

SETTLEMENT LIQUIDITY AND MONETARY POLICY IMPLEMENTATION—LESSONS FROM THE FINANCIAL CRISIS

- The U.S. dollar clearing and settlement system performed dependably during the financial crisis, processing record volumes and values of trades executed in stressed financial markets.
- Emergency policy measures employed by the Federal Reserve to provide liquidity and stability to the financial system during and after the crisis had important effects on settlement liquidity and thus on the efficiency of clearing and settlement system activity.
- The measures led to a substantial decrease in daylight overdrafts extended by the Federal Reserve and an improvement in payment settlement timing.
- The reduction in overdrafts lowered the Federal Reserve’s credit risk while the earlier settlement time suggested significant efficiency gains and diminished operational risks.

1. INTRODUCTION

The U.S. dollar clearing and settlement system was little noticed during the recent financial crisis, mainly because it performed dependably, processing record volumes and values of trades made in stressed financial markets.¹ Its successful operation was in part a result of the collaborative efforts undertaken by stakeholders over decades to improve risk management and operational resiliency. Under the smooth surface, though, the dollar clearing and settlement system experienced important changes during the crisis.

This article focuses on the ease with which market participants can discharge their payment and settlement obligations. We denote this as *settlement liquidity*. Our main interest is on the settlement liquidity of the Federal Reserve’s Fedwire Funds Service, the major large-value payment system in the United States. We discuss how to measure settlement liquidity, and document the evolution of some of its key drivers over time. In particular, we show how the policy measures aimed at achieving financial and economic stability during and after the financial crisis have had a major impact on settlement

¹ Exceptions include the tri-party repo market (see Copeland, Martin, and Walker [2010]), the settlement fails that plagued several fixed-income markets, and the uncertainty that initially surrounded the settlement process of credit default swaps following credit events. Ultimately, the process was orderly (Senior Bank Supervisors Group 2008).

Morten L. Bech is a senior economist at the Bank for International Settlements; Antoine Martin is an assistant vice president and James McAndrews an executive vice president and the director of financial research at the Federal Reserve Bank of New York.
Corresponding authors: antoine.martin@ny.frb.org,
jamie.mcandrews@ny.frb.org

The authors thank Adam Biesenbach for excellent research assistance and the Payments Risk Committee’s Working Group on Intraday Liquidity Flows for fruitful discussions. The views expressed are those of the authors and do not necessarily reflect the position of the Bank for International Settlements, the Federal Reserve Bank of New York, or the Federal Reserve System.

liquidity and thus on the efficiency and inherent risks of payment and settlement system activity.

The massive expansion of reserve balances since fall 2008 and the payment of interest on reserve balances have altered the intraday liquidity management practices of financial

The massive expansion of reserve balances since fall 2008 and the payment of interest on reserve balances have altered the intraday liquidity management practices of financial institutions. This has led to a notable quickening of settlement relative to the prior period and a substantial decrease in daylight overdrafts extended by the Federal Reserve.

institutions. This has led to a notable quickening of settlement relative to the prior period and a substantial decrease in daylight overdrafts extended by the Federal Reserve.

Importantly, the earlier time at which payments are settled implies significant efficiency gains as well as a reduction in operational risks. Moreover, the decrease in daylight overdrafts reduces credit risk for the Federal Reserve and the public sector more broadly, when taking into account the effects on the deposit insurance fund in the case of a bank failure.

Interestingly, both of these improvements were the desired goals of the revisions to the Federal Reserve's Payment System Risk policy, proposed in March 2008, adopted in late 2008, and implemented on March 24, 2011.² By offering collateralized overdrafts at no fee, the Federal Reserve aimed to facilitate intraday risk management and efficient payment flows for the banking system while mitigating the credit exposures of the Federal Reserve Banks from daylight overdrafts. To a large extent, the desired outcome was achieved ahead of the policy changes.

The amount of reserves available to the banking system and the opportunity cost of holding such reserves are at the center of any monetary policy implementation framework. Hence, we believe that this period offers important lessons for the choice of such a framework, especially now that the Federal Reserve has the authority to pay interest on reserves. A system for implementing monetary policy that keeps the opportunity cost of holding reserves very close to zero may contribute significantly to a more efficient and safe payment system.

² <http://www.federalreserve.gov/newsevents/press/other/20100930a.htm>.

Our study proceeds as follows: Section 2 provides an overview of the clearing and settlement system. The system is viewed as a network of platforms connected via funding links. In section 3, we introduce the concept of settlement liquidity—the ease with which financial institutions can discharge their payment and settlement obligations. Section 4 discusses measurement of settlement liquidity and section 5 shows how such liquidity has varied over time and improved recently. In section 6, we argue that changes in monetary policy implementation were the main driver of the significant enhancements in settlement liquidity, while in section 7 we draw some policy lessons going forward. Section 8 concludes.

2. THE CLEARING AND SETTLEMENT NETWORK

An often overlooked, but crucial, part of the financial system is the clearing and settlement system.³ *Clearing* refers to “the process of transmitting, reconciling and, in some cases, confirming payment orders or security transfer instructions prior to settlement, possibly including the netting of instructions and the establishment of final positions for settlement” and *settlement* refers to the “act that discharges

The clearing and settlement system for U.S.-dollar-denominated wholesale transactions is the largest and arguably the most important in the world. It is probably also the most complex.

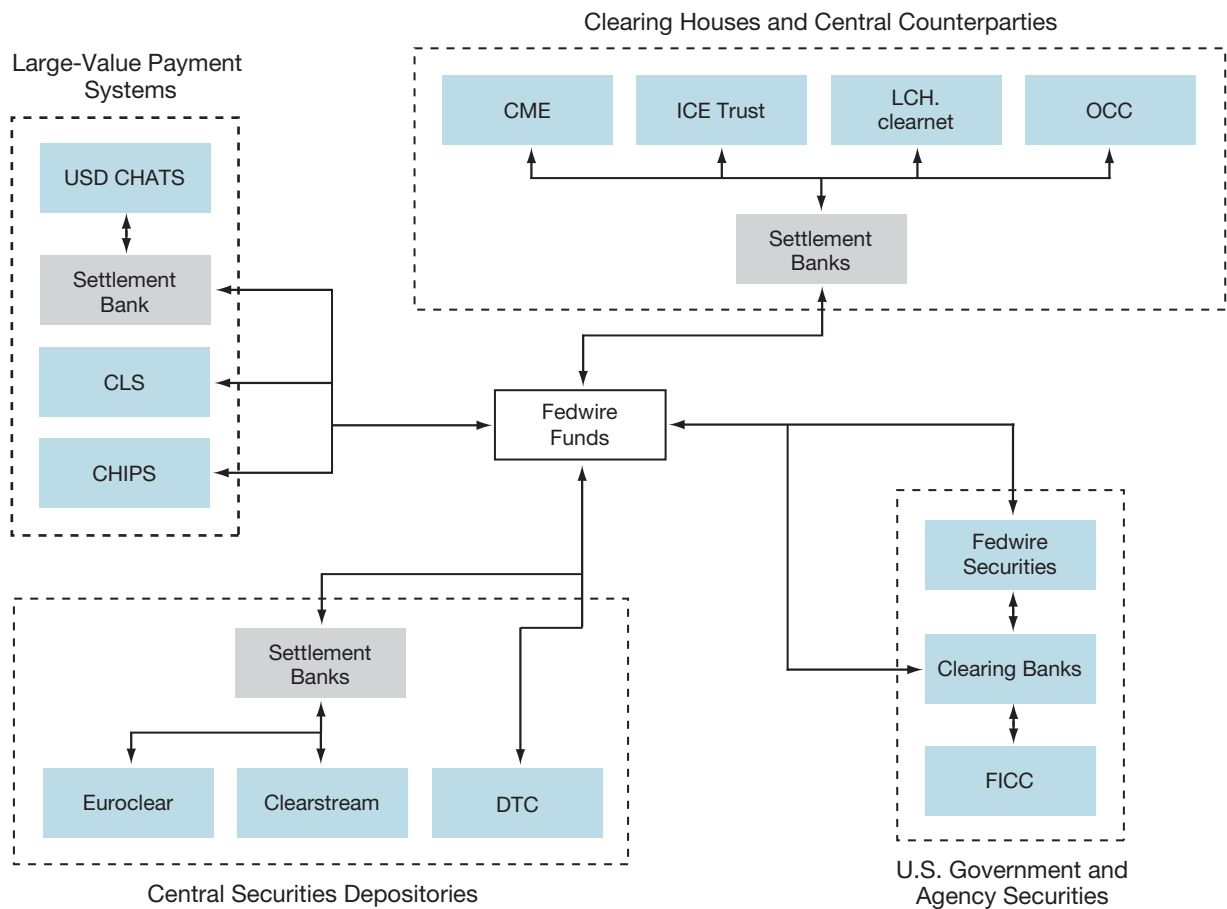
obligations in respect of funds or securities” (Bank for International Settlements 2003).⁴ Often a distinction is made between systems that process retail and wholesale transactions.

The clearing and settlement system for U.S.-dollar-denominated wholesale transactions is the largest and arguably the most important in the world. It is probably also the most complex, in part due to the greater diversity of financial products traded in dollars than in any other currency. In any case, the clearing and settlement system consists of a multitude

³ The clearing and settlement system is at times referred to as the “plumbing” of the financial system. The analogy is fitting in the sense that—as with plumbing—very few people know how it works, but everyone realizes that it is messy when it does not.

⁴ Some clearing and settlement systems are vertically integrated with a single trading platform or exchange, while others are horizontally integrated across different products.

The U.S. Dollar Wholesale Clearing and Settlement Network



of different platforms that have evolved over time and stretches across borders and time zones. Together, these clearing and settlement platforms form the nodes in an intricate network, with the nodes linked together by funding relationships. A simplified graphical representation of this network is shown in the exhibit; it includes the most important wholesale clearing and settlement platforms.

The Federal Reserve’s Fedwire Funds Service (Fedwire Funds) sits at the center of the network. Fedwire Funds is the system that commercial banks use to send large-value or time-critical payments to each other across the accounts of the

Federal Reserve. Fedwire Funds is a real-time gross settlement (RTGS) system that provides irrevocable and unconditional settlement during 21.5 hours of a business day. (It is described in more detail in Box 1.) The remaining platforms are grouped into four categories, based either on the type of clearing and settlement platforms they contain or the type of financial instruments that platforms settle in unison.⁵

⁵ In the exhibit, note that clearing banks (blue boxes) can also be settlement banks (gray boxes).

The Fedwire Funds Service

The Federal Reserve's Fedwire Funds Service is a real-time gross settlement (RTGS) system that enables participants to initiate credit transfers of balances held at the Federal Reserve that are immediate, final, and irrevocable once processed.^a The service is generally used to make large-value, time-critical payments among participants and serves as a settlement mechanism for other, ancillary payment and settlement systems.^b As such, it serves as the backbone of the U.S. payment and settlement system.^c

Fedwire traces its origin back to the years immediately following the creation of the Federal Reserve in 1914. In 1918, the Federal Reserve inaugurated a network of wire communications among the individual Reserve Banks. This new system of wire-initiated book-entries allowed funds to be transferred on behalf of the member banks and helped abolish regional and seasonal exchange rates for the U.S. dollar associated with the costs of physically shipping gold and currency across the country (Garbade and Silber 1979). Over the years, Fedwire grew more sophisticated as technological advances were implemented (see Gilbert, Hunt, and Winch [1997]).

Currently, Fedwire's operating day begins at 9:00 p.m. Eastern time on the preceding calendar day and ends at 6:30 p.m. ET.^d Institutions that hold an account with the Federal Reserve are eligible to participate in Fedwire.^e In 2008, approximately 7,300 participants made funds transfers.

Fedwire processes an astonishing amount of payments every day. During the first quarter of 2010, slightly less than 500,000 payments worth \$2.4 trillion were originated on average each day.^f More than 920,000 payments were processed on the highest-volume day and payments worth almost \$4.1 trillion were exchanged on the highest-value day.^g

The beginning was more modest. During the first year of Fedwire operation, the system was used only by a limited number of member banks, and the Federal Reserve Bank of New York

^aFor a discussion of RTGS systems, see, for example, Bank for International Settlements (2005) and Bech and Hobijn (2007).

