THREE ESSAYS ON THE FEDERAL FUNDS MARKET

by

Brian Joseph Bonis
A Dissertation
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of
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The Requirements for the Degree
of
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George Mason University
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Three Essays on the Federal Funds Market

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

by

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DEDICATION

This dissertation is dedicated to my children, Jacob and Allie. Since their birth, I have been in graduate school while working full time. I hope this accomplishment serves as an inspiration to them that having a long-term view in life and deferring leisure can pay large dividends.

I dedicate this dissertation to my other half, Kelly. Her consistent love and support enabled me to see this journey to its end.

I dedicate this dissertation to my parents, Barbara and Lenny. They endowed me with a combination of good genes and opportunities which allowed me to make it to this point today. They provided unwavering support and talked me through the toughest of times along the way.

I dedicate this dissertation to my sister, Jessica. The competitive spirit innate in sibling rivalry has been a motivating force throughout this effort.

I dedicate this dissertation to Grandma Marie. Since her passing, she has been the invisible force protecting my life and guiding it to the most fortunate of outcomes.

I dedicate this dissertation to Grandpa Henry and Grandma Julia. Broadway and boats have shown me that culture and experiences make life full, fun and worth living.

I dedicate this dissertation to Bryce, Rich, Jennifer, Uncle Joe, Mike, Ryan, Adam, Tony, Adam again, and all of my family and friends. It truly takes a village.

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ABSTRACT

THREE ESSAYS ON THE FEDERAL FUNDS MARKET

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Economist James D. Hamilton once wrote, “The federal funds market is a good place to start for an understanding of either finance or monetary policy.” In this dissertation, I do a deep dive into the federal funds market and explore how it has evolved since the Great Financial Crisis of 2007-2009 (GFC). Additionally, I investigate changes to Treasury cash management policies and analyze their impacts on taxpayers and the federal funds market. Finally, I advance the federal funds literature by updating Hamilton’s federal funds rate model in his 1997 *AER* paper with contemporary data, and then I create a new federal funds model to better explain the modern-day federal funds market.

In chapter 1, I explore the various characteristics of the federal funds market by carefully defining what constitutes a federal funds trade, explaining how the federal funds rate is calculated, and describing the market participants. Then, I review how the federal funds market operated in the decades leading up to the GFC. I go on to explain how the federal funds market has drastically changed since the GFC and how it operates

today. Finally, I describe the origins of the federal funds market and highlight some market dynamics in its first several decades.

In chapter 2, I describe the Treasury's cash management policies both before and after the GFC. This lays the groundwork for a more in-depth discussion where I examine taxpayer funding costs associated with Treasury cash management policies and potential monetary policy implications related to changes in the size of the Treasury General Account.

In chapter 3, I advance the federal funds market literature by updating Hamilton's 1997 federal funds rate model with data from 2018-2019 to show that the liquidity effect he described in his paper no longer exists in the selected time period. Then, I create a new model to reflect policy and market structure changes that have emerged in recent years.

CHAPTER ONE: EVOLUTION OF THE FEDERAL FUNDS MARKET

Section One: Introduction

"The federal funds market is a good place to start for an understanding of either finance or monetary policy." ~ James D. Hamilton, 1996

Soon after the Federal Reserve's inception in 1913, banks began to trade funds on deposit at their Federal Reserve Bank with one another. This market, the federal funds market, would grow and evolve into one of the most important money markets in finance. Prior research has shown the federal funds interest rate has been the basis for which all other money market rates are anchored (Goodfriend and Whelpley, 1986) and has influenced the term structure of longer-term interest rates (Balduzzi, Bertola, and Foresi, 1997). More broadly, research has shown that the federal funds rate affected the real economy and macroeconomic variables such as unemployment and consumption (Bernanke and Blinder, 1990).

As a central bank, the Federal Reserve takes actions in order to achieve its macroeconomic goals set forth by Congress.[1] These actions are broadly referred to as

[1] The macroeconomic goals set forth by Congress have changed over time. In 1977, Congress amended the Federal Reserve Act to direct the Federal Open Market Committee and the Board of Governors "to promote effectively the goals of maximum employment, stable prices and moderate long-term interest rates."

"monetary policy." Setting the federal funds interest rate has been a critical monetary policy tool used by the Federal Reserve for many decades.

The rest of this chapter proceeds as follows. In section two, I explore the various characteristics of the federal funds market by carefully defining what constitutes a federal funds trade, explaining how the federal funds rate is calculated, and describing the market participants. In section three, I review how the federal funds market operated in the decades leading up to the Great Financial Crisis of 2007-2009 (GFC). In section four, I explain how the federal funds market has drastically changed since the GFC and how it operates today. Finally, in section five, I summarize the origins of the federal funds market and highlight some market dynamics in its first several decades.

Section Two: What is the Federal Funds Market?

Financial markets can broadly be thought of as markets where funds are transferred from lenders to borrowers (Cook and LaRoche, 1998). The federal funds market, then, refers to the market where federal funds are borrowed. In layman's terms, federal funds can be thought of as funds that banks (and some other financial institutions) hold on deposit at the Federal Reserve, the central bank of the United States. These funds are commonly referred to as "reserves". The federal funds interest rate is the market rate paid by the borrower of the federal funds to the lender.

The federal funds interest rate plays an important role in both the American and global economies. As put forth in the *Purposes & Functions* (Federal Reserve System, 2016), "a change in the target for the federal funds rate normally will be accompanied by changes in other interest rates and in financial conditions more broadly; those changes will then affect the spending decisions of households and businesses and thus will have implications for economic growth, employment, and inflation."

Forthcoming in this chapter, I will discuss market dynamics that influence changes in the federal funds rate, but I begin by defining some fundamental terms and characteristics of the federal funds market.

1.2.1 Definition of a Federal Funds Transaction

Plainly speaking, a federal funds trade is when banks borrow money, or reserves, from other banks and financial institutions between their accounts held at the Federal

Reserve. The Federal Reserve Bank of New York (FRBNY) defines a federal funds transaction as an unsecured loan of U.S. dollars to a "borrower" or "purchaser" that is a depository institution from a "lender" or "seller" that is a depository institution, foreign bank, government-sponsored enterprise (e.g. Federal Home Loan Banks, Fannie Mae, and Freddie Mac) or other eligible entity.[2,3] Federal funds trades are conducted as privately negotiated contracts.

1.2.2 Federal Funds Trade Contracts

Financial institutions engage in a federal funds trade by finding a willing counterparty, either bilaterally or through a federal funds broker, and then negotiating the terms of a federal funds contract. The contract terms of federal funds transactions include characteristics such as the amount of the loan, duration of the loan, recurrence of the loan, and importantly, interest rate on the loan.

The amounts of a federal funds loans are determined by the two counterparties involved in the federal funds trades. The durations of federal funds loans are predominantly overnight, although trades with longer terms do occur on occasion. Counterparties sometimes choose to have an open trade (also called a continuing contract

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[2] https://www.newyorkfed.org/aboutthefed/fedpoint/fed15.html

[3] A more technical approach to defining a federal funds trade is to go directly to the FR 2420 Report of Selected Money Market Rates instructions. The FR 2420 is a transaction-based report created by the Federal Reserve that collects daily data, including federal funds data, from commercial banks, thrifts, and U.S. branches and agencies of foreign banks. In the FR 2420 instructions, federal funds purchased are defined as "unsecured borrowings denominated in U.S. dollars from counterparty types that are exempt entities as defined in Section 204.2(a)(1)(vii)(A) of Regulation D."
See the FR 2420 instructions at
https://www.federalreserve.gov/reportforms/forms/FR_242020181001_i.pdf

or rollover) with no specific maturity date. In an open trade contract, a maturity date is not specified and advance notice to terminate the contract is not required. An essential component of a federal funds contract is the interest rate to be paid by the borrower, which is negotiated among the two counterparties.

1.2.3 Effective Federal Funds Interest Rate

There are tens of billions of dollars worth of federal funds trades taking place each business day and, as described above, each trade has its own privately negotiated interest rate. The FRBNY publishes a widely referenced summary statistic called the effective federal funds rate (EFFR). The EFFR is the key policy interest rate that is targeted by the Federal Open Market Committee (FOMC), the policymaking body of the Federal Reserve System.

Currently, the FRBNY calculates the EFFR by using the volume-weighted *median* of overnight federal funds transactions as reported by federal funds borrowers in a daily data collection called the FR 2420 Report of Selected Money Market Rates.[4] Prior to the creation of the FR 2420 Report (which began in April 2014), FRBNY collected federal funds transaction data from federal funds brokers, and published the EFFR based on the volume-weighted *mean* of the trades.[5] By 9 a.m. E.T. each weekday morning, the FRBNY publishes the daily EFFR for the prior business day.

[4] https://apps.newyorkfed.org/markets/autorates/fed%20funds
[5] See the March 2015 statement from FRBNY: https://www.newyorkfed.org/markets/opolicy/operating_policy_150202.html

1.2.4 Market Participants

As described in the FRBNY's definition of a federal funds transaction, participants in the federal funds market include the borrowers which are made up of domestic and foreign depository institutions (banks) and the lenders which are comprised of domestic and foreign depository institutions and government-sponsored enterprises. Federal funds transactions are typically made either between two banks or between a bank and a government-sponsored enterprise such as a Federal Home Loan Bank. These categories of participants are more clearly defined in the Federal Reserve's FR 2420 Report instructions which define the types of institutions that are required to report that they have borrowed federal funds, as well as the counterparty types that they are borrowing federal funds from.[6]

Even though federal funds trades are settled in accounts held at the Federal Reserve, some smaller banks that *do not* have accounts at the Federal Reserve participate in the federal funds market as well. These banks are referred to as respondent banks; they establish accounts with larger banks that *do* have accounts at the Federal Reserve and are willing to trade on their behalf. These larger banks are referred to as correspondent banks, and they have increasingly become more active in the federal funds market since the 1950's (Willis, 1967).[7]

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[6] The FR 2420 is not a comprehensive collection of federal funds trades. Some trades do not have to be reported based on the size and activity of the institutions.
7 For more information on Correspondent/Respondent relationships, please see: https://www.frbservices.org/financial-services/accounting/service-setup/respondent-correspondent.html

The composition of federal funds borrowers and lenders have changed over time and are the subject of the forthcoming sections.

1.2.5 Federal Funds Rates and Volumes

To give a sense for the federal funds rate over time, the daily effective federal funds rate has averaged about 4 ¾ percent since 1954 as shown in figure 1. More recently, in response to COVID-19 and the ensuing financial shock, the FOMC lowered the EFFR target range to 0 to 25 basis points, its zero lower bound. After the target range was reduced, effective March 16, 2020, the EFFR averaged just under 10 basis points throughout 2020, as shown in figure 2.[8]

[8] See the FOMC policy statement for March 15, 2020: https://www.federalreserve.gov/newsevents/pressreleases/monetary20200315a.htm

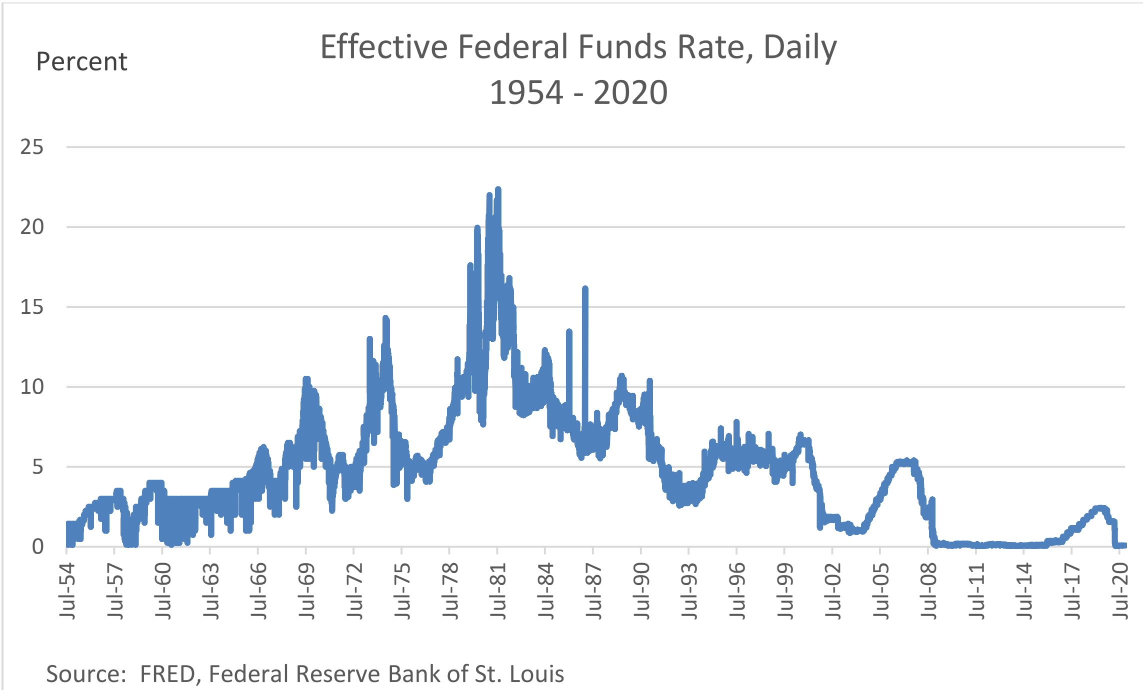

Figure 1

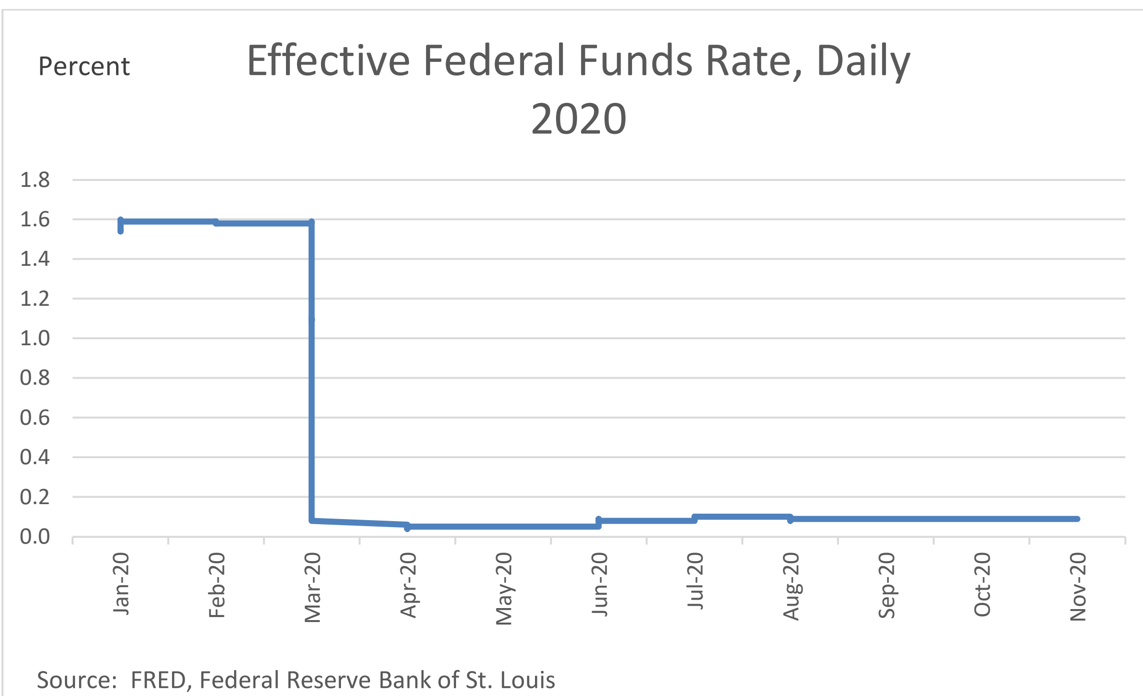

Figure 2

Federal funds overnight trading volumes, as reported by the relatively new FR 2420 data collection, have averaged about $75 billion per day from 2016 to 2020, as plotted in figure 3 below.

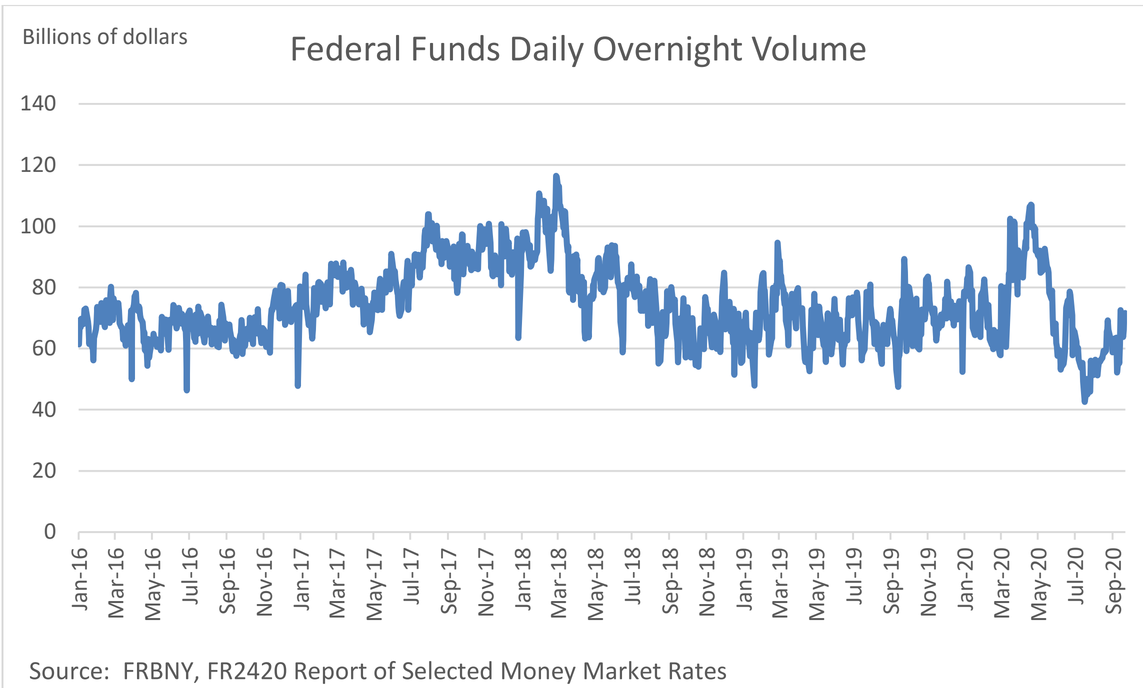

Figure 3

Rates and volumes have varied over the decades based on policy decisions as well as evolving market dynamics and regulations. The evolution of the federal funds market since its inception is the topic of the forthcoming sections.

Section Three: Federal Funds Market Dynamics Prior to the 2007-2009 Great Financial Crisis

The GFC was a major turning point for the federal funds market and monetary policy implementation. Bank balances held at the Federal Reserve (reserves) soared from about $800 billion to over $2.5 trillion from 2007 to 2014. This increase in reserves had major implications for the federal funds market.

In this section, I will describe the dynamics of the federal funds market in the scarce reserves environment that existed for about 50 years leading up to the GFC. In section four, I will outline how the federal funds market has changed since the crisis and how it operates today. In section five, I will summarize how the federal funds market operated in the first half of the twentieth century.

1.3.1 Reserves

As noted in the previous section, federal funds can be thought of as funds that banks (and some other financial institutions) hold on deposit at the Federal Reserve. These funds, plus banks' holdings of vault cash, are described as *reserves*. Prior to the GFC, the total supply of reserves played a key role in determining the federal funds interest rate.

The level of reserves for a bank fluctuates each day. Bank deposits or receipts add to the level of bank reserves and withdrawals or expenditures decrease the level of reserves (Hamilton 1996). To get a sense for the daily volatility in the level of reserves, figure 4 below shows a daily times series for reserve balances of banks from March 1989 to November of 1991 that were obtained and made public by Hamilton:

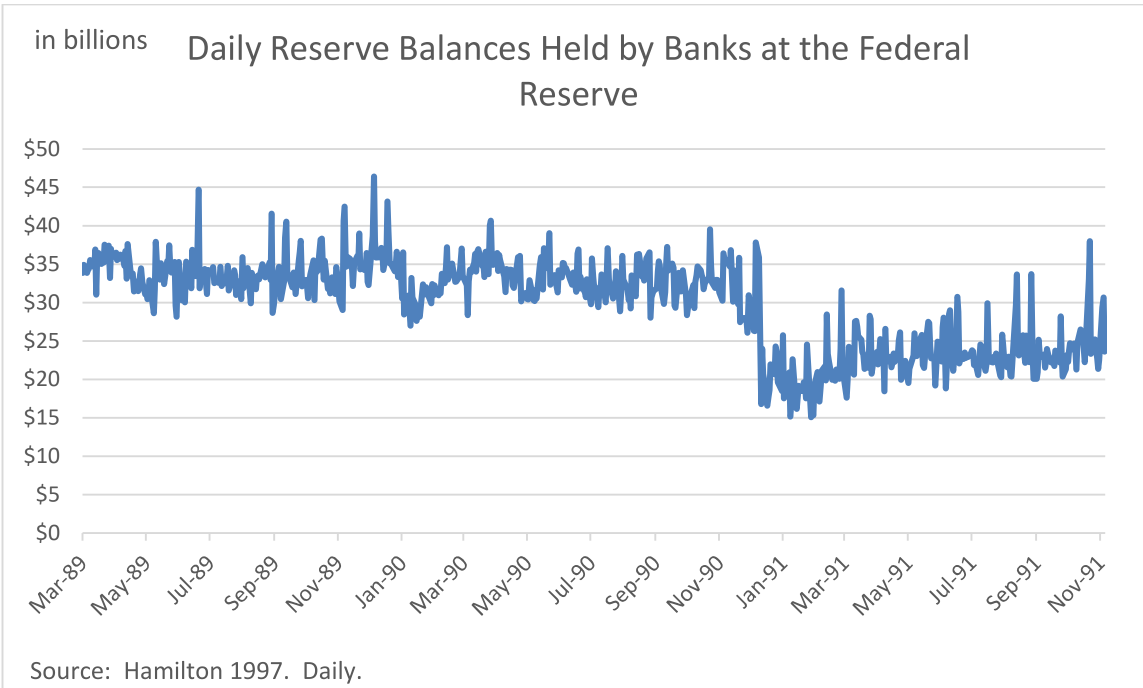

Figure 4

Looking at the time period leading up to the GFC, bank reserves were low relative to today's levels and steady, averaging about $17 billion from 2005 through 2007, and then soared as a result of the Federal Reserve's response to the GFC, as shown in figure 5.

