The Payment System Benefits of High Reserve Balances
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Abstract

The policy measures taken since the financial crisis have greatly expanded the size of the Federal Reserve's balance sheet and have thus raised the level of aggregate bank reserves as well.
Over the same period there has been a significant shift in the timing of payments made over the Federal Reserve's Fedwire Funds Service toward earlier settlement. This paper documents this timing change and presents regression results suggesting that the increase in overall reserve balances explains the vast majority of this development. The paper also discusses the benefits of high aggregate reserve balances for the robustness of the payment system and the potential implications for policy going forward.

Key words: Fedwire, settlement liquidity, reserves, monetary policy implementation

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1 Introduction

Since the financial crisis, a profound transformation in the structure of payments sent over the Federal Reserves Fedwire Funds service has taken place. That change is a dramatic shift in the timing distribution of the value of settlement earlier in the day—hours earlier throughout a large portion of the distribution. Coinciding with this change in the payment system was a massive expansion of the size of the Federal Reserve's balance sheet. This increase came as a result of policy choices made by the Federal Reserve to combat the effects of the financial crisis and recession through credit extensions and large-scale asset purchases (LSAPs). These measures resulted in a significant increase in the reserve balances in accounts of commercial banks with Federal Reserve Banks.

Although the increase in reserve balances was not the direct intent of policymakers (see Bernanke (2009)), the increase in reserves altered the incentives faced by Fedwire participants. The ample liquidity of financial institutions after the crisis reduced the costs of completing payments early, in part by reducing commercial banks reliance on costly intraday credit from Federal Reserve Banks. These circumstances are associated with a system-wide quickening of settlement.

The system-wide quickening of settlement is an enhancement to the efficiency and resilience of the payment system. A game-theoretical model by Bech and Garratt (2003) suggests that banks have a strategic incentive to delay payments to reduce their costs, at the expense of greater delay costs being borne by bank customers and counterparties. In their model, the socially efficient outcome is a settlement strategy in which banks avoid delay and its social costs. The model also suggests that a central bank may be able to enact policies to reduce banks costs of early payment submission and therefore reduce their incentives to delay payments. Furthermore, the delay of payments can amplify the effects of operational disruptions when positions are left unsettled when the disruption occurs.

Is the creation of large amounts of bank reserves wasteful, even as it promotes quicker submission of payments? Milton Friedman (1969) suggested that the social costs of creating money was essentially zero, and that therefore, any policy that causes banks to economize on their holdings of bank reserves is inefficient. So long as the assets purchased by a central bank to create reserves are safe and do not entail credit risk, the expansion of the central bank balance sheet mainly affects the costs of borrowing by the consolidated government, and does not entail other social costs (see Del Negro et al. (2013)).

The phenomenon of quickening settlement was first documented by Bech et al. (2012). Utilizing the methodology of Armantier et al. (2008) with regard to analyzing settlement liquidity, this article aims to update the analysis of this change in the payment system by documenting it with more recent data, identifying the most significant associated factors through regression analysis, and using these data as motivation for a discussion of policy choices with regard to the size of the Federal Reserve's balance sheet moving forward.

The article is organized as follows. Section 2 provides an overview of the Fedwire Funds Service. Section 3 discusses the measurement and recent improvement of settlement liquidity over the Fedwire Funds system. Section 4 motivates the idea that high reserve balances are the primary causal factor in explaining this change in settlement liquidity, while section 5 establishes this causal relationship using regression analysis. Section 6 provides a discussion of the policy implications of this relationship, and Section 7 concludes.

2 Fedwire

The Fedwire Funds Service is a real-time gross settlement (RTGS) system operated by the Federal Reserve Banks that offers dollar transfers between accounts at Federal Reserve Banks that are immediate, final, and irrevocable. It's approximately 7,500 participants include depository institutions and some other institutions that hold an account with a Federal Reserve Bank.[1]

In addition to payment settlement, the Federal Reserve also offers intraday credit to its participants by allowing overdrafts on accounts when using Fedwire or other Federal Reserve settlement services. The default risk associated with this extension of credit is largely managed with collateralization. Borrowers are incentivized to post collateral for any overdraft use, since collateralization allows the institution to avoid a fee for the service. The extension of credit by Federal Reserve Banks is governed by the Federal Reserve's Payment System Risk (PSR) policy. The policy was first written in 1985, and has been amended multiple times since its inception. Each eligible borrower faces a maximum limit, or net debit cap on overdrafts. The PSR policy was modified in 1992 to charge participants fees for their use of intraday credit, which went into effect in April 1994. In 2001, changes to the PSR policy allowed institutions meeting certain criteria to have collateralized overdrafts above their net debit caps.

[1] For more information on the Fedwire Funds Service, see https://www.frbservices.org/serviceofferings/fedwire/fedwire_funds_service.html.

In 2008, the policy was again revised with respect to intraday credit by setting the fee for collateralized overdrafts at zero and raising the fee for uncollateralized overdrafts to 50 basis points. This policy was intended to improve payment liquidity while also limiting the credit exposure of Federal Reserve Banks. Those changes went into effect on March 24, 2011.[2]