^bThe maximum payment allowed is one penny short of \$10 billion.

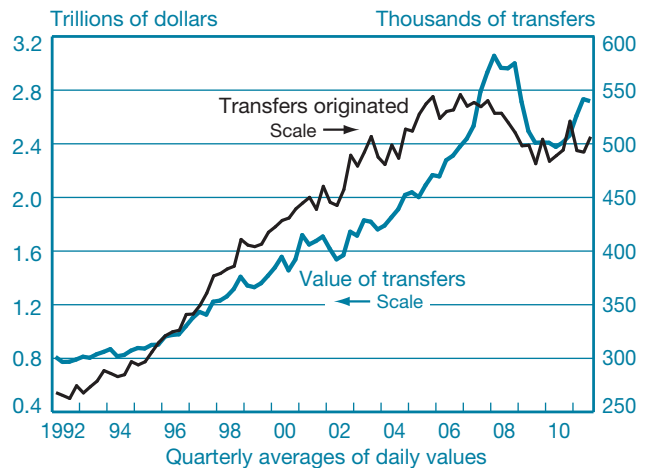
^cThe Federal Reserve also provides the Fedwire Securities Service. The Securities Service is a book-entry depository and settlement system for securities issued by the U.S. Treasury, other federal agencies, government-sponsored enterprises, and certain international organizations such as the World Bank.

^dFor example, the Fedwire Funds Service opens for a nonholiday Monday at 9:00 p.m. on the preceding Sunday. Under certain circumstances, operating hours may be extended.

^eDepository institutions represent the majority of eligible Fedwire participants, but certain other financial institutions, such as government-sponsored enterprises, are also eligible to participate.

CHART 1

Value and Volume of Payments Originated over Fedwire



Source: http://www.federalreserve.gov/paymentsystems/fedfunds_qtr.htm.

processed around 100 wires per day; ten years later, the Bank was processing about 600 wires per day (Bech and Hobijn 2007). By the early 1990s, the volume of transfers originated over Fedwire had increased many-fold, to just short of 270,000 payments on average per day.^h Over the next fifteen years, the volume of transfers roughly doubled and the number of payments peaked at 545,000 per day during the last quarter of 2006 (see Chart 1 above). The value of transfers originated across Fedwire saw even stronger growth during the decade and a half preceding the financial crisis. Value quadrupled. In the early 1990s, roughly \$800 billion in payments was exchanged on average per day, but dollar volume reached more than \$3.2 trillion on average for the month of September 2008.

^fBoth the value and volume settled over Fedwire vary considerably from day to day. Part of this variation follows regular patterns, such as the first and last business days of a month or quarter, as well as certain key settlement dates for financial securities. Hence, it is helpful to smooth out this variation when trying to ascertain the long-run trends and changes thereto. Unless otherwise noted, the figures cited reflect quarterly averages of daily values.

^gAs of July 2, 2010.

^hData on the average daily volume and average daily value of transfers over the Fedwire Funds Service are available at http://www.frb-services.org/operations/fedwire/fedwire_services_volume_value_statistics.html.

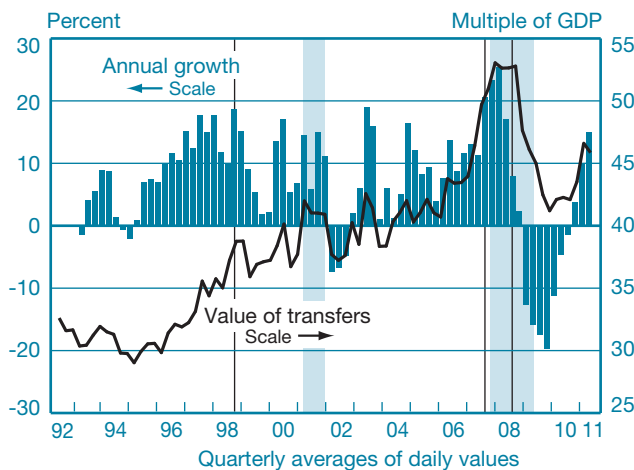
The Fedwire Funds Service (*Continued*)

Needless to say, part of the growth of dollars transferred over Fedwire reflects the concurrent growth in prices and size of the overall economy. Hence, it is also instructive to scale turnover with that growth. A natural candidate is U.S. GDP. From this perspective, the annual value of transfers across Fedwire was equivalent to roughly thirty times GDP in the early 1990s. In other words, a value equivalent to the economic output of the United States was transferred via Fedwire every eight to nine business days. Following fifteen years of almost uninterrupted growth, turnover exceeded more than fifty times U.S. GDP during 2008, with a notable runup in 2007, before falling to forty times GDP in the first quarter of 2010 (see Chart 2 below).

While Fedwire is referred to as a large-value payment system, it also handles a surprisingly large number of payments of relatively modest size. During the first quarter of 2010, more than 5 percent of payments were for less than \$300, the median payment was below \$17,500, and 75 percent of payments were for less than \$125,000 (about half the average price of a single-family home). However, at the same time, the service also processed a small percentage of very large payments, and these payments constitute a substantial share of the total value transferred. For example, 1 percent of all payments were larger than \$70 million during the first quarter of 2010, and this top 1 percent accounted for more than 85 percent of the total value of payments.

CHART 2

Value of Payments Originated over Fedwire Annual Growth and Value to GDP



Sources: U.S. Department of Commerce, Bureau of Economic Analysis, GDP Press Release (Table 3); http://www.federalreserve.gov/paymentsystems/fedfunds_qtr.htm; authors' calculations.

Notes: Vertical lines denote September 23, 1998, August 9, 2007, and September 15, 2008. Bands denote NBER recessions.

2.1 Nodes of the Clearing and Settlement Network

The first group of platforms—starting in the upper-left-hand corner—consists of a number of wholesale or large-value payment systems. We begin with the Clearing House Interbank Payment System (CHIPS)—a private sector system operated by the Clearing House Payments Company.⁶ At times, CHIPS is referred to as a *hybrid* system, as it employs an algorithm that combines both gross settlement (like Fedwire Funds) and end-of-day netting features (like more traditional interbank payment systems).⁷ Historically, CHIPS settled the vast majority of international dollar transactions, such as the dollar legs of foreign exchange transactions and eurocurrency loans. Settlement of the dollar legs of foreign exchange transactions has become a smaller part of CHIPS business because of the introduction of the Continuous Linked Settlement (CLS) system in the early 2000s. CLS primarily settles foreign exchange transactions via a risk-reducing mechanism known as payment versus payment (PvP). PvP ensures that a final transfer of one currency occurs if and only if a final transfer of the other currency or currencies takes place.⁸

In addition, a limited number of large-value payment systems around the world clear dollar payments in their local jurisdictions. These systems are commonly referred to as *offshore* systems and are exemplified in the exhibit by the U.S. dollar Clearing House Automated Transfer System (CHATS) in Hong Kong. The U.S. dollar CHATS is built on the same infrastructure and operates in the same manner as the local Hong Kong dollar system. Like Fedwire, it provides RTGS for U.S. dollar payments; like CLS, it allows for PvP of U.S. versus Hong Kong dollars.⁹

The second group of platforms—moving clockwise in the exhibit—comprises clearing houses and central counterparties (CCPs). Clearing houses are infrastructures that provide clearing services to institutions such as commodity and stock exchanges. CCPs facilitate clearing and risk management by becoming the buyer to every seller and seller to every buyer of a specified set of financial contracts, such as those executed on a particular exchange or set of exchanges. The largest clearing

⁶ Established in 1853, the Clearing House Payments Company is the nation's oldest banking association and payments company (see <http://www.theclearinghouse.org>).

⁷ See Bech, Preisig, and Soramäki (2008) for a discussion.

⁸ The risk that a counterparty does not deliver the other leg of a foreign exchange transaction is known as Herstatt risk, after a German bank that failed in the early 1970s.

⁹ CHATS also provides delivery versus payment (DvP) for U.S.-dollar-denominated securities (bonds and equities) listed in Hong Kong.

houses and CCPs processing transactions in dollars are CME Clearing, ICE Trust, LCH.clearnet, and the Options Clearing Corporation (OCC). CME Clearing provides clearing for the Chicago Mercantile Exchange (CME), the Chicago Board of Trade, the New York Mercantile Exchange, and the Commodity Exchange, Inc. ICE Trust is a limited-purpose trust company that serves as a central clearing facility for credit default swaps. LCH.clearnet, formed by a merger of the London Clearing House Limited and Paris-based Clearnet, clears a broad range of asset classes in fifteen currencies. The U.S.-based OCC offers clearing and settlement services for futures, options on futures, and certain securities lending contracts.

The next group consists of different platforms associated with the clearing and settlement of U.S. government and agency securities. Besides the Fedwire Funds Service, the Federal Reserve provides the Fedwire Securities Service—the central securities depository (CSD) for U.S. government and agency securities. A CSD holds securities and enables transactions in these securities to be processed by book-entry.

Most financial institutions cannot hold accounts with the Federal Reserve and, hence, hold their U.S. government and agency securities with one or more custodial agents.

In addition to safekeeping, a CSD often incorporates clearing and settlement functions (Bank for International Settlements 2003). Fedwire Securities settles transactions using a DvP mechanism. As with Pvp, the mechanism ensures that both legs of a transaction (here, cash and securities) are settled at the same time.

However, most financial institutions cannot hold accounts with the Federal Reserve and, hence, hold their U.S. government and agency securities with one or more custodial agents.¹⁰ The main custodial agents are JPMorgan Chase and Bank of New York Mellon. These institutions are also the clearing banks for the tri-party repurchase agreement (repo) market that many broker-dealers use to finance their trading operations. As a result, the two banks are often just referred to as *the clearing banks*. In addition, many broker-dealers use the

¹⁰ Different types of market participants typically use different custodial agents. Active dealers normally use the clearing banks. Institutional investors—such as pension funds, insurance companies, hedge funds, and nonfinancial corporations—use the services of a custodial bank (which could be one of the clearing banks). Individual and smaller institutional investors typically leave the securities with their dealer for safekeeping. In the case of Treasuries, individual investors can also use the U.S. Treasury’s Treasury Direct service.

services of the Fixed Income Clearing Corporation (FICC) to clear interdealer trades. FICC services include trade comparison and multilateral netting.

The last group of platforms in the exhibit consists of the largest CSDs for other dollar-denominated securities. The group includes the Depository Trust Company (DTC), Clearstream, and Euroclear. DTC is based in New York, while Clearstream and Euroclear are based primarily in Luxembourg and Belgium, respectively.¹¹ These CSDs service many different asset classes including, but not limited to, equities, corporate and municipal bonds, investment funds, and money market instruments, as well as certain information services for over-the-counter derivatives.

2.2 Funding Links in the Clearing and Settlement Network

Importantly, Fedwire Funds is linked to all the other platforms in the wholesale clearing and settlement system. The links to other platforms or systems are either *direct* or *indirect*. A direct link implies that participants prefund their activities in the linked system by using Fedwire Funds to transfer funds into a designated Federal Reserve account belonging to the ancillary platform.¹² Once clearing and settlement positions are finalized by the ancillary platform, participants with a positive net position receive via Fedwire Funds back funds owed. The systems with a direct link to Fedwire Funds are Fedwire Securities, CHIPS, CLS, and DTC.

For all other platforms, the link is indirect, as the funding of the ancillary platforms occurs via intermediaries known as settlement banks. That is, participants transfer funds to the Federal Reserve account of a settlement bank via Fedwire Funds—if required—with the beneficiary being the clearing and settlement platform in question.¹³ Once settlement is completed, the account of net sellers at the settlement banks is credited. Participants may then choose to leave the funds with the settlement banks or request that they be transferred to another institution, typically via Fedwire.

A key fact, to which we return to below, is that any funds transferred to an ancillary clearing and settlement system are not available for other transactions over Fedwire. In other words, these systems can act as “funding sinks.” This is a concern particularly if Fedwire itself is running low on

¹¹ Clearstream International was formed in 2000 through the merger of Cedel International and Deutsche Börse Clearing.