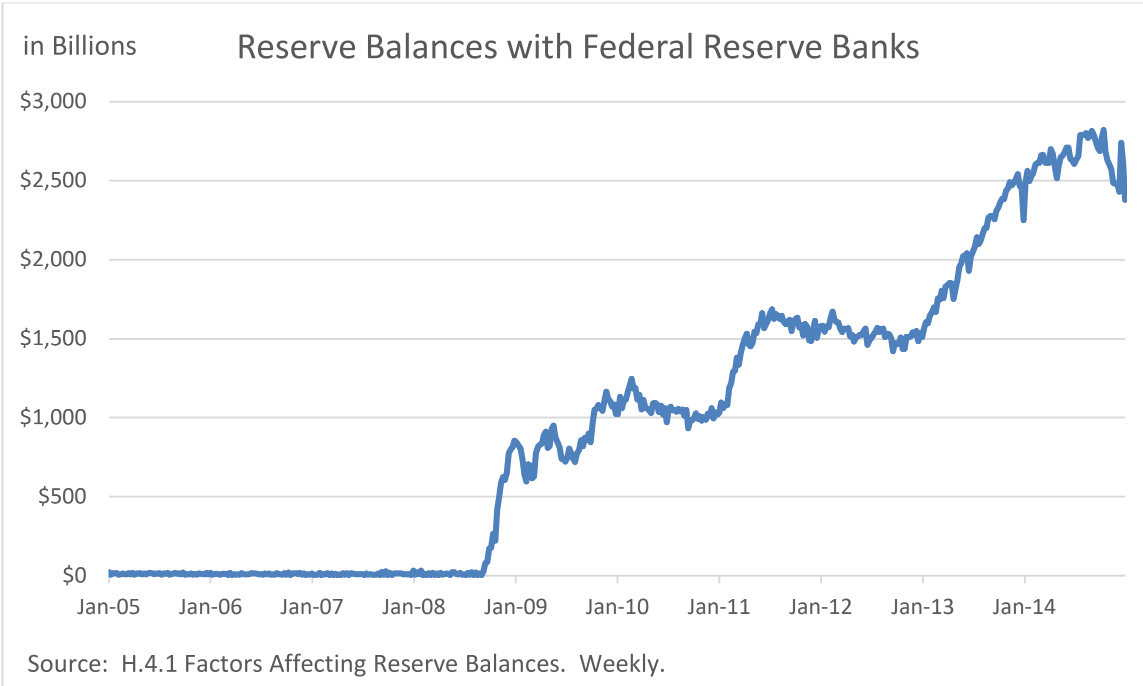

Figure 5

1.3.2 Demand for Reserves

Even without supervision or regulations, banks are motivated to hold reserves (Hamilton 1996). A bank that doesn't have funds available for the needs of its customers wouldn't fair very well. Banks analyze the inflows and outflows of their customers' accounts so that they can forecast how many reserves are needed on hand each day.

While day to day reserve volatility exists, banks also have to deal with intraday volatility. The Federal Reserve aids intraday bank transfers by allowing banks to send funds to another bank, even if they have zero deposits on hand at that time. One step the Federal Reserve takes to protect itself against banks being overdrawn is it implements and enforces a reserve requirement for each bank. The reserve requirement necessitates that banks hold reserves at a certain ratio to the size of their customers' deposits (Hamilton 1997).[9] The reserve requirement was a major source of reserve demand for banks.

Banks may want to hold reserves above and beyond their reserve requirements. These reserves are typically referred to as "excess reserves". Excess reserves can provide cushion for day to day volatility, as well as opportunities for banks to earn interest by lending them out in the federal funds market (Poole 1968).

1.3.3 Supply of Reserves

The aggregate supply of reserves in the banking system is influenced by a variety of factors. Table 1 of the Federal Reserve's H.4.1 Factors Affecting Reserve Balances of Depository Institutions and Condition Statement of Federal Reserve Banks, lists the different factors that both add to and detract from the supply of reserves.[10]

Some notable factors that add to the supply of reserves include the Federal Reserve's Securities Held Outright, Repurchase Agreements, and Loans to Depository Institutions. Securities Held Outright include Treasuries and other securities that the Federal Reserve purchases from *primary dealers*. Primary dealers are counterparties that are approved to engage in transactions with the FRBNY.[11] When the Federal Reserve

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[9] In March 2020, the Federal Reserve lowered its reserve requirement to $0.
[10] H.4.1 Release: https://www.federalreserve.gov/releases/h41/
[11] Primary dealers are expected to make markets for the FRBNY and are expected to bid in the FRNBY auctions. For more information on primary dealers, please see: https://www.newyorkfed.org/markets/primarydealers

purchases a security, say at a face value of $100 as an example, the primary dealer's bank account at the Federal Reserve, which is a liability of the Federal Reserve, is credited with the $100, and hence, total reserves held at the Federal Reserve increases by $100. The par value of the security is added to the asset side of the Federal Reserve's balance sheet, as shown in the T-account in table 1.

Table 1 – Federal Reserve purchases securities

Federal Reserve's Balance Sheet	
Assets	**Liabilities**
Securities held outright ↑ $100	Reserves ↑ $100

On the contrary, when the Federal Reserve sells securities to primary dealers, the Federal Reserve's securities holdings go down, and the primary dealer's account at the Federal Reserve is debited. An accounting example of the Federal Reserve selling a $100 security is shown in table 2.

Table 2 – Federal Reserve sells securities

Federal Reserve's Balance Sheet	
Assets	**Liabilities**
Securities held outright ↓ $100	Reserves ↓ $100

Repurchase agreements have a similar, although temporary, effect. When the Federal Reserve purchases a security on a temporary basis through a repurchase agreement, reserves go up until the seller of the security buys it back at a later date.[12] And finally, Loans to Depository Institutions, which include bank loans made at the commonly referred to "Discount Window", increase when the Federal Reserve credits bank accounts as part of their loan issuance.

Many factors drain reserves from the banking system including the selling of securities, as described above, Currency in Circulation and the U.S. Treasury, General Account (TGA). Currency in Circulation refers to Federal Reserve notes in circulation. Roughly speaking, when a customer goes to their bank's ATM to withdraw money, Currency in Circulation increases and reserves decrease. The TGA, which is the subject of the second chapter of this dissertation, is a deposit account held at the Federal Reserve that is owned by the U.S. Treasury. When it increases, for example due to the Internal

[12] In a repurchase agreement, or "repo" for short, the Desk purchases Treasury, agency debt, or agency mortgage-backed securities from a counterparty subject to an agreement to resell the securities at a later date. Federal Reserve repo purchases temporarily increase the quantity of reserve balances in the banking system. For more information on Federal Reserve repo purchases, see: https://www.newyorkfed.org/markets/domestic-market-operations/monetary-policy-implementation/repo-reverse-repo-agreements

Revenue Service collecting taxes, reserves fall as bank customers decrease funds from their bank accounts and transfer them to the U.S. Treasury.

1.3.4 Supply and Demand for Reserves – Pre-GFC

The pre-GFC standard framework for the supply and demand of reserves is shown in figure 6 below, as originally shown in Ihrig, et al. (2015).

Banks' Demand for and the Fed's Supply of Reserve Balances before the Financial Crisis

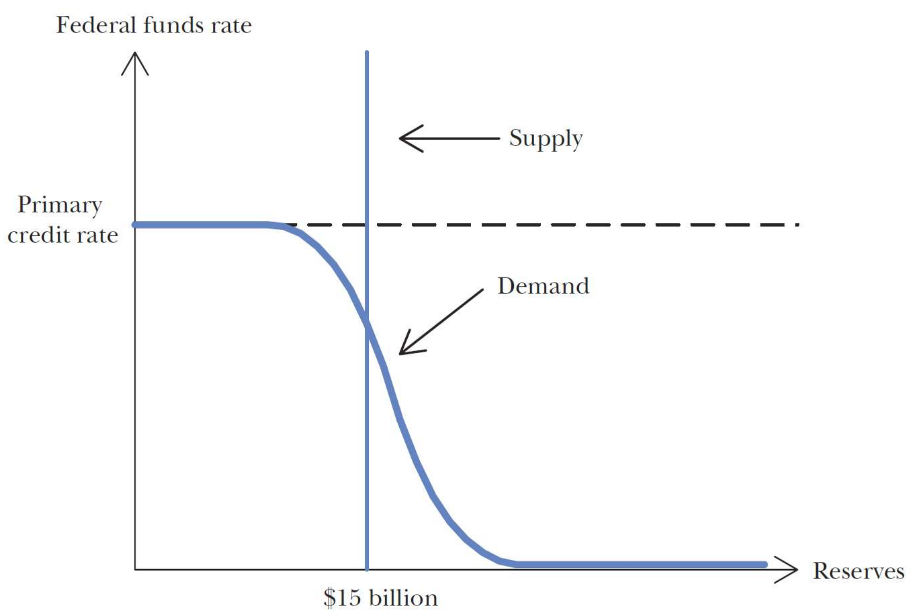

Figure 6

This figure illustrates some key characteristics of the federal funds market pre-GFC. With respect to the demand curve, there are three important points to highlight.

First, there is a theoretical cap to the federal funds rate equal to the primary credit rate. The primary credit rate, more commonly referred to as the discount window rate, is the rate at which the Federal Reserve loans funds to banks in need of funding that meet certain requirements, including having sufficient amounts of specified collateral. If a bank is certain of its reserve needs and can borrow money from a trustworthy counterparty (such as the Federal Reserve) at the primary credit rate, then, in theory, they would not pay an interest rate above the primary credit rate in the federal funds market (Poole, 1968). It is important to point out here, that there is a major caveat to this that is well documented in federal funds market literature. There exists a "stigma effect" where banks fear that by borrowing from the Federal Reserve's discount window, they are signaling to markets that they are in some duress. Hence, banks may choose to borrow funds in the federal funds market at rates that are above the discount window rate in order to preserve anonymity (Armantier et al., 2015).

Second, the demand curve for the federal funds rate has some lower bound. Presumably, the federal funds rate could fall to the net interest rate banks earn by simply leaving their funds at the Federal Reserve. In the pre-GFC environment, there were virtually zero costs for storing funds at the Federal Reserve, and, these balances did not earn any interest. This resulted in a net interest rate return of zero percent. Hence, in theory, banks would not lend their reserves out in the federal funds market at a rate below zero percent. This lower bound is often referred to as the zero lower bound (ZLB).

Third, the demand curve for the federal funds rate is downward sloping. As the supply of bank reserves decreases, banks are willing to bid higher in the federal funds market to obtain the scarce reserves in order to maintain levels of reserves that are above their reserve requirements (Poole 1968). As the supply of bank reserves increase, more and more banks are meeting or exceeding their reserve requirements, and therefore, there is less demand for banks to borrow reserves, and so lenders will accept lower rates of interest.

The supply curve for reserves is perfectly inelastic. Although there are many factors that influence the aggregate supply of reserves, as explained earlier in this section, given that the Federal Reserve can add or subtract reserves by purchasing or selling securities, conducting repurchase agreements or reverse repurchase agreements, or making loans, the Federal Reserve ultimately can determine the banking system's aggregate level of reserves.

1.3.5 Conclusion

Throughout the period leading up to the GFC, the federal funds market was a vibrant market where banks would borrow excess reserves from other banks in order to meet their reserve requirements. The Federal Reserve added or subtracted reserves along the downward sloping part of the demand curve, by purchasing and selling securities and repos, and making loans, which would move the federal funds rate to be where the FOMC directed it to be as part of its monetary policy implementation.

Much research has been done attempting to quantify how much a change in the supply of reserves impacts the federal funds rate. For example, Hamilton estimated that, in the early 1990's, if the Federal Reserve were to make an unanticipated open market sale of $440 million in securities, the federal funds rate would increase by 10 basis points (Hamilton 1997).

These estimates would soon lose their relevance as the Federal Reserve moved to an abundant reserves regime post-GFC, which is the topic of the next section.

Section Four: Federal Funds Market Dynamics After the 2007-2009 Great Financial Crisis

In response to the GFC, the FOMC began a series of large-scale asset purchase programs (LSAPs) and ramped up its lending programs. As mentioned in section three, securities purchases made by the Federal Reserve and the issuance of loans increase the level of bank reserves. From 2007 to 2014, reserves in the system rose from $800 billion to over $2.5 trillion.

As will be discussed below, the Federal Reserve implemented two new tools to maintain control over the federal funds rate in this new regime of abundant reserves. First, in October 2008, the Federal Reserve began to pay banks interest on their excess reserves (IOER). Second, in 2013, the Federal Reserve began conducting daily overnight reverse repurchase agreement (ON RRP) operations.

The increase in reserves, the implementation of the Federal Reserve's new tools, and an evolving regulatory environment had major implications for the federal funds market and how monetary policy was implemented.

1.4.1 Interest on Reserves

The Financial Services Regulatory Relief Act of 2006 provided the Federal Reserve with the authority to pay banks interest on their reserves. In October 2008, the Federal Reserve began paying interest on reserves at spreads of 10 basis points below the federal funds rate target for required reserves and 75 basis points below the target for excess reserves (Ireland 2019).[13] By the end of 2008, the federal funds rate target range had been lowered to 0 to 1/4 percent, and the interest paid on both required and excess reserves was set at 1/4 percent, where it would remain for the next 7 years.

1.4.2 Supply and Demand for Reserves – Post-GFC

In section 3.4 Supply and Demand for Reserves – Pre-GFC, I described the lower bound for the reserves demand curve being at zero percent. Given that banks earned a net interest rate of zero percent on their reserves held at the Federal Reserve, they would be open to accepting the best interest rate they can in the federal funds or other money markets, so long as it is above zero percent. After the implementation of IOER, the lower bound changed. Figure 7 below shows the demand and supply of reserves in the post-GFC abundant reserves environment from Ihrig, et al. (2015).

[13] The Financial Services Regulatory Relief Act of 2006 authorized the Federal Reserve to begin paying interest on reserves on October 1, 2011. This effective date was moved up to October 1, 2008, in the Emergency Economic Stabilization Act of 2008.

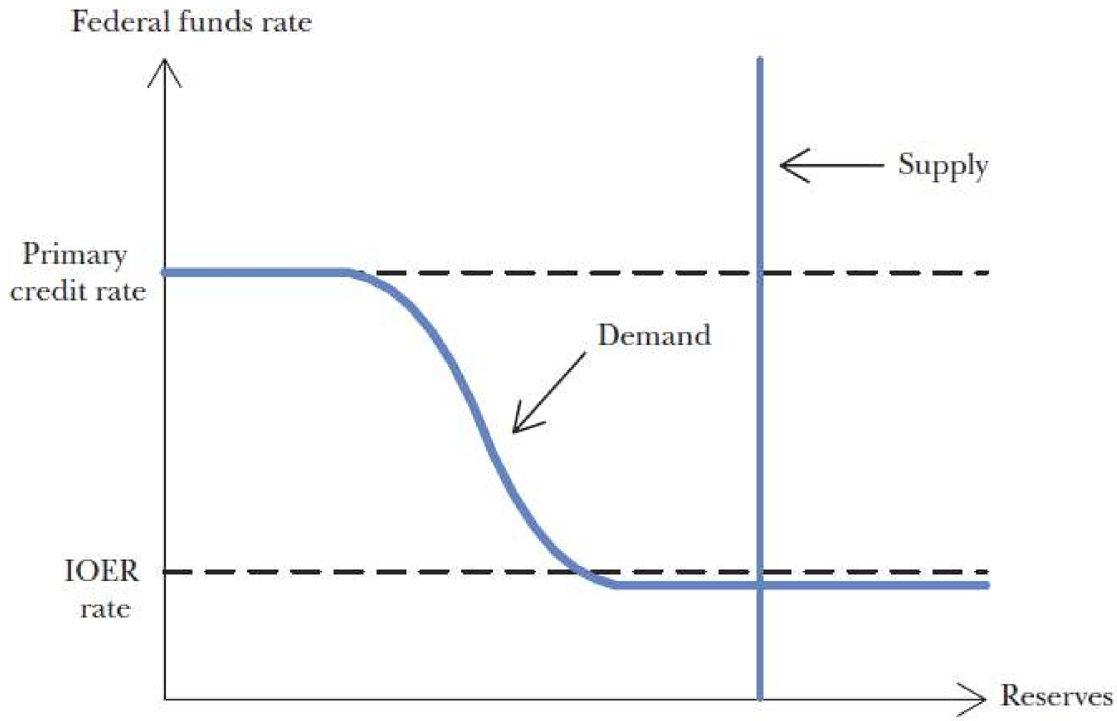

Figure 7 – Demand and Supply of Reserves – Post GFC

As a result of the increases in Federal Reserve loans and large-scale asset purchase programs in response to the GFC, the level of reserves in the banking system moved up markedly. The vertical reserves supply curve shifted to the right along the x-axis (Reserves) and intersects the flat portion of the reserves demand curve. On this perfectly elastic end of the demand curve, small changes to the supply of reserves do not impact the interest rate banks are willing to pay to borrow federal funds. Reserves are so abundant, that most banks easily meet their reserves requirements and have no need to borrow federal funds in order to avoid shortfalls to their reserve requirements.

The primary factor driving the federal funds rate in an abundant reserves regime is the opportunity cost to lending outside the federal funds market; more specifically, the interest rate reserves earn from the Federal Reserve through IOER, or, the interest rate that can be earned by lending into other money market instruments such as Treasury bills or repurchase agreements.

In effect, the IOER rate serves as the new floor for the federal funds rate, as opposed to zero percent in the pre-GFC federal funds market. In theory, a bank will only lend in the federal funds market if it can earn an interest rate that is above IOER. As IOER moves up, the federal funds rate that a bank is willing to lend for in the federal funds market for moves up. The same principle holds, in reverse, when the IOER rate falls. It is this mechanism which makes setting the IOER the primary tool for moving the federal funds rate in an abundant reserves regime (Ireland, 2019).

1.4.3 Leaky Floor

Figure 7 illustrates that, in theory, the IOER should serve as a floor for the federal funds rate. Practitioners at the Federal Reserve confirmed that notion in statements in 2008.[14] However, in reality, the federal funds rate typically printed below the IOER rate, as shown in figure 8.

[14] In the August 5, 2008, FOMC meeting transcript, System Open Market Manager William Dudley stated "we continue to press for legislation that would accelerate the timing of the Federal Reserve's authority to pay interest on reserves. Being able to pay interest on reserves would put a floor under the federal funds rate."

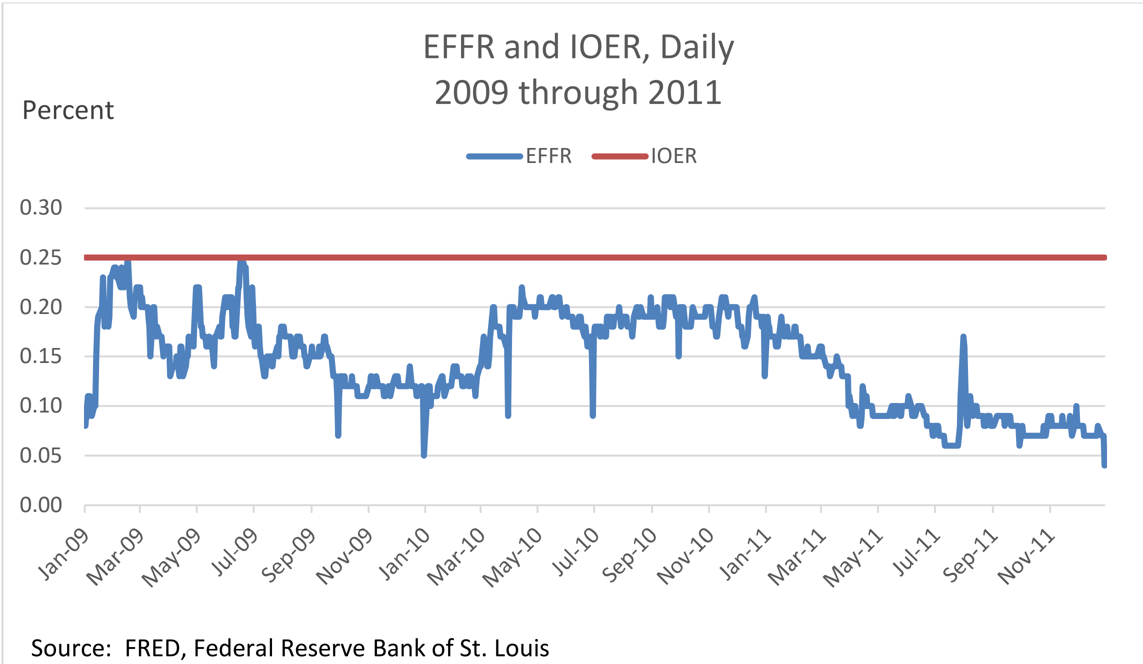

Figure 8

Why would a financial institution lend reserves into the federal funds market at a rate *lower* than the rate they can earn by simply leaving the funds in their account which earn IOER? The answer is that many of the lenders in the federal funds market during this time period were government-sponsored enterprises that were not eligible to earn IOER.

Due to this ineligibility, the opportunity costs for government-sponsored enterprises to lend are either zero percent, or, whatever else they can earn in other money market instruments. If we add in other money market interest rates to figure 8, you can see some other lending opportunities the GSE's had available to them, such as Treasury bills and repurchase agreements, shown in figure 9 below.

