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Fedwire Funds Service: Payments, Balances, and Available Liquidity

Anton Badev, Lauren Clark, Daniel Ebanks, Jeffrey Marquardt, David Mills*

October 5, 2021

Abstract

We analyze the universe of payments settled through the Fedwire Funds Service—the primary U.S. real-time gross settlement service operated by the Federal Reserve—for the period January 2004 to December 2020. We report on trends in payments volume, payments value, balances, and overdrafts, in addition to documenting changes in the behavior of financial institutions transacting via the Fedwire Funds Service.

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Highlights

Volume and Value Trends

- Annual volume and dollar value of payments on the Fedwire Funds Service (Fedwire) were increasing steadily in the years leading up to the 2008 financial crisis. From 2008 to 2010, annual volume fell 5 percent while annual value fell 18 percent. After 2010, annual volume resumed steady growth, averaging 5 million additional payments per year and reaching 184 million payments in 2020. Annual value exhibited subperiods of growth and decline, with a peak of $883 trillion in 2014 and a trough of just below $700 trillion in 2019. In 2020, the final year of our sample, annual value grew again to $840 trillion.

- Over our sample period, trends in daily payments volume were relatively uniform across transactions between institution types: domestic depository institutions, foreign depository institutions, and government-sponsored enterprises. However, trends in daily payment values diverged between institution-type transactions. Domestic-to-domestic daily value steeply declined after 2009 before becoming relatively stable after 2012, while both domestic-to-foreign and foreign-to-domestic values grew from 2009 to 2014 and then declined. The daily values of all domestic-to-domestic, domestic-to-foreign, and foreign-to-domestic payments grew in 2020.

- Lagged annual gross domestic product (GDP) growth is positively and significantly correlated with annual growth in the value of domestic-to-domestic Fedwire transactions, with a correlation coefficient of 0.77. This high correlation is suggestive of a relationship between GDP and large-value payments which we only note, while leaving proper exploration of this relationship for the future.

- Over our sample period, the daily payment size distribution exhibited a consistently long left tail, with many lower-value transactions and a small number of very high-value ones. Payments greater than $1 million accounted for approximately 10 percent of the daily volume, but close to 98 percent of the value. The average daily payment values fluctuated between $3 million and $7 million, with the median daily payment value closer to $30,000.

- Our sample suggests a significant concentration of payments within a relatively small number of institutions. The top 10 accounts by volume sent made up approximately 50 percent of the total daily volume settled over Fedwire, and the top 10 accounts by value sent accounted for, on average, 65 percent of the total daily value settled.

Payments Behavior

- Over our sample period, the timing of payments shifted to earlier in the day, with most of the shift occurring between 2009 and 2012. Between the beginning and the end of the sample period, the percentage of payments value settled by 10:00 a.m. increased from 10 percent to 30 percent, and the percentage of payments value settled by noon increased from 25 percent to 50 percent. In terms of payments volume, the biggest change occurred in the percentage of payments settled by 10:00 a.m., which increased from 25 percent to 30 percent. These changes are a continuation of the trend toward earlier payments that is noted in the previous literature.

- The velocity of payments, as measured by payments volume and value per minute, gradually increased between 2005 and 2020. In 2005, the median payments volume and value per minute were in the neighborhood of 200 and $250 millions respectively, while in 2020 these were in the neighborhood of 400 and $1 billion respectively.

Reserve Balances, Aggregate Liquidity, and Daylight Overdrafts

- Changes in monetary policy implementation that occurred during our sample period affected reserve balances and daylight overdrafts. In 2008, the Federal Reserve began to pay interest on required and excess reserve balances held in Federal Reserve accounts and implemented the first stage of quantitative easing (QE). Following these changes, end-of-day reserve balances increased dramatically from 2008 to 2015, then declined until March 2020, the last installment of QE. Throughout the remainder of 2020, end-of-day reserve balances recovered, reaching levels slightly greater than those of 2015. Daylight overdrafts declined significantly and remained low till the end of our sample.

- The Payment System Risk (PSR) policy was shaped by stable net debit caps after the financial crisis in 2008 and, in 2011, incorporated a zero fee for collateralized daylight overdrafts. After 2011, daylight overdrafts remained stable and significantly below their historical levels. The PSR policy may have played a role in this trend. However, because of their concurrence, we are unable to ascribe the change in daylight overdrafts to monetary or PSR policy, or to some proportions thereof.

- In 2020, aggregate instantaneous payments liquidity, defined as the sum of aggregate net debit caps and end-of-day reserves, was around $5 trillion. According to this measure, in 2020 there was sufficient available liquidity to cover about 150 percent of the value of daily Fedwire payments before necessarily recycling available liquidity. This is a twofold increase compared to the levels before the financial crisis in 2008.

Contents

1 Introduction

We provide an overview of trends in payments settled through the Fedwire Funds Service,[1] the primary real-time gross settlement (RTGS) system of the United States, from 2004 to 2020, analyzing patterns of payments, reserve balances, and available liquidity. We update previous literature on Fedwire, extending existing available statistics for a longer, more recent period and at a more granular level. We document changes in payments behavior that occurred in response to monetary and payments policy developments following the 2008 financial crisis. In addition to standard measures of payments activity used in previous studies, we calculate novel measures of payments velocity and aggregate instantaneous liquidity to assess the functioning of the payment system. We also offer suggestive evidence for a largely unaccounted relationship between Fedwire payments and measures of the real economy.

Large-value payment systems (LVPS) transfer and settle funds of potentially large values between financial institutions, generally handling wholesale payments as opposed to retail payments. Complementary to LVPS, retail payment systems typically handle a large volume of relatively low-value payments in such forms as checks, credit transfers, direct debits, and card payments. Today, the primary implementation of LVPS around the world is via RTGS, an approach that allows for individual payments to be settled on a transaction-by-transaction basis immediately, with finality, and irrevocably. RTGS systems largely replaced deferred net settlement (DNS) systems as the preeminent implementation of LVPS globally toward the end of the 20th century.[2]

Our analysis focuses on Fedwire, which is not only the oldest RTGS system globally, but also has the most participants. Fedwire services are provided by the Federal Reserve Banks. In general, unless otherwise specified by federal statute, entities that are member banks or meet the definition of a depository institution under section 19(b) of the Federal Reserve Act

[1] From here on, "Fedwire" refers to the Fedwire Funds Service.

[2] Unlike RTGS, DNS is a settlement arrangement by which individual payments are netted throughout the day, and then settled at some predefined later time (BIS, 2012). In the United States, as in many developed economies, LVPS services constitute the foundation of payment and settlement activity.

are legally eligible to apply for Federal Reserve accounts and access to Federal Reserve financial services, including the Fedwire Funds Service. Eligible depository institutions can include certain commercial banks, thrift institutions, and credit unions.[3] Government-sponsored enterprises (GSEs) are also legally eligible to apply.[4] Payments made via Fedwire are settled through adjustments to balances of depository institutions (or other accountholders) in their accounts at the Reserve Banks.

The remainder of the paper is organized as follows. We start with a brief overview of the existing literature and provide some additional historical information about Fedwire. In section 2, we describe the data. In section 3, we present basic statistics such as overall number of participants, volume, value, and reserve balances at annual levels. We then examine payments composition by institution type, payment size, and size of the sender (measured by sender' payments volume and value) at daily levels. In section 4, we present an update on previously documented shifts in intraday timing of Fedwire payments and introduce novel measures of payments velocity. In section 5, we discuss how monetary and PSR policies have affected institutions' payments behavior. Section 6 concludes our analysis.

1.1 Literature Review

A main contribution to the comparative RTGS literature comes from Bech, Preisig, and Soramaki (2008), who provide a comprehensive overview of the global evolution of RTGS from the 1980s through the mid-2000s. They analyze the growth and diffusion of RTGS in the context of an increasingly internationalized and technologically advanced payments ecosystem using data from members of the Committee on Payment and Settlement Systems[5], a body under the auspices of the Bank for International Settlements (BIS). Inspired by their study, this paper focuses on Fedwire but with wider lenses to document a broad range of

[3]Depository institutions include commercial banks, savings banks, savings and loan associations, credit unions, U.S. branches and agencies of foreign banks, Edge corporations, and agreement corporations.

[4]In addition to GSEs, foreign central banks, designated financial market utilities, and certain international organizations can apply for a Federal Reserve account and access to Federal Reserve services.

[5]As of September 2014, the name of the Committee on Payment and Settlement Systems (CPSS) was changed to the Committee on Payments and Market Infrastructures (CPMI).

payments trends and patterns. Rather than a comparative analysis, our purpose is to report on the most rich set of unfiltered statistics collectively describing the evolution of Fedwire over the recent past.

A number of specialized studies have documented and analyzed recent developments in the sphere of large-value payments. These range from event studies (see Garratt, Martin, and McAndrews (2014)) to more topical studies exploring the connection between the monetary policy implementation and settlement liquidity captured by the dynamics in reserve balances and daylight overdrafts (see Bech, Martin, and McAndrews (2012)). From the topical literature, the most documented aspects of large value payments is intraday timing and concentration (see below). This paper present an up-to-date account of all developments documented in the specialized studies.

Intraday payments timing has implications for liquidity usage and risk within a system. Bech and Garratt (2003) analyze strategic interactions on payment systems and argue that, depending on whether the central bank provides liquidity in the form of priced or collateralized intraday credit, payment delays can be efficient, if leading to liquidity savings. Mills and Nesmith (2008) study strategic environments where participants interact in both payment and security settlement systems. Ultimately, they argue that Fedwire payments are concentrated in the afternoon, whereas payments linked to government securities transfers are sent earlier in the day as a response to incentives for the origination of transactions built around overdraft pricing. Mills and Husain (2013) contribute further to this theory by showing that regardless of how Fedwire funds and securities settlement systems are arranged or designed, under certain assumptions the equilibrium timing outcome is always for payments to be settled in the afternoon and securities in the morning. More recently, Nellen (2019) studies intraday payments equilibria and argues that a fixed-cost (as opposed to variable-cost) credit regime alleviates the need to coordinate payments and that a strictly positive late settlement fee may incentivize early settlement.

1.2 Fedwire and the Expansion of RTGS around the World

In the United States, RTGS appeared in nascent form in 1918 with the introduction of Fedwire as a payment system based on a telegraphic network interconnecting the Reserve Banks. By the 1980s, Fedwire and several other systems had become fully computerized. Coinciding with a rapid rise in the values settled globally in LVPS that increased settlement risk, these technological innovations and globalization enabled most major economies to replace DNS with RTGS for their large-value systems in the latter part of the 20th century.[6] The transition to RTGS allowed for immediate settlement of payments within countries or currency areas. CHIPS, the private-sector alternative to Fedwire in the United States, was established in 1970 as a DNS system, settling funds transfers the morning after they were initiated. In 1981, increasing payments volume prompted a transition to same-day settlement and eventually in 2001 CHIPS became a hybrid system, allowing both real-time and netted intraday settlement and payments (FRBNY, 2002).

The switch to newly developed RTGS services was in part a response to a rapid increase in payment values settled over LVPS in the 1980s, according to Bech, Preisig, and Soramaki (2008). They argue that the finality and immediacy of real-time settlement reduces the systemic risk posed by a DNS system. Their overview of the global evolution of LVPS from the 1980s through the mid-2000s points out that from 1999 to 2005, the total value settled over all RTGS worldwide increased from $727 trillion to $1,274 trillion. Data sources document that this upward trend has continued in spite of the financial crisis of 2008, expanding to $3,090 trillion in 2016 (BIS, 2017).

Between 1999 and 2005, among CPSS members, banking consolidation caused the average number of institutions participating in LVPS to shrink in all but four countries: PNS (France), SIC (Switzerland), EURO1 (Eurozone), and LVTS (Canada)[7]. Over these six years, the number of institutions participating directly in Fedwire dropped from 9,994 to

[6] Some jurisdictions created hybrid systems, incorporating both DNS and RTGS. For more details, see Bech, Preisig, and Soramaki (2008).

[7] For more details, see Bech, Preisig, and Soramaki (2008).

6,819. While this decline has continued to some extent, Fedwire remains the largest RTGS worldwide by number of participants.

2 Fedwire Data

We analyze transaction level data on the universe of payments made over the Fedwire Funds Service from January 4, 2004, to December 26, 2020. Further, our study combines data on individual payments with end-of-minute and end-of-day account balances for institutions holding accounts at a Federal Reserve Bank. While previous work on RTGS has analyzed daily data (Soramaki et al., 2006) , and even 10-minute (Benos, Garratt, and Zimmerman, 2012) or 20-minute (Becher, Millard, and Soramaki, 2008) intervals of data from a selected set of days, the available data were limited to periods shorter than those discussed here.

We analyze payments of domestic and foreign banks and GSEs, and balances of domestic and foreign banks, both aggregated and separately.[8] Domestic banks include commercial banks, thrift institutions, credit unions, and separately chartered banks owned by foreign banking organizations. Foreign banks are those that are a branch or agency of a foreign banking organization. The GSE category includes the Federal Home Loan Banks, Farm Credit System, Fannie Mae, Freddie Mac, Financing Corporation, Resolution Funding Corporation, and Sallie Mae (before becoming privatized in 2004 (FRB, 2017b)). For purposes of our analysis, we group GSEs together with other institutions that are not treated as depository institutions in the Board's PSR policy. While this group of institutions play an important role in the U.S. economy, their payments behavior is marked by notably different incentives than private banks.[9] Similarly, foreign and domestic banks may exhibit distinct patterns of behavior. We study domestic banks, foreign banks, and GSEs both separately and as a whole to understand the payments behaviors within, between, and across the types of institutions.