¹² In the case of Fedwire Securities, the link is even stronger, as the two components of Fedwire share the same cash account.

¹³ In the case of multiple settlement banks, the clearing and settlement system may consolidate the funds during the day at one of the settlement banks, known as the concentration bank. In principle, CHIPS may be used as well.

available funds for settlement or if the amounts transferred are not closely managed. However, any “underfunding” of the ancillary systems—either in the aggregate or from the perspective of an individual participant—will tend to delay the completion of their respective settlement processes.

The same is true for the settlement banks, with a small caveat. The difference is that there is not necessarily a one-to-one relationship between the funds transferred to the settlement banks via Fedwire and the funding available for the

The dollar clearing and settlement system is an intertwined collection of diverse subsystems in use around the globe. Fedwire Funds (and by extension, the Federal Reserve) plays a vital role in the smooth operation of this system as the provider of final settlement in central bank money.

clearing and settlement systems. This lack of correspondence occurs if the settlement bank either provides intraday credit to the participants or facilitates netting of positions across participants or systems.

In sum, the dollar clearing and settlement system is an intertwined collection of diverse subsystems in use around the globe. Fedwire Funds (and by extension, the Federal Reserve) plays a vital role in the smooth operation of this system as the provider of final settlement in central bank money. While the system affords significant benefits to the global economy, its sheer size, complexity, and interconnectedness imply risks and challenges that have to be carefully controlled by stakeholders. At the top of the list is the need to ensure that the clearing and settlement platforms—both in the aggregate and individually—are liquid. We now discuss *settlement liquidity*.

3. SETTLEMENT LIQUIDITY

The recent financial crisis underscored the importance of liquidity for the smooth functioning of the financial system. Liquidity can mean different things depending on the context in which it is used. For our purposes, it is important to stress that, regardless of its definition, liquidity can depend both on the actions taken by the agents in the economy and on factors outside their control.

In the financial system, it is often useful to distinguish between different types of liquidity. One dimension of liquidity is the availability of credit or ease with which financial institutions can take on leverage. This is generally referred to as *funding liquidity*. Another dimension is the ease with which market participants can transact or the ability of markets to absorb large purchases and sales with little impact on prices. This is generally referred to as *market liquidity*. A third dimension of liquidity, relevant for payment and settlement systems, is the ease with which market participants can discharge their settlement and payment obligations at a time either agreed upon by the parties to the transaction or determined by market conventions. We refer to this form of liquidity as *settlement liquidity*. All else equal, a liquid clearing and settlement system is more efficient, as obligations are settled more quickly, reducing the uncertainty with regard to the finality of transactions between agents. Ensuring a liquid system is an important policy goal for a central bank.

The different types of liquidity are interlinked. The link between market and funding liquidity is well documented (Brunnermeier and Pedersen 2009). Traders provide market liquidity, and their ability to do so depends on the availability of funding. Conversely, traders’ funding—that is, their capital and margin requirements—depends on the assets’ market liquidity. There are also important links between settlement

Liquidity can depend both on the actions taken by the agents in the economy and on factors outside their control.

liquidity and market and funding liquidity. For example, if it is difficult to settle a financial asset, then trading might be curtailed or be unnecessarily risky. The events in the repo market that preceded the failure of Bear Stearns in March 2008 and the bankruptcy of Lehman Brothers in September 2008 highlighted the links between funding liquidity and settlement liquidity. In the U.S. tri-party repo market, the ease with which a dealer can fund its securities currently depends on the willingness of its clearing banks to provide intraday credit. That credit contributes to the dealer’s settlement liquidity. Should the clearing bank refuse to extend credit, the dealer would be unable to settle its deliveries of securities and would be unlikely to survive. Uncertainty concerning settlement liquidity in that market may have contributed to Bear Stearns’ and Lehman Brothers’ difficulties (see Adrian, Burke, and McAndrews [2009, Box 3] and Copeland, Martin, and Walker [2010]).

4. MEASURING SETTLEMENT LIQUIDITY

Liquidity in financial markets is difficult to quantify and can vary unexpectedly. Rarely is it possible to devise a single, all-encompassing measure and, thus, proxies are often used. Market liquidity, for example, is studied using bid-ask spreads, trading volume or trading frequency, trade or quote sizes, and price-impact coefficients, among other proxies (see Fleming [2003]). During the financial crisis, the spreads between the London interbank offered rate in different currencies and the rate on same-maturity overnight indexed swaps were widely used as proxies for funding liquidity.

In the context of central banks, liquidity is often taken as synonymous with the amount of reserves (that is, overnight balances) supplied to the banking system via open market operations or lender-of-last-resort facilities (see, for example, Cecchetti and Disyatat [2010]). While injections of additional reserves into the banking system in general tend to improve liquidity, this is not a perfect measure in the clearing and settlement system.

First, focusing solely on reserves ignores the substantial amount of credit that central banks provide intraday to ensure the smooth operation of the clearing and settlement system. For example, prior to the financial crisis, the peak amount of intraday credit supplied by the Federal Reserve averaged about \$150 billion per day, or 17 percent of the size of the Federal Reserve's balance sheet when reserves averaged \$20 billion (see Box 2). It is important to observe that an increase in intraday credit extensions adds to the Federal Reserve's credit risk

Liquidity in financial markets is difficult to quantify and can vary unexpectedly. Rarely is it possible to devise a single, all-encompassing measure and, thus, proxies are often used.

exposure, as the Federal Reserve guarantees the finality of payments transferred across Fedwire.¹⁴

The sum of overnight reserves and intraday credit is a better measure of settlement liquidity, but it ignores two important sources of funds from the perspective of an individual participant in the clearing and settlement system: incoming payments and credit extensions from other participants, such as interbank loans, as outlined in McAndrews and Rajan (2000). While these sources of funds do not add to the available stock, they facilitate the redistribution of the settlement asset,

¹⁴ Finality means that once a payment is made, it is not possible for the Federal Reserve to claw back the amount should the sender not repay any intraday credit used to fund the payment.

increasing its potential use. If the speed by which the settlement asset is circulated is high and if participants are willing to extend credit to one another, then funds are going to be more readily available where needed. However, if the opposite is true, then settlement liquidity is going to suffer.¹⁵ In other words, settlement liquidity may depend crucially on the actions taken by the participants. It is thus important to consider measures that can shed light on changes in behavior, and these are rarely captured well by dollar amounts. However, any measure of settlement liquidity that takes behavior into account is likely to be—at least to some extent—system-specific, as incentives often depend on the exact nature of the institutional details.

5. SETTLEMENT LIQUIDITY OF FEDWIRE FUNDS

In the context of an RTGS system such as Fedwire Funds, one approach to measuring settlement liquidity is to focus on the degree to which payments are being delayed. For many types of payments, banks have considerable flexibility in choosing the time at which payments are settled, as they only need to be settled on a particular day but not at a specific time during the day. Delays may be costly for certain types of payments. A cost of delay arises for several reasons. For example, delaying customer payments may have reputational costs for a bank if customers value early settlement. Delaying a payment also exposes a bank to the risk that an operational problem with the settlement system could prevent the bank from settling the payment later that day. Hence, all else equal, banks should not wish to delay payments.

However, there are benefits to delaying payments. Suppose “Thrifty Bank” must make a payment to “Receiver Bank,” but lacks enough reserves to do so. Thrifty Bank could borrow from the central bank, but this may be costly—either because the central bank charges a fee for the credit it provides or because it requires Thrifty Bank to post collateral, which has a cost because the assets serving as collateral cannot be put to another use. However, Thrifty Bank could delay the payment, which in general would result in a cost of delay being suffered by itself, its customer, and the intended receiver of the payment. Now, if Thrifty Bank delays the payment, it may later receive a payment from another bank, say “Flush Bank.” The payment from Flush Bank would increase Thrifty Bank's reserve position, allowing it to make its delayed payment to Receiver Bank without the need to borrow from the central

¹⁵ One way to classify the different types of settlement liquidity is by using the notions of inside and outside settlement liquidity. The former represents liquidity generated within the system itself and the latter represents funds supplied from the outside. The measures we emphasize are analogous to velocity measures of money.

Daylight Overdrafts

The Federal Reserve provides daylight overdrafts to depository institutions under certain conditions to promote the efficient functioning of Fedwire.^a First, Fedwire participants must satisfy a range of regulatory criteria designed to ensure that they are adequately capitalized to have access to intraday credit. This allows only relatively creditworthy institutions to borrow. Nonetheless, the value of assets held by a financial institution, such as a bank, can fluctuate rapidly. Consequently, there is a small risk that a Fedwire participant could have access to uncollateralized credit before the Federal Reserve realizes that the participant's financial condition has deteriorated. Second, since 1986 the Federal Reserve has been imposing quantitative limits, known as caps, on the overdrafts a bank can incur.^b The need for access to intraday credit (that is, a nonzero cap) is based on a self-assessment by the individual bank (for banks in good condition), and the size of a potential cap is tied to the bank's capital. In 1994, the Federal Reserve began applying a fee for every dollar of daylight overdrafts it extends. At first, the fee was set at 24 basis points (the annual rate quoted on the basis of a twenty-four-hour day), but in 1995 it was raised to the current 36 basis points.

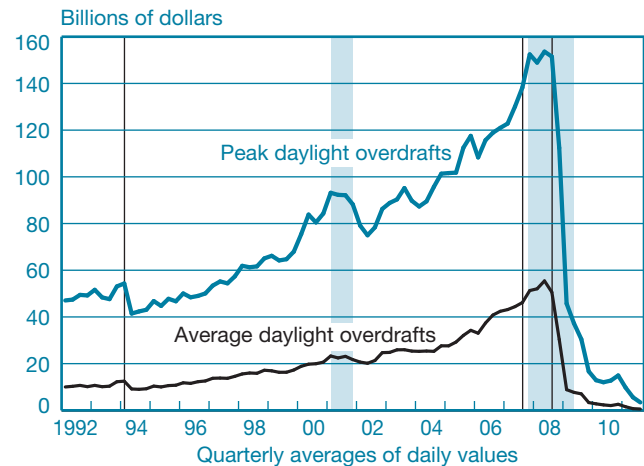
When trying to understand the use of daylight overdrafts, it is important to take into account that they vary considerably over the course of the operating day. Hence, it is helpful to focus on both the average and peak levels of daylight overdrafts. In the early 1990s, the average aggregate amount of daylight overdrafts was around \$10 billion, while peak daylight overdrafts hovered just below \$50 billion (see Chart 1, right). The introduction of fees in 1994 led to a decrease in the use of daylight overdrafts, but the fee hike in 1995 did not. Nonetheless, while the application of fees and caps has been instrumental in making banks manage their use of daylight overdrafts more closely, the fees did not prevent daylight overdrafts from growing—at least in absolute terms.^c By early

^aAs discussed in Martin and McAndrews (2010), reserves borrowed intraday are a substitute for reserves held overnight.

^bFor many depository institutions, the overdrafts were de facto secured by prepositioned collateral at the discount window. Hence, as a practical matter, the uncollateralized risk exposure to the Federal Reserve is likely to be smaller than the outstanding amount of daylight credit.

CHART 1

Fedwire Funds Daylight Overdrafts



Source: http://www.federalreserve.gov/paymentsystems/psr_data.htm.

Notes: Vertical lines denote January 1, 1994, August 9, 2007, and September 15, 2008. Bands denote NBER recessions.

2007, average and peak daylight overdrafts increased to about \$45 billion and \$125 billion, respectively.

Yet at the height of the crisis, following the bankruptcy of Lehman Brothers, average and peak daylight overdrafts reached even higher levels. Over the maintenance period that ended on October 8, 2008, daylight overdrafts averaged \$83 billion and peak daylight overdrafts averaged \$246 billion.^d Since fall 2008, however, daylight overdrafts have decreased dramatically and reached their lowest levels in more than twenty-five years.

