convex function $C(R_i) = r_p \int_{R_i}^{+\infty}(x - R_i)f(x)\,\mathrm{d}x$, then $C'(R_i) = -r_p \Pr\left[L_i \geq R_i\right]$ and $C''(R_i) = -r_p f(R_i) \geqslant 0$.

possibility of a bank run is captured by an increase of $Pr\left[L_i \geq R_i\right]$ in the model. The model can be easily transformed to a log-linearized version that facilitates reduced-form estimation using bank-level data.

We can assume that banks perceive deposit withdrawals L_i as draws from a Pareto distribution with density function

$$f(L_i) = \frac{\theta L_{0,i}^{\theta}}{L_i^{\theta+1}}; \quad L_{0,i} < L_i < \infty, \tag{4}$$

where $L_{0,i} > 0$ denotes the location parameter and $\theta < 0$ the shape parameter for the distribution. The location parameter shifts the distribution right and left, while the shape parameter governs the variance of withdrawals.

Under this specification, the probability that withdrawals exceed reserves becomes

$$\Pr\left[L_i \geq R_i\right] = \left(\frac{R_i}{L_{0,i}}\right)^{-\theta}, \tag{5}$$

which can be inserted in Equation 3, as follows:

$$r_p \left(\frac{R_i}{L_{0,i}}\right)^{-\theta} = r_A - r_{IOR} - \lambda, \tag{6}$$

and so becomes, in logarithmic terms,

$$\log R_i = \log L_{0,i} - \frac{1}{\theta} \log \left(\frac{r_A - r_{IOR} - \lambda}{r_{p,i}}\right). \tag{7}$$

Under this specification, reserves depend negatively on the ratio between the interest rate and penalty rate scaled by a parameter, θ, that governs the variance of deposit withdrawals. A larger location parameter, $L_{0,i}$, translates into a right shift of the withdrawal distribution: For a given level of the ratio of interest to penalty rates, the i-th bank desires to keep larger reserves when $L_{0,i}$ is higher. We assume that this scale parameter depends on the strength of a bank's precautionary motive and is positively correlated with the financial weakness of a bank. Financial weakness can be approximated by a variety of measures. In this paper, we assume that financial weakness shifts the location parameter, $L_{0,i}$, as follows:

$$L_{0,i} = \alpha D_i^{\eta} FW_i; \quad \alpha, \eta, \epsilon > 0, \tag{8}$$

where FW_i is a measure of financial weakness. We assume that financial weakness is a composite measure of bad loans and bank capital. Using the specification for the precautionary motive captured in equation (7) by $L_{0,i}$, we obtain

$$\begin{aligned} \log R_i &= \log \alpha + \eta \log D_i - \frac{1}{\theta} \log \left(\frac{r_A - r_{IOR} - \lambda}{r_p} \right) \\ &\quad + \psi_1 \log BL_i + \psi_2 K_i, \end{aligned} \tag{9}$$

where $B_L i$ represents a measure of bad loans for bank i and K_i represents bank i's capital. Because under $\lambda > 0$ the reserve requirements are constraining ($R_i = \delta D_i$), we have a system of equations as follows:

$$\log R_i - \log \delta D_i = \begin{cases} = 0 \\ = \log \alpha - \log \delta_i + (\eta - 1) \log D_i + \frac{1}{\theta} \log \left(\frac{r_A - r_{IOR}}{r_p} \right) \\ -\psi_1 \log BL_i + \psi_2 \log K_i \end{cases} \tag{10}$$

that can be estimated using censored regression methods.

5 The Determinants of Reserve Accumulation

5.1 Data and Descriptive Statistics

We create two datasets, one for commercial banks and one for thrifts. The primary sources of financial information on banks and thrifts we use are the quarterly Reports of Condition and Income database (commonly called the Call Reports [CRs]) and the Thrift Financial Reports [TFRs].

The CRs contain regulatory information for all banks regulated by the Federal Reserve System, the Federal Deposit Insurance Corporation (FDIC), and the Comptroller of the Currency. In this dataset, banks report their individual-entity activities on a consolidated basis for the entire group of banks owned by the reporting entity at the end of each quarter. Entities typically belong to bank holding companies (BHCs).[11] For our estimation procedures, we use data for the quarters between 2008:Q3 and 2010:Q2 and also include 2008:Q2 as a pre-interest-on-reserves (pre-IOR) quarter for comparison.[12] The number of entities in the CRs fell from 7,769 in the pre-IOR quarter, 2008:Q2, to 7,182 in 2010:Q2 as a result of failures, mergers, and acquisitions. We

[11] The most frequent proprietary structure is an individual BHC controlling an individual bank. In many instances, however, an individual BHC may control many banks or a combination of banks and thrifts.

[12] Problems in the commercial banking system, including thrifts, did not become apparent in the data on lending until 2008:Q3.

use the National Information Center's files on bank and thrift mergers, acquisitions, and failures to remove the effects of these discrete events.

The TFRs contain similar but less-detailed information. Because there is no one-to-one correspondence between CRs and TFRs for particular variables required for our analysis, we cannot merge the data; instead we carry out two parallel sets of analyses when possible. The number of thrifts reporting in 2008:Q2 was 829; by 2010:Q2, this number was reduced to 753.

We make several adjustments to the data to deal with complications generated by particular entities. We first remove investment banks and financing arms of large corporations that acquired charters in the 2008-09 period from our data set and exclude them from our analysis of reserve accumulation. These "new" commercial banks are financial entities not historically regulated as banks (and hence did not file CRs) but acquired charters in 2008-09 because they either applied for a charter or were acquired by regulated commercial banks.[13] These "banks" are likely to have reserve accumulation patterns that are significantly different from other commercial banks due to the distinct nature of the intermediation function they perform. In addition, we omit foreign-owned banks. There is evidence that international banks managed intra-group liquidity within their internal capital market very differently from other banks during the crisis (see Cetorelli and Goldberg, 2011).

In order to estimate the model derived in Section 4, we construct an empirical counterpart using information from the CRs and the TFRs.[14] Our measure of excess reserves is computed as a difference between total cash, including reserve balances at the Fed, and required reserves calculated as a percentage δ of deposits according to the reserve requirements for the period under consideration which are listed in Table 1.[15] This is our key dependent variable and the empirical counterpart of variable $R_i - \delta D_i$ in the model. Cash and reserves can be maintained in various forms, not necessarily as deposits at the Federal Reserve Bank. We calculate required reserves based on information on reserve requirements from the Board of Governors which is reported in table 1. Since we cannot calculate required reserves precisely, as the basis for their calculation changes daily, we consider our dependent variable to be cash including excess reserves as any holdings greater than 110 the calculated required reserves for each bank.

[13] Namely, Goldman Sachs, Morgan Stanley, Merrill Lynch, American Express, CIT Group Inc., Hartford Financial Services, Discover Financial Services, GMAC Financial Services, IB Finance Holding Company, and Protective Life Corporation.

[14] Table 13 describes the matching between the relevant variables in the CRs and TFRs.

[15] Total cash and reserve balances at the Federal Reserve is variable rcfd 0010 in the Reports of Income and Condition.

It is important for the robustness of our analysis, that the dependent variable is accurately measured. There are three ways it could be mis-measured. The first two ways involve our calculation of reserve requirements. We may have under or over estimated reserve requirements. If we under-estimated reserve requirements, then some excess reserves are actually required reserves. In this case, a change in deposits would automatically give us a change in 'excess reserves'. To the extent that our covariates are correlated with deposits, increases in deposits could bias the coefficients upwards. We check whether the reserve requirements calculated on end of quarter deposits are underestimated and find they are to some extent as 174 entity-quarter observations have negative excess reserves, 125 of these are small bank observations, 33 are large banks, and 82 are thrifts. The solution for this is simple, we calculate excess reserves as cash and reserve holdings 110 percent above calculated reserve requirements. Using this restriction, there are zero observations with negative excess reserves. Alternatively, if we over-estimated reserve requirements, then our measure of cash and excess reserve holdings would be systematically too small. Since this is a level effect, that is constant cross-sectionally and over time, it is not clear there would be any systematic bias on our coefficients. So long as this over-measurement did not impact cross-sectional or time series variation in a heterogeneous manner (e.g., disproportionately affecting large banks), we would not expect any meaningful impact on our coefficients except that they could be downward biased. Since we have no evidence of differential impact, we conclude that any over-estimation of required reserves only has a level effect which should be reduced by scaling excess reserves by total deposits (banks with similar amounts of transaction deposits, should have the same estimated required reserves). Finally, our measure of 'excess reserves', as noted earlier includes cash and other cash-equivalents in addition to reserve holdings at the Federal Reserve. The way this type of mismeasurement affects our coefficients is not easy to determine. Since our estimation equation is derived from the first order conditions of the bank's reserve management problem, not a portfolio allocation problem, we are possibly not capturing all the determinants for holding non- or low-interest bearing assets. If depository institutions are holding more cash than strictly excess reserves (ER), then for a given change in a covariate that impacts ER but not cash in excess of ER, we would observe a smaller effect than the actual one. In that case, our coefficient estimates provide a minimum bound for the measurement of the relationship between these covariates and excess reserves.

Figure 6 is a plot of the cross-sectional distribution of our measure of the cash plus

excess reserves-to-required reserves ratio between the quarter before our sample begins, 2008:Q2, and 2010:Q2, the last quarter in our sample. Each histogram represents one quarter and is left-censored at zero (as no bank holds less than the required reserves) and right-censored at 75 (as our data contain some banks ratios in excess of 75).[16]

Over the 2008:Q3-2010:Q2 period, we observe that in Figure 6, the distribution of the excess-to-required reserves ratio became more dispersed (less peaked and with a fatter tail) compared to 2008:Q2, indicating that more banks have accumulated larger amounts of excess reserves, in parallel with the expansion of the Federal Reserve budget. This outward movement has also been documented by Ennis and Wolman (2012), who focus on large banks, but the explanation for why the distributions became more dispersed represents an open research question that we shed some light on in our study.

Using the theoretical model developed in Section 4 as a guide for choosing appropriate co-variates, we choose a set of proxies available in the data. Table 2 displays a set of descriptive statistics for each co-variate discussed below.

We use total deposits (D_i) as a scale variable and to correct for the heterogeneity in bank sizes. Deposits include (i) total transactions and non-transactions accounts, (ii) non-interest and interest bearing deposits, and (iii) money market deposit accounts.

We use the interest differential between 1-year Treasury bills and the IOR as the opportunity cost institutions' face for holding excess reserves and cash. We considered a variety of other measures, including the rate on 3-month Treasury bills and the effective federal funds rate, but believed that the 1-year rate best captured alternative low-risk investment opportunities. Figure 7 displays each of the interest rate variables in the empirical model. We discuss other measures of the opportunity cost of holding cash and excess reserves in the section on robustness below (section 5.2.3).

For a measure of the penalty rate—the rate banks would theoretically pay for maintaining insufficient cash and reserves, we use an index of daily rates on (30 day) Treasury bill repurchase agreements aggregated to a quarterly basis using either averaging over the quarter or choosing the last observation in each quarter.[17]

We then construct the following three measures of bank loan health, each progressively more inclusive of less-distressed loans. The first measure (*non-accruing loans*,

[16] For each of the 9 quarters reported in these histograms, we counted the following number of banks exceeding a excess-to-required reserve ratio of 75: 38, 45, 77, 107, 114, 143, 126, 3, and 4.

[17] This index, called the DTCC GCF Repo Index, is created by The Depository Trust & Clearing Corporation (DTCC). According to the DTCC website, the index tracks the average daily interest rate paid on the most-traded GCF Repo contracts for U.S. Treasury bonds, federal agency paper and mortgage-backed securities [MBS] issued by Fannie Mae and Freddie Mac. The index's rates, according to the website, are par-weighted averages of daily activity in the GCF Repo market and reflect actual daily funding costs experienced by banks and investors.

labeled "bad loans 1" in the regression tables) contains the category of loans most likely to turn into permanent losses. Non-accruing loans are defined as the outstanding balances of loans and lease financing receivables the bank has placed in non-accrual status, as well as all restructured loans and lease financing receivables in non-accrual status.[18]

The second measure of bad loans (*non-performing loans*, labeled "bad loans 2" in the regression tables) includes both non-accruing loans and loans that are due and unpaid for 90 days or more in addition to all restructured loans and leases.

The third measure of all bad loans (*bad loans*, labeled "bad loans 3" in the regression tables) adds to non-performing loans the full outstanding balances (not just delinquent payments) of loans and lease financing receivables that are past due and upon which the bank continues to accrue interest.[19]

Figure 8 displays histograms of these three types of loans (non-accruing, non-performing, and all 'bad' loans) as a percentage of total loans. Each graph plots the frequency of the ratios for the cross-section of banks (top three graphs) and thrifts (bottom three graphs) at the beginning and end of our sample.[20] The figures show quite strikingly the outward movement of the cross-sectional distribution of bad loans (in each category) between the beginning and the end of the window we consider. During this period, the number of banks and thrifts with fewer distressed loans declined and the number of banks and thrifts with 10 percent or more of their total loans classified as troubled increased markedly. These shifts are also consistent with the increase in bank and thrift failures during this period as a larger share of bad loans is correlated with the likelihood of an institution failure (Aubuchon and Wheelock, 2010).

As a measure of capital adequacy, we use the equity-asset ratio, adjusted in the numerator and denominator to remove intangibles (primarily good-will). Intangibles shows a strong positive trend due to mergers and acquisitions and in general are unable to absorb losses (see Lee and Stebunovs, 2012, for a discussion). We experimented with other measures of capital adequacy, including a measure of risk-weighted capital based on the ratio of Tier 1 capital to risk adjusted assets. We report the results

[18] Loans and lease financing receivables are reported as non-accruing status if (i) they are maintained on a cash basis because of deterioration in the financial position of the borrower, or (ii) the principal or interest has been in default for a period of 90 days or more unless the obligation is both well secured and in the process of collection.

[19] In particular, it includes closed-end monthly installment loans, lease financing receivables, and open-end credit in arrears by two or three monthly payments; installment loans with payments scheduled less frequently than monthly when one scheduled payment is due and unpaid for 30 to 89 days; amortizing real estate loans after one installment is due and unpaid for 30 days to 89 days; single-payment and demand notes providing for payment of interest at stated intervals after one interest payment is due and unpaid for 30 days to 89 days; single-payment notes providing for payment of interest at maturity, on which interest or principal remains unpaid for 30 days to 89 days after maturity; unplanned overdrafts, whether or not the bank is accruing interest on them, if outstanding 30 to 89 days after origination.