[8]For convenience, the term "bank" is used interchangeably with "depository institution" in this paper.

[9]For more details, see the (undated) report "A Brief History of the Housing Government-Sponsored Enterprises" published on the website of the Office of Inspector General (available here).

In order to accurately assess payments behavior, we exclude transactions between atypical account holders such as central banks, designated financial market utilities, excess balance accounts, and international organizations (for example, the International Monetary Fund and the Inter-American Development Bank) because activity between these accounts is not indicative of typical interbank payments behavior. In our analysis of account balance data, in addition to the exclusions made for the transaction data, GSEs (including institutions not treated as depository institutions) are excluded. The reactions of such institutions to changes in the PSR policy that we consider in this paper are not informative and would simply add noise to our policy analysis.

The Fedwire transaction data contain information on all payments made over Fedwire and, for each transaction, include a sending bank identification number, a receiving bank identification number, a time stamp, and the value transmitted. Neither the reason a payment was sent nor other descriptive information, such as beneficiary information on whether a single payment may be linked to another payment, is recorded. This latter point is relevant technically because the value of a single Fedwire payment is restricted to one cent less than \$10 billion, so we cannot know with certainty if payments greater than \$10 billion are being transmitted over the system through multiple transactions. We analyze aggregate annual and daily transactions, individual transactions, and minute-by-minute dynamics of transactions in a given year. The minute-by-minute observations will be referred to as "dollars per minute" and "payments per minute," and together these two measures will constitute the basic notion of transaction velocity.

In order for the participating institutions to settle payments on Fedwire, the system debits and credits their respective master accounts at the Federal Reserve Banks. Account balances are reported separately from transactions; they are recorded on a minute-by-minute basis in a time series for all open accounts every business day. That is, unlike transaction data, balances do not update in real time, but are rather updated in one minute intervals.

Using the balance data, we examine the number of open accounts on the Fedwire system.

An open account is any account that has an open balance at the Federal Reserve and that is listed as active at the start of the business day. This does not necessarily mean the account has a non-zero balance, nor that it has transacted on a particular day. The number of open accounts reflects the total number of participants in the system, but not the total number of participants who transmit funds on a given day.[10] Section 3.2 overviews the dynamics of the number of accounts with positive balances over time and examines the payment compositions by the types of institutions participating in Fedwire.

3 Volume and Value Trends

3.1 Basic Metrics

The most basic metrics of activity on an RTGS system are the volume (number) of payments transmitted across the system and the value of those payments. In 2020, the total value that was settled over Fedwire was about 40 times U.S. GDP.[11] Given the scale of payments transacted over Fedwire, measuring volume and value provides insight into both the functioning of financial markets and the real economy. Because it services the largest economy in the world, it is not surprising that Fedwire settles the greatest total value of wholesale payments among RTGS systems worldwide (BIS, 2017).[12]

Figure 1 and table 1 show annual aggregate volume and value for 2004 through 2020. Before 2013, annual payments volume reached a maximum of 134 million payments per year in 2007, and then experienced a period of decline during the financial crisis. After reaching a relative low point in 2009, the annual volume of payments settled over Fedwire

[10]Note that banks may participate in Fedwire indirectly through banking correspondents.

[11]In 2020, U.S. GDP was close to $21 trillion. The link between Fedwire payments activity and real economic activity as measured by GDP is only indirect because Fedwire activity predominately reflects activity in the financial sector. It is worth noting that the size of the financial sector as part of GDP has grown significantly over the past 30 years (Greenwood and Scharfstein, 2013).

[12]Fedwire statistics do not reflect all large-value payments activity in the United States. In 2020, CHIPS settled $1.8 trillion per day on average (TCH, 2021). Combined, the value of payments settled over Fedwire and CHIPS was more than 60 times U.S. GDP in 2020.

Figure 1: Annual Volume and Value of Fedwire Payments

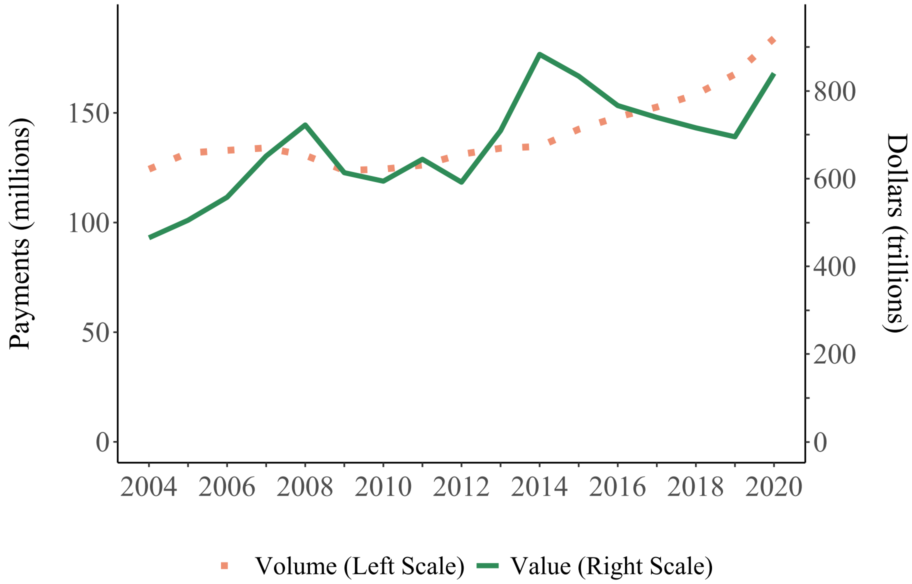


Table 1: Annual Volume and Value of Fedwire Transactions

Year	Volume (millions)	Value ($ trillions)
2004	124.32	465.23
2005	131.74	505.23
2006	132.92	557.70
2007	134.02	651.61
2008	130.66	722.42
2009	123.75	613.64
2010	124.35	594.32
2011	126.18	644.36
2012	131.15	592.00
2013	133.87	709.41
2014	134.70	883.42
2015	142.54	833.68
2016	148.13	766.68
2017	152.64	739.65
2018	158.42	715.87
2019	167.64	695.47
2020	184.00	840.15

Note: The annual payment statistics exclude the activity of central banks, designated financial market utilities, excess balance accounts, and international organizations.

grew consistently at a rate of around 5.5 million payments per year, reaching 184 million payments in 2020. In contrast, the annual value of all transactions settled on Fedwire experienced growth patterns with alternating subperiods of growth and decline. The annual value had a peak of $883 trillion in 2014 and a trough of just below $700 trillion in 2019. In 2020, the final year of our sample, the annual value grew again to $840 trillion. To gain more understanding of these aggregate trends, later we investigate trends in individual payments and at minute-by-minute intervals.

Table 2 reports summary statistics on individual Fedwire payments by year. Throughout the entirety of the period observed, the mean payment value was far greater than the median payment value, indicating a persistence in the clear rightward skew in the distribution of payments value. That is, the distribution of Fedwire payments was concentrated among mostly smaller values with a relatively small number of high-value payments.[13] The average payment value in each year generally fluctuated between $3.74 million and $6.75 million, with noticeable peaks mirroring those in the aggregate annual volume: $5.53 million in 2008 and $6.56 million in 2014. The behavior of the median payment value diverged from that of the average payment value, reaching its highest levels – just over $30,000 – before 2007. This indicates that the peaks in average value were driven by unusually large payments, rather than shifts in the size of all payments.

Table 3 concludes our basic metrics with a summary of aggregate end-of-day balances. The mean of end-of-day balances grew from $17 billion in 2004 to almost $2.4 trillion in 2014 to, after a five-year period of slow decline, $2.5 trillion in 2020. This growth resulted in part from changes in monetary policy that expanded the Federal Reserve System's balance sheet and allowed banks to receive interest payments on excess reserve balances, which incentivized holding greater amounts of reserves. After the beginning of the Great Recession, commercial banks kept much larger reserve balances at the Federal Reserve, with the median end-of-day balances at $2.4 trillion in 2014 and at $2.7 trillion in 2020. When examining the capacity

[13] This feature was noted much earlier in Soramaki et al. (2006) for Fedwire and in Bech, Preisig, and Soramaki (2008) for other LVPS.

Table 2: Descriptive Statistics of Individual Fedwire Payments by Year

Year	Mean ($ millions)	Min ($)	1st Quartile ($ thousands)	Median ($ thousands)	3rd Quartile ($ thousands)	Max ($ billions)
2004	3.74	0.01	4.20	30.00	180.00	10
2005	3.84	0.01	4.53	31.75	186.00	10
2006	4.20	0.01	4.47	30.00	185.08	10
2007	4.86	0.01	4.06	27.37	183.49	10
2008	5.53	0.01	3.62	23.79	171.36	10
2009	4.96	0.01	2.99	19.92	148.50	10
2010	4.78	0.01	2.90	18.34	137.66	10
2011	5.11	0.01	2.89	18.00	134.17	10
2012	4.51	0.01	2.96	19.50	146.70	10
2013	5.30	0.01	3.00	19.93	146.53	10
2014	6.56	0.01	3.00	19.74	141.72	10
2015	5.85	0.01	3.07	20.32	151.36	10
2016	5.18	0.01	3.18	20.87	155.85	10
2017	4.85	0.01	3.12	20.00	147.44	10
2018	4.52	0.01	3.23	20.00	147.35	10
2019	4.15	0.01	3.30	20.00	157.64	10
2020	4.57	0.01	3.58	24.50	196.32	10

to make payments within the Fedwire system, we will examine the relationship between aggregate end-of-day balances and the value of transactions to measure the system's ability to absorb liquidity shocks (see section 5).

3.2 Payments Composition by Types of Institutions Participating on Fedwire

In this section we disaggregate the payments universe by the type of participating institutions. We distinguish between domestic, foreign, and GSE institutions. Such a disaggregation allows us to identify which classes of institutions follow or diverge from the changes observed in aggregate payments over time. Before we move to our analysis, we take stock of the overall number of participating institutions.

Figure 2 illustrates the evolution of the number of master accounts with positive balances over our sample period. Consolidation in the U.S. banking market and the stresses of the financial crisis of 2008 led to a notable decline in the number of accounts with balances

Table 3: Summary Statistics of End-of-Day Balances by Year

Year	Mean	StD	Min	1st Quartile	Median	3rd Quartile	Max
2004	17	3	10	15	17	19	31
2005	16	4	8	13	16	18	27
2006	14	4	7	11	13	17	25
2007	12	4	6	9	12	15	45
2008	132	217	6	10	15	142	699
2009	726	154	452	632	689	821	1,053
2010	909	64	775	864	897	937	1,102
2011	1,298	156	877	1,258	1,345	1,404	1,509
2012	1,294	40	1,164	1,268	1,294	1,321	1,419
2013	1,830	293	1,266	1,584	1,836	2,091	2,319
2014	2,390	91	2,111	2,337	2,389	2,465	2,576
2015	2,357	112	1,739	2,300	2,376	2,429	2,572
2016	2,067	142	1,553	1,943	2,113	2,171	2,275
2017	2,055	83	1,764	2,010	2,061	2,121	2,211
2018	1,813	155	1,433	1,684	1,803	1,935	2,079
2019	1,434	72	1,240	1,383	1,421	1,490	1,603
2020	2,500	522	1,471	2,421	2,672	2,903	3,101

Note: All values reported in billions of U.S. dollars. Distributional statistics are calculated by summing all account balances at the end of each operating day. Averages and quartiles are then computed across aggregated end-of-day balances for each year.

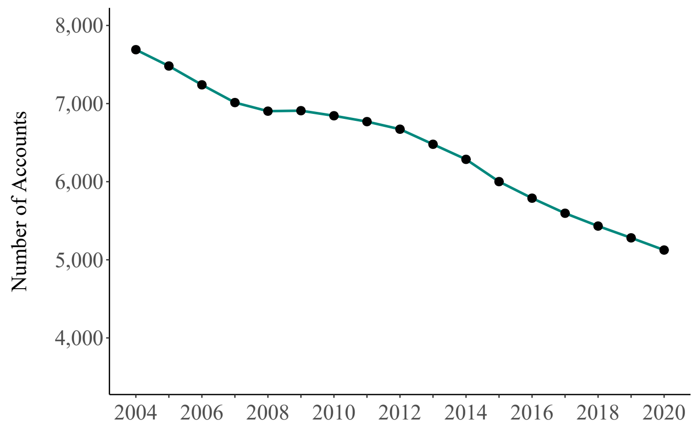
at the Federal Reserve. Over the full 17 years of our sample, the number of accounts with balances fell from 7,690 in 2004 to 5,125 in 2020, an average decline of 150 accounts per year. This number includes only master accounts that can settle funds transfers, hold opening and closing balances, and maintain correspondent banking relationships with non-account-holding institutions.[14]

We now turn to the main analysis of this section where we group the participating institutions into domestic, foreign, and government-sponsored ones. Figures 3, 4, and 5 present the data separated into "type-to-type" groups. For example, "domestic-to-domestic" refers to payments sent from a domestic bank to another domestic bank, while "domestic-to-foreign" refers to payments sent from a domestic bank to a foreign bank.[15] In figure 5, we

[14] One master account may have many subaccounts. Subaccounts serve a number of designated purposes and are mainly an accounting feature that does not bear relevance for our analysis. Separate balances are not computed for subaccounts. Thus, we roll up transaction data to the master-account level for comparability between transactions and balances. See the "Federal Reserve Account Structure, Transaction Settlement and Reporting Guide" (FRB, 2017a) for greater detail on account structure.

