A New Environment for Monetary Policy: Interest Bearing Reserves and Policy Implementation

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Abstract

I examine and critique the literature surrounding interest on reserves (IOR), from its theoretical backing to current implementation. I examine early theories around the conduct of IOR and its interaction with the fed funds market. I then examine how the implementation of IOR has differed from these theories, and, through a simple model of the fed funds market, I show how IOR reshaped the market for reserves. Finally, I examine IOR's effects on the overall economy. As a whole, the IOR literature still has faces many questions about how IOR influences financial markets and how optimal policy should be conducted.

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1 Introduction

The conduct of monetary policy has undergone a seismic shift over the last 15 years. Prior to 2008, the Federal Reserve mainly conducted policy by affecting the quantity of reserves in the banking system to move the overnight interbank interest rate. If they wanted to raise the interest rate, they would simply decrease the quantity of reserves, increasing the interest rate. To lower the interest rate, they would increase the quantity of reserves. Monetary economists such as Milton Friedman (1960) have theorized that paying interest on reserves (IOR) centralizes more of the money supply at the central bank, giving them greater influence over the money supply and short term interest rates because banks demand a higher quantity of reserves. What's more, interest on reserves was even mentioned in Lauchlin Currie's proposed 1935 banking reforms as a way to offset banks' inability to acquire interest bearing assets with new deposits in a 100% reserves system (Phillips & Minsky, 1996). In 2006, Congress passed a law to give the Fed the ability to pay interest on reserves beginning in 2011. The law intended to incentivize banks to hold reserves beyond what was required. However, the Fed moved the start date up due to the financial crisis, and the Fed began paying IOR in October 2008. The Bank of England started paying interest on reserves shortly thereafter in 2009, while the European Central Bank had since its inception in 1999. Shortly after the policy was implemented, the amount of reserves in the system increased significantly and has continued to stay high since (Figure 1) due to a greater incentive to hold reserves, a desire by banks to hold more reserves in response to the financial crisis, and quantitative easing.

Since the financial crisis, the macroeconomic literature has been preoccupied with the recent recession and slow to examine the effects of paying interest on reserves. The reality of interest on reserves as standard policy worldwide is merely a decade old, and the literature behind it is just now beginning to blossom. Given the newness surrounding the subject, the literature is still primarily focused on how paying interest on reserves changes a central bank's traditional instruments. Accordingly, there is still much debate on the proper way to

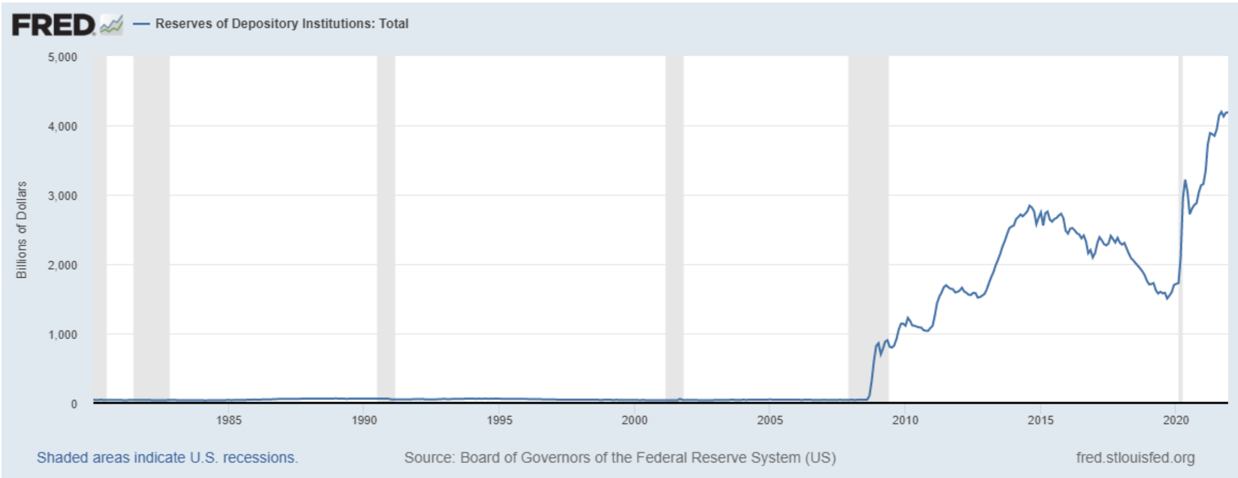

Figure 1: Quantity of reserves

model interest on reserves and some ambiguity around the effects of the policy on both the interbank market and the economy as a whole. Some of this ambiguity lies in the uncertainty around the proper model to use. The literature thus far has largely focused on the Federal Reserve but has somewhat ignored the bank side of the market and, to a certain extent, financial markets. A focus on how banks allocate assets when interest is paid on reserves can give insight into how IOR changed the Fed's instruments. The structure of this paper is as follows: section II examines the theoretical benefits of the policy, section III looks at the financial market effects of a two pronged policy, section IV analyzes the effects on the real economy, and section V concludes.