[20] We collect institutions with ratios larger than 15 (banks) and 10 (thrifts) in a unique bin.

using the equity-asset ratio as this is a measure primarily determined by market rather than regulatory factors. For thrifts, we lack an adequate measure of equity holdings, therefore we use the ratio of Tier 1 capital to risk adjusted assets as a measure of capital adequacy. We note that the effect on ER of changes in Tier 1 capital for thrifts is therefore not directly comparable to the effect of changes in the equity-asset ratio for banks due to our inability to control for the expectation of regulatory changes in Tier 1 capital.

The final measure of loan portfolio health we include is the ratio of loan loss provision to assets. The loan loss provision is an income statement variable that is triggered by write-downs of the bank's loan portfolio. When a loan loss provision is taken, the loan loss reserve must be re-built depending on the risk-assessment of the remaining loan portfolio. The loan loss provision is an indicator of the extent to which a bank has removed non-performing loans from its books.

We estimate a tobit model, using the log of the ratio of excess reserves and cash to deposits as the dependent variable and also taking the log of each of our independent quantity variables scaled by deposits.[21] We include four key variables as regressors: a measure of the return to alternative investments, a measure of the penalty rate for holding insufficient reserves, measures of the delinquency status of the loan portfolio (based on our three measures of distressed loans) and a measure of capital adequacy.

We run the same set of regressions using a censored least absolute deviations estimator (CLAD) model for data that admits a corner solution (see Powell, 1984). The advantage of the CLAD estimator is that it is robust to heteroskedasticity and consistent and asymptotically normal for a variety of error distributions. As a quantile regression method, it is also not as sensitive to outliers as the tobit model. We report results from tobit and CLAD regressions below.

5.2 Results

In this section, we present the results from our tobit and CLAD specifications. The log of the ratio of cash including excess reserves (calculated as cash and reserve holdings 110 percent above required reserves) to deposits is the dependent variable. The regressions in Tables 3 and 4 report coefficient estimates from tobit and CLAD specifications with a left-censored value at zero; clustered (at the entity level) standard errors are in

[21] We considered whether our problem could be better estimated using a Heckman selection model. Please see section 5.2.4 for a discussion.

brackets and all regressions include quarterly time dummies (not reported).[22]

5.2.1 All Banks

We first look at tobit and CLAD regressions for all banks (table 3), second banks by size (tables 4 and 5) and third for thrifts (table 6).[23] We focus on the CLAD results for the reasons outlined above but note that they are quite similar for the group of all banks.

In table 3, we find the difference between the 1 year Treasury bill rate and the interest rate paid on reserve balances at the Fed has a negative and significant effect on excess reserves/cash accumulation, while the penalty rate has a positive and significant effect. These two effects are as predicted by our theoretical model. When the opportunity cost of holding reserves rises, ceterus paribus, banks should reduce excess reserve holdings. The fact that our regressions show that banks are sensitive to the opportunity cost of holding reserves suggests that the lack of alternative investment opportunities was not a frivolous motivation. Our estimation results imply that a .1 percent increase in the opportunity cost of holding reserves is consistent with a decrease in the excess reserve plus cash to deposit ratio of 1 percent.

When banks face heightened uncertainty about withdrawal rates, according to our model, they will be more sensitive to movements in the penalty rate for keeping insufficient reserves. In the regressions reported in table 3, we use a daily index of Treasury bill repo rates, taking the last observation per quarter as a measure of the penalty rate. During our observation window (2008:Q3-2010:Q2), there was significant disruption in the repo/reverse-repo market which is a significant source of short term funding for banks. This disruption, which began with a 30 percent drop in Federal funds and reverse repo trading volumes in November 2008, recovered to some extent by April 2009, after which volumes again declined significantly and continued to decline through the end of our sample so that by 2010:Q2, the volume of trading in this market was only 36 percent of its value in 2008:Q3.

Unsurprisingly, we find excess reserves and cash holdings respond strongly to increases in the penalty rate. For every .1 percent increase in the penalty rate, the ratio of excess reserves and cash to deposits increases by approximately 5 percent. The

[22] The interpretation of the coefficients on covariates measured in levels or ratios (the price variables and capital adequacy ratios) require exponentiation of the coefficients on the level covariates to get the effect on the dependent variable, whereas the log-log specification can just be read as percentage changes from the tables.

[23] In the tables of tobit results, we report the effects of the covariates on the latent variable (observing positive excess reserves) rather than the marginal effects because the number of censored observations is sufficiently small that the tobit coefficients approach their OLS counter-parts so that the marginal effects differ from the reported results only at the 4th decimal place.

strength of this response may also detect the reluctance of banks to provide negative market signals regarding their liquidity by borrowing in the overnight market during the financial crisis (see Armantier, Ghysels, Sarkar, and Shrader, 2011; Gilbert, Kliesen, Meyer, and Wheelock, 2012). Maintaining cash and excess reserves reduces banks' reliance on the overnight market.

Next we turn to the impact of measures of bank health and loan performance on cash and reserve accumulation. Our measures of bank health are loan quality, provisions for loan losses and the capital ratio. Bank capital ratios provide a measure of how adequately a bank is prepared for unexpected losses.

Our results on the effect of capital adequacy are unstable across the tobit and CLAD methods. Using the tobit method, we found that a .1 percent increase in capital adequacy (equity/assets) results in a 3.5 percent increase in excess reserve and cash as a ratio to deposits, holding the loan loss provision at 0. Under the CLAD specification, we find that a similar increase is consistent with a .6 percent fall in the ratio of excess reserves and cash to deposits, holding the loan loss provision at zero. Although the effects are small in both cases, we believe the CLAD results are more reliable. The total effect of the capital ratio is the sum of its individual effect (for the loan loss provision at zero) plus the coefficient on the interaction times loan loss provision, exponentiating due to the semi-log format. We calculated the total effect of a 1 percent increase in the capital ratio (based on the coefficients in the CLAD regressions) to be -5.2 percent at the median level of loan loss provision, -4.4 at the 75th percentile, .03 percent at the 90th and 8.8 at the 95th percentile of loan loss provision. Banks with well-performing loan portfolios likely have low loan loss provisions and therefore, higher capital adequacy translates into lower excess reserve and cash accumulation. For banks weighted down with large amounts of non-performing and non-accruing loans, increases in capital adequacy may be coming from reductions in assets due to write downs rather than increases in equity, so higher capital adequacy results in more precautionary accumulation of reserves and cash. Another possibility is that banks with high loan loss provisions may have additional write-offs in the near future so that higher capital adequacy is not entirely protective. Banks with fewer bad-loans and a lower loan-loss provision may have already cleaned their books and hence have lower capital and a lower capital ratio.[24]

These results also make sense of the coefficient instability across specifications. Since the tobit estimations are more sensitive to outliers, the coefficients on the interaction

[24]See Calomiris and Wilson (2004) for a discussion of this relationship during the Great Depression.

between capital adequacy and loan loss provision as well as loan-loss provisions are likely unduly influenced by banks with large loan provisions (the standard deviation of loan loss provision is larger than the mean).

Evidence that this interpretation may be correct is provided by looking at the total effect of loan loss provisions, which equals the coefficient on the ratio of loan loss provisions to assets (holding the capital ratio equal to zero) plus the coefficient on the interaction between loan loss provisions and the capital ratio at various levels of the capital ratio. We find the total effect of a .1 percent increase in loan loss provision holding the capital ratio constant at the 50th percentile is a 4.1 percent increase in the excess reserves and cash to deposit ratio, at the 75th percentile, there is a 5.3 percent increase, and at the 95th, an 11 percent increase, and a 158 percent increase at the 99th percentile of the capital ratio. Banks with very high capital ratios (e.g., 99th percentile) possibly have such high ratios due to loan-write-downs rather than large increases in equity. An increase in the loan loss provision at such a high ratio is consistent with a strong precautionary accumulation. Alternatively, these may be recently merged or banks or banks with recent acquisitions. One last point, there may also be tax considerations for the timing of loan loss provisions that are not considered here.

The last group of determinants of reserve accumulation we consider is a set of three nested measures of bad loans, where the first measure includes the most troubled loans (total non-accruing), the second measure includes non-accruing and adds non-performing (90 plus days late) loans, and the third measure includes the first two plus loans that are between 30 and 90 days past due. We find all of our measures of bad loans have a similar effect on excess reserve and cash accumulation.[25] We find that a 1 percent increase in the ratio of bad loans to deposits portfolio of 1 percent results in about a 0.3 percent increase in the excess reserves and cash to deposit ratio, suggesting a precautionary motive for accumulation.

In sum, first, we find evidence of precautionary accumulation by banks from the response of reserves and cash to the deterioration of their loan portfolio and the relationship between capital adequacy and loan loss provisions. Second, we find that banks are sensitive to the opportunity cost of holding low-interest bearing assets, suggesting limited low-risk lending opportunities. Third, we find banks are very sensitive to the penalty for holding insufficient reserves in the event of a payment or withdrawal shock.

[25] The fact that the standard errors are significantly different across the two methods suggest some heteroskedasticity in the residuals though this does not effect the coefficient estimates.

This result may be related to disruptions in the interbank and Repurchase markets that occurred during our sample period.

5.2.2 Banks differentiated by size

We next differentiate banks by size and consider whether large banks had different cash and reserve accumulation responses than small banks. We define large banks as the top two percent of banks measured by assets and small banks as those with assets below the 95th percentile (leaving an intermediate group between large and small). In 2008:Q3, there were 148 banks classified in the top 2 percent, by 2010:Q2, there were 128 banks in this category, a 16 percent decline. This attrition reflects mergers/acquisitions and failures. Since we use a pooled sample rather than a panel, sample attrition is unlikely to have a significant effect. Figure 9 displays the cross-sectional distribution of excess reserve accumulation as a ratio to required reserves for small versus large banks.

We find some noteworthy differences reported in tables 4 and 5.[26] We focus on the CLAD results, though the tobit results are similar.[27]

First, we find that large and small banks have a similar response to an increase in the opportunity cost of holding cash and excess reserves—a 0.1 percent increase in the opportunity cost (measured as the difference between the yield on 1 year Treasury bills and the IOR), is consistent with a 1 percent decline in excess reserve and cash holdings. The response is slightly smaller for small banks; tests of the equality of coefficients across groups rejects equality at the 1 percent confidence level.

Second, we find a huge response to an increase in the penalty rate (measured by an index of interest rates on Treasury Bill repos) for large banks and a much smaller response by small banks (the responses are significantly different at the 1 percent confidence level). For small banks, a 0.1 percent increase in the repo rate is consistent with a 3 percent increase in their excess reserve and cash to deposit ratio. We find that the response of large banks to a 0.1 percent increase in the penalty rate is consistent with an increase in excess reserves and cash of 40 percent. In the previous regressions with "all banks", the strong response to the penalty rate is largely driven by large banks.

Returning to our discussion of disruptions in the repo and Federal Funds markets in 2008:Q3-2009:Q2 and 2009:Q4-2010:Q2, we find that small banks experienced a much

[26] Approximately 2 percent of the observations for the large bank sample are censored and 0.15 percent of the small bank sample.

[27] The large coefficients on the r1yr-IOR measure of the opportunity cost for large banks are similar to the coefficients in the CLAD regression when we exponentiate them.

smaller decline in trading volume in this market than large banks. While there was a decline in volumes of small bank activity, the decline, particularly between the end of 2009 and mid-2010 was much milder than the decline in large bank activity. For large banks, trading volume dropped by more than half (in 2010:Q2, trading volume was 27 percent of what it was in 2008:Q3 for large bank trading), whereas for small banks, trading volumes were 51 percent of what they were in 2008:Q3.

To determine the effect of a larger capital ratio on excess reserve and cash accumulation, we consider the total effect, which is the sum of the coefficient on the adjusted capital ratio and the coefficient on the interaction term for various levels of loan loss provision (exponentiated). First, looking at the effect of the capital ratio when the loan loss provision is 0, for large banks, a 1 percent increase in the capital ratio, results in about a 25 percent increase in the excess reserves plus cash to deposit ratio (focusing on the two specifications where there is significance), whereas for small banks, holding loan loss provision at zero, a 1 percent increase in capital adequacy results in a 4 percent decline in excess reserve and cash holdings. These differences are statistically significant at the 1 percent level. Why do we observe this discrepancy? In order to sort this out, we consider the total effect first for large banks and then for small banks focusing on the coefficients for the regression that includes 'bad loans 2', since the coefficients on the relevant covariates are significant for both large and small banks for this specification. The total effect of a 1 percent rise in capital adequacy for large banks holding loan loss provisions constant at the 50th percentile, results in a 27 percent increase in excess reserves and cash holdings (as a ratio to deposits), at the 75th percentile the effect is a 19 percent increase, and an 11.5 percent and a 42.4 percent *decrease* in reserve holdings at the 95th and 99th percentile of loan loss provision. For small banks, we find the opposite pattern. The total effect of a 1 percent rise in capital adequacy for small banks holding loan loss provisions constant at the 50th percentile, results in a 3 percent decrease in excess reserves and cash holdings (as a ratio to deposits), at the 75th percentile the effect is a 2 percent decease, but a 2.7 percent increase at the 90th percentile, and a 3 percent and a 13 percent increase in reserve holdings at the 95th and 99th percentile of loan loss provision. The behavior of small banks makes sense: as loan provisions increase, the probability of near future write-downs rises, so that we observe a small positive relationship between capital ratios (which may be increasing due to the increase in loan loss reserves) and reserve and cash accumulation–the high loan loss provisions reflect a risky position for the small bank.

The behavior of the large banks is more difficult to understand. Loan assets are reported on bank balance sheets net of the loan loss reserve. When the bank increases its loan loss provision (an expense item against profits on the income statement), its loan loss reserves rise by the same amount. Therefore, higher loan loss provisions, mean lower net assets (net of loan loss reserves), increasing the capital ratio. When a loan is written off, loan receivables are decreased by the size of the loan and the loan loss reserve is also reduced by the amount of the loan. These actions should not change net asset positions in the quarter in which the charge-off occurred. However, in the next quarter, the loan loss provision needs to be built back up and so the loan loss provision increases. Banks may increase their loan loss reserves when the probability of immanent losses is higher. These accounting facts make disentangling the relationships among capital ratios, loan loss provisions and reserve and cash accumulation more difficult. So why do large banks with high loan loss provisions decrease their excess reserve holdings? When we look at the large bank behavior for the broader category of problem loans (bad loans 3), we find a 4 percent and 22 percent decline in excess reserves at the 95th and 99th percentile of loan loss provisions for a 1 percent rise in the capital ratio– a smaller effect compared to the previous specification but we still find the unusual decrease in cash and reserve holdings. Another consideration is that large banks may be increasing their loan loss provisions under a different strategy than smaller banks. Large banks may have high loan loss provisions as an attempt to smooth income, i.e., for the tax savings they generate in times of reduced income, and so their loan portfolio is not as risky at the 99th percentile as the loan portfolio for small banks and so they are not as concerned with holding more excess reserves and assets. Alternatively, these results may reflect TARP-CPP funds. Most large banks received TARP funding during this time period and the differential behavior of excess reserve holdings may be due to higher equity holdings (in addition to lower asset holdings) from TARP investments.