3 Settlement Liquidity Over Fedwire

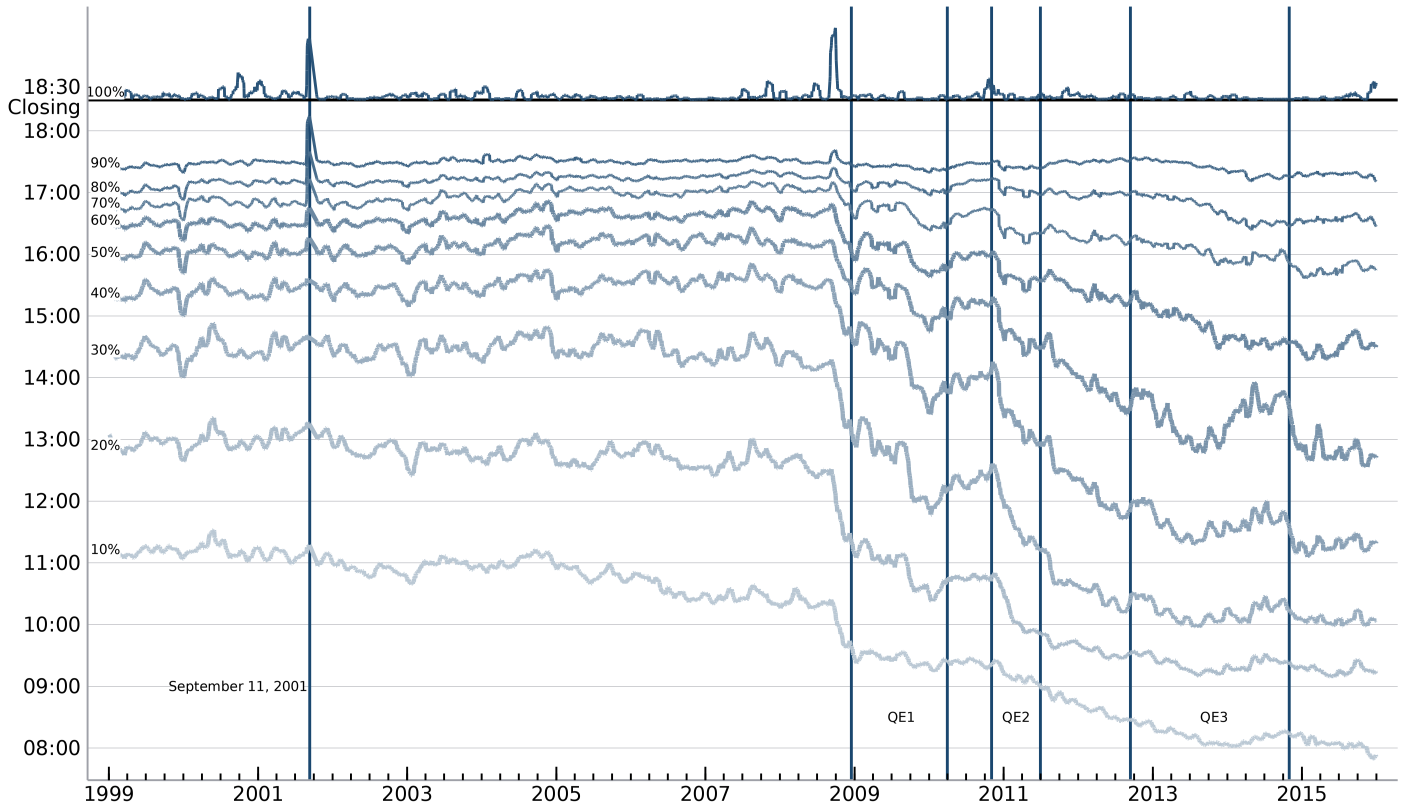
One way to gauge the availability of settlement liquidity on Fedwire (see Bech et al. (2012)) is to analyze the extent to which payments are being delayedi—that is, the length of time between when a payment is requested and when it is completed. The greater the delay, the more restricted is the availability of liquidity, as participants in the system delay payments in the expectation that other participants will make payments to them, replenishing their liquidity. In the case of Fedwire, delay cannot be measured directly with transaction data, since one can only observe when the payment took place, but not when it was requested.

If one can reasonably assume that the distribution of payment requests is fixed, then changes in the timing distribution of payments can serve as a proxy for changes in payment delays and hence for liquidity. Some support for this hypothesis is found in examining the behavior of transfers requested by bank customers and those initiated for the bank itself. We find that the timing of customer transfers is much less sensitive to the increase in reserve balances than are bank transfers, which suggests that the changes we measure are not simply the result of changed timing of payment requests of customers.

Figure 1 shows the time series for the past sixteen years of the timing of Fedwire payments expressed as the times at which particular deciles of intraday value have been settled. For example, the height of the 50% line denotes the time at which half of the overall value of the corresponding day had been settled. Prior to the financial crisis, the timing of payments was relatively stable with a slight upward trend in the upper deciles and a slight downward trend in the bottom two deciles. Since the crisis, however, there has been a striking shift in the timing distribution of Fedwire payments toward earlier settlement. The 20^{th} through 50^{th} percentiles of value, for example, are now settled approximately 3 hours earlier than they were pre-crisis.

[2]The Federal Reserve Board's Payment System Risk Policy is available at http://www.federalreserve.gov/paymentsystems/psr_overview.htm#tocIA.

Figure 1: Time Series of Settlement Liquidity



Notes: Twenty-one-day centered moving average.
Values exclude payments related to CHIPS, CLS, DTC, and P&I payment funding.

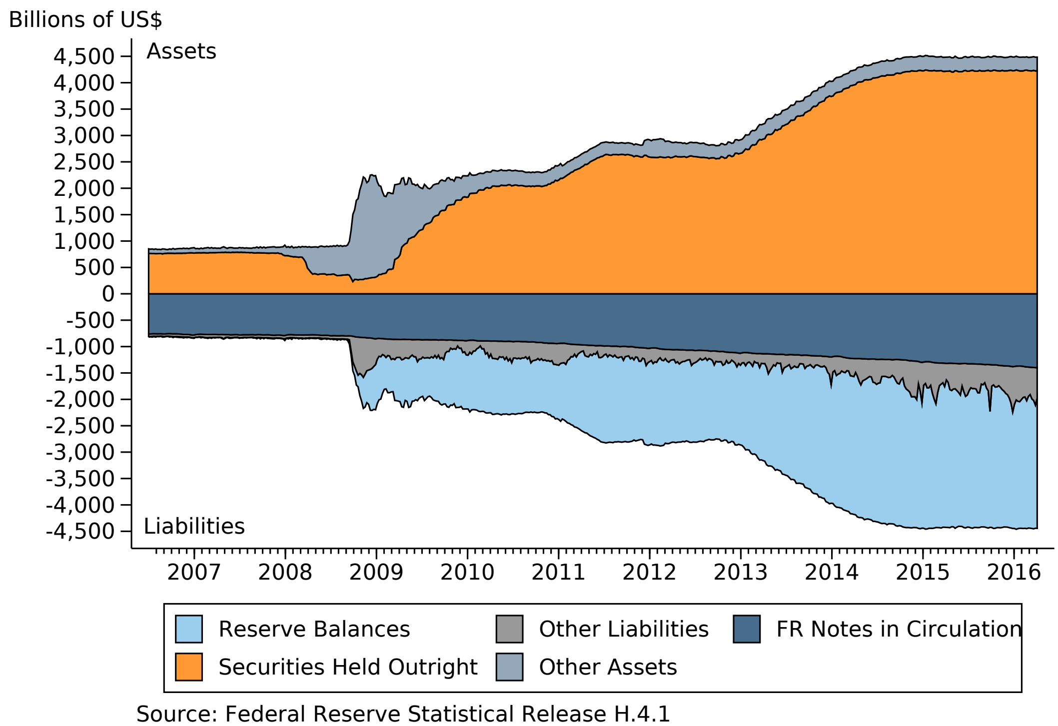
Sources: Federal Reserve Bank of New York, Authors' calculations.