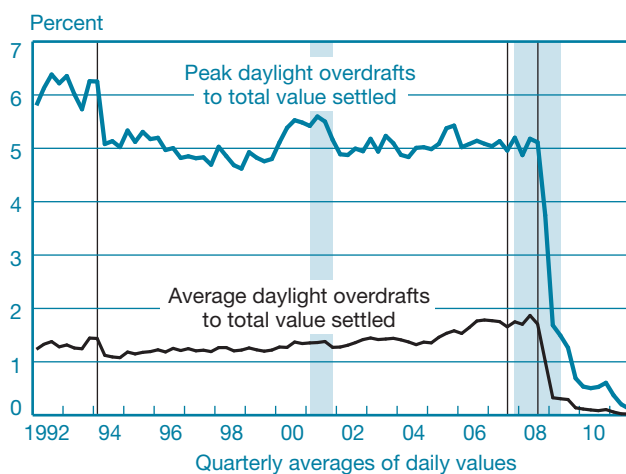
^cThe introduction of fees had a much larger and permanent effect on daylight overdrafts incurred in the Fedwire Securities Service. See Coleman (2002) and Mills and Nesmith (2008).

^dSee http://www.federalreserve.gov/paymentsystems/psr_dlod.htm.

Daylight Overdrafts (*Continued*)

As shown in Chart 2 below, the decrease in daylight overdrafts was not driven by a decline in the total amount of payments sent. Indeed, when daylight overdrafts are measured relative to the total amount of payments, the decrease is still apparent. This is striking because the use of daylight overdrafts had been more or less unchanged over the decade and a half preceding 2008. In fact, following the implementation of priced overdrafts in 1994, peak daylight overdrafts have been remarkably stable, at around 5 percent of total payment value (average overdrafts increased slightly faster than the value of payments in the mid-2000s). During the first quarter of 2010, average and peak daylight overdrafts were \$3 billion and \$13 billion, respectively. These levels are less than a third of the daylight overdrafts experienced in the early 1990s and less than a tenth of their peak measures.

CHART 2
Fedwire Funds Daylight Overdrafts Relative to Value Transferred



Sources: http://www.federalreserve.gov/paymentsystems/fedfunds_qtr.htm; http://www.federalreserve.gov/paymentsystems/fedfunds_qtr.htm; authors' calculations.

Notes: Vertical lines denote January 1, 1994, August 9, 2007, and September 15, 2008. Bands denote NBER recessions.

bank. This imposes a delay cost on the system, but reduces the cost of funds for Thrifty Bank and shifts these costs to other members of the payment system. As a result, all members of the payment system have an incentive to put off their payments, resulting in excessive delays.¹⁶

It is difficult to measure delay because a system operator with access to transaction data can typically observe the time at which a payment is settled, but not the time at which an institution becomes aware that a payment must be sent. For example, a payment settled at 3:00 p.m. may have been delayed

several hours if the sending bank learned about the payment at 8:00 a.m., or just a few minutes if the payment request was received at 2:58 p.m. Hence, computing an accurate measure of settlement delay can be challenging. Instead, one typically has to rely on changes in settlement times to identify changing liquidity conditions and, ultimately, gauge efficiency.¹⁷ For this to be a suitable approach, it must be the case that the underlying arrival process of payment requests reasonably can be assumed to be fixed.

Given the difficulties measuring settlement liquidity, estimating the benefits of settlement liquidity requires a quantitative model of the participants' possible actions. Atalay, Martin, and McAndrews (2010) calibrate the benefits of earlier payments using Fedwire data. Their quantitative results suggest that benefits in terms of reduced delays and overdraft charges are economically significant, on the order of tens or hundreds of millions of dollars per year.

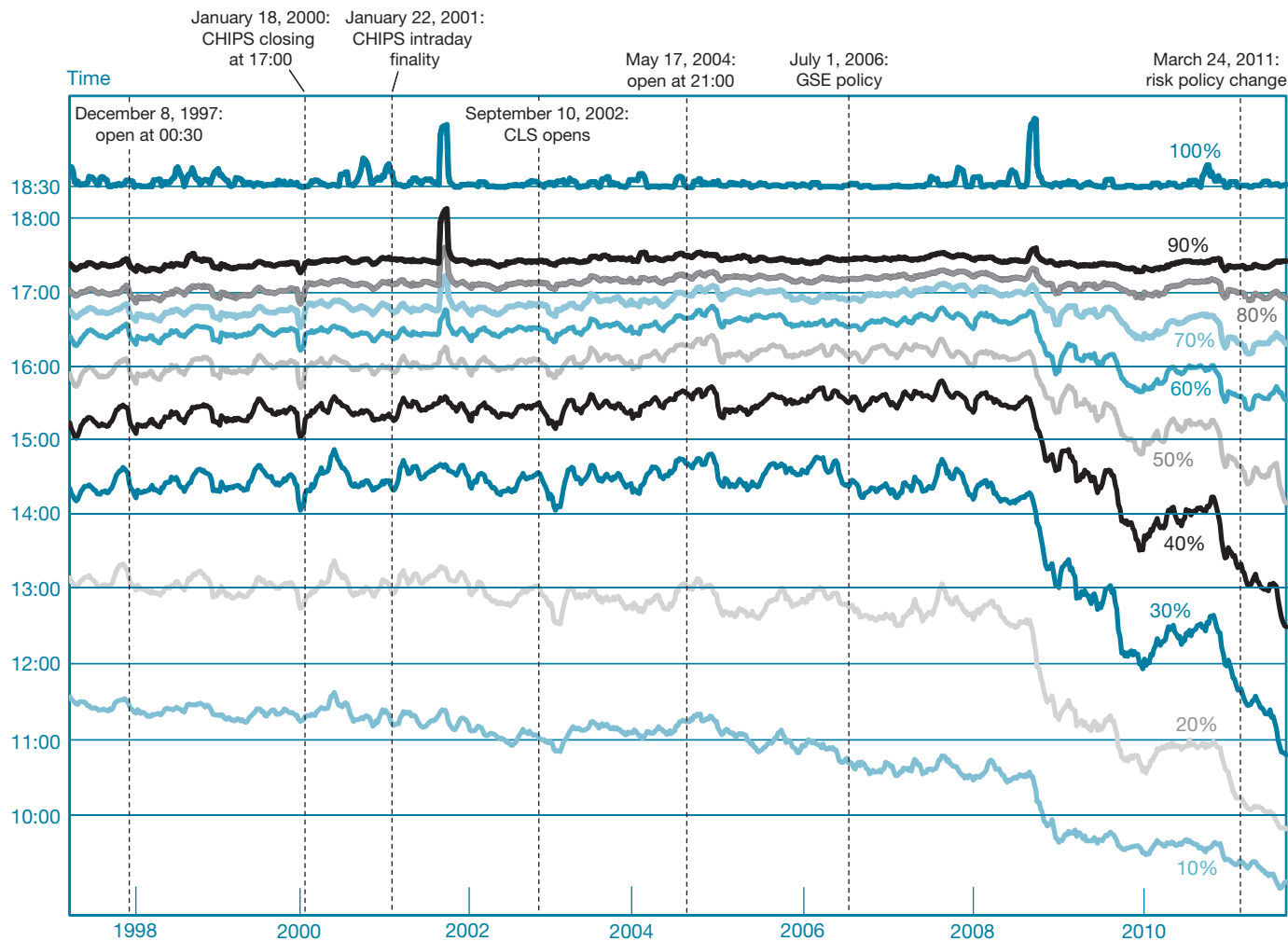
For the decade prior to the financial crisis, the distribution of settlement times on Fedwire generally drifted later in the day (see Armantier, Arnold, and McAndrews [2008]). In particular, payments in the 40th-90th percentiles, which settle in the afternoon, moved even later.¹⁸ Chart 1 shows the evolution of the distribution of timing on Fedwire over the last fourteen years. The horizontal lines in the chart measure the time by which the 10th-90th percentiles of value settled on Fedwire were completed; the vertical lines indicate several discrete events that may have affected the timing of Fedwire payments. From an operational risk perspective, waiting to send large payments until late in the day increases the potential magnitude of liquidity dislocations and risk in the financial

¹⁶ For example, strategic submission delays by participants can reduce the liquidity and thus the efficiency of a system. Using a game-theoretical framework, Bech and Garratt (2003) show that banks may have incentives to delay their payments (see also Angelini [1998] and Martin [2004]). Bech and Garratt (forthcoming) show how illiquidity in the interbank payment system following a widescale disruption, such as the events of September 11, 2001, is dependent on the strategic actions taken by the participants. The incentives to delay payment are likely to become particularly strong during periods of high uncertainty. The payment system's participants are expected to be reluctant to send payments to any institution that is perceived to be unlikely to make its own payments, either because of operational difficulties or because it may default. But institutions that do not receive the payments they expect will have incentives to delay, propagating the problem further. Such situations can result in significant delays relative to a "normal" day (McAndrews and Potter 2002). Bech and Soramäki (2001) and Martin and McAndrews (2008) show how a liquidity-saving mechanism can mitigate this trade-off.

¹⁷ See, for example, Armantier, Arnold, and McAndrews (2008) and Becher, Galbiati, and Tudela (2008) for analyses of the timing of payments in Fedwire and in the CHAPS system in the United Kingdom.

¹⁸ The extraordinary, but temporary, delays that occurred after September 11, 2001, are clearly visible in Chart 1 as well. During normal times, the last half-hour of Fedwire operation is closed for customer payments in order to allow banks time to square their accounts prior to the close. Hence, normally the value settled through the last half-hour is less than 2 percent. However, due to the disruptions, Fedwire opening hours were extended and payments occurred much later.

CHART 1
Deciles of Fedwire Value Settled throughout Day
Deciles of Fedwire Value Time Distribution



Sources: Federal Reserve Bank of New York; authors' calculations.

Notes: A twenty-one-day centered moving average is used. Values exclude payments related to CHIPS, CLS, DTC, and principal and interest payment funding.

industry should an operational disruption occur. An increase in such risk is particularly troublesome in an era of heightened concern about operational disruptions generally (Board of Governors of the Federal Reserve System 2008).

Previous research has ascribed this development to a confluence of drivers. Armantier, Arnold, and McAndrews (2008) find that much of the later settlement of payments was driven by three factors. First, increases in the number and value of Fedwire payments between 1998 and 2006 contributed to later payments overall by increasing the demand for scarce liquidity. Second, increases in industry concentration were found to have an empirical association with later settlement,

and accounted for some of the additional delays. Finally, changes in the timing of ancillary payment systems, particularly CHIPS, contributed to later Fedwire settlement. In 2000, CHIPS changed its settlement time from 4:30 p.m. to 5:00 p.m. and Fedwire payments followed the pattern set by CHIPS.

In addition, the Payments Risk Committee—a private sector group of senior managers from banks active in the United States and sponsored by the Federal Reserve Bank of New York—studied the increase in late-day activity in many markets that directly or indirectly rely on same-day settlement via Fedwire. The study suggests that many financial institutions

send payments late in the day, in part because the instructions to execute payments are received late (Payments Risk Committee and Wholesale Customer Advisory Group 2007, p. 3).

Remarkably, as shown in Chart 1, a fundamental change has occurred in the settlement dynamics of Fedwire since fall 2008, resulting in a dramatic quickening of settlement times. In the immediate aftermath of the Lehman bankruptcy, there was a sharp but temporary increase in late-day payments driven by the uncertain environment. High uncertainty gives banks an

Remarkably . . . a fundamental change has occurred in the settlement dynamics of Fedwire since fall 2008, resulting in a dramatic quickening of settlement times.

incentive to wait as long as possible for some of this uncertainty to be resolved before sending payments. For example, banks that play a correspondent role for other banks have an incentive not to send payments on behalf of client banks that may fail during the day. This increase dissipated within a matter of weeks, and all measures of settlement time have moved sharply earlier since.

There are many ways to measure the wholesale quickening of payments. As shown in Chart 1, the 30th percentile of payment value settled after 2:00 p.m. until 2008; as of mid-2011, it settled more than three hours earlier, just after 11:00 a.m. Alternatively, as of mid-2011, less than 45 percent of the value of payments settled after 3:30 p.m., an unprecedented drop of 15 percentage points compared with the previous norm. Moreover, the share of payments settled after 5:00 p.m. is close to the level of 20 percent seen a decade ago.¹⁹

Interestingly, it is not only the settlement timing of Fedwire that has improved. As suggested by our review of the clearing and settlement network above, improvements in the settlement liquidity of Fedwire Funds are likely to spread to other parts of the network. A lack of information on settlement timing and funding prevents us from tracing such effects for many parts of the system. However, available data from CHIPS show that such positive spillovers are indeed at work.

