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Bank Lending and Interest on Excess Reserves

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This paper analyzes the relationship between bank lending and the Federal Reserve's policy of paying interest on excess reserves (IOER). We argue that the Fed's IOER policy deviates from the standard interest-rate floor framework in ways that influence banks' incentives to hold loans and reserves. Using quarterly data from the start of 2000 through the third quarter of 2017, we find that banks' holdings of loans and reserves are related to GDP growth and employment but are not related to measures of loan demand or economic uncertainty. Accounting for these factors, banks' loan holdings are inversely related to both the rate of IOER and to its premium above short-term market interest rates. We estimate that the Fed's IOER policy accounts for more than half of the post-crisis decline in bank loan allocations.

JEL Codes: E51; E52; E58; E44; E47

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1. Introduction

During the financial crisis of 2008, the Federal Reserve initiated a variety of new and unprecedented policies. One such change transformed the Fed's monetary policy framework by allowing it to pay interest on the excess reserves (IOER) that banks hold at the Fed.[1] Though garnering fewer headlines than its quantitative easing (QE) program and its ad hoc last-resort lending facilities,[2] the Fed's IOER policy and its effect on bank reserves is "one of the most notable and important policy issues in U.S. banking" (Dutkowsky and VanHoose 2017, p.1). There is, however, little research on the empirical impacts of IOER policy and in particular "little analysis of how reserves affect bank lending when interest is paid on reserves" (Martin et al. 2016, pp.216-217).

The Fed was granted the power to pay IOER by the Financial Services Regulatory Relief Act of 2006. The effective date was originally set as October 1, 2011, but due to the turmoil of the financial crisis, the Emergency Economic Stabilization Act of 2008 allowed IOER to be implemented early, effective as of October 1, 2008. The rate was set at 0.25% from December 2008 to December of 2016, when it was raised to 0.5% and then to 1.5% by December of 2017.[3] The quantity of reserves held at the Fed increased from $29 billion in mid-2008 to $2.7 trillion by 2015. Over that period, lending declined, and GDP growth stagnated, leading some to speculate that these trends might be causally related.

The theoretical basis and practical precedent for IOER as a monetary policy tool were well established prior to its adoption in the United States. Theories of IOER go back at least to Tolley (1957) and Friedman (1959). Marvin Goodfriend (2000; 2002) proposed a "floor" system of IOER, the model for which is also commonly used to study the "corridor"

[1] The Fed pays interest on both required and excess reserves. Although we are mostly concerned with factors affecting excess reserves, we make no distinction between excess and required reserves since required reserves are now comprise only a small portion of the total and are not quantitatively important for our analysis. We therefore use the term "reserves" in reference to banks' total reserves held at the Fed.

[2] See, for example, Kohn (2010), Fleming (2012), Hogan, Le, and Salter (2015), and Yu (2016).

[3] The rate was first set at 0.75%, then briefly raised to 1.15% before being cut to 0.25% by December 2008.

or "channel" system.[4] Corridor systems have been used for decades in several countries, including Japan, Sweden, Australia, England, and Canada.[5] The European Central Bank (ECB) has operated its monetary policy as a corridor system since 1999, and in 2014, began paying negative rates on its deposit facility (Coeuré 2016). New Zealand operated a corridor system starting in 1999 before adopting a floor system in 2006.

Although the Goodfriend model provides a simple and intuitive framework for understanding the theoretical impacts of IOER, we argue that it cannot be used to evaluate the impacts on bank lending of the Fed's IOER policies. First, the Fed's IOER system deviates from the assumptions of the Goodfriend model since fed funds consistently trade below the rate of IOER. As Goodfriend (2015, p.4) describes, "The interest on reserves floor for the federal funds rate failed, and continues to fail to this day." This deviation is often attributed to arbitrage from nonbank financial institutions (Carlstrom and Fuerst 2010; Bech and Klee 2011). As discussed in section 2, however, the phenomenon of fed funds trading below the rate of IOER may simply be due to the fact that the Fed sets its target range for the fed funds rate below the rate of IOER. By setting its fed funds target below the rate of IOER, the Fed's IOER system influences banks' asset allocations, which violates the Goodfriend model's assumption of "separate interest rate and bank reserves channels of monetary policy transmission" (Goodfriend 2002, p.3). It is thus impossible to know from the model how banks' reserves, loans, and other assets might be affected.

Second, the Goodfriend model considers the aggregate quantity of bank reserves in the economy, but it does not identify the quantity of loans, which are assumed to be unaffected by either the aggregate quantity of reserves or the rate of IOER. As many studies point out, there is no direct tradeoff between the aggregate quantities of loans and reserves in the banking system (Keister and McAndrews 2009; Martin et al. 2016). There is, however, a

[4]See, for example, Ennis and Weinberg (2007), Keister et al. (2008), Hornstein (2010), and Kahn (2010).

[5]See Bindseil et al. (2006), Keister et al. (2008), Kahn (2010), and Bowman, Gagnon, and Leahy (2010).

tradeoff between loans and reserves at the individual bank level. Each bank decides what percentage of its assets to hold as reserves or distribute as loans, which allows funds to propagate through the banking system, but the total quantity of reserves is determined by the Fed. The aggregate quantity of loans, however, might be large or small depending on the proportions banks allocate to loans and reserves, a decision influenced by the rates of return on these assets. Thus, the effects of IOER on lending are better examined at the individual bank level rather than in the aggregate.

Two theoretical studies consider the effects of IOER on the banking sector. Dutkowsky and VanHoose (2017) model banks' balance-sheet allocations across multiple asset markets where returns in each market affect allocation. They find that if the rate of IOER is above the fed funds rate, then banks will curtail their commercial and fed funds lending, and they provide evidence of severe negative effects on the fed funds market. Martin et al. (2016) use a different model of bank allocation but similarly find that "large quantities of reserves may, surprisingly, have a contractionary effect on bank lending" (p.197). Following these works, we use a model of bank investment allocations as basis for our empirical analysis.

We investigate the effects of the Fed's IOER policy on US banks' allocations of loans and reserves. Section 2 discusses models of IOER based on Goodfriend (2000; 2002) and the implementation of IOER policy in the United States. Section 3 sets forth a simple model of banks' investment allocations, and section 4 discusses the data used in our analysis. Section 5 uses regression analysis to test a variety of factors that might affect banks' allocations of loans and reserves. We find that banks' holdings of loans and reserves are related to GDP growth and employment but not to uncertainty or loan demand. Accounting for these factors, we find that both the rate of IOER and the premium of IOER above 90-day Treasury rates are positively related to banks' reserve holdings and inversely related to bank loans. We estimate that the Fed's IOER policy is responsible for approximately 72% of the post-crisis decline in loans as percentages of bank assets.

2. Background

The theoretical foundations of IOER policy have been discussed by many studies as early as Tolley (1957, pp.477-485) and Friedman (1959, pp.71-76). The most common model of IOER policy is set forth by Goodfriend (2000, 2002). Goodfriend (2000) discusses tools that might stimulate economic activity in situations where interest rates approach the zero lower-bound, including a carry tax on electronic reserves that "could allow a central bank to target negative nominal interest rates" (p.1031). Goodfriend (2002) expands on this proposal by arguing that the Fed's monetary policy might be more effective if it "could replace its current operating procedures with a new *interest-on-reserves regime*" (p.78, emphasis in original) and provides a basic model for managing the quantity of reserves.

The Goodfriend model has become the standard framework used in the literature.[6] The original Goodfriend model outlined a "floor" system in which the central bank uses the rate of IOER both as a floor for short-term interest rates and as its interest rate target. A variation on this model is the "channel" or "corridor" system in which the central bank sets a range for short-term interest rates with the rate of IOER as a floor and some penalty rate acting as a ceiling, and it sets its target rate within the corridor.

Figure 1 shows three variations on the Goodfriend framework. Subfigure 1a shows the corridor system used by many central banks. The quantity of reserves is shown on the x-axis, and the y-axis represents the market interest rate of alternative investments. Banks' demand for reserves is shown as a downward-sloping line since their reserve holdings will tend to increase as the opportunity cost of holding reserves falls. Demand becomes horizontal as interest rates decline to a level approaching the yields on other short-term, liquid assets. Marked on the y-axis are the rates the central bank uses as policy tools to influence market interest rates and bank reserves.

[6] Variations of this model are used by Ennis and Weinberg (2007), Ennis and Keister (2008), Keister et al. (2008), Hornstein (2010), and Kahn (2010). Alternative models of IOER include Sargent and Wallace (1985), Cochrane (2014), Ireland (2014), Dressler and Kersting (2015), and Williamson (2015).

[Figure 1: Models of monetary systems: Corridor, floor, and Fed IOER]

In a corridor system, the central bank has some target for short-term interest rates, in the Fed's case the federal funds rate, shown by the dotted line in figure 1a. To prevent large deviations from its target rate, the central bank uses the rate of IOER as the floor and provides a short-term lending facility, in the Fed's case the discount window, as a ceiling for short-term interest rates. The interest rate (fed funds) target is set somewhere between the ceiling (discount rate) and the floor (rate of IOER), which serve to keep short-term interest rates within the corridor. The Fed's supply of reserves is shown as a vertical line that can be adjusted by the Fed to achieve its interest rate target.

The floor system shown in figure 1b is the same as in figure 1a except that the target interest rate is set equal to the rate of IOER. In this case, it is assumed that the Fed can adjust the quantity of reserves as desired anywhere in the flat area of the demand curve since banks will gladly accept the consumer surplus gained at any quantity in this region. Monetary policy in this model can thus be "divorced" from any impacts on reserves or other bank assets (Keister et al. 2008). "[T]he central bank could use open market operations to target bank reserves, and *independently* use interest on reserves to pursue interest rate policy" (Goodfriend 2002, p.3 emphasis added). The floor system can be more effective, even necessary, when banks holds such large reserve balances that the demand for reserves becomes highly elastic to changes in market interest rates (Keister 2012).

Unfortunately, the Fed's IOER policy in the United States has been implemented in a way that is not consistent with the floor or corridor systems. Since the establishment of IOER, the fed funds market has consistently traded at rates below the rate of IOER. "In contrast to predictions of simple theories, the IOR rate has not acted as a floor on the federal funds rate" (Ennis and Wolman 2010, p.2). This phenomenon is generally attributed to arbitrage from financial institutions that have access to the fed funds market but cannot hold reserves at the Fed, primarily the government-sponsored enterprises (GSEs) Fannie Mae and Freddie

Mac (Carlstrom and Fuerst 2010; Bech and Klee 2011). These institutions lend their excess cash holdings to banks who then hold them on reserve at the Fed.

We argue, however, that the phenomenon of feds funds trading below the IOER rate is not simply a product of arbitrage but is partly an intentional result of Fed policy. In Q4 of 2008, the Fed switched from using a single target for the fed funds rate to using a fed funds target *range*, with the upper limit of the range set equal to the rate of IOER. As Bernanke and Kohn (2016, emphasis added) describe, "the Fed is currently [as of February, 2016] targeting a 25-basis-point range for the federal funds rate, *with the interest rate on reserves at the top end of that range*." Subfigure 1c shows this case with the fed funds target rate below the rate of IOER as implemented by the Fed, which deviates from the standard models of the floor and corridor frameworks.

While arbitrage may have caused this phenomenon during the early years of IOER policy, the Fed now has wider-ranging tools for influencing short-term interest rates that are less affected by inter-market arbitrage. Since 2013, the Fed has used overnight reverse repurchase agreements (ON RRPs) to target the fed funds rate since the effectiveness of traditional open market operations is diminished by banks' large reserve balances. ON RRP transactions are open to a variety of nonbank financial institutions, including the GSEs, although participation is dominated by money-market mutual funds.[7] The Fed describes the ON RRP rate as a "subfloor" that is necessary to supplement the rate of IOER (Williamson 2016), but it is unclear why the FOMC has chosen to set the ON RRP rate, and thus the fed funds target, below rather than equal to the rate of IOER.