4 Causes of the Quickening of Payments

The dramatic shift in the timing of interbank payments coincides with another dramatic change in the financial system—the size of the Federal Reserve's balance sheet. The measures taken by the Federal Reserve since 2008 in order to preserve the stability of the financial system and to carry out monetary policy were unprecedented in their effects on the quantity of reserve balances. The magnitude of the LSAPs conducted pursuant to the directives of the FOMC entailed a large increase in the overall size of the Federal Reserve's balance sheet.

Looking at Figure 2, one can see the amount of assets held by the Federal Reserve has more than quadrupled since the crisis owing to credit programs and asset purchases. On the liabilities side, reserves have by far been the primary source of financing for these assets. This massive increase

Figure 2: Time Series of the Federal Reserve's Balance Sheet



in reserves was not directly intended to improve settlement liquidity. Nonetheless, large reserve balances alter the incentives of banks sending payments over the Fedwire system. A bank with pending obligations must choose when to discharge them. There are costs to delaying payments, including the risk of operational problems with payment systems leading to breaches of agreements and reputational costs if customers prefer early payment. There are also benefits to delaying payments. Delaying a payment could reduce the funding costs for the bank by reducing the need to rely on private credit markets or on a costly overdraft in its account with the Federal Reserve. These benefits are especially acute in times of uncertainty about the availability of credit. A large increase in reserves would have the effect of diminishing or eliminating the benefits of delaying payment, however, since banks should have ample liquidity to make payments without reliance on credit.

The primary claim of this analysis is that the increase in the level of system reserves accounts for the vast majority of the quickening of payment timing since 2008. Quantifying and identifying this effect is done with regression analysis and is discussed in the subsequent section.

5 Results

In order to more explicitly associate this timing shift with various potential factors, regression analysis is used on the daily time series of the Fedwire timing distribution. Like the model used by Armantier et al. (2008), the model consists of 100 linear regressions, one for each percentile of value settled on Fedwire throughout the day. The time period considered is the week after the collapse of Lehman Brothers in September, 2008 to the end of March, 2015.

The dependent variable in each regression is the change in time (in minutes) by which the corresponding percentile of the total Fedwire transfer value of the day, excluding transfers of settlement institutions and transfers for principal and interest payments by GSE's,[3] has been settled. A number of explanatory variables are utilized (for a complete list, see the appendix), including the sum of opening reserve balances of all Fedwire participants and many explanatory factors, including calendar effects, measures of the magnitude of activity over Fedwire, the market structure with respect to the distribution of payments and reserves, government policies, and the activity of settlement institutions.

To address the issue of nonstationarity, every variable is differenced from one business day to the next. To address problems of potential serial correlation of the error terms and heteroskedasticity,

[3]The value transferred by settlement institutions and principal and interest payments by GSE's were excluded due to the regularity in terms of time and value with which these payments occur.

the method developed by Newey and West (1987) is utilized to correct standard errors. A maximum lag length of 10 is used for the Newey-West procedure.

The model can be specified as the following:

$$
\begin{aligned}
\Delta p_t^1 &= \beta_0^1 + \beta_1^1 \Delta OpenBal_t + \beta_2^1 \Delta x_t + \varepsilon_t^1 \\
\Delta p_t^2 &= \beta_0^2 + \beta_1^2 \Delta OpenBal_t + \beta_2^2 \Delta x_t + \varepsilon_t^2 \\
&\ldots \\
\Delta p_t^{100} &= \beta_0^{100} + \beta_1^{100} \Delta OpenBal_t + \beta_2^{100} \Delta x_t + \varepsilon_t^{100}
\end{aligned}
$$

where Δ represents the change from one business day to the next. The dependent variable represents the time (expressed as the number of minutes since the beginning of the corresponding day t) at which the percentile of Fedwire value i has been settled on day t. $OpenBal_t$ is the sum of opening balances across Fedwire participants on day t. And finally $\mathbf{x}_t$ is a vector of explanatory variables.