2 Pricing of Reserves

The buildup of reserves in 2008 was not the first time banks voluntarily held large quantities of reserves. Frost (1971) explain that banks also held excess reserves in response to the Great Depression, despite not receiving interest on these reserves. He explain this demand for reserves through an inventory model: banks hold excess reserves to reduce the cost associated with meeting reserve requirements. However, this demand function is kinked at very low rates, like those seen in the Great Depression. With these low rates, it is profitable for a bank to hold large quantities of reserves because the cost of frequently changing reserve holdings is greater than the interest the bank would earn on a highly-liquid security. Dow (2001) empirically tests the predictions made by this inventory model after the Great Depression, namely that reserve demand is inversely related to interest rates and positively related to a bank's transaction deposits. He finds that this theory largely holds even after the Great Depression: banks reduce their reserve holding at higher rates, but build up a reserve buffer as a precaution against outflows from greater transaction deposits.

Paying interest on reserves theoretically gives a central bank a greater amount of control over the economy by putting a floor on the overnight rate (2) and allowing policymakers to better dictate inflation expectations. The primary rationale for paying interest on reserves was put forth by Goodfriend (2002). Goodfriend discusses how innovations in payment methods began to worry economists that central banks could lose some control over interest rates in the future. Competition among currencies, especially with the introduction of cryptocurrency, lessens a central bank's power over the market by shrinking the relative size of their instruments. Put another way: if fewer people transact in dollars and choose instead to use a currency such as Bitcoin, people are less sensitive to the interest rate on dollars. Additionally, the 1990's in Japan showed that deflation could occur at the zero lower bound. Central banks needed to further consider what can or should be done in this case, and whether they have the correct tools to implement an appropriate policy.

Goodfriend lays out how a central bank can implement interest on reserves by first satiating the market for reserves. A satiated market for reserves will drive the interest rate to its lower bound because there will already exist supply to satisfy changes in demand. In tandem, the central bank can institute interest on reserves. This can act as a floor for the overnight market for reserves: banks will not lend below the IOR rate because they can simply hold their excess reserves and earn interest. As a result, a central bank would be free to use open market operations to pursue short-run financial stability, changing the quantity of reserves to ensure banks are adequately capitalized. A central bank can move

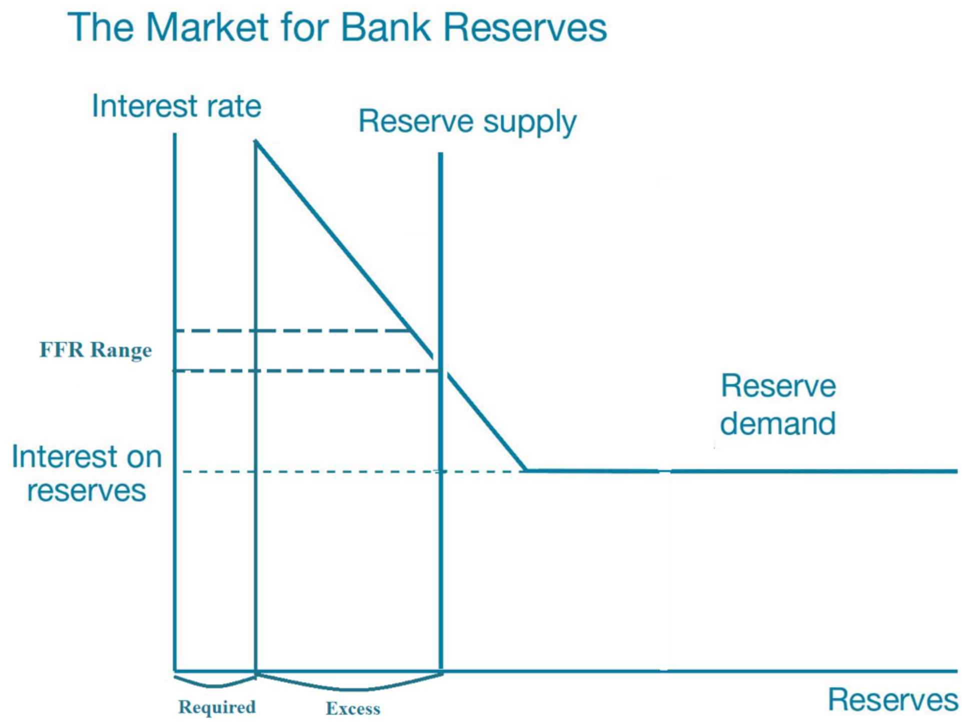

Figure 2: Market for reserves

the interest rate in the overnight market for reserves by simply adjusting the IOR rate, then adjusting bank reserves to smooth shocks to the financial system. The policy would also aid a bank's risk profile by allowing it to shift from riskier interest bearing assets to a perfectly safe interest bearing asset of reserves. This allows a central bank to limit how much of its own capital is used for investment in private credit by banks. In short, Goodfriend (2002) sees paying interest on reserves as an effective way to combat changes in the structure around monetary policy without compromising the effectiveness of policy in the short run.