[15] As a reminder, domestic banks include commercial banks, thrift institutions, and credit unions. Foreign

Figure 2: Number of Accounts with Balances



Note: To compute this metric we first exclude the activity of central banks, designated financial market utilities, excess balance accounts, and international organizations. From the remaining accounts, we keep only those that have positive balances.

aggregate daily transaction value both to and from institution-type pairs (that is, "foreign-domestic" is equivalent to the sum of both "foreign-to-domestic" and "domestic-to-foreign"). The pairs of graphs, unless otherwise noted, are oriented such that payments between same types are on the left, and payments between different types are on the right.

The evolution of daily transaction volume from 2004 to 2020 reflects a pattern of growth in transactions between all types of institutions, consistently dominated by domestic-to-domestic transactions. Shown in figure 3, domestic-to-domestic daily volume increased by 40 percent, from slightly more than 450,000 payments per day in 2004 to 750,000 in 2020, with a slight dip in the years following the financial crisis of 2008 and a growth spurt in 2020. Both domestic-to-foreign and foreign-to-domestic payments also experienced increases in daily total volume over the sample period at slightly greater rates than domestic-to-domestic payments; the former transaction type increased from 16,000 payments per day in 2004 to 25,000 in 2020, and the latter from 25,000 in 2004 to 38,000 in 2020. Overall, after 2009, volume rose for all types of transactions (see also figure 1). Domestic-to-domestic

banks include branches and agencies of foreign chartered banks. Separately chartered banks owned by foreign banking organizations are treated as domestic banks.

Figure 3: Daily Fedwire Transaction Volume by Institution Types

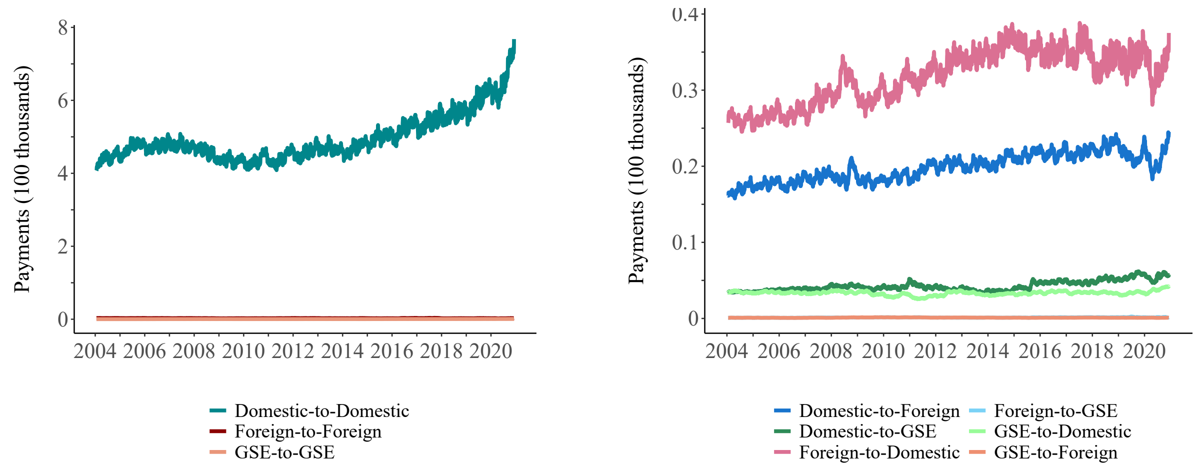


Figure 4: Daily Fedwire Transaction Value by Institution Types

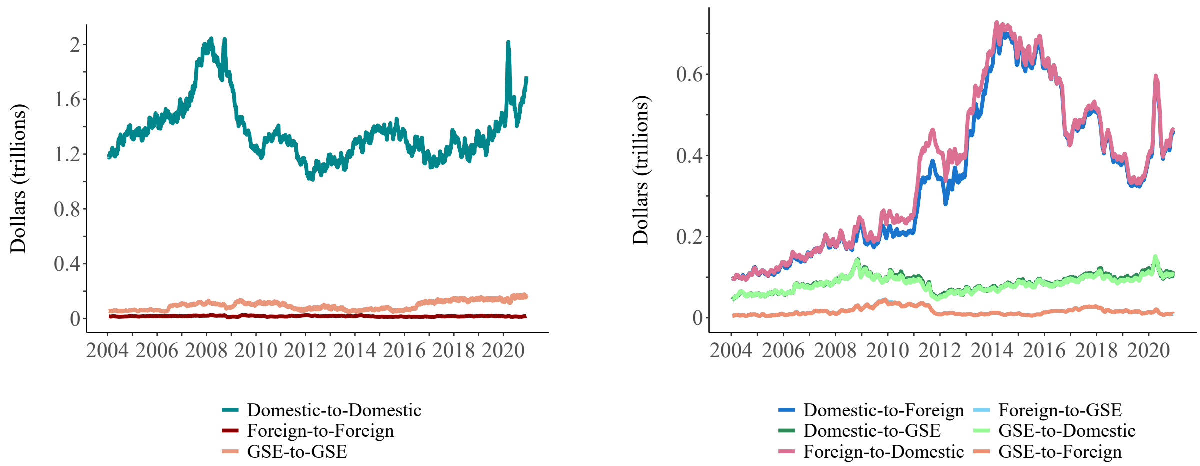
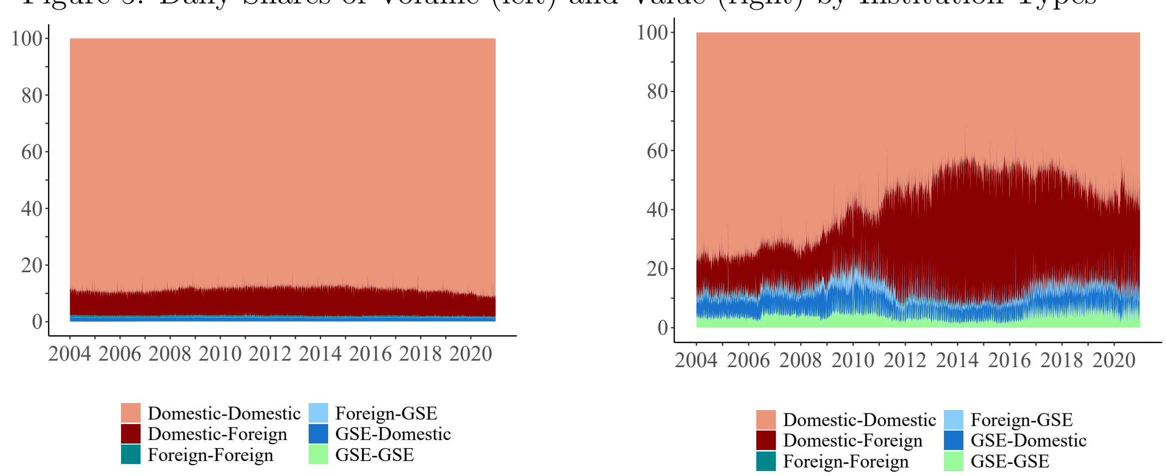


Figure 5: Daily Shares of Volume (left) and Value (right) by Institution Types



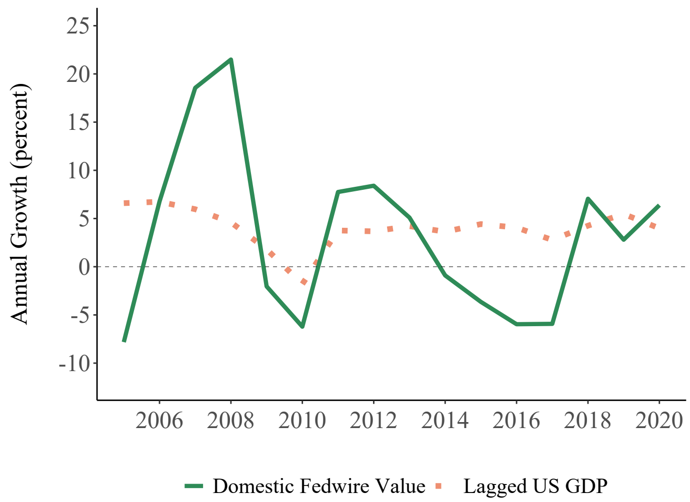
transactions consistently dominated the composition of total daily Fedwire volume since 2004, as depicted in the left-hand graph in figure 5. Domestic-to-domestic transactions constituted approximately 90 percent of the total volume, and foreign-domestic transactions accounted for almost all of the remaining 10 percent of transactions.

Turning to the analysis of daily total value, transactions between foreign and domestic banks contributed a larger share of daily value compared to 2004, although that share slightly declined after 2015. While the value of domestic-to-domestic transactions is greater than all other types of payments for all years, foreign-domestic payment values increased significantly after 2011. These trends are illustrated in figure 4, which shows that daily total value transmitted between domestic institutions peaked at $2 trillion in 2009, fell by almost a half in 2012 (to a little over $1 trillion), before rising again to almost $1.8 trillion by the end of 2020, mirroring the growth in daily volume from figure 3. Both domestic-to-foreign and foreign-to-domestic transaction values increased from 2004 to 2014 with a particularly fast growth after 2011. Transaction value in either direction between domestic and foreign institutions peaked at $700 billion in 2014 and then declined to $400 billion in 2018, which were the levels in 2012. Most recently, after 2018, these have experienced growth similar to domestic-to-domestic daily value.

Figure 5 further demonstrates the extent to which transactions between foreign and domestic institutions have evolved over the past decade. After 2008, foreign-domestic payments grew from 10 percent of Fedwire's total daily value to 40 percent in 2016 and then gradually stabilized at 30 percent after 2017. Over the same period, domestic payments shrank from 75 percent to 50 percent of daily value in 2016 and then stabilized at 60 percent. This increase in foreign banks' Fedwire activity could likely be explained, in part, by the increase in the role of foreign banks in the fed funds market.[16] In particular, policy changes in response to the financial crisis (see the discussion in section 5.1 for further explanation of monetary policy during the crisis) lessened the need for domestic banks to borrow on the fed funds

[16]The fed funds market is an overnight lending market between depository institutions.

Figure 6: Domestic Fedwire Value and Lagged GDP



market (Craig and Millington, 2017). As a result, foreign banks borrowed a greater share of fed funds loans than domestic banks after 2009 (Afonso, Entz, and LeSueur, 2013). Disbursement and repayment of these fed funds loans translate to Fedwire transactions, and are therefore consistent with the fact that the domestic-to-foreign and foreign-to-domestic values tracked one another so closely and, also, with the increase in domestic-foreign daily value. While other avenues of payments activity also contributed to domestic-foreign Fedwire payments, fed funds market activity provides some insight into the observed trends.

We conclude this section with a digression on the relation between yearly domestic value transacted on Fedwire and yearly GDP that, to the best of our knowledge, has not been documented in the past. Generally, separating Fedwire payments activity by institution type reveals trends that may have specific and disparate implications for policymakers, and for understanding broader economic conditions in the United States. While the influx of value from transactions involving foreign banks is notable, the value of solely domestic Fedwire transactions also exhibited interesting behavior over the sample period: The growth of domestic daily value is positively correlated with the growth in GDP with a one-year lag. This relationship has a correlation coefficient of 0.77 (standard error: 0.19), with a t-statistic of 4.12 and a p-value of 0.0014. Figure 6 illustrates the co-movement between one-year-lagged

GDP growth and the growth in domestic Fedwire value. Table 5 in the appendix presents statistical tests on this co-movement.[17] [18]

3.3 Daily Volume and Value by Payments Size and Senders' Size

We further examine payments composition with respect to payments size and the size of payers' activity on Fedwire. As in the previous section, the granularity of our analysis is at a daily frequency. Figure 7 revisits the dynamics of volume and value, clearly illustrating that there is a substantial day-to-day variation around a long term (28-day moving average graphed in black). The evolution of the daily volume appears very smooth, mimicking the annual dynamic from figure 1 with a notable gradual increase of the day-to-day variation after 2012. In particular, the payments volume varied from 400,000 to 1.6 million per day toward the end of the sample.

The average daily total value of all Fedwire transactions denoted by the green line in the right-hand graph of figure 7 fluctuated much more than volume over our sample period. The average daily value dropped from approximately \$3 trillion in 2008 to around \$2.5 trillion in 2010. After 2013, average daily value quickly exceeded pre-crisis levels, reaching \$3.5 trillion in 2015 before once again declining and then recovering again. Visually, the period 2015 to 2020 resembles the period 2009 to 2015. The daily fluctuations in value exhibited seasonal effects, with peaks in value at the end of the reporting year and dips near the end of the first quarter. The fact that daily transaction volume grew steadily after its low during the crisis, while daily value fluctuated, reflects the variation in average payment value noted in table 2.

Next, we examine the composition dynamics of daily transaction volume and value.

[17]As previously noted, the dependency between real economic activity and Fedwire transfers is only indirect since Fedwire transfers may reflect activity in the financial sector to a greater degree than in the non-financial sector. However, it is also possible that the composition of payments over Fedwire has been changing somewhat over time.

[18]Eisenbach, Frye, and Hall (2019) document a complementary relation at similar frequencies as ours. They note that since the financial crisis, there is a strong co-movement between total payments and the level of aggregate reserves.