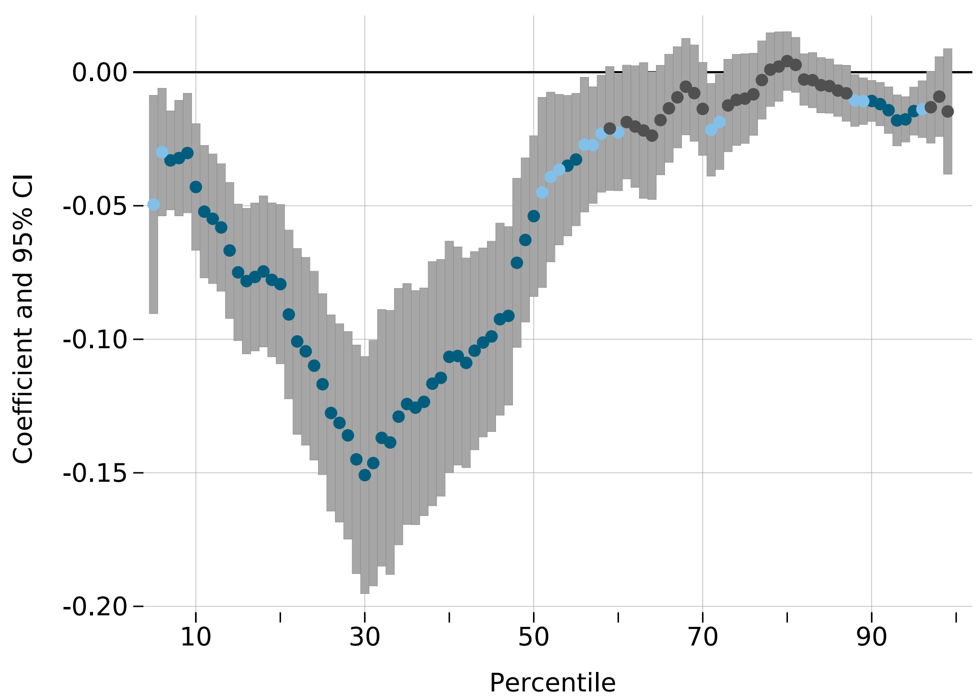
Table 1: Regression Results

	Percentile								
Explanatory Variables	10	20	30	40	50	60	70	80	90
Change in Sum of Opening Balances	-0.0430***	-0.0794***	-0.1509***	-0.1066***	-0.0539***	-0.0226*	-0.0137	0.0042	-0.0108**
Effect on Timing	-1:49	-3:22	-6:25	-4:32	-2:17	-0:57	-0:35	0:10	-0:27
Change in HHI of Opening Balances	0.0191**	0.0180*	0.0411*	0.0256	0.0038	0.0130	0.0053	0.0035	0.0072
Effect on Timing	-0:12	-0:12	-0:27	-0:17	-0:02	-0:08	-0:03	-0:02	-0:04
Change in Customer Transfer Value	-0.0039	-0.0089	-0.0242*	-0.0206*	0.0018	0.0068	-0.0012	0.0041	0.0034
Effect on Timing	0:01	0:02	0:06	0:05	-0:00	-0:01	0:00	-0:01	-0:00
Change in Brokered Federal Funds Volume	-0.0098	0.1343	0.1092	0.0528	0.0218	0.0199	0.0490	0.0415	0.0345
Effect on Timing	0:00	-0:09	-0:08	-0:03	-0:01	-0:01	-0:03	-0:03	-0:02
Change in Target Federal Funds Rate	-1.7875	15.5923	-9.0337*	-5.2388	27.1300*	19.7192***	11.3606***	4.1554***	0.9919
Effect on Timing	0:03	-0:27	0:16	0:09	-0:48	-0:35	-0:20	-0:07	-0:01
Change in Deviation from Target Rate	-1.5663	-10.0127*	-0.7803	-7.8381	-6.7848	-10.0323*	-4.2048	-0.7917	-1.9093*
Effect on Timing	0:00	0:06	0:00	0:04	0:04	0:06	0:02	0:00	0:01
Change in Extension of Fedwire Hours	-0.0014	0.0325	0.0100	0.0578	0.0501	0.0414	0.0575***	0.0505***	0.0461***
Effect on Timing	0:00	-0:00	-0:00	-0:01	-0:01	-0:01	-0:01	-0:01	-0:01
Change in Value of Tri-Party Repo	0.0726	0.1439**	0.3159***	0.3589***	0.1327*	0.1565**	0.0811*	0.0535*	0.0254
Effect on Timing	-0:01	-0:03	-0:08	-0:09	-0:03	-0:04	-0:02	-0:01	-0:00
Change in Volume (Non-Settlement)	-0.0062	0.0094	0.0146	0.0153	-0.0057	-0.0136	0.0002	0.0045	0.0033
Effect on Timing	0:00	-0:00	-0:00	-0:00	0:00	0:00	-0:00	-0:00	-0:00
Change in HHI of Value Sent	0.0209	0.0843***	0.1383***	0.1311***	0.0349*	0.0207	0.0183*	-0.0028	-0.0017
Effect on Timing	-0:02	-0:11	-0:18	-0:17	-0:04	-0:02	-0:02	0:00	0:00
Change in ON RRP Deliveries	0.0405**	-0.0098	-0.0524	-0.1424**	-0.0872	-0.0525	-0.0545	-0.0750***	-0.0431**
Effect on Timing	0:04	-0:01	-0:05	-0:15	-0:09	-0:05	-0:06	-0:08	-0:04
Change in ON RRP Returns	-0.0801***	-0.0242	0.0312	0.1961***	0.1136*	0.0859**	0.0395	0.0278*	-0.0060
Effect on Timing	-0:08	-0:02	0:03	0:20	0:12	0:09	0:04	0:03	-0:01
Change in Credit Risk Policy	-4.1889***	7.9802***	15.9208***	24.8013***	15.4637***	8.3106***	-6.6747***	-2.7564***	1.2673*
Effect on Timing	-0:04	0:08	0:16	0:25	0:15	0:08	-0:07	-0:03	0:01
Actual Change in Timing	-2:00	-2:40	-3:53	-3:52	-2:51	-2:05	-1:20	-0:44	-0:17
Number of Observations	1536	1536	1536	1536	1536	1536	1536	1536	1536

Notes: ***p<0.01, **p<0.05, *p<0.10

Regression results for deciles 10 to 90 along with the estimated timing effect of each variable on timing are shown in Table 1. After controlling for a multitude of factors, the coefficients for opening balances are significant at the 99% level in 6 of the 9 deciles. Furthermore, with the exception of the insignificant coefficient of the 80^{th} percentile, the coefficient in every decile is negative, indicating that, under the assumption that the distribution of the timing of payment requests into banks have remained stable, an increase in reserves quickens the rate of payment settlement. Figure 3 shows graphically the coefficient for the 5^{th} through 99^{th} percentiles of time.

Figure 3: Coefficients on the Sum of Opening Balances



Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

In addition to being statistically significant, the time change associated with the daily changes in reserve balances are shown to be extremely large. In every decile, the sum of opening reserve balances explains the majority of the timing decrease, shown clearly in Figure 4.

In addition to the controls mentioned in the appendix, the robustness of the results was also verified with regard to other liquid securities and different payment types. The coefficients on opening balance were found to be robust after controlling for a weekly time series of treasury and agency holdings by U.S. commercial banks (from the H.8 statistical release) as a proxy for liquid holdings more generally, suggesting that reserves are treated very differently by banks than other forms of liquid assets, even at low rates of interest.