While Goodfriend (2002) showed a simple policy regime with interest on reserves, his prediction that this interest rate would impose a floor on the Fed Funds Rate largely did not come to pass. The interest rate on reserves operated more similar to a ceiling on the Fed Funds than a floor for the first 11 years of the policy, as seen in Figure 3. What's more, transcripts from the Federal Reserve's meetings shortly after implementing interest on reserves showed many Fed officials struggling to understand this phenomenon. Given this, the Fed had to rethink how an interest on reserves regime would work and how it would interact with the Fed's more traditional policy instruments.

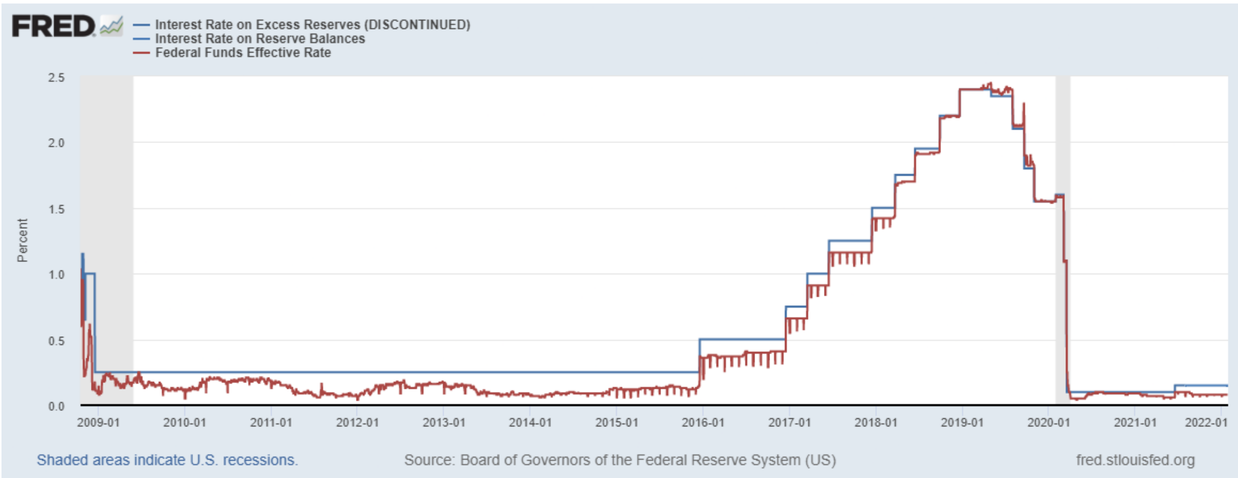

Figure 3: Fed Funds and IOR since 2008

Ihrig et al. (2015) and Ihring et al. (2020) lay out the Federal Reserve's perspective on policy under an interest on reserves regime. Ihrig et al. discuss that the Fed has five primary ways it can adjust interest rates. First, it can increase the interest rate on reserves. This encourages arbitrage between the interbank rate and the reserve rate as banks attempt to borrow in the fed funds market to make a risk-free return. This puts an upward pressure on the interbank interest rate as loaners can demand a higher return. While the Fed has the ability to pay interest on both required and excess reserves, interest on required reserves does not incentivize a bank to hold more reserves: they are required to hold that amount regardless of whether or not it pays interest. As such, the Fed's primary policy tool is the interest rate on excess reserves. Next, the Fed can offer reverse repurchase agreements. This can also increase the scarcity of reserves as more reserves are used in the agreements. Third, they can offer term deposits. Similar to repurchase agreements, this encourages arbitrage among banks looking for a risk free return and decreases the quantity of reserves available to be loaned in the interbank market. Fourth and fifth, the Fed can attempt to adjust the fed funds rate the way it did before 2008: by decreasing its security holdings or increasing the reserve requirements. This increases the scarcity of reserves in the system, thereby increasing the price of reserves. Because of the large quantity of reserves now in circulation, the Fed worries that it would have to decrease the quantity of reserves too substantially to return to its pre-crisis policy. As a result, while the Fed continues to target the overnight interbank rate, it now largely does so through both changing the quantity of reserves by adjusting its security holdings and adjusting the interest rate on reserves, somewhat similar to the system laid out in Goodfriend (2002). Changing the interest rate on reserves allows the Fed to adjust the Fed Funds rate without involvement in the market for reserves via open market operations. Given this, it is clear the interest rate on reserves is now a primary tool used by central banks to implement policy.

However, as Ihrig et al. (2020) discusses, the amount of reserves in the banking system affects the implementation of IOR. Ihrig et al. notes the Fed prefers to set policy with an “ample reserves” approach wherein the Fed doesn’t need to actively manage reserves to set policy, similar to the framework in Goodfriend (2002). In contrast, prior to the introduction of IOR in 2008, the Fed followed a “scarce reserves” regime which required the active management of reserves to set policy. This ample reserve regime allows the Fed to control interest rates without daily interventions in reserves markets, ensuring enough system-wide liquidity. However, the successful implementation of an ample reserve regime requires the Fed to carry a large balance sheet going forward, as well as remain vigilant to changes in the demand for reserves.