We can examine the effect of loan loss provisions at a given capital ratio to try to answer these questions. We find that the total effect of the loan loss provision on excess reserve and cash accumulation holding the capital ratio at the 50th percentile, is a decrease of 41 percent and 30 percent, for large and small banks respectively. At a capital ratio in the 90th percentile, the reduction in excess reserves and cash is 60 percent for large banks and 46 percent for small, at the 95th it is 70 percent and 57 percent for large and small respectively. Thus the differential effect of increasing capital ratios for a given loan loss provision must be related to some difference in large and small bank accounting for loan loss provisions.

Finally, considering the effect of distressed loans on reserve and cash accumulation, we find larger effects for large banks, in the range of .6 to 1 percent, while the effect is between .1 and .2 percent for small banks. Large banks have significantly higher ratios of bad loans to deposits than small banks and the variation across large banks is significantly higher than small banks (the standard deviation of the ratio of bad-loans 1 to deposits for large banks is 132 whereas it is .03 for small banks). These effects are different at the 1 percent significance level.

In sum, we find that large banks have a much stronger response to increases in the penalty rate than small banks, a stronger precautionary accumulation motive and the relationship among loan loss provisions, capital ratios and excess reserves is significantly different and possibly accounted for by accounting issues or different sources of funds.

The only comparison to our findings is provided by (Ashcraft, McAndrews, and Skeie, 2011) that examines high frequency (intra-daily) movements in excess reserve balances, instead of lower frequency quarterly data. They find that small banks appear to have credit constraints that prevent them from actively borrowing in the market like large banks, they also have limited borrowing or lending at the end of the day and hold larger intradaily and overnight reserve balances. Controlling for balance sheet characteristics, small banks are reluctant to lend at the end of the day potentially due to the unpredictability of their payment shocks and the large fixed cost to enter the interbank market. (Ashcraft, McAndrews, and Skeie, 2011) find that in response to higher uncertainty about payments, banks, especially small banks, were reluctant to lend excess reserves when balances were high and those borrowing were more aggressive in biding for borrowed funds when balances were low. Even though large banks may be relatively unconstrained and able to access funds easily on the market, aggregate reserve balances can become stuck at the end of the day in the accounts of small banks leading unconstrained large banks to also keep precautionary balances. Our results are consistent in the sense that large banks stronger response to increases in the penalty rate and distressed loans could be derived from lack of available liquidity in the interbank market.

5.2.3 Thrifts

Thrifts are savings and loans institutions with separate charters than domestic commercial banks. Thrifts were originally created with a special function to channel loans to the housing market. Their loan portfolios and the types of securities they can hold are also more closely regulated than commercial banks (Kwan, 1998). For example,

thrifts have restrictions on the percentage of consumer and commercial and industrial loans in their asset portfolio and the percentage of nonconforming loans secured by residential or farm property that banks do not have Office of the Comptroller of the Currency (2013). There are also a number of other restrictions on lending that would reduce the risk of thrifts' loan portfolios. In addition, in order to maintain its status as a qualified thrift lender (QTL), which requires, among other things, maintaining qualified thrift investments equal to at least 65 percent of its asset portfolio. These investments include loans to purchase, refinance, etc, domestic residential or manufactured housing, home equity loans, educational loans, small business loans and loans made through credit cards as well as securities based on mortgages on domestic residential or manufactured housing. Our results likely reflect these restrictions.

Thrifts respond similar to all banks to the opportunity cost of holding reserves, a 0.1 percent increase in the opportunity cost is consistent with a 1 percent decline in excess reserves and cash. Thrifts have a large positive response to increases in the penalty rate (the repo rate evaluated at the mean) larger even than the response of large banks.[28] We do not have a comparable measure of equity holdings for thrifts so we use the Tier 1 capital ratio as a measure of capital adequacy. We find that thrifts behave similarly to small banks in terms of the relationship among Tier 1 capital requirements, loan loss provisions and excess reserve and cash accumulation. A 1 percent increase in the capital ratio when loan loss provisions are zero is consistent with a 17 percent decrease in excess reserve and cash accumulation. Holding loan loss provisions at the 50th percentile, a 1 percent increase in the capital ratio generates a 16.5 percent decline in excess reserve and cash holdings. As the loan loss provision rises, a 1 percent increase in capital adequacy has a sequentially smaller negative effect on excess reserve and cash accumulation. When loan loss provisions are at the 99th percentile, a 1 percent increase in capital adequacy generates only a 1 percent decline in excess reserve and cash holdings.

Thrifts' reserve and cash accumulation response to an increase in distressed loans is similar to the response of large banks. A 1 percent increase in bad loans generates a 6 percent increase in excess reserve and cash as a ratio to deposits.

In previous research, Contessi and Francis (2011) found that the lending behavior of thrifts during the financial crisis behaved quite similarly to that of small banks. We find that thrift cash and reserve accumulation patterns are similar to small banks except in

[28] We could not separately identify the effect of opportunity costs and penalty rates using the last observation in the quarter for the index of Treasury repo rates.

two dimensions, the response to the penalty rate is much more similar to large banks and the responsiveness to bad loans is much greater than small banks. Differences in the regulation framework for thrifts and banks may contribute to explain the differences in behavior we observe. For instance, thrifts, on average, have larger portion of their loan portfolio invested in residential loans and small bank lending. Thrifts also have greater restrictions on other assets and securities they can hold. Their loan portfolios are also subject to much stricter controls, in terms of capital adequacy and the percentage of assets they can leverage than banks. This may make thrifts especially sensitive to the penalty rate but their loan portfolios may be better managed.

5.2.4 Robustness checks

As a first robustness test, we consider whether using a censored regression method was the correct approach for our data. Typically, in the presence of significant data censoring ordinary least squares estimates will tend to be biased and inconsistent. Tobit methods correct for data sensoring, however, in order for the estimates to be consistent, linearity, homoskedasticity, and normality is required. We computed an LM-statistic and found that we could not reject the null that the tobit specification is appropriate for our model at the 1 percent level. However, there is evidence of heteroskedasticity and outliers on several of the covariates that are not easy to reduce either through re-scaling (for heteroskedasticity) or through omitting observations in a logical rather than ad hoc manner. In this case, the CLAD specification is the best choice for a censored model.

Second, we consider whether a Heckman selection model is preferable, as we could consider the set of banks holding positive excess reserves to be subject to selection. Since the choice of holding zero or excess reserves is continuous and banks are able to switch between holding positive excess reserves zero without cost, we felt that the Heckman specification was not appropriate, as there was no true sense in which banks holding positive excess reserves were selected. Moreover, we could not find significant differences between the set of bank-quarter observations holding zero excess reserves from those holding zero reserves which would make identification of the selection effect difficult.

Third, we ran four sets of robustness tests, testing different specifications for the dependent variable, for the penalty rate, the opportunity cost of holding cash and reserves, and the measure of capital adequacy.

We re-estimated our tobit and CLAD regressions defining excess reserves and cash

to be reserves accumulated 150 percent above required reserves.[29] We find our results robust to this narrower definition of excess reserves as we find similar coefficients, in size, sign and significance. The only difference between the two sets of results we find is that using the narrower definition, we find that the broader definition of bad loans also has a positive significant coefficient. We also tested a ratio of excess reserves and cash to deposits (not logged) and the log of the ratio of excess reserves and cash to assets. We find similar results in sign and size though under some specifications we are unable to separately identify the opportunity cost and penalty rate.

Next, we consider different penalty rates: an index of average interest rates paid on federal agency paper or on mortgage-backed securities issued by Fannie Mae and Freddie Mac repurchase agreements and a penalty calculated as the official Federal Funds rate plus 25 basis points. The official federal funds rate shifted from a target rate to a band in 2008:Q4. We use the upper limit of this band for the federal funds rate once the shift occurs. The effective federal funds rate diverged from the target and the upper limit of the band during this time; in general it was lower. We use the higher rate as a penalty rate as it likely is more reflective of what banks would have to pay to receive an overnight loan. We find the same sign and significance on our coefficients although with agency paper and MBS rates, we cannot separately identify the opportunity cost and penalty rate.

Then we consider a different capital ratio: Tier 1 capital divided by risk weighted assets. We find the same results for signs and significance when we calculate the total effect of capital adequacy combined with loan loss provision.

Finally, the last robustness check we perform is to consider bank holding companies as our unit of observation. Our results may be influenced by the fact we are using individual bank call reports rather than considering balance sheets consolidated across all banks within a bank holding company (BHC). There is evidence that liquidity problems, for example, may be weaker for banks operating under the umbrella of a multi-bank holding company. Internal capital markets within BHCs may reduce constraints faced by individual banks who had trouble accessing funds, either through raising deposits or issuing equity, during the crisis, see Campiello (2002). Reserve accumulation by banks belonging to financial conglomerates may thus be less sensitive to external market factors such as interest rate differentials and the penalty rate as well as to their own balance sheets. Therefore, we re-ran our regressions for BHCs. We find the results consistent with those obtained for banks on their own: The signs and

[29] These results are not reported in the tables but are available from the authors.

significance of the coefficients did not change. The only notable difference between the two groups was that the coefficients on the interest rate differential and penalty rate were smaller in absolute value for the BHCs than for the banks.

5.3 Responsiveness of Cash and Reserve Accumulation

We analyze how responsive excess reserve and cash accumulation is to changes in the penalty rate, opportunity cost, and distressed loans in table 7. We first look at how excess reserves and cash respond to unit variations in these covariates for all banks, large banks (top 2 percent by assets and small banks (bottom 95 percent), and thrifts.

We find that excess reserves and cash do not respond very strongly (less than unit elasticity) to the opportunity cost (yield on 1 year Treasury bills minus IOR) or the average interest rate on Treasury bill repurchase agreements but there are some differences between banks by size. The elasticity of the opportunity cost and repo rate for large banks is significantly higher than for small banks (though still below unit elasticity). The elasticity of distressed loans is significantly higher for large banks than for small banks—in fact the elasticity on the broadest category of distressed loans is above unity and positive, meaning that a 1 unit increase in distressed loans generates a more than 1 percent increase in excess reserve and cash holdings. This suggests that cash and excess reserve accumulation by large banks was strongly influenced by precautionary motives, much more so than small bank accumulation. The elasticity of penalty rates and opportunity costs for thrifts is similar to large banks, but the elasticity of distressed loans is more similar to small banks—very small and not significant.

5.4 Response of Reserve and Cash Accumulation to Uncertainty

We consider two measures of macroeconomic uncertainty. One based on the COBE volatility index, or VIX, which is an estimate of market expectations of short term volatility based on movements in the S&P 500 stock index option prices (Goldberg and Grisse (2013) for a discussion of the relationship between the VIX and asset prices) and a measure of macroeconomic uncertainty derived from movements in industrial production.

The second measure of uncertainty we use is calculated based on a technique outlined in Baum, Caglayan, and Ozkan (2009) of fitting a generalized ARCH model to the monthly industrial production series and using the conditional variance derived from the model as a measure of uncertainty (they also fit a GARCH model to the consumer

inflation series, but we focus only on industrial production). Baum, Caglayan, and Ozkan (2009) find that macroeconomic uncertainty generates a misallocation of banks' loanable funds. Assuming that a similar mechanism might affect excess reserve and cash holdings (which is part of the portfolio allocation problem), we believed this would be a good measure of uncertainty affecting bank behavior.

We find no effects of these measures when we combine all the banks, but separating them into large and small banks, we can see the reason for this. Table 8 includes the results for the effect of the VIX level, changes in the VIX, and the conditional variance of industrial production for large and small banks. We only report the coefficients on our 3 measures of uncertainty but the tobit regressions included the co-variates from our previous regressions focusing on the bad-loans 1 case (the signs and significance of the other coefficients remain the same as previously reported). The dependent variable is the log of the excess reserve (and cash) ratio to deposits. For large banks, a 1 unit increase in the VIX results in a .1 percent decrease in excess reserves and cash holdings, a similar effect occurs for the growth in the VIX. For small banks, there is no effect. This is not necessarily the result we expected–we assumed macroeconomic uncertainty would cause all banks to *increase* their cash and reserve holdings.

Turning to the conditional variance of industrial production, we find that for large banks, a 1 unit increase in this measure results in a .8 percent increase in the excess reserve and cash to deposit ratio. For small banks, a 1 unit increase is consistent with a .03 percent decline in the excess reserves and cash to deposit ratio. These results are more in line with our prior assumptions.

We also considered the St. Louis Federal Reserve Stress Index and the impact on reserve and cash accumulation of movements in the spreads between high-yield and risk free bonds and found no effect.

Although these results are suggestive, they are to some extent inconsistent with the model we developed, so we are cautious about their interpretation. The only role for uncertainty in our theoretical model is through increase in payment volatility, captured by the θ parameter. Thus, we expect that an increase in the VIX or its growth rate would only affect reserve and cash accumulation through its effect (if any) on the volatility of payments (or withdrawals), not as an independent additive effect. The primary effect of macroeconomic uncertainty for banks is likely to be associated with new lending or the allocation of liquidity across different assets. If a bank has a good portfolio of loans and is adequately capitalized, it is unclear how an increase in macroeconomic uncertainty would independently affect reserve and cash accumulation,

setting aside the risks associated with securities holdings. Our results also point to the fact that banks were primarily concerned about their own balance sheets and managing their own liquidity risks and not as concerned about counter-party risk, a conclusion that Acharya and Merrouche (2013) also reach.

One aspect of uncertainty that we have not explored is the effect of regulatory uncertainty. The financial crisis generated many proposals for new regulations on both banking activity and sources of bank funding, such as overdraft fees. In addition, depository institutions may also have been concerned about future litigation. This type of heightened regulatory and litigation uncertainty could generate excessive cash and reserve accumulation. This is an avenue we intend to explore in future work.

6 Did TARP Beneficiaries Accumulate More Excess Reserves?

In this section, we discuss whether the CPP program under the TARP umbrella induced banks that were beneficiaries of the program to over-accumulate cash and reserves. We first describe our data and empirical methodology and then the results of our analysis.