Figure 4: Predicted Timing Impact of Opening Balances

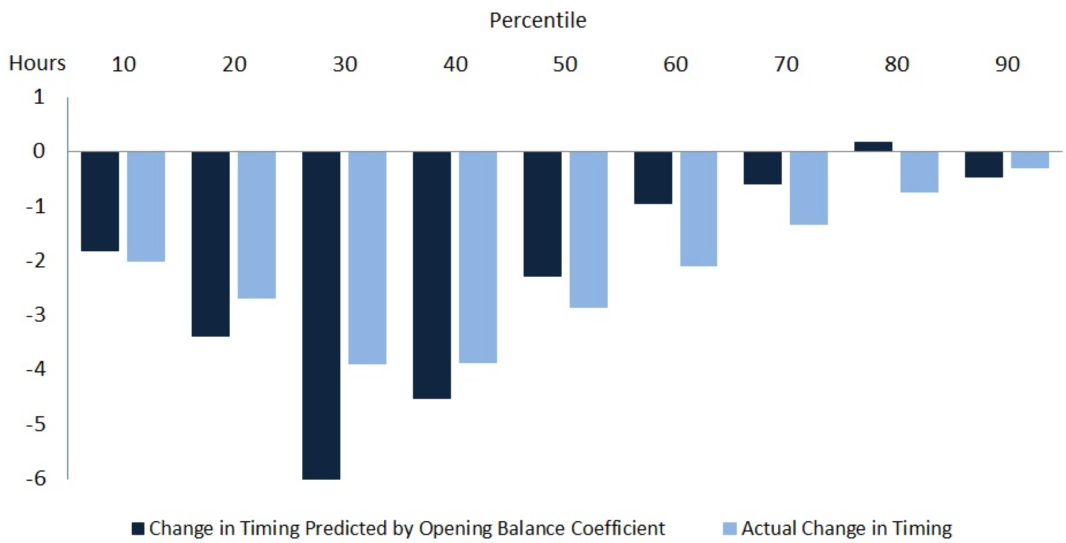
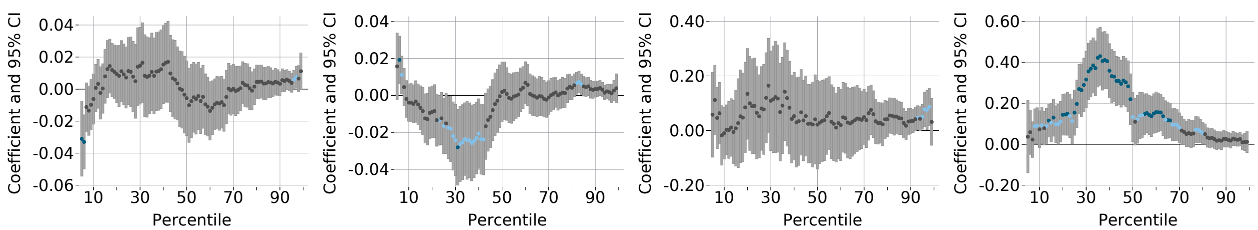


Figure 5 plots the coefficients for a number of variables related to the magnitude of activity in the payment and settlement system. Of the measures of payment activity, significant effects are not observed with the exception of a proxy for payments associated with tri-party repo. There is a statistically significant relationship between high levels of tri-party repo activity and slower payments on Fedwire. Over the time time period, however, this effect appears to be relatively small in magnitude (a few minutes—see Table 1).

The full range of the coefficients for variables related to government policy are shown in Figure 6. The indicator for the days on which GSEs dispense principal and interest payments for mortgage backed securities is highly significant. Payments tend to be quicker on these days, which is consistent with the early payments made to banks by the GSEs. Operating hours are extended when the Fedwire Funds service accedes to customer requests, under certain circumstances, to op-

Figure 5: Coefficients on Payment System Activity Variables



(a) Number of Payments (b) Customer Payment Value (c) Brokered Fed Funds Volume (d) Tri-Party Repo Value Proxy

Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

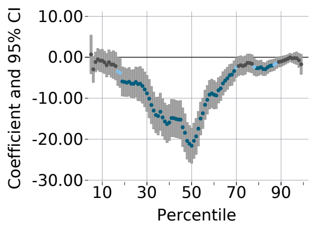
erate beyond normal hours. Not surprisingly, such actions tend to delay the settlement of payments on Fedwire, particularly in the late percentiles of the Fedwire time distribution. The value of ON RRP deliveries tend to quicken payments slightly and the value of ON RRP returns tends to delay payments slightly, though the intuition for this phenomenon is unclear. A dummy variable was added for the change in the risk policy on March 24, 2011, which does not take into account expectations and learning about the change, and we do not believe that the significant effect found was a permanent effect.

Figure 7 shows the coefficients for variables related to the activity of settlement institutions whose operations involve using the Fedwire Funds system. The payment activity of settlement institutions, which is excluded from the timing distribution measured by the dependent variable, does not appear to effect the timing distribution of Fedwire payments outside of their operations, perhaps because of the regularity of the timing of such payments.

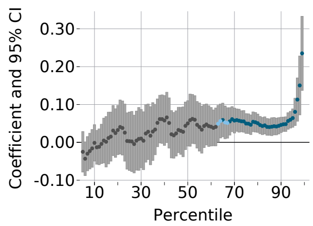
Fedwire payments tend to settle more quickly across nearly all of the calendar effects included. The days we included are days on which there is typically a high value of payments settled, and for which there may be increased urgency for early settlement. The coefficients for calendar effects are shown in Figure 8.

The more concentrated the value of payments on Fedwire, the slower the payments tend to be settled. This is possibly due to the heightened strategic nature of payment timing as fewer participants await receipt of payments from others. The coefficients for two measures of concentration—

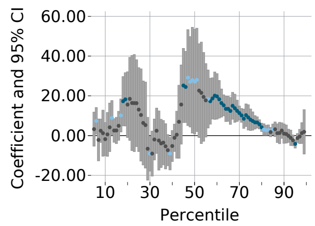
Figure 6: Coefficients on Government Policy Variables