¹⁹ In addition, the amount of payments settled during the last half-hour of Fedwire operation is at its lowest level, likely reflecting the fact that banks have less incentive to manage their end-of-day balances closely, as the opportunity cost of holding such balances overnight is smaller with the implementation of interest on reserves.

6. WHY DID SETTLEMENT LIQUIDITY IMPROVE?

A natural question to ask is why settlement timing for Fedwire Funds has improved so substantially since fall 2008. We show that the improvements in settlement timing were a by-product of the Federal Reserve's policy responses to the financial crisis and subsequent recession. These policy responses were not intended primarily to improve payment system efficiency, but nonetheless provided banks incentives to modify their payment behavior. In particular, the unprecedented increase in reserve balances eliminated virtually any need for banks to delay their submission of payment requests. During the days following the bankruptcy of Lehman, stress and uncertainty in the financial system mounted rapidly. In an attempt to restore liquidity and stability to the U.S. financial system in general and the banking system in particular, public authorities took a number of unprecedented actions.²⁰ The increase in reserve

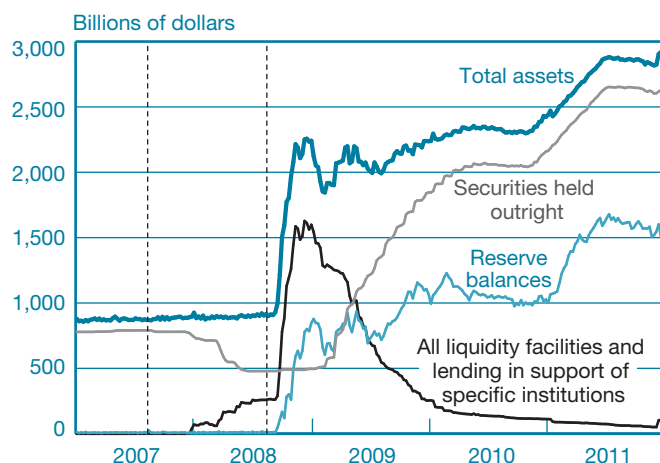
A natural question to ask is why settlement timing for Fedwire Funds has improved so substantially since fall 2008. We show that the improvements in settlement timing were a by-product of the Federal Reserve's policy responses to the financial crisis and subsequent recession.

balances was so large that the Federal Reserve was not able to sterilize it by selling U.S. Treasuries, as it had done earlier in the crisis. Consequently, the level of reserve balances ballooned from \$10 billion on average during August 2008 to \$850 billion by year-end.

In addition, the Federal Reserve bought \$1.725 trillion in Treasuries, agency debt, and agency mortgage-backed securities (MBS) from late 2008 through early 2011. However, reserve balances did not start to grow further throughout much of 2009 because the increase in reserves from the large-scale asset purchases was partially offset by a runoff in the use of the Federal Reserve's emergency liquidity facilities. The level of

²⁰ For example, the Federal Reserve, with the full support of the Treasury, agreed to provide support to American International Group, and the Federal Reserve augmented many of its existing lending facilities, such as the Term Auction Facility and reciprocal currency arrangements (swap lines) with foreign central banks. In addition, the Federal Reserve took several steps to ease investor concerns about the money market mutual fund industry and support the functioning of the commercial paper market.

CHART 2
Reserve Balances



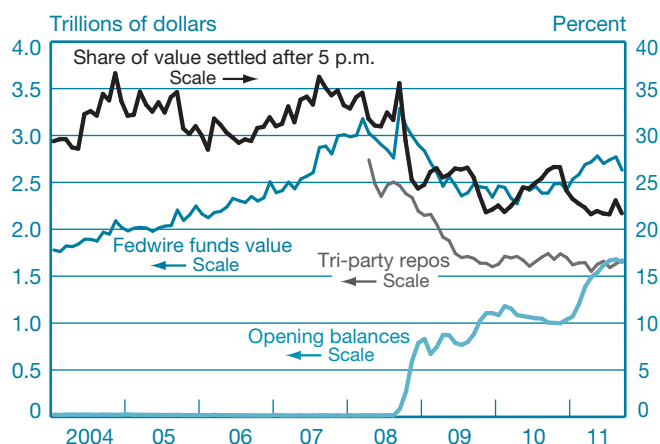
Source: Federal Reserve Statistical Release H.4.1.

Notes: Vertical lines denote August 9, 2007, and September 15, 2008. “All liquidity facilities” includes term auction credit; primary credit; secondary credit; seasonal credit; Primary Dealer Credit Facility; Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility; Term Asset-Backed Securities Loan Facility; Commercial Paper Funding Facility; and central bank liquidity swaps. “Lending in support of specific institutions” includes net portfolio holdings of the three Maiden Lane LLCs and preferred interests in AIA Aurora LLC and ALICO Holdings LLC.

reserve balances grew further, to more than \$1 trillion in the last quarter of 2009 and reached \$1.2 trillion in February 2011. Following the completion of securities purchase programs, reserve balances slowly began to fall back to \$1 trillion, due to principal payments and a continuing runoff in the liquidity facilities. However, in August 2010 the Federal Reserve announced that it would keep its holdings of longer-term securities constant at their then-current level by reinvesting principal payments from agency debt and agency MBS in longer-term Treasury securities. This halted the fall in reserve balances. Then, in November, the Federal Open Market Committee (FOMC) announced that it intended to purchase an additional \$600 billion of longer-term Treasury securities by the end of the second quarter of 2011. Consequently, reserves grew to more than \$1.5 trillion. The evolution of reserves, as well as other components of the Federal Reserve’s assets, is displayed in Chart 2.²¹

²¹ With the banking system awash in reserves, the rate at which banks were willing to buy and sell these funds—the federal funds rate—dipped well below the intended policy target rate set by the FOMC in the weeks following the Lehman bankruptcy. This situation created a tension for the Federal Reserve: While the emergency measures were helping to improve market functioning, the resulting increase in reserve balances was exerting downward pressure on the federal funds rate. See Bech and Klee (2011) for a discussion.

CHART 3
Opening Balances, Fedwire Funds Value,
Tri-Party Repos, and Settlement Time



Sources: Federal Reserve Bank of New York; authors’ calculations.

With so many reserves in the banking system, banks no longer need to economize on their reserves; as a result, payments are being made more quickly, which reduces delays and resolves uncertainty for businesses and individuals. As illustrated in Chart 3, the changes in settlement time (measured by the proportion of payments settled after 5:00 p.m.) since the Lehman bankruptcy appear to be inversely related to the amount of opening balances available. The share of total value settled after 5:00 p.m. has generally dropped as reserve balances have increased. However, the chart also suggests that other factors may have influenced the improvement in settlement timing, such as the value of payments settled over Fedwire Funds and the amount of tri-party repos traded. We explore this in the following section using regression analysis.

6.1 Regression Analysis

To measure the relative importance of the potential drivers of improved settlement liquidity, we extend the Fedwire timing analysis of Armantier, Arnold, and McAndrews (2008; hereafter “AAM”). We perform nine regressions, one for each decile of payment value settled below 100 percent. In each regression, the dependent variable is defined as the change in the time at which the corresponding decile (“percentiles” in AAM) of value settled on a specific day, measured in the number of seconds since the day’s Fedwire opening. The same set of explanatory variables is used in each of the nine regressions.

In addition to the explanatory variables employed by AAM, we include the total amount of opening balances available to banks on the specific day, a measure of tri-party repo activity, and a measure of the distribution of balances across banks: the Herfindahl-Hirschmann Index (HHI) of balances.²² Furthermore, we estimate the decile regressions over two sample periods. The first period, which we label *pre-Lehman*, runs from August 2002 through August 2008. The second period, which we label *post-Lehman*, runs from September 2008 through March 2011.

A couple of technical points are worth highlighting. First, following AAM, we rely on the approach developed by Newey and West (1987) to correct the estimated standard errors to address possible serial correlation and heteroskedasticity problems. Second, in the original AAM analysis it was reasonable to treat the settlement time percentiles as being stationary, as they fluctuated around a relatively fixed mean with relatively constant volatility over the sample. However, when using our post-Lehman period this is no longer a reasonable assumption, as the time series properties have changed significantly. To address issues of nonstationarity (unit roots), we estimate the regressions in changes rather than in levels, as in the original AAM paper.²³

In sum, we estimated the following equations:

$$\begin{aligned}\Delta p_t^{10} &= \beta_0^{10} + \beta_1^{10} \times \Delta OpenBal_t + \beta_2^{10} \times \Delta 3PRepo_t \\ &\quad + \Delta x_t^{AAM'} \times \beta_{AAM}^{10} + \varepsilon_t^{10} \\ \Delta p_t^{20} &= \beta_0^{20} + \beta_1^{20} \times \Delta OpenBal_t + \beta_2^{20} \times \Delta 3PRepo_t \\ &\quad + \Delta x_t^{AAM'} \times \beta_{AAM}^{20} + \varepsilon_t^{20} \\ &\quad \dots \\ \Delta p_t^{90} &= \beta_0^{90} + \beta_1^{90} \times \Delta OpenBal_t + \beta_2^{90} \times \Delta 3PRepo_t \\ &\quad + \Delta x_t^{AAM'} \times \beta_{AAM}^{90} + \varepsilon_t^{90},\end{aligned}$$

where Δ denotes the change from one business day to another in a variable, p_t^i ; $i \in \{10, 20, \dots, 90\}$ denotes the time at which first the 1st-9th deciles in terms of value settled on day t ; $OpenBal_t$ is the opening balances at day t ; $3PRepo_t$ is the proxy for tri-party-repo-related payments on day t , as discussed below; and $x_t^{AAM'}$ is a vector of the explanatory variables used in the original AAM paper.

²² The explanatory variables used by AAM can be organized into five categories: value and volume, Federal Reserve policies and operations, settlement system activities, other control variables, and calendar effects. A full list as well as the sources can be found in Appendix A.

²³ This choice can be justified by noting that it is better to under-difference rather than over-difference the data. Ordinary least squares is inconsistent in the former case and consistent but inefficient in the latter. We use robust standard errors to partly mitigate this concern.

The regressions for the 30th, 60th, and 90th percentiles are presented in Table 1, with the exception of calendar and some policy dummies only relevant for the pre-Lehman period.²⁴ We summarize the main results here. As expected, our results for the pre-Lehman period are consistent with those reported in AAM. The small differences can be explained, in part, by the different sample periods. The key insights are highlighted in Chart 4, which consists of a 2x3 matrix of panels. Each column focuses on one of three explanatory variables: opening balances, tri-party-repo-related payments, and customer transfers. The rows reflect the two sample periods. Each panel shows the estimated coefficients for the 1st-9th decile as well as the 95 percent confidence intervals around them.

The first column of panels looks at the effect of opening balances on the settlement time distribution. In the pre-Lehman period, the estimated effects are positive for all deciles, which is somewhat counterintuitive. However, the estimates are insignificant—at the standard 5 percent level—for all deciles with the exception of the 7th. In contrast, for the post-Lehman period, our analysis finds the expected negative relationship between opening balances and settlement time. The estimated effects are significant for the first six deciles as well as the last decile but insignificant for 7th and 8th deciles.

The second column of panels presents the estimated effects for a new variable relative to the original AAM analysis. This variable seeks to capture the amount of payments transferred across Fedwire Funds related to tri-party repos.

As a proxy, we use any payment larger than \$1 billion that flows from (or to) one of the clearing banks—JPMorgan Chase or Bank of New York Mellon—to (or from) one of the two main custodial banks for the major tri-party-repo cash providers (for example, money market mutual funds)—State Street and Northern Trust.

Prior to the Lehman bankruptcy, our tri-party payment proxy is found to have no effect on settlement timing. The estimated effects are not significantly different from zero for any deciles. For the post-Lehman period, lower values of tri-party-repo-related payments are found to drive settlement time earlier for the 3rd-6th deciles.