Is the Fed intentionally targeting a fed funds rate below the rate of IOER? Statements by Fed officials (emphasis added) indicate it is. For example, the FOMC instructs the New York Federal Reserve Bank to "set the *IOER rate equal to the top of the target range* for the federal funds rate and set the offering rate associated with an ON RRP facility equal to the bottom

[7] See Potter et al. (2017). Frost et al. (2015) discuss the the introduction and effectiveness of ON RRPs.

of the target range."[8] Lorie Logan (2017), Senior Vice President of the Federal Reserve Bank of New York, similarly describes the trading desks' responsibility for "maintaining the federal funds rate *in the FOMCs target range*." According to a recent report from the Federal Reserve Bank of New York (Potter et al. 2017, p.1), this strategy has been "successful at keeping the effective federal funds rate (EFFR) *within the FOMCs relevant target range*." These statements demonstrate that the Fed intentionally targets a fed funds rate below the rate of IOER. While arbitrage is the proximate cause of this phenomenon, the underlying cause may actually be Fed policy.

Figure 2 shows the Fed's interest rate targets compared to short-term interest rates from 2013 through June of 2017. The dashed line represents the rate of IOER, and the dotted line represents the lower-bound fed funds target rate, which is lower than the IOER rate throughout the period. The solid black and gray lines respectively represent the market rates on fed funds and 90-day Treasuries. The fed funds market consistently trades around 10 basis point below the rate of IOER. The rates on 90-day Treasuries are even lower, trading near the low end of the fed funds target range. Both rates consistently trade within the fed funds target range, which is below the rate of IOER.

[Figure 2. Rates on fed funds and short-term Treasuries vs. targets for fed funds and IOER]

In addition to violating the assumptions of the Goodfriend model, setting the rate of IOER above its short-term interest rate target may also be a violation of the Fed's statutory authority as granted in the Financial Services Regulatory Act (FSRA) of 2006 and the Emergency Economic Stabilization Act (EESA) of 2008. As Selgin (2016) explains, the FSRA of 2006 authorized the Fed to pay IOER "at a rate or rates not to exceed the general level of short-term interest rates." The EESA of 2008 accelerated the timing of IOER but did not alter the actions authorized by the FSRA. Thus, by paying a rate of IOER that is

[8]https://www.federalreserve.gov/monetarypolicy/policy-normalization.htm

higher than the fed funds rate and other short-term rates, the Fed may have gone beyond its legal authority as granted by the FSRA and EESA.[9]

The Goodfriend model assumes that if the Fed raises the rate on IOER that the market interest rates on similar low-risk assets will rise accordingly. If so, then banks will have no incentive to adjust their asset allocations, and their reserve holdings will not be affected. In practice, however, the rate of IOER has been higher than other short-term interest rates, which gives banks the incentive to buy reserves and sell other short-term assets. Figure 3 shows banks' reserves held at the Fed from 2000 through Q3 of 2017. The black area shows the quantities owned by FDIC-insured US commercial banks. Since the Fed's adoption of its IOER policy in Q4 of 2008, the quantity of US bank reserve held at the Fed has increased from less than $29 billion in Q2 of 2008 to more than $1.5 trillion in Q1 of 2015 and has since fallen back around $1.2 trillion as of Q3, 2017.

[Figure 3. Reserves held at the Fed: US banks vs. total]

Another side effect of IOER policy is the large quantity of Fed reserves held by foreign banks. The gray area in figure 3 represents holdings by the US subsidiaries of foreign banks. These holdings account for over $1 tillion as of Q3 of 2017, approximately 45% of reserves held at the Fed. Banegas and Tase (2016, p.15) explore IOER arbitrage by foreign banking organizations (FBOs) and find that FBOs have even greater incentives than domestic GSEs to profit from IOER arbitrage, but they also hold reserves at the Fed in order to satisfy regulatory restrictions based on Basel III.

While figures 2 and 3 show that the practical implementation of IOER policy can deviate from the standard model, there is still a question of whether the deviations are of great

[9] Fed officials argue that such payments are within their delegated authority. During her June, 2016 testimony before the House Financial Services Committee, Fed Chair Janet Yellen was asked by Chairman Jeb Hensarling whether the Fed has the legal authority to pay a rate of IOER that is higher than the fed funds rate. She responded, "I consider a 12 basis point difference to be really quite small and in line with the general level of interest rates." She later added, "I believe that the way we are setting it is legal and consistent with the act." For further discussion, see Selgin (2016).

enough magnitude to have important effects on banks' investment allocations. Bernanke and Kohn (2016) ask, "Does paying interest on reserves prevent banks from lending?" In their estimation, the rates of IOER are simply too small to have important effects on bank lending since "the only potential loans that would have been affected [are] surely a tiny fraction of the total."[10] Ennis and Wolman (2015, p.253) similarly find that "changes in rates of return on lending were small and not tightly linked to changes in the reserve allocation across large banks. The evidence, though, is far from conclusive" (p.284).

Dutkowsky and VanHoose (2017) analyze banks' allocation decisions between commercial loans, federal funds loans, and holdings of excess reserves based on the costs and rates of returns to each asset. Considering multiple equilibria, they find a switching effect where there is no impact on reserves when IOER is low, but high rates of IOER can cause banks to reallocate funds out of other assets and into reserves. Switching conditions exist when the IOER rate exceeds the fed funds rate, within some small margin. The authors find evidence that such a switch occurred following the financial crisis and was largely responsible for the massive declines in the volume of fed funds trading. Although their study focuses on the fed funds market, their model indicates that the switching conditions create similar tradeoffs between reserves and bank loans.

Similarly, Martin et al. (2016) create a general equilibrium model in which banks interact with other sectors of the economy and allocate funds between sectors based on marginal expected returns. In this model, "Banks lend up to the point where the marginal return on lending equals the return on holding reserves, which is equal to the interest rate on reserves set by the central bank" (pp.196-197). In contrast to the Goodfriend model's assumption that loans and reserves are independent, the authors find that "large quantities of reserves may, surprisingly, have a contractionary effect on bank lending" (p.197).

[10]While Bernanke and Kohn (2016) present their views in a Brookings Institution blog post rather than in an academic paper, we maintain that when the former Chairman and Vice Chairman of the Federal Reserve make quantitative statements regarding the effects of Fed policy, their thoughts are worthy of consideration.

3. Model

We analyze banks' asset allocation decisions based on the rates of return on their potential investments in loans and reserves. We assume that banks have some amount of investable funds to be allocated between loans and reserve. This runs counter to the claim that banks' reserves "are not displacing other assets on their balance sheets, like loans to businesses or consumers" (Keister 2016, p.5). This assumption will be empirically tested in section 5.1. Although we restrict our analysis to two potential assets, the model could be expanded to consider any number of potential investments.

We assume that each bank i has some exogenously determined quantity A_i of investable funds to be allocated between loans L_i and reserves R_i such that $A_i = L_i + R_i$. Figure 4 shows a model of investment markets for these two assets. Subfigure 4a shows a regular loanable funds market in which banks are the suppliers of loans, and the demanders are borrowers seeking loans to fund activities such as mortgages or business investments. The x-axis shows the quantity L_i of loans, and the y-axis represents the market interest rate r_L on loans. The supply curve is drawn with a nonlinear upward slope since higher rates of lending likely exhibit higher marginal costs. The demand curve is drawn as linear, although other functional forms might be used.

[Figure 4: Markets for loanable funds and reserves held at the Fed]

Subfigure 4b shows the market for reserves held at the Fed. The upward-sloping supply curve represents banks willingness to hold higher quantities of reserves at the Fed as the rate of IOER increases. Unlike the supply of loans, the supply curve for reserves is linear since there is little if any additional marginal cost of holding higher quantities of reserves at the Fed. The Fed's demand for loans is shown as a horizontal line since the quantity of reserves held at the Fed is not influenced by the rate they offer to pay but rather is set by the Board of Governors based on the recommendations of the FOMC. The Fed sets the rate of IOER and accepts whatever quantity of reserves that banks wish to supply at that rate.

We can use this model of banks' investment allocations in figure 4 to study the factors that might affect banks holdings of loans and reserves. For example, a negative loan demand shock would shift the demand curve to the left, resulting in a decline in the quantity of loans and an increase in banks' supply of reserves. Conversely, an increase in the rate of IOER paid by the Fed might also result in a higher quantity of reserves and a decrease in banks' willingness to supply loans. We can use this model to test if either of these factors are quantitatively related to loans or reserves. For reasons discussed in section 5.1, we analyze the quantities of loans and reserves as percentages of banks' total assets. If a bank's assets are entirely allocated between loans and reserves, then $A_i = 1$, but it might be that banks invest in a variety of assets and designate some smaller portion of their assets $0 < A_i < 1$ to be allocated to loans and reserves. In either case, L_i and R_i must fall in the range $0 \leq L_i \leq A_i$ and $0 \leq R_i \leq A_i$.

A bank's profit function π_i is given by equation 1. The bank earns returns r_L on its loans L_i times a factor δ_L representing a discount for potential losses due to asset risk. The term αL_i^2 in equation 1 represents the increasing marginal cost of lending. This term could use any exponent greater than 1 to indicate increasing marginal costs, but for simplicity, we follow Dutkowsky and VanHoose (2017) in assuming a quadratic form.[11] The bank also earns some return r_R on its reserves R_i and pays some cost of funding on assets γA_i. Reserves are also shown as having a discount factor δ_R, but we will assume that $\delta_R = 1$ since the riskiness of reserves held at the Fed is very close to zero.

$$\pi_i = \delta_R r_R R_i + \delta_L r_L L_i - \alpha L_i^2 - \gamma A_i \tag{1}$$

To set π_i in terms of L_i, we substitute $R_i = A_i - L_i$ into the term $\delta_R r_R R_i$ in equation 1 and substitute $A_i = L_i + R_i$ into term γA_i. Assuming banks are profit maximizers, we take

[11] The functional form of this model is a simplified version of that used by Dutkowsky and VanHoose (2017). It also follows Selgin (2017, pp.24-27) in analyzing the marginal tradeoffs between loans and reserves.

the derivative of π_i with respect to L_i and set it equal to zero. We re-arrange to solve for L_i as a function of the rates r_L paid on loans and r_R on reserves as shown in equation 2.

$$L_i = -\frac{1}{2\alpha}r_R + \frac{\delta_L}{2\alpha}r_L - \frac{\gamma}{2\alpha} = \beta_R r_R + \beta_L r_L + \beta \tag{2}$$

Equation 2 indicates that the percentage of bank assets allocated to loans L_i will be a linear function of the rate paid on loans r_L, the rate paid on reserves r_R, and a constant, where higher rates on loans are expected to increase the quantity of loans, and higher rates of IOER decrease the quantity of loans. Substituting the parameters for β coefficients gives us a basic regression equation. This equation could alternatively be written to analyze the quantity of reserves rather than loans since we could substitute $L_i = A_i - R_i$ to show that higher rates on loans are expected decrease reserves, and higher rates of IOER are expected increase reserves.

We can alter equation 2 to test the effects of changes in loan demand. The market interest rate for loans r_L in figure 4a is determined not only by loan supply but also demand. Let us assume that loan demand is some function of GDP growth, employment, and economic uncertainty where $r_L = f(Y, E, U)$ as shown in equation 3. If we assume that loan demand is linear as shown in figure 4, then we can substitute these variables into equation 3 as seen in equation 4. We will discuss in section 5 the variables and functional form used in our regression analysis.

$$L_i = \beta_R r_R + \beta_L f(Y, E, U) + \beta \tag{3}$$

$$= \beta_R r_R + \beta_{L1} GDP + \beta_{L2} EMP + \beta_{L3} UNCERTAINTY + \beta \tag{4}$$

4. Data

We conduct our analysis using data on FDIC-insured banks and the economy from Q1 of 2000 through Q3 of 2017. Quarterly data on US banks are gathered from the *Consolidated*

Reports of Condition and Income (Call Reports) of US commercial banks.[12] The data are provided at the individual bank level, but many of these banks are owned by bank holding companies (BHCs). As is common in the literature, data for banks held by BHCs are summed in each quarter to the holding company level so that all banks owned by the same BHC are counted together as a single bank. Our resulting sample averages more than 7,000 bank observations per quarter.

Table 1 provides summary statistics of our dataset. The primary bank variables include total assets, loans, and reserves held at the Fed. Total assets range from a minimum of $66 thousand, which rounds to zero in the table, to a maximum of almost $2.29 trillion with an average of about $1.75 billion. Loans range from zero to $976 billion with an average of $976 million. Reserves at the Fed average $70 million with a low of zero and a maximum of $471 million. While it may seem odd that the assets categories show minimum values of zero, these represent outlier observations of a few failed banks. As discussed later, controlling for such outliers does not affect the results of our analysis.