Figure 7: Daily Fedwire Volume (left) and Value (right)

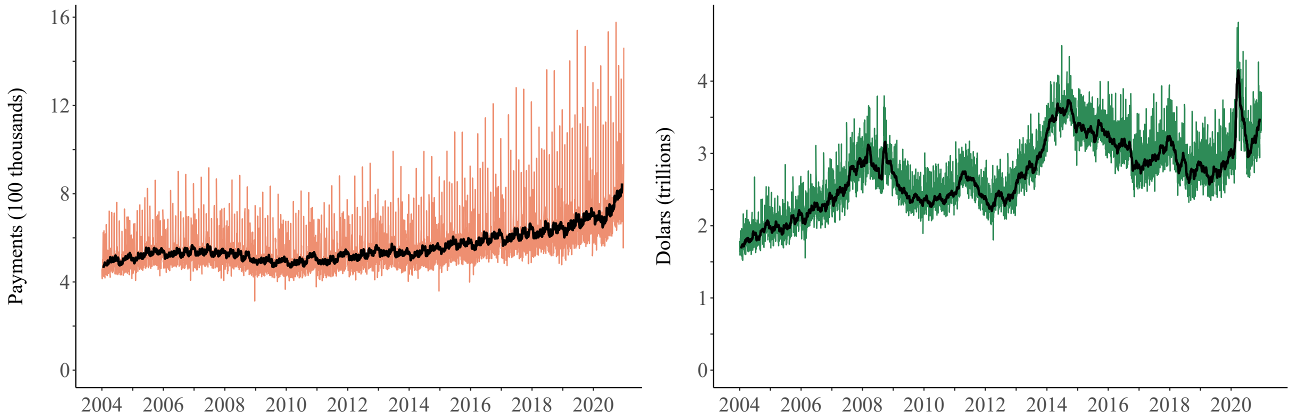


Figure 8: Composition of Daily Fedwire Volume (left) and Value (right) by Payment Size

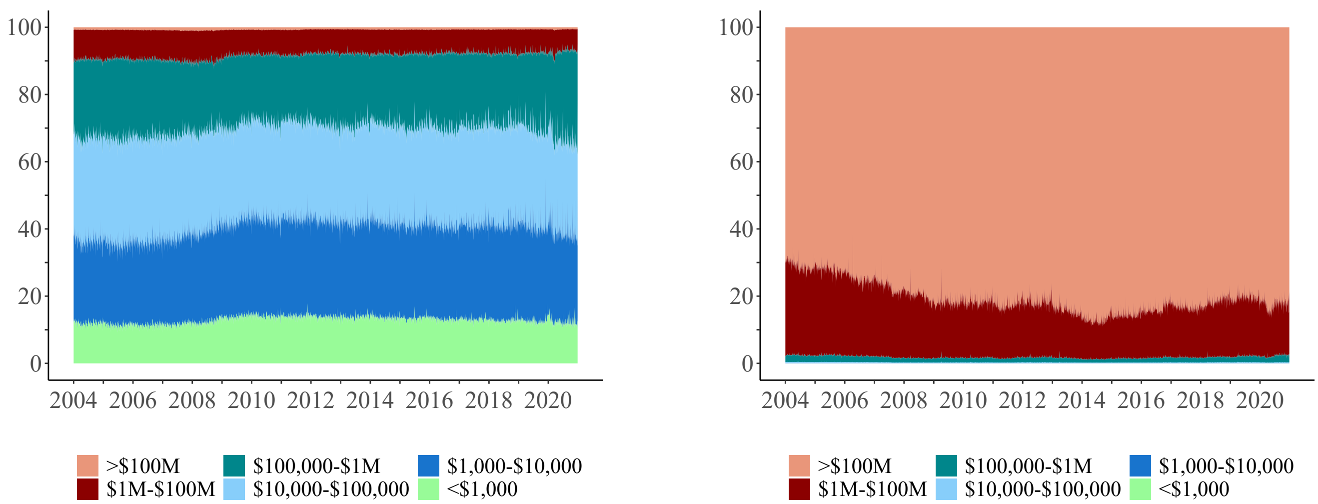


Figure 9: Composition of Daily Fedwire Volume (left) and Value (right) by Senders' Rank

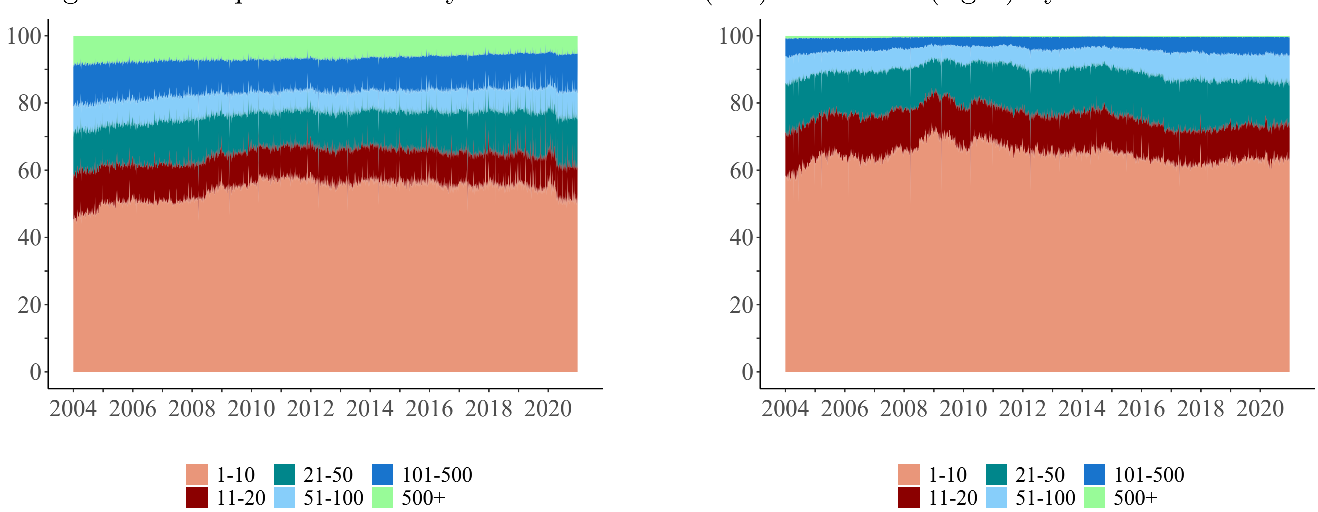


Figure 8 decomposes the total daily volume and value sent over Fedwire by payment size. These graphs show a stark contrast between the composition of volume and value: While payments over $100 million constituted a mere 1 percent of volume, they made up close to 75 percent of value. In general, payments exceeding $1 million accounted for 10 percent of total volume and 98 to 99 percent of total value. This suggests that the distribution of payment values and volumes in Fedwire were skewed in opposite directions; the majority of payments volume came from smaller-value transactions, whereas most of the value came from large-value payments. While there was a slight but noticeable shift in 2009 away from high-value payments, overall the composition of volume by payment size was relatively stable on the Fedwire system. The composition of value by payment size was more dynamic, with payments greater than $100 million increasing as a percentage of total value through May 2014, reaching 89 percent. Following 2014, these high-value payments declined as a share of total value but did not recede to 2004 levels.

Next, we partition the Fedwire participants in groups according to the size of their payment activities and, after that, analyze the universe of payments according to which group they originate from. In particular, every day we rank accounts by volume and value sent over Fedwire. The daily rankings are represented in six groups: top 10, top 11 to 20, top 21 to 50, top 51 to 100, top 101 to 500, and after 500. Note that for each day there are two different but closely related rankings – one based on sent volume and one based on sent value. For each of the six groups, we calculate volume and value. The left side of figure 9 breaks down daily volume by the volume ranking, and the right side does the same for value by the value ranking. For example, on the left side, the top 10 band shows the proportion of the daily volume originated by the top 10 Fedwire participants when participants have been ranked in terms of the volume of sent transactions.[19]

Our findings complement the concentrated nature of Fedwire payments that we noted in the payment size composition analysis. The top 10 accounts consistently made up the

[19] In principle, the identities of participants in each group can vary from day-to-day. However, persistence in payment behavior means that the composition of each group is largely stable over time.

largest share of all daily volume and value transacted over Fedwire. In terms of daily volume transacted, the fraction of these 10 accounts ranged from a low of 45 percent in 2004 to a high of 70 percent during late 2016. After 2016 this fraction slowly declined and was around 55 percent in 2020. The concentration of payments in the large accounts is more pronounced in terms of daily value transacted. The fraction of the top 10 accounts slightly grew from below 55 percent in 2004 to 70 percent in 2009 and after 2009 quickly reverted to the mean for the period of 65 percent. The dynamic of the top 20 banks paints a picture of even greater concentration. This dynamic follows a similar pattern as the top 10, with a low of 55 percent of daily volume in 2004, a high of 80 percent in late 2016, and an average for the period of 65 percent. In terms of value, the fraction of the top 20 slightly grew from 70 percent in 2004 to above 80 percent in 2009, after which it quickly reverted to the mean for the period of 75 percent. On average, the remaining active Fedwire accounts (outside of the top 20) constituted less than 40 percent of the total volume transacted and about 25 percent of the total value transacted.

4 Payments Behavior and Liquidity Risk

The fact that high-value Fedwire payments are so heavily concentrated in a small number of large institutions increases liquidity risk in the system, as the proper functioning of each of these large institutions is tied closely to the smooth flow of payments through the system. To more fully understand the risks presented by payments behavior of both large and small institutions, we investigate the payments timing distribution and the velocity of payments. These two interpretations of payments behavior are reflected in various metrics we compute. We also provide benchmarks against which one can compare a “normal” day to a potential stress day based on the timing and speed of payments over the course of the day.

4.1 Payments Timing

Building on the analysis of volume and value composition, we examine payments timing behavior on Fedwire and note the distribution of volume and value in a given day. Intraday liquidity and payments timing behavior on RTGS systems have liquidity risk implications for financial markets. Previous research has shown that Fedwire participants have tended to concentrate payments later in the day. Historically, this has contributed to system-wide daylight overdrafts, amounting to $280 billion system-wide at their peak. In contrast, RTGS systems in other developed countries, such as TARGET2 and BoJ-NET, tend to transmit most payments much earlier in the day (Inaoka et al., 2004; Massarenti, Petriconi, and Lindner, 2012). Beginning in 2008 the Federal Reserve significantly expanded the reserves of the banking system. Further, in response to pre-crisis concerns about the late timing of payments, the Federal Reserve Board also modified its PSR policy to allow collateralized intraday overdrafts at a zero fee. These changes appear to have had a marked influence on the timing of Fedwire payments.[20]

We begin by loosely following the work of Aramantier, Arnold, and McAndrews (2008), observing the timing inverse percentiles—that is, the percentile of payments volume and value that are settled by a given time in the business day. This descriptive analysis is then augmented using properties of the empirical distribution of payments timing to verify our observations, and to establish an ordered relationship in the timing of payments across three years: the beginning of our sample period (2004), the midway point (2012), and the final year (2020).

4.1.1 Evidence from the Timing Distribution

Figure 10 plots the percentile of Fedwire volume and value completed by 10 a.m., 12:00 p.m., 2:00 p.m., and 4:00 p.m. As evident from the general upward shift in both the volume and

[20] The Reserve Banks also implemented an end-of-day transfer origination surcharge in 2011 for Fedwire payments originated after 5:00 p.m.

Figure 10: Timing of Daily Fedwire Volume (left) and Value (right)

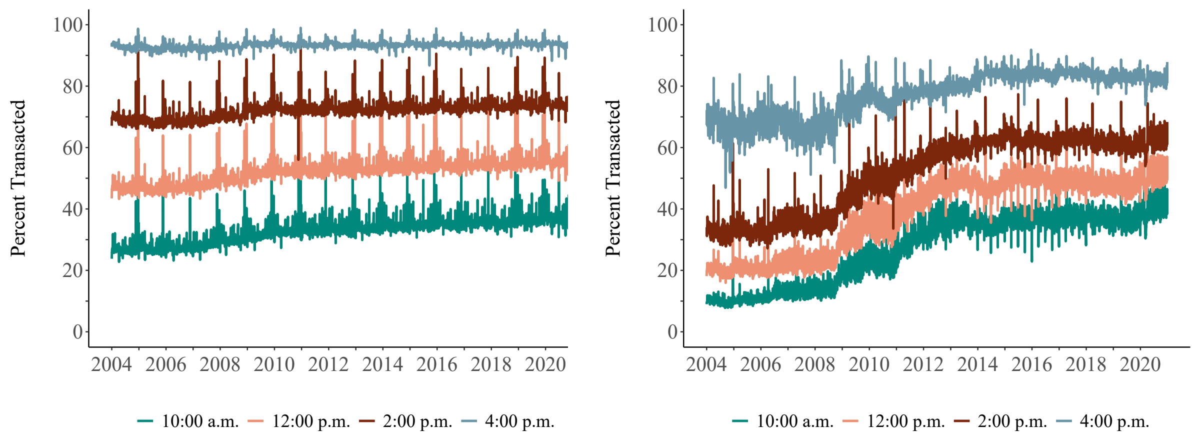


Figure 11: CDF for the Timing of Volume (left) and Value (right)