Finally, the last column focuses on payments identified as customer transfers. The parameters corresponding to the total value transferred by banks on behalf of their customers over Fedwire prior to the Lehman bankruptcy are negative and significant for all deciles below 40 percent. As noted in AAM, Fedwire Funds payments seem to settle earlier when the value of transactions transferred by banks' customers is high. This result may be explained by the fact that banks face a higher cost

²⁴ We ran the regression with and without a constant term, and our results were unaffected.

TABLE 1

Regression Results (Excluding Calendar Dummies)

Explanatory Variables	30 Percent, Pre-Lehman	30 Percent, Post-Lehman	60 Percent, Pre-Lehman	60 Percent, Post-Lehman	90 Percent, Pre-Lehman	90 Percent, Post-Lehman
Change in sum of opening balances	0.136 [0.0950]	-0.131** [0.0377]	0.0700 [0.0564]	-0.0613* [0.0254]	0.0526 [0.0488]	-0.0273* [0.0113]
Change in HHI of opening balances for top 100	0.000381 [0.000657]	0.0337* [0.0140]	0.000632 [0.000329]	0.0162* [0.00714]	-0.000791 [0.000461]	0.00550 [0.00399]
Change in customer transfer value	-0.0474** [0.0119]	-0.0229 [0.0236]	0.00757 [0.00755]	0.0402 [0.0293]	0.00975** [0.00378]	0.0338* [0.0162]
Change in DTC final payout value	0.00639 [0.0465]	-0.469 [0.535]	0.0389 [0.0214]	0.328 [0.417]	0.00276 [0.0229]	-0.0958 [0.186]
Change in eurodollar borrowing value	0.0500 [0.0374]	0.0211 [0.0576]	0.0214 [0.0201]	0.103 [0.0531]	-0.0174 [0.0159]	0.0589* [0.0261]
Change in eurodollar lending value	0.138** [0.0522]	0.0395 [0.0536]	0.0850* [0.0337]	0.0862 [0.0598]	0.0366 [0.0216]	0.0462 [0.0268]
Change in length of an extension of Fedwire operating hours	0.0760* [0.0350]	0.0382 [0.0552]	0.0460** [0.0174]	0.0260 [0.0259]	0.172* [0.0737]	0.0384** [0.0122]
Change in value of fed funds deliveries	0.103* [0.0456]	-0.0972 [0.0753]	0.0264 [0.0231]	0.0189 [0.0499]	-0.00168 [0.0334]	0.000221 [0.0272]
Change in deviation from fed funds target rate	-3.240 [4.859]	-3.302 [4.610]	-8.300* [3.391]	-5.861 [3.665]	-3.620 [2.338]	0.878 [1.624]
Change in value of fed funds returns	0.0666 [0.0341]	-0.169* [0.0781]	0.0274 [0.0222]	-0.146** [0.0419]	-0.0279 [0.0225]	-0.0240 [0.0225]
Change in final payouts, total value of payments	0.0626 [0.0422]	-0.103 [0.0706]	0.0671** [0.0217]	-0.0156 [0.0322]	0.00851 [0.0129]	-0.00987 [0.0160]
Change in HHI of value sent	0.158** [0.0420]	0.158** [0.0353]	0.0578 [0.0329]	0.110** [0.0371]	0.0165* [0.00799]	0.0430* [0.0197]
Change in fed funds target rate	537.9 [543.0]	98.77 [286.1]	325.7 [305.3]	653.8* [292.1]	-147.2 [318.7]	-107.9 [183.4]
Change in tri-party repo activity	-0.00401 [0.0738]	0.426** [0.119]	-0.0115 [0.0389]	0.227** [0.0738]	-0.0675* [0.0306]	0.0298 [0.0322]
Change in total volume of Fedwire (nonsettlement)	0.0414** [0.0159]	0.0147 [0.0200]	0.0115 [0.00673]	-0.0242 [0.0172]	0.00199 [0.00584]	-0.0153 [0.00995]
Change in September 11-18, 2001	-24.33 [15.23]	— —	36.62* [15.71]	— —	79.83** [27.69]	— —
Constant	-0.0392 [0.135]	0.0631 [0.301]	-0.0267 [0.0696]	0.107 [0.198]	-0.0241 [0.0678]	0.0557 [0.0983]
Observations	1,810	760	1,810	760	1,810	760
R ²	0.449	0.535	0.595	0.535	0.480	0.501

Sources: Federal Reserve Bank of New York; authors' calculations.

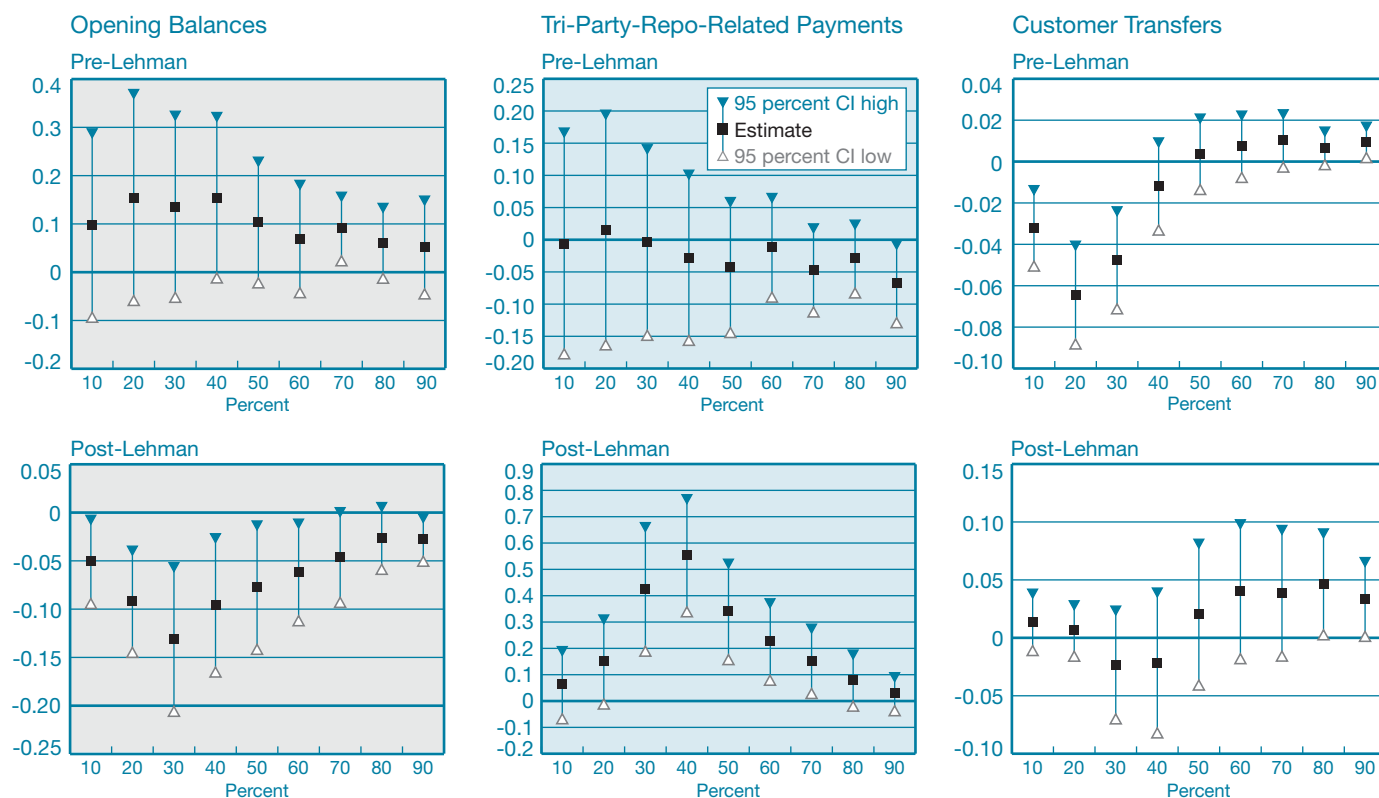
Notes: Standard errors are in brackets. HHI is the Herfindahl-Hirschmann Index. The eurodollar borrowing and lending values as well as the federal funds deliveries and returns are estimated variables; the precise quality of the estimates has not been determined.

**p < 0.01.

*p < 0.05.

CHART 4

Estimated Parameters and 95 Percent Confidence Intervals (CIs) from the Regressions for Pre- and Post-Lehman Sample Periods



Sources: Federal Reserve Bank of New York; authors' calculations.

of delay when acting on customers' requests for payments. In particular, banks may be asked by their customers to execute their transfers by a certain time.

Interestingly, this effect disappears in the post-Lehman period, suggesting that banks currently do not change their behavior depending on whether or not they have more payments on behalf of customers. One interpretation is that banks submit all their payments earlier, as the opportunity cost of funds is low.

The size of the effects can be better understood by reviewing Table 2. In the table, we again show the coefficient estimate and use asterisks to display its level of significance. Under each coefficient, we calculate the variable's mean estimated impact on the timing of Fedwire, holding all other variables constant, where the mean is taken over the sample period (so we multiply the mean change in the variable over the period by its coefficient estimate). Finally, at the bottom of the table, we present in each column the actual change in timing for that percentile of Fedwire value. First, consider the estimated effects of opening balances, shown in the first row.²⁵ The coefficients

are significant at the 10 percent level, at least, for the 10th-60th percentiles as well as for the 90th percentile. For the 30th percentile, the effect of opening balances alone is to quicken the time of settlement by three hours and three minutes, while the actual time of settlement quickened by three hours and thirty-seven minutes. No other variable led to quicker payments by more than forty-five minutes. The HHI of the distribution of balances for the top 100 investors, shown in the second row, fell over the period, and this distribution of balances seemed to also affect payment timing considerably. For example, all else equal, this distribution of balances led payments to settle forty-three minutes earlier for the 30th percentile. Table 2 makes clear that both the level and distribution of balances had very large

²⁵ Note that the sum of time for the variables displayed in Table 2 need not equal the actual time change. Each time in a cell is equal to the estimated coefficient multiplied by the average daily change in that specific variable multiplied by the number of days in the sample period, holding all other variables equal to their sample means. Hence, because there is no "total effect" in the columns, they should not equal the actual time, even with estimation error. Nevertheless, they represent a way to measure the influence or explanatory power of the separate variables on timing.