Additionally, Cochrane (2014) lays out how the introduction of reserves as an interest bearing asset reduces frictions by increasing liquidity in financial markets. Because the Federal Reserve pushed the fed funds rate to zero in 2008 and saturated the market for reserves, financial markets have been awash with liquidity. As laid out by Goodfriend (2002), highly liquid financial markets are theoretically important for an interest on reserves regime to function properly by driving the interbank rate to its lower bound and using the rate on reserves to adjust the lower bound. Cochrane also argues highly liquid financial markets can also make the financial system as a whole safer. In this way paying interest on reserves improves a financial market's ability to withstand liquidity shocks. The size of a central bank's balance sheet is less relevant, as buying and selling assets becomes an unnecessary instrument because the market is already so liquid. In turn, many of the monetary frictions central banks use to control output largely disappear: there is no longer a liquidity effect, whereby a lower quantity of reserves decreases the liquidity of the market and increases the interest rate, that can be controlled by open market operations.

The introduction of reserves as an interest-bearing asset has blurred the line between reserves and Treasury bond for banks: they can hold reserves and earn interest or buy Treasury bonds and earn nearly the same interest rate. To show this, Cochrane (2014) uses a model of the interaction between monetary and fiscal policy without frictions such as price stickiness. In this model, monetary policy must work by simply setting the interest rate on reserves to incentivize banks to hold excess reserves. Banks then optimize such that other interest rates adjust to reflect the new central bank policy. Further, unexpected inflation is only caused by unexpected fiscal shocks. This means the primary way for a central bank to influence the real economy is through expectations. If the central banks raise interest rates and there is no corresponding liquidity effect from fewer reserves, other interest rates in the economy must rise. Additionally, with no liquidity effect, an increase in interest rates will not lower expected inflation, but instead raise expected inflation. This occurs because interest rates must converge such for the Fisher equation to hold, so expected inflation rises until the nominal interest rate is simply the equilibrium real interest rate plus the expected inflation rate. A central bank can use monetary policy to control inflation without control over money. However, because inflation is largely driven by inflation expectations, a central bank has less control over long run inflation. Indeed, these results hold if Cochrane introduces price stickiness to the aggregate price level.

3 Two-Pronged Approach to Policy

The addition of interest on reserves gives a central bank an additional tool to use when conducting monetary policy. However, the additional tool clouds whether optimal policy focuses on both rates independently, just the IOR rate, or the spread between the two rates. The introduction of interest on reserves also changes any optimal conduct rule the central bank can have. Given this, optimal policy must now be two-pronged but also respect any gap between the two rates, assumed by Ireland (2014) to simply be an autoregressive process. However, other papers assume the central bank can set both rates independently. In many of the prevailing models, the central bank can conduct policy by changing the spread between the interest rate for overnight funding and the rate on reserves or changing the level at which this spread occurs. Taken together, there is little consensus on whether a central bank can set rates independently.

Many of these papers start with a framework of a model of the interaction between the central bank and banks, similar to the one used in Armenter and Lester (2016). In the model, lenders are nondepository institutions, such as government sponsored entities, who cannot deposit their reserves at the central bank, but they can loan through the interbank market to a depository institution who can deposit it at the central bank and earn the interest on reserve rate, r^{ior}. Each depository institution, j, can hold these deposits at the central bank and will then keep a portion of the return as its own profit for the transaction. However, it is possible that not all lenders match with depository institutions, so lenders who do not match can enter the overnight reverse repurchase (ON RRP) facility and earn a smaller interest rate, r^{rrp}. A depository institution bears a balance sheet cost, c_j, which increases if it holds reserves for lenders. Lastly, if a depository institution offers a lower interest rate in the interbank market, they have a lower probability of matching because lenders will attempt to match with another depository institutions. However, if a depository institution offers a higher interest rate, they have a higher probability of matching, but have to pay forward more of the interest on reserves rate. A timeline of events and a visual summary of the market used in Armenter and Lester (2016) are shown in Figures 4 and 5. As a result, lenders maximize their utility using the interbank market rate, r^{ff}:

$$u(r^{ff}, q_j) = \left[\frac{1 - e^{-q_j}}{q_j}\right] r^{ff} + \left[1 - \frac{1 - e^{-q_j}}{q_j}\right] r \tag{1}$$

$$u(r^{ff}, q_j) = U \tag{2}$$

$\frac{1-e^{-q_j}}{q_j}$ in equation (1) is the probability that the lender is matched with a depository institution, where q_j is the ratio of lenders to depository institutions. A depository institution's choice to enter the interbank market depends on their balance sheet cost, c_j. A matched firm receives the interbank rate, r^{ff}. The second term $(1 - \frac{1-e^{-q_j}}{q_j})$ is the probability the lender is not matched and enters the ON RRP facility. Equation (2) says that for a depository institution to attract lenders, their expected payoff must be equal to market utility. Solving (1) and (2) gives for the interbank rate gives:

$$r^{ff} = r^{rrp} + \left[\frac{q_j}{1 - e^{-q_j}}\right] (U - r^{rrp}) \tag{3}$$