[Table 1. Summary statistics]

We supplement the banking data with a variety of interest-rate and economic data gathered through the Federal Reserve Bank of St. Louis's database of Federal Reserve Economic Data (FRED).[13] The primary interest rates used in our analysis are the rate of IOER, the yields on 90-day US Treasuries, and the prime lending rate in each quarter. To match the bank balance-sheet data, interest rates are taken as of the end of the quarter. The rate of IOER averages 0.15% with, ranging from a minimum of zero for most of our sample to a high of 1.25%. The prime rate, gathered by the Board of Governors, is measured as the prime lending rate most commonly used by the largest 25 US commercial banks. The mean prime rate is 5.04% with a range from 3.25% to 9.50%. 90-day Treasury yields average 1.75% with

[12] Available at https://www5.fdic.gov/sdi/download_large_list_outside.asp.
[13] Available at https://fred.stlouisfed.org.

a low of 0.00% to a high of 6.03%. The Treasury yield is used to calculate the premium of IOER over short-term interest rates in all periods when IOER is higher than the fed funds rate. For reasons discussed later, we calculate the IOER premium for our base-case analysis as the rate of IOER minus the yield on 90-day Treasuries rather the premium of IOER above the fed funds rate as used by Dutkowsky and VanHoose (2017). All interest rates are measured as the annualized values the the end of each quarter.

We test several alternative interest rates as robustness checks. As an alternative to Treasury yields, we calculate the IOER premium using bank-level returns on fed funds. We test two substitutes for the prime lending rate: the 12-month London Inter-Bank Offer Rate (LIBOR) and banks' loan interest margin, calculated as gross income on bank loans during the quarter divided by the value of loans at the end of the quarter. Figure 5 shows these three lending rates. All show similar patterns, although average loan interest margin has less variation and is mostly in the range of 4% to 8%.

[Figure 5. Interest rates on loans: Prime, LIBOR, and average loan interest margin]

Economic variables include quarterly values for real GDP growth, the growth rate of the US labor force, the Treasury-Eurodollar (TED) spread, and a survey of loan demand. GDP growth over the sample averages 1.88% and ranges from an annualized quarterly minimum of -8.45% in Q4 of 2008 to a maximum of 7.56% in Q2 of 2000. The average growth in the labor force is 0.80% with a minimum of -2.30% and a maximum of 6.44%. Some studies use changes in the unemployment rate as a proxy for employment, but this measure was distorted during the post-crisis period due to unusual changes in labor force participation. We therefore use labor force growth as our primary measure of labor and employment.

The TED spread, a common indicator of economic uncertainty, ranges from 0.15% to 2.45% with an average of 0.45%. Figure 6 shows the TED spread over the period of our sample along with the VIX index, another common measure of economic uncertainty. Both measures show large spikes during the financial crisis but quickly return to their long-run levels. While Ashcraft et al. (2011) and Berrospide (2013) find heightened demand for precautionary liquidity during the financial crisis, we see in figure 6 that the TED and VIX both decline following the crisis and remain low through the rest of our sample.

[Figure 6. Measures of economic uncertainty: the TED spread and VIX index]

As a measure of demand, we use the net percentage of banks reporting higher loan demand in each quarter as reported by the Federal Reserve Board of Governors.[14] The average is slightly negative at -3.58% with a minimum of -63.50% and a maximum of 52.50%. Figure 7 shows the results of this survey in each quarter from 2000 through Q3 of 2017. The two dotted lines indicate the trends before and after Q4 of 2008, the quarter in which the Fed implemented IOER. Contrary to the perception that loan demand was low following the crisis, we see in figure 7 that demand was actually low in the years preceding the crisis. By early 2009, demand had already rebounded into positive territory and generally followed a positive trajectory through 2017.

[Figure 7. Net percentage of banks reporting higher demand for loans]

5. Analysis

We use regression analysis to test several empirical questions introduced in the previous sections. First, our model assumes that banks allocate funds between loans and reserves. Section 5.1 examines banks' holdings of loans, reserves, and other assets and finds an inverse relationship between loans and reserves. We examine in sections 5.2 and 5.3 the factors that might affect these allocations including the rates of return on loans and reserves as well as loan demand and economic activity.

[14] Because the Fed Board of Governors altered the parameters of its surveys over this period, we create a continuous series by combining three surveys: demand for all mortgage loans from 2000 through Q1 of 2007, prime mortgage loans from Q2 2007 to Q3 of 2014, and GSE-eligible mortgage loans from Q4 of 2014 through Q3 of 2017. Alternative surveys such as for subprime loans, jumbo and nonconforming loans, and commercial real estate loans all show similar patters.

5.1. Reserves and Loans

Is there a tradeoff between banks' holdings of loans and reserves? It might be the case that reserves are only substitutes for liquid assets such as fed funds or short-term Treasuries, or perhaps banks' new reserve holdings are simply additions to their balance sheets that have no effect on their other asset holdings. Keister (2016, p.5 emphasis in original), for example, argues that "reserves are, in general, held *in addition to* banks other assets." As evidence for this proposition, Bernanke and Kohn (2016) point out that while banks' reserve holdings have increased since the financial crisis, bank lending has increased as well. In dollar terms, this claim is clearly correct. Figure 8 shows the sums of all loans, reserves, and other assets in the banking system, all of which are increasing over the period of our sample.

[Figure 8. Total loans, reserves at the Fed, and assets of all US banks (in trillions of $)]

Although banks' holdings of loans and reserves have both increased in the post-crisis period, this does not prove that there is no relationship between loans and reserves since total assets were also growing over the period. For example, it might be the case that banks compensated for slower-than average loan growth with higher-than average increases in their reserve holdings. To consider this possibility, we analyze banks' holdings of loans and reserves as percentages of banks' total assets.

Figure 9 shows the total quantities for all US banks of loans and reserves held at the Fed as a percentage of banks' total assets over the period from 2000 through Q3 of 2017. We see that the sum of loans and reserves is consistently around 60% of total bank assets. The decline in the percentage of loans that began in 2008 was almost fully offset by increases in reserves held at the Fed. Not until 2010 does the percentage of loans begin to increase again, pushing the total of loans and reserves just above 60%. The consistency around the 60% level appears to indicate an almost 1-to-1 tradeoff between loans and reserves. This contradicts the theories that banks' loans and reserves are independent and that reserves are only substitutes for other liquid assets. It is consistent, however, with the assumption of our model that banks allocate funds between loans and reserves and shows that the percentage A_i allocated to these assets averages around 60%.

[Figure 9. Total loans and reserves at the Fed as percentages of US bank assets]

It is important to note that figures 8 and 9 show the aggregates of loans and reserves for the entire banks system. The aggregate quantity of reserves is controlled by the Fed, and there is no theoretical tradeoff between total reserves and total loans. There is, however, a tradeoff at the individual bank level since banks have the option of allocating funds between loans and reserves. As Selgin (2017, pp.18-20) explains, banks convert their excess reserves into required reserves by creating loans, which increases required reserves and decreases excess reserves, even though the total quantity of reserves remains unchanged. Thus, a given quantity of aggregate reserves might support a large or small quantity of loans, depending on banks' incentives to lend. We therefore test for tradeoffs between loans and reserves at the individual bank level, which could be reflected in the aggregates as seen in figure 9.

We use regression analysis to test for an empirical tradeoff between loans and reserves since Q1 of 2009. Equation 5 shows a regression equation with $RESERVES_{it}$ for bank i at time t as the dependent variable and $LOANS_{it}$ as the primary independent variable. We then switch the variables to use $LOANS_{it}$ as the dependent variable and $RESERVES_{it}$ as the primary independent variable. As controls, we add non-reserve cash and US Treasury securities, which are liquid assets that might be held as substitutes for reserves at the Fed. All variables are measured as percentages of bank assets. We use OLS regressions with bank-clustered standard errors and bank-fixed effects, represented in equation 5 by the term α_i for bank i, a constant γ, and the error term ϵ_{it}. If reserves are only held as substitutes for liquid assets and not for loans, then we should find statistically significant negative coefficient estimates for those assets categories but not for bank loans.

$$RESERVES_{it} = \beta_1 LOANS_{it} + \beta_2 CASH_{it} + \beta_3 TREASURIES_{it} + \alpha_i + \gamma + \epsilon_{it} \qquad (5)$$

Table 2 shows the results of these regressions. The first two columns show the results using $RESERVES$ as the dependent variable, and the last two columns use $LOANS$ as the dependent variable. We seen in the first two columns that the coefficient estimates for $LOANS$ are negative and statistically significant, indicating that an increase in loans is associated with a statistically significant decrease in reserves. The first column coefficient shows that a one percent increase in loans corresponds to an 8 basis point decrease in reserves. Controlling for changes in Treasuries and non-reserve cash, column 2 shows that a one percent increase in loans corresponds to a decrease in reserves of 12.5 basis points. The coefficient of loan is statistically significantly larger than for Treasuries but significantly smaller than for non-reserve cash, indicating that loans are a closer than Treasuries as a substitute for reserves but cash is closer.

[Table 2. Tradeoffs between loans, reserves, and other assets, Q1 2009 - Q3 2017]

Columns 3 and 4 in table 2 show the results of regressions using the dependent variable of loans as percentages of banks' total assets. The third column coefficient estimate for reserves is negative and statistically significant with a magnitude of -0.523, indicating that a one percent increase in reserves causes loans to decrease by 0.523%. In the final column, the coefficient estimate for reserves increases in magnitude to -0.668, which is statistically significantly larger than for Treasuries or non-reserve cash and indicates that reserves are a closer tradeoff for loans than are cash or Treasuries. The magnitude is roughly consistent with figure 9 which shows an almost 1-to-1 tradeoff between loans and reserves.

These result confirm the intuition from figure 9 of the apparent tradeoff between loans and reserves, but they provide no evidence regarding the causality of the relationship. On the one hand, it might be that banks in the wake of the financial crisis intentionally reduced lending due to uncertainty or lack of demand and chose to hold their unused funds as reserves at the Fed. On the other hand, it could be that higher rates of IOER make holding reserves more profitable relative to lending, which has caused loan allocations to decline. To evaluate these theories, the following sections will analyze the effects of interest rates, loan demand, uncertainty, and economic activity on banks' holdings of loans and reserves.

5.2. Effects on Reserves

Section 3 provides a theoretical basis for analyzing the impacts on reserves of the rate of IOER and other factors such as loan demand and economic activity. We first test whether economic factors and loan demand are related to banks' reserve holdings. We then consider the relationship of reserves to the interest rate on bank loans, rate of IOER, and the premium of IOER above short-term interest rates.

Equation 6 shows our first regression equation based on equation 4. The dependent variable $RESERVES_{it}$ represents reserves a percentage of total assets of bank i in time period t. Variables representing the growth rates of GDP and the labor force are expected to be related to economic activity and therefore to lower reserves in each quarter. As discussed in section 4, our variable $LOANDEMAND$ is the net percentage of banks reporting higher loan demand in each quarter. If depressed loan demand in the post-crisis period caused banks to hold greater reserves, then we should find an inverse relationship between reserves and loan demand. The variable TED is the average TED spread in each quarter, which is a common measure of economic uncertainty that may be related to reserves as found by Berrospide (2013). The bank-level variable $LOGASSETS_{it}$ represents the natural log of total assets for bank i in quarter t. We include dummy variables for each quarter, represented by Ω_q, to account for seasonality, a bank-level fixed effect α_i for each bank i, a constant term γ, and the error term ϵ_{it}. The β coefficients are numbered from 4 to 8 since we plan to add the interest rates in the following regressions as variables 1 through 3.

$$RESERVES_{it} = \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it} \quad (6)$$

The results of this regression are shown in the first column of table 3. The coefficient estimates of GDP and $LABOR$ are negative and statistically significant, indicating, as expected, that better economic activity is associated with lower levels of bank reserves. The coefficient estimate for $LOGASSETS$ is positive and statistically significant. The coefficient estimate for $LOANDEMAND$ is positive and statistically significant, and the coefficient estimate for the TED spread is statistically significantly negative. The R-squared statistic is 42.0%.

[Table 3: Analysis of reserves as percentages of bank assets]

What explains the unexpected signs for our measures of loan demand and economic uncertainty? As previously seen in figure 7, loan demand was trending downward from 2003 through Q3 of 2008 and was already showing improvements by early 2009. Because loan demand and banks' reserve holdings were both increasing through the latter half of our sample, we find a positive, rather than negative, coefficient estimate for $LOANDEMAND$. The fact that higher GDP growth and labor force growth are related to lower reserves, but higher loan demand is not, may indicate that these economic variables are related to supply-side effects of banks being more willing to lend during periods of economic expansion. Alternatively, it might simply be that GDP and labor force growth are more accurate than bank survey responses as indicators of actual loan demand.