6.1 Data

To allow for this comparison, we attempt to identify systematic differences between these two groups. We first describe the notable features of CPP beneficiaries using non-CPP DIs for comparison. We group institutions using information on the TARP funds distribution from the TARP Transaction Reports that were updated weekly by the U.S. Treasury since the program's inception in October 2008.[30] Figure 10 plots the patterns of monthly disbursements and repayments derived from these data using the TARP Transaction Reports releases.[31] The figure shows the total number of beneficiaries by month (vertical bars), the total disbursement (squares), and the monthly disbursement

[30] The allocation of CPP funds to BHCs, instead of individual banks and thrifts, has raised some criticism (Coates and Scharfstein, 2009) in terms of whether it promotes more lending at the bank level. It also creates various issues in our dataset because, unlike the TFRs and the CRs, which provide us with financial information, the TARP Transaction Reports list the BHCs. Therefore, we organized the data as follows. First, we determined the entity identification numbers for all DIs listed to make the TARP information compatible with our CR and TFR information. By using the Competitive Analysis and Structure Source Instrument for Depository Institutions (CASSIDI) database managed by the Federal Reserve Bank of St. Louis and the Federal Financial Institutions Examination Council's institutional history database we determined the set of institutions each BHC controls, BHC by BHC. We organized our data into five categories. If the BHC controls only a single bank or thrift, we match the TARP Transactions Report information with the single bank or thrift's Federal Reserve entity identification number. When the BHC controls several different banks or a mix of banks and thrifts, all of the loans (and other financial information) at the individual bank and thrift level are totaled and the group is given the BHC's entity identification number. Additionally, we separated out the funds distributed to large lenders and other beneficiaries that are either non-financial institutions (namely, General Motors and Chrysler) or "new" commercial banks and thrifts.

[31] See the relevant files on the Financial Stability website. The Congressional Oversight Panel (2009) reported some difficulties in confirming the exact value of the Treasury disbursements using these figures.

net of repayments (circles). Over the first 15 months of its life, the CPP allowed the injection of almost $205 billion of capital into approximately 730 financial entities (U.S.Treasury, 2009).[32] As of December 31, 2009, 71 institutions had redeemed their preferred stocks and about $83 billion remained invested in the remaining beneficiaries. It should be noted that the observational units in the Transaction Reports are financial holdings (as detailed in footnote 30) and not individual banks or thrifts per se. The institutions that received funding under the program could allocate the funds to any of the institutions (e.g., banks and thrifts) they control. Therefore, in the remainder of the analysis we reaggregate individual DIs that have a charter (and an entity number in the CRs and TFRs) into a consolidated entity. In our dataset, 28 CPP "multi-unit" beneficiaries control 110 banks and thrifts.

We match the Treasury data on the CPP disbursements with the unbalanced panel created from the CRs. With few exceptions, most capital injections were granted to BHCs, not to banks. In the case of a single-bank BHC, we attribute the capital injection to the bank that maintains its CR identifier. In the case of a multi-unit BHC, it is impossible to determine the ultimate beneficiary of the CPP so we keep the BHC identifier. We sum the relevant CR variables for all subsidiaries that belong to the BHC group that received the CPP and use the BHC identifier. We analyze case by case and include the banks in the panel only if the substantial majority of the banking group activity (measured by deposits) is carried out by commercial banks in the group.[33] After creating appropriate banking groups for multi-unit banks, we matched the CPP information collected from the TARP Transaction Reports using either the CR identifiers or the BHC identifiers. Our TARP/CPP information includes the amount of the CPP, the date of the CPP announcement, dummy variables and dates for double payments, repayments, and the number of banks and thrifts in the multi-unit BHCs.

Tables 9 (all DIs) and 10 (banks and thrifts separately) compare relevant variables and ratios across institutions that received CPP funding (first column) and those that did not (second column), as well as the entire population of DIs (third column). Summary statistics are calculated before the regrouping of multi-unit DIs, which leaves 614 banks and 54 thrifts for a total of 668 CPP beneficiaries. The number of observations is reported in the tables. All variables for banks and thrifts are comparable except for

[32]The latest available TARP Transaction Report was accessed on January 31, 2010, and contains information for the period ending January 13, 2010. See http://www.financialstability.gov/latest/reportsanddocs.html for details.

[33]The largest imbalance we found was a three-unit BHC in which a thrift held about 5% of the total group deposit. In all other cases, the share held by thrifts was substantially smaller. While there is a chance that all of the CPP injection was channeled into the thrift, we think this is an unlikely event.

cash.

The comparison between CPP and non-CPP DIs shows that CPP beneficiaries are larger than non-beneficiaries in terms of total loans and total assets (on average about 20 times larger, but this is skewed by the fact that the largest DIs, e.g., Citibank, JP Morgan Chase, and Bank of America, received CPP support). CPP DIs extend a slightly larger share of real estate and commercial and industrial loans and have slightly larger leverage and lower deposit-to-assets ratios. These differences characterize both the thrifts and the banks that received CPP funds.

6.2 Estimation Strategy

To evaluate the impact of the CPP, ideally we would like to compare the performance of a BHC that receives a capital injection to what its performance would have been had it not received support. Although this counterfactual is not available, performance comparisons between the beneficiaries and the non-beneficiaries can be made provided we can minimize the econometric problems that arise from such a comparison. The main econometric concern is the sample selection problem, namely, the BHCs receiving CPP funds are not a random sample from the population as would be the case in an experimental setting. If better-performing banks were awarded funds from the CPP, CPP status becomes endogenous invalidating the use of simple correlation estimation.

To control for endogeneity, we use propensity score matching (PSM) techniques.[34] The basic idea is to construct control and treatment groups, where receiving funds through the CPP is the treatment. Our goal is to find a set of control banks that are a priori equally likely to receive a capital injection as those banks which ultimately did receive one. PSM is then combined with a difference-in-differences approach to measure the average divergence in the performance paths between the BHCs in the CPP group and those in the non-CPP group.

We match individual bank identifiers to BHC identifiers. Information available at the BHC level is assumed to carry over to individual banks within the BHC group. For example, (i) we collect information on whether BHCs are publicly traded from a publicly available dataset at the Federal Reserve Bank of New York and construct a dummy variable equal to 1 for each bank in the publicly traded BHC; (ii) we use the

[34]The high dimensionality of the observable characteristics increases the difficulty of finding exact matches for each BHC in the CPP group. Conditioning on a vector of variables requires a choice regarding which dimensions should be used to match across units or which weighting scheme to apply. Rosenbaum and Rubin (1983) and Dehejia and Wahba (2002) demonstrate that the propensity score provides a natural weighting scheme that yields unbiased estimators of the treatment impact. Thus, conditioning on the propensity score is equivalent to conditioning on all variables in the treatment model, hence reducing the dimensionality issue.

BHC identifier to match each bank with our proxy for management quality.[35]

To formalize the PSM procedure, we define the cash-to-assets ratio that we would like to evaluate as Y. Let Y^1 and Y^0 denote cash-to-assets ratios for the BHCs in the CPP group and the non-CPP group, respectively. Let CPP be a binary variable indicating whether a BHC received CPP support. The aim of the analysis is to estimate the following causal effect of CPP funds on the outcome Y:

$$E\left[Y^1 - Y^0 | CPP = 1\right] = E\left[Y^1 | CPP = 1\right] - E\left[Y^0 | CPP = 0\right], \tag{11}$$

which is the difference between the dynamic path of the cash-to-assets ratio for BHCs that received CPP (first term) and the analogous outcome for the same BHCs had they not been granted CPP (second term).

The PSM technique is used to approximate the unavailable counterfactual by drawing comparisons conditional on the observables, X, see Dehejia and Wahba (2002) for a discussion. We thus assume that, conditional on the observable characteristics relevant for the CPP decision, the mean of the outcome for the BHCs in the CPP group, had they not been granted CPP funds, should be the same as the mean for those in the non-CPP group:

$$E\left[Y^0 | X, CPP = 1\right] = E\left[Y^0 | X, CPP = 0\right], \tag{12}$$

that is, the selection bias is removed, conditional on X.

The propensity score is the probability that a BHC receives CPP funds conditional on a set of covariates, denoted as $p(X)$. We define

$$p(X) = Prob(CPP = 1 | X) = E\left[CPP | X\right]. \tag{13}$$

The second part of our strategy is to adopt a difference-in-differences approach. This approach enables us to determine differences in the evolution of the cash-to-assets ratio between the BHCs who received CPP funds and the matched control BHCs that had characteristics similar to those BHCs that received CPP funds in the quarter before they were awarded funds. Blundell and Costa Dias (2000) emphasize the benefits of combining matching and a difference-in-differences approach to control for observable as well as unobservable constant differences between treatment and control units.

[35] The "CRSP-FRB Link" dataset is available at this url: http://www.newyorkfed.org/research/banking_research/datasets.html.

Define the average treatment effect on the treated group (ATT) as follows. Assume that t denotes the quarter that the BHCs received CPP funds (TARP quarter), $t-1$ is the pre-CPP (pre-TARP) quarter, and $t+1, t+2, \cdots, t+6$, are the first, second, $\cdots$, sixth quarters after the TARP quarter, respectively. Let $ATT1_{t+j}$, where $j = 0, 1, \cdots, 6$, be the ATT in the TARP quarter and the following quarters compared with the ATT in the previous quarter. The expression for the ATT1 is thus

$$ATT1_{t+j} = \frac{1}{n_j}\sum_{i=1}^{n_j}\left(Y^1_{i,t+j} - Y^0_{i,t+j}\right) - \frac{1}{n_{j-1}}\sum_{i=1}^{n_{j-1}}\left(Y^1_{i,t+j-1} - Y^0_{i,t+j-1}\right),$$

where $n_{-1}, n_0, n_1, \cdots, n_6$ is the count of the matched BHCs in the pre-TARP quarter, the TARP quarter, and the first, $\cdots$, sixth quarters after the TARP quarter. We also construct $ATT2_{t+j}, j = 0, 1, \cdots, 6$, the ATT in the TARP quarter and the following quarters compared with the ATT in the pre-TARP quarter:

$$ATT2_{t+j} = \frac{1}{n_j}\sum_{i=1}^{n_j}\left(Y^1_{i,t+j} - Y^0_{i,t+j}\right) - \frac{1}{n_{-1}}\sum_{i=1}^{n_{-1}}\left(Y^1_{i,t-1} - Y^0_{i,t-1}\right).$$

6.3 Timing

In order ensure the timing is correct for the pre-TARP and post-TARP quarters outlined above, we use information about the CPP from the U.S. Treasury as well as media sources. When the CPP was announced in October 2008, a number of applications were submitted to the U.S. Treasury. However, at this point, and despite various lawsuits under the Freedom of Information Act of 1966, the U.S. Treasury has not disclosed the list and the timing of applications. Thus, we must rely on informal evidence on the application timing and the pool of applicants. We have two pieces of information that can assist us with the timing. First, Treasury officials revealed that "thousands of applications" for funds were received, but only a few hundred BHCs qualified for funds through the CPP based on their CAMEL scores. Second, the United States Department of Financial Stability (2010) stated that the rate at which applications were submitted declined rapidly in early 2009. The report cites three key reasons for this decline. (i) In February 2009, Congress adopted more restrictive executive compensation requirements for all TARP recipients. (ii) Many banks felt there was a stigma associated with participation in the program. (iii) The impact of the crisis on DIs started to appear less dramatic.

Based on this information, we treat the entire population of banks, with the exception of foreign banks, which were excluded from receiving funds under the program, as the pool of applicants. We also exclude "new" commercial banks (credit card companies and investment banks) for reasons explained in Section 5. We conjecture that the majority of applications were submitted in the fall of 2008. Based on this assumption, we estimate the probability of receiving CPP funds based on observable characteristics measured at the end of the third quarter of 2008.

6.4 An Empirical Model of the Capital Purchase Program

The first part of our approaches relies on a reduced-form empirical model of CPP participation. CPP beneficiaries differ from non-CPP banks along many dimensions (Contessi and Francis, 2011) and, in fact, our data reveal substantial dissimilarities in terms of capital ratios, size, and loan composition. We observe banks becoming CPP beneficiaries along with a matrix of observable indicators. A natural approach to model this event is to use a probit model for the probability a bank received CPP funds based on a set of observable characteristics. We assume that local economic conditions affect the probability of applying for and being granted CPP funds, along with key bank-level characteristics. The explanatory variables are measured at the end of the third quarter of 2008, as the application process opened in the fourth quarter of 2008, and according to U.S. Treasury documents, most applications were received by the beginning of 2009.[36]

We report the results for the probit estimates in Table 11. We estimate the probit model using three groups of regressors: a set of standard financial indicators for banks, geographic variables meant to capture changes in demand, and other variables likely to affect selection into the program. We use the following specific variables in our specification of the probit model:

- Capital adequacy: We use three measures of capital adequacy-the ratio of total equity to total assets, and the Tier 1 capital ratio in levels and squared.
- Asset size and composition: We use the logarithm of total assets, commercial and industrial loans as a share of total assets, and cash and reserves as a share of total assets, and all "other securities" (quarterly average) as a share of total assets.

[36] An alternative route is to estimate a probit model based on observables measured at the end of the quarter in which CPP funding was granted; however, anecdotal evidence suggests that a large number of applications were submitted in the first few months of the program.

- Bad loans: We use loan-loss reserves, the provision of possible loan losses as a share of earning assets, loan losses as a share of equity, and net loan charge-offs as a share of total loans.[37]

- Composition of liabilities: We use deposits as a share of total assets and borrowed funds with maturity longer than one year as a share of total assets.

- Other variables: We include a measure of leverage (the ratio between total loans and deposits), a dummy variables for whether a BHC is publicly traded or a top 40 BHC ranked by assets, as well as a dummy variable equal to 1 if any of the managers of a BHC is also sitting on a regional Federal Reserve Board in the fall of 2008. Hypothetically, a BHC may be more likely to receive CPP funds if its political connection is stronger. Duchin and Sosyura (2010), for example, argue that political connections as measured by contributions to House members on finance committees and representation at the Federal Reserve as board members have significant positive marginal effects on the probability of a bank being granted CPP (TARP) funds. Alternatively, a BHC could have been excluded from CPP funding because a bank manager did not apply for them due to his/her strong anti-government intervention beliefs (CNNMoney.com, 2010). These types of unobservable determinants of CPP funding are likely to be time-invariant and can be eliminated by the difference-in-differences approach. [38]

- Management quality: We construct a proxy of management quality using the number of corrective actions taken against bank management by their regulator in the 2006-09 period.[39]

- Earnings: We use the the ratio of pretax net income and total earning assets (the sum of total loans and total securities) and the ratio of net income to operating income to capture earnings.

For the probit estimation, we perform both forward and backward stepwise procedures and select the model specification with the highest pseudo-R-squared. All the coefficients reported in table 11 are significant at the 5 percent level or better. We compute the predicted probability, i.e., propensity score, based on the parameter estimates in the selected model, and match the BHCs in the TARP group with those

[37] The sum of net loans charge-offs and the loan-loss provision is defined as gross charge-offs.

[38] We include this variable because a banker who is a member of a regional Board may be more likely to know about TARP perhaps because of better information on the program.