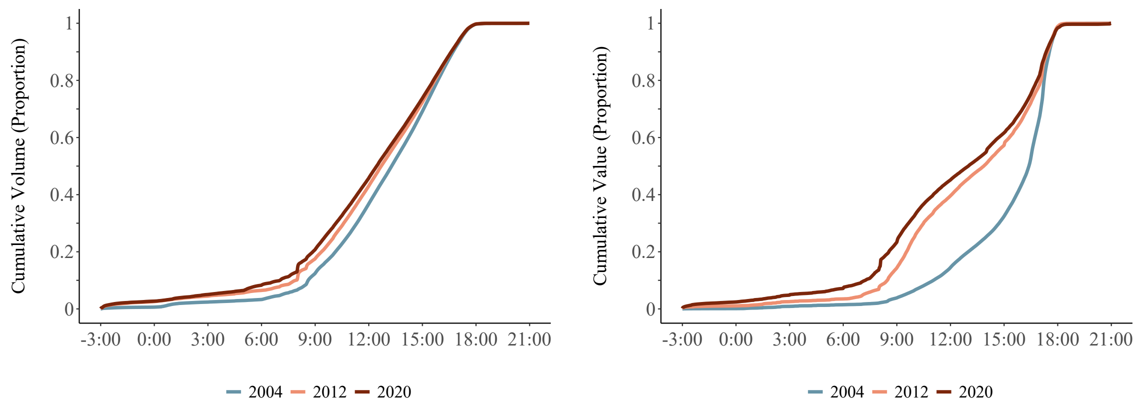
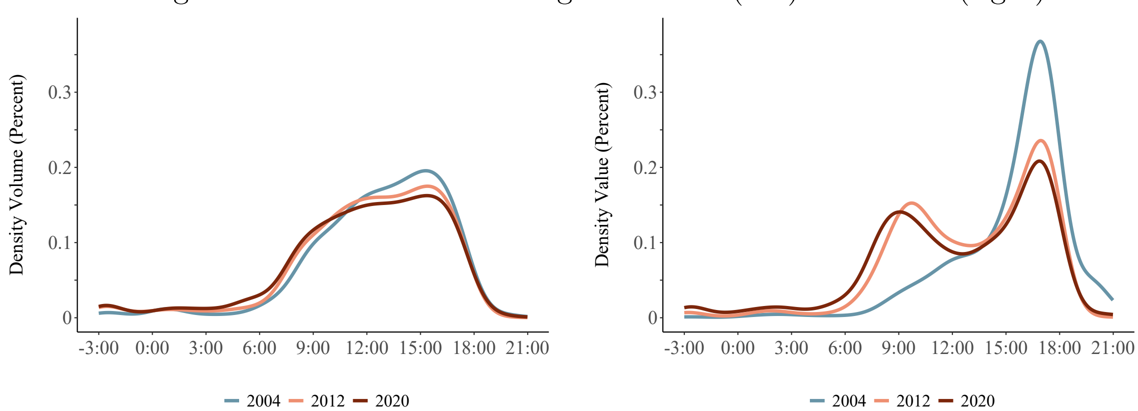


Figure 12: PDF for the Timing of Volume (left) and Value (right)



Note: Cumulative volume (value) shows the percentage of daily volume (value) settled by a given time, e.g. 25 percent of the daily value was settled by noon in 2004 while in 2020 this percentage doubled (top right). Density of volume (value) shows the percentage of volume (value) settled in a given minute, e.g. 0.4 percent of the daily value was settled for each minute around 17:00 in 2004 while in 2020 this percentage dropped in half (bottom right).

value lines there was a shift in payments activity to earlier in the day. In 2004, approximately 25 percent of the daily volume of payments was made before 10:00 a.m., while in 2020 this statistic averages above 30 percent. The change is most pronounced in the value timing distribution, which saw the percentage of total daily value settled before 10:00 a.m. increased from below 10 percent in 2004 to more than 30 percent in 2020. The changes were driven by sharp increases in the percentages of payments settled before 10:00 a.m., 12.00 p.m., and 2:00 p.m. in 2009, which continued to increase more gradually through 2015. Overall this shift is the reverse of the one documented by Aramantier, Arnold, and McAndrews (2008), who found that from 1998 to 2006, the highest peak in value transferred over Fedwire moved 23 minutes later in the day, from 4:48 p.m. to 5:11 p.m., with a general shift to greater concentration of payments after 5:00 p.m.

4.1.2 Evidence from the Empirical Distribution

In order to examine, in a statistically meaningful way, the evidence for changes in payments timing over time, we make use of the empirical distribution of payments. Treating each year as its own independent random process, we use observations at the level of dollars and payments per minute to construct an empirical density function.

For the purposes of this empirical exercise, we analyze volume and value data at three points in time, constructing empirical cumulative distribution function (CDF) and probability density function (PDF) for 2004, 2012, and 2020. We summarize payments timing behavior for each year using annual averages of payments volume and value timing. First, we aggregate our sample to the minute-period level for each year. We then use these annual minute-level averages to construct the CDF and PDF functions. We weight the probability of drawing an individual minute by the value/volume sent in that minute relative to the average total value/volume sent over the day. Each dollar/payment sent during the day can be thought of as a draw from a distribution where the outcome is a time of the day.

Figure 11 plots the volume and value CDFs of Fedwire payments timing for the three selected years. The findings are consistent with the trends observed in figure 10: there was little discernible movement in the timing of payments volume over time, while the concentration of payments value moved earlier in the day since 2004. The change in timing is evident by the leftward movement of mass for the lines in 2012 and 2020, indicating that a greater portion of the total value sent over an average day was settled earlier in the day. Further, figure 12 examines the evolution of the value settled per minute over the course of a Fedwire day. In 2012 there were two loci where high values were being settled. The first locus was at 9 a.m. where 0.15 percent value was settled per minute (about 10 percent per hour). The second locus was at 5:00 p.m. and had more mass—about 15 percent of the daily value was settled in the hour preceding the closing of Fedwire after 2012. In 2004 this same percentage exceeded 20 percent.

4.2 Transaction Velocity

We compute two measures of payments velocity: volume (number of payments) per minute and value (dollars) per minute.[21] These velocity measures provide an additional angle for analyzing payments dynamics both within a day—for example, comparing a selected minute's velocity to that day's intraday median velocity (that is, a "typical minute")—and also across days, allowing a reference point to benchmark daily statistics against a typical day. To conceptualize volume and value speed during a "typical minute" on Fedwire, figure 13 plots the intraday median velocities of volume and value. In addition, figures 14 and 15 present the intraday maximums and standard deviations of payments and dollars per minute. As before, the black lines in these graphs track four-week rolling averages of the respective daily measure. For example, in figure 13 the black line represents a four-week rolling average of the median intraday number of payments volume (left) and value (right) per minute. Finally, table 6 in the appendix tabulates these same velocity metrics at a yearly frequency. These can be used as an alternative reference point for a typical day in a given year.

[21]Benos, Garratt, and Zimmerman (2012) also consider the velocity of volume measures.

Figure 13: Median Intraday Payments Velocity for Volume (left) and Value (right)

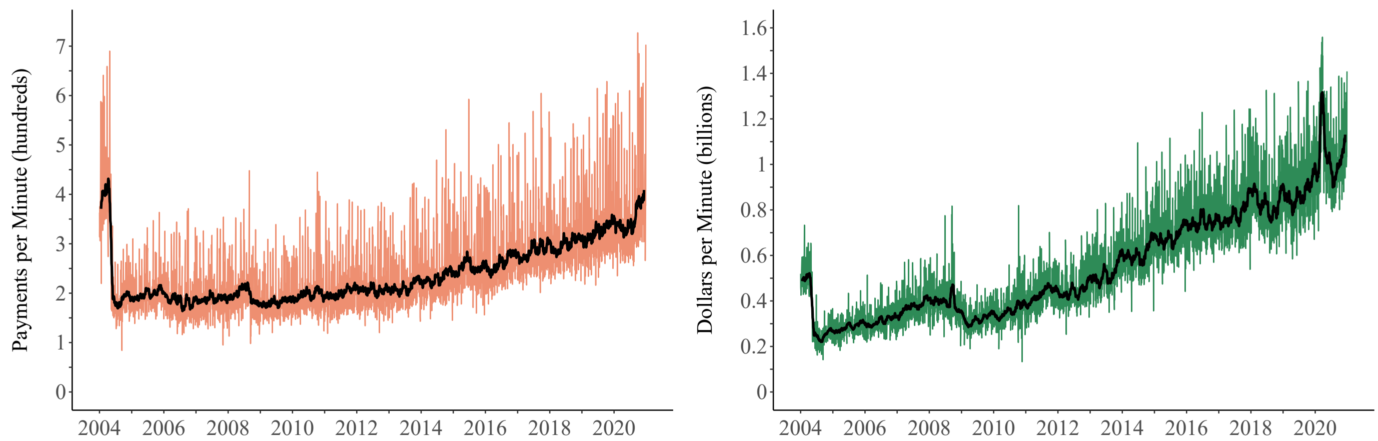


Figure 14: Maximum Intraday Payments Velocity for Volume (left) and Value (right)

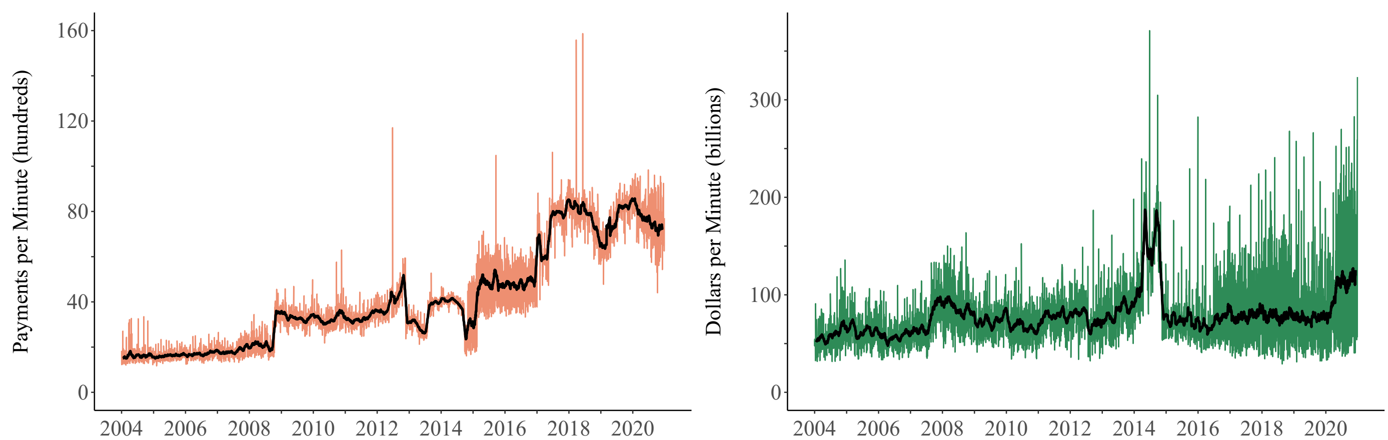


Figure 15: Intraday Variation (StD) in Intraday Payments Velocity for Volume (left) and Value (right)

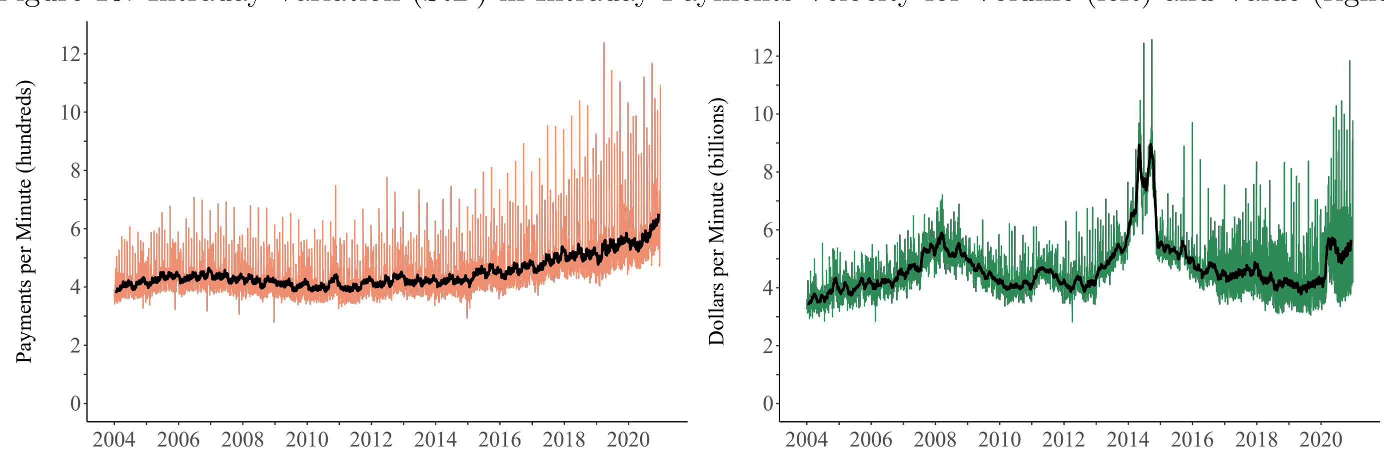


Figure 13 indicates that payments velocity, as measured by intraday median velocities, was increasing after 2005. During 2004 the median number of payments made per minute fell from levels above 400 to levels below 200 and the median dollars per minute fell from levels around $500 million to $200 million. These drops for both speed metrics are in excess of 50 percent, and are likely a result of an expansion in Fedwire operating hours from 18 to 21.5 hours that was implemented in the second quarter of 2004. With this expansion, the number of minutes in the operating day increased from 1,080 to 1,290.[22] After 2005, the median number of payments per minute remained close to 200 until 2013, at which time the velocity of volume began an upward trend, increasing to 400 payments per minute over the last couple of years of our sample. On the other hand, intraday median dollars per minute increased after 2004, reaching $400 million. This growth halted in 2008 when the financial crisis began, with the median velocity of value dipping to $280 million in 2009, then resumed and continued through 2020. In 2020, the median velocity of value approached $1 billion per minute, far exceeding the levels of early 2004. The growth observed in the velocities of volume and value over the past 10 years implies that during a typical minute of a Fedwire operating day, the system was handling increasingly high payments traffic.