The negative coefficient estimate for the TED spread seems to contradict the theory that increases in banks' reserve holdings have been caused by economic uncertainty. One explanation for the unexpected sign is that it represents a noncausal correlation due to the time period of our sample. Berrospide (2013), for example, finds preliminary evidence that higher TED spreads are associated with higher bank reserves. The sample time period used in that study, however, is only through 2009, a period when reserves and uncertainty were both high. During the years included in our study but not in Berrospide (2013), the TED spread fell while reserves increased, perhaps leading to an inverse, noncausal relationship. While economic uncertainty and bank reserves may be positively related over short periods, the evidence does not support a persistent positive relationship.

Bank reserves might also be related to the rates paid on bank loans and reserves. We test the relationship between reserves and the rate on bank loans using equation 7, which is the same as equation 6 but with the new variable $PRIME_t$ representing the prime lending rate in period t. Column 2 of table 3 shows the results of this regression. The coefficient estimate for $PRIME$ is negative and statistically significant, indicating that higher returns on bank loans are associated with lower bank reserves. As before, the coefficient estimates for GDP and $LOGASSETS$ are statistically significant with the expected signs, while the coefficients for $LOANDEMAND$ and TED are not, and the sign of the coefficient estimate for $LABOR$ is now negative instead of positive. The R-squared statistic shows a modest increase to 40.9%.

$$\begin{aligned} RESERVES_{it} = {} & \beta_3 PRIME_t + \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t \\ & + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it} \end{aligned} \tag{7}$$

One of the main questions of our analysis is whether banks' holdings of reserves at the Fed are related to the rate of IOER since these are theoretically independent in the Goodfriend model. We test this theory using regression equation 8 with the primary independent variable $IOER_{it}$ for bank i in period t. We denote this as a bank-level variable since each bank actually earns the rate $IOER_{it}$ in its reserves, in contrast to $PRIME_t$ which is an average across banks. We include the other variables from equation 7, which allows us to test the relationship between reserves and IOER after controlling for the effects of loan demand, uncertainty, and economic activity.

$$
\begin{aligned}
RESERVES_{it} = {} & \beta_2 IOER_{it} + \beta_3 PRIME_t \\
& + \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t \\
& + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it}
\end{aligned} \tag{8}
$$

Column 3 of table 3 shows the results of this analysis. The coefficient estimate for $IOER$ is positive and statistically significant at the 1% level. This indicates that higher rates of IOER are related to higher reserves at the bank level, although as previously discussed, the aggregate quantity of reserves may not be affected. As in column 2, the coefficient estimate of $PRIME$ is negative and statistically significant, again indicating that higher returns on bank loans are associated with lower holdings of reserves, although the magnitude is smaller since it is offset by the $IOER$ variable.

The magnitude of the IOER coefficient of 0.785 indicates that a 1% increase in the rate of IOER will increase banks' reserve holdings by 0.785% of total assets. Since the advent of IOER policy in Q4 of 2008, the average rate of IOER has been 0.40%. Multiplying this by the coefficient estimate indicates that IOER increased banks' reserve holdings by about 0.31% of total bank assets. Since average reserve holdings were around 1.3% of bank assets during this period, the estimate indicates that approximately 24% of that total is attributable to the rate of IOER.

As discussed in section 2, Dutkowsky and VanHoose (2017) find that banks' reserves will only be affected if the rate of IOER is set at a premium above the rates on short-term liquid assets. We test this theory by substituting the variable $PRIMEIUM$ in equation 8 for $IOER$ as shown in equation 9, where the $PREMIUM_{it}$ for bank i is the rate of IOER in time period t minus the yield on 90-day Treasuries rate in period t.

$$
\begin{aligned}
RESERVES_{it} = {} & \beta_1 PREMIUM_{it} + \beta_3 PRIME_t \\
& + \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t \\
& + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it}
\end{aligned} \tag{9}
$$

Column 4 of table 3 shows the results of this regression. The $PREMIUM$ variable is positive and statistically significant as expected, indicating that a higher premium of IOER above Treasuries is associated with higher reserves. The coefficient estimate for the prime lending rate is negative and statistically significant, and the coefficient estimates for the other control variables all have the same signs and statistical significance as before except a negative coefficient for labor force growth as in column 1. The magnitude of the $PREMIUM$ coefficient is 4.704, and the average premium since Q4 of 2008 is 0.18%, indicating that the IOER premium increased banks' reserve holdings by 0.85% of bank assets since that time. Since bank reserves averaged 1.3% of bank assets during that period, the IOER premium accounts for 65% of banks' reserve holdings.

The regressions using the rate of IOER and the IOER premium have similar R-squared statistics at 41.1% and 42.0%, but the economic effects of their coefficient estimates are quite different. To judge which is the better indicator of reserves, we re-run our regression analysis using both the $IOER$ and $PREMIUM$ variables as shown in equation 10. The results of this regression are shown in the final column of table 3. The coefficient estimates for the IOER premium is positive and statistically significant, while the coefficient estimate for the rate of IOER is negative and significant, indicating that the IOER premium is the better indicator as predicted by theory and consistent with the results of our prior regressions. The magnitude of the $PREMIUM$ coefficient estimate and the R-squared statistic are similar to those in column 4, indicating that the premium of IOER accounts for most of the impact.

This is consistent with Dutkowsky and VanHoose (2017) who find that the premium of IOER above short-term interest rates is the important determinant of banks' reserve holdings.

$$\begin{aligned} RESERVES_{it} = {} & \beta_1 PREMIUM_{it} + \beta_2 IOER_{it} + \beta_3 PRIME_t \\ & + \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t \\ & + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it} \end{aligned} \tag{10}$$

We test the robustness of our results with several adjustments to our base-case analysis.[15] First, we consider two variations to the interest rates on loans. One might worry about the endogeneity of the prime lending rate since it is calculated as the average prime rate listed by the top 25 US banks. As an alternative, we use the 12-month LIBOR rate in place of the prime lending rate. Results for the signs and magnitudes of the coefficient estimates for the lending rate and IOER premium are similar when using the 12-month LIBOR rate.

As another alternative we calculate the loan interest margin for each bank as the interest earned on loans over the quarter divided by the bank's loan balance at the end of the quarter. While having the benefit of being a bank-level variable, loan margin is a backward-looking variable since the interest is based on past loans. Average loan interest margin in figure 5 has a similar but muted pattern relative to the prime rate and LIBOR. In addition, loan interest margin is a gross rate that does not reflect the cost of lending, which can vary greatly between banks. We exclude a small number of outliers with loan interest margins of less than zero or more than 25%. Using loan interest margin in our regressions rather than the prime rate, we find that the coefficient estimate for the IOER premium is similar to the base case, but the coefficient for loan interest margin is not statistically significant.

Second, we make similar changes to the IOER premium variable. Dutkowsky and VanHoose (2017) consider the rate of IOER relative to the fed funds rate. Our base case uses

[15] The results of these analyses are available in Appendix A, tables A1 through A3.

the IOER premium as the rate of IOER minus the yield on 90-day US Treasuries in order to avoid the issue of data stretching as described by Greenberg et al. (1989). The fed funds rate is a market aggregate, so not every bank lends funds at this rate. Using the aggregate rate rather than the bank-level rate could bias the results. Our base case aims to avoid this problem since all banks have access to holding US Treasuries and holding reserves at the Fed, so the rates of IOER and the 90-day Treasury yield are not aggregates but are the actual rates earned by the bank. It might be argued, however, that not all banks earn these rates since not all banks hold Treasuries and reserves. Restricting our sample to only observations with positive values for Treasuries and reserves, the signs of the interest rate coefficient estimates are similar to the base case, but the magnitudes are larger.

As another alternative, we test the fed funds interest margin for each bank, calculated as the interest earned on fed funds loans issued during the quarter divided by the asset value of fed funds at the end of the quarter.[16] This may be problematic, however, since fed funds holdings are volatile that the end of each month and may not accurately represent the holdings over the quarter.[17] Some banks reduce their end-of-quarter fed-funds holdings to almost zero, making their calculated quarterly margins appear in the thousands of percent. To attenuate this issue, we drop observations with the highest and lowest 25% of bank-level fed funds rates in each quarter. We then calculate the IOER premium as the rate of IOER minus the bank-level fed funds rate for all periods in which the rate of IOER is higher than the market fed funds rate. As expected, the coefficient estimate for the rate of IOER is positive and statistically significant, while the coefficient estimate for the lending rate is negative and statistical significant, although the magnitudes of these coefficients are smaller than the base case. Despite the high variation due to end-of-quarter irregularities,

[16]We do not count any fed funds liabilities in the quarter, only assets since we are considering banks' asset allocations and not their other business activities.

[17]In 2016, for example, "quarter-ends saw declines in trading volume of 26 percent and 33 percent, respectively, for the effective rate and the overnight bank funding rate" (Potter et al. 2017, p.10).

the analysis supports the base-case result that the IOER premium is related to higher reserve holdings, while higher lending rates are associated with lower reserve holdings.

Third, we test alternatives to our loan demand and uncertainty variables. We consider changes in housing prices as a rough proxy for loan demand. In general, an increase in housing prices might be caused by an increase in demand or a reduction in supply. Since US housing supply was increasing over this period, an increase in housing prices is likely to indicate that increases in demand were outpacing supply. We use an index of real residential property prices created by the Bank for International Settlements (BIS).[18] The index was rising from 2000 through 2006, falling through 2011, and then rising through the rest of the sample, which is consistent with the surveys of loan demand shown in figure 7. Using the quarterly growth rate in the housing price index in place of loan demand in our regression analysis, we find that the coefficient estimate for housing price growth is positive and statistically significant, indicating that higher loan demand as indicated by rising home prices is associated with higher holdings of bank reserves. Although only a rough proxy for demand, this supports our base-case result that the consistent increase in bank reserves during the post-crisis period was not driven by a lack of loan demand.

We also test several indicators of economic uncertainty as alternatives to the TED spread. These include the VIX index, the Federal Reserve Bank of St. Louis's Financial Stress Index, and the Federal Reserve Bank of Philadelphia's Leading Indicator Index. Similar to the TED, the coefficient estimates for the VIX index and the financial stress index are both negative and statistically significant, and the coefficient estimate for the leading indicator index is positive and statistically significant. All results indicate that economic uncertainty was not a cause of the consistent build up of bank reserves over the post-crisis period.

As discussed in section 4, our dataset contains a few outlier observations with low asset values, mostly banks on the cusp of failure. In addition, there are a few ultra-safe banks with

[18] Available from the Federal Reserve Bank of St. Louis at https://fred.stlouisfed.org.

reserves of more than 90% of assets. We exclude these outliers by dropping observations the highest and lowest 1% of loans and reserves as percentages of assets. We also try excluding economy-level controls and lagging our interest rate variables by one to two quarters. These changes do not affect our results in terms of the signs or statistical significance of the coefficient estimates.

5.3. Effects on Loans

Does the rate of IOER affect the allocation of bank loans? Studies such as Ennis and Wolman (2015) and Bernanke and Kohn (2016) acknowledge the potential tradeoff between loans and reserves, but they tentatively find that the marginal rate of IOER is too small to have important effects on bank lending. We provide empirical tests of the hypotheses that banks' loan holdings are related to the rate of return on loans, the rate of IOER, and the premium of IOER above short-term interest rates.

We repeat our analysis from the previous section using loans rather than reserves as the dependent variable in our regressions. Equation 11 shows the variable $LOANS_{it}$ of loans as a percentage of bank assets for bank i at time t. Similar to equation 6, loans are regressed on control variables for GDP and labor force growth, loan demand, the TED spread, and the natural log of bank assets. We include dummies Ω_q for each quarter q, a bank-level fixed effect variable α_i for each bank i, a constant term γ, and error term ϵ_{it}. The rest of the regression equations in this section are not shown since they follow the regressions from section 5.2 except that, like equation 11, they use $LOANS_{it}$ as the dependent variable.

$$\begin{aligned} LOANS_{it} = \beta_4 GDP_t + \beta_5 LABOR_t + \beta_6 LOANDEMAND_t \\ + \beta_7 TED_t + \beta_8 LOGASSETS_{it} + \Omega_q + \alpha_i + \gamma + \epsilon_{it} \end{aligned} \tag{11}$$

The results of this regression are shown in the first column of table 4. The coefficient estimates for GDP and labor force growth are positive and statistically significant, indicating as expected that higher economic activity is associated with higher bank lending. The coefficients for loan demand and the TED spread are statistically significant but again with unexpected signs. The coefficient estimate for log assets is positive and statistically significant. The R-squared statistic is 77.9%.