[39] As in Duchin and Sosyura (2010), who generously provided the raw data, we have a total of 1,681 orders issued to 961 commercial banks. Enforcement actions include prohibitions from further participation in banking activities, orders to cease and desist, and orders to pay civil monetary penalties.

in the non-TARP group using one-to-one nearest neighbor matching on the propensity score. The average TARP effect on the TARP group is then calculated using a difference-in-differences approach described in Section 6.2.

6.5 Results

First, we consider the BHC characteristics that increased the probability of receiving TARP-CPP. We find that larger banks (higher log of total assets) and banks with more commercial lending were more likely to receive TARP. Banks with a higher loan loss provision—indicating significant default risk in their loan portfolio—larger percentage of loans in non-current status, higher loan-loss ratios and loan charge-offs as a percent of total loans were less likely to receive TARP. However, banks with larger loan loss reserves were more likely to receive TARP. A loan loss provision is taken when the risk of loan default is higher. Loan loss reserves are based on a risk assessment of the loan portfolio but could be a measure of prudence.

We find evidence of that publicly traded and larger (e.g., BHCs in the Top 40 BHCs by asset size) banks were more likely to receive funds. BHCs with higher real estate exposure or in states with more unemployment insurance claims were also more likely to receive funds.

The most significant variables for understanding the allocation of TARP funds relate to capital adequacy. We have no clear prior about the sign of the coefficient on the capital adequacy variables. A positive coefficient suggests that the decision to grant CPP funds was geared toward reinforcing the capital position of healthy banks. A negative coefficient, on the other hand, suggests that funds predominantly supported relatively weaker banks. As the relationship may be non-linear, we introduced a quadratic term.

We find that the coefficient on Tier 1 capital is negative and the coefficient on the quadratic term is positive, indicative of a convex relationship between receipt of CPP funds and capital adequacy. This result could be interpreted as supportive of the spirit of the CPP legislation. Banks with weaker capitalization, but still above a threshold Tier 1 capitalization, separating healthy from unhealthy (or likely to fail) institutions, were more likely to apply for and be granted a capital injection.

Assuming that our propensity scoring exercise created a well-matched set of treated and control BHCs by removing observable differences, we can now use difference-in-difference estimation to consider how cash to asset ratios of the treated and control groups differed, removing unobservable fixed differences between the two groups.

First we find our matching procedure performs well as our matched pairs of BHCs

are only 0.07 percentage point apart in terms of the propensity score. Moreover, the ratio of cash-to-assets for the TARP group in the pre-TARP and TARP quarters are larger than for the non-TARP groups (first two rows and columns of Table 12).

Second, we report the average treatment effects (average treatment on the treated) in two different ways as described in Section 6.2. While ATT1, which compares cash-to-asset ratios in the target quarter with that in the previous quarter, does not produce a general pattern, ATT2, which compares cash-to-asset ratios in the target quarter with that in the pre-TARP quarter, does exhibit a notable pattern. The reason for this is possibly due to fact that cash to asset ratios experienced a rising trend during this period.

We find that the cash-to-assets ratio for both groups increased over time (looking at ATT2 rows or alternatively comparing actual cash to asset ratios in the top two rows). Comparing the treatment group (who received TARP) with the control group between the pre-TARP period and one period following the treatment, we find that treated banks had approximately 1 percent lower cash to asset ratios than the control group (see ATT2 in table 12). We find that this effect persists for at least 4 quarters. In the period of treatment, the average treatment effect (on the treated) is small and not significant. Our interpretation of this result is that the capital injections were initially left idle on the asset side of the balance sheet (when the payment was made), but in subsequent quarters, TARP treated banks reduced their cash holdings (possibly by increasing their lending though they may also have purchased other assets, like securities), maintaining lower cash-to-asset ratios on average. This interpretation is consistent with the view that the capital injection provided precautionary liquidity for the beneficiaries. Alternatively, considering reasons why the control group's cash to asset ratios displayed a larger increase, these banks, on average, may have moved more loans into non-accrual status, reducing their asset position and raising their cash-to-asset ratio.

Although treated banks had lower ratios than non-treated banks, there is a rising trend for cash to asset ratios during this period. Deposits were increasing by an average of 1 percent; 3.5 percent for CPP banks and 0.52 percent for non-CPP banks. Increasing deposits likely impacted banks cash holdings both as a matter of accounting (deposits are initially most likely held as cash and cash equivalents), and due to the results we found in the previous section—banks were very sensitive to penalty rates, there may have additionally been insufficient lending opportunities of low risk. The fact that banks receiving CPP funds in this environment accumulated less cash suggests that

possibly the CPP injection resulted in more risk taking in the form of new lending and less precautionary accumulation, see Black and Hazelwood (2012) for a formal analysis of this conjecture. Our results are suggestive regarding lending, but we cannot draw formal inference based on them. Lower cash ratios, ceterus paribus, are also consistent with larger securities holdings for example.

In conclusion, based on our matching procedure, we find evidence that banks (or BHCs) receiving TARP funds maintained approximately 1 percent lower cash-to-assets ratios (and thus reserve ratios) post-treatment than similarly matched banks for at least one year beyond their receipt of TARP funds.

7 Conclusion

This paper undertakes a systematic analysis of the massive accumulation of excess reserves using bank-level data for more than 7,000 commercial banks and almost 1,000 savings institutions during the U.S. financial crisis. We propose a simple stochastic model of reserve determination when interest is paid on reserve holdings. We derive a log-linearized version of our model that we estimate using bank-level data and censored regression methods.

To answer the question – why would profit-maximizing banks hoard liquidity – we focus on institutions' balance sheet risk, concerns about payment shocks, and the opportunity cost of hoarding liquidity. Like Acharya and Merrouche (2013), our evidence points strongly to precautionary motives for reserve accumulation, due to banks' concerns about their balance sheet risks and doubts about the availability of short term liquidity. We did not find evidence that the generalized rise in macroeconomic uncertainty, as measured by standard markers, played a role in banks' reserve accumulation strategy, suggesting that concerns about counter-party risk as the crisis developed were not a prime factor. Another potential explanation is that the frequency of our data may not be enough to capture high-frequency changes in counter-party risk or alternatively that such risks were heightened during our period of observation and therefore not separately identifiable.

We find evidence of a precautionary motive for reserve accumulation as well as evidence that banks respond strongly to the differential between interest on reserves and an alternative investment option. We found that banks of all sizes and also thrifts respond strongly to increases in the opportunity cost of holding low-interest assets–our estimated coefficients suggest a 10 basis point increase would result in approximately

a 1 percent decline in the excess reserve to deposit ratio. On the other hand, a 10 basis point increase in the penalty rate would result in approximately a 6 percent increase in the cash plus excess reserve ratio (to deposits). We also find substantial heterogeneity between the reserve accumulation behavior of large and small banks, with small banks reserve holdings being more sensitive to their adjusted capital ratio and loan loss provisions, whereas large banks were more responsive to the penalty rate and distressed loans on their balance sheets. We cautiously interpret the responsiveness of large banks' reserve accumulation to the penalty rate to be the reaction to the problems in the interbank and repurchase markets that surfaced during the crisis. Lack of liquidity in the interbank lending market, which large banks access to meet short-term liquidity needs, was likely an important factor in reserve accumulation although our analysis does not allow us to draw sharp conclusions about this avenue.

We found that thrifts were much more responsive to distressed loans on their balance sheets than either small or large banks; they had a similarly strong response to changes in the penalty rate as large banks. But they behaved more like small banks in terms of their responsiveness to changes in capital adequacy. These differences are possibly explained by differences in regulations and constraints on thrift lending activities.

We then examined whether Capital Purchase Program funding contributed to the massive reserve accumulation by combining a propensity score matching technique with a difference-in-difference approach. We found that banks who received CPP funds accumulated fewer reserves. Bank holding companies who received CPP funds had cash to asset ratios that were 1 percent lower for at least one year beyond their receipt of funds. Our interpretation of this result is that the capital injections were initially left idle on the asset side of balance sheet when the payment was made while in later quarters, banks maintained, on average, lower cash-to-asset ratios. This interpretation is consistent with the view that the capital injection provided precautionary liquidity for the beneficiaries.

Although our analysis provides information on the determinants of excess reserve and cash accumulation, we do not provide any link between reserve accumulation (at the individual depository institution level) and lending behavior. The question we are most interested in is, how did reserve and cash accumulation during the crisis and the following quarters of low economic activity affect lending? With the guidance of recent theoretical contributions (Martin, McAndrews, and Skeie, 2013), empirically examining the effects of reserve and cash accumulation on lending in the aggregate as well as across the distribution of banks by size, capitalization, institution type and by

receipt of TARP funds is an important exercise that we leave for future research.

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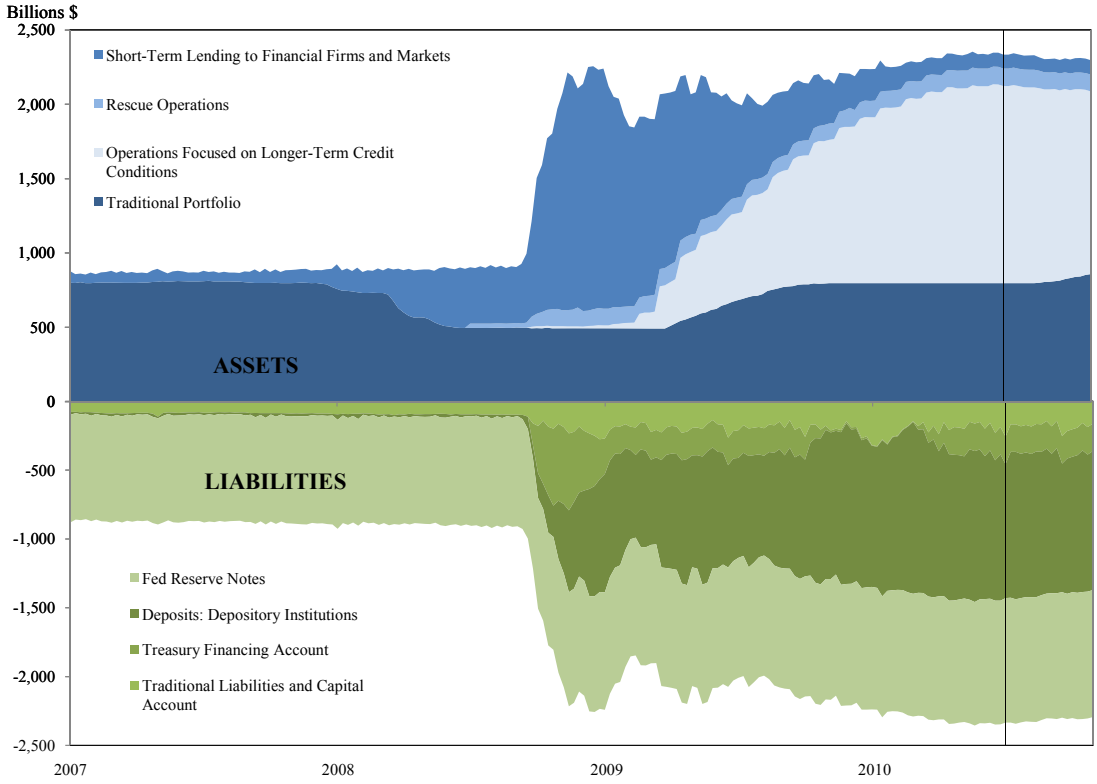
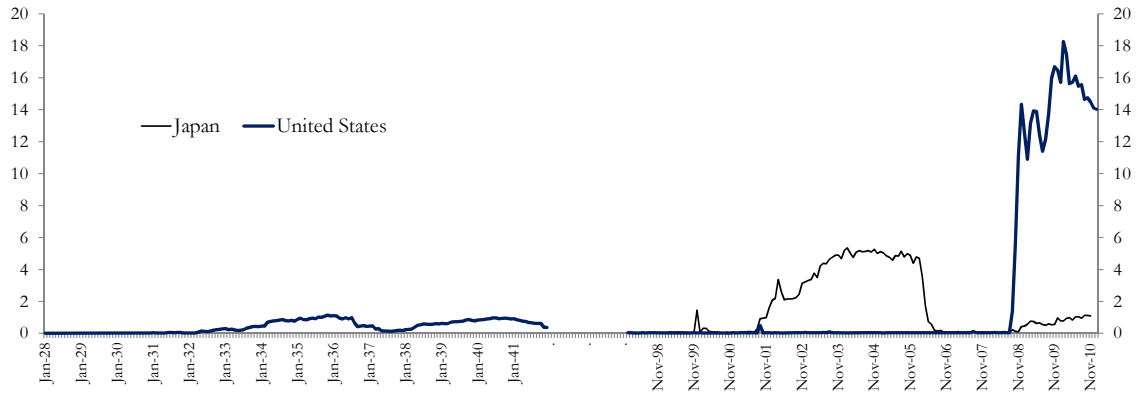
Figure 1: Federal Reserve Bank Balance Sheet, 2007-2010



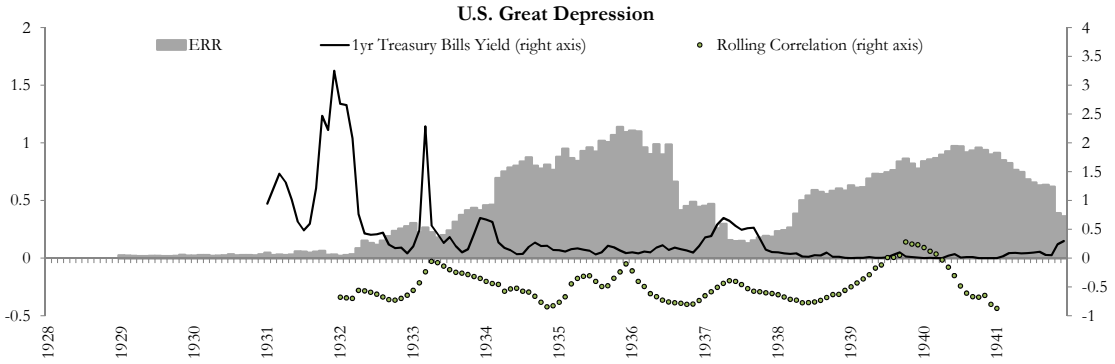
Source: Federal Reserve Board.