Depository institutions with balance sheet cost c_j who choose to enter the interbank market solve:

$$\max_{r^{ff},\, q_j} [1 - e^{-q_j}](r^{ior} - c_j - r^{ff}) \tag{4}$$

Subject to equation 3. Solving equation 4 gives the optimal interbank interest rate and market tightness:

$$r^{ff} = r + \log\left(\frac{r^{ior} - c_j - r^{rrp}}{U - r^{rrp}}\right) \left[\frac{(r^{ior} - c_j - r^{rrp})(U - r^{rrp})}{(r^{ior} - c_j - U)}\right] \tag{5}$$

$$q_j = \log\left(\frac{r^{ior} - c_j - r^{rrp}}{U - r^{rrp}}\right) \tag{6}$$

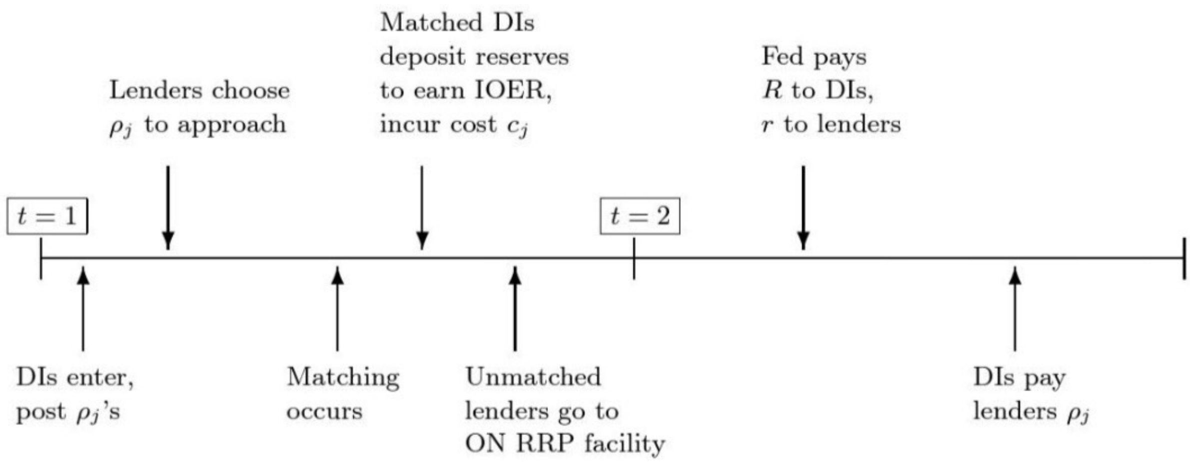

Figure 4: Timing of decisions in the interbank market

It should be noted that in none of these models does a depository institution choose whether to lend its own funds in the overnight funding market or to simply collect interest on its excess reserves. Including this would allow the model to more fully account for the decisions facing banks.

Data have shown that the IOR rate has not served as a lower bound to the overnight market the way Goodfriend (2002) had believed (Figure 3). Bech and Klee (2009) point to two primary factors: first, not all firms who participate in the fed funds market are eligible to receive interest on reserves. Many nondepository institutions, such as "shadow banks" and government sponsored entities, rely on the overnight market for their day-to-day funding and cannot receive interest on reserves or do not hold reserves. Next, many banks are able to borrow funds from these nondepository institutions and hold them at the Federal Reserve to collect interest on them, allowing for arbitrage in the banking market. In turn, many government sponsored entities have tightened their credit lines. Bech and Klee incorporate banks' and nonbanks' market power into a model similar to that above by weighting the probability of matching in equations (1) and (4) by the bargaining power of the firm. Their model shows that there will exist a spread between the interest rate on reserves and the fed funds rate because of this discrepancy between firms in the fed funds market and those with access to interest on reserves. The central bank can still control this overnight rate by