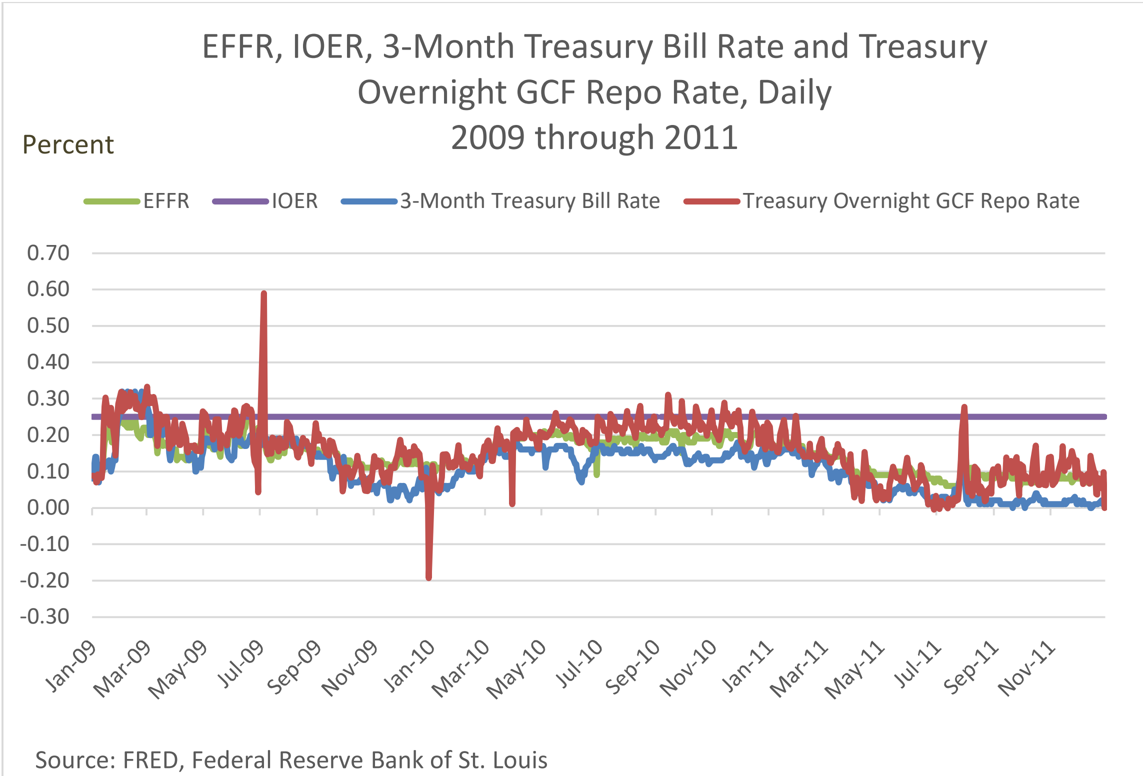

Figure 9

This constellation of money market rates, including the EFFR, printing below the IOER created an arbitrage opportunity for financial institutions who *are* eligible for IOER. If a bank can borrow funds in the federal funds market at the EFFR, then they can leave those funds in their bank accounts at the Federal Reserve and earn a profit equivalent to the spread between IOER and the EFFR. The overwhelming majority of federal funds activity in the post-GFC era reflect this arbitrage trade (Banegas and Tase, 2020).

1.4.4 Overnight Reverse Repurchase Agreement Tool

In an effort to gain even greater control over the EFFR, the Federal Reserve began testing, and ultimately implementing, overnight reverse repurchase agreement (ON RRP) operations in 2013. In an ON RRP, the Federal Reserve sells a security to a counterparty and agrees to buy the security back the next day.[15] The Federal Reserve accepts bids from counterparties in an auction process subject to counterparty limits and a maximum offering interest rate (ON RRP rate) that is set by the FOMC.

A key element to the design of the ON RRP was to allow a wide range of counterparties to participate which included GSEs, money market mutual funds, primary dealers and banks. By allowing a wide range of counterparties to participate, the ON RRP rate serves as a more solid floor under the EFFR as the GSEs are reluctant to lend at federal funds rates that are below what they can earn in the ON RRP facility. In addition, given that the counterparty list includes a large number of the biggest money market participants, such as large money market mutual funds, the ON RRP rate influences other money market rates more broadly (Anderson and Huther, 2016). As of late 2020, there were over 120 eligible counterparties.[16] Figure 10 shows that the ON RRP rate did indeed serve as a solid floor for the EFFR and was a key tool used, in conjunction with IOER, in lifting the federal funds rate off of the zero lower bound in December 2015 and the subsequent rate hike in December 2016.

[15] See https://www.federalreserve.gov/monetarypolicy/overnight-reverse-repurchase-agreements.htm
[16] The most recent counterparty list can be found here: https://www.newyorkfed.org/markets/rrp_counterparties.html

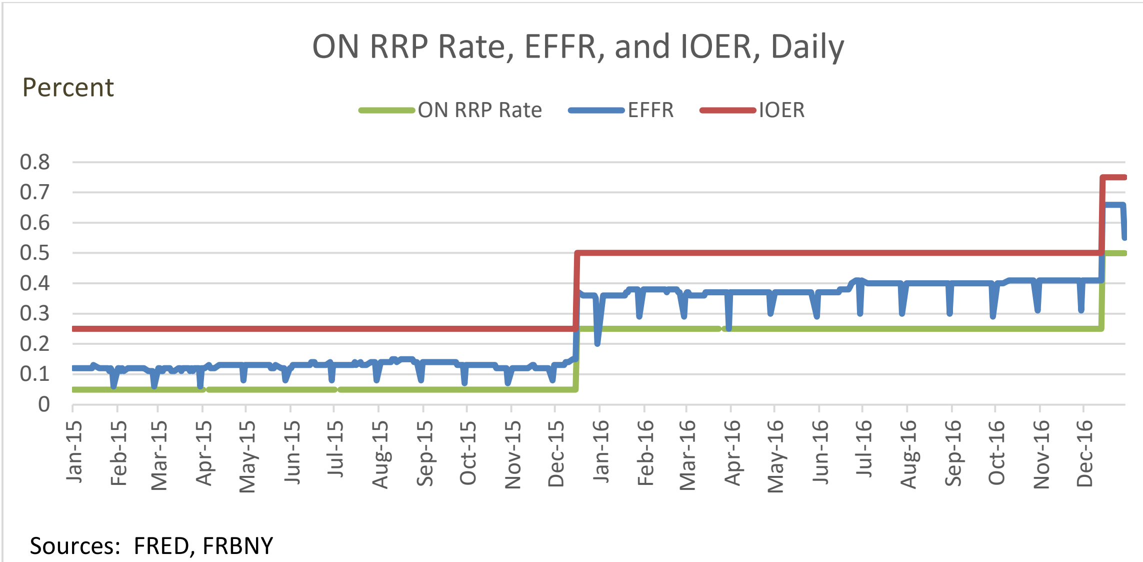

Figure 10

1.4.5 Post-GFC Regulatory Considerations

There are several regulatory considerations to take into account when looking at the post-GFC federal funds market (Banegas and Tase, 2020). First, effective April 1, 2011, Federal Deposit Insurance Company (FDIC) altered their fee assessment base to include domestic banks' total assets. This alteration increased the cost for domestic banks holding reserves relative to foreign banks. As a result, the foreign banks were in better position to profit from the IOER – EFFR arbitrage spread relative to domestic banks, and hence, the composition of federal funds transactions and reserves holdings held by foreign banks increased relative to domestic banks.

In addition, regulatory changes under the Basel III framework impacted bank demand for reserves. In the new liquidity coverage ratio (LCR), excess reserves were viewed favorably, as a level 1 high quality liquid asset, and as a result, banks demand for reserve balances increased. Furthermore, foreign banks were subject to quarter-end Basel III leverage ratio reporting. Foreign banks would decrease their reserve holdings on quarter-end dates to get more favorable leverage ratios. As a result, money market mutual funds (MMMFs) that typically lent to foreign banks would have to find alternative quarter-end investments as the banks were incentivized to not borrow as much from the MMMFs on quarter-end dates. This resulted in increased usage of the Federal Reserve's ON RRP facility by MMMFs on quarter-ends.

1.4.6 Conclusion

The GFC resulted in major changes in how monetary policy was implemented and how the federal funds market operated. Prior to the GFC, the federal funds demand was driven primarily by banks borrowing reserves to meet their reserve requirements and lenders trying to earn as much interest as they could in the absence of IOER. Monetary policy was implemented using a "corridor" framework where the federal funds rate was influenced by the supply and demand for reserves, and the rate reliably printed in the corridor between the zero lower bound and the primary credit rate.

Subsequent to the GFC, as reserves in the banking system became abundant, the Federal Reserve shifted to a "floor" operating regime, in which two administered interest rates, the IOER and ON RRP rates, were used to control the federal funds rate through arbitrage and opportunity rate channels. The Federal Reserve continues to operate in the floor regime today.

In the next section, I recap the early days of the federal funds market and how it evolved from its infancy in the early 20^{th} century up until the pre-GFC regime.

<u>Section Five: The Early Years of the Federal Funds Market</u>

The previous two sections are relevant for understanding how the federal funds market has operated in recent decades. But the federal funds market first came into existence soon after the Federal Reserve System was created in 1913. In this section, I summarize the origins of the federal funds market and highlight some market dynamics in its first several decades.

1.5.1 The Origin

Soon after the Federal Reserve Act was passed in 1913, the Federal Reserve System began to operate. Member banks opened accounts with their regional Federal Reserve Banks, and hence, federal funds were born. Banks soon were able to transfer funds from one account to another using the Federal Reserve System's telegraphic network (Spahr 1926).

By the early 1920's, banks were entering into agreements to borrow funds from other banks that had excess deposits above and beyond their reserve requirements. The borrower would refund the lender by issuing a cashier's check, which included an interest component, to a clearinghouse (Anbil et al. 2020). These trades were similar to the types of trades that occurred in the pre-GFC federal funds market described in section three, although the size of this market was pretty small at the time relative to other money markets.

Much of the federal funds trades at the time were transacted through the New York Clearing House. Many trades outside of New York were done locally on a bank to bank basis. Securities dealers (known as "discount houses" in the 1920s) played a role in facilitating federal funds trades at the time. They would often sell acceptances or government securities to the Federal Reserve Banks in exchange for federal funds. They would use those federal funds for some of their purchases. As the discount houses were active in buying and selling federal funds, some acted as federal funds brokers and they would help facilitate federal funds transactions between banks. It was reported in the *Herald Tribune* at the time that the leading brokers were four or five of the large discount houses (Anbil et al. 2020).

The federal funds loans first started in the New York City region, but expanded to other Federal Reserve districts through the remainder of the 1920's (Anbil et al. 2020). Federal funds daily trading volume increased from about $20 million in 1921 to $100 - $250 million after 1925, with about 30-40 banks actively trading (Willis 1967).

Anbil (et al. 2020) created a federal funds rate series going back to 1928 by using daily market quotes published in the *New York Herald Tribune* and *Wall Street Journal*. The federal funds rate consistently printed above the zero lower bound (even after the Great Depression was under way). It often printed below the FRBNY discount window rate, similar to how the federal funds rate behaved in the pre-GFC monetary corridor regime. Though at times, the print exceeded the discount rate, possibly due to the fact that the member banks didn't have enough eligible collateral to qualify for a discount loan, or the fact that nonmember banks did not have access to the discount window but still participated in the federal funds market.

1.5.2 The Federal Funds Market in the 30's and 40's

Soon after the Great Depression, the federal funds market had dried up. As a result of open market operations taken by the Federal Reserve, and lack of lending opportunities due to the depressed economy, the amount of reserves held at the Federal Reserve increased from about $200 million dollars in 1929 to $1.5 billion dollars by the end of 1939. This increase in reserves led to an environment where banks no longer needed to borrow federal funds to meet their reserves requirements. It wasn't uncommon to see the *Wall Street Journal* indicate that federal funds were offered at a certain rate, but with no takers (Anbil et al. 2020). In that way, much of the 1930's federal funds market was low in volume, somewhat similar to that of the post-GFC, high reserves, environment described in section four.

After the start of World War II, the Federal Reserve and Treasury agreed to take action to cap Treasury interest rates to ease the funding of the war. Long-term Treasury yields were capped at 2 ½ percent.

With respect to Treasury bills, the Federal Reserve implemented a policy to buy bills at 3/8 percent. Additionally, the Federal Reserve allowed the sellers of the bills to purchase them back at a later date at the same 3/8 percent rate. On top of that, the Federal Reserve announced that these transactions would settle on the same day. Put together, these policies made bills virtually equivalent to cash. Banks held bills as a substitute to excess reserves, and earned a risk-free return of 3/8 percent (Anbil et al., 2020). In that sense, the interest banks earned on the bills had a similar effect to how IOER and ON RRP work in conjunction to put upward pressure on the federal funds rate today. This is evidenced by the fact that the federal funds rate printed above the 3/8 percent rate for the majority of the time that the Federal Reserve's bills purchasing program was in place.

Additional changes in federal funds rate dynamics in the 1940's relative to its early years were the fact that the federal funds rate printed more consistently below the discount rate. With high Treasury debt issuance as a result of the funding of World War II, banks had more eligible collateral to qualify for discount loans, if needed.

With respect to market middlemen, another difference in the market at the time was that the majority of the federal funds trades were being facilitated by the lead broker at the time, Garvin Bantel Corporation. In addition, major banks began trading with their respondent banks on a bilateral basis (Anbil et al., 2020).

1.5.3 The Federal Funds Market in the 50's, 60's and 70's.

In the early 1950's, banks were flush with excess reserves and Treasury securities that could easily be converted to reserves. This resulted in low volume in the federal funds market and banks were easily meeting their reserves requirements. As the economy began to grow, banks began to issue more and more loans. Additionally, the Federal Reserve's cap on Treasury security yields ended and the Federal Reserve began a tightening cycle in 1954. Bank reserves were getting scarce and banks had to start paying attention to reserve management again to ensure they didn't fall below their reserve requirements and to warrant they could satisfy their customer's needs. As a result, activity in the federal funds market picked up again (Anbil and Carlson, 2019).

The uptick in federal funds activity attracted more market participants, which encouraged even more middlemen to get involved. Several other brokers entered the market, in addition to Garvin Bantel, and bilateral trading among banks increased as well (Willis, 1967). The increased participation led to lower minimum trade sizes and allowed smaller banks to participate, which also contributed to a boost in federal funds volumes.

In the 1960's, correspondent banking activity grew. Smaller regional banks, that typically had limited lending opportunities, were looking to lend out their large inflows of deposits. As banking technology improved, and as regulations changed, including the Comptroller of the Currency eliminating capital adequacy restrictions on federal funds purchases in 1963 and the Federal Reserve Board allowing member banks to purchase federal funds from nonmember respondents in 1964, large banks began borrowing all that the smaller respondent banks would sell to them. Daily volumes from 46 money market banks grew from $1.1 billion in 1960 to $8.3 billion in 1970 (Maerowitz, 1981).

The federal funds market experienced even more growth in the 1970s as Regulation D was amended to exempt borrowings from savings and loan associations, mutual savings banks, and U.S. Government agencies from reserve requirements. Throughout the 1970s, the federal funds rate was the principle operating target for monetary policy. The federal funds rate target was raised when money growth was above the desired growth path, and similarly, the federal funds rate target was lowered when more monetary growth was desired. The Desk would accomplish this by selling and buying securities, similar to how it does today (Maerowitz, 1981). The federal funds market would remain an active, informative, market for over 30 more years until the major changes that resulted from the GFC.

Section Six: Conclusion

The federal funds market plays a critical role in monetary policy implementation, in communicating money market funding conditions, and in achieving macroeconomic outcomes. The market dynamics of these unsecured borrowings of reserves by banks from other banks and GSEs have evolved a great deal over time.

During the pre-GFC era, when reserves were scarce, banks kept only enough reserves on hand to satisfy their reserves requirements, customers' needs, and desired liquidity buffers. Banks and GSEs would willingly lend to other banks, to the tune of hundreds of billions of dollars a day, so that they could earn interest on their excess reserves via lending at a federal funds rate. Banks would actively borrow in the federal funds market when they had shortfalls to their reserves requirements. The discount window served as ceiling for the federal funds rate, and zero percent served as a floor.

In response to the GFC, the Federal Reserve flooded the banking system with reserves by issuing large amounts of loans and buying trillions of dollars worth of Treasury securities and MBS. As banks were saturated with reserves, they no longer needed to borrow federal funds to satisfy reserves requirements. The federal funds rate fell to the zero lower bound. Policymakers implemented two new tools to serve as floors and put upward pressure on the federal funds rate in this high reserves environment. They established IOER, where banks would earn interest, as specified by the Federal Reserve, on their reserves left at the Federal Reserve. The policymakers also implemented ON RRP operations, where banks, money market mutual funds, GSEs and other counterparties could lend money to the Federal Reserve and earn interest in the form of an overnight reverse repurchase agreement. Together, these tools were used to lift the federal funds rate off of the zero lower bound in December 2015 and to continue help implementing future changes to the federal funds rate target range.

This post-GFC federal funds market can be characterized as one of arbitrage and regulation-driven demand. From an arbitrage standpoint, banks borrow federal funds from GSEs whom are not eligible to earn IOER. The borrowing banks then earn the spread between IOER and the federal funds rate. Banks also desire reserve holdings to satisfy their HQLA requirements as part of the liquidity coverage ratio regulations that came out of Basel III. With the Federal Reserve's response to the COVID-19 crisis including loan issuance and the purchasing of securities, this post-GFC federal funds market continues on today.

The federal funds market has been evolving since its inception. From its beginnings as a market that primarily worked through the New York Clearing House, to a vibrant market consisting of brokers, correspondent-respondent bank relationships, and bilateral trading, volumes in the federal funds market grew over time. In the 1920's and then again in the 1950's, the market behaved similarly to how it behaved pre-GFC. In the late 1930's and 1940's the market was less active as banks were flush with reserves, similar to how the market looks today.

Although the dynamics of the federal funds market have changed over the years, it still remains an important market to understand and monitor today. The remaining two chapters of this dissertation focus on key topics related to the federal funds market. In my second chapter, I do a deep dive into the Treasury General Account; one of the most important accounts that affects the supply of reserves in the system, and hence, influences the federal funds market. In my third chapter, I update Hamilton's 1997 federal funds model to reflect how the federal funds market behaves in a contemporary environment.

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CHAPTER TWO: THE TREASURY GENERAL ACCOUNT: HOW CHANGES IN TREASURY CASH MANAGEMENT POLICIES IMPACT TAXPAYERS AND MONETARY POLICY

Section One: Introduction

"Treasury cash management practices are altering monetary conditions quite independently of the decisions of monetary policymakers" ~ Jerry L. Jordan, Former President of the Federal Reserve Bank of Cleveland, 2017

Over the past 15 years, changes in the Department of the Treasury's (Treasury) cash management policies have resulted in the average cash balance of the Treasury General Account (TGA), the Treasury's operational account held at the Federal Reserve, ballooning from $5 billion to over $1.5 trillion. Changes in the TGA balance have consequences on government funding costs to the taxpayer. Additionally, fluctuations in the TGA balance have effects in the monetary policy domain given they directly impact the aggregate amount of reserves in the banking system and significantly affect short-term interest rates (Hamilton 1997).

These institutional intersections between the Treasury and the Federal Reserve are not new. In describing Treasury cash management policy and its impact on monetary policy during the 1930's, Edward Simmons wrote:

> "By varying the size of the balance which it carries with the Federal Reserve banks, the Treasury can effectively control the reserve position of the member

> banks . . . There is some evidence that some of these movements have been deliberately induced in order to control the volume of member-bank reserves." (Simmons 1940).

The rest of this chapter proceeds as follows. In section two of this chapter, I describe the Treasury's cash management policies both before and after the great financial crisis of 2007-2009 (GFC). In section three, I construct an accounting analysis to describe how taxpayers are impacted by changes in the Treasury's cash management policies, and I examine how changes in the TGA can interfere with the Federal Reserve's conduct of monetary policy (Jordan 2017). I conclude the chapter in section four.

Section Two: Background on Treasury Cash Management Policy and the Treasury General Account

As part of the Treasury's primary debt management goal "to finance the government at the lowest cost over time," the Treasury must make decisions with respect to their cash holdings.[17] Specifically, they must decide how much of a cash buffer to hold, and where to deposit that cash. These decisions, which can broadly be referred to as cash management policy, fall under the authority of the Office of Debt Management at the Treasury.

In developing its debt and cash management policies, the Treasury must pay attention to a wide array of potential challenges and uncertainties including unexpected changes in borrowing needs, changes in the demand for Treasury securities, and factors that could inhibit the timely sale of securities, such as terrorist attacks, natural disasters, and cyber-attacks.[18]

In this section, I will describe the Treasury's cash management policies both before and after the GFC. This will lay the groundwork for a more in-depth discussion in section three where I explore taxpayer funding costs associated with Treasury cash management policies and potential monetary policy implications related to changes in the size of the TGA.

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[17] https://home.treasury.gov/policy-issues/financing-the-government

[18] The Treasury's May 6, 2015 Quarterly Refunding Statement referenced the terrorist attacks on September 11, Superstorm Sandy, and cyber-attacks as part of their cash balance policy strategy. https://www.treasury.gov/press-center/press-releases/Pages/jl10045.aspx

2.2.1 Background

Similar to households and businesses, the Treasury maintains a cash buffer to ensure it has enough funds to cover outflows even when unexpected fluctuations in receipts and disbursements occur. The questions of how large of a buffer to hold and where to deposit that buffer are the essential issues that fall under the Treasury's cash management policies. The Treasury places its cash into two different types of accounts; the TGA and the Treasury Tax and Loan (TT&L) accounts (Santoro 2012).

The TGA, which first came into existence in 1916, is held at the Federal Reserve as part of the Federal Reserve's statutory obligation as a fiscal agent of the United States.[19] Importantly, the account does not earn interest.

The TT&L accounts were established in 1917. These interest-earning accounts are held at private institutions. There are three types of interest-earning TT&L accounts that the Treasury can deposit funds into:

1. Conventional Main Account Balances. These accounts earn an interest rate equal to the effective federal funds rate (EFFR) less 25 basis points.
2. Term Investment Option (TIO) program. This program, which first began in 2002, consisted of the Treasury auctioning funds to institutions for a specified term. The TIO program typically earned higher interest for the Treasury relative to the Conventional Main Accounts given the funds were lent for a specified term as opposed to being subject to daily calls (Santoro, 2012).

[19] Annual Report of the Secretary of the Treasury, 1916, p.6.

3. Overnight repurchase agreement program. This program began in 2006 and consisted of the Treasury lending funds overnight, secured by Treasury collateral.

All three TT&L programs required the investing institution to collateralize the funds.