Figure 2: Ratio of Excess-to-Required Reserves in Japan and the U.S., 1928:M1-2010:M12



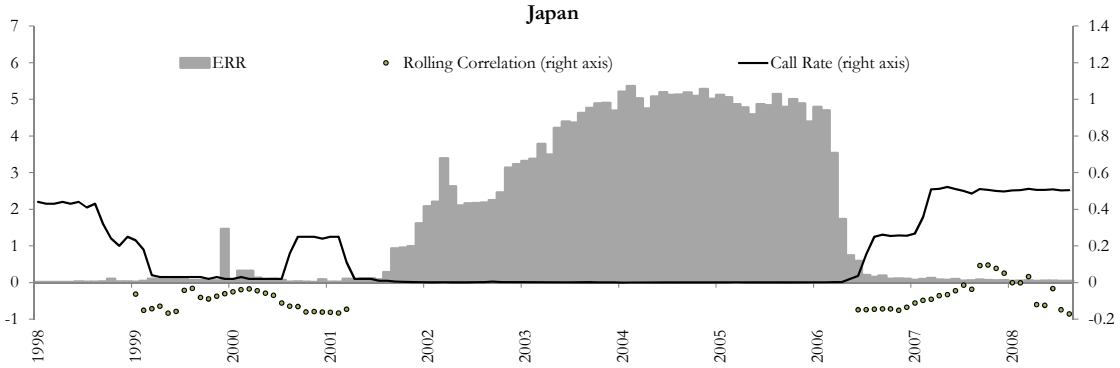
Source: Bank of Japan, Federal Reserve Board.

Figure 3: Yield on 1-year Treasury Bonds and Excess Reserves Ratio in the United States during the Great Depression



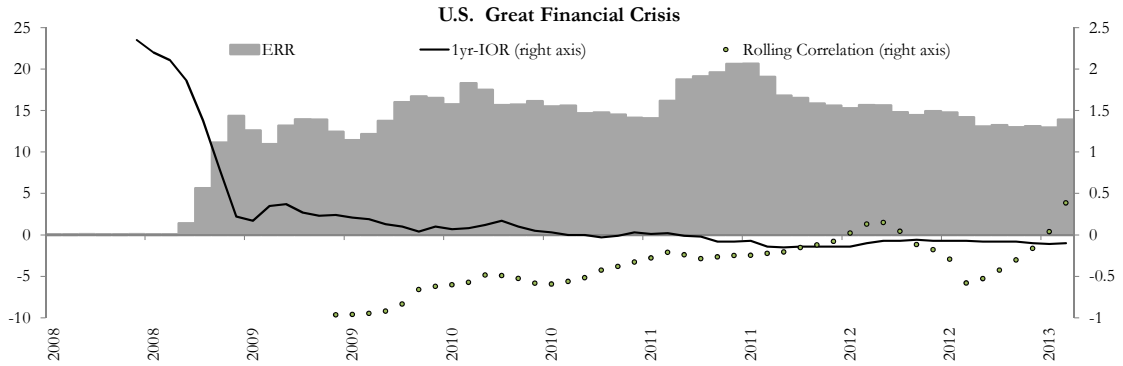
Source: Fraser and Fred II of the Federal Reserve Bank of St. Louis.

Figure 4: Call Rate and Excess Reserves Ratio in Japan during the Quantitative Easing Years



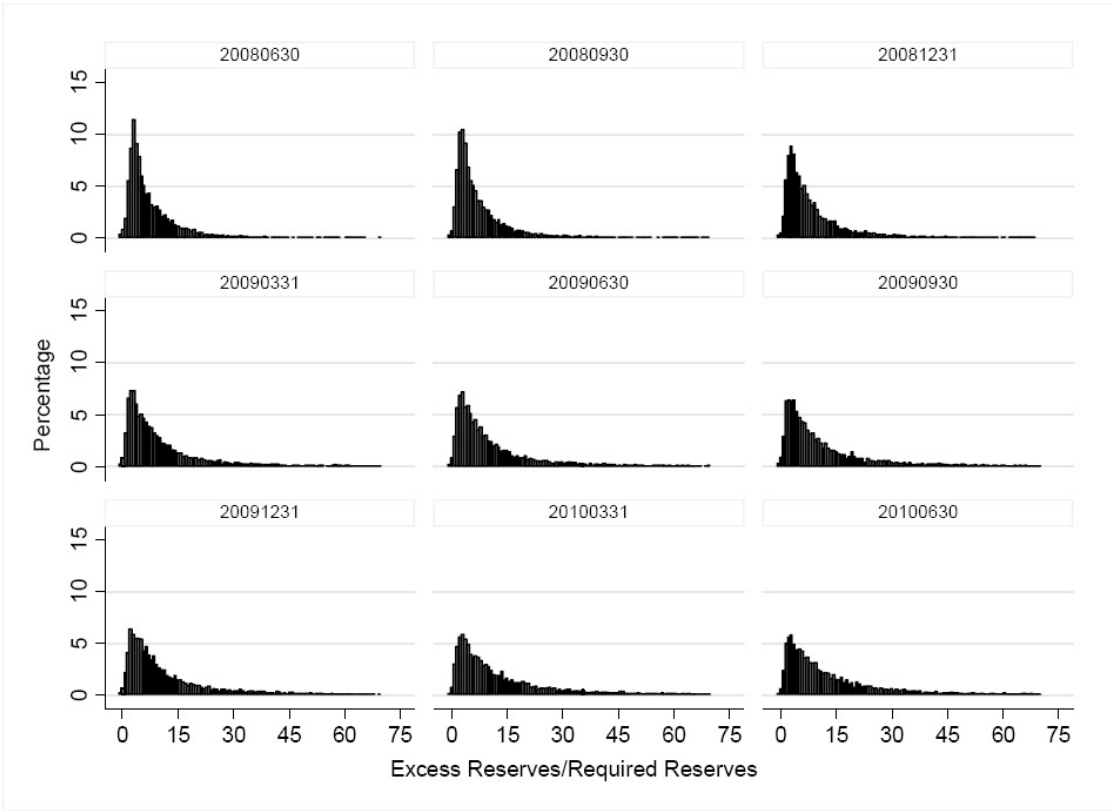
Source: Bank of Japan.

Figure 5: Differential between Yield on 1-year Treasury Bonds and IOR and Excess Reserves Ratio in the United States since the beginning of the Great Financial Crisis



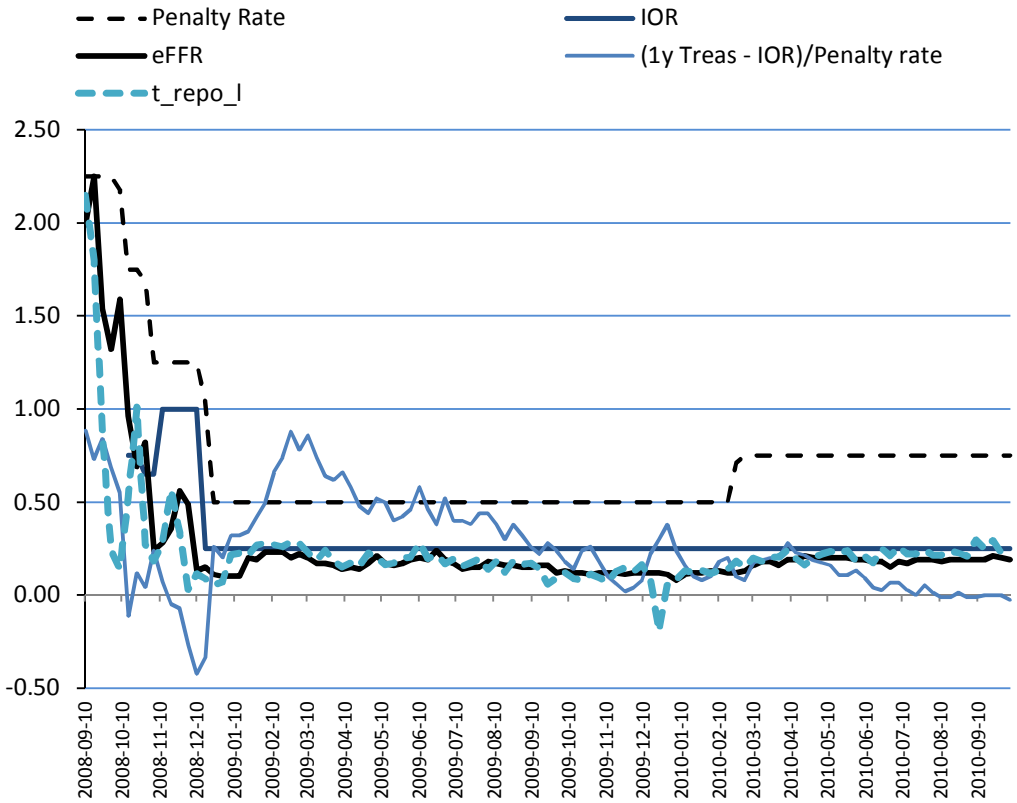
Source: Fred II of the Federal Reserve Bank of St. Louis

Figure 6: Cross-Sectional Distribution of Excess Reserves Ratio for Commercial Banks, 2008:Q2-2010:Q2



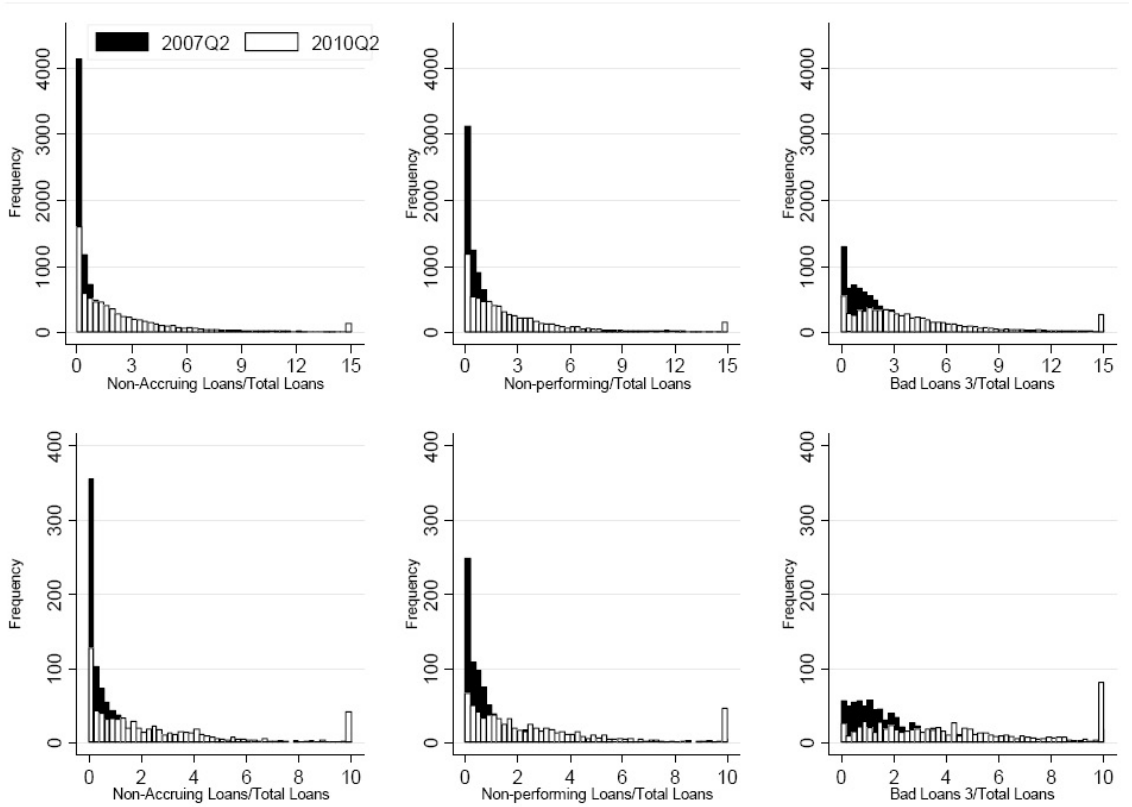
Note: We truncate our histograms at a ratio of 70. Source: Authors' calculations based on the Call Reports.

Figure 7: Federal Funds Rates, Interest on reserves, Primary Credit Rate, and adjusted Differential between 1 Year Treasury Bonds and Interest on Reserves, 2008:M7-2010:M12



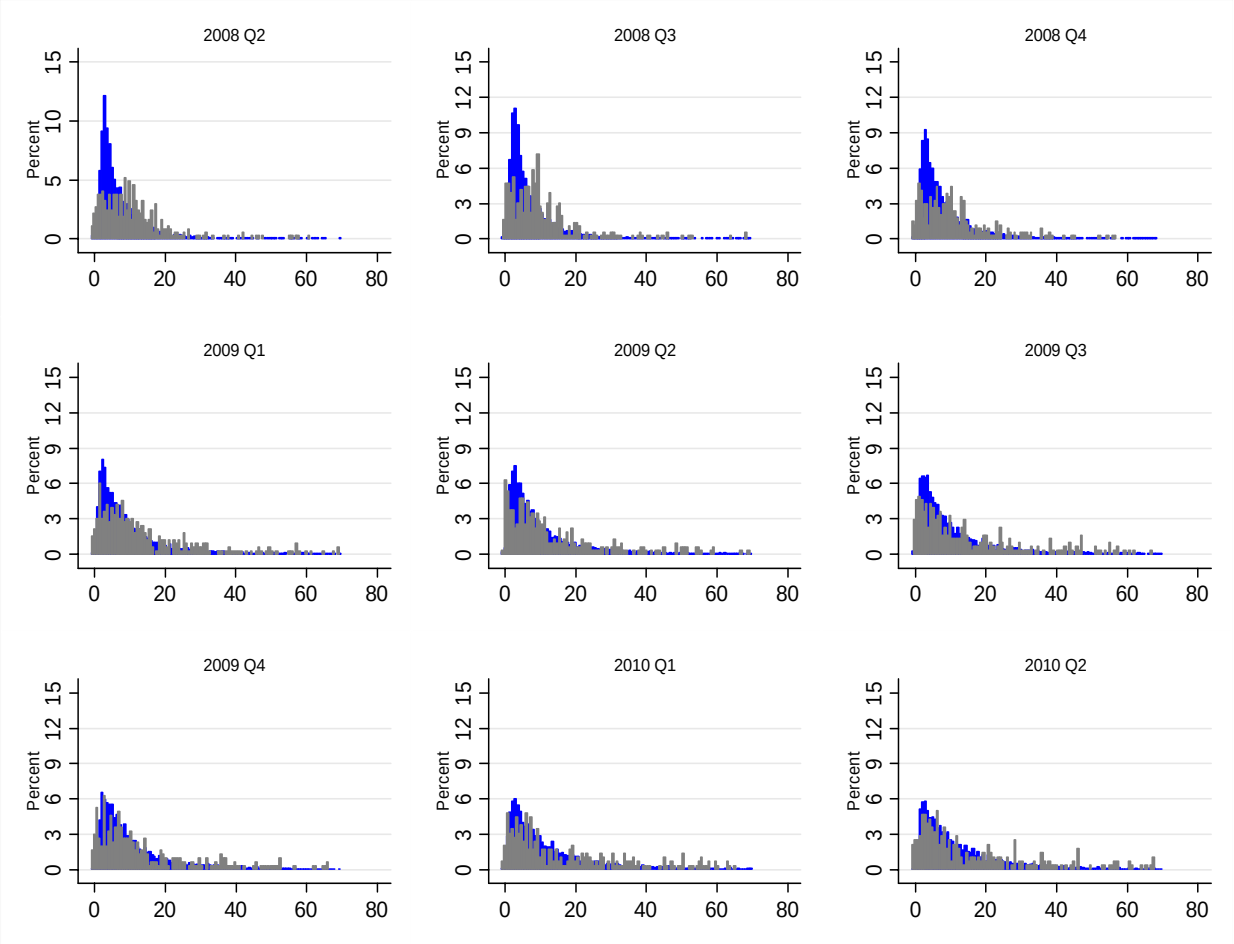
Source: Fred data repository, Federal Reserve Bank of St. Louis.