The concentration of payments within a minute, as measured by the intraday maximum velocity, exhibits distinct volume and value dynamics.[23] Figure 14 suggests that, unlike the intraday median velocity of volume, the intraday maximum number of payments per minute experienced little change from 2004 to 2009, remaining close to but below 2,000 payments per minute. Then it doubled and stayed around 4,000 payments per minute between 2009 and 2013. After 2013, the intraday maximum velocity of volume followed a somewhat stepped pattern, with few prolonged dips in 2013, 2015, and 2019. In the past five years, the levels appear to stabilize around a longer-term trend of 7,000 payments per minute.

There is much less variation in the intraday maximum velocity of value. Intraday maxi-

[22]Thereby increasing the denominator of the velocity of both volume and value, thus causing declines in the measures.

[23]For each Fedwire operating day, intraday maximum velocities represent the most highly concentrated minute of that day.

mum dollars per minute remained close to \$60 billion for most of the sample period except between 2013 and 2015, when the maximum velocity of value increased to levels around \$200 billion per minute, and late 2020, when these levels shifted to about \$100 billion per minute. These jumps correspond with the 2014 and 2020 peaks in annual and daily payments value previously noted, likely driven by a few high-value payments on a single day. The intraday maximum velocities of both volume and value were far greater than the respective intraday median velocities, which implies that the minutes in which payments reach top speeds were atypical for Fedwire.

The intraday standard deviation of the velocity of volume and value provides insight into the amount of volatility in the Fedwire system, acting as a measure of how smoothly payments flow throughout Fedwire operating hours. If there is a high variance in payments or dollars per minute, then participating banks' systems may either be backed up (slowing down the velocity) or transferring an unusually large volume of payments (speeding up the velocity). Figure 15 shows that the intraday standard deviation of payments per minute remained relatively steady after 2004, at approximately 400 payments per minute. After 2011, the intraday standard deviation of the velocity of volume was increasing and passed 500 payments per minute towards the end of the sample period. The standard deviation of dollars per minute was more volatile than that of payments per minute, with peaks in 2008 and 2015 and what appears to be a shift in early 2020. In 2020, the intraday standard deviation of velocity of value remained close to \$5 billion per minute. Both standard deviations of intraday velocity of volume and value appear to have wider day-to-day fluctuations toward the end of our sample period. Overall, these fluctuations in the intraday standard deviation of velocity are subject to interpretation but nevertheless provide more granular insight into the flow of payments among Fedwire participants than aggregate day-level observations.

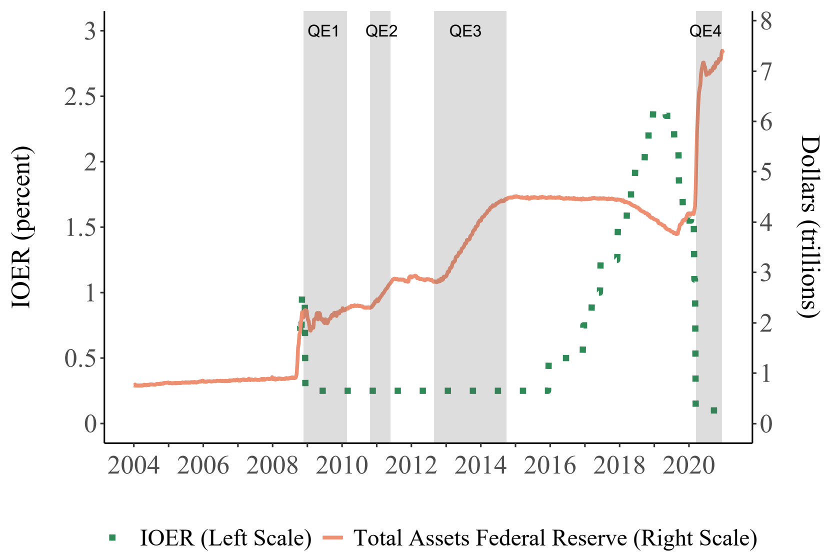
5 The Effect of Monetary and PSR Policies on Fedwire Payments and Daylight Overdrafts

One manifestation of liquidity risk on Fedwire is the incidence of daylight overdrafts, which occur when an institution's Federal Reserve account is in a negative position at any point during the business day (FRB, 2012a). After the Great Recession, daylight overdrafts declined significantly following changes in monetary and PSR policies. Two important Federal Reserve responses to the Great Recession were the implementation of QE using open market purchases and the payment of interest on excess reserves (IOER). In addition, the Federal Reserve had been exploring changes to its PSR policy before the recession in order to help ease risks from late-day Fedwire payments. In 2011, the PSR policy incorporated differential fees for collateralized and uncollateralized daylight overdrafts to encourage the voluntary use of collateral. The fee for the former was set to zero and for the latter to 50 basis points (annual rate), an increase from 36 basis points (annual rate). While these roughly concurrent monetary and PSR policy actions make it difficult to tease out their separate, and likely opposite, effects on daylight overdrafts, the data show a very significant decline in daylight overdrafts since 2009.

5.1 Monetary Policy Tools Pre- and Post-Crisis

Before the financial crisis, the Federal Reserve primarily exerted influence over the level of reserve balances through open market operations, pushing the interest rate at which banks lend reserves to one another overnight closer to the Federal Open Market Committee's target federal funds rate. The Federal Reserve used open market operations to adjust the daily supply of reserve balances in accordance with forecasted demand for reserves (Kroeger, McGowen, and Sarkar, 2017). During this period, the level of reserve balances was low because institutions could not receive interest payments on reserves and therefore aimed to minimize balances beyond the required level. The scarcity of reserves allowed the Federal

Figure 16: Monetary Policy Tools: IOER and QE



Data source: Board of Governors of the Federal Reserve System (US), retrieved from FRED, Federal Reserve Bank of St. Louis.

Reserve a great deal of control over the federal funds rate; when the rate increased, banks faced a higher opportunity cost of holding reserves. However, this low-reserves method of implementing monetary policy coupled with large and growing payment needs often resulted in banks incurring daylight overdrafts.

As the economy slid into recession in the mid-2000s, the Federal Reserve responded by lowering the federal funds rate to a range of 0 to 0.25 percent by December 2008 (Rich, 2013). To help address concerns about an effective lower bound of zero percent on the federal funds rate, the enactment of the Emergency Economic Stabilization Act of 2008 allowed for the Federal Reserve to begin paying interest on required and excess reserve balances in October 2008, a provision that had initially been approved in the Financial Services Regulatory Relief Act of 2006 to take effect in 2011 (FRB, 2019b). IOER incentivizes banks to maintain higher balances in their accounts. The left-hand graph in figure 15 displays the IOER rate since it was introduced through December 2020. Increases in the rate since 2016 resulted in a rate of 2.4 percent at the end of 2018. The IOER rate started to gradually decline in 2019, but in the begining of 2020 sharply declined to 0.1 percent and remained at this level after March

2020. Adjustments to the IOER rate gives the Federal Reserve more control over the federal funds rate, acting as a lower bound for the market interest rate.

Also in 2008, as a response to the worsening economic conditions of the Great Recession, the Federal Reserve implemented a policy of QE, using open market operations to increase the size of its balance sheet, with the goal of lowering long-term interest rates. Through open market purchases of U.S. Treasury bonds, mortgage-backed securities, and U.S. agency securities, the Federal Reserve increased the supply of money in the economy in the form of reserves which it credited to banks' Federal Reserve accounts to pay for asset purchases. QE was implemented in three distinct stages between 2008 and 2014.[24] These stages are reflected in the stepped pattern observed in the total assets held by all Federal Reserve Banks, as shown by the shaded areas of figure 16. Total assets increased in response to the beginning of each stage, eventually climbing from just below \$2 trillion in 2009 to over \$4 trillion in 2014. After the end of QE3, the Federal Reserve allowed assets to passively mature without actively selling them off (FRB, 2014). The latest QE period started on March 23 2020 and resulted in a further increase of total assets to above \$7 trillion.

5.2 PSR Policy: Net Debit Caps and Daylight Overdraft Fees

While monetary policy tools have a large effect on the liquidity available to banks for transferring value over Fedwire, PSR policy tools affect intraday liquidity through the intraday credit that banks may generate via daylight overdrafts in their reserve accounts. Giving institutions access to intraday credit provides a form of temporary liquidity that allows banks to smooth out the processing of payments and avoid possible gridlock in the payment system. The PSR policy aims to mitigate liquidity and operational risk in the payment system overall while helping combat credit and other risks that individual institutions may generate for Reserve Banks and the system overall.

The introduction of the PSR policy in 1985 established net debit caps, which stipulate

[24]For details and a discussion, see Williamson (2017).

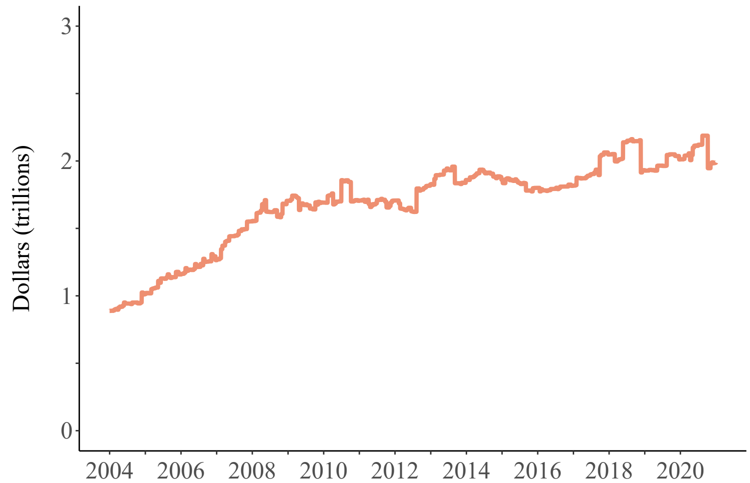
the maximum amount of daylight overdrafts the Federal Reserve will allow an institution to incur in its account (FRB, 2017b). The policy persists today; institutions holding an account at the Federal Reserve can either be assigned or can establish for themselves a net debit cap. Under the current policy, an individual institution's net debit cap is calculated as the product of a cap multiple and a capital measure for the institution. In general, there are six defined categories of caps based on different multipliers that range from "zero" (a multiplier of zero) to "high" (a multiplier of 2.25), intended to allow low-risk, healthy institutions greater daylight overdraft capacity. Banks that are eligible for discount window credit are eligible to establish a net debit cap. In particular, domestic and foreign institutions have access to net debit caps, while GSEs and other institutions that cannot regularly access the discount window do not have a net debit cap.

Despite an initial decline in daylight overdrafts resulting from the introduction of net debit caps, after 1989 overdrafts increased significantly (Coleman, 2002). This led to a 1994 change to the PSR policy introducing pricing for daylight overdrafts, and a further fee increase in 1995. While the introduction of fees in 1994 reduced daylight overdrafts by 40 percent, they once again began trending upward in 1995 (Coleman, 2002).

A historical concern about the introduction of daylight overdraft fees was that banks might have incentives to hold payments until the end of the business day in order to reduce the duration of daylight overdrafts and associated fees. The unintended consequence of shifting payments to the end of the day could have significant operational risk and severe liquidity gridlocks late in the day. These concerns were capture in the proposal to change the PSR policy (FRB, 2008).

> "Given the growing demand for intraday central bank money and accompanying daylight overdrafts, as well as the shift of larger Fedwire payments to later in the day, the Board believes that significant further steps are appropriate to mitigate the growing credit exposures of the Reserve Banks, while also improving intraday liquidity management for the banking system and augmenting liquidity

Figure 17: Aggregate Net Debit Caps



provided."

A change to the Federal Reserve's PSR policy took effect on March 24, 2011, implementing a system of voluntary collateralization of daylight overdrafts provided at a zero fee (FRB, 2017b). In addition, the fee on uncollateralized overdrafts was raised in order to increase the incentive to collateralize daylight overdrafts.

Figure 17 shows the aggregate of the net debit caps of all account holders at the Federal Reserve. In 2004, the aggregate level of net debit caps was approximately $1.2 trillion. In the next 15 years, this total increased to just under $2 trillion. Between 2004 and 2008 there was a significant increase in the aggregate value of net debit caps, after which the incline became more stepped. For the entire period (2004-2020), the growth of net debit caps averaged $65 billion per year. In section 5.3.2, we interpret the aggregate net debit caps, in combination with the aggregate level of overnight reserve balances, as an outer bound of the amount of intraday liquidity available for transfer over the Fedwire or FedACH system.[25]

As previously noted, the pricing structure of daylight overdrafts changed significantly in

[25]Note that unlike some central banks, the Federal Reserve allows intraday credit to be used to settle payments involving central bank payment services other than RTGS services. For example, the FedACH service is one such service provided by the Reserve Banks that can also generate overdrafts. FedACH is batched payment services that enable an electronic exchange of debit and credit transactions through the Automated Clearing House (ACH) network.

the 2011 revision, creating a system that places a zero fee on collateralized overdrafts, and a 50 basis-point annual fee on uncollateralized daylight overdrafts. This change was made to "explicitly recognize[s] the role of the central bank in providing intraday balances and credit to healthy depository institutions" (FRB, 2012b). Essentially, this allows institutions to access intraday credit for free from the Federal Reserve so long as the overdrafts are collateralized. After this 2011 policy change, the percentage of average daylight overdrafts over Fedwire that were collateralized did not fall below 90 percent (FRB, 2019a).