[Table 4: Analysis of loans as percentages of bank assets]

Like table 3, the second column of table 4 represents the same regression as column 1 but with the added variable for the prime lending rate. The coefficient estimate for $PRIME$ is positive and statistically significant, indicating as expected that higher rates of return on bank loans are associated with higher percentages of assets allocated to lending. The magnitude of 0.764 indicates that a 1% increase in the prime lending rate is associated with an increase in loans of 0.764% of bank assets. The coefficient estimates for loan demand, TED spread, and log assets have the same signs and statistical significance as in column 1. The coefficient estimates for GDP and labor force growth are negative and statistically significant in column 2 and in all cases when the prime lending rate is included as an independent variable, possibly indicating that the lending rate already reflects the important variations in production and employment.

The third column of table 4 tests the hypothesis that banks' loan allocations are related to the rate of IOER. The coefficient estimate for IOER is negative and statistically significant, indicating that higher rates of IOER are associated with lower bank loan allocations. The magnitude of -2.388 indicates that a rate of IOER of 1% is associated with a decrease in loans of about 2.4% of bank assets. The average rate of IOER since Q4 of 2008 has been 0.40%, indicating that the rate of IOER accounts for a decrease in bank lending of about 0.96% of bank assets. The $PRIME$ coefficient estimate is less than one-third the magnitude of the $IOER$ coefficient, indicating that the bank lending rate has a smaller marginal effect than the rate of IOER, possibly because these interest rates to not include the costs of such investments, which are much higher for loans than reserves.

Column 4 of table 4 shows the results of our regression using the IOER premium as the primary independent variable. The coefficient estimate for $PREMIUM$ is negative and statistically significant with a magnitude of -17.042. The IOER premium has averaged 0.181% since Q4 of 2008, indicating that loans have been about 3.06% lower as a percentage of bank assets due to the IOER premium over that period. In our sample, the percentage of bank assets allocated to loans averaged 59.85% prior to Q4 of 2008 but fell to an average of 53.42% after and including Q4 of 2008, a decline of 6.43% of bank assets. Thus, the decline of 3.06 percentage points indicated by the coefficient estimates represents 47.6% of the total 6.43 percentage point decline in loan allocations in the post-crisis period. The R-squared statistic is 78.7%.

The final column of table 4 shows the regression results using both the rate of IOER and its premium over the 90-day Treasury rate. The coefficient estimate for the premium variable is negative and statistically significant as expected with a magnitude similar to column 4. The coefficient for the rate of IOER, however, is positive and statistically significant with a magnitude about the same as in column 3. The R-squared statistic of 78.8% is roughly the same as in column 4. The results in table 4 are consistent with those in table 3 regarding the effects of the rates on loans, IOER, and the IOER premium.

As with the regressions on reserves, we conduct several variations to test the robustness of our results.[19] First, we consider different interest rates as previously discussed. Results using 12-month LIBOR are similar to the base case, as are those when restricting our sample to only observations with positive reserve and Treasury holdings. We also test bank-level variables for loan interest margin and fed funds interest margin. Again, we find that the coefficient estimate for the bank-level fed funds premium is statistically significant but smaller in magnitude. Unlike with reserves, we find, despite the inherent variation in both of these variables, that the coefficient estimates for bank-level loan interest margin and bank-level

[19]The results of these analyses are available in Appendix A, tables A4 through A6.

IOER premium are both statistically significant with the expected signs. These results support our prior findings that higher lending rates are associated with higher loan allocations, while higher premiums of IOER above short-term interest rates are associated with lower loan allocations.

We also test alternative variables for loan demand and uncertainty as done with the regressions on reserves. Using changes in the residential housing price index as a proxy for loan demand, the coefficient estimate is negative and statistically significant, indicating that higher housing prices are associated with lower loan allocations. Consistent with the surveys of loan demand, this result indicates that the post-crisis decline in bank lending was not driven by a lack of loan demand. For our alternative measures of uncertainty, we find that the coefficient estimates for the VIX index and the financial stress index are positive and statistically significant, while the coefficient estimate for the leading indicator index is negative and statistically significant. All results indicate that higher uncertainty is associated with higher, rather than lower, loan allocations. Consistent with the base case, the results indicate that the decline in lending was not driven by consistently high uncertainty during the post-crisis period.

As with the regressions on bank reserves, we control for outlier observations that might bias the results of our analysis. We exclude the highest and lowest 1% of loans and reserves as percentages of assets. The results are consistent with the base case in terms of the signs and magnitudes of the coefficient estimates. Overall, the results of our analysis consistently find that higher interest rates on loans are associated with higher bank loan allocations, while higher IOER premiums are associated with lower loan allocations.

Given this evidence, we use the regression model in column 5 of table 4 to estimate the percentage of loans for the entire banking system. We make two adjustments to estimate the percentage of total loans. First, we set $LOGASSETS_T$ equal to the mean of the natural log of assets over the period. Second, we must set a fixed effect value α_T for the banking system since the mean percentage of loans for individual banks of 62.7% is different than the mean percentage for the banking system as a whole of 56.9% due to nonlinear size effects. We therefore set α_T equal to the mean percentage for individual banks minus the mean for the banking system.

The estimates using these assumptions are shown in figure 10. The gray area represents the actual percentage of loans in each quarter from 2000 through Q3 of 2017, and the dashed line is the estimated percentage of loans. We see that the regression estimates provide a close approximation of the actual loan percentages, although the model tends to underestimate loans in the period up to 2008 and slightly overestimate in the IOER period.

[Figure 10: Loans as percent of US bank assets: Actual vs. estimated]

In addition, we use the model to estimate the percentage of loans that banks would have held had the rate of IOER been set equal to the fed funds rate. Figure 11 again shows a gray area as the actual percentage of loans and a dotted line as the estimated percentage assuming that the rate of IOER is equal to fed funds, indicating a premium of zero. The dashed line indicates that banks' loan allocations would have been much higher in this scenario. While the actual percentage of loans declined to less than 52% of bank assets in 2011 and early 2012, the dashed line shows that had the rate of IOER been set equal to the fed funds rate, the percentage of loans would have remained steady around 57% to 58% of assets since 2010 and would have climbed back above 60% by Q2 of 2017.

[Figure 11: Loans as percent of US bank assets: Actual vs. estimated with IOER = fed funds rate]

How big is the effect of IOER on bank loans? As previously discussed, total bank loan allocations averaged 59.85% prior to Q4 of 2008 but have averaged only 53.42% since that time, a decline of 6.43 percentage points. We estimate with the rate of IOER set equal to the fed funds rate that loans would have averaged 58.05% of bank assets in the IOER period, a decline of only 1.80 percentage points from the pre-IOER period. The difference of 6.43 minus 1.80 indicates that the Fed's IOER policy accounts for 4.63 percentage points. Dividing the 4.63 percentage point attributed to IOER by the total decline of 6.43, we find that IOER accounts for 72.01% of the post-crisis decline in loan allocations.

The calculation that IOER accounts for 72% of the decline in loan allocations is higher than, but similar in magnitude to, the 47.6% decline that we calculated from the coefficient estimates in table 4. It is also consistent with the finding from section 5.2 that IOER policy accounts for 65% of the increase in bank reserves. Estimates are similar using the regression model from column 4 of table 4. Setting the IOER premium equal to zero, we find that loans would have averaged 57.36% of bank assets from Q4 of 2008 through Q3 of 2017, indicating that IOER policy would have accounted for 61.3% of the decline in loan allocations. In contrast to theories that the rate of IOER is not related to bank lending, these estimates indicate that the Fed's IOER policy accounts for the majority of the decline in bank loan allocations during the post-crisis period.

6. Conclusion

This study contributes to the important debate regarding the effects of the Fed's IOER policy. Using a model of banks' allocation of funds between loans and reserves and accounting for changes in loan demand and economic activity, we find that the rate of IOER influences banks' allocations of loans and reserves. While higher GDP and labor force growth are associated with higher loan allocations and lower reserves, loan demand and precautionary liquidity demand have no lasting impact on loan or reserve holdings. We use these findings to estimate the percentage of bank assets allocated to loans had the rate of IOER been set equal to the fed funds rate. We find that banks' loan allocations would have been 4.63 points higher as a percentage of total assets since Q4 of 2008. The Fed's IOER policy thus accounts for approximately 72% of the decline in banks' post-crisis loan allocations.

In considering these findings, it is important to keep in mind the limitations of our analysis. First, our model is based on a simple theory of bank investment allocation in only two potential assets. Martin et al. (2016) and Dutkowsky and VanHoose (2017) provide similar models with more asset classes, and our model might be expanded accordingly. Second, our estimates of loan allocations implicitly assume the equilibrium lending rate to be exogenous to our analysis, which could cause our model to overestimate loan allocations in the alternative scenario shown in figure 11. On the other hand, had lending not declined so precipitously in 2008 and 2009, perhaps GDP, and in turn the demand for loans, might have been much higher following the crisis, causing our model to underestimate the levels of bank lending. Such endogenous dynamics cannot be evaluated using the simple methods used in our analysis, which do not consider the macroeconomic effects of IOER policy.

While IOER provides an additional instrument for the Fed's policy toolkit, it is unclear whether this will improve or hinder the effectiveness of Fed policy. Taylor (2016, p.719), for example, argues that IOER policy "enables the Fed to be more like a discretionary multi-purpose institution rather than the rule-like limited purpose institution that has delivered good policy in the past and that can deliver good policy in the future." In practice, the Fed's IOER policy has not functioned as predicted by theoretical models. Even Goodfriend (2015, p.1) has argued that the Fed should revise its IOER system: "The Federal Reserve should fix the interest rate on reserves floor for the federal funds rate to facilitate the normalization of interest rate policy without interfering in financial markets."

Our model of bank allocation expands on previous IOER models of the floor and corridor frameworks. By separating the markets for loans and reserves, the model allows us to test the relationship between banks' loan allocations and a variety of factors such as the interest rates on loans and reserves, loan demand, and measures of economic activity. We hope this study helps improve our understanding of the effects of the Fed's IOER policy.

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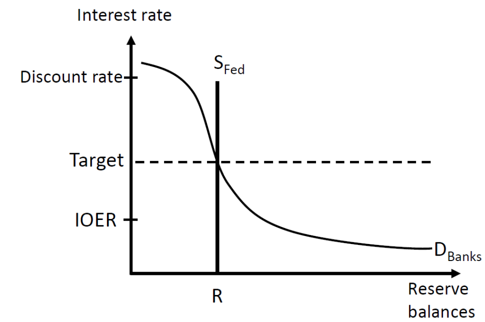
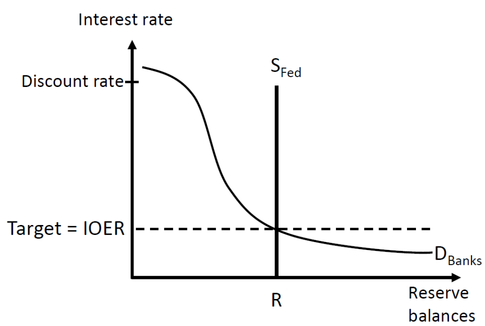
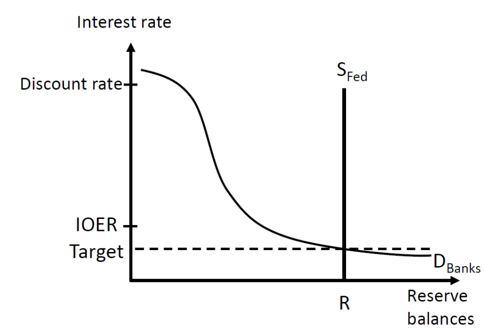


(a) Corridor system



(b) Floor system



(c) Fed IOER system

Figure 1: Models of monetary systems: Corridor, floor, and Fed IOER
Source: 1a and 1b based on Keister (2012)