Figure 8: Cross-Section Distribution of bad, non-performing, and non accrual loans of banks and thrifts, 2007:Q2-2010:Q2



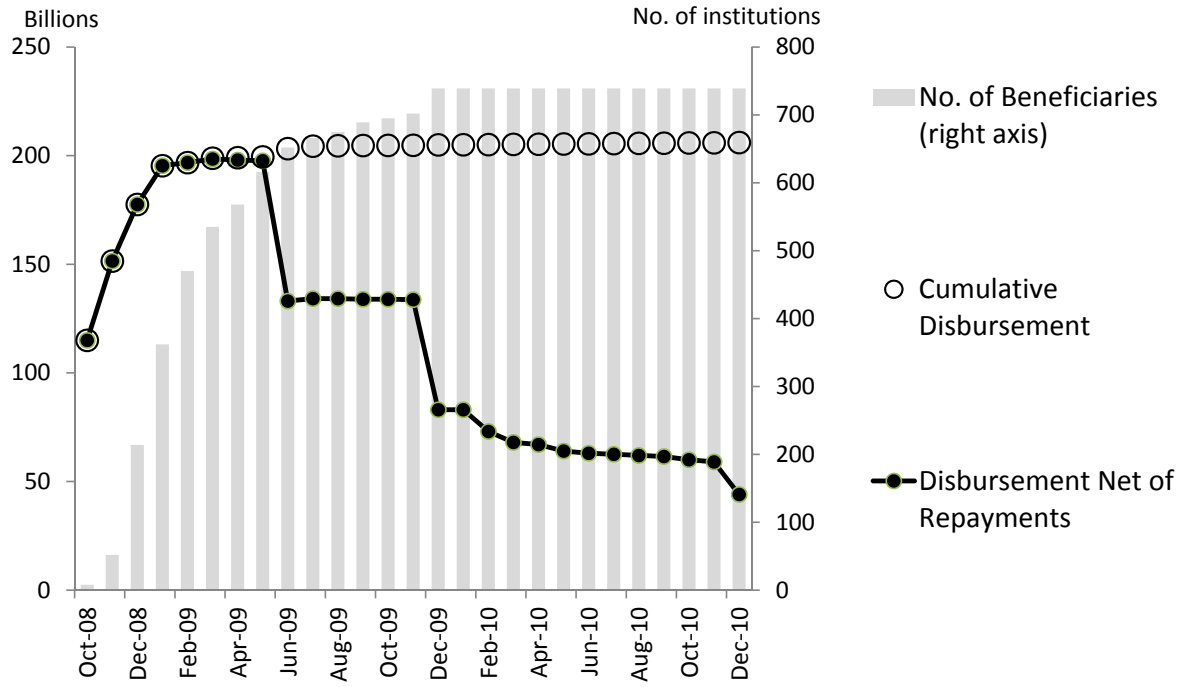
Note: These figures represent the frequency of three ratios of bad loans to assets in the population of banks (top three histograms) and thrifts (bottom three histograms). Black bars identity the first quarter used in our analysis (2007Q1) and white bars identify the last quarter (2010Q2). From left to right: (i) Non-accruing loans as a share of total assets, (ii) Non-accruing loans and non-performing loans with payments due for 90 days or more as a share of total assets, and (iii) Non-accruing loans and non-performing loans with payments due for 30 days or more as a share of total assets. We right-censored the histogram at 15 for banks and at 10 for thrifts. Source: Authors' calculations based on CRs and TFRs.

Figure 9: Cross-Section Distribution of Excess Reserves Ratio for large and small commercial Banks, 2008:Q2 through 2010:Q2



Note: These Figures represent the distribution (by percent) of the excess-to-required reserves ratio (ER-RR) for large (grey bars) and small (blue bars) commercial banks for the period analyzed in the paper. Source: Authors' calculations based on CR.

Figure 10: CPP disbursements and repayments, 2008:M10-2010:M12



Source: Authors calculations based on U.S. Treasury Transaction Reports data. Note: This figure represents the U.S. Treasury disbursement of CPP funds in billions of U.S. dollars, the disbursement net of repayment and the number of beatifically institutions.

Table 1: U.S. Reserves Requirements

Liability Type	Percent of Liabilities	Effective Date
Net Transaction Accounts		
$0 to $9.3 million	0	12/20/2007
$0 to $10.3 million	0	1/1/2009
$0 to $10.7 million		12/31/2009
$9.3 million to $43.9 million	3	12/20/2007
$10.3 million to $44.4 million	3	1/1/2009
$10.7 million to $55.2 million	3	12/31/2009
More than $43.9 million	10	12/20/2007
More than $44.4 million		1/1/2009
More than $55.2 million		12/31/2009
Non-personal time deposits	0	12/27/1990
Eurocurrency liabilities	0	12/27/1990

Source: Board of Governors of the Federal Reserve.

Table 2: Descriptive Statistics for Banks and Thrifts

All Banks	Obs	Mean	Std. Dev.	Min	Max
Log ER/Deposits	58124	-2.998403	1.041908	-12.81178	9.16059
r1yr-IOR	59747	0.0032707	0.0038605	0.0008	0.0131
Treasury Repo (last)	59747	0.001097	0.0018296	-0.00193	0.00474
Adjusted capital ratio	58846	0.1144739	0.0979229	-2.679617	1
Adj Cap Ratio * Loan loss	58846	0.0004159	0.0012071	-0.0175545	0.0938285
Log of loan loss provision (to dep)	50627	-5.993882	1.45527	-15.00516	8.49254
Log bad-loans 1 (to dep)	50753	-4.618918	1.529698	-13.57177	8.868217
Log bad-loans 2 (to dep)	53790	-4.486885	1.483462	-13.57177	7.736125
Log bad-loans 3 (to dep)	56182	-3.83434	1.231332	-12.07498	8.151846

Thrifts	Obs	Mean	Std. Dev.	Min	Max
Log ER/Deposits	6140	-4.274379	1.216473	-11.82187	2.813491
r1yr-IOR	6280	0.0032914	0.0038753	0.0008	0.0131
Treasury Repo (mean)	6280	0.0040954	0.0056216	0.0010527	0.0185442
Tier 1 capital ratio	6280	0.1340678	0.1280314	-0.2382593	0.9819683
Tier 1 capital*loan loss	6275	0.0003924	0.0028135	-0.0407261	0.0847798
Log of loan loss provision (to dep)	5037	-6.738302	1.595352	-12.6494	-1.401558
Log bad-loans 1 (to dep)	5241	-4.440089	1.46893	-12.6937	2.477554
Log bad-loans 2 (to dep)	5716	-4.334777	1.397109	-12.34652	2.477554
Log bad-loans 3 (to dep)	5919	-3.563909	1.124428	-11.09375	2.624031

Notes: this data is based on the quarterly Reports of Condition and Income database (commonly called the Call Reports and the Thrift Financial Reports. Interest rate data is taken from the FRED II repository of the Federal Reserve Bank of St. Louis and the Treasury repo rate is from the DTCC GCF Repo Index of Treasury bill repurchase agreements. The negative values for the adjusted capital ratio and interaction term are due to the fact that equity is calculated net of unrealized losses on marketable equity securities. Also the capital ratio is adjusted for intangibles which may make the numerator (equity net of intangibles) negative when intangibles are large.

Table 3: Tobit & CLAD Regressions of (log) Excess Reserves to deposit ratio, All Banks

	TOBIT			CLAD		
	(1)	(2)	(3)	(4)	(5)	(6)
r1yr-IOR	-2.727***	-2.729***	-2.735***	-4.434***	-4.455***	-4.383***
	(0.08)	(0.079)	(0.079)	(0.234)	(0.205)	(0.221)
Treasury Repo (last)	1.900***	1.911***	1.923***	1.790***	1.183***	1.602***
	(0.152)	(0.152)	(0.151)	(0.493)	(0.432)	(0.462)
Adjusted capital ratio	0.301***	0.301***	0.301***	-0.0567***	-0.0822***	-0.0629***
	(0.003)	(0.003)	(0.003)	(0.0161)	(0.0143)	(0.0153)
Adj Cap Ratio * Loan loss	2.878***	2.822***	2.859***	3.822***	3.636***	3.898***
	(0.149)	(0.148)	(0.144)	(0.563)	(0.577)	(0.569)
Log of loan loss provision	0.00564***	0.00564***	0.00564***	-0.000357	-0.000745*	-9.44e-05
	(0.0001)	(0.0001)	(0.0001)	(0.000480)	(0.000431)	(0.000457)
Log bad-loans 1	0.00266***			0.00276***		
	(0.0001)			(0.000390)		
Log bad-loans 2		0.00266***			0.00281***	
		(0.0001)			(0.000344)	
Log bad-loans 3			0.00266***			0.00293***
			(0.0001)			(0.000367)
Constant	0.731***	0.731***	0.731***	0.767***	0.769***	0.771***
	(0.0006)	(0.0006)	(0.0006)	(0.00287)	(0.00261)	(0.00274)
sigma	0.101***	0.101***	0.101***			
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	45831	45831	45831	45,929	45,807	45,855

Notes: Clustered (bank level) standard errors are reported in parentheses. CLAD regressions have bootstrapped standard errors with 1000 repetitions. Approximately 0.2 percent of the observations are left censored at zero. *** p<0.01, ** p<0.05, * p<0.1. The standard deviation of the ratio of the log of excess reserves to deposits is 0.116. We define excess reserves and cash as funds over 110 percent of reserve requirements. $r1yr - IOR$ is the difference between the one year return on US treasury bills and the interest paid on reserves. Bad-loans 1, 2, and 3 are nested, with bad-loans 1 being the narrowest definition and bad-loans 3 the broadest. Adj-cap ratio*loanloss is the interaction effect between the adjusted capital ratio and the loan loss provision as a ratio to assets. The remaining variables are defined in the text.

Table 4: Tobit Regressions of (log) Excess Reserves to deposit ratio , Banks by Size

	Large banks $> 97th$ percentile by assets			Small banks $< 95th$ percentile by assets		
	(1)	(2)	(3)	(4)	(5)	(6)
r1yr-IOR	-843.7***	-843.7***	-843.7***	-1.869***	-1.869***	-1.869***
	(207.2)	(207.2)	(207.2)	(0.071)	(0.071)	(0.071)
Treasury Repo	83.42***	83.42***	83.42***	2.266***	2.266***	2.266***
	(20.43)	(20.43)	(20.43)	(0.123)	(-0.123)	(0.123)
Adjusted capital ratio	0.675*	0.675*	0.675*	-0.0234***	-0.0234***	-0.0234***
	(0.316)	(0.316)	(0.316)	(0.005)	(0.005)	(0.005)
Adj Cap Ratio * Loan loss	-23.36**	-23.36**	-23.36**	1.965***	1.965***	1.965***
	(8.469)	(8.469)	(8.469)	(0.147)	(0.147)	(0.147)
Log of loan loss provision	0.053***	0.053***	0.053***	0.0001	0.0001	0.0001
	(0.015)	(0.015)	(0.015)	(0.00001)	(0.0001)	(0.0001)
Log bad-loans 1	0.0257			0.001***		
	(0.013)			(0.0001)		
Log bad-loans 2		0.0257			0.001***	
		(0.013)			(0.0001)	
Log bad-loans 3			0.0257			0.001***
			(0.013)			(0.0001)
Constant	1.915***	1.915***	1.915***	0.763***	0.763***	0.763***
	(0.25)	(-0.25)	(-0.25)	(-0.0005)	(-0.0005)	(-0.0005)
sigma	0.167***	0.167***	0.167***	0.0805***	0.0805***	0.0805***
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1013	1013	1013	42673	42673	42673

Notes: Clustered (bank level) are reported in parentheses. Approximately 2 percent of the large bank data is left censored at zero and 0.15 percent of the small bank data. We define excess reserves as funds over 110 percent of what banks are required to hold as reserves. $r1yr - IOR$ is the difference between the one year return on US treasury bills and the interest paid on reserves. Bad-loans 1, 2, and 3 are nested, with bad-loans 1 being the narrowest definition and bad-loans 3 the broadest. adj-cap ratio*loanloss is the interaction effect between the adjusted capital ratio and the loan loss provision. The remaining variables are defined in the text. The coefficient estimates are significantly different across bank size at the 1 percent level. *** p<0.01, ** p<0.05, * p< .10

Table 5: CLAD Regressions of Excess Reserves (log), Banks by Size

	Large banks $> 97th$ percentile by assets			Small banks $< 95th$ percentile by assets		
	(1)	(2)	(3)	(4)	(5)	(6)
r1yr-IOR	-6.956***	-6.827***	-5.069***	-4.372***	-4.334***	-4.162***
	(0.814)	(0.947)	(0.844)	(0.247)	(0.230)	(0.267)
Treasury Repo (last)	10.13***	10.97***	3.766**	1.327**	1.130**	0.714
	(1.762)	(1.991)	(1.803)	(0.519)	(0.482)	(0.561)
Adjusted capital ratio	0.112	0.285***	0.165**	-0.0479***	-0.0343**	-0.0252
	(0.0758)	(0.0798)	(0.0722)	(0.0169)	(0.0161)	(0.0184)
Adj Cap Ratio * Loan loss	-5.947***	-11.01***	-5.599***	5.117***	4.716***	3.129***
	(1.042)	(1.511)	(1.146)	(0.739)	(0.618)	(0.815)
Log of loan loss provision	0.0219***	0.0246***	0.0220***	-0.00201***	-0.000782	-0.00130**
	(0.00169)	(0.00189)	(0.00162)	(0.000527)	(0.000481)	(0.000574)
Log bad-loans 1	0.00788***			0.00251***		
	(0.00154)			(0.000408)		
Log bad-loans 2		0.0130***			0.00132***	
		(0.00171)			(0.000384)	
Log bad-loans 3			0.00571***			0.00236***
			(0.00145)			(0.000446)
Constant	0.943***	0.962***	0.933***	0.753***	0.753***	0.755***
	(0.00760)	(0.00828)	(0.00736)	(0.00323)	(0.00298)	(0.00356)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,015	1,008	1,009	42,730	42,766	42,727