5.3 Policy Analysis

5.3.1 Dynamics of Reserve Balances

Figure 18 shows the aggregate level of end-of-day reserves. Before the financial crisis, aggregate reserves were relatively low at levels generally below $25 billion. With the introduction of each QE stage and the purchase of additional assets, there was a quick and substantial increase in the level of reserves. In turn, after the conclusion of each QE stage there was a gradual decline in the level of reserves. As of the end of 2018, aggregate reserves had fallen from a $2.7 trillion high in 2015 to approximately $1.5 trillion. After March 2020, the end-of-day reserves grew again to $3 trillion. The high levels of reserves held by banks at the Federal Reserve played a role in decreasing daylight overdrafts. With higher reserves, institutions have a greater pool of liquidity that they are able to tap in order to make payments over Fedwire, thereby reducing the likelihood that an overdraft will occur. The aggregate end-of-day reserve balances held in Federal Reserve accounts at the beginning and end of each QE period are displayed in table 4, further exemplifying the effect that QE had on reserve balances.

5.3.2 Aggregate Instantaneous Payments Liquidity

Next, we propose a system-wide measure of liquidity availability for payments over Federal Reserve systems: aggregate instantaneous payments liquidity ("aggregate liquidity"). We

Figure 18: End-of-Day Reserve Balances Held in Federal Reserve Bank Accounts

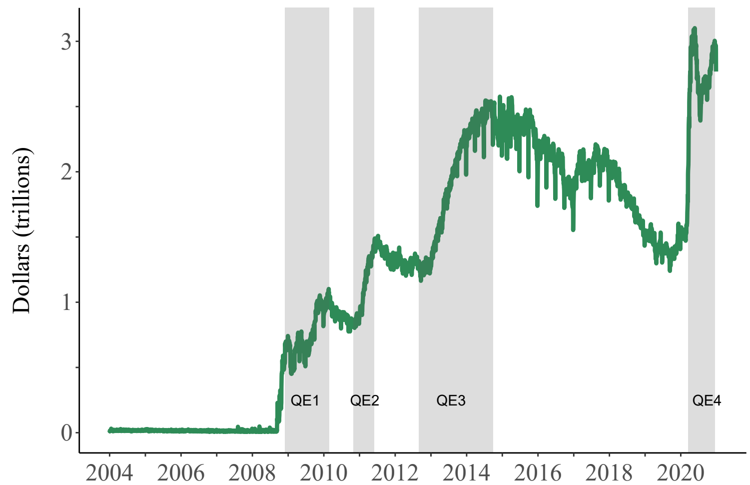


Table 4: Stages of QE and Aggregate Reserve Balances

QE Period	Start Date	End Date	Start Balances ($ trillions)	End Balances ($ trillions)
QE1	Dec. 2008	Mar. 2010	0.54	1.03
QE2	Nov. 2010	June 2011	0.82	1.44
QE3	Sept. 2012	Oct. 2014	1.36	2.52
QE4	Mar. 2020	-	1.5	~ 3

Source: Williamson (2017); end-of-minute balance data.

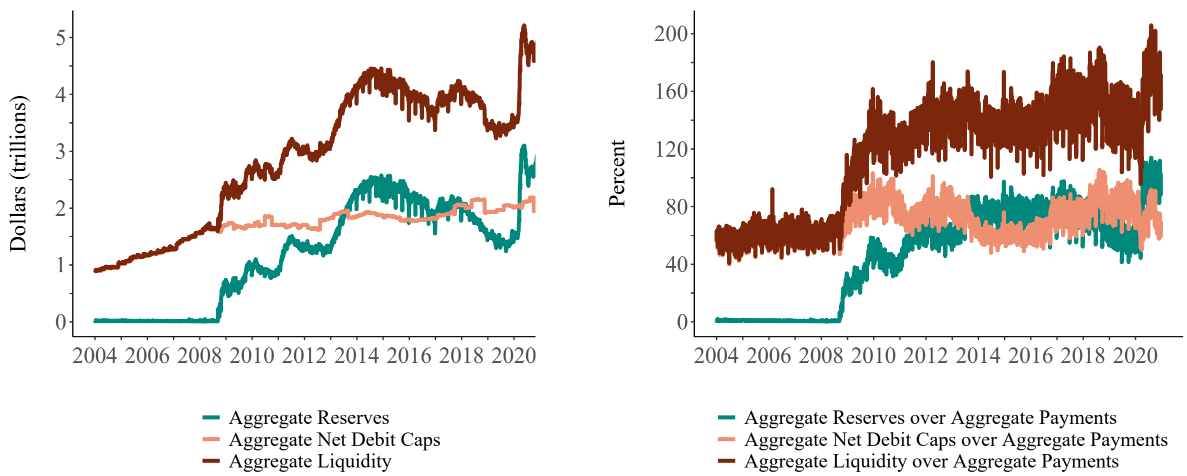
calculate aggregate liquidity as the sum of all institutions' end-of-day reserve balances and net debit caps, thereby capturing both funds and intraday credit available to Federal Reserve accountholders.[26] This measure provides a theoretical upper bound of "instantaneous" payments liquidity—that is, the amount of payments the system can settle in an instant, without considering flows of funds between accounts from payments activity throughout the day that alter the distribution of aggregate liquidity. These considerations dispense the possibility for liquidity recycling and, thus, the proposed metric is only a coarse measure of payments liquidity available to accountholders.[27]

The monetary and PSR policy tools previously discussed spurred an increase in aggregate

[26]Recall that a net debit cap is the maximum amount of daylight overdrafts available to Fedwire participants.

[27]Note that the distribution of aggregate liquidity and how efficiently it can be used are important determinants for whether liquidity requires recycling to complete Fedwire (and other) payments.

Figure 19: Aggregate Instantaneous Payments Liquidity (left) and Ratio of Aggregate Instantaneous Payments Liquidity to Daily Aggregate Payments Value (right)



Note: Aggregate Instantaneous Payments Liquidity is computed as the sum of the End of day balances plus aggregate Net Debit Caps in a given day. The ratios in the right plots are computed by dividing the series from the left plot with the daily aggregate payment value.

liquidity beginning in 2009 with the sharp expansion of end-of-day balances. Depicted in the left side of figure 19, aggregate liquidity illustrates a theoretical upper bound of the value of payments Federal Reserve accountholders could make on any day over the sample period. Together, the value of net debit caps and end-of-day balances available to accountholders (shown by the dark red line of figure 19) increased from less than $1 trillion in 2004 to almost $5 trillion in 2020, with peak aggregate liquidity in 2014 reaching $4.6 trillion. Comparing this measure of aggregate liquidity with the value of daily Fedwire payments provides insight into the extent to which Fedwire payments may strain the availability of liquidity to Federal Reserve accountholders.

In order to assess the dynamics of aggregate liquidity over time, we calculate the ratio of aggregate liquidity to the total daily value of Fedwire payments. Intuitively, an increase of this ratio over time indicates a greater supply of liquidity available to accountholders relative to their payments. In addition, a ratio well above 1 suggests a particular abundance of payments liquidity as compared with the daily needs for settling all payments.

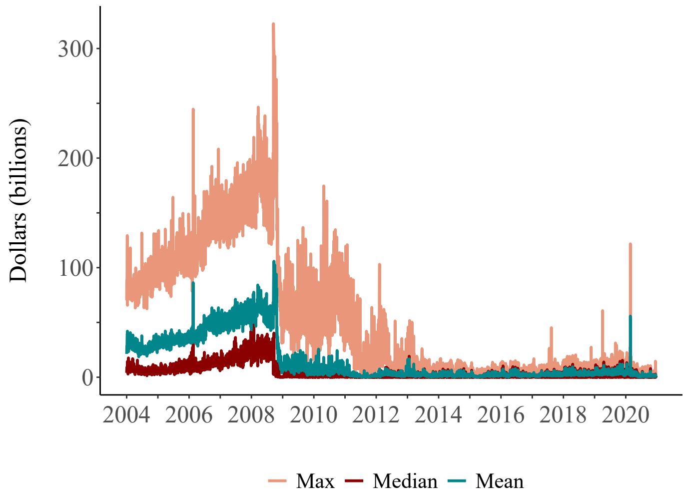
The right side of figure 19 shows the ratio of aggregate liquidity to daily Fedwire payments value, in addition to the ratio of both components of aggregate liquidity to daily Fedwire payments, across all years in our sample. Before the crisis, the low level of reserve balances (shown by the green line of figure 19) were a negligible share of the daily value settled over Fedwire. During this period, aggregate liquidity consisted almost entirely of the sum of all institutions' net debit caps (shown by the light red line), and consequently the combined value of reserve balances and net debit caps (shown by the dark red line) was equivalent to just 80 percent of daily payments value. In 2014, the value of aggregate end-of-day balances surpassed the value of aggregate net debit caps for the first time, such that reserve balances alone were capable of instantaneously funding 80 percent of daily payments value. This ratio grew to 130 percent in 2014 and later in 2020 to 150 percent. That is, consistently after 2014 the aggregate liquidity could theoretically provide sufficient liquidity to cover more than 130 percent of daily Fedwire payments before exhausting aggregate available liquidity in the event of a liquidity shock. However, depending on the type of liquidity shock and its incidence, the full amount of the system's theoretical liquidity might not be properly distributed or available to fund all payments.[28]

5.3.3 Dynamics of Daylight Overdrafts

As previously mentioned, the level of daylight overdrafts decreased following changes in monetary and PSR policy. In 2006, around 6 percent of the average Fedwire payment value—an average of $51 billion during operating hours—was funded through daylight overdrafts because low reserve balances necessitated that banks use intraday credit to complete payments on time (Kroeger, McGowen, and Sarkar, 2017). As seen in figure 20, the two-week rolling average of maximum intraday daylight overdrafts across all institutions holding balances at the Federal Reserve peaked at about $300 billion per minute during the height of the crisis. Implementing QE and IOER shortly after the peak of daylight overdrafts resulted in a quick

[28] Liquidity shocks could originate from a range of hazards (physical, cyber, or otherwise) to accountholders and their equipment, as well as from financial shocks to accountholders. The effect of such a shock would potentially degrade or even eliminate the technical or financial ability of one or more accountholders to make or receive payments.

Figure 20: Intraday Daylight Overdrafts

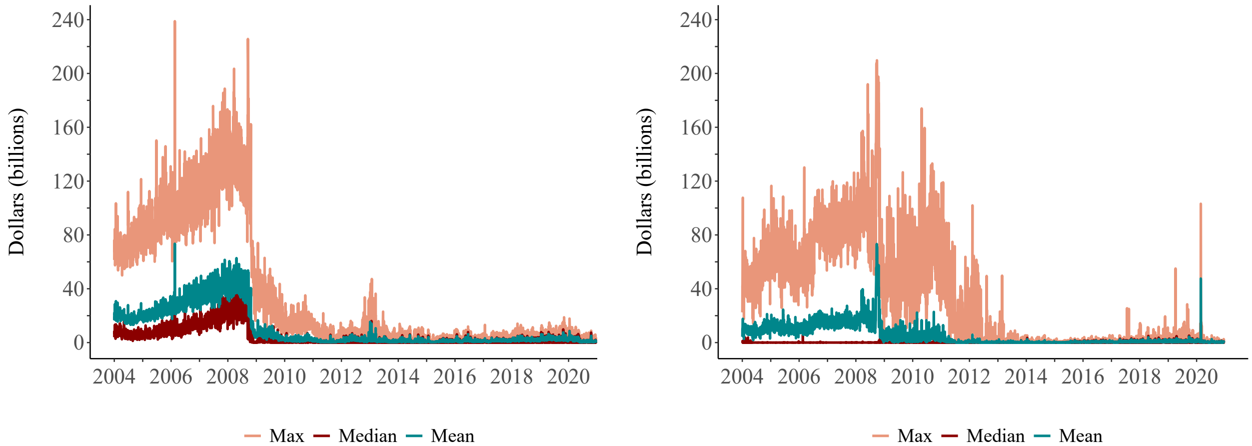


reduction in median aggregate intraday daylight overdrafts from levels close to \$20 billion to just \$1 billion from 2008 to 2009. After this initial decline, median aggregate intraday daylight overdrafts remained below \$30 billion.

There are several reasons why an accountholder may go into overdraft in their Federal Reserve account. In addition to settling payments on Fedwire (Fedwire funds), Federal Reserve accounts may also be used in processing activity related to the Fedwire Securities service, the National Settlement Service (NSS), the FedACH service, and Federal Reserve check payment services. Thus, an account may be overdrawn during a given minute of a day because of any one of these payment activities. We develop a methodology to identify the contributions of various payment activities to an instance of overdraft. In the end, we obtain separate overdrafts from Fedwire funds payment activity (funds or Fedwire overdrafts) and from non-funds payment activity (non-funds or non-Fedwire overdrafts). This separation enables us to examine the drivers of daylight overdrafts.

To separate the funds from non-funds overdrafts, we first dynamically allocate the opening balance of each accountholder at each minute to funds and non-funds activity according to the demands for liquidity by those activities. Our proposed dynamic allocation follows the

Figure 21: Funds (left) and Non-Funds (right) Transfer Overdraft Statistics



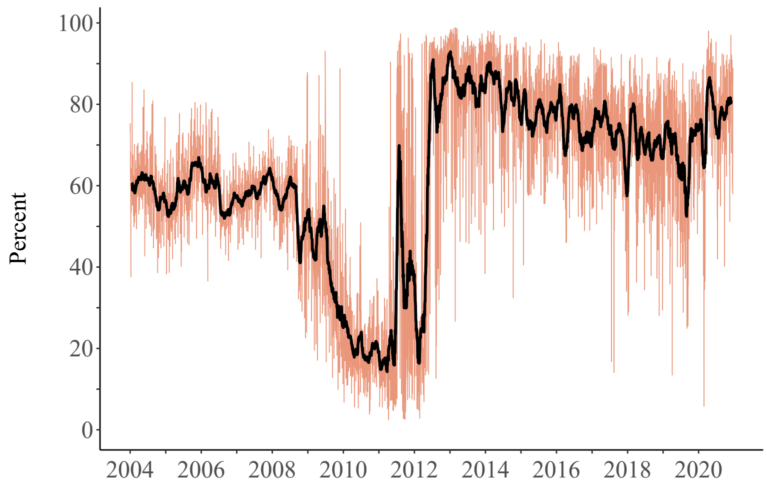
ratio between the cumulative balance from funds activity and the cumulative balance from non-funds activity.[29] Once we have allocated the opening balance between funds and non-funds activity, computing the funds overdrafts at a given minute amounts to adding the opening balance for funds to the cumulative balance from funds activities.