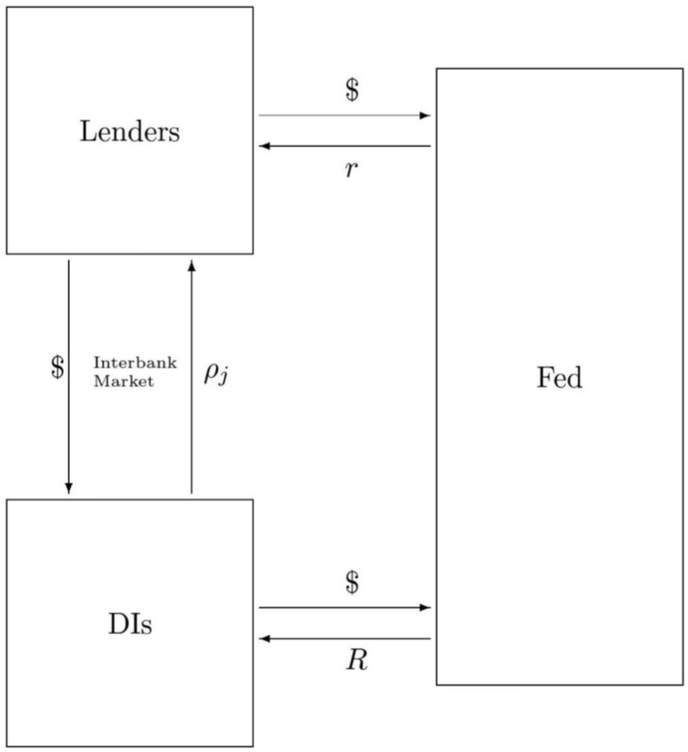

Figure 5: Visual representation of the interbank market

changing the interest on reserve rate. An increase in the interest on reserves rate does change the incentive of banks, but the different market power means that this change will likely not happen in a one for one manner. However, Bech and Klee suggest that when the spread between the interest rates becomes too large, the central bank can still control the spread by draining reserves from the system. While this will not affect the firms getting interest on reserves, it will increase the interest rate charged by firms without access to interest on reserves. This occurs by changing the relative market share of these firms in the overnight market by reintroducing many of the banks earning interest on reserves to the overnight market. In short, Bech and Klee (2009) show that interest on reserves can still have many of the benefits espoused by Goodfriend (2002), like using open market operations to influence financial stability and the reserve rate to influence the real economy, but banks' market power contributes significantly to how the spread between the IOR rate and the Fed Funds rate changes.

Berentsen and Monnet (2008) explore how these staggered funding decisions occur through a channel system in which the central banks sets upper and lower bounds for its target rate and allows the market to equilibrate in that range. They build on the above model by adding a goods market to model the real economy and a loan settlement market to explore how interbank rates change with changes to the central bank's target rate. They define the policy rate to be the average of the rate on reserves and the discount rate, ($P = \frac{r^d + r^{ior}}{2}$) and assume the discount rate is always greater than or equal to the interest rate on reserves ($r^d \geq r^{ior}$). Using a Fisher equation and the interbank rate as the nominal interest rate, they find that inflation increases as the policy interest rate increases. Perhaps most importantly, policy can be tightened by simply increasing the size of the spread. When the spread increases, there is less relative liquidity in the financial system, increasing interest rates across the board and decreasing consumption. As a result, Berentsen and Monnet point out that optimal policy in an interest on reserves world must focus on the interest rate corridor, that is it must specify both the upper and lower bounds of policy.

While the above models largely focus on how the central bank can adjust the interbank funding rate in addition to the interest rate on reserves to control policy, central banks can also control the ON RRP market rate. Armenter and Lester (2016) build on the above model by incorporating the concerns espoused in Bech and Klee (2009) about market power and having the central bank target the interest rate on reserves and the ON RRP rate. However, the Federal Reserve expressed interest in phasing out the ON RRP market, so Armenter and Lester use this model to explore how much control the central bank can have over the fed funds market without an ON RRP market ("Policy Normalization and Plans", September 17, 2014). Without an ON RRP market, the central bank struggles to raise the overnight lending market rate by raising the interest rate on reserves. Additionally, with a cap on the volume of ON RRP market, the fed funds rate dips outside the target range only in extreme circumstances. In this scenario, depositors' have increased power in the interbank market: if a depositor knows the lender cannot participate in the ON RRP market, they will offer a lower interbank rate and the lender will have greater pressure to take it. Taken as a whole, Armenter and Lester show that with interest on reserves, the central bank must utilize its control in lending markets for it to be able to influence interbank interest rates.

While the above models largely focus on the interbank market alone, Güntner (2015) nests an interbank market into an real business cycle model to examine the market in general equilibrium. In this model, banks face liquidity risk and voluntarily enter the interbank market. Banks hold excess reserves as a precaution against liquidity risk and limited participation in the interbank market, similar to Frost (1971), and interbank lending emerges because of uncertainty about future deposits. While IOR and large excess reserve balances does not influence the transmission of traditional monetary policy, it does dull the transmission of quantitative easing. With the interest rate against the zero-lower bound, banks simply hold the additional reserves created by quantitative easing rather than lending. In turn, QE leads to a buildup of excess reserves and a decline in interbank market participation.

In contrast, Kashyap and Stein (2012) explore how the central bank can use its additional tools to combat externalities created by bank debt. They build on the base model by allowing banks to change their maturity positions at the start of each period. As a bank sells off its shorter term assets in favor of long term assets, it depresses the price of short term assets. This tightens constraints on other institutions in the market, forcing them to change their maturity position as well to reflect the new asset values. In turn, banks create an externality by changing their maturity position. Kashyap and Stein use their model with a representative bank to explore how monetary policy can implement a sort of Pigouvian tax or cap and trade regulation to curb the effect of these externalities. These pseudo-regulatory policies can be implemented through changes in the reserve requirement and changes in the scarcity of reserves. However, for a central bank to implement this through controlling the scarcity of reserves, it cannot have an excessively large balance sheet as described by Goodfriend (2002). The introduction of interest on reserves gives a central bank an additional tool, allowing it to use the interest rate on reserves to change a bank's optimal maturity position and change the quantity of reserves to influence financial market liquidity. In this system, a central bank can control financial stability through its management of the total quantity of reserves and reserve requirements, thereby forcing the market to internalize its externality. Additionally, a central bank can control inflation through its manipulation of the interest rate on reserves.