Notes: Bootstrapped standard errors are reported in parentheses. Approximately 2 percent of the large bank data is left censored at zero and 0.15 percent of the small bank data. We define excess reserves as funds over 110 percent of what banks are required to hold as reserves. $r1yr - IOR$ is the difference between the one year return on US treasury bills and the interest paid on reserves. Bad-loans 1, 2, and 3 are nested, with bad-loans 1 being the narrowest definition and bad-loans 3 the broadest. Adj-cap ratio*loanloss is the interaction effect between the adjusted capital ratio and the loan loss provision ratio to assets. The remaining variables are defined in the text. The coefficient estimates are significantly different across bank size at the 1 percent level. *** p<0.01, ** p<0.05, * p< .10

Table 6: Tobit & CLAD Regressions for (log) Excess Reserve to deposit ratio, Thrifts

	TOBIT			CLAD		
	(1)	(2)	(3)	(4)	(5)	(6)
r1yr-IOR	-367.2**	-272.6**	-267.8**	125.5	-568.4***	-134.3
	(148.0)	(137.4)	(133.9)	(204.3)	(192.4)	(196.6)
Treasury Repo (mean)	97.15**	71.14*	70.38*	-33.45	162.1***	32.84
	(43.69)	(40.96)	(39.96)	(60.90)	(57.22)	(58.42)
Tier 1 capital ratio	-0.319***	-0.330***	-0.322***	-0.169***	-0.224***	-0.184***
	(0.0724)	(0.0720)	(0.0726)	(0.00970)	(0.00979)	(0.00906)
Log of loan loss provision	-0.00333	-0.00107	0.000490	-0.450***	0.0446	-0.322**
	(0.00252)	(0.00262)	(0.00249)	(0.143)	(0.122)	(0.148)
Tier 1 capital ratio*loan loss	5.268***	5.012***	4.949***	4.399***	3.874***	4.210***
	(1.067)	(1.270)	(1.278)	(0.519)	(0.510)	(0.495)
Log bad-loans 1	0.00146			0.0670***		
	(0.00312)			(0.002)		
Log bad-loans 2		-0.00285			0.0633***	
		(0.00371)			(0.00203)	
Log bad-loans 3			-0.00675			0.0574***
			(0.00446)			(0.00234)
Constant	0.845***	0.791***	0.785***	0.589***	0.951***	0.732***
	(0.0765)	(0.0706)	(0.0691)	(0.102)	(0.0961)	(0.0982)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sigma	0.115***	0.119***	0.119***	-	-	-
	(0.00688)	(0.00697)	(0.00682)	-	-	-
Observations	4,506	4,806	4,921	6,275	6,275	6,275

Notes: Clustered (at the thrift level) standard errors and bootstrapped (for CLAD estimation) standard errors are reported in parenthesis. We define excess reserves and cash as funds over 110 percent of what banks are required to hold as reserves. Approximately 1.9 percent of the sample is left censored at 0. $r1yr - IOR$ is the difference between the one year return on US treasury bills and the interest paid on reserves. Bad-loans 1, 2, and 3 are nested, with bad-loans 1 being the narrowest definition and bad-loans 3 the broadest. Tier 1 cap ratio*loanloss is the interaction effect between the ratio of Tier 1 capital to risk adjusted assets and the loan loss provision as a ratio to assets. The remaining variables are defined in the text. *** p<0.01, ** p<0.05, * p< 0.10

Table 7: Elasticities of Excess Reserves, All Banks and Thrifts

All Banks	(1)	(2)	(3)
r1yr-IOR	-0.159***	-0.163***	-0.166***
Treasury repo rate (last)	0.027***	0.0281***	0.0281***
Log (bad-loans 1/dep)	0.0445**		
Log (bad-loans 2/dep)		0.0453***	
Log (bad-loans 3/dep)			0.0503***
Large Banks	(1)	(2)	(3)
r1yr-IOR	-0.4524***	-0.312***	-0.2808**
Treasury repo rate (last)	0.367***	0.250***	0.187**
Log (bad-loans 1/dep)	0.640***		
Log (bad-loans 2/dep)		0.920***	
Log (bad-loans 3/dep)			1.154***
Small Banks	(1)	(2)	(3)
r1yr-IOR	-0.139***	-0.1427***	-0.147***
Treasury repo rate (last)	0.008**	0.008**	0.009***
Log (bad-loans 1/dep)	0.023***		
Log (bad-loans 2/dep)		0.0151*	
Log (bad-loans 3/dep)			0.0007
Thrifts	(1)	(2)	(3)
r1yr-IOR	-0.294***	-0.237***	-0.261***
Treasury repo rate (mean)	0.409***	0.325***	0.349***
Log (bad-loans 1/dep)	-0.000238		
Log (bad-loans 2/dep)		-0.04522	
Log (bad-loans 3/dep)			-0.0833

Note: These coefficients measure the elasticity of ER to changes in each of the covariates. Since the first two covariates are logs and the dependent var is a log, the log covariate eleasticities are evaluated as dLog(y)/dLog(x). The second group of are levels or ratios so they are evaluated as (dLog(y)/dx)*x-covariates. All variables are defined in the text. *** p<0.01.

Table 8: Role of Uncertainty: Tobit Regressions of Excess Reserves (log), Banks by Size

	Large banks $> 97th$ percentile by assets			Small banks $< 95th$ percentile by assets		
	(1)	(2)	(3)	(5)	(6)	(7)
VIX	-0.0100***			0.0002		
	(0.0026)			(0.0002)		
Δ VIX		-0.008***			0.0001	
		(0.0020)			(0.0002)	
IP con-var			0.579***			-0.0345***
			(0.147)			(0.0003)
Observations	1,013	1,013	1,013	42,673	42,673	42,673

Notes: We define excess reserves as funds over 110 percent of what banks are required to hold as reserves. Regressions include time dummies, r1yr-IOR, Treasury repo rate, Bad loans 1, Loan loss provision, Adjusted capital ratio, interaction between loan loss provision and the adjusted capital ratio. IP con-var is a measure of the conditional variance of industrial production estimated from a GARCH model. Clustered (at the bank level) standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 .

Table 9: Descriptive statistics for selected variables (2009:Q3)

All Depository Institutions

Observations		CPP N= 924			Non-CPP N= 7,186			All DI N= 8,110		
		Mean	Median	Max.	Mean	Median	Max.	Mean	Median	Max.
Total loans	***	($) 9.64 b	305 m	740 b	481,840	88 m	361 b	1.53 b	101 m	740 b
Total assets	***	($) 19.50 b	434 m	1670 b	891,658	134 m	548 b	3.01 b	151 m	1670 b
Real estate loans	***	($) 5.56 b	231 m	448 b	313,717	64 m	201 b	0.91 b	74 m	448 b
C&I loans	***	($) 1.93 b	40 m	154 b	72,693	9 m	70.8 b	0.28 b	10 m	154 b
Individual loans	***	($) 1.25 b	6 m	114 b	67,806	3 m	92.8 b	0.20 b	3 m	114 b
Real estate/Total loans	***	0.78	0.81	1	0.77	0.80	1	0.77	0.80	1
C&I/Total loans	***	0.17	0.15	1	0.15	0.12	1	0.15	0.13	1
Individual/Total loans	***	0.05	0.02	1	0.08	0.05	1	0.08	0.05	1
Loans/Assets	***	0.69	0.71	1	0.60	0.63	1	0.61	0.64	1
Deposits/Assets	***	0.79	0.81	0.98	0.82	0.84	0.98	0.82	0.83	0.98
Leverage	***	10.4	10.4	64.1	10.1	9.9	99.1	10.2	10.0	99.1
Cash/Assets	***	0.06	0.03	0.67	0.07	0.04	0.81	0.07	0.04	0.81

Notes: Includes all banks and thrifts in our sample (subject to the exclusion of investment banks and "new banks" discussed in the data section above). C&I refers to commercial and industrial loans; individual loans are loans to consumers typically with no collateral provided e.g., credit card lines. b=billions; m=millions. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level in a t-test for difference in the mean of each variable between CCP and non-CPP DIs.

Table 10: Descriptive Statistics for Selected Variables (2009:Q3)

Banks

Observations		CPP N= 860			Non-CPP N= 6,493			All Banks N= 7,353		
		Mean	Median	Max.	Mean	Median	Max.	Mean	Median	Max.
Total loans	***	($) 10.2 b	301 m	740 b	448 m	86 m	361 b	1.6 b	98 m	740 b
Total assets	***	($) 20.8 b	425 m	1670 b	850 m	130 m	548 b	3.2 b	148 m	1670 b
Real estate loans	***	($) 5.9 b	227 m	448 b	278 m	61 m	201 b	0.9 b	70 m	448 b
C&I loans	***	($) 2.0 b	40 m	154 b	75 m	9 m	70.8 b	0.3 b	11 m	154 b
Individual loans	***	($) 1.3 b	6 m	114 b	65 m	3 m	92.8 b	0.2 b	4 m	114 b
Real estate/Total loans	***	0.78	0.81	1	0.76	0.79	1	0.76	0.79	1
C&I/Total loans	***	0.18	0.15	0.96	0.16	0.13	1	0.16	0.14	1
Individual/Total loans	***	0.05	0.02	1	0.08	0.05	1	0.08	0.05	1
Loans/Assets	***	0.68	0.71	0.95	0.59	0.62	1	0.60	0.63	1
Deposits/Assets	***	0.80	0.81	0.98	0.82	0.84	0.98	0.82	0.84	0.98
Leverage	***	10.4	10.3	64.1	10.2	9.9	99.1	10.2	10.0	99.1
Cash/Assets	***	0.06	0.04	0.67	0.07	0.05	0.81	0.07	0.05	0.81

Thrifts

Observations		CPP N= 64			Non-CPP N= 693			All Thrifts N= 757		
		Mean	Median	Max.	Mean	Median	Max.	Mean	Median	Max.
Total loans		($) 1667 m	463 m	19.8 b	794 m	125 m	50.1 b	867 m	135 m	50.1 b
Total assets		($) 2410 m	531 m	31.6 b	1280 m	177 m	89.7 b	1375 m	186 m	89.7 b
Real estate loans		($) 936 m	374 m	9.1 b	651 m	110 m	36.5 b	674 m	115 m	36.5 b
C&I loans		($) 503 m	25 m	12.8 b	49 m	2 m	11.5 b	87 m	3 m	11.5 b
Individual loans		($) 228 m	8 m	6.0 b	94 m	2 m	16.7 b	105 m	2 m	16.7 b
Real estate/Total loans	***	0.83	0.89	1	0.89	0.94	1	0.89	0.94	1
C&I/Total loans	***	0.11	0.08	0.70	0.06	0.02	1	0.06	0.03	1
Individual/Total loans	***	0.06	0.03	0.34	0.05	0.02	1	0.05	0.02	1
Loans/Assets	*	0.73	0.74	0.93	0.69	0.74	1	0.69	0.74	1
Deposits/Assets		0.74	0.75	0.91	0.76	0.78	0.98	0.76	0.78	0.98
Leverage	*	10.5	10.7	23.0	9.9	9.5	97.9	9.9	9.7	97.9
Cash/Assets		0.02	0.01	0.08	0.02	0.01	0.34	0.02	0.01	0.34

Notes: Includes all banks and thrifts in our sample (subject to the exclusion of investment banks and "new banks" discussed in the data section above). C&I refers to commercial and industrial loans; individual loans are loans to consumers typically with no collateral provided e.g., credit card lines. b=billions; m=millions. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level in a t-test for difference in the mean of each variable between CCP and non-CPP DIs.

Table 11: Probit Estimates for TARP Beneficiaries and Non-TARP Banks

Variables	Estimates	Standard errors
Total equity/TA	4.2972	1.5750
Total noncurrent loans/TL	-9.2568	1.7117
Loan-loss provision/TA	-42.184	21.4046
Commercial Loans/TA	2.3500	0.3865
Loan Loss Reserves/TL	33.2920	8.800
Pre-tax net income/TA	-14.8823	2.7643
Brokered deposits/TA	0.5483	0.2760
Other borrowed funds maturing 1Yr/TA	1.0752	0.6340
Pledged securities/TA	0.2387	0.0884
Pre-tax net Income/TA	-9.0192	2.7835
Log of TA	0.0928	0.0268
Tier 1 Capital ratio	-12.144	1.3878
Tier 1 Capital ratio squared	2.4288	0.3814
Loans/Deposits	0.6880	0.1578
Loan-losses/Equity	-3.8049	1.1162
Net loan charge-offs/TL	-48.2618	22.3336
Gross charge-offs/TL	33.3657	17.6223
Net income/Operating income	-0.0929	0.0377
Net interest income/Earning assets	-12.5649	4.9608
All other securities (Q average)/TA	-1.4425	0.6729
Cash and reserves/TA	-0.0681	0.8837
Publicly traded	0.8230	0.0872
Management penalties	0.0248	0.0102
Business bankruptcy filings	-0.0004	0.0002
Business bankruptcy filings (y-y)	0.0027	0.0009
Conventional mortgage home price index (y-y)	-0.0464	0.0165
Unemployment insurance claims	0.000004	1.45e-06
Unemployment insurance claims (y-y)	0.0027	0.001
Top 40	1.379	0.5504
Fed Board	0.5051	0.2036
ints55y5	0.0688	0.0267
Constant	-2.0308	0.4437
Psedo-R^2	0.2816	
Log-Likelihood	-1414.077	

Notes: This is the final probit result from running a forward and backward stepwise procedure to determine the vector of significant covariates we use in calculating the propensity score. We estimate this probit at the level of BHC. ints55y5 is the interaction of real estate loan shares with real estate prices, top 40 indicates the bank holding company is among the largest 40 BHCs by assets. Fed Board is a dummy variable for whether any of the managers of the BHC have a current position on a regional Federal Reserve Board in the fall of 2008. All covariates are significant at the 5 percent confidence level or better.

Table 12: Difference-in-Differences Analysis: Cash-to-Asset Ratios

	Pre-TARP	TARP	TARP+1	TARP+2	TARP+3	TARP+4
TARP group	0.0387	0.0475	0.0492	0.0538	0.0574	0.0634
Non-TARP group	0.0318	0.0425	0.0556	0.0583	0.0649	0.0678
ATT1		-0.0019	-0.0102^*	0.0013	-0.0019	0.0031
		(0.0038)	(0.0031)	(0.0034)	(0.0031)	(0.0034)
ATT2		-0.0019	-0.0121^*	-0.0109^*	-0.0127^*	-0.0097^*
		(0.0038)	(0.0042)	(0.0044)	(0.0048)	(0.0054)
Number of matched pairs	539	523	519	513	517	497

ATT1 is the difference between the ratio of cash-to-assets in the target quarter and that in the previous quarter; ATT2 is the difference between the ratio of cash-to-assets in a given quarter and the previous quarter. $*$ indicates statistical significance at the 5% level.