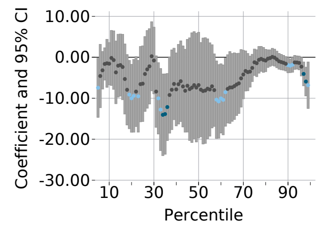
(a) MBS P&I Payment Day



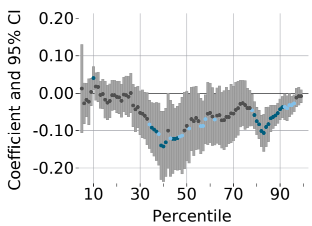
(b) Operating Hour Extension



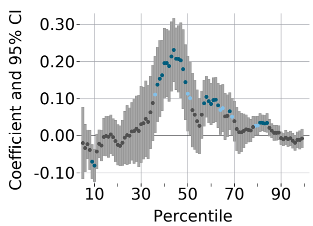
(c) Federal Funds Target Rate



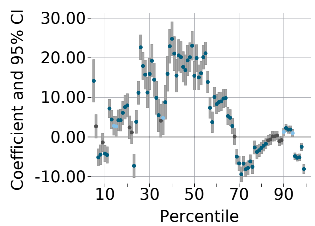
(d) Federal Funds Rate Deviation



(e) ON RRP Deliveries



(f) ON RRP Returns

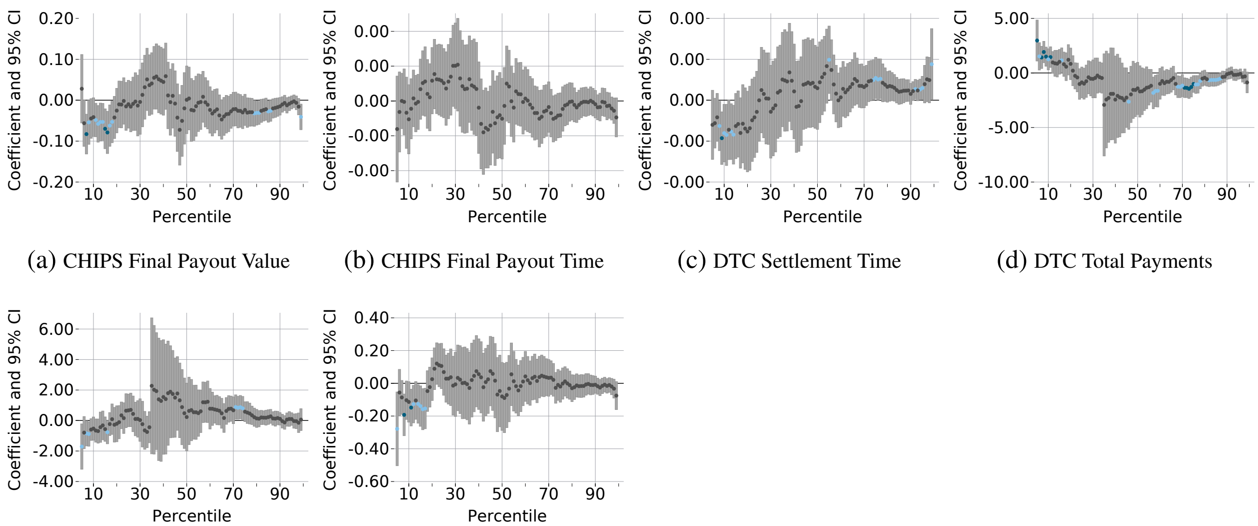


(g) Risk Policy Change

Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

the Herfindahl-Hirschman Index of the opening balances on Fedwire and the Herfindahl Hirschman Index of the value sent over Fedwire–are shown in Figure 9.

Figure 7: Coefficients on Settlement Institution Variables

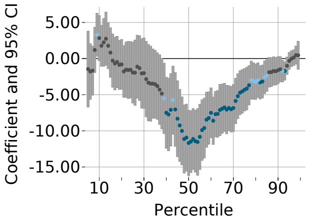


(a) CHIPS Final Payout Value (b) CHIPS Final Payout Time (c) DTC Settlement Time (d) DTC Total Payments

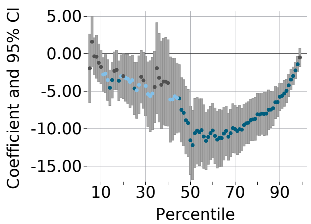
(e) DTC net-net Credits (f) CLS USD Value

Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

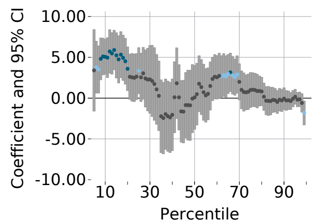
Figure 8: Coefficients on Calendar Variables