While most papers have focused on the theory behind interest on reserves, recent work has begun to empirically test IOR's effects. Hendrickson (2017) estimated how the introduction of IOR changed banks' demand for reserves. He finds that IOR increased the demand for reserves. Further, this greater demand for reserves likely dulled the effect of quantitative easing, similar to the finding in Güntner (2015). However, Keating and Macchiavelli (2017) find that this increased demand for reserves is concentrated in US branches of foreign banks. These banks have access to interest on reserves, but do not have to pay FDIC oversight fees. In turn, they are better able to take advantage of the arbitrage opportunity described in Armenter and Lester (2016) and Bech and Klee (2009). Hogan (2021) takes a broader view, looking at how bank behavior and asset management changed after the introduction of IOR. Using call report data, Hogan finds that bank lending is inversely related to the IOR rate, and that the introduction of IOR accounts for more than half of the decline in loans after the 2008 financial crisis.

4 IOR and the Real Economy

While the above papers look primarily at the effect paying interest on reserves has on the interactions between banks and a central bank, they do not look at the effect on the real economy. Ireland (2014) uses a standard New Keynesian model with a representative household, bank, intermediate good firm, final good firm, and monetary authority using a Taylor rule to explore the real effects of the monetary authority paying interest on reserves. Additionally, Ireland assumes the rate on reserves is set as a function of the overnight rate, or $r_t^{ior} = \tau_t \left[r_t^{ff} \right]^{\alpha}$, where τ_t is an autoregressive process that reflects the interest rate spread.

First, the common association between higher interest rates and tight money no longer holds true. With no liquidity effect, an increase in the interest on reserves rate does not cause firms to scale back. Instead, higher interest rates simply pass through fairly quickly as higher inflation expectations. As a result, when households optimize and reallocate their assets, the monetary authority could have to increase the supply of reserves when raising the overnight rate. Additionally, banks' demand for reserves is higher when those reserves earn a positive return. Therefore, the monetary base must be larger to accommodate banks' greater desire for reserves and keep the total amount of money in circulation from decreasing. This will hold true as the Federal Reserve attempts to normalize its balance sheet, indicating that central banks' balance sheets will likely need to be considerably larger in an interest on reserves regime.

In this model, higher interest rates increase a bank's demand for reserves on their own. However, these higher rates also lead to greater household saving, increasing the demand for reserves even further. As interest rates increase and reserve demand grows, Ireland suggests intuitively that the Fed might start to need overnight loans from the Treasury to finance its day to day operation, potentially compromising some of the Fed's independence. Using a wider interest rate spread, his model suggests the long term consequences of this would be minimal, but would require large open market operations to decrease the amount of excess reserves in the financial system. Lastly, much of the experience surrounding interest on reserves comes from the United States and other countries with highly developed banking sectors. However, introduction of interest on reserves in a country with a less developed financial system could have larger consequences as the central bank is not able to respond as effectively as the Fed would to such pressures.

While the standard New Keynesian model used by Ireland (2014) shows the effects of paying interest on reserves throughout the economy, Ireland's model largely focuses on constraints created by banking costs such as maintaining branches. Instead, Ennis (2015) buillds a model wherein banks face both capital and liquidity constraints. Further, he differs from

Ireland by not including an intermediate good firm and final good firm, but instead includes entrepreneurs and investors. Entrepreneurs represent the demand side in a market for loans and investors are suppliers in the market for capital. Taken as a whole, Ennis's model takes a greater focus into the savings side of the market whereas Ireland looks more into consumption and production. In this model, banks must choose how to allocate monetary assets from the central bank, splitting between lending the assets to increase the currency in circulation and keeping the assets as bank reserves and earning interest. Additionally, the model includes costs banks face when expanding the size of their balance sheet. Paying higher interest on reserves makes holding monetary assets as reserves more enticing and decreases the cost associated with expanding the balance sheet, thereby raising the total demand for reserves throughout the financial system. Therefore, similar to the result in Ireland (2014), when a central bank raises its target interest rate, it must also increase the total amount of reserves in a system to satisfy the higher reserve demand. Additionally, when the financial system is awash with liquidity and none of the constraints bind, the central bank has little control over the price level by adjusting the interest rate on reserves. Movements in the price level are determined by factors outside of what the central bank pays on reserves because banks do not face liquidity constraints and are indifferent between holding securities or deposits. However, if the constraints begin to bind, the central bank can influence the price level with changes in the interbank rate. If the capital constraint binds, then the price level moves in a one to one manner with the target rate. In turn, Ennis suggests that there is a limit to how much the central bank can finance new securities without also influencing the price level.