2.2.2 Treasury Cash Management Policy Pre-GFC

Prior to the GFC, the Treasury targeted a balance in the TGA of at least $5 billion (Santoro 2012). The $5 billion buffer provided assurance to the Treasury that it would not overdraw its account. This is especially important given that the Federal Reserve is not authorized to lend money directly to the Treasury, and hence, the Federal Reserve cannot lend funds to the Treasury in the form of an overdraft. On more volatile cash management days, such as tax payment days, the Treasury would bump up their TGA balance by a couple of billion dollars to ensure they do not overdraw. The remainder of the Treasury's cash would be invested into the TT&L program so that it could earn interest.

The Treasury's pre-GFC cash management policy accomplished three important outcomes. First, it mitigated against the risk of the Treasury overdrawing its TGA. Second, by depositing excess cash into the TT&L accounts, it allowed the Treasury to earn interest on behalf of the taxpayer, which is directly in line with the Treasury's goal of financing the government at the lowest cost over time. And third, it kept the balance at the TGA relatively stable around $5 - $7 billion which was beneficial for the Federal Reserve's implementation of monetary policy. Given that changes to the TGA directly affect levels of reserves at the Federal Reserve, large, unpredictable daily swings in the

TGA result in large, unpredictable daily swings in reserves at the Federal Reserve, which ultimately affect the EFFR (Hamilton 1997).

From the Federal Reserve's perspective, forecasting the supply of reserves and controlling the EFFR is a complicated task. Adding another element of uncertainty in the form of the Treasury making unpredictable cash management decisions in how they allocate cash to their TGA and TT&L accounts would have further complicated the Federal Reserve's implementation of monetary policy. This will be discussed in more detail in the next section.

Figure 11 below gives a sense for volumes of the TGA and TT&L programs from 1993 through 2007. On average, from 1993 through 2007, the Treasury had $25.8 billion in cash balances; $5.8 billion was placed in the TGA and $20.0 billion was invested into the TT&L accounts, on average.

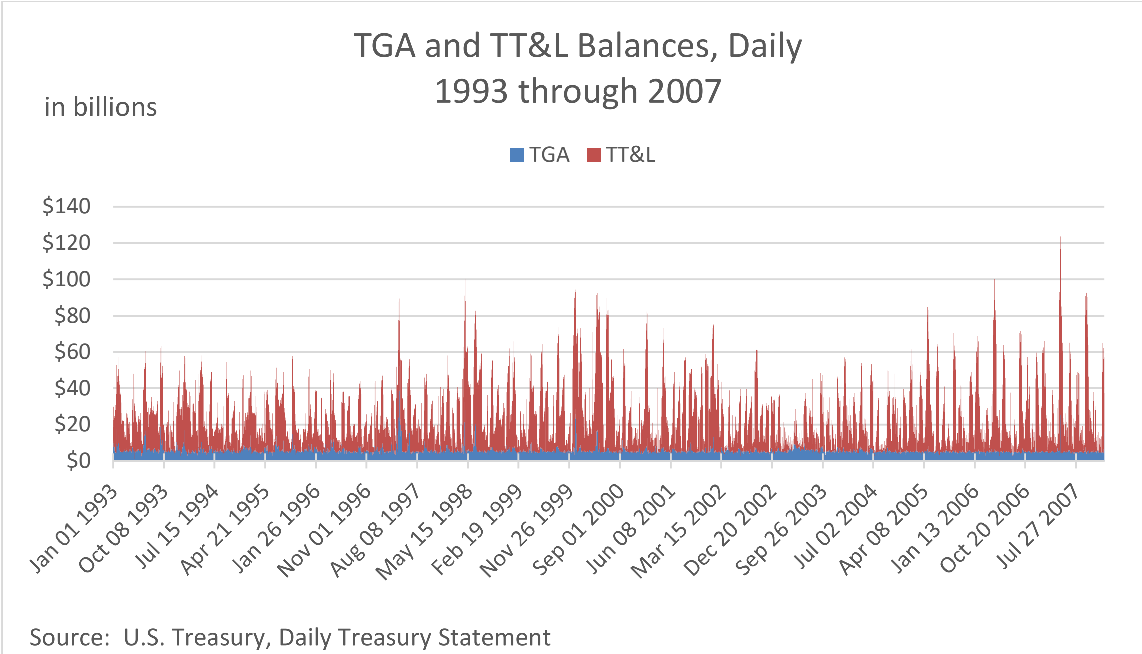

Figure 11

From an interest-earning perspective, the EFFR averaged around 4 percent from 1993 through 2007, and as a result, the Conventional Main Accounts in the TT&L were earning around 3.75 percent in interest, on average, to the Treasury.

2.2.3 Treasury Cash Management Policy Post-GFC

In response to the GFC, the Federal Reserve implemented three monetary policy actions that would radically alter how the Treasury would conduct its cash management policies (Ihrig et al. 2015). First, the Federal Reserve began paying interest on excess reserves (IOER) at a rate of 25 basis points following the onset of the GFC. Second, the Federal Reserve lowered its EFFR target range to 0 to 25 basis points. And third, the

Federal Reserve issued a large amount of loans and conducted several large-scale asset purchase programs which drastically increased the amount of reserves held at the Federal Reserve.

These monetary policy actions had meaningful implications to the existing Treasury cash management policy. In order to understand how the Federal Reserve's decision to begin paying interest on reserves influenced the Treasury's borrowing costs and ultimately, cash management policies, it's important to highlight a couple of key accounting practices.

First, the Federal Reserve's net income earnings are remitted to the Treasury. Therefore, any Federal Reserve interest expenses, including paying IOER, reduce remittances to the Treasury. Second, the Treasury balances held in the TT&L accounts are on deposit at private banking institutions which deposit their funds at the Federal Reserve. Therefore, the TT&L balances are ultimately held as reserves at the Federal Reserve. Taking into account these two accounting practices, when the Federal Reserve implemented the IOER payments (at 25 basis points for the years following the GFC), any Treasury balances held in TT&L accounts were costing the Federal Reserve 25 basis points in interest expense. The 25 basis point interest expense that was being paid out by the Federal Reserve on TT&L balances was ultimately passed through as a 25 basis point interest cost to the Treasury.

As mentioned earlier, the Conventional Main Accounts in the TT&L paid interest at a rate of 25 basis points below the EFFR. Given the EFFR had now fallen below 25 bps during the GFC, the interest rate paid from the TT&L was reduced to zero. Put together with the implementation of IOER, any Treasury balances held in the TT&L accounts would earn 0 percent interest and cost the Treasury 25 basis points in interest, for a net loss to the Treasury of 25 basis points. These circumstances ultimately led the Treasury to alter its cash management policy and place all of its cash in the TGA, where the balances earned 0 percent interest, and none in the TT&L accounts, where they were earning negative 25 basis points of interest.

Finally, as previously noted, the Treasury had typically kept its TGA stable around a $5 billion target. This had significant benefits for the Federal Reserve's implementation of monetary policy, as the Federal Reserve did not have to forecast large daily swings in the TGA, which ultimately would lead to large daily swings in total reserves held at the Federal Reserve. As a result of this switch to an all-TGA Treasury cash management policy, there were large swings in the daily TGA balance. But given the Federal Reserve's switch to a "floor" monetary policy implementation framework, as discussed in more detail in Chapter 1, the Federal Reserve's administered rates, such as IOER and the overnight reverse repurchase agreement facility rate (ON RRP), are what largely control the federal funds rate, as opposed to large swings in reserves (Armenter and Lester 2017).

The change in the Treasury's cash management policy and their switch from depositing cash in TT&L accounts to instead depositing in the TGA can be seen clearly in figure 12 below. Figure 12 shows the Treasury's TGA and TT&L balances from 2006, just before the GFC, through 2014. From 2006 through 2008, the TT&L averaged a little over $20 billion each day. The TT&L daily balances declined to just under $2 billion from 2009 through 2011, and there have been zero deposits in the TT&L since the end of 2011. On the contrary, the TGA grew from under $10 billion per day in 2006 through 2008 to over $60 billion from 2009 through 2014, with some wild daily swings reaching as high as $220 billion.

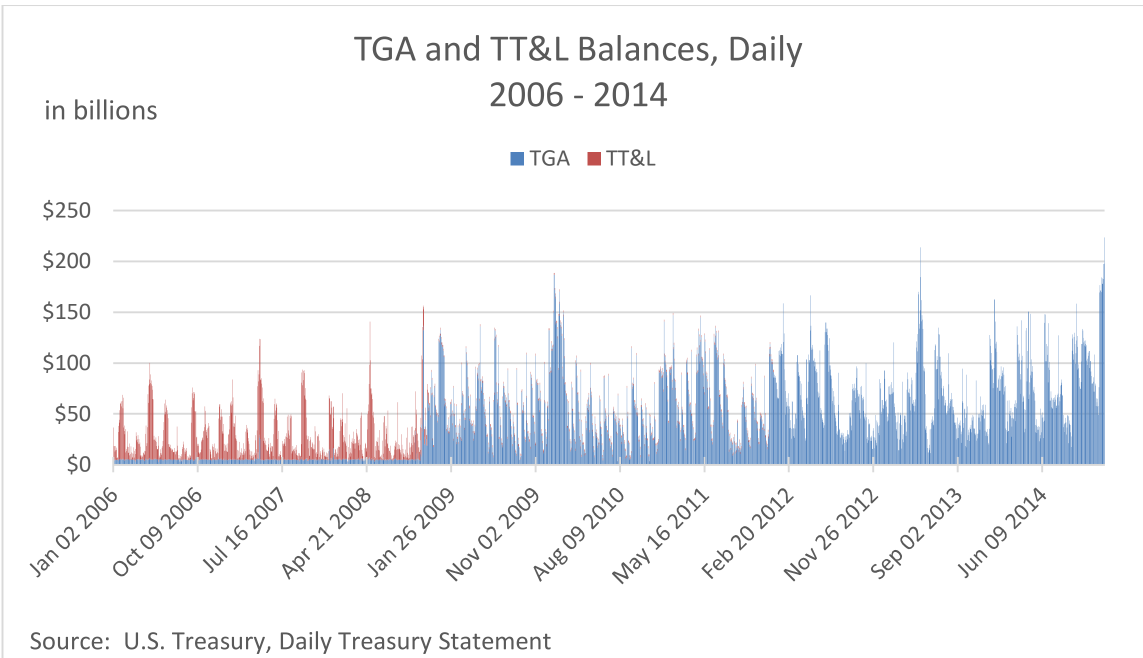

Figure 12

2.2.4 Treasury Cash Management Policy Change in 2015

In the May 2015 quarterly refunding statement, the Treasury announced a major change in its cash management policy.[20] In its statement, the Treasury noted that recent events, such as the terrorist attacks on September 11th and Superstorm Sandy, have caused disruptions to the broader financial system and Treasury's auction capabilities. As a result of the Treasury's review of recommendations from the Treasury Borrowing Advisory Committee (TBAC) and after a review and assessments of emerging threats, such as potential cyber-attacks, the Treasury announced that in order to "help protect against a potential interruption in market access, the Treasury will hold a level of cash generally sufficient to cover one week of outflows in the Treasury General Account, subject to a minimum of roughly $150 billion."[21]

This change in cash management policy had an immediate effect on TGA balances as shown in figure 13.

[20] https://www.treasury.gov/press-center/press-releases/Pages/jl10045.aspx

[21] The TBAC is an advisory committee governed by federal statute that meets quarterly with the Treasury Department. Its membership is comprised of senior representatives from buy and sell side institutions such as banks, broker-dealers, asset managers, hedge funds, and insurance companies. More information on TBACs can be found at: https://home.treasury.gov/policy-issues/financing-the-government/quarterly-refunding/treasury-borrowing-advisory-committee-of-the-securities-industry-and-financial-markets-association-tbac

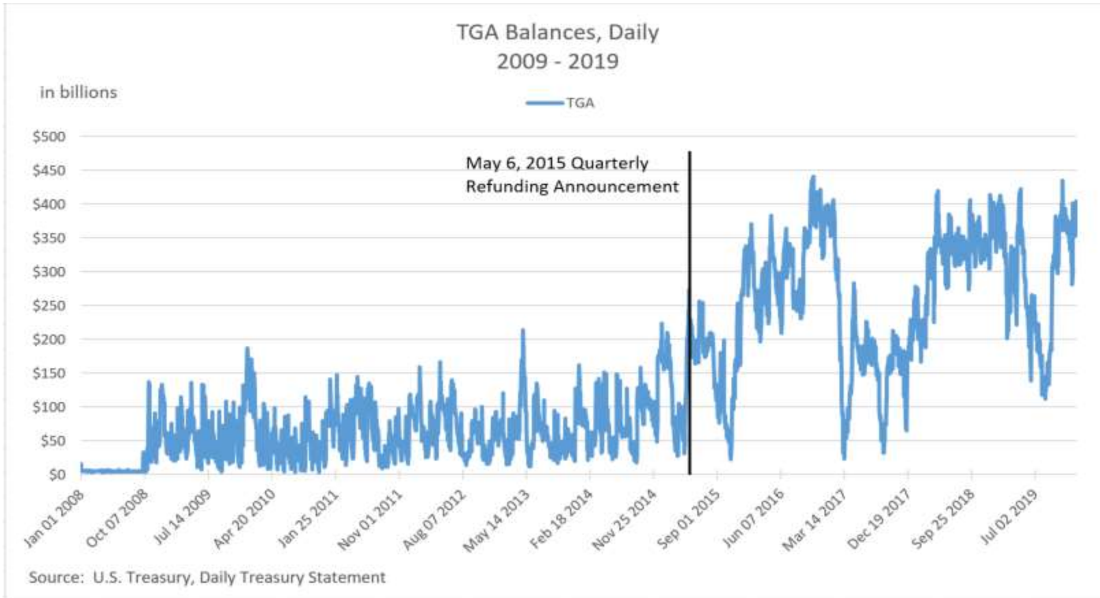

Figure 13

The average TGA balance increased from $63 billion in 2009 through 2014, to $250 billion from 2015 through 2019.

2.2.5 Treasury Cash Management Policy During COVID-19

Given that the Treasury's cash management policy is to generally hold a TGA balance high enough to cover one week of outflows, the federal government's response to the COVID-19 outbreak impacted the level of cash held in the TGA. In the May 2020 Treasury Quarterly Refunding Statement, the Treasury announced:

"Treasury's borrowing needs have increased substantially as a result of the federal government's response to the COVID-19 outbreak. Since the end of March, Treasury has raised an unprecedented $1.464 trillion on net and the Treasury cash balance has reached historically high levels. Over the next quarter, Treasury's cash balance will likely remain elevated as Treasury seeks to maintain prudent liquidity in light of the size and relative uncertainty of COVID-19 outflows."[22]

In the Treasury's August 2020 Quarterly Refunding Statement they clarified their cash management policy further and stated:

"For prudent risk management, Treasury holds a substantial cash balance to allow it to cover anticipated outflows in case of a temporary interruption to market access. This policy was implemented in 2015 and its objective has not changed. Treasury's recent record-high cash balances are driven by several factors, including the unprecedented size and ongoing uncertainty regarding the timing of COVID-19 related outlays."[23]

Figure 14 shows the record-high TGA balances which averaged $1.2 trillion in 2020, reaching a peak of $1.83 trillion on July 27, 2020.

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[22] The Treasury's May 6, 2020 Quarterly Refunding Statement: https://home.treasury.gov/news/press-releases/sm1001

[23] The Treasury's August 5, 2020 Quarterly Refunding Statement: https://home.treasury.gov/news/press-releases/sm1081

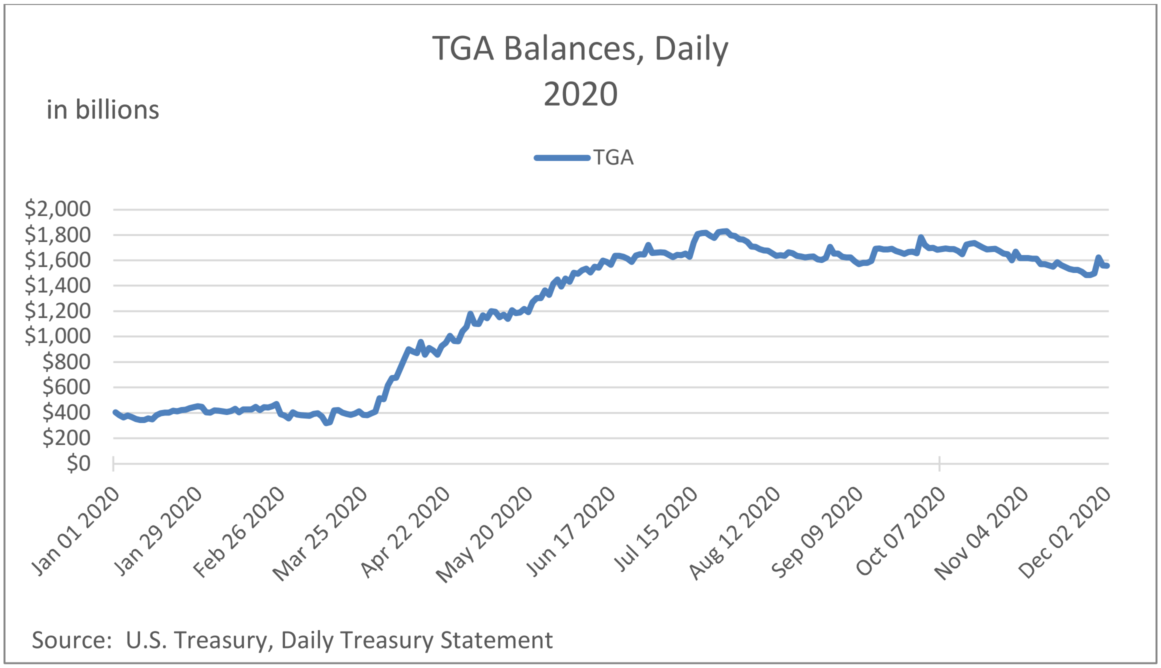

Figure 14

2.2.6 Conclusion

For over 100 years, the Treasury has maintained a cash account at the Federal Reserve and has made cash management decisions regarding how much cash to hold as a buffer and where to deposit it. As a result of the GFC, it no longer became economical for the Treasury to deposit money in its TT&L accounts, and so it moved its cash holdings into the zero-interest earning TGA at the Federal Reserve.

Over the past 15 years, the balance of the TGA has soared from averaging just over $5 billion per day to over $1 trillion per day. This sharp increase was largely the result of a change in the Treasury's cash management policy to increase its buffer to cover a week's worth of outflows in case there are disruptions to Treasury auction operations. With the recent high federal government outflows related to COVID-19, the Treasury has increased its buffer in the TGA sharply.

In the next section, I do an analysis to see how the Treasury cash management policy changes are affecting the taxpayer and I explore how changes in the TGA could potentially impede on the monetary policy space.

<u>Section Three: Cash Management Policy Impacts to Taxpayers and TGA Effects on Monetary Policy</u>

Treasury cash management policies are important, in part, because they directly impact the cost of the government funding its debt, which ultimately affects taxpayers. Given the Treasury's primary debt management goal "to finance the government at the lowest cost over time," it is important to understand how cash management policies affect the Treasury's cost of financing. The Treasury's desire over the past decade to hold higher cash balances comes with a cost, and that cost is dependent on several factors.

In this section, I do an accounting exercise to make clear the key variables that determine the costliness of different cash management policies, and I summarize the results in table form. I estimate that the cost to fund the current size of the TGA can cost taxpayers anywhere from being essentially free to costing up to $24 billion each year, depending on whether or not the TGA is funded by taxpayers or new Treasury issuance.

I then explore how changes in the Treasury's cash management policies impact broader markets such as the federal funds market, and other short-term markets. I look at potential implications of large swings in size of the TGA on monetary policy.

2.3.1 Treasury Net Interest Expense Accounting Exercise

In order to look at how the Treasury's cash management policy impacts its funding costs, it is helpful to develop a stylistic set of accounting identities. A starting point is looking at the Treasury's overall net interest expense.

$$(1)\ T_{NIE} = T_{IE} - T_{II}$$

Where, T_{NIE} is Treasury net interest expense, T_{IE} is Treasury interest expense and T_{II} is Treasury interest income. We can further break out T_{IE} and T_{II} to:

$$(2)\ T_{IE} = Tsy_{par} * Tsy_{IR}$$

$$(3)\ T_{II} = T_{FR} + T_{TTL}$$

Where, Treasury interest expense is further broken down to reflect total par value of Treasury securities outstanding, Tsy_{par}, times, Tsy_{IR}, the interest rate paid on them. Of course, the interest the Treasury pays on its securities varies across the maturity spectrum and the date of issuance, but here, for simplicity, Tsy_{IR} represents a summary statistic such as a weighted average coupon (WAC), reflective of the Tsy_{par} distribution across the maturity spectrum (Carpenter et al., 2015). Treasury interest income is shown to be comprised of, T_{FR}, Treasury income earned from Federal Reserve remittances to the Treasury and, T_{TTL}, Treasury income earned from the Treasury's TT&L program. We can further break down T_{TTL} and T_{FR}:

$$(4)\ T_{TTL} = TTL_{bal} * TTL_{IR}$$

$$(5)\ TTL_{IR} = EFFR - 25_{bp}$$

$$(6)\ T_{FR} = F_{II} - F_{IE}$$

Where, $T_{TTL,}$ is comprised of, TTL_{bal}, or TT&L balances, times, TTL_{IR}, the interest rate earned in the TT&L program, which, as described earlier in this chapter is the EFFR less 25 basis points. Federal Reserve remittances to the Treasury are the net of F_{II}, Federal Reserve interest income, and, F_{IE}, Federal Reserve interest expense. We can then break down the Federal reserve interest income and interest expense to more granular levels:

$$(7)\ \ F_{II} = \left(SOMA_{par} * Tsy_{IR}\right) + \ O_I$$

Where F_{II} is composed of $SOMA_{par}$, the par value of the Federal Reserve's System Open Market Account (SOMA) securities holdings, times the interest earned on those securities, which I've simplified to be Tsy_{IR}, or the interest rate on Treasuries, plus some additional income (Carpenter et al., 2015).[24] To give a sense of the sizes of these, SOMA net income makes up over 99 percent of the Federal Reserve's total interest income.[25] Breaking down Federal Reserve interest expense, we get:

$$(8)\ F_{IE} = [(TTL_{bal} + OtherFedBal) * IOER] + (TGA_{bal} *\ 0) + O_E$$

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[24] A more nuanced approach to calculating Federal Reserve interest income would be to calculate SOMA income at the security level. SOMA largely consists of Treasury securities of varying tenors and mortgage-backed securities each of which earn their own interest rate. Given SOMA has traditionally been comprised primarily of Treasury securities and still make up the majority of SOMA holdings (70 percent as of February 2021), I assume SOMA securities are all Treasuries and their durations match Treasuries outstanding.