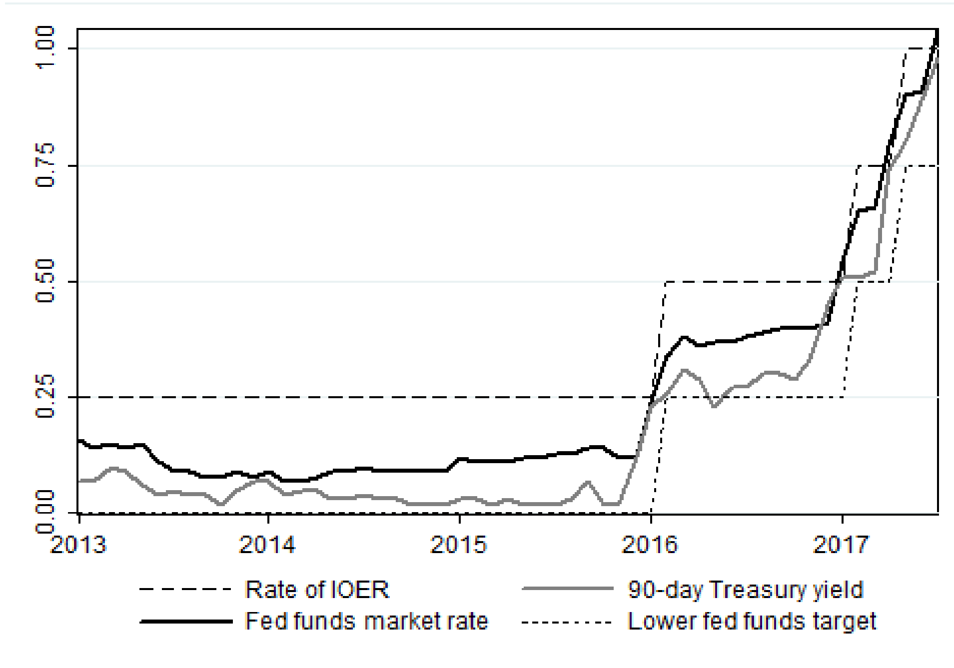


Figure 2: Rates on fed funds and short-term Treasuries vs. targets for fed funds and IOER

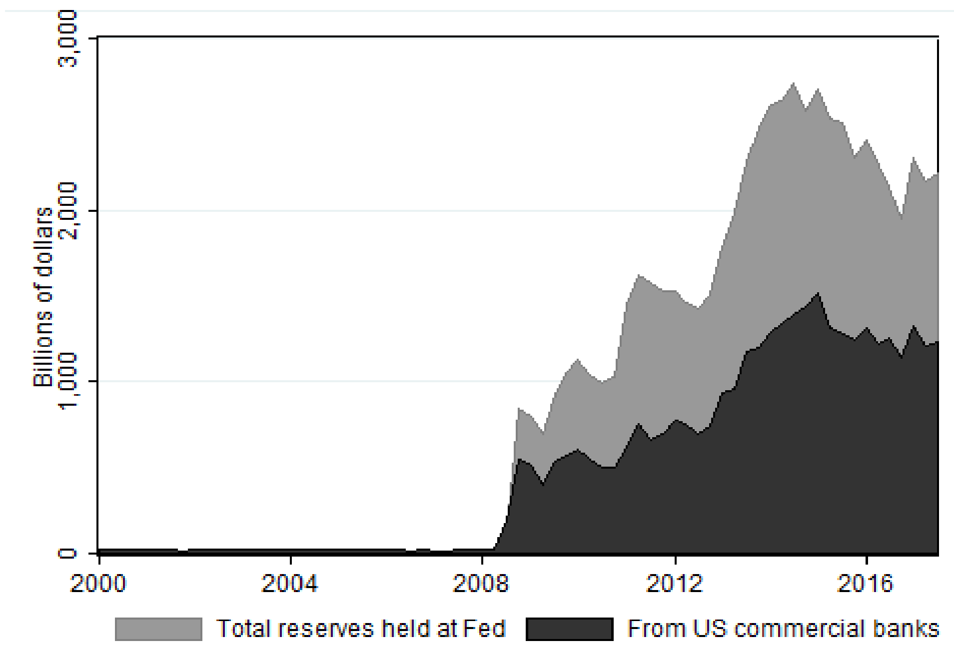
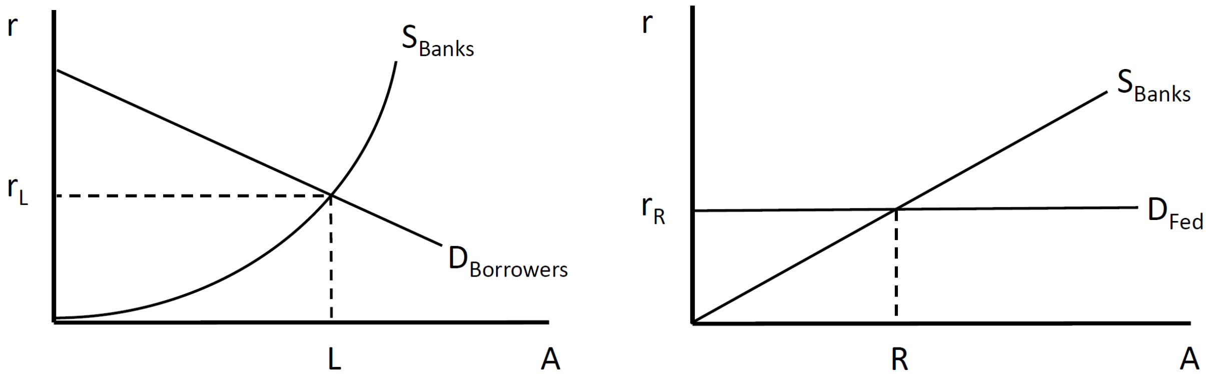


Figure 3: Reserves held at the Fed: US banks vs. total



(a) Supply and demand for bank loans (b) Supply and demand for reserves

Figure 4: Markets for loanable funds and reserves held at the Fed

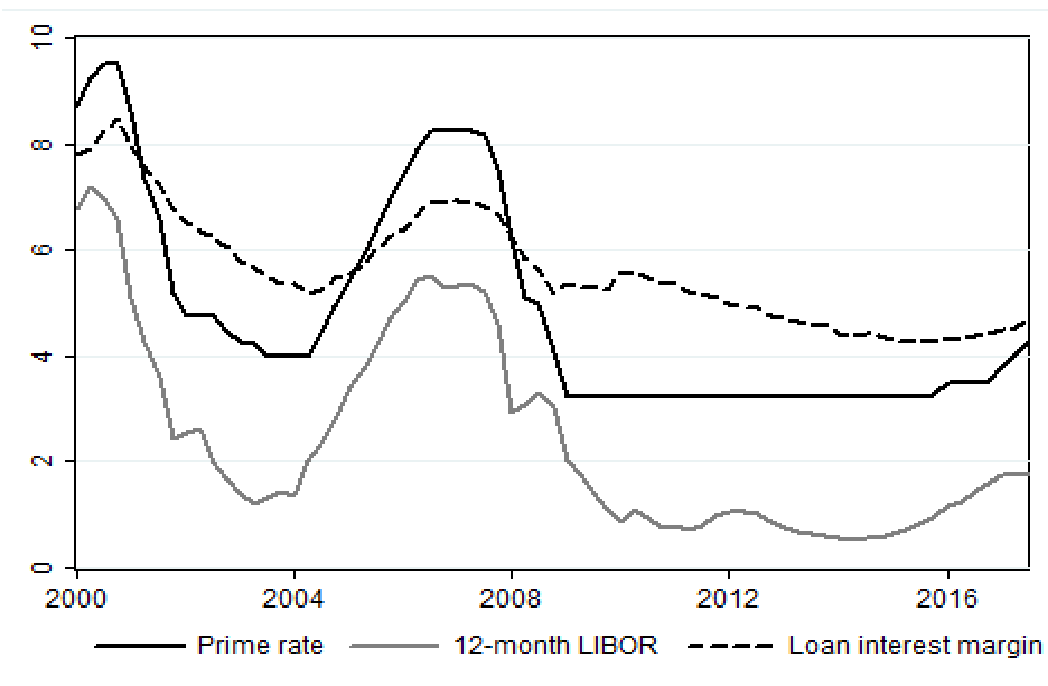


Figure 5: Interest rates on loans: Prime, LIBOR, and average loan interest margin

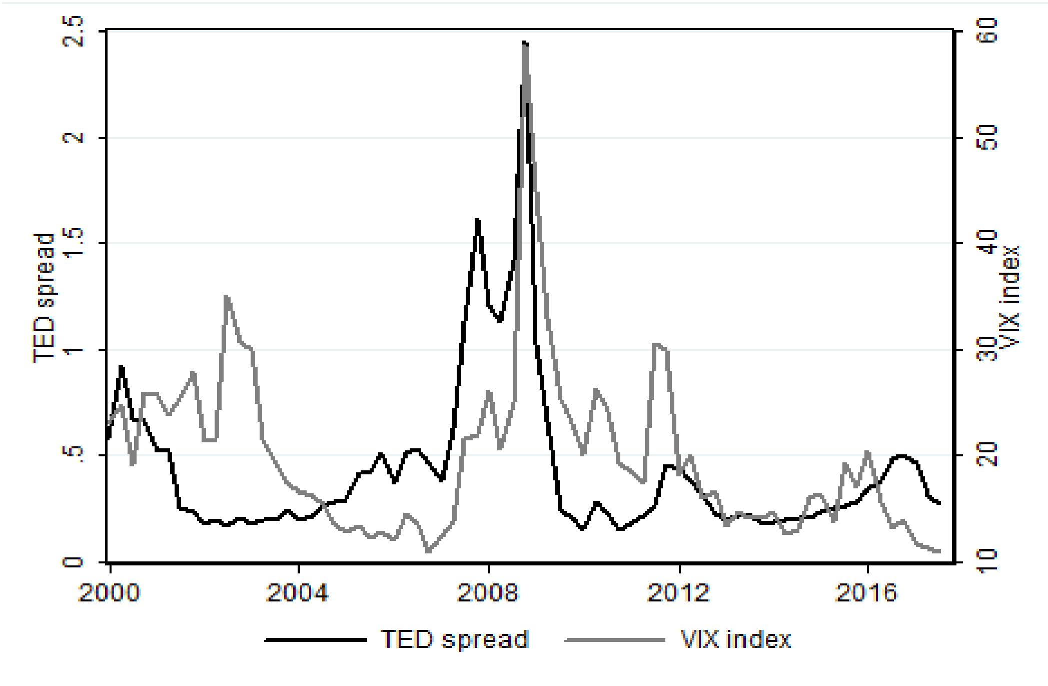


Figure 6: Measures of economic uncertainty: the TED spread and VIX index

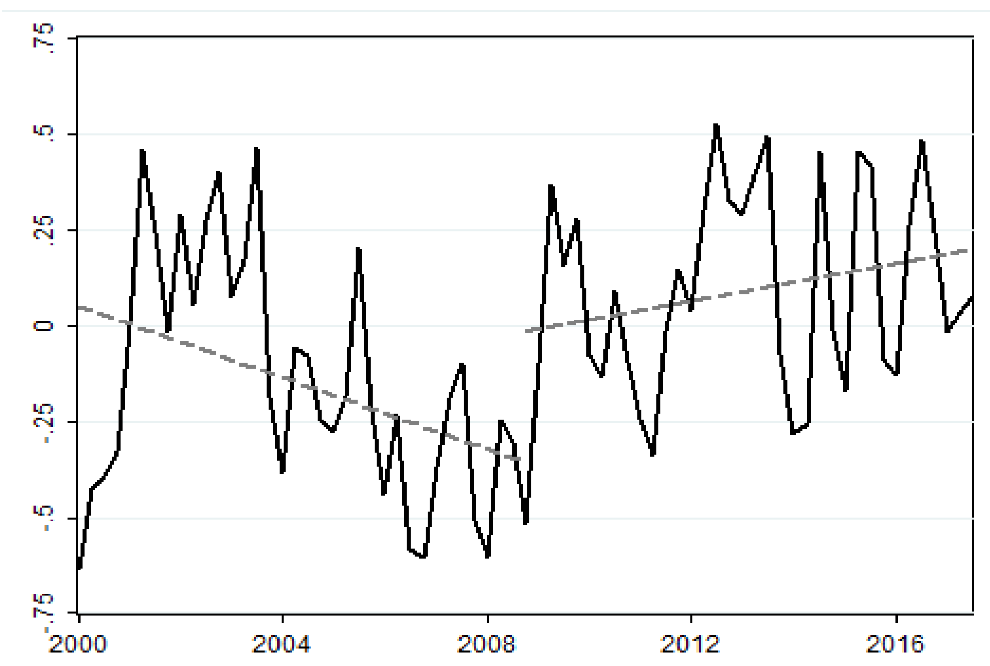


Figure 7: Net percentage of banks reporting higher demand for loans
Source: Board of Governors of the Federal Reserve System