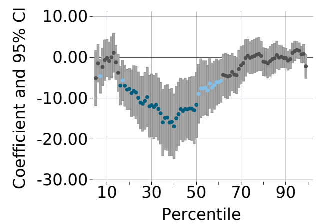
(a) Day After a Holiday



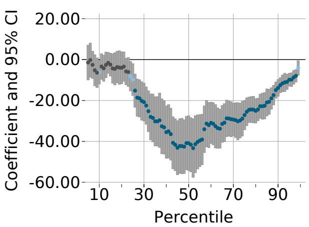
(b) Day Before a Holiday



(c) First of the Month



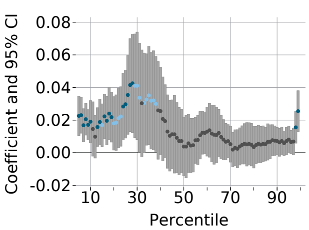
(d) Last Day of the Month



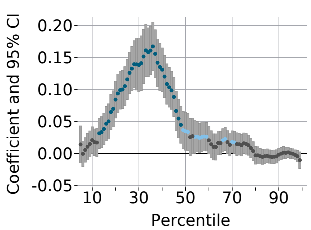
(e) Last Five Days of the Year

Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

Figure 9: Coefficients on Payment System Concentration Variables



(a) HHI of Opening Balances



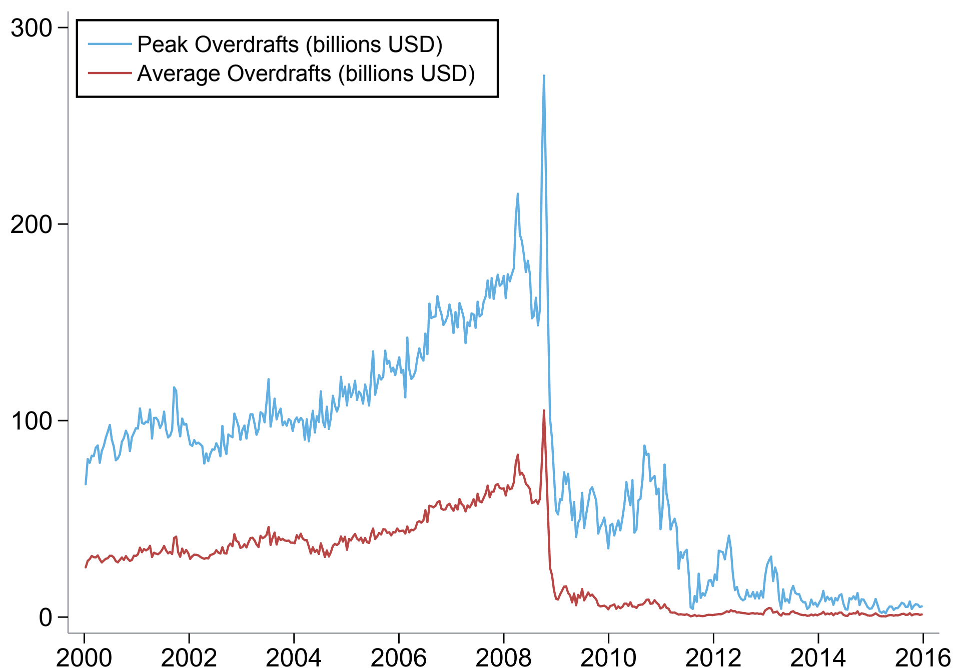
(b) HHI of Fedwire Value

Sources: The Federal Reserve Bank of New York, authors' calculations.
Notes: Independent OLS regressions with Newey-West standard errors (max lag = 10) for the 5th-99th percentile of value time. The color of the point indicates the significance of the coefficient: blue = 1%, light blue = 5%, dark gray = insignificant

6 Discussion

The effect of this reserve-driven quickening of payments on payment system risk is twofold. First, it has decreased greatly the extent to which Fedwire participants are relying on intraday credit (see Figure 10) from the Federal Reserve in order to make payments. The level of overdrafts among Fedwire participants has dropped dramatically since the crisis, likely owing to the increasing quantity of reserves in the banking system. This reduced reliance on credit has minimized the potential for losses for the Federal Reserve, and decreased the costs for banks that make payments that could otherwise lead to an overdraft in their accounts. Large reserve balances thus achieve the aims set out by the revised PSR policy of 2008–to reduce the credit exposure of Federal Reserve Banks while simultaneously increasing payment liquidity.

Figure 10: A Time Series of Daylight Overdraft Use by Maintenance Period



Sources: The Federal Reserve Board, authors' calculations.

Second, earlier payment settlement reduces risk in the payment system itself. Delays in the discharging of obligations increases the potential for harm to the financial system should an operational disruption in the payment systems occur at some point after the opening of Fedwire. Delays in this case are undesirable for an individual bank, since the disruption could lead to a breach of contract that entails both explicit and reputational costs. This is also undesirable for the financial system as a whole, as it could lead to more widespread coordination failures.

One source of funding for banks is expected incoming payments (see McAndrews and Rajan (2000)). For example, in order to have ample liquidity to make a payment to Bank C, Bank A may be waiting on the receipt of a payment from Bank B. If a disruption occurs resulting in Bank B being unable to meet its obligations, Bank A may be unable to make good on its obligation to Bank C, which in turn could affect Bank Cs counterparties and so on. This interconnectedness can cause spillover effects when certain aspects of the payment system are interrupted, such the effects following the events of September 11, 2001. Damage to communications systems in Lower Manhattan led to the inability of many banks to complete payments and resulted in heavy use of the discount window across the system as other banks received fewer payments than expected (McAndrews and Potter, 2002).

Fewer delays in intraday payments reduces the amount of unfulfilled obligations should a disruption occur. Furthermore, higher reserve balances reduce the extent to which financial institutions must rely on incoming payments as a source of liquidity. This limits the impact of idiosyncratic shocks, such as an isolated bank failure or a geographically-limited disruptive event, to the functioning of the payment system as a whole.

While high reserve balances are the result of extraordinary monetary policy measures, policy normalization does not necessarily entail that the benefits of a high reserve balance system must be relinquished. New tools at the Federal Reserves disposal in the implementation of monetary policy can accommodate control over the policy rate even in a high-reserve balance environment. The two primary tools are interest on excess reserves (IOER) and the Overnight Reserve Repurchase Agreement (ON RRP) facility. The authority to pay interest on reserves was granted to the Federal Reserve System by the Financial Services Regulatory Relief Act of 2006 and was planned to go into effect on October 1, 2011. The effective date was pushed forward to October 1, 2008, however, by the Emergency Economic Stabilization Act of 2008.[4] The ON RRP facility allows a wider set of counterparties to make collateralized overnight loans to the Federal Reserve Bank of New York.

[4]For more information on interest on reserves, see http://www.federalreserve.gov/monetarypolicy/reqresbalances.htm

The FOMC announced in September 2014 its intention to use the ON RRP facility as needed to help control the federal funds rate.[5]

While traditionally monetary policy has been carried out by carefully rationing the amount of reserve balances in the financial system, these new policy tools can break this link by supplanting it with a floor system, whereby market participants will have no incentive to lend to one another at rates below those offered by the Federal Reserve (Keister et al., 2008). When seeking to tighten monetary policy, the Federal Reserve can raise the IOER and ON RRP rates appropriately.

7 Conclusion

One of the primary conclusions of the preceding analysis was to identify the link between the large increase in reserves and the improvement of settlement liquidity over the Fedwire Funds system. Under the assumption that the distribution of payment requests has not changed much over the time period, then the link we've identified is a causal one. The improvement in the timing of payments both has reduced the credit risk exposure of the Federal Reserve and made the payment system more resilient to negative idiosyncratic and operational shocks.

Recognizing these benefits has important policy implications. New mechanisms for monetary policy implementation, such as interest on excess reserves and the reverse repurchase agreement facility, make it possible to maintain high reserve balances, while pursuing the appropriate monetary policy by controlling short-term interest rates, thus preserving the gains in the robustness of the payment system realized since the recession.