[25] See the September 30, 2020 Federal Reserve Banks Combined Quarterly Financial Report here: https://www.federalreserve.gov/aboutthefed/2020-september-federal-reserve-banks-combined-quarterly-financial-report-unaudited.htm

Where, F_{IE}, the Federal Reserve's interest expense is comprised of reserves held at the Federal Reserve times the interest on excess reserves interest rate (IOER), plus other expenses (Carpenter et al., 2015). It's helpful here to look at Federal Reserve balances as being comprised of TT&L balances, or TTL_{bal}, which are a subset of bank deposits at the Federal Reserve, and then other bank deposits at the Federal Reserve, or $OtherFedBal$. The Federal Reserve does not pay IOER on Treasury General Account balances, TGA_{bal}, though it's helpful to include here as they are part of Treasury's cash management decisions. Other expenses, O_E, make up less than one percent of total Federal Reserve interest expense. For simplicity, we can drop the negligible O_I and O_E from equations 7 and 8, respectively, and substitute equations 2 through 8 into 1 to get:

$$(9)\ T_{NIE} = (Tsy_{par} * Tsy_{IR}) - (SOMA_{par} * Tsy_{IR}) + [(TTL_{bal} + OtherFedBal) * IOER] + (TGA_{bal} * 0) - [TTL_{bal} * (EFFR - 25_{bp})]$$

Gathering like terms, we get:

$$(10) T_{NIE} = [Tsy_{IR} * (Tsy_{par} - SOMA_{par})] - [TTL_{bal} * (EFFR - IOER - 25_{bp})] + (TGA_{bal} * 0) + [OtherFedBal * IOER]$$

Looking at equation 10, there are a couple key decision trees to highlight. First, in the example where the Treasury wants to increase its cash buffer size, it can raise the funds by issuing new debt (so, increasing Tsy_{par}), or, by taxing the public (so, decreasing $OtherFedBal$). Second, the Treasury has the option of holding this increase in excess cash in the TTL_{bal} or TGA_{bal}. These decisions are largely influenced by the interest rates in equation 10. For example, additional balances in TTL_{bal} only help to reduce the Treasury's interest expense if EFFR – IOER is greater than 25 basis points. Figure 15 below shows the EFFR – IOER spread since 2008:

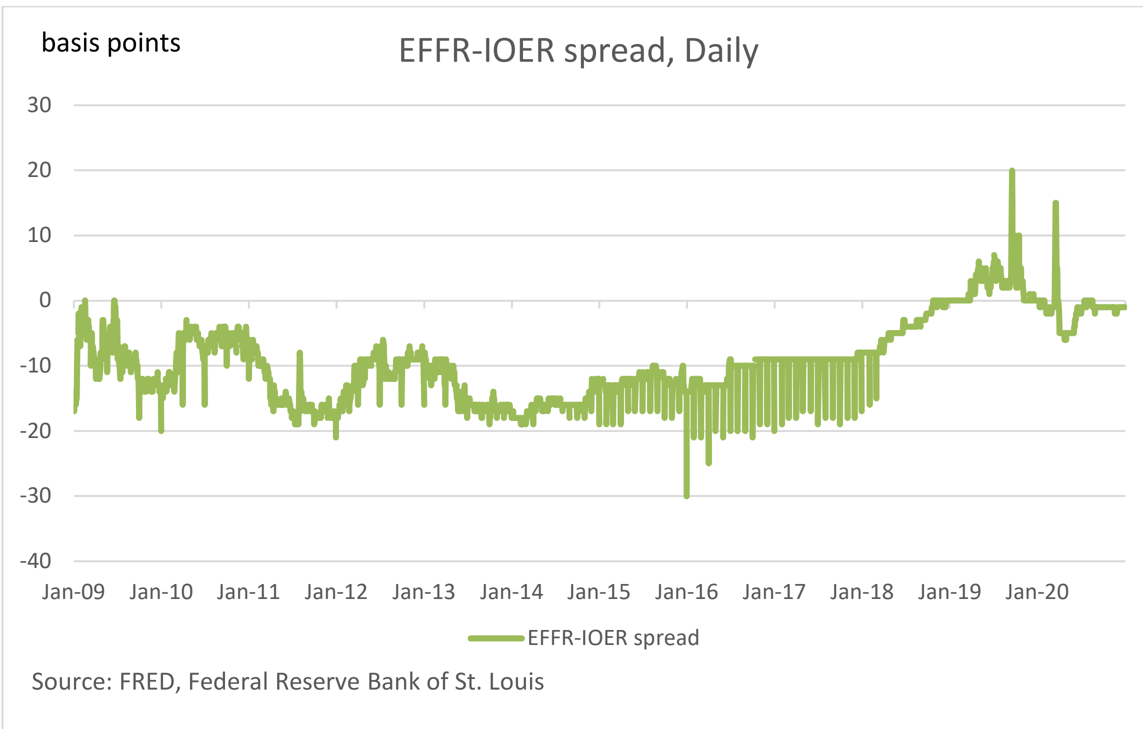

Figure 15

The EFFR-IOER spread has typically been negative since the GFC and so placing cash buffers in the TGA_{bal} has benefitted the taxpayer relative to placing cash buffers in the TTL_{bal}. If the spread were to rise in a sustained manner above 25 basis points, then the Treasury could consider a change to its cash management policy. These decision trees can be better described in table form.

2.3.2 Treasury Cash Management Cash Buffer Cost Table

The observations regarding the effects of cash management decisions on interest expense are particularly important when the Treasury chooses to significantly increase the size of its cash holdings. As highlighted in section one, the size of the Treasury's cash holdings have increased from $25 billion to over $1.5 trillion in just the last two decades.

When raising cash buffers, the Treasury has two key decisions to make. First, they must choose how to raise the funds. They can issue new debt (increase Tsy_{par}) or they can transfer funds from the private sector such as in the form of a tax (decrease $OtherFedBal$). Second, they must choose where to deposit that cash. They can deposit it into the TGA_{bal} or the TTL_{bal} accounts. In table 3 below, I summarize the net cost of funding extra cash from equation 10. I assume $SOMA_{par}$ is constant, though it's important to note that changes to the size of SOMA impact Treasury funding costs as well (Greenwood et al., 2015A)

Table 3 - Net Cost of Funding Cash Buffer

Means of Funding	Deposit into TGA	Deposit into TT&L
Issuing New Debt	Tsy_{IR}	Tsy_{IR} – (EFFR - IOER - 25 bp)
Taxing	-IOER	– (EFFR - 25 bp)

During typical times in the pre-GFC environment, IOER was 0 and the EFFR was well above 25 basis points. Looking at table 3, regardless of the means of funding, depositing into the TT&L dominates depositing into the TGA when looking to minimize the net cost of funding cash. That's precisely what the Treasury chose to do.

In the post-GFC environment, where IOER is positive and EFFR is typically less than 25 basis points above IOER, depositing into the TGA dominates depositing into the TT&L. For example, a realistic set of interest rates for early 2021 are the IOER being set to 10 basis points and the EFFR printing at 8 basis points. Since 8 – 10 – 25 is negative 27, the cost of funding cash is the Treasury rate plus 27 basis points (which is more than just the Treasury rate if you were to deposit into the TGA). Using the same rates as an example, funding through taxation would cost you IOER, or 10 basis points, if the funds are deposited into the TGA, and 27 basis points if the funds were deposited into a TT&L program. Hence, today's cash buffers are deposited into the TGA.

It's important to also point out that while table 3 makes it clear which deposit account reduces costs for the Treasury, the cost of raising cash buffers depends on how it's funded. In the post-GFC environment, raising funds for the TGA buffer costs TSY_{IR}

when funded by new debt issuance. On the contrary, if the TGA buffer is increased through taxation, the Treasury earns (or saves) the IOER that was previously being paid on those bank reserves.

A crude estimate of the cost of funding the current TGA through new debt issuance can be derived by taking the TGA balance as of February 2021, $1.6 trillion, and multiplying it by the average Treasury interest rate on marketable debt of 1.5 percent, which results in a $24 billion cost to the taxpayer.[26] If the cash buffer funding were raised through taxation, then the $1.6 trillion would be taken from $OtherFedBal$, and if we assume an IOER rate of 0.10 percent, as it was in February 2021, then the cost to fund the cash buffer would be -$1.6 million. Put another way, the Treasury would *earn* $1.6 million by building its cash buffer through taxation. A key takeaway is that the more the Treasury can fund its cash buffer through taxation as opposed to new Treasury issuance, the less it will cost the taxpayer in today's IOER environment.

Of course, these calculations have all assumed that $SOMA_{par}$ is constant. In the case where the cash buffer is raised by new Treasury issuance, to the extent that Treasury issuance is being bought in the secondary market by the Federal Reserve, and hence increases $SOMA_{par}$, the net interest expense to Treasury falls, as shown in equation 10.

[26] Treasury General Account balance obtained from the February 4, 2021 H.4.1 Release of Factors Affecting Reserve Balances of Depository Institutions and Condition Statement of Federal Banks: https://www.federalreserve.gov/releases/h41/20210204/
Treasury average interest rate, as of January 31, 2021, from Treasury Direct: https://www.treasurydirect.gov/govt/rates/avg/2021/2021_01.htm

There are other interest rate considerations to consider such as the spread between short-term and long-term interest rates. If the Treasury curve is steep, then funding cash balances by issuing debt further out on the yield curve, would result in larger funding costs to the taxpayer in the near term. Funding the cash balance on the short end of the curve could provide other benefits as well such as reducing financial fragility by crowding out private-sector short-term debt issuance (Greenwood et al., 2015B).

2.3.3 The TGA and Short-term Interest Rates

In addition to the Treasury's cash management policy affecting the taxpayer, it also affects short-term interest rates, and monetary policy more generally. The decision to hold cash in the TGA versus the TT&L program has a direct effect on the amount of bank deposits, or reserves, held at the Federal Reserve.

As stated earlier in this section, TT&L balances are held at private banks, and hence, are apart of bank reserves held at the Federal Reserve which are available for trading in the federal funds market. The TGA is a separate government operational account whose funds are not available for federal funds trading. If the Treasury decides to shift money from the TT&L into the TGA, it causes a decrease in reserves at the Federal Reserve. Similarly, if the Treasury chose to build up the size of its cash buffer in the TGA either by issuing more debt, or, by imposing a tax, in both scenarios, money would flow from bank accounts and into the TGA, causing a reduction in bank reserves (Simmons 1940). Conversely, if the Treasury were to issue payment out of the TGA and not refill it, the TGA would shrink, and bank reserves would increase.

This change in the size of the TGA and necessarily the change in the amount of reserves has major implications in the federal funds market. For example, Hamilton estimated that a $1 billion unanticipated increase in the TGA balance resulted in a 10 basis point increase in the federal funds rate (Hamilton 1997). Using an even longer dataset than Hamilton, and data available directly from the Federal Reserve, Carpenter and Demiralp also found that unexpected changes in the TGA led to changes in the federal funds rate (Carpenter and Demiralp 2006).

Research has shown that federal funds rate changes can have even broader market impacts. Goodfriend and Whelpley have shown that the federal funds interest rate is the basis for which all other money market rates are anchored (1986) and Balduzzi, Bertola, and Foresi have shown that the federal funds market influences the term structure of longer-term interest rates (1997). Other studies have shown that changes in reserves have an impact on other short-term interest rates as well. Anderson and Huther show that the federal funds rate is correlated with other short-term interest rates and increases in reserves due to ON RRP operations significantly affect short-term interest rates (Anderson and Huther 2016).

Given that the federal funds rate is the primary monetary policy tool, as explored in Chapter 1, the fact that Treasury cash management policies influence the federal funds rate is remarkable. As a thought experiment, what if the Treasury decided it no longer needed a cash buffer in its TGA, and so it let its TGA drain from $1.5 trillion to $5 billion in a short period of time? That type of event may cause the Federal Reserve to lose control over its primary monetary policy rate. Or, conversely, what if the Treasury decided it needed to sharply increase its cash buffer in the TGA from $1.5 trillion to $2.5 trillion? Or $10 trillion? There would be serious implications and questions as the Treasury's cash management space would be overlapping with the Federal Reserve's monetary policy space.

2.3.4 Conclusion

The stylistic accounting exercise above articulates the motivation for the Treasury choosing to deposit its cash in the TT&L program pre-GFC and into the TGA post-GFC. In determining its cash management policy, the Treasury must be mindful of several key factors.

First, the costs of raising the buffer size of the TGA, say to protect against cyberthreats or terrorism as has been the case recently, vary depending on how the funds are raised. In the post-GFC environment, when issuing new debt, the Treasury's cost is dependent on Treasury rates at the time. If the Treasury raises cash through taxation, their interest expense savings is dependent on IOER. The cost of funding the cash buffer increases the more it is funded by new debt issuance as opposed to taxation.

Second, the constellation of interest rates matters. When the EFFR is less than 25 basis points above IOER, it benefits the taxpayer to deposit funds into the TGA. The Treasury cash management policies must account for these spreads. Other interest rate considerations include the spread between short-term and long-term interest rates. If the Treasury curve is steep, then funding cash balances by issuing debt further out on the yield curve, would result in larger funding costs to the taxpayer in the near term.

Third, net interest expenses for the Treasury are in part determined by the pace at which overall Treasury outstanding debt is growing *relative* to the pace of the size of the Federal Reserve's SOMA securities. Hence, the Federal Reserve's policy decisions play a direct role in the Treasury's funding costs.[27]

Finally, given that changes in the size of the TGA result in changes in the amount of reserves held at the Federal Reserve, and given these changes in reserves affect the federal funds rate and other short-term money market rates, there is potential for some overlap of policy space. As the TGA grows larger, the opportunity for large swings in TGA balances exists, and that could cause issues and limitations for the Federal Reserve's conduct of monetary policy.

[27] The Federal Reserve's influence on Treasury interest rates also indirectly affects the Treasury's funding costs. And, the Federal Reserve's choice of composition of its SOMA securities affects its remittances to the Treasury, and ultimately, the Treasury's funding costs.

Section Four: Conclusion

In conclusion, the cash management polices of the Treasury have changed drastically over the past couple of decades. Both the size of their cash buffer has changed, increasing from $5 billion to over $1.5 trillion, and the deposit account composition has changed, shifting from the Treasury primarily depositing excess cash in TT&L accounts to depositing all of their cash in the TGA. These changes were largely the result of shifts in interest rates and the new legal authority given to the Federal Reserve to pay IOER.

The cash management policy changes have important implications to costs for the taxpayer and for monetary policy implementation. Depending on how the cash buffers are funded, the cost of the cash buffers vary widely. The current $1.6 trillion TGA balance, when funded by new Treasury issuance, is costing the taxpayer about $24 billion annually. To the extent the cash buffer is funded by taxation, that cost comes down, and if the entire cash buffer were funded by taxation, the Treasury could theoretically earn money by increasing its cash buffer based on current Federal Reserve interest expense dynamics.

The Treasury's decisions to deposit excess cash in the TT&L versus the TGA have monetary policy implications as well. Given that changes in the TGA and TT&L result in changes in the reserves in the banking system, these reserves changes have been shown to effect short-term interest rates back when reserves were scarce and the Federal Reserve used a corridor monetary policy framework. Current Treasury cash management policies could conceivably impact the monetary policy frameworks the Federal Reserve chooses to use.

The Treasury's and Federal Reserve's policy decisions intersect each other in many areas and they have so for a long time. Recent changes to the Treasury's cash management policies have brought these issues back to the forefront and these institutional interactions should be in the purview of policymakers.

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CHAPTER THREE: HAMILTON'S FEDERAL FUNDS MODEL REVISITED AND UPDATED

Section One: Introduction

In Hamilton's JPE paper (1996), he wrote that a good place to start for an understanding of either finance or monetary policy is the federal funds market. In that paper, Hamilton developed a model for the daily market for federal funds. Soon after, in his AER paper (1997), Hamilton demonstrated and measured a liquidity effect in the federal funds market. As part of that effort, he created a model to forecast the Treasury general account (TGA), an important factor which affects the supply of reserves. He used the errors in his TGA model as a proxy for unanticipated changes in reserves, which mimic the effect of monetary policy operations. He would go on to show that unexpected changes in reserves significantly affect the federal funds rate on certain days of the two-week reserves maintenance period. After decades of other researchers' contributions attempting to empirically explain the mechanism through which monetary policy works, Hamilton had finally created a convincing and robust result using daily data.

However, much has changed in the federal funds market since the time of Hamilton's papers. In response to the Great Financial Crisis of 2007-2009 (GFC), the Federal Reserve began a series of large-scale asset purchase programs (LSAPs) and ramped up its lending programs. These securities purchases made by the Federal Reserve and the issuance of loans sharply increased the level of bank reserves. As a result, from 2007 to 2014, reserves in the system rose from $800 billion to over $2.5 trillion.

In order to maintain control of the federal funds rate in an abundant reserves environment, the Federal Reserve changed its monetary policy implementation framework (Ihrig et al., 2015) from a corridor system to a floor system. In a floor system, the banking system is flush with excess reserves and the federal funds rate is largely controlled by rates administered by the Federal Reserve, namely, the interest on excess reserves (IOER) rate and overnight reverse repurchase agreement (ON RRP) rate.

In this new monetary policy environment, the federal funds rate was stable and did not experience much day to day volatility with the exception of regulatory reporting dates (Banegas and Tase, 2020). Research on the federal funds market had dried up, as the market was predictable and easily explained by changes to administered rates.

Beginning in the fourth quarter of 2017, reserves began to decline as a result of the Federal Reserve's balance sheet normalization policies.[28] Over time, as excess reserves left the banking system, some day to day volatility started to return to the federal funds market. While the market was not as vibrant as it was pre-GFC, certain factors were able to explain movements in the federal funds market again. This period of declining reserves would not last long, however. The Federal Reserve stopped reducing bank reserves in August 2019, and then, as a result of extreme money market volatility in September 2019 (Anbil et al., 2020), the Federal Reserve began repurchase agreement operations which would initiate an uptrend in reserve levels. In response to the 2020 COVID-19 pandemic and ensuing economic downturn, the Federal Reserve began

[28] See the FOMC's Addendum to the Policy Normalization Principles and Plans, June 2017: https://www.federalreserve.gov/monetarypolicy/files/FOMC_PolicyNormalization.20170613.pdf

purchasing Treasury and agency mortgage-backed securities, and increased its loan issuance, which would further increase reserve levels. Similar to after the GFC, the volatility in the federal funds rate mostly vanished.

In this chapter, I examine the federal funds market in 2018-2019, when reserves are declining and volatility returns to the federal funds market, offering a glimpse of contemporary federal funds market dynamics.[29] I look at the market through the lens of Hamilton's 1997 federal funds model, and I empirically demonstrate that the liquidity effect described in Hamilton's paper no longer exists. I then create a new model to reflect major changes that have occurred since Hamilton's paper including the establishment of IOER and ON RRP rates and the changes in the regulatory environment, such as the establishment of the supplementary leverage and liquidity ratios.

The insights learned in my updated federal funds model are useful in explaining federal funds dynamics in 2018-2019 and may provide intuition into causes for federal funds movements should we return to an environment where reserves are not super abundant.

The rest of this chapter proceeds as follows. In section two of this chapter, I discuss the literature on the federal funds market. In section three, I revisit the federal funds model in Hamilton (1997) and I show the liquidity effect he described no longer applies to a contemporary federal funds market. In section four, I update Hamilton's

[29] As discussed in Chapter 1, the federal funds market dynamics have changed notably since Hamilton's 1997 paper. In addition to the new monetary policy framework, the lenders in the market have largely shifted from banks to government sponsored enterprises such as Federal Home Loan Banks and much of the marketplace is driven by IOER arbitrage.

federal funds model using daily federal funds data from 2018-2019. I conclude in section five.

Section Two: Literature Review

There is a tremendous amount of literature that attempts to empirically demonstrate how monetary policy works and what the effects of monetary policy are on the macroeconomy. Researchers have implemented many different econometric techniques, made various assumptions, and used innovative strategies to understand how exogenous monetary policy changes affect interest rates, unemployment, consumption, and other macroeconomic variables.

Central to this research is the identification and estimation of the liquidity effect; that is, the negative relationship between money and interest rates. One stream of literature provides evidence that the data do not support the existence of a liquidity effect. For example, Reichenstein (1987) and Leeper and Gordon (1992) show that the relationship between changes to monetary aggregates and interest rates often varies over time, is uncertain, and frequently shows that interest rates move in the opposite direction as one would expect.

One way around this problem is to skip over the liquidity effect and assume interest rates themselves reflect monetary policy changes. Using structural vector autoregressions (VARs), Bernanke and Blinder (1992), Sims (1992), and Christiano and Eichenbaum (1992) show that changes in interest rates are correlated with changes in macroeconomic variables and money aggregates as one would expect. However, these papers do not show the direct linkage between monetary policy operations and interest rates.

Further research included other model assumptions which would lead to different empirical results. Strongin (1995) assumed that monetary policy does not alter the total supply of reserves available to the banking system, but instead, alters the composition of types of reserves, borrowed and nonborrowed. Gordon and Leeper (1994) assumed that long-term bond yields are unaffected by current monetary policy.

In Hamilton (1996), he creates a federal funds model using daily data and accounts for outliers and various important dummy variables including day of the week, and quarter- and year-end dates. In Hamilton (1997), the focus of this chapter, he creates a daily model for the TGA and uses errors in that model as a proxy for unanticipated, exogenous changes in the supply of reserves. By inserting these errors into his daily federal funds model, Hamilton estimates a significant liquidity effect in the federal funds market on certain days of the two-week maintenance period.

Carpenter and Demiralp (2006) use the Federal Reserve's staff projections and errors for the TGA and confirm Hamilton's result, that a significant liquidity effect exists in the daily data on certain days of the week. Judson and Klee (2010) update the daily federal funds model with more recent data from 1998 to 2007 and show that the liquidity effect still existed during that period, though it had diminished, potentially due to improved reserve management and increased transparency in monetary policy.