Figure 21 plots separately summary statistics for the aggregate values of funds and non-funds daylight overdrafts. The trends in daylight overdrafts from funds transfers closely follow the trends in total overdrafts. The trends in daylight overdrafts from non-funds transfers, however, show an upturn between 2009 and 2012, which diverges from the concurrent decrease in daylight overdrafts attributable to funds transfers. Note that because maximum and median are order statistics, the levels in figure 21 for those statistics do not add up to the aggregate levels in figure 20.

Figure 22 examines further the relationship between funds and non-funds overdrafts. The plotted line follows the ratio between the daily maximum funds overdraft to the daily maximum non-funds overdraft. The percentage of funds overdrafts was noticeably low between 2009 and 2012, which was already suggested by figure 21. From 2012 on, funds transfers generally accounted for the majority of total daylight overdrafts.

[29]For example, consider bank A on a given day with opening balance of 10 million. If at noon, the cumulative balance of funds activity is -8 million and the cumulative balance from non-funds activity is -4 million then this ratio is 2 to 1. Thus, at noon A's overdraft will be 2 million, the funds overdraft will be $\frac{2}{3}10 - 8 = 1.4$ million, and the non-funds overdraft will be $\frac{1}{3}10 - 4 = 0.6$ million.

Figure 22: Percentage of Total Daylight Overdrafts Attributable to Funds Transfers



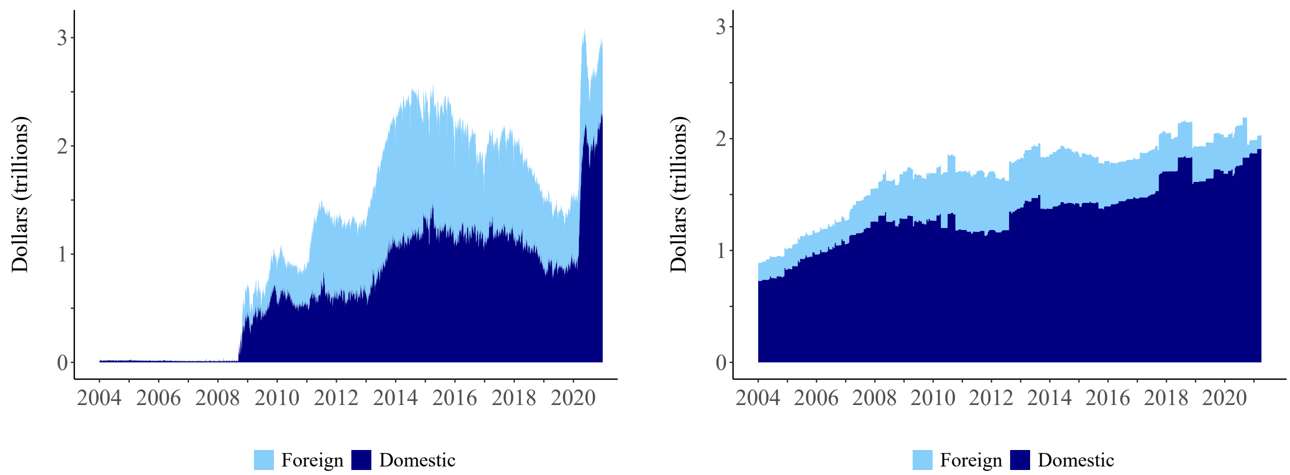
The distinction between overdrafts from funds and non-funds transfers is important because overdrafts incurred from most of the non-Fedwire funds activity is traditionally less susceptible to flexible intraday timing controls and can make it more difficult to discern how banks' payments behavior evolves over time and/or reacts to policy changes. In particular, in the non-Fedwire services, banks sending payments are likely to initiate debits to a receiving bank's account, over which the receiving bank may have limited intraday control.[30] Additionally, PSR policy regulating and pricing daylight overdrafts applies to an account with a negative balance, regardless of how that negative balance occurred. It is therefore important to be cognizant of the fact that policy changes either intentionally or unintentionally targeting a specific type of payment may also affect payments behavior in payment systems other than, for instance, Fedwire funds.

5.3.4 Composition of Reserve Balances and Daylight Overdrafts

When examining payments composition, it is informative to decompose reserve balances and daylight overdrafts by both the types of institutions and the size of the institutions holding reserves.

[30]Note that while ACH debit transactions are sender-initiated debits, ACH credit transactions do involve sender-initiated credits to the receiver's account.

Figure 23: Reserve Balances (left) and Net Debit Caps (right) by Institution Type



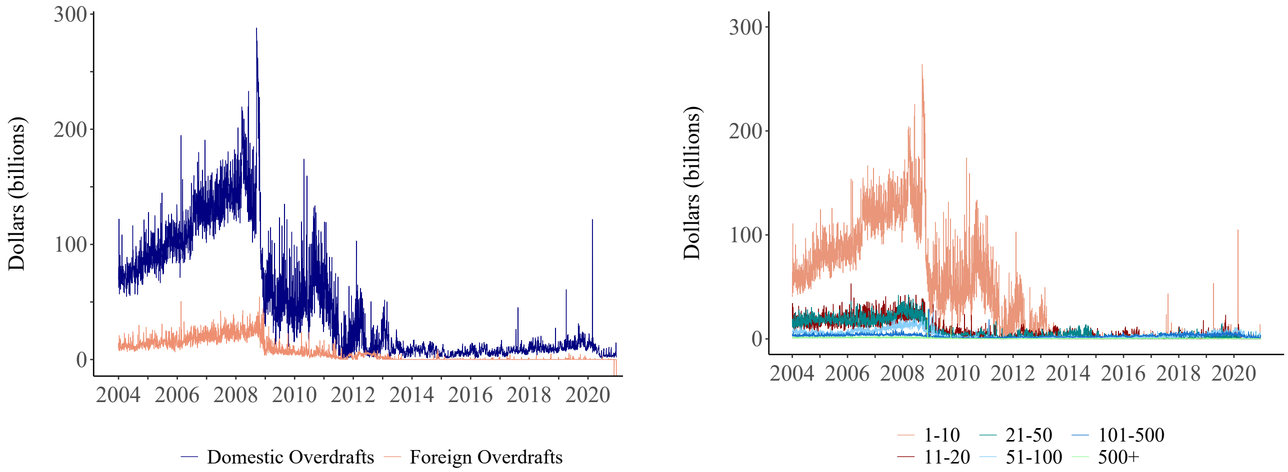
The left-hand graph in figure 23 decomposes the aggregate end-of-day reserve balances (from figure 18) to those held by domestic and foreign institutions. The end-of-day reserve balances held by domestic and foreign institutions followed similar trends and, notably, their similarity persisted even through the sharp jump in reserves in 2020.[31] Interestingly, the level of reserves of these two groups were comparable in size until the very end of our sample. Given that there are many fewer foreign institutions with accounts at the Federal Reserve, the similarity in balance totals suggests that on average foreign institutions were holding higher balances in their accounts.

Complementary to the decomposition of aggregate end-of-day reserve, the right-hand graph in figure 23 shows the decomposition of net debit caps. In contrast, the aggregate domestic net debit caps were substantially greater than aggregate foreign net debit caps. Furthermore, foreign net debit caps decreased after 2014 while domestic net debit caps initially dipped in 2014 but then recovered to levels higher than in 2014.

The left-hand graph in figure 24 shows the maximum daylight overdrafts by institution type. As previously noted, daylight overdrafts are mainly incurred by domestic institutions. The payments capacity of foreign banks covers their total daily payments value, resulting in few-to-no daylight overdrafts.

[31]Note that the graphs in figure 23 do not include GSEs.

Figure 24: Max Daylight Overdrafts by Institution Type and Rank



Finally, the right-hand plot of figure 24 shows the maximum value of domestic daylight overdrafts grouped by institution sizes, as measured by value concentration. The top 10 institutions in terms of value sent over Fedwire drove the majority of daylight overdrafts pre-crisis, particularly in 2008 when the average value of overdrafts by the top 10 institutions peaked at over $90 billion. After 2012, institutions of all sizes incurred daylight overdrafts at low levels, with no one group of institutions contributing significantly more to the system overdrafts than any other.

6 Conclusion

The sheer volume and value of payments settled over Fedwire suggests that Fedwire is an integral part of the U.S. economy and that it is worth examining Fedwire to understand how it is used and how it contributes to the smooth functioning of interbank payments. Using minute-level data collected from the Fedwire transaction log, we show that the total daily volume of payments settled over Fedwire has been increasing since the end of the Great Recession, while daily total value of payments settled has experienced intermittent periods of growth and decline, driven by payments between domestic and foreign institutions. Breaking the volume and value of Fedwire payments down by payments size and banks' payments activity reveals a highly-concentrated system in which relatively few banks generate disproportionately high value of payments and, also, high-value payments constitute a majority of the value transacted.

To better understand how this concentration affects the flow of liquidity over Fedwire, we further examine payments behavior. As evidenced by both the timing distribution and empirical distribution of payments, we show that the concentration of Fedwire payments has moved earlier in the day since 2004. Furthermore, the velocity of payments in terms of both payments and dollars per minute have been increasing since 2009. We hope these indicators of payments behavior provide useful information to researchers and policymakers on the functioning of interbank payments.

Finally, we examine the response of reserve balances and daylight overdrafts to changes of monetary and PSR policies over our sample period. The end-of-day reserve balances have increased dramatically since the Great Recession and continue to be high compared with historical levels before that. Since 2011, daylight overdrafts remain stable and significantly below their historical levels. To assess the dynamics of available liquidity and liquidity needs, we compare the aggregate instantaneous payments liquidity, defined as the sum of the aggregate net debit caps and end-of-day reserves, and the value of daily Fedwire payments. Our calculations suggest that their ratio grew over time to current levels substantially above 100 percent. Future research could benefit from looking to understand the evolution of liquidity risks that might exist in the system, in light of the behavior and trends documented here.

A Additional Plots and Tables

Table 5: Correlation Between GDP Growth and Fedwire Value Growth

Period	GDP Growth	Fedwire Growth	Correlation	p-Value	Standard Error
Annual	None	None	0.132	0.640	0.275
Annual	Lag	None	0.768	0.001	0.178
Annual	None	Lag	-0.507	0.064	0.249
Quarterly	None	None	0.245	0.053	0.124
Quarterly	1 Lag	None	0.432	0.000	0.115
Quarterly	2 Lags	None	0.322	0.011	0.122
Quarterly	3 Lags	None	0.295	0.021	0.124
Quarterly	None	1 Lag	0.124	0.337	0.128
Quarterly	None	2 Lags	0.086	0.510	0.130
Quarterly	None	3 Lags	-0.147	0.262	0.130

Table 6: Fedwire Transaction Volume per Minute (Top) and Value per Minute (Bottom)

Year	Mean (ppm)	StD (ppm)	Min (ppm)	1st Quartile (ppm)	Median (ppm)	3st Quartile (ppm)	Max (ppm)
2004	413	412	1	20	256	781	3,348
2005	417	436	1	14	195	810	2,340
2006	416	441	1	12	182	820	2,572
2007	417	440	1	16	185	818	2,727
2008	403	428	1	18	191	782	4,557
2009	382	415	1	22	177	734	5,056
2010	382	412	1	24	191	723	6,296
2011	389	410	1	32	198	731	4,429
2012	404	430	1	36	203	756	11,706
2013	412	428	1	37	210	770	5,275
2014	415	430	1	39	227	766	5,134
2015	438	457	1	42	246	807	10,481
2016	456	472	1	48	256	834	6,847
2017	470	500	1	50	279	848	10,619
2018	488	528	1	48	295	875	15,869
2019	516	560	1	51	318	913	29,988
2020	561	597	1	58	342	993	9,840
	($ billions)	($ billions)	($ millions)	($ millions)	($ millions)	($ billions)	($ billions)
2004	1.5	3.8	0	5	332	1.5	135.8
2005	1.6	4.0	0	2	283	1.5	108.1
2006	1.7	4.2	0	2	306	1.6	109.7
2007	2.0	4.9	0	4	369	1.9	133.5
2008	2.2	5.4	0	5	389	2.1	163.7
2009	1.9	4.6	0	4	315	1.9	124.7
2010	1.8	4.1	0	5	344	2.0	152.4
2011	2.0	4.5	0	7	419	2.1	131.1
2012	1.8	4.2	0	10	430	1.9	186.8
2013	2.2	5.1	0	13	506	2.2	198.1
2014	2.7	7.4	0	18	594	2.7	371.0
2015	2.6	5.3	0	23	660	2.9	229.3
2016	2.4	4.7	0	38	724	2.9	282.4
2017	2.3	4.6	0	38	761	2.8	224.1
2018	2.2	4.4	0	43	809	2.8	267.9
2019	2.1	4.2	0	54	850	2.7	266.3
2020	2.6	5.4	0	76	1008	3.2	323.4

Note: Figures reported in payments per minute (ppm) in the top half and dollars per minute in the bottom half. with no re-scaling. Distributional statistics were calculated by counting all transactions in a minute. Averages and quartiles were then computed across minute-level data in a given year.

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