[5] For more information on the Overnight Reverse Repurchase Agreement facility, see http://www.federalreserve.gov/monetarypolicy/overnight-reverse-repurchase-agreements.htm.

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A Description of the Model

The model discussed herin was specified as the following:

$$
\begin{aligned}
\Delta p_t^1 &= \beta_0^1 + \beta_1^1 \Delta OpenBal_t + \beta_2^1 \Delta x_t + \varepsilon_t^1 \\
\Delta p_t^2 &= \beta_0^2 + \beta_1^2 \Delta OpenBal_t + \beta_2^2 \Delta x_t + \varepsilon_t^2 \\
&\ldots \\
\Delta p_t^{100} &= \beta_0^{100} + \beta_1^{100} \Delta OpenBal_t + \beta_2^{100} \Delta x_t + \varepsilon_t^{100}
\end{aligned}
$$

where Δ represents the change from one business day to the next.

A.1 Variable Descriptions

p_t^i represents the time (expressed as the number of minutes since the beginning of the corresponding day t) at which the percentile of Fedwire value i has been settled on day t. Excluded from this calculation are payments to or from settlement institutions, namely the Clearing House Interbank payments System (CHIPS), the CLS Group, or the Depository Trust Corporation (DTC). Payments associated with the interest and redemption payments of government-sponsored enterprises (GSEs) are also excluded, as they merely represent movements between different accounts of the securities issuer.

$OpenBal_t$ or *Sum of Opening Balances* is the total of all reserve balances for all institutions with an account with the Federal Reserve at the time at which Fedwire opens.

The vector x_t is a vector of controls, including:

A.1.1 Measures of Payment System Activity

Customer Transfer Value is the sum of all payments (in billions USD) of all Fedwire Funds transfers with a business function code indicating customer payment.

Brokered Federal Funds Volume is the value (in billions USD) of federal funds loans brokered by major dealers on the corresponding business day. This data is provided voluntarily to the the Federal Reserve Bank of New York.

Value of Tri-Party Repo is an estimate of aggregate tri-party repo activity. It is defined as the sum of all payments greater than $1 billion that flow to/from the major clearing banks (JP Morgan Chase and the Bank of New York Mellon) from/to the major custodial banks (State Street and Northern Trust).

Volume (Non-Settlement) is the number of transactions cleared over Fedwire with the exception of transactions involving settlement institutions or principal and interest funding of government-sponsored enterprises.

A.1.2 Market Structure

HHI of Opening Balances is the Herfindahl-Hirschmann Index of the account balances (measured at the opening time of Fedwire) for the 100 highest account balances.

HHI of Value Sent is the Herfindahl-Hirschman Index of the daily transfer value of reserve accounts aggregated to the master level.

A.1.3 Government Policies and Operations

Operating Hour Extension is equal to the number of minutes Fedwire operations were extended beyond normal hours.

Federal Funds Target Rate is the Federal Open Market Committees (FOMC) objective for the interbank lending rate. After the FOMC chose to adopt a range of 0 to 0.25% for the target rate, this variable is set equal to 0.

Federal Funds Rate Deviation is the difference between the federal funds rate target and the effective federal funds rate reported by the Federal Reserve Bank of New York.

Principal and Interest Payment Day is a binary variable equal to 1 on the days Fannie Mae and Freddie Mac make interest and redemption payments on mortgage-backed securities (MBS), and equals 0 otherwise. These days occur on the 15th and 25th of the month, or the first business day thereafter.

ON RRP Deliveries is the value (in billions USD) of overnight reverse repurchase agreements initiated by the Federal Reserve Bank of New York on the respective day. This value is the amount lent to the Federal Reserve Bank of New York by eligible institutions.

ON RRP Returns is the value (in billions USD) of overnight reverse repurchases agreements that mature on the respective business day. These are values that the Federal Reserve Bank of New York pays out to repurchase securities.

Risk Policy Change is a binary variable equal to 1 for all days on or after March 24, 2011–the day revisions to the Payment System Risk (PSR) went into effect. The changes included eliminating fees for collateralized overdrafts and raising the fee for uncollateralized overdrafts.

Maintenance Period Day is a vector of binary variables indicating the day within the 2-week reserve maintenance cycle. The reserve maintenance cycle is a way of granting depository institutions flexibility with regard to reserve requirements. An institution is in compliance as long as its average reserve balance over the 2-week period is above the minimum requirement.[6] To measure this effect distinctly from day of the week effects, binary variables for the days of the second week of the maintenance period are included.

A.1.4 Settlement Institution Activity

CHIPS Final Payout Value is the value of the end-of-day payouts sent by the Clearing House Interbank Payments System (CHIPS) to CHIPS participants with a positive net position.

CHIPS Final Payout Time is the time (measured in minutes since the beginning of the day) at which CHIPS completed its final to participants with net positions.

DTC Settlement Time is the value-weighted average time at which the Depository Trust Corporation (DTC) sent payments over Fedwire after 16:00.

DTC Total Value is the sum of all payments sent by DTC after 16:00.

DTC Final Payout Value is the sum of all DTC payments to participants with a net credit position.

CLS USD Value is the sum of all dollar payments sent by CLS over Fedwire.

[6]For more information about the reserve maintenance period, see http://www.federalreserve.gov/monetarypolicy/rmm/Chapter_4_Maintenance_of_Reserve_Balance_Requirements.htm

A.1.5 Calendar Effects

First Day of the Month is a binary variable equal to 1 if the observation corresponds to the first business day of the month and 0 otherwise.

Last Day of the Quarter is a binary variable equal to 1 if the observation corresponds to the last business day of the quarter and 0 otherwise.

Last Five Days of the Year is a binary variable equal to 1if the observation corresponds to the last five business days of the year and equal to 0 otherwise.

Day After a Holiday is a dummy variable equal to 1 on the day after a holiday and 0 otherwise.

Day Before a Holiday is a dummy variable equal to 1 on the day before a holiday, and 0 otherwise.

Day of the Week is a vector of dummy variables indicating the day within the business week. Wednesday is excluded as the reference group.

A.1.6 Other

NYSE Closed Early is a binary variable equal to 1 if the New York Stock Exchange closed early on the corresponding business day and 0 otherwise.

NYSE Closed is a binary variable equal to 1 if the New York Stock Exchange was not operating on the corresponding day and 0 otherwise.