In the subsequent sections, I will advance the literature in two ways. First, I will update Hamilton's federal funds model (1997) with data from 2018-2019 to show that the liquidity effect he described in his paper no longer exists in the selected time period.

Then, I will create a new model to reflect policy and market structure changes that have taken place since he created the model.

Section Three: Hamilton's Federal Funds Model Revisited

In Hamilton (1997), he creates a federal funds rate model which demonstrates a liquidity effect. That is, he shows that when the Federal Reserve buys a Treasury security in the open market, the federal funds rate falls, all else equal. Below is the model specification from Hamilton (1997). I replicated his model and compare my coefficients and standard errors with his in Appendix 1.

3.3.1 Hamilton's Model Specification

The statistical framework that Hamilton uses is as follows:

(1) $y_t = x_t'\beta + \varepsilon_t$

Where y_t is the federal funds rate and x_t is a vector of variables that govern the mean of y_t.

(2) $\varepsilon_t = \sigma_t \upsilon_t$

Where υ_t is independently and identically distributed with mean 0 and σ_t is a function of current and lagged values of z_t, a vector of variables that influence the variance.

The conditional mean of y_t is given by $x_t'\beta$:

(3) $E(y_t | Y_t) = x_t'\beta$

Similar to Hamilton's 1996 paper, he assumes υ_t is drawn from a mixture of normal distributions with probability p, $\upsilon_t \sim N(0,1)$ and probability $1 - p$, $\upsilon_t \sim N(0, \tau^2)$, so that the density of υ_t is given by:

(4) $g(v_t) = \frac{p}{\sqrt{2\pi}} \exp\left(\frac{-v_t^2}{2}\right) + \frac{1-p}{\sqrt{2\pi\tau}} \exp\left(\frac{-v_t^2}{2\tau^2}\right)$

The variance of the distribution is:

(5) $E(v_t^2) = p + (1-p)\tau^2$

The conditional variance of y_t is $\sigma_t^2 E(v_t^2)$

(6) $E[\,(y_t - x_t'\beta)^2 \mid Y_t] = \sigma_t^2 E(v_t^2)$

The magnitude of σ_t^2 obeys the following modification of Nelson's 1991 EGARCH model:

(7) $\ln(\sigma_t^2) - z_t'\kappa = \delta[\ln(\sigma_{t-1}^2) - z_{t-1}'\kappa] + \alpha[q(v_{t-1}) - Eq(v_{t-1}) + \aleph v_{t-1}]$

And q(·) is the absolute value function:

(8) q(v) = |v|

3.3.2 Key Variables in x_t

As for the selection of variables to include in x_t, Hamilton largely based them on institutional factors. For example, given that the primary reason banks held reserves was to satisfy their reserve requirements, which were based on an average of daily reserve levels across a 10-day maintenance period, Hamilton included a dummy variable for each day of the maintenance period. The intuition as to why the day of the maintenance period matters is best explained in stylized examples. If, for example, a bank held reserves short of its reserves requirement on the first day of the maintenance period, it has 9 additonal days to increase its 10-day average to a level that satisfies its reserve requirement. However, if a bank's average level of reserves on the tenth day of the maintenance period was insufficient in satisfying its reserve requirement, then it would have to scramble and pay up to make sure it obtained enough reserves on the last day of the maintenance period to increase its 10-day average. Hence, the desperation for banks and willingness to pay higher prices in order to obtain reserves and meet their reserves requirements are at their peaks on the last day of the maintenance period.

Another critical variable that Hamilton includes in x_t is the error component from his TGA model. When measuring a liquidity effect, it may appear straightforward that you can just include a variable for the size of an open market operation for the day, and then see how it correlates with the federal funds rate to estimate how much a monetary policy operation influences the interest rate. This is problematic, however, as the Federal Reserve chooses its open market operation size after taking into account expected reserve levels for the day. In other words, it may be the case that, for example, the Federal Reserve purchases $100 million in Treasury securities to offset an expected drain of reserves of $100 million due to tax payments from banks to the Treasury. This is a type of operation that may result, intentionally, in no change at all in the federal funds rate.

Hamilton gets around this endogeneity by creating an instrument correlated with an unexpected change in reserves instead of simply using open market operations. Hamilton creates a model to forecast the daily level of the Treasury General Account. He assumes the Federal Reserve's staff model and private banks' models are similar to his, and hence any error in Hamilton's TGA model would be a proxy for the error in the Federal Reserve's or market participant's model, and therefore, would represent an unanticipated change in reserves. Put another way, a miss in the TGA model is similar to a surprise open market operation from the perspective of a bank as it's an unexpected change to the supply of reserves.

Other variables included in x_t are dummy variables for days preceding and following 1-day holidays and 3-day holiday weekends, given that the holidays extend the duration of the federal funds loans. Additionally, Hamilton included dummy variables for days surrounding quarter- and year-end dates, given money market dynamics that exist surrounding these balance sheet reporting dates.

3.3.3 Hamilton's Results

Using daily balance sheet data from 1989 to 1991 (as these were the dates made available to Hamilton from the Federal Reserve), Hamilton finds that unanticipated changes in the TGA on the 10^{th} day of the maintenance period are significantly correlated with changes in the federal funds rate. Unanticipated changes in the TGA do not have a significant correlation with changes in the federal funds rate on days 1 through 8 of the maintenance period, and only a minor significant effect exists on day 9. Figure 16 illustrates these results and is taken directly from figure 6 in Hamilton (1997):

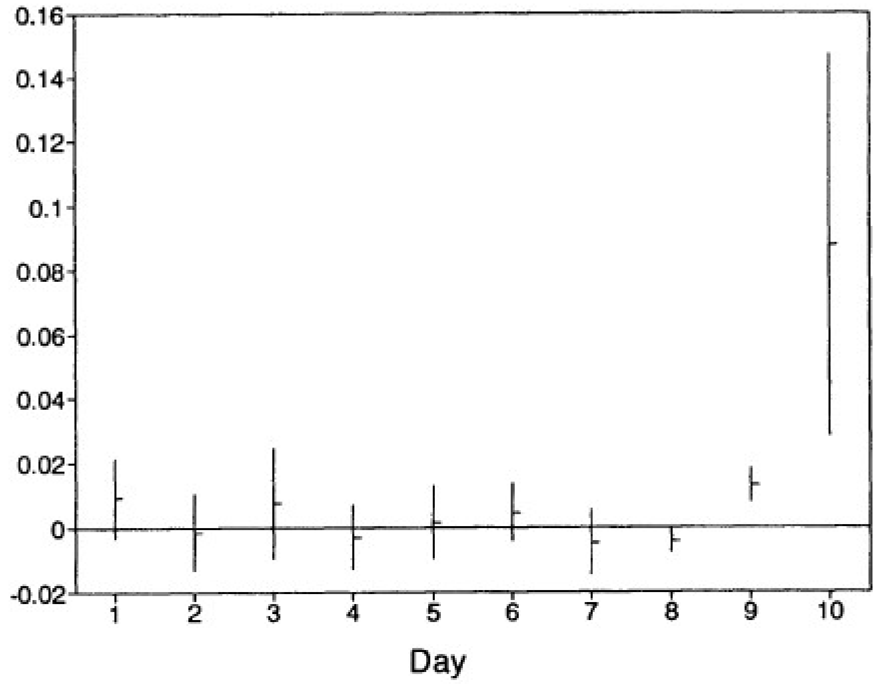

Figure 16 – Effect of Treasury Forecast Error on the Federal Funds Rate

Source: Hamilton (1997), Figure 6.

The short horizontal bars reflect the effect of an unanticipated increase in the TGA on the federal funds rate for each day, 1 through 10, of the reserve maintenance period. The vertical bars represent the 95 percent confidence intervals.

3.3.4 Updating Hamilton's Model With Contemporary Data

Given the sharp rise in reserves following the GFC, banks were largely flush with reserves and held levels much higher than they were required to hold. Volume in federal funds trading declined overall and trading among banks with the intent to meet reserve requirements was non-existent. Over this period, it was common for the federal funds rate to print at the same rate as it did the preceding day. Hence, updating Hamilton's model with data for most of the post-GFC period would lead to no federal funds rate effects, as the rate typically did not budge.

Beginning in 2015, reserves began to decline as the Federal Reserve's large-scale asset purchase programs had concluded and other liabilities on its balance sheet had increased such as Federal Reserve notes and the TGA. Additionally, as a result of the Federal Reserve's Policy Normalization plans, beginning in 2017, the Federal Reserve allowed Treasury and agency mortgage-backed securities to roll off its balance sheet until late 2019. These declines in reserves are shown in figure 17 below:

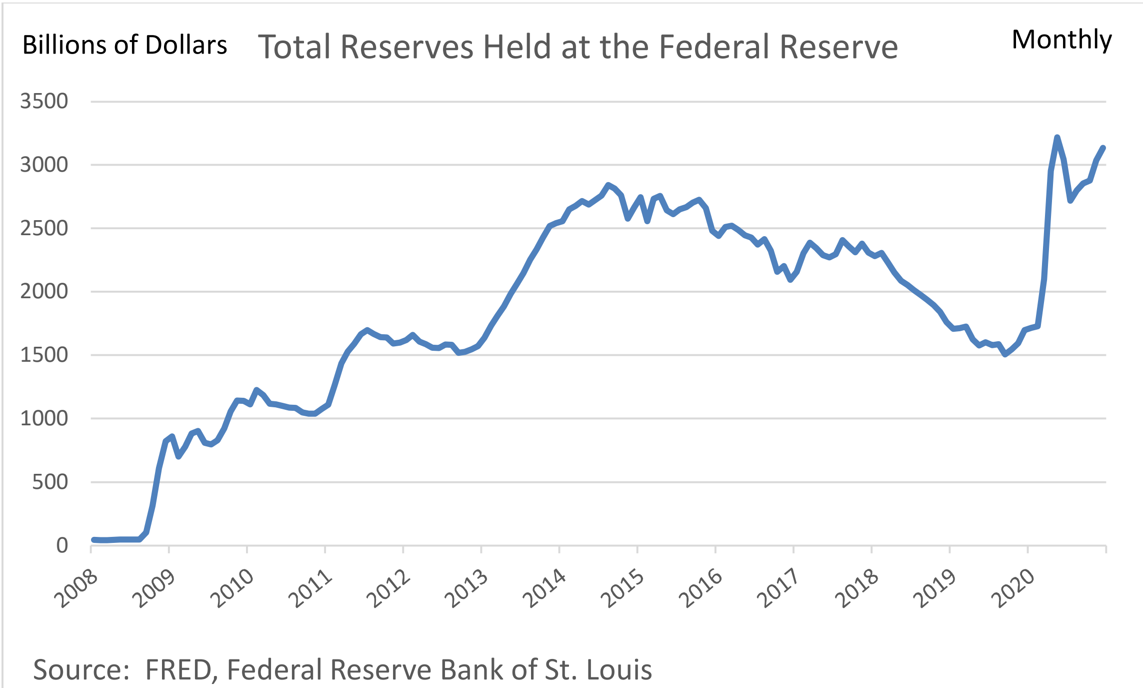

Figure 17

As a result of some of the relative scarcity in reserves, especially in 2018 and 2019, some day to day volatility in the federal funds rate started to return. Daily standard deviations in the federal funds market, by year, from 2015 through 2019 are shown in figure 18.[30]

[30] Similar in spirit to Hamilton's 1997 model, I exclude quarter-end dates and adjacent dates. I also exclude month-end dates and adjacent dates due to regulatory dynamics that cause movement in the federal funds rate around month-end. In addition, I use 2019 data through September 13, 2019, to avoid the volatility from the money market episode in 2019.

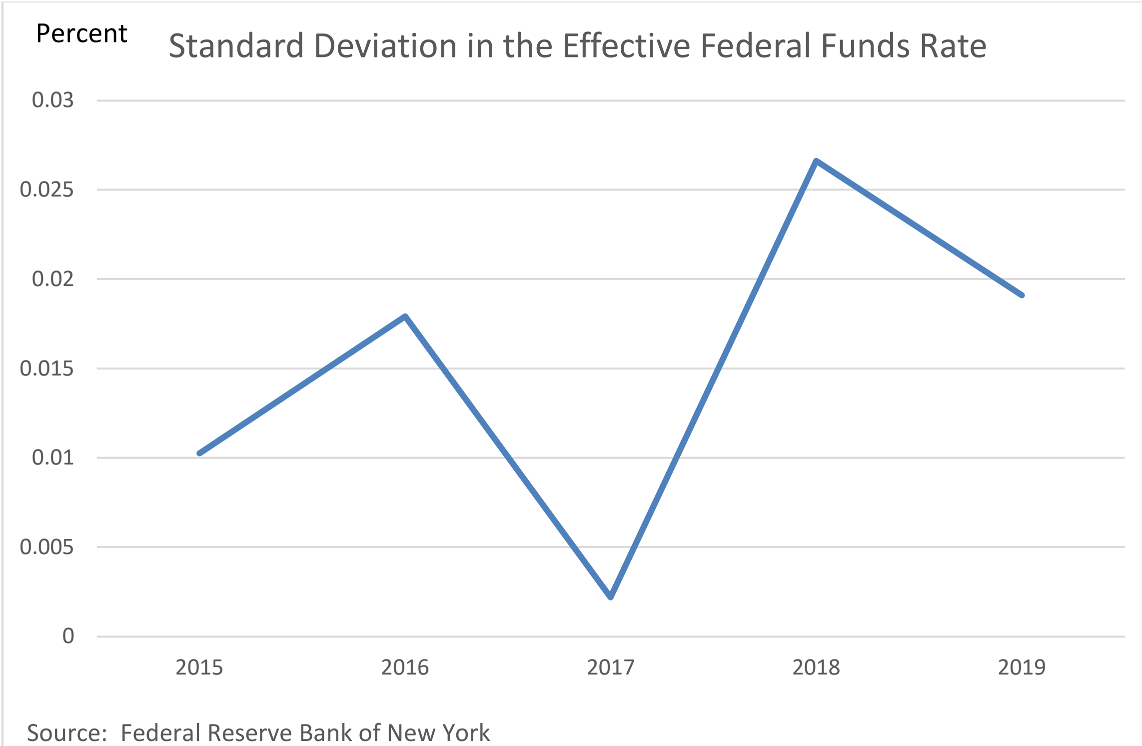

Figure 18

Given the return of some volatility in 2018 and 2019, I choose to use January 1, 2018 through September 13, 2019, as my dataset for updating Hamilton's federal funds model. I exclude the remainder of 2019 as that was the beginning of the repo episode and large RP operations. Similar to Carpenter and Demiralp (2006), I use errors in the Federal Reserve staff TGA model, and then, using the same statistical framework in Hamilton's federal funds rate model, I replicate figure 6 from his 1997 paper. This replication with updated data is shown in figure 19 below:

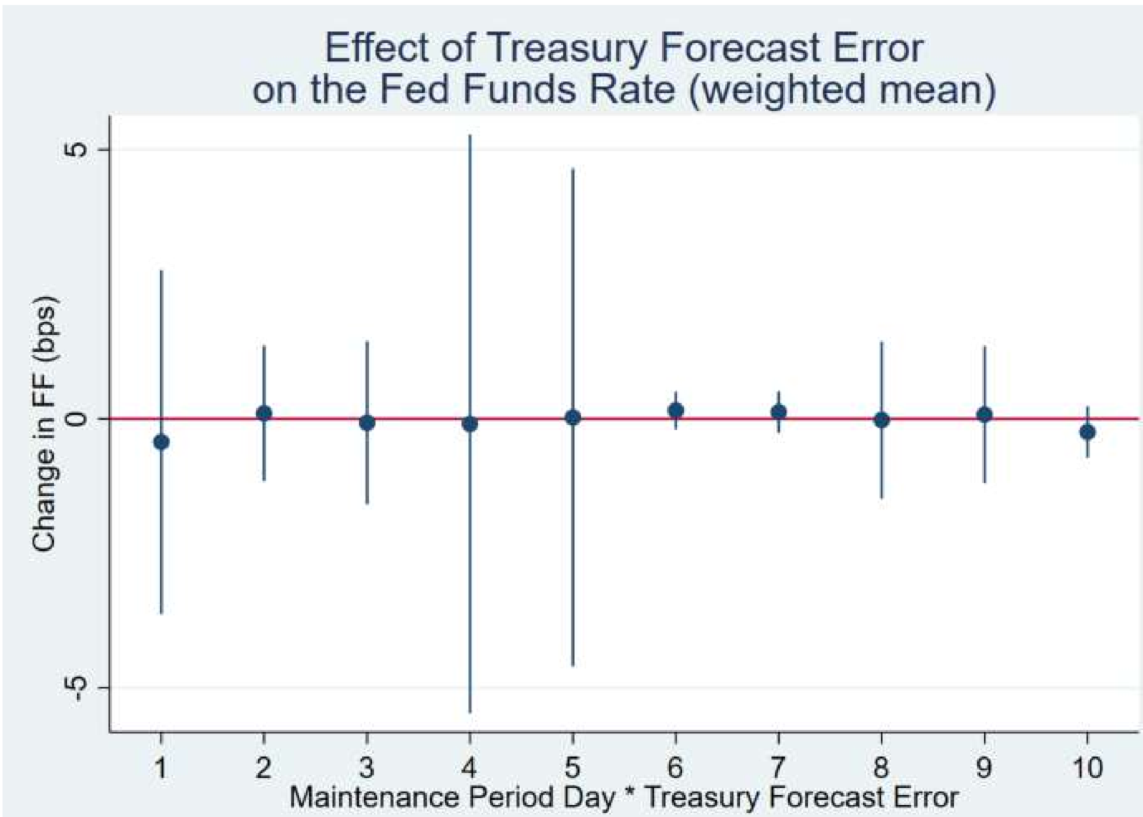

Figure 19

As is shown in figure 19, unanticipated changes in the TGA interacted with the day of the maintenance period are no longer significantly correlated with changes in the federal funds rate, even on the 10^{th} day of the maintenance period. This result matches the basic intuition that banks are holding far more reserves than they are required to, and hence, the day of the maintenance period has no effect on the federal funds rate.

During 2018 and 2019 where we start to see the return of some day to day volatility in the federal funds rate, if reserve requirements are not having an impact, and if the Federal Reserve is not actively purchasing or selling securities, then what are the factors that drive the federal funds rate? That's the topic of discussion in section four.

Section Four: An Updated Federal Funds Model

In this section, I create a federal funds rate model which incorporates daily, internal Federal Reserve data and reflects contemporary federal funds rate dynamics. As I discussed in the previous section, I use data from January 2018 into September 2019 due to the increase in day to day volatility in the federal funds rate at that time. The federal funds rate during this time period is shown in figure 20 below:

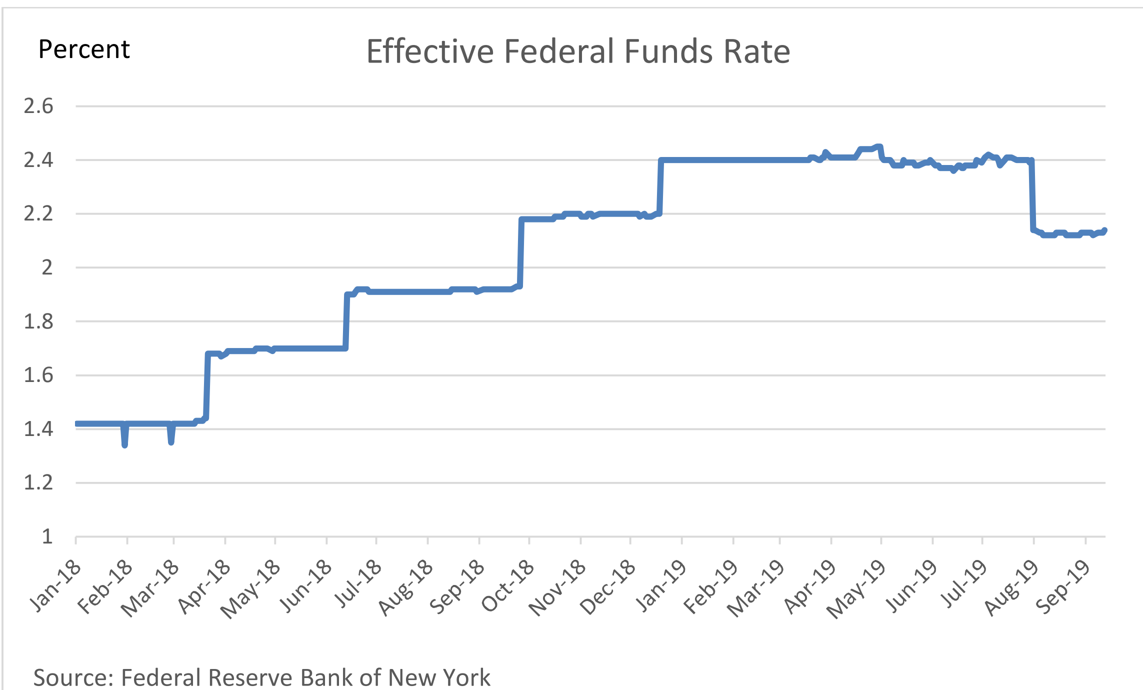

Figure 20

3.4.1 Updating a Federal Funds Rate Model with IOER

Looking at figure 20, we can see there are 5 major discrete step movements; four to the upside in 2018 and one to the downside in 2019. The steps correspond with changes to the IOER rate. In the floor framework, the federal funds rate is largely driven by the IOER, and so, far and away, the most important variable in explaining the federal funds rate is the IOER rate. I begin modelling the federal funds rate with a simple OLS regression below:

(1) $y_t = ioer\beta + \varepsilon_t$

Where y_t is the weighted mean federal funds rate and $ioer$ is the IOER rate. The model outputs the following regression results:[31]

Table 4 - Regression 1

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.115	0.002	446.49	0.000	1.110	1.120	***
Constant	-25.011	0.522	-47.95	0.000	-26.036	-23.985	***

Mean dependent var	205.361	SD dependent var	34.272
R-squared	0.9979	Number of obs	427.000
F-test	199351.860	Prob > F	0.000
Akaike crit. (AIC)	1605.808	Bayesian crit. (BIC)	1613.921