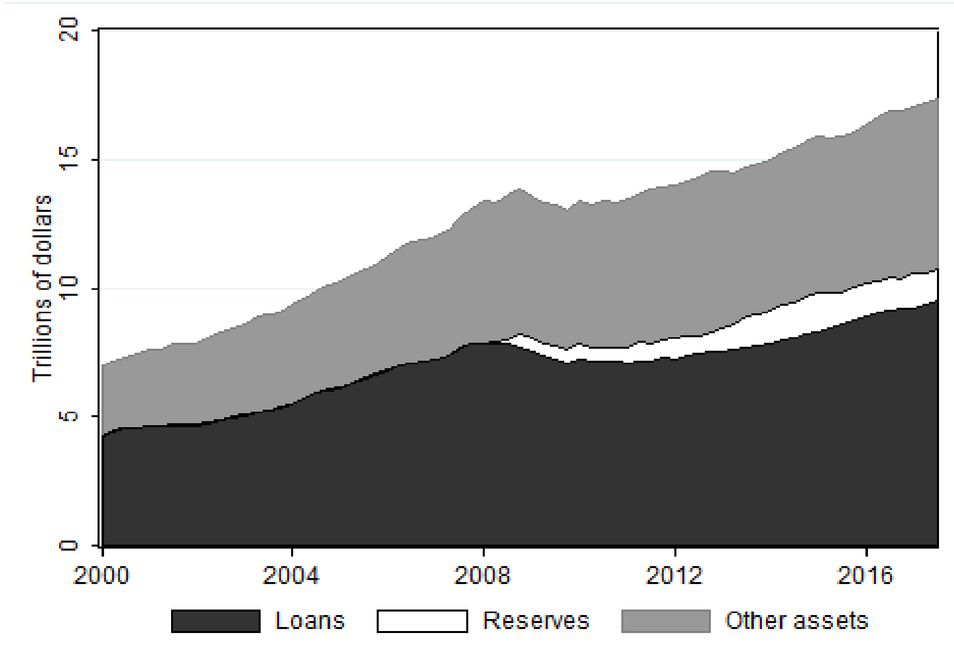


Figure 8: Total loans, reserves at the Fed, and assets of all US banks (in trillions of $)
Source: FDIC Call Reports

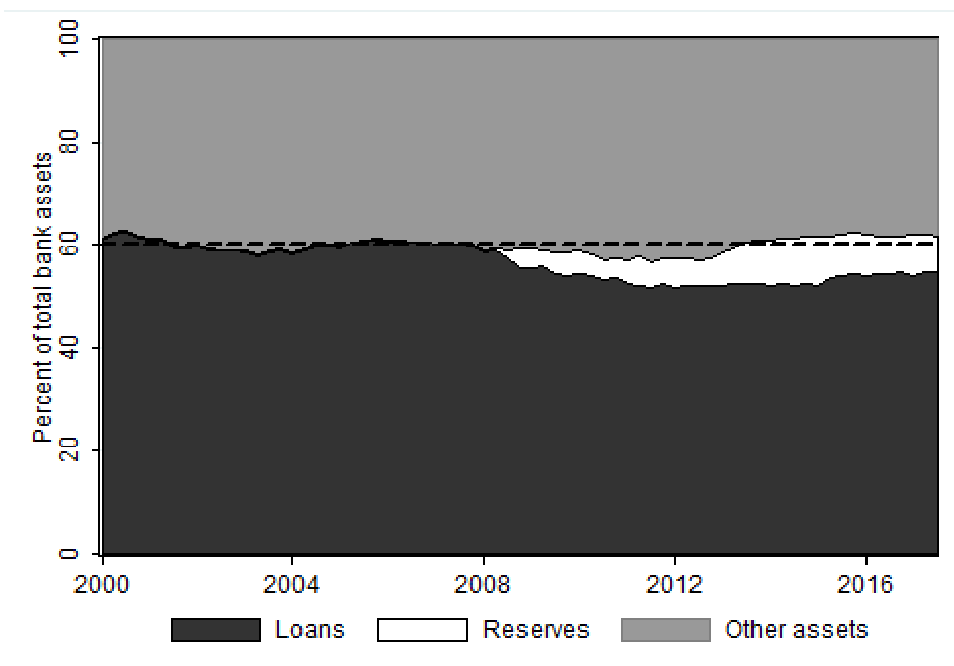


Figure 9: Total loans and reserves at the Fed as percentages of US bank assets
Source: FDIC Call Reports

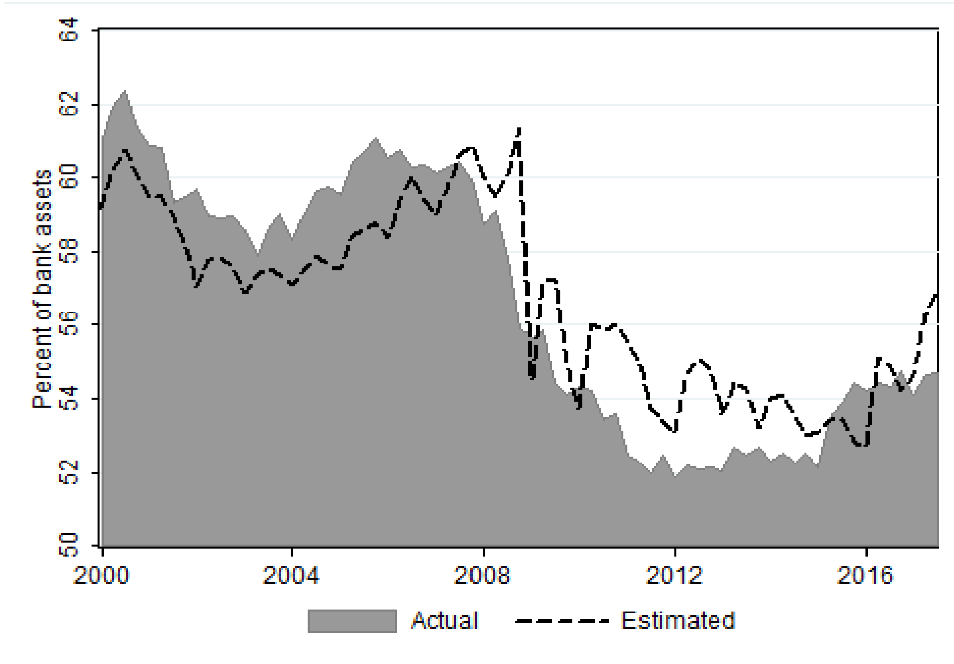


Figure 10: Loans as percent of US bank assets: Actual vs. estimated
Source: FDIC Call Reports and authors' calculations

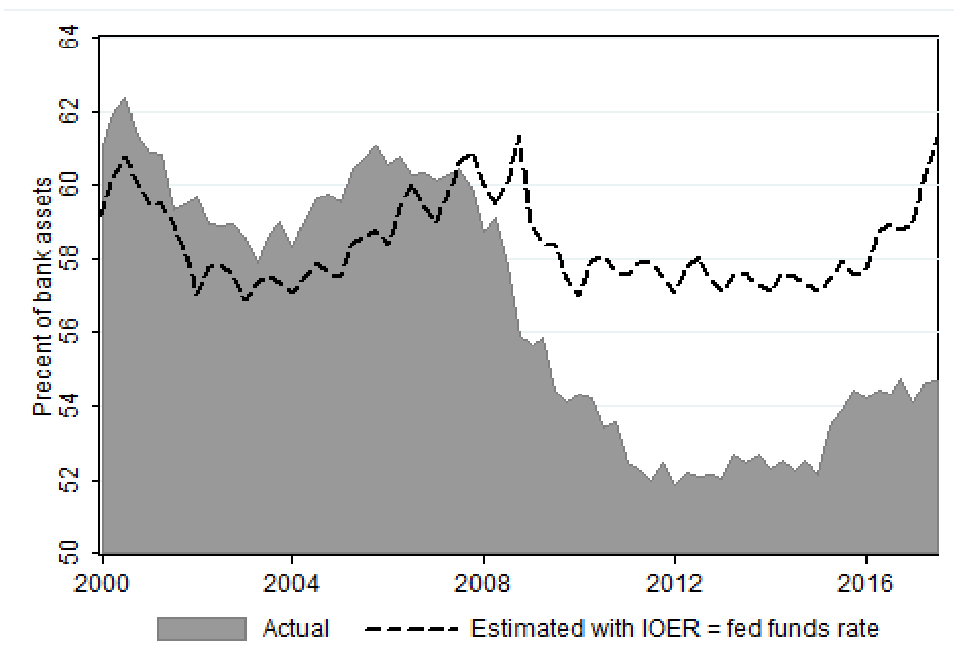


Figure 11: Loans as percent of US bank assets: Actual vs. estimated with IOER = fed funds rate
Source: FDIC Call Reports and authors' calculations

Table 1: Summary statistics

	Mean	Std. Dev.	Min.	Max.	Obs.
Bank assets (in millions)					
Total assets	1,747	33,016	0	2,288,237	503,850
Total loans	976	16,259	0	976,289	503,850
Reserves held at the Fed	70	2,772	0	471,388	503,850
Non-reserve cash	141	3,976	0	539,255	503,850
US Treasuries	23	880	0	114,704	503,850
Interest rates					
Rate of IOER	0.15%	0.22%	0.00%	1.25%	503,850
90-day Treasury yield	1.75%	1.92%	0.00%	6.03%	503,850
Prime lending rate	5.04%	2.07%	3.25%	9.50%	503,850
Fed funds rate	1.97%	2.10%	0.07%	6.53%	503,850
12-month LIBOR	2.61%	1.96%	0.55%	7.18%	503,850
Average loan interest margin	5.73%	1.09%	4.25%	8.48%	503,850
Economic data					
Real GDP growth	1.88%	2.44%	-8.45%	7.56%	503,850
Labor force growth	0.80%	1.48%	-2.30%	6.44%	503,850
Banks with high loan demand	-3.58%	31.31%	-63.50%	52.50%	503,850
TED spread	0.45%	0.39%	0.15%	2.45%	503,850

Note: Bank data gathered from quarterly Call Reports represent the sums for all federally insured US commercial banks. Loan interest margin calculated as sum of all interest on loans in each quarter divided by total value of loans in the quarter. Economic data gathered from the Federal Reserve Bank of St. Louis database Federal Reserve Economic Data.