Dressler and Kersting (2015) take this examination a step further by incorporating a limited participation money market into a monetary DSGE model. In their model, banks can endogenously choose between holding excess reserves or lending out their reserves. Similar to Ennis's examination of banks reserve and capital constraints, Dressler and Kersting then examine the effects of monetary policy under two regimes: a scarce reserve regime (where banks mostly only hold required reserves) and an ample reserve regime (where banks tend to hold many excess reserves). They find that monetary policy has a traditional effect under a scarce reserve regime. That is, a monetary contraction leads to a decline in output and inflation. However, in an ample reserve regime, a monetary contraction and increase in interest rates leads to a a small increase in output and inflation. Put simply, in an ample reserve regime, a small decline in the quantity of reserves has little effect on a bank's reserve constraint. Thus, banks choose to lend more to take advantage of higher interest rates. This leads to a similar effect to that in Ennis (2015), Cochrane (2014) and Ireland (2014) that higher interest rates lead to higher inflation through the Fisher Equation.

While Cochrane (2014), Ireland (2014), Ennis (2015), and Dressler and Kersting (2015) consider IOR when the reserve requirement does not bind, Canzoneri et al. (2017) consider the policy under a scarce reserve regime where the central bank can independently set IOR and the interbank rate. Under this regime, a bank's reserve requirement is binding, and IOR has largely different effects. Canzoneri et al. incorporate IOR into a cash-in-advance DSGE model with financial intermediaries and an interbank market. With these scarce reserves, the central bank faces a trade-off: they can pay a positive IOR to reduce a bank's transaction cost, or they can pay negative IOR to address the monetary distortions discussed in Kashyap and Stein (2012). Canzoneri et al. analytically find that IOR can optimally be set between -.2% and -.4% while adjusting the interbank rate based on macroeconomic conditions.

Paying interest on reserves can also change how the economy reacts to changes in the size of the central bank's balance sheet. Williamson (2018) develops a two sector banking model similar to Armenter and Lester (2016) and others described above to examine how paying interest on reserves changes how a bank operates given balance sheet costs. These banks face capital constraints, which restricts how much they can borrow. Further, many of these banks' assets are used as collateral, so banks are further restricted when borrowing. Both the collateral and capital constraints can bind in equilibrium of Williamson's model because there is a shortage of collateral created by governments facing tighter budget constraints, limiting the quantity of bonds. Many banks are holding reserves that are on the balance sheet of other banks, which is costly. In turn, a reduction in the size of a central bank's balance sheet is welfare improving because it decreases the amount of reserves in the system, reducing this reserve-holding cost to banks and increasing the amount of collateral in the market. However, this can decrease liquidity in the financial sector, increasing risk. Further, with an introduction of an ON RRP facility into the model, a reduction in the size of the balance sheet continues to be welfare improving, but the ON RRP rate also puts a floor on the overnight funding rate. A bank with excess reserves can choose to either hold these reserves and earn interest, lend in the interbank market, or go to the ON RRP facility. A bank will not lend in the interbank market if it can earn a greater return in through the ON RRP, thereby putting a lower bound on the interbank rate. Additionally, an active ON RRP market decreases the spread between the overnight funding rate and the interest rate on reserves. In Williamson's model, the interest rate on reserves is higher than the overnight funding rate, so the imposition of a floor in the ON RRP market can raise the overnight funding rate and shrink the spread with the interest rate on reserves. The introduction of the ON RRP rate as an explicit floor of the overnight rate brings this model closer to the belief set out in Ihrig et al (2015) that the Federal Reserve can use the ON RRP facility to control the interbank rate.

5 Summary and Future Research Agenda

While many strides have been made in understanding interest on reserves over the past decade, there is still more to learn. The papers thus far focus largely on whether the central bank can continue to influence real outcomes and inflation through manipulating interest rates. However, there is not yet a consensus about whether the central bank can effectively target both the interest rate on reserves and the overnight funding rate when the market is satiated with reserves. Indeed, while some of the models assume high amounts of liquidity, others assume there is a scarcity of liquidity the central bank can manipulate. Additionally, many of the papers do not focus on whether the size of the central bank's balance sheet is important for policy in a new regime. Finding a consensus in how liquid the interbank market should be in a model is among the first steps to a greater understanding of a central bank's tools changed with interest on reserves. Moreover, the interbank market and excess reserves have similar maturities, but there is little examination into how this influences the term structure of interest rates throughout the economy. The current literature does not focus on how these other interest rates respond to changes in the interest rate on reserves. An examination into the response of financial markets and the yield curve will give a clearer picture of the ramifications of this new policy.

Taken together, future research should be two pronged. It should examine to a greater extent the asset allocation decisions banks make with interest on reserves. Banks will naturally allocate assets differently when reserves change from a non-interest bearing asset to an interest bearing asset, and these decisions can affect how policy trickles down into the real economy. While models such as Armenter and Lester (2016) look into a bank's choice to enter the interbank market, they do not examine how this influences other aspects of the bank. Further, there is little research thus far into optimal policy with interest on reserves. Berentsen and Monnet (2008) examine how optimal policy must now focus on the interest rate corridor, but there has not yet been a comprehensive model to derive how policy should optimally be conducted in this new regime. An optimal policy rule for the rate on reserves, similar to the Taylor rule, gives models of the real economy such as Ireland (2014) better insight into both how the rate on reserves changes in response to real changes in the economy and vice versa.

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