*** *p<0.01, *** *p<0.05, ** *p<0.1*

[31] The effective federal funds rate is a weighted *median* rate and often does not change day to day. To get some more volatility in the federal funds rate measure, I use an internal weighted *mean* rate based on federal funds trades collected in the Federal Reserve's daily FR2420 Report of Selected Money Market Rates. For more information on the FR2420 report, please see: https://www.newyorkfed.org/banking/reportingforms/FR_2420.html

The very high R-squared and nearly one to one pass through of the IOER to the federal funds are not surprising and in fact, are the intention of the floor monetary policy framework. If we account for IOER and look at the spread of the federal funds rate to IOER, we get figure 21 below:

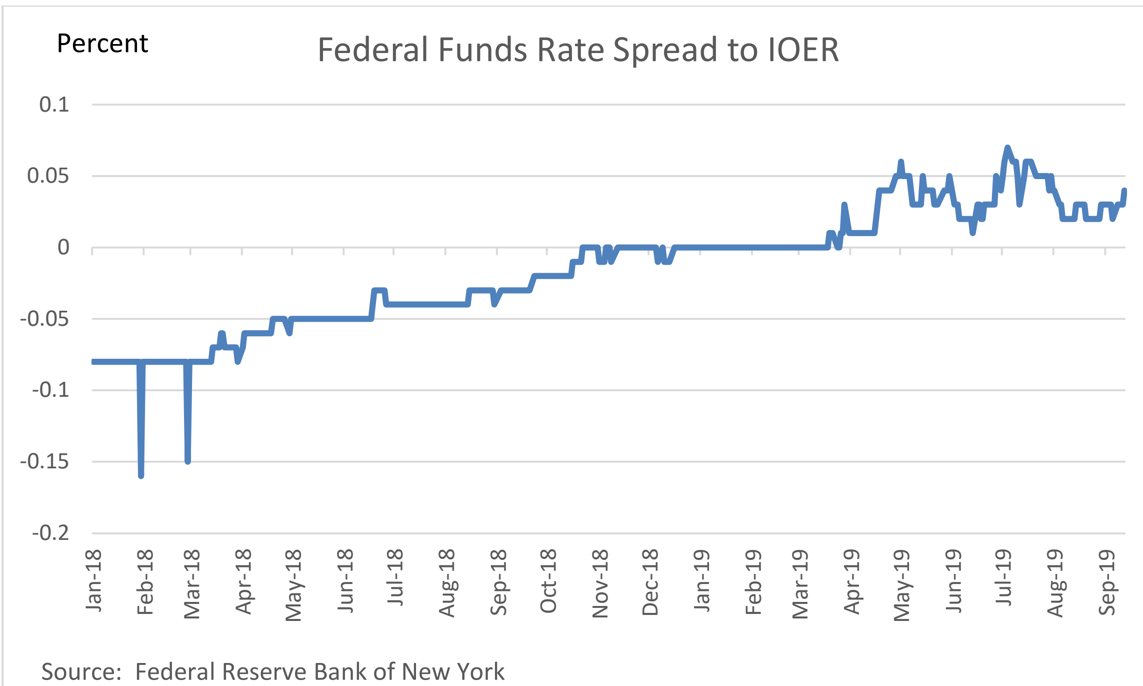

Figure 21

The most notable discrete movements in the spread occur on month-end dates early in the sample. These outsized rate movements can largely be explained by the fact that many foreign regulators look at bank balance sheets on month-end or quarter-end for purposes of computing regulatory formulas such as supplementary leverage and liquidity ratios. As a result, many foreign banks engage in "window dressing" and shrink their balance sheets on these regulatory reporting dates (Banegas and Tase, 2020). The incentive to reduce the size of their balance sheets leads to a decline in demand for federal funds, and as a result, the clearing interest rate in the federal funds market falls.

There is also a clear up trend in the federal funds rate spread to IOER. This can be explained by the ongoing reserves tightening that was taking place during this time period.

3.4.2 Removing Month Ends and Adding in Reserve Balances

In order to improve the federal funds rate model described in equation 1, I address the month-end outliers and uptrend shown in figure 21. Given that many month-end and quarter-end dates are anomalies relative to typical non-regulatory reporting dates, I remove them from my sample so that I can get a more clear picture as to what is driving the federal funds rate on a day to day basis.

The uptrend in the federal funds rate in 2018 and 2019 can be explained by the decrease in reserves during this same time frame. If we overlay figure 22 with total reserves, a strong inverse relationship can be observed, as shown in figure 22 below.

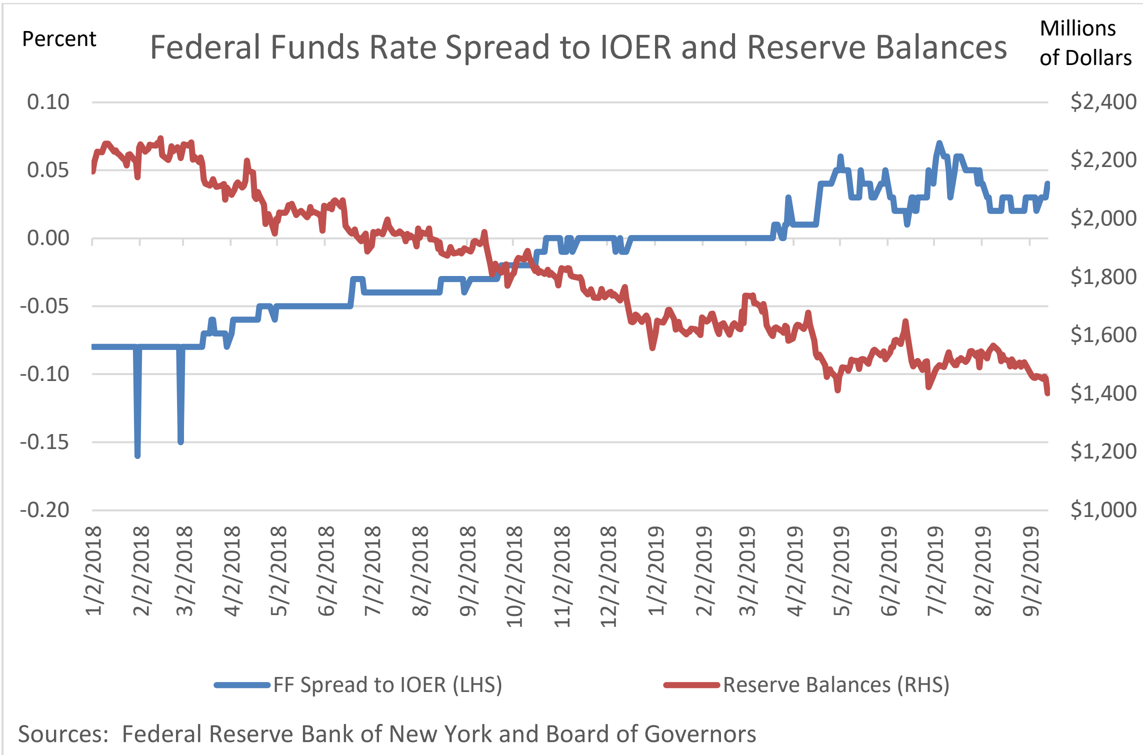

Figure 22

After dropping month ends and updating equation 1 with total reserve balances, I update the regression as follows:

(2) $y_t = ioer\beta_1 + reserves\beta_2 + \varepsilon_t$

Where $reserves$ is total reserve balances held at the Federal Reserve. I get the following OLS output:

Table 5 - Regression 2

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.020	0.003	402.07	0.000	1.015	1.025	***
Reserves	-0.013	0.000	-40.29	0.000	-0.013	-0.012	***
Constant	17.770	1.070	16.60	0.000	15.666	19.873	***

Mean dependent var	205.253	SD dependent var	34.203
R-squared	0.9996	Number of obs	407.000
F-test	537053.982	Prob > F	0.000
Akaike crit. (AIC)	825.736	Bayesian crit. (BIC)	837.762

*** *p<0.01,* ** *p<0.05,* * *p<0.1*

The negative coefficient for reserves implies a liquidity effect of some sort. Increases in reserves are correlated with decreases in the federal funds rate. Regression 2 implies that a $100 billion increase in reserves is correlated with a 1.3 bp decline in the federal funds rate, after accounting for IOER. The direction of this coefficient is in line with Hamilton's 1997 federal funds model.

Both explanatory variables are statistically significant and the R-squared has improved. The Akaike and Bayesian information criterion show a better fit as well. However, reserve balances change based on a large number of factors. In order to get an even more in-depth understanding of the federal funds rate, it's helpful to look at each factor that causes changes in reserve balances and estimate how much of their changes pass through to the federal funds rate.

3.4.3 Breaking Down Reserve Balance Changes

A good place to start for a look at factors that affect reserves is the Federal Reserve's H.4.1 release, Factors Affecting Reserve Balances of Depository Institutions and Condition Statement of Federal Reserve Banks. Table 1 of the H.4.1 lists all of the factors that supply reserves and all of the factors that absorb reserves. I was able to obtain internal, daily data for each of the factors that supply and absorb reserves listed in Table 1.

Some notable factors that supply reserves include Treasury securities, mortgage-backed securities, and loans. For example, when the Federal Reserve purchases Treasury securities, it adds funds to its counterparties' bank accounts at the Federal Reserve which leads to an increase in the amount of reserves in the system. Some notable factors that absorb reserves include currency in circulation, reverse repurchase agreements, and the TGA. For example, if the Treasury collects corporate taxes, the TGA balance will go up, and the corporation's bank account balance will go down, reducing the total reserves in the system.

I updated my regression by replacing reserve balances with all of the individual factors that affect reserve balances:

(3) $y_t = ioer\beta_1 + x_t\beta_2 + \varepsilon_t$

Where x_t is an array of factors that supply and drain reserves. The regression results are shown below:

Table 6 - Regression 3

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.024	0.004	231.25	0.000	1.015	1.033	***
Bills	-0.396	0.103	-3.83	0.000	-0.600	-0.193	***
Notes/Bonds	-0.022	0.004	-4.88	0.000	-0.031	-0.013	***
TIPS	-0.281	0.055	-5.10	0.000	-0.389	-0.172	***
Infl Comp	1.538	0.189	8.15	0.000	1.167	1.909	***
Fed Agcy Debt	0.100	0.094	1.07	0.286	-0.084	0.284	
MBS	-0.032	0.009	-3.50	0.001	-0.050	-0.014	***
Unam. Premiums	0.430	0.148	2.89	0.004	0.138	0.721	***
Unam. Discounts	-0.673	0.935	-0.72	0.472	-2.510	1.165	
Repos	1.229	2.856	0.43	0.667	-4.386	6.843	
Loans	-1.338	0.546	-2.45	0.015	-2.412	-0.265	**
Float	0.085	0.155	0.55	0.583	-0.220	0.391	
CB Swaps	-0.154	0.027	-5.79	0.000	-0.207	-0.102	***
Other Assets	-0.004	0.011	-0.36	0.718	-0.025	0.017	
Foreign Assets	-0.681	0.158	-4.31	0.000	-0.991	-0.370	***
o.Gold Stock	0.000	.	.	.	.	.	
o.SDR Certif	0.000	.	.	.	.	.	
Tres Curr Outs	-6.248	4.652	-1.34	0.180	-15.395	2.900	
Currency	0.042	0.009	4.50	0.000	0.024	0.061	***
Foreign RRP	0.006	0.003	1.91	0.057	0.000	0.013	*
ON RRP	0.018	0.004	4.11	0.000	0.009	0.027	***
Tsy Cash	10.756	2.162	4.98	0.000	6.506	15.006	***
Term Deposits	0.000	0.000	0.07	0.940	0.000	0.000	
TGA	0.010	0.001	13.31	0.000	0.009	0.011	***
Forgn Offic Dep	0.305	0.501	0.61	0.543	-0.680	1.290	
Other Deposits	0.004	0.004	0.94	0.345	-0.004	0.011	
Other Liabs/Cap	-0.036	0.035	-1.04	0.298	-0.105	0.032	
Constant	267.328	238.930	1.12	0.264	-202.458	737.113	

Mean dependent var			205.253
R-squared	0.9998	Number of obs	407.000
F-test	70203.084	Prob > F	0.000
Akaike crit. (AIC)	648.098	Bayesian crit. (BIC)	752.327

*** *p<0.01,* ** *p<0.05,* * *p<0.1*

Yet again, we get an increase in R-squared and the Akaike and Bayesian information criterion show the model is a better fit. That said, there are some variables that are insignificant at the 90 percent confidence interval. Federal agency debt was insignificant. This makes sense given the Federal Reserve does not purchase agency debt outside of agency MBS anymore. The existing agency securities slowly roll off over time, in a predictable schedule, and are not of great magnitudes. Repurchase agreements, or repos, also were not significant. Prior to September 2019, the only repos conducted were small-value test operations, and they were known by market participants well in advance. The remainder of the insignificant variables were unsurprising given how small, and uncorrelated they are with market conditions, such as Other Assets, which includes assets such as Federal Reserve purchases of buildings for employees to work in, or Term Deposits, which are only conducted periodically for testing purposes.

Additionally, some variables were omitted such as gold stock and special drawing rights certificates. These variables remained constant over the sample period, hence, it makes sense to omit them.

After removing the insignificant and omitted variables, I update my regression and get the results below:

Table 7 - Regression 4

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.022	0.004	246.85	0.000	1.014	1.030	***
Bills	-0.285	0.069	-4.14	0.000	-0.420	-0.150	***
Notes/Bonds	-0.025	0.004	-6.52	0.000	-0.032	-0.017	***
TIPS	-0.263	0.052	-5.10	0.000	-0.364	-0.161	***
Infl Comp	1.368	0.153	8.93	0.000	1.067	1.669	***
MBS	-0.028	0.007	-4.24	0.000	-0.041	-0.015	***
Unam. Premiums	0.565	0.096	5.87	0.000	0.376	0.754	***
Loans	-1.609	0.469	-3.43	0.001	-2.532	-0.686	***
CB Swaps	-0.132	0.024	-5.47	0.000	-0.179	-0.084	***
Foreign Assets	-0.449	0.126	-3.56	0.000	-0.697	-0.201	***
Currency	0.044	0.008	5.33	0.000	0.028	0.060	***

Foreign RRP	0.004	0.003	1.66	0.098	-0.001	0.009	*
ON RRP	0.017	0.004	3.97	0.000	0.009	0.026	***
Tsy Cash	8.318	1.452	5.73	0.000	5.463	11.173	***
TGA	0.010	0.001	14.13	0.000	0.009	0.011	***
Constant	-58.091	15.967	-3.64	0.000	-89.484	-26.698	***

Mean dependent var	205.253	SD dependent var	34.203
R-squared	0.9998	Number of obs	407.000
F-test	117569.919	Prob > F	0.000
Akaike crit. (AIC)	636.681	Bayesian crit. (BIC)	700.822

**** p<0.01, ** p<0.05, * p<0.1*

Regression 4 shows a better fit according to the Akaike and Bayesian information criterion. At this point, all of the explanatory variables are significant at the 99 percent confidence interval with the exception of Foreign Reverse Repos, hence, I drop that item and we get an even better fit, shown below:

Table 8 - Regression 5

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.021	0.004	249.77	0.000	1.013	1.029	***
Bills	-0.284	0.069	-4.12	0.000	-0.419	-0.148	***
Notes/Bonds	-0.025	0.004	-6.70	0.000	-0.032	-0.018	***
TIPS	-0.268	0.052	-5.20	0.000	-0.369	-0.167	***
Infl Comp	1.405	0.152	9.25	0.000	1.106	1.704	***
MBS	-0.030	0.007	-4.49	0.000	-0.043	-0.017	***
Unam. Premiums	0.575	0.096	5.97	0.000	0.386	0.764	***
Loans	-1.747	0.463	-3.77	0.000	-2.657	-0.837	***
CB Swaps	-0.123	0.023	-5.22	0.000	-0.169	-0.076	***
Foreign Assets	-0.425	0.126	-3.39	0.001	-0.672	-0.178	***
Currency	0.043	0.008	5.20	0.000	0.027	0.059	***
ON RRP	0.016	0.004	3.70	0.000	0.007	0.024	***
Tsy Cash	8.177	1.453	5.63	0.000	5.320	11.033	***
TGA	0.010	0.001	14.33	0.000	0.009	0.012	***
Constant	-53.266	15.735	-3.38	0.001	-84.202	-22.331	***

Mean dependent var	205.253	SD dependent var	34.203

R-squared	0.9998	Number of obs	407.000
F-test	125408.049	Prob > F	0.000
Akaike crit. (AIC)	637.532	Bayesian crit. (BIC)	697.664

*** *p<0.01*, ** *p<0.05*, * *p<0.1*

In looking at the coefficient directions for each variable, it's reasonable to expect that, consistent with a liquidity effect, the Federal Reserve assets have negative coefficients and the Federal Reserve liabilities have positive coefficients. Since higher assets lead to higher reserves, you would expect the Federal Funds rate to decline as more assets are added to the system. The opposite is true for Federal Reserve liabilities. Since reserves are also a liability, if any other liability increases, reserves will likely decrease, leading to a higher federal funds rate.

The directions of the coefficients largely match this intuition with just a couple of exceptions.[32] At this point, the model is looking like a good fit, though there may be some other variables worth investigating that are not listed on the H.4.1 release.

3.4.4 Other Factors

In the spirit of revisiting Hamilton's 1997 model, I was able to obtain daily, internal staff forecasts for the TGA. In Hamilton's federal funds rate model, he created

[32] Inflation compensation and unamortized premiums are both assets that had positive coefficients. In the case of inflation compensation, to the extent inflation is positively correlated with interest rates, then if the federal funds rate and other interest rates move in the same direction, it's feasible that the coefficient for inflation compensation would be positive. In the case of premiums on securities, a lot of its effect is already captured by Treasury and agency-MBS securities since premiums tend to move directly in line with those items (the more securities you purchase, the higher the likelihood that premiums on securities increases). I ran a regression including premiums on securities and taking out Treasury and agency-MBS variables and the coefficient was significantly negative.

his own forecast for the TGA and included the error in that model as an explanatory variable in his federal funds rate model to reflect an unanticipated change in the supply of reserves. Similar to Carpenter and Demiralp in 2006, I use the actual staff model misses.[33]

When thinking about other factors to include in a federal funds rate model, it's important to reflect the fact that federal funds are an interest-earning asset on bank balance sheets. Other competing money market instrument interest rates factor into bank decisions relating to their desired composition and size of assets. For example, if a bank can earn more interest lending in a repurchase agreement relative to lending federal funds, they may choose that over lending in the federal funds market. To reflect money market interest rates, I add in the Tri-Party General Collateral Rate (TGCR) to my model.[34] The TGCR is a public reference rate and is available at a daily frequency. I chose to use the TGCR as opposed to the Broad General Collateral Rate (BGCR) or Secured Overnight Financing Rate (SOFR) to avoid rate dynamics based on niche markets, such as the GCF interdealer repo market, or based on supply and demand for specific securities. The updated regression is shown below:

$$(4)\quad y_t = ioer\beta_1 + x_t\beta_2 + tgamiss\beta_3 + tgcr\beta_4 + \varepsilon_t$$

[33] TGA Miss is defined as the staff forecast for the TGA less the actual TGA on a given day. The larger the TGA miss, the larger the Federal Reserve (and quite likely, other market participants) expected the TGA would be. Put another way, the larger the TGA miss, the less reserves the Treasury (and, likely market participants) anticipated in the system, which would lead to a higher federal funds rate.

[34] For more information on the TGCR, see: https://www.newyorkfed.org/markets/reference-rates/tgcr

Table 9 - Regression 6

Fed Funds Rate	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
IOER	1.006	0.007	144.30	0.000	0.993	1.020	***
Bills	-0.257	0.069	-3.73	0.000	-0.393	-0.122	***
Notes/Bonds	-0.026	0.004	-6.98	0.000	-0.033	-0.019	***
TIPS	-0.251	0.051	-4.88	0.000	-0.353	-0.150	***
Infl Comp	1.159	0.141	8.23	0.000	0.882	1.435	***
MBS	-0.034	0.006	-5.29	0.000	-0.047	-0.021	***
Unam. Premiums	0.600	0.095	6.31	0.000	0.413	0.786	***
CB Swaps	-0.126	0.024	-5.36	0.000	-0.173	-0.080	***
Foreign Assets	-0.429	0.130	-3.30	0.001	-0.685	-0.173	***
Currency	0.037	0.009	4.18	0.000	0.020	0.055	***
ON RRP	0.014	0.004	3.42	0.001	0.006	0.023	***
Tsy Cash	7.470	1.452	5.15	0.000	4.617	10.324	***
TGA	0.009	0.001	12.27	0.000	0.008	0.011	***
TGA Miss	-0.048	0.020	-2.37	0.018	-0.089	-0.008	**
TGCR	0.019	0.006	3.18	0.002	0.007	0.030	***
Constant	-35.259	17.878	-1.97	0.049	-70.408	-0.110	**

Mean dependent var	205.121	SD dependent var	34.225
R-squared	0.9998	Number of obs	405.000
F-test	116760.546	Prob > F	0.000
Akaike crit. (AIC)	634.953	Bayesian crit. (BIC)	699.015

*** *p<0.01,* ** *p<0.05,* * *p<0.1*

This model fit improves even more as evaluated by both the Akaike and Bayesian information criterion. In looking at the coefficients for TGA and TGA Miss, the TGA Miss coefficient is over 5 times greater than the TGA variable coefficient. This result is in line with Hamilton's model with respect to the fact that an unanticipated change in reserves has an outsized effect on the federal funds rate compared to an expected change in reserves.

3.4.5 Addressing Heteroskedasticity

One concern of Hamilton's in his 1997 Federal Funds model was the need to address heteroskedasticity. Below is a plot residual and fitted values from equation 4.