Table 2: Tradeoffs between of loans, reserves, and other assets, Q1 2009 - Q3 2017

	(1) Reserves	(2) Reserves	(3) Loans	(4) Loans
Loans	-0.084***	-0.125***		
	(0.001)	(0.001)		
Reserves			-0.523***	-0.668***
			(0.005)	(0.005)
Non-reserve cash		-0.144***		-0.596***
		(0.001)		(0.003)
U.S. Treasuries		-0.070***		-0.391***
		(0.004)		(0.009)
Constant	0.066***	0.103***	0.623***	0.675***
	(0.001)	(0.001)	(0.000)	(0.000)
Observations	222,897	222,897	222,897	222,897
R-squared	0.679	0.698	0.869	0.894

Notes: All variables calculated for as percentages of total assets per bank. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table 3: Analysis of reserves held at the Fed as percentages of bank assets

	(1)	(2)	(3)	(4)	(5)
IOER premium				4.704***	5.751***
				(0.238)	(0.250)
Rate of IOER			0.785***		-0.632***
			(0.066)		(0.047)
Prime lending rate		-0.115***	-0.091***	-0.018***	-0.016***
		(0.008)	(0.006)	(0.004)	(0.004)
GDP growth	-0.019***	-0.007***	-0.007***	-0.006***	-0.006***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Labor force growth	-0.027***	0.036***	0.015*	-0.024***	-0.020**
	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)
Loan demand	0.005***	0.002***	0.002***	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
TED spread	-0.367***	-0.176***	-0.157***	-0.141***	-0.148***
	(0.015)	(0.013)	(0.014)	(0.013)	(0.014)
Log assets	0.010***	0.008***	0.006***	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Q1	0.000***	0.000***	0.000*	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q2	-0.001***	-0.000***	-0.001***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q3	-0.001***	-0.001***	-0.001***	-0.000***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.027***	0.028***	0.023***	0.012***	0.012***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Observations	503,850	503,850	503,850	503,850	503,850
R-squared	0.406	0.409	0.411	0.420	0.420

Notes: Dependent variable is bank reserves held at the Fed as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table 4: Analysis of loans as percentages of bank assets

	(1)	(2)	(3)	(4)	(5)
IOER premium				-17.042***	-22.111***
				(0.752)	(0.683)
Rate of IOER			-2.388***		3.058***
			(0.237)		(0.141)
Prime lending rate		0.764***	0.691***	0.413***	0.402***
		(0.025)	(0.021)	(0.019)	(0.019)
GDP growth	0.039***	-0.040***	-0.042***	-0.045***	-0.045***
	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Labor force growth	0.071**	-0.347***	-0.284***	-0.131***	-0.148***
	(0.035)	(0.030)	(0.029)	(0.030)	(0.030)
Loan demand	-0.026***	-0.010***	-0.008***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
TED spread	2.527***	1.259***	1.203***	1.132***	1.167***
	(0.051)	(0.059)	(0.061)	(0.060)	(0.061)
Log assets	0.042***	0.055***	0.059***	0.069***	0.067***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Q1	-0.004***	-0.004***	-0.004***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.007***	0.006***	0.007***	0.004***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.012***	0.008***	0.008***	0.006***	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.683***	0.678***	0.692***	0.736***	0.734***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Observations	503,850	503,850	503,850	503,850	503,850
R-squared	0.779	0.783	0.783	0.787	0.788

Notes: Dependent variable is bank loans as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for $p<0.01$, ** for $p<0.05$, and * for $p<0.1$

Appendix A Robustness regressions

Table A1: Analysis of reserves using different interest rate variables

	(1)	(2)	(3)	(4)	(5)	(6)
IOER premium	18.383***	5.793***	5.663***			
	(1.696)	(0.246)	(0.225)			
Bank-level IOER premium				1.014***	1.028***	0.989***
				(0.147)	(0.147)	(0.147)
Prime lending rate	-0.182***			-0.015***		
	(0.044)			(0.002)		
12-month LIBOR		-0.012***			-0.011***	
		(0.005)			(0.003)	
Bank-level interest margin			0.006			-0.010
			(0.018)			(0.006)
Rate of IOER	-0.553	-0.628***	-0.674***	1.108***	1.127***	1.082***
	(0.359)	(0.048)	(0.046)	(0.069)	(0.069)	(0.066)
GDP growth	-0.058***	-0.007***	-0.007***	-0.002*	-0.002*	-0.002**
	(0.009)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Labor force growth	-0.081***	-0.005***	-0.007***	0.006***	0.006***	0.005***
	(0.015)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)
Loan demand	-0.002	0.000**	0.001***	0.000**	0.000**	0.001***
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
TED spread	-0.431***	-0.151***	-0.176***	-0.014	-0.016*	-0.025***
	(0.108)	(0.015)	(0.012)	(0.009)	(0.009)	(0.009)
Log assets	0.005	0.004***	0.006***	0.003***	0.003***	0.003***
	(0.008)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Q1	-0.001	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.001***	0.001***	0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.000	-0.000	-0.000*	-0.000***	-0.000***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.026***	0.012***	0.014***	0.008***	0.008***	0.009***
	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	41,139	503,850	497,172	332,393	332,393	327,774
R-squared	0.577	0.420	0.438	0.346	0.346	0.366

Notes: Dependent variable is bank reserves held at the Fed as percentage of assets in each quarter. Columns 1, 3, and 5 include only observations for banks with positive holdings of US Treasuries and reserves at the Fed. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table A2: Analysis of reserves using different loan demand and uncertainty variables

	(1)	(2)	(3)	(4)
IOER premium	5.174***	5.730***	5.363***	4.953***
	(0.240)	(0.246)	(0.222)	(0.221)
Rate of IOER	-0.149*	-0.664***	-0.662***	-0.499***
	(0.078)	(0.047)	(0.047)	(0.045)
Prime lending rate	-0.014***	-0.028***	-0.020***	-0.028***
	(0.004)	(0.004)	(0.003)	(0.004)
GDP growth	-0.007***	-0.007**	-0.021***	-0.042***
	(0.001)	(0.003)	(0.003)	(0.003)
Labor force growth	-0.017***	-0.004	-0.010***	-0.021***
	(0.002)	(0.002)	(0.002)	(0.002)
Housing price growth	0.000***			
	(0.000)			
Loan demand		0.001***	0.001***	0.002***
		(0.000)	(0.000)	(0.000)
TED spread	-0.127***			
	(0.013)			
VIX index		-0.000***		
		(0.000)		
Financial stress index			-0.001***	
			(0.000)	
Leading indicator index				0.002***
				(0.000)
Log assets	0.005***	0.004***	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Q1	-0.000***	-0.000	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.001***	0.000***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.013***	0.013***	0.012***	0.011***
	(0.002)	(0.001)	(0.002)	(0.002)
Observations	481,425	503,850	503,850	503,850
R-squared	0.421	0.420	0.421	0.422

Notes: Dependent variable is bank reserves held at the Fed as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table A3: Analysis of reserves without controls, lagged interest rates

	(1) Without control vars	(2) Excluding outliers	(3) Lag one quarter	(4) Lag two quarters
IOER premium	5.819***	4.684***		
	(0.247)	(0.153)		
Rate of IOER	-0.627***	-0.582***		
	(0.047)	(0.031)		
Prime lending rate	-0.031***	-0.007***		
	(0.003)	(0.002)		
IOER premium, L1			5.746***	
			(0.261)	
Rate of IOER, L1			-0.664***	
			(0.062)	
Prime lending rate, L1			-0.025***	
			(0.004)	
IOER premium, L2				4.830***
				(0.251)
Rate of IOER, L2				-0.371***
				(0.086)
Prime lending rate, L2				-0.047***
				(0.005)
GDP growth		-0.002**	-0.014***	-0.034***
		(0.001)	(0.001)	(0.002)
Labor force growth		-0.002	-0.058***	-0.010***
		(0.001)	(0.003)	(0.002)
Loan demand		0.000***	-0.000	0.001***
		(0.000)	(0.000)	(0.000)
TED spread		-0.148***	-0.157***	-0.146***
		(0.008)	(0.015)	(0.022)
Log assets	0.004***	0.004***	0.004***	0.005***
	(0.001)	(0.000)	(0.001)	(0.001)
Q1	-0.000*	-0.000**	0.000**	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.001***	0.000***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.000***	-0.000	0.000**	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.012***	0.011***	0.014***	0.017***
	(0.002)	(0.001)	(0.002)	(0.002)
Observations	503,850	483,990	492,190	480,731
R-squared	0.420	0.412	0.425	0.428

Notes: Dependent variable is bank reserves held at the Fed as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table A4: Analysis of loans using different interest rate variables

	(1)	(2)	(3)	(4)	(5)	(6)
IOER premium	-12.454***	-21.066***	-23.293***			
	(2.333)	(0.669)	(0.703)			
Bank-level IOER premium				-4.648***	-4.588***	-4.911***
				(0.430)	(0.430)	(0.423)
Prime lending rate	0.407***			0.464***		
	(0.062)			(0.019)		
12-month LIBOR		0.545***			0.582***	
		(0.021)			(0.022)	
Bank-level interest margin			0.068			0.272***
			(0.047)			(0.044)
Rate of IOER	3.524***	2.752***	3.589***	-5.175***	-5.375***	-4.400***
	(0.439)	(0.143)	(0.137)	(0.391)	(0.391)	(0.378)
GDP growth	-0.046***	-0.045***	-0.011**	-0.041***	-0.040***	-0.019***
	(0.016)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Labor force growth	-0.018	-0.060***	0.002	-0.017**	-0.042***	-0.024***
	(0.020)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)
Loan demand	-0.004**	0.000	-0.010***	-0.004***	0.002*	-0.015***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
TED spread	1.956***	0.872***	1.799***	0.908***	0.722***	1.391***
	(0.198)	(0.066)	(0.054)	(0.066)	(0.070)	(0.061)
Log assets	0.025***	0.068***	0.051***	0.072***	0.073***	0.053***
	(0.007)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)
Q1	-0.002***	-0.003***	-0.003***	-0.002***	-0.002***	-0.003***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.002***	0.001***	0.003***	0.007***	0.006***	0.009***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.002***	0.003***	0.006***	0.008***	0.005***	0.010***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.599***	0.744***	0.721***	0.735***	0.748***	0.705***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Observations	41,139	503,850	497,172	332,393	332,393	327,774
R-squared	0.842	0.788	0.779	0.817	0.817	0.813

Notes: Dependent variable is bank loans as percentage of assets in each quarter. Columns 1, 3, and 5 include only observations for banks with positive holdings of US Treasuries and reserves at the Fed. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table A5: Analysis of loans using different loan demand and uncertainty variables

	(1)	(2)	(3)	(4)
IOER premium	-21.731***	-21.789***	-18.061***	-16.381***
	(0.624)	(0.673)	(0.627)	(0.634)
Rate of IOER	4.352***	3.513***	3.391***	2.095***
	(0.230)	(0.136)	(0.139)	(0.143)
Prime lending rate	0.399***	0.524***	0.421***	0.497***
	(0.018)	(0.018)	(0.017)	(0.017)
GDP growth	-0.021***	0.029***	0.135***	0.203***
	(0.005)	(0.010)	(0.009)	(0.007)
Labor force growth	0.022***	-0.034***	0.021**	0.072***
	(0.008)	(0.008)	(0.009)	(0.007)
Housing price index growth	-0.001***			
	(0.000)			
Loan demand		-0.009***	-0.008***	-0.012***
		(0.001)	(0.001)	(0.001)
TED spread	1.176***			
	(0.047)			
VIX index		0.001***		
		(0.000)		
Financial stress index			0.012***	
			(0.000)	
Leading indicator index				-0.015***
				(0.000)
Log assets	0.053***	0.071***	0.073***	0.070***
	(0.003)	(0.002)	(0.002)	(0.002)
Q1	-0.003***	-0.002***	-0.002***	-0.003***
	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.000	0.004***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.003***	0.006***	0.006***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.708***	0.721***	0.741***	0.745***
	(0.005)	(0.004)	(0.005)	(0.005)
Observations	481,425	503,850	503,850	503,850
R-squared	0.801	0.788	0.789	0.790

Notes: Dependent variable is bank loans as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1

Table A6: Analysis of loans without controls, lagged interest rates

	(1) Without control vars	(2) Excluding outliers	(3) Lag one quarter	(4) Lag two quarters
IOER premium	-22.721***	-21.102***		
	(0.667)	(0.659)		
Rate of IOER	2.972***	3.329***		
	(0.140)	(0.137)		
Prime lending rate	0.520***	0.379***		
	(0.016)	(0.018)		
IOER premium, L1			-20.866***	
			(0.690)	
Rate of IOER, L1			3.846***	
			(0.185)	
Prime lending rate, L1			0.401***	
			(0.018)	
IOER premium, L2				-17.674***
				(0.618)
Rate of IOER, L2				3.203***
				(0.248)
Prime lending rate, L2				0.445***
				(0.019)
GDP growth		-0.048***	-0.001	0.056***
		(0.005)	(0.005)	(0.006)
Labor force growth		-0.044***	0.132***	-0.030***
		(0.007)	(0.010)	(0.008)
Loan demand		-0.004***	-0.004***	-0.011***
		(0.001)	(0.001)	(0.001)
TED spread		1.256***	1.279***	1.176***
		(0.057)	(0.062)	(0.081)
Log assets	0.070***	0.062***	0.055***	0.048***
	(0.002)	(0.002)	(0.003)	(0.003)
Q1	-0.004***	-0.003***	-0.005***	-0.004***
	(0.000)	(0.000)	(0.000)	(0.000)
Q2	0.000**	0.002***	0.007***	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.003***	0.005***	0.004***	0.011***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.740***	0.727***	0.707***	0.689***
	(0.005)	(0.004)	(0.005)	(0.005)
Observations	503,850	483,990	492,190	480,731
R-squared	0.787	0.766	0.800	0.807

Notes: Dependent variable is bank loans held at the Fed as percentage of assets in each quarter. OLS regressions using bank-level fixed effects. Clustered standard errors shown in parentheses. Statistical significance indicated by *** for p<0.01, ** for p<0.05, and * for p<0.1