TABLE 2

Estimated Coefficients and Effects on Timing for Post-Lehman Period

Explanatory Variables	Percentile								
	10	20	30	40	50	60	70	80	90
Change in sum of opening balances									
Coefficient	-0.0503*	-0.0917**	-0.1313**	-0.0956**	-0.0772*	-0.0613*	-0.0458	-0.0259	-0.0273*
Effect on timing	-1:10	-2:08	-3:03	-2:13	-1:47	-1:25	-1:04	-0:36	-0:38
Change in HHI of opening balances for top 100									
Coefficient	0.0181**	0.0176*	0.0337*	0.024*	0.0088	0.0162*	0.0071	0.0032	0.0055
Effect on timing	-0:23	-0:22	-0:43	-0:30	-0:11	-0:20	-0:09	-0:04	-0:07
Change in customer transfer value									
Coefficient	0.0141	0.0067	-0.0229	-0.0213	0.0204	0.0402	0.0389	0.0467*	0.0338*
Effect on timing	-0:07	-0:03	0:11	0:10	-0:10	-0:19	-0:19	-0:23	-0:16
Change in DTC final payout value									
Coefficient	0.6192	0.4665	-0.4688	0.5587	-0.2970	0.3278	-0.3297	-0.2230	-0.0958
Effect on timing	-0:01	0:00	0:00	-0:01	0:00	0:00	0:00	0:00	0:00
Change in eurodollar borrowing value									
Coefficient	0.0625**	0.0489	0.0211	0.0735	0.1178**	0.1030	0.0920	0.0848*	0.0589*
Effect on timing	-0:07	-0:05	-0:02	-0:08	-0:13	-0:12	-0:10	-0:11	-0:06
Change in eurodollar lending value									
Coefficient	0.0325	0.0390	0.0395	0.0806	0.0962	0.0862	0.0953	0.0794	0.0462
Effect on timing	-0:04	-0:05	-0:06	-0:12	-0:14	-0:12	-0:14	-0:11	-0:06
Change in length of an extension of Fedwire operating hours									
Coefficient	-0.0171	0.0453	0.0382	0.0688	0.0442	0.0260	0.0472*	0.042**	0.0384**
Effect on timing	0:04	-0:12	-0:10	-0:18	-0:11	-0:06	-0:12	-0:11	-0:10
Change in value of fed funds deliveries									
Coefficient	0.0041	-0.0914	-0.0972	-0.1549*	-0.0678	0.0189	0.0262	0.0108	0.0002
Effect on timing	0:00	0:10	0:11	0:18	0:08	-0:02	-0:03	-0:01	0:00
Change in deviation from fed funds target rate									
Coefficient	-1.7189	-9.6522*	-3.3020	-10.0093	-2.5737	-5.8609	0.9172	3.6761	0.8779
Effect on timing	0:01	0:05	0:01	0:05	0:01	0:03	0:00	-0:02	0:00
Change in value of fed funds returns									
Coefficient	-0.0594	-0.1259*	-0.1686*	-0.2491**	-0.2326**	-0.1463**	-0.1166**	-0.0504	-0.0240
Effect on timing	0:04	0:09	0:12	0:18	0:17	0:10	0:08	0:03	0:01
Change in final payouts, total value of payments									
Coefficient	-0.0344	-0.1068*	-0.1030	-0.0184	-0.0383	-0.0156	-0.0171	-0.0312	-0.0099
Effect on timing	-0:02	-0:06	-0:06	-0:01	-0:02	0:00	-0:01	-0:01	0:00
Change in HHI of value sent									
Coefficient	0.0445*	0.0977**	0.1585**	0.1478**	0.1172**	0.1103**	0.1128**	0.0705**	0.043*
Effect on timing	-0:02	-0:05	-0:08	-0:08	-0:06	-0:06	-0:06	-0:03	-0:02
Change in fed funds rate									
Coefficient	83.5125	1,085.895**	98.7725	63.6994	1,145.6930	653.774**	287.0886	-14.1479	-107.8923
Effect on timing	-0:02	-0:36	-0:03	-0:02	-0:38	-0:21	-0:09	0:00	0:03
Change in tri-party repo activity									
Coefficient	0.0634	0.1508	0.4257**	0.5536**	0.3406**	0.2273**	0.1544*	0.0810	0.0298
Effect on timing	-0:02	-0:06	-0:19	-0:25	-0:15	-0:10	-0:07	-0:03	-0:01
Change in total volume of Fedwire (nonsettlement)									
Coefficient	-0.0112	0.0078	0.0147	0.0178	-0.0080	-0.0242	-0.0153	-0.0222	-0.0153
Effect on timing	-0:04	0:02	0:05	0:06	-0:02	-0:08	-0:05	-0:08	-0:05
Actual change in timing (hours)	-1:47	-3:01	-3:37	-3:02	-2:10	-1:39	-0:57	-0:36	-0:24

Sources: Federal Reserve Bank of New York; authors' calculations.

Notes: "Coefficient" is in minutes/billions of dollars; "effect on timing" is in hours. HHI is the Herfindahl-Hirschmann Index. The eurodollar borrowing and lending values as well as the federal funds deliveries and returns are estimated variables; the precise quality of the estimates has not been determined.

**p < 0.01.

*p < 0.05.

impacts on the timing of Fedwire payments over the period, while other variables, with the exception of the decreased tri-party repo activity proxy, had relatively small effects.

All told, our statistical analysis is consistent with the hypothesis that the large increase in reserve balances induced banks to change their intraday liquidity management practices, as it eliminated much of the incentive that banks had to economize on funds by holding back payments. As a result, payments are being settled more quickly, which reduces delays and resolves uncertainty for businesses and individuals.

7. PAYMENT SYSTEM RISK AND MONETARY POLICY

As mentioned in the introduction, in March 2008 the Board of Governors of the Federal Reserve System proposed revisions to its daylight overdraft policy that could improve settlement liquidity on Fedwire. The revisions followed a review of long-term developments, including the increased use of daylight overdrafts and increased Fedwire payments late in the day described in the previous section. The stated goal of the new policy was to reduce the credit risk borne by the Federal Reserve and bring forward the time of payment settlement.²⁶ The revisions included a new approach with a fee-based incentive for depository institutions to collateralize overdrafts. Under the new voluntary collateral regime, the pledging of collateral to cover daylight overdrafts would be encouraged by providing collateralized daylight overdrafts at a zero fee and by raising the fee for uncollateralized daylight overdrafts to 50 basis points.²⁷ The policy changes were approved in December 2008 and implemented March 24, 2011.

The new regime is now in place, but its goals were largely achieved prior to implementation, as documented in the previous sections and in Box 2. The amount of daylight overdrafts, and thus the size of the potential risk exposure of the Federal Reserve from this particular source, was lower in 2010 than at any time in more than twenty-five years. Payments are currently being submitted and settled much earlier than has been the case in the last ten years.

We did not find a consistent effect of this policy change in our regression analysis. Recall that the change went into effect on March 24, 2011, and we tried to model the change as a step function by adding a dummy variable to the estimation for that

²⁶ While reducing the credit risk of the Federal Reserve is an admirable goal in and of itself, one should keep in mind that part of any given risk reduction achieved may just reflect a shift of risk to other public authorities, such as the Federal Deposit Insurance Corporation.

²⁷ This refers to an annual rate based on a twenty-four-hour day.

day and for some subsequent days. However, the sign of the dummy varied depending on which day we modeled the change as being effective, so we believe that the result is not robust to specification of the way that the policy was understood and put into effect within banks. Consequently, we cannot be sure how this policy change affected Fedwire timing.

Similar overall effects of increases in reserve balances have been observed in the settlement systems of other countries, as central banks have injected large amounts of reserves into their respective banking systems during the financial crisis. The residual demand for funds for payment purposes and the utilization of intraday credit facilities have diminished.²⁸ It is important to note that, while the increase in the supply of reserves arose as a response to the crisis, the Federal Reserve does not necessarily need to return to its previous monetary policy implementation framework as the need for accommodative monetary policy subsides. Indeed, because it

The amount of daylight overdrafts, and thus the size of the potential risk exposure of the Federal Reserve from this particular source, was lower in 2010 than at any time in more than twenty-five years.

can pay interest on excess reserves, the Federal Reserve can increase the policy rate without changing the supply of reserves if it needs to. As noted by Keister, Martin, and McAndrews (2008), the quantity of reserves and the interbank interest rate can be set independently within the operational framework of a so-called floor system.²⁹ This would allow the gains in settlement liquidity to be sustained while avoiding the need for banks to shuffle collateral back and forth to the Federal Reserve—potentially intraday—to satisfy the requirements of the new Payment System Risk policy.³⁰

²⁸ As a corollary, the overnight rate for reserves in many countries has been trading close to the rate at which the central bank remunerates reserves (see Bowman, Gagnon, and Leahy [2010]).

²⁹ When the quantity of reserves is large, the interbank interest rate will be close to the interest paid on reserves. Changing the interest on reserves allows the Federal Reserve to steer the interbank interest rate to the rate set by the FOMC for the conduct of monetary policy. At the same time, the quantity of reserves can be large enough to meet the needs of the banking system even in times of high stress and uncertainty.

³⁰ In addition, the increased level of reserves has not only improved the efficiency of the payment system, it has also—withstanding the issue of a soft floor—improved the precision by which monetary policy is being implemented in a subtle way by removing idiosyncratic variation in the effective federal funds rate observed previously across days depending on the amount of payments settled over Fedwire Funds (Hilton 2005).

The fact that monetary policy can be conducted with a large quantity of excess reserves is illustrated by the case of New Zealand. In 2006, the Reserve Bank of New Zealand implemented a new liquidity management regime that discontinued its intraday credit facility. Instead, the Bank chose to supply a significantly higher level of reserves sufficient to enable participants to settle payments efficiently (see Reserve Bank of New Zealand [2006]).³¹ This change of policy was decided on and implemented before the start of the recent crisis and is intended to be permanent.

8. CONCLUSION

The dollar clearing and settlement system performed dependably during the financial crisis. This performance reflects decades of collaborative efforts to develop policies and robust operational procedures to maintain a resilient system serving the payment needs of the economy. The crisis led to some extreme levels of activity on the Fedwire Funds Service. Very high values and volumes of transactions were demanded at different times during and immediately preceding the crisis, but their settlement was managed smoothly.

The Federal Reserve's monetary policy response to expand its balance sheet starting in September 2008 and to remunerate interest on reserves starting on October 9, 2008, provided a natural experiment for the behavior of Fedwire Funds. In particular, economic theory had posited that ample, low-opportunity-cost reserves would reduce delays in the payment system that exist because of banks' incentives to avoid the cost of acquiring reserves for settlement purposes. Our review of bank behavior strongly supports this theory; as banks were endowed with larger reserve balances and as the opportunity cost of holding balances fell with the payment of interest on those balances, payments were made earlier and earlier during the day. It is unlikely that the time at which the underlying payment

³¹ The change was necessitated by a growing scarcity of New Zealand government securities.

orders were submitted by banks and their customers changed dramatically; hence, it appears that payment delays decreased as reserves increased and their opportunity costs fell, just as theory would predict. Our regression analysis suggests that the higher level of balances accounts for the lion's share of the quickening of payment timing that has occurred since fall 2008.

In addition to the quickening of payments, the significant increase in reserve balances resulted in a dramatic reduction in the demand for daylight credit provided by the Federal Reserve. Because banks were no longer constrained by their lack of reserves, they did not need to draw on credit supplied by the Federal Reserve Banks when making a payment. This reduced level of daylight credit has the benefit of reducing the risk exposure of Federal Reserve Banks and the deposit insurance fund, whose losses—in the event of a failure of a bank that at the time of its failure had pledged loans and securities to the Federal Reserve Bank to collateralize a daylight overdraft—would be greater than the collateral available to pay other creditors of the bank. In a sense, under a high-reserve system as is currently the case, banks largely “prepay” for their liquidity needs by maintaining large reserve balances with which they can fund their outgoing payments. In that sense, provision of large reserve balances by the Federal Reserve Banks reduces the provision of daylight credit by them. By paying interest on reserves, maintaining these balances is made less expensive for banks, as they suffer little or no opportunity costs by holding reserves overnight and throughout the day.

This natural experiment of much higher reserve balances and the payment of interest on those balances has resulted in much faster payments being made with much less credit provided by the Federal Reserve. This outcome supports the objectives of the changes made by the Federal Reserve to its Payment System Risk policy in 2008, which were to speed payments and lessen the risk exposure to the Federal Reserve. The reduced delay of payments has large benefits to society, as shown by prior research. These observations lead us to suggest that maintaining high balances in bank accounts and paying interest on those balances, as described by Keister, Martin, and McAndrews (2008), can be a good way to capture the benefits of a more efficient and safe payment system.

APPENDIX A: DATA

Our primary data source is Federal Reserve Bank of New York records of every Fedwire Funds Service transaction. Unless otherwise stated, data are used to construct the variables below associated with Fedwire Funds activity. We have data on Fedwire Funds transfers between April 1997 and September 30, 2011. Our variables are defined below. As noted earlier, there are a number of calendar day dummies that are excluded from the regression results in Table 1. In both the pre- and post-Lehman regressions, the following calendar dummies have been suppressed from output (where necessary, these variables are defined below): *MBS P&I payment day*, *day after a holiday*, *day before a holiday*, *first of the month*, *last business day of quarter*, *last five business days of year*, *NYSE closed early*, *NYSE holiday/or closure*, *day of the week*, *maintenance period day*.

In addition, in the pre-Lehman regression results the following dummies have been suppressed: *CHIPS intraday finality*, *CHIPS extension*, *Opening hours moved to 21:00*, *CHIPS end-of-day settlement at 17:00*, *CLS Bank Opens*, *GSE Daylight Credit Removed*.

DEFINITIONS

ith percentile of value time is the time at which *i* percent of the total daily value has settled. We exclude payments to or from CHIPS, CLS Bank, and DTC. We also exclude payments associated with interest and redemption payments of government-sponsored enterprises (GSEs) and international institutions after the Federal Reserve's Payment System Risk policy change on July 1, 2006. These payments related to P&I (principal and interest) are Fedwire Funds payments between two different accounts of the securities issuer, that is, payments from the general account to the funding account and from the funding account to the distribution account.

Opening Balances are currently found using the IAS opening balances from DORPS (the Federal Reserve's Daylight Overdraft Reporting and Pricing System) daily activity data as the opening balance for each master account. Prior to the third quarter of 2010, the opening balance for each master account was calculated by adjusting the DORPS end-of-minute balance for the first minute of the operating day and for Fedwire Funds activity that occurred during that first minute.

Foreign Capital Equivalency Policy is a binary variable equal to 1 on and after February 21, 2002, when the Federal Reserve

changed the criteria for determining U.S. capital equivalency for foreign banks. This policy change increased the sum of the net debit caps of all Fedwire Funds participants by \$123 billion, or 12 percent (see Board of Governors of the Federal Reserve System [2001]).

GSE Daylight Credit Removed is a binary variable equal to 1 on and after July 1, 2006. The Federal Reserve changed its Payment System Risk policy to require GSEs and international organizations to fully fund interest and redemption payments on securities before the funds are sent, and it removed the provision of free intraday credit to these issuers (Board of Governors of the Federal Reserve System 2004; McAndrews 2006).

MBS P&I payment day, pre-GSE policy is a binary variable equal to 1 on the 15th and 25th of the month, or the first business day thereafter, before the change in GSE credit policy on July 1, 2006. On these days, Fannie Mae and Freddie Mac make interest and redemption payments on mortgage-backed securities (MBS). These are generally the largest interest and redemption payment days of the month.

MBS P&I payment day, post-GSE policy is a binary variable equal to 1 on the 15th and 25th of the month, or the first business day thereafter, after the change in GSE credit policy on July 1, 2006.

Opening hours moved to 21:00 is a binary variable equal to 1 for all days on or after May 17, 2005. On that date, the Federal Reserve extended the operating hours of the Fedwire Funds Service from 18 hours to 21.5 hours by moving the opening time from 00:30 to 21:00 (Board of Governors of the Federal Reserve System 2003).

Operating hour extension is the number of minutes that the Fedwire Funds Service remains open after 18:30. The Federal Reserve will occasionally extend Fedwire's operating hours at the request of a participant having operational difficulties or if the system is experiencing operational problems (Bank for International Settlements 2005).

Maintenance period day is the day of the maintenance period that the date falls on.

Fed funds target rate — Source: <http://www.ny.frb.org/markets/omo/dmm/fedfunds.cfm>.

Interbank payment value is the sum of the payment values of all Fedwire Funds transfers that are not fed funds deliveries,

APPENDIX A: DATA (CONTINUED)

fed funds returns, customer payments, or settlement payments for CHIPS, CLS Bank, or DTC, or that are not principal and interest redemptions.

Customer transfers value is the sum of the payment values of all Fedwire Funds transfers with a business function code of customer payment.

Fed funds deliveries is the total value of new fed funds loans. These loans were identified from Fedwire Funds transactions, as in Furfine (2000).

Fed funds returns is the total value of returns of the fed funds loans. It is equal to the value of fed funds deliveries for the previous business day plus the interest on those loans. These loans were identified from Fedwire Funds transactions, as in Furfine (2000).

Payments > \$10 mn. is the fraction of daily value from payments greater than or equal to \$10 million. This excludes all CHIPS, CLS Bank, DTC, and P&I funding payments. The threshold value of \$10 million is the value used in a survey of bank intraday liquidity management conducted by the Payments Risk Committee and the Wholesale Customer Advisory Group (2007).

Tri-party repo activity is defined as all payments larger than \$1 billion that on a given day flow from (or to) one of the two clearing banks—JP Morgan Chase or Bank of New York Mellon—to (or from) one of two main custodial banks—State Street and Northern Trust—for the major cash providers (such as money market mutual funds) in the tri-party-repo market.

Eurodollar lending value is the estimated total value of eurodollar lending over Fedwire. Interbank loans were identified from Fedwire Funds transactions, as in Furfine (2000). Among these, loans with business function code “CTR” are labeled eurodollar transactions.

Eurodollar borrowing value is the estimated total value of eurodollar borrowing over Fedwire. Interbank loans were identified from Fedwire Funds transactions, as in Furfine (2000). Among these, loans with business function code “CTR” are labeled eurodollar transactions.

Number of payments is the daily number of Fedwire Funds payments, including interbank, customer, and fed funds

transactions, but excluding all CHIPS, CLS Bank, DTC, and P&I funding payments.

CHIPS settlement at 17:00—*CHIPS settlement time* is a binary variable equal to 1 for all days on or after January 18, 2000. On that date, the time at which end-of-day CHIPS payouts occurred moved from approximately 16:45 to 17:10.

CHIPS intraday finality is a binary variable set to 1 for all dates on or after January 22, 2001. This is the date when CHIPS moved from an end-of-day multilateral net debit system to a mixed-payment system with intraday finality.

CHIPS final payout value is the value of the end-of-day payouts sent by CHIPS over Fedwire to CHIPS participants with a net credit position.

CHIPS extension is a binary variable for a later-than-normal close of operations.

CHIPS final payout time. This is defined as a CHIPS final payout occurring after 17:00 for days before January 18, 2000, and after 17:15 otherwise.

DTC settlement time is the value-weighted mean time of Fedwire Funds payments sent by DTC after 16:00.

DTC net-net credit value is the sum of all Fedwire Funds payments sent by DTC after 16:00.

DTC final pay-out value is the value of the end-of-day payouts sent by DTC over Fedwire to DTC participants with a net credit position.

CLS Bank opens is a binary variable equal to 1 for all days on or after September 10, 2002, when CLS Bank International began settling U.S. dollar transactions.

CLS Bank USD value is the daily sum of payments sent by CLS Bank over Fedwire. It is equivalent to the value of all U.S. dollar legs settled by CLS Bank.

Sep. 11-18, 2001, is a binary variable equal to 1 for those dates. This is the period in which the Fedwire payment system was disrupted by the terrorist attacks of September 11 (McAndrews and Potter 2002).

NYSE closures and NYSE early closures — Source: <http://www.nyse.com/pdfs/closings.pdf>.

APPENDIX A: DATA (CONTINUED)

Reserve maintenance cycle days are binary variables for the days in a reserve maintenance cycle. The maintenance cycle is a two-week period starting on a Thursday (see Federal Reserve Banks [2006] for the starting and ending dates of maintenance cycles). We include dummies for all days of the week with Thursdays—the first day of the reserve maintenance cycle—as the excluded group. To disentangle the effect of the maintenance cycle above from any day-of-week effects, we include binary variables for maintenance days in the second week of the maintenance cycles, that is, days 6-10.

HHI of Fedwire value is the Herfindahl-Hirschmann Index of the value of Fedwire Funds payments sent by master accounts.

HHI of opening balances for top 100 is the Herfindahl-Hirschmann Index of the 100 participants in Fedwire with the largest opening balances.

Fed funds deviation is the difference between the effective fed funds rate and the target fed funds rate. Source: <http://www.ny.frb.org/markets/omo/dmm/fedfunds.cfm>.

CHIPS

CHIPS is a private, large-value U.S. dollar payment system owned and operated by the Clearing House Payments Company (Bank for International Settlements 2005). As of April 2007, CHIPS had 45 members and settled 329,000 transactions valued at \$1.7 trillion per day (source: <http://www.chips.org/about/pages/001221.php>). From its opening in 1970 until 2001, CHIPS operated as an end-of-day multilateral net debit settlement system: After CHIPS closed at 04:30 (05:00 after January 18, 2000), participants with negative net positions would send payments to CHIPS over Fedwire to cover their positions; CHIPS would then send payments to those participants with net positive positions.

On January 22, 2001, CHIPS adopted intraday payment finality with a continuous offsetting algorithm to optimize liquidity. All CHIPS participants must fund their accounts with a Fedwire transfer to CHIPS between the opening of Fedwire and 09:00 before they can send or receive payments. These balances, totaling about \$3 billion, are used to settle payments during CHIPS operating hours. At the close of CHIPS at 17:00, any unsettled payments are multilaterally netted. These net positions are settled over Fedwire via transfers to and from CHIPS.

CLS BANK

CLS Bank is a payment-versus-payment settlement system that settles foreign exchange transactions in fifteen currencies (Bank for International Settlements 2005). CLS Bank is operated by CLS Bank International, a bank-owned Edge Act corporation incorporated in the United States. CLS Bank was founded in response to concerns raised by the G-10 central banks about settlement risk in foreign exchange transactions.

CLS Bank began operation in September 2002; as of December 2006, it had 57 members and settled an average of 290,000 transactions valued at \$3.3 trillion per day (source: <http://www.cls-group.com/news/article.cfm?objectId=78EA8ED8-EC63-6345-C60967F0ECA7E5C3>).

CLS Bank uses a payment-versus-payment method in which funds to settle trades are exchanged simultaneously in different currencies. In order to accomplish simultaneous transfers, CLS Bank is open during the five-hour settlement window—01:00 to 06:00 Eastern time—when real-time gross settlement systems in Europe, the Americas, and Asia are open.

DTC

DTC is a securities settlement system that settles the majority of U.S. corporate securities and commercial paper transactions. It is a wholly owned subsidiary of Depository Trust & Clearing Corporation (Bank for International Settlements 2005). DTC has 407 participants and 86 settling banks. On average, it settles 800,000 transactions valued at \$896 billion per day (Payments Risk Committee and Wholesale Customer Advisory Group 2007).

DTC participants fund their accounts through Fedwire transfers (via a settlement bank for many) to the DTC Federal Reserve account. Money market instruments represent 62 percent of DTC value. The ability of paying agents to accept maturing securities is limited by the agents' net debit cap. To remove the debit cap constraint, agents will make progress payments to their accounts via Fedwire transfers to DTC. The majority of this activity occurs between 12:00 and 14:00. At 16:00, the DTC settlement process begins. Banks with net debits send the net amount to DTC over the net settlement system at 16:35. At 16:40, DTC sends Fedwire Funds transfers to participants with net credits (Payments Risk Committee and Wholesale Customer Advisory Group 2007).

REFERENCES

- Adrian, T., C. R. Burke, and J. J. McAndrews.* 2009. "The Federal Reserve's Primary Dealer Credit Facility." Federal Reserve Bank of New York *CURRENT ISSUES IN ECONOMICS AND FINANCE* 15, no. 4 (August).
- Angelini, P.* 1998. "An Analysis of Competitive Externalities in Gross Settlement Systems." *JOURNAL OF BANKING AND FINANCE* 22, no. 1 (January): 1-18.
- Armantier, O., J. Arnold, and J. McAndrews.* 2008. "Changes in the Timing Distribution of Fedwire Funds Transfers." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 14, no. 2 (September): 83-112.
- Atalay, E., A. Martin, and J. McAndrews.* 2010. "Quantifying the Benefits of a Liquidity-Saving Mechanism." Federal Reserve Bank of New York *STAFF REPORTS*, no. 447, May.
- Bank for International Settlements.* 2003. "A Glossary of Terms Used in Payments and Settlement Systems." March. Available at <http://www.bis.org/publ/cpss00b.pdf>.
- . 2005. "New Developments in Large-Value Payment Systems." CPSS PUBLICATIONS, no. 67. Available at <http://www.bis.org/publ/cpss67.htm>.
- Bech, M. L., and R. Garratt.* 2003. "The Intraday Liquidity Management Game." *JOURNAL OF ECONOMIC THEORY* 109, no. 2 (April): 198-219.
- . Forthcoming. "Illiquidity in the Interbank Payment System following Wide-Scale Disruptions." *JOURNAL OF MONEY, CREDIT, AND BANKING*.
- Bech, M. L., and B. Hobijn.* 2007. "Technology Diffusion within Central Banking: The Case of Real-Time Gross Settlement." *INTERNATIONAL JOURNAL OF CENTRAL BANKING* 3, no. 3 (September): 147-81.
- Bech, M. L