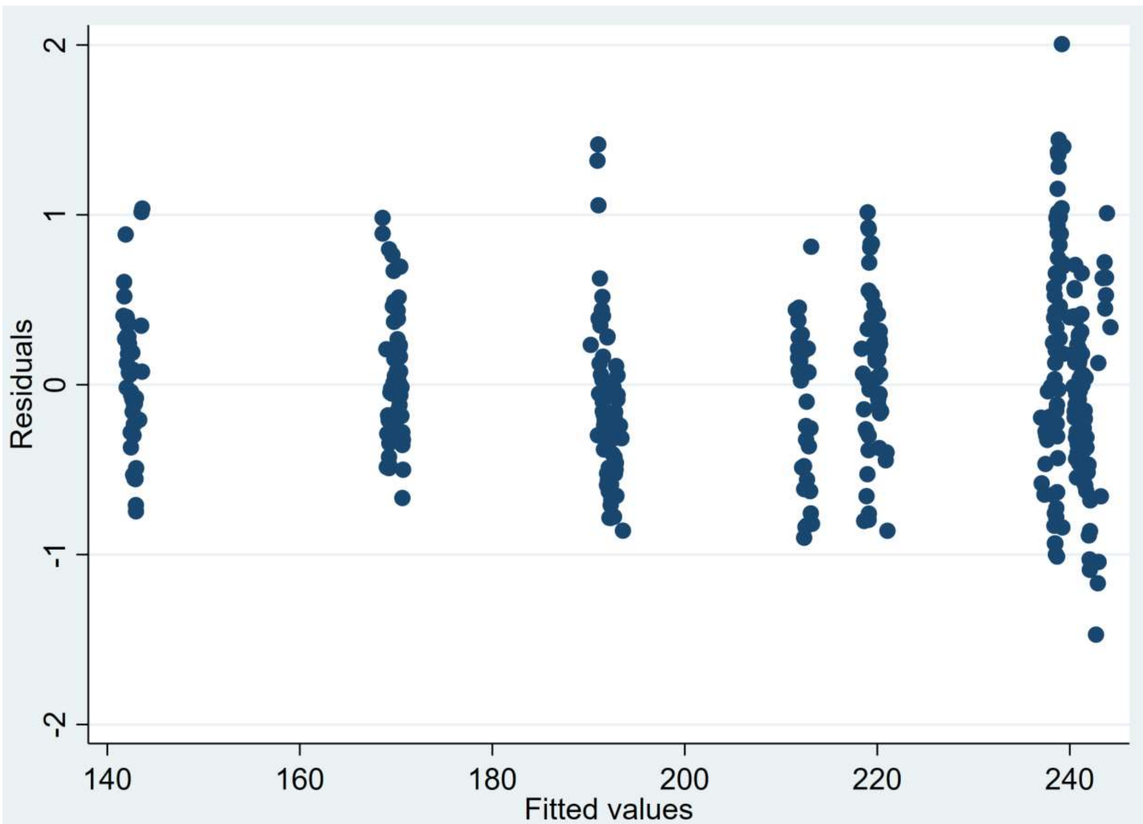

Figure 23

There doesn't appear to be any skewness in the residuals, though, the variance does look to expand some as the fitted values increase. If we do a Breusch-Pagan / Cook-

Weisberg test for heteroskedasticity, we reject the null hypotheses of constant variance, shown below:

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of ff_wmean

         chi2(1)      =    20.87
         Prob > chi2  =   0.0000
```

To address the heteroskedasticity, I use a multiplicative heteroskedastic regression using maximum likelihood estimation. The log-likelihood function I use is as follows:

$$(5)\ \ln L = \sum_{i=1}^{n} \frac{w_i}{2}\left\{\frac{(y_i - x_i\beta)^2}{\exp(z_i\alpha)}\right\} - \ln(2\pi) - z_i\alpha$$

Where y_i, i = 1, . . . , n, is the dependent variable; $x_i = (x_{1i}, x_{2i}, \ldots, x_{ki})$ are the k independent variables that model the mean function; $z_i = (z_{1i}, z_{2i}, \ldots, z_{mi})$ are the m variables that model the variance function; and w_i are the weights. β is a column vector of unknown parameters in the mean function and α is a column vector of unknown parameters in the variance function. The regression output is as follows:

Table 10 - Regression 7

Fitting full model:
Iteration 0: log likelihood = -302.83541
Iteration 1: log likelihood = -301.48035
Iteration 2: log likelihood = -301.47643
Iteration 3: log likelihood = -301.47642
Heteroskedastic linear regression Number of obs = 405
ML estimation

Log likelihood = -301.4764 Prob > chi2 = 0.0000

Fed Funds Rate	Coef.	Std.Err.	z	P>z	[95%Conf.	Interval]
Fed Funds Rate						
IOER	1.006	0.007	147.230	0.000	0.993	1.020
Bills	-0.257	0.068	-3.810	0.000	-0.389	-0.125
Notes/Bonds	-0.026	0.004	-7.120	0.000	-0.033	-0.019
TIPS	-0.251	0.050	-4.980	0.000	-0.350	-0.153
Infl Comp	1.159	0.138	8.400	0.000	0.888	1.429
MBS	-0.034	0.006	-5.400	0.000	-0.047	-0.022
Unam. Premiums	0.600	0.093	6.440	0.000	0.417	0.782
CB Swaps	-0.126	0.023	-5.470	0.000	-0.172	-0.081
Foreign Assets	-0.429	0.127	-3.370	0.001	-0.679	-0.179
Currency	0.037	0.009	4.260	0.000	0.020	0.055
ON RRP	0.014	0.004	3.490	0.000	0.006	0.022
Tsy Cash	7.470	1.423	5.250	0.000	4.682	10.259
TGA	0.009	0.001	12.520	0.000	0.008	0.011
TGA Miss	-0.048	0.020	-2.410	0.016	-0.088	-0.009
TGCR	0.019	0.006	3.240	0.001	0.007	0.030
_cons	-35.259	17.521	-2.010	0.044	-69.600	-0.919
lnsigma2						
_cons	-1.349	0.070	-19.200	0.000	-1.487	-1.211

Using this model, the Akaike and Bayesian criterion are 637 and 705, respectively, and hence, do not show much improvement to the model in equation 4. All of the explanatory variables are still statistically significant, and the coefficient sizes do not differ much at all.

3.4.6 Discussion

Since the GFC, the federal funds market has been very stable and predictable, almost entirely driven by changes in the Federal Reserve's administered interest rates, namely, the IOER and ON RRP rates. During the Federal Reserve's balance sheet normalization that took place in 2018 and 2019, we get a rare glimpse of a contemporary federal funds market in a declining reserves environment where some daily volatility returns to the market.

Of course, the IOER is still the main driver of the federal funds rate, but in this chapter, I estimate other factors that explain movements in the federal funds rate. Looking at the output from equation 4, nearly all of the Federal Reserve assets are inversely correlated with the federal funds rate, and all of the Federal Reserve liability coefficients have the same sign as the federal funds rate. This makes intuitive sense given that a Federal Reserve asset, such as a loan, increases the supply of reserves, which leads to a lower federal funds rate. The opposite is true for Federal Reserve liabilities.

Different factors that change the level of reserves are correlated with different sized effects on the federal funds rate. For example, according to our output in Regression 6, a Federal Reserve purchase of bills has an estimated ten times larger downward effect on the federal funds rate relative to a purchase of a longer duration Treasury. This may be explained by the fact that Treasury bills can sometimes be viewed as substitutes for federal funds due to their liquidity and how they are viewed in regulators' leverage ratios. So, a purchase of bills acts as a direct draw on the supply of a substitute to federal funds. Similarly, to the extent bills purchases impact Treasury bill yields, that would impact federal funds interest rates as these money market rates are closely interrelated. Meanwhile, purchases of agency mortgage-backed securities have a much more muted impact on the federal funds rate.

Looking on the liability side, the TGA level is positively correlated with the federal funds rate, but TGA model miss has a much stronger positive correlation. Just as

Hamilton showed, an unanticipated change in reserves may lead to strong effects in the federal funds rate. More predictable liabilities, such as currency, seem to have a muted effect on the federal funds rate. ON RRP takeup is positively correlated with the federal funds rate as well. This is a more contemporary factor, given ON RRP operations ramped up in 2013 as the Federal Reserve looked to gain more control of the federal funds rate in its floor policy framework. This is the type of variable that wasn't meaningful back when Hamilton was researching the federal funds market. There is a significant correlation with other money market rates, such as the TGCR. This is unsurprising given how closely linked many money markets are.

Put together, we now have some insight into dynamics that move the federal funds rate in contemporary times. Should the Federal Reserve choose to reduce reserves again, we may end up in a period where reserves are no longer super abundant similar to 2018-2019, in which case these estimates and insights may be helpful for the Federal Reserve to maintain control of the federal funds rate and for market participants to understand what factors affect this important interest rate.

Section Five: Conclusion

In this chapter, I revisited Hamilton's 1997 federal funds rate model and updated it using data from 2018-2019. I show that the liquidity effect, as described by Hamilton, no longer exists. As a result of a significant increase in the supply of reserves, banks no longer trade federal funds with each other for the purpose of meeting their reserve requirements. There is no longer a significant unanticipated change in reserves effect on the federal funds rate on the 9^{th} and 10^{th} business days of the two-week maintenance period.

I go on to explore what contemporary dynamics cause the federal funds rate to move around. I chose the years 2018 and 2019 as that's when the Federal Reserve implemented its balance sheet normalization policy and reduced reserve holdings. This led to some relative scarcity in reserves, which brought some day to day volatility back into the federal funds rate.

I was able to obtain internal daily Federal Reserve balance sheet data as well as internal staff forecasts of the TGA balance. My federal funds model shows that while IOER explains the overwhelming majority of movement in the federal funds rate, there are other factors which change the supply of reserves and explain the remaining movement in the federal funds rate.

Asset purchases put downward pressure on the federal funds rate, with bills purchases having a much stronger effect than Treasury notes and bonds, or agency mortgage-backed securities.

ON RRP takeup is an example of a liability that's been important only recently, and has been positively correlated with the federal funds rate. The TGA puts upward pressure on the federal funds rate, and in line with Hamilton's work, the unanticipated change in the TGA has an even stronger effect on the federal funds rate. The federal funds rate is also correlated with rates in other money markets such as the TGCR. Contemporary regulations matter as well, as shown by some outliers in the data during my sample period.

In conclusion, these estimates and insights into the contemporary federal funds market will help the Federal Reserve and market participants to understand the drivers of the federal funds rate. This research will be even more relevant should the Federal Reserve begin a period of balance sheet normalization in the future.

APPENDIX 1

Replication Results of Hamilton's 1997 Models

Hamilton's Treasury General Account Model

	Hamilton 1997 Results		My Results	
Parameter	Coefficient	Standard Error	Coefficient	Standard Error
U_{t-1}	0.54	0.04	0.57	0.05
U_{t-2}	-0.05	0.03	-0.01	0.03
U_{t-3}	0.08	0.02	0.09	0.03
D_{1t}	-3.64	0.71	-2.72	1.15
$D_{1t}\ U_{t-1}$	0.46	0.07	0.33	0.08
$D_{1t}G_{1t}$	8.92	1.31	7.70	3.0
$D_{1t}G_{1t}\ U_{t-1}$	-0.99	0.08	-0.83	0.15
D_{2t}	0.67	0.24	1.06	0.26
D_{3t}	-0.36	0.09	-0.46	0.09
V_{4t}	-0.46	0.13	-0.30	0.19
G_{3t}	-0.32	0.16	-0.63	0.22
G_{4t}	0.61	0.17	0.42	0.15
G^n_t	0.94	0.37	1.75	0.96
Constant	2.35	0.22	2.05	0.23

Parameter definitions from Hamilton 1997:
U_t are Federal Reserve deposits held by U.S. Treasury in billions of dollars.
$D_{1t} = 1$ if $U_{t-1} > 8$
$D_{2t} = 1$ for major tax-collection periods
$D_{3t} = 1$ if *t* falls on a Friday
$V_{4t} = 1$ if day *t* falls in month *j* for *j* = 1, 2, …, 12
$G_{1t} = 1$ if day *t* falls on the *jth* business day of the month for *j* = 1, 2, …,23
$G^n_t = 1$ if day *t* falls on the last business day of the month

Hamilton's Federal Funds Rate Model

	Hamilton 1997 Results		My Results	
Parameter	Coefficient	Standard Error	Coefficient	Standard Error
T_{1t}	0.00	0.01	-0.02	0.03
T_{2t}	-0.04	0.01	-0.10	0.03

T_{3t}	0.01	0.01	-0.01	0.03
T_{4t}	-0.02	0.01	-0.08	0.03
T_{5t}	-0.02	0.01	-0.06	0.03
T_{6t}	0.01	0.01	-0.02	0.03
T_{7t}	-0.04	0.01	-0.12	0.03
T_{8t}	0.03	0.01	-	-
T_{9t}	0.00	0.01	-0.05	0.03
T_{10t}	0.13	0.04	0.16	0.07
$T_{1t}E_t$	0.01	0.01	0.01	0.01
$T_{2t}E_t$	0.00	0.01	0.00	0.01
$T_{3t}E_t$	0.00	0.01	0.01	0.02
$T_{4t}E_t$	0.00	0.01	-0.01	0.01
$T_{5t}E_t$	0.00	0.01	0.00	0.01
$T_{6t}E_t$	0.01	0.00	0.04	0.00
$T_{7t}E_t$	-0.01	0.01	0.03	0.01
$T_{8t}E_t$	0.00	0.00	-0.01	0.02
$T_{9t}E_t$	0.01	0.00	0.00	0.01
$T_{10t}E_t$	0.09	0.04	0.16	0.03
D_{11t}	-0.04	0.02	-0.15	0.03
D_{12t}	-0.01	0.01	0.02	0.03
D_{13t}	-0.01	0.04	0.02	0.14
D_{14t}	0.12	0.01	0.17	0.03
$D_{15t}(i_{t-1} - i_{t-3})$	-0.83	0.03	-0.80	0.02

Parameter definitions from Hamilton 1997:
T_{1t} = 1 if *t* falls on day *j* of a reserve maintenance period for *j* = 1, 2, …, 10
E_t = estimated residual from TGA model
D_{11t} = 1 if *t* precedes a one-day holiday
D_{12t} = 1 if *t* precedes a three-day holiday
D_{13t} = 1 if *t* follows a one-day holiday
D_{14t} = 1 if *t* follows a three-day holiday
D_{15t} = 1 if *t* is the first day of a new maintenance period or if *t* is the first day of a new quarter.

APPENDIX 2

Model Variable Definitions

Below are definitions for the variables used in my federal funds rate model. Federal Reserve balance sheet variable definitions are sourced from: https://www.federalreserve.gov/monetarypolicy/bst_fedsbalancesheet.htm

For more detailed information on the Federal Reserve balance sheet variables, please see: https://www.federalreserve.gov/aboutthefed/financial-accounting-manual-2021.htm.

Note: Interest rates are in basis points and all other variables are in billions of U.S dollars. Displayed in the same order as regression results in the chapter.

IOER:	Interest rate paid on excess reserves.
Bills:	The current face value of the Federal Reserve's outright holdings of Treasury bills.
Notes/Bonds:	The current face value of the Federal Reserve's outright holdings of nominal Treasury notes and bonds.
TIPS:	The current face value of the Federal Reserve's outright holdings of inflation indexed Treasury notes and bonds.
Infl Comp:	Inflation compensation reflects adjustments for the effects of Inflation to the principal of inflation-indexed securities.
Fed Agcy Debt:	The current face value of federal agency obligations held by Federal Reserve Banks. These securities are direct obligations of Fannie Mae, Freddie Mac, and the Federal Home Loan Banks.
MBS:	The current face value of mortgage-backed obligations held by Federal Reserve Banks. These securities are guaranteed by Fannie Mae, Freddie Mac, or Ginnie Mae.
Unam. Premiums:	The unamortized portion of the premiums over the face value for securities purchased by the Federal Reserve.
Unam. Discounts:	The unamortized portion of the discounts less than the face value for securities purchased by the Federal Reserve.
Repos:	Repurchase agreements reflect some of the Federal Reserve's temporary open market operations.
Loans:	Loans is the sum of "Primary credit," "Secondary credit," "Seasonal credit," and credit extended through the "Primary Dealer Credit Facility," "Paycheck Protection Program Liquidity Facility," and "Other credit extensions".
Float:	Reserve balances can be affected by mismatches in check-clearing operations. When a check is received by a Reserve Bank, the depositing institution's account is credited according to a fixed schedule, regardless of when the check is presented to the bank on

	which it is drawn. When there are delays in the presentment of checks to the paying institution, the receiving institution's account is credited before the account of the paying depository institution is charged, elevating reserve balances. Conversely, if the paying institution's account is debited faster than the schedule for crediting the receiving institution's account, reserve balances are reduced. These increases or decreases in reserve balances that result from mismatches in the timing of check clearing are known as float.
CB Swaps:	Temporary reciprocal currency arrangements (central bank liquidity swaps) with certain foreign central banks to help provide liquidity in U.S. dollars to overseas markets.
Other Assets:	The major components of other Federal Reserve assets include: Accrued interest, which represent the daily accumulation of interest earned but not yet received on U.S. government securities -other than bills--owned by the Federal Reserve or held under repurchase agreements, on loans to depository institutions, and on foreign currency investments. Interest is accrued daily. Reserve Bank premises and operating equipment less allowances for depreciation, which state the value, at initial cost, of the land and buildings of the Reserve Banks and branches net an allowance for depreciation on buildings, including building-related machinery and equipment. Also includes other accounts receivable.
Foreign Assets:	Foreign currencies are revalued daily to reflect movements in market exchange rates each day. If the dollar depreciates relative to a foreign currency, the dollar value of the respective foreign currency denominated asset increases.
Gold Stock:	The gold stock of the United States is held by the Treasury and consists of gold that has been monetized: the Treasury has issued certificates reflecting the value of the gold to the Federal Reserve in return for a credit for the same dollar value to the Treasury's accounts. The gold stock also includes unmonetized gold, against which certificates have not been issued by the Treasury (although virtually all the Treasury's gold has been monetized since 1974).
SDR Certif:	Reserve Banks hold special drawing rights certificates (SDRs), an international monetary reserve asset created by the International Monetary Fund in 1970. Under the law providing for the United States' participation in the SDR system, the Secretary of the Treasury is authorized to issue SDR certificates, somewhat similar to gold certificates, to the Reserve Banks, which are required to purchase the SDRs for the purpose of financing SDR acquisitions or exchange stabilization operations. The value of the SDRs is established monthly, based on the exchange rates of a number of the underlying currencies.
Tres Curr Outs:	Coin and paper currency (excluding Federal Reserve notes) held

	by the public, financial institutions, Reserve Banks, and the Treasury are liabilities of the U.S. Treasury. This item consists primarily of coin, but includes about a small amount of U.S. notes -that is, liabilities of the U.S. Treasury--that have been outstanding since the late 1970s. U.S. notes are no longer issued.
Currency:	Estimated.
Foreign RRP:	Cash value of agreements, which are collateralized by U.S. Treasury securities, federal agency debt securities, and mortgage backed securities.
ON RRP:	Cash value of agreements, which are collateralized by U.S. Treasury securities, federal agency debt securities, and mortgage backed securities.
Tsy Cash:	Treasury cash holdings include paper currency and coin held in Treasury vaults, including silver bullion, silver dollars, coinage metal, and unmonetized gold. The value of Treasury cash holdings is estimated using Treasury data
Term Deposits:	Term deposits are deposits with specified maturity dates that are held by institutions that are eligible to receive interest on their balances at Reserve Banks. Term deposits are separate and distinct from balances maintained in an institution's master account at a Federal Reserve Bank as well as from those maintained in an excess balance account.
TGA:	Treasury General Account. This account is the primary operational account of the U.S. Treasury at the Federal Reserve. Virtually all U.S. government disbursements are made from this account. Some tax receipts, primarily individual and other tax payments made directly to the Treasury, are deposited in this account, and it is also used to collect funds from sales of Treasury debt.
Forgn Offic Dep:	Foreign official deposits are balances of foreign central banks and monetary authorities, foreign governments, and other foreign official institutions with accounts at FRBNY. These balances usually are relatively small because the accounts do not bear interest. While transactions in these accounts are handled by FRBNY for balance sheet purposes, the deposits are allocated across all of the Reserve Banks based on each Reserve Bank's capital and surplus.
Other Deposits:	Other deposits at Federal Reserve Banks include balances of international and multilateral organizations with accounts at FRBNY, such as the International Monetary Fund, United Nations, International Bank for Reconstruction and Development (World Bank); the special checking account of the ESF (where deposits from monetizing SDRs would be placed); and balances of U.S. government agencies and government-sponsored enterprises, such

	as Fannie Mae and Freddie Mac. Also includes balances of financial market utilities that are designated as systemically important by the Financial Stability Oversight Council under Title VIII of the Dodd-Frank Wall Street Reform and Consumer Protection Act. Also includes deposits held by depository institutions in joint accounts in connection with their participation in certain private-sector payment arrangements and certain deposit accounts other than the U.S. Treasury, General Account, for services provided by the Reserve Banks as fiscal agents of the United States.
Other Liabs/Cap:	Includes deposits held at the Reserve Banks by international and multilateral organizations, government-sponsored enterprises, designated financial market utilities, and deposits held by depository institutions in joint accounts in connection with their participation in certain private-sector payment arrangements. Also includes certain deposit accounts other than the U.S. Treasury, General Account, for services provided by the Reserve Banks as fiscal agents of the United States. Includes the liability for earnings remittances due to the U.S. Treasury.
TGAMiss:	Federal Reserve staff forecast for the TGA less the actual TGA on a given day.
TGCR:	Tri-Party General Collateral Rate. Measure of rates on overnight, specific-counterparty tri-party general collateral repurchase agreement (repo) transactions secured by Treasury securities.

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BIOGRAPHY

Brian Joseph Bonis has a Bachelor of Science in Management Science and Statistics from the University of Maryland College Park (2003), and a Master of Professional Studies in Applied Economics from the University of Maryland College Park (2013).

Brian's research at the Federal Reserve has been featured in the Wall Street Journal, the Financial Times, Bloomberg, and CNBC and has been cited in research by economists such as former Federal Reserve Chair Ben Bernanke and in public speeches by economists such as Treasury Secretary and former Federal Reserve Chair Janet Yellen.

After a ten year career with Travelers Insurance, Brian joined the Money Market Analysis section in the Division of Monetary Affairs at the Board of Governors of the Federal Reserve System. In 2016, Brian was awarded the Board of Governors prestigious Special Achievement Award by then Federal Reserve Chair Janet Yellen. In 2020, the Board of Governors appointed Brian as an officer in the role of Assistant Director of the Secretariat of the Federal Open Market Committee.

Brian currently resides with his family in Laytonsville, Maryland. In his leisure time, he enjoys playing tennis, visiting the "Jersey Shore," and listening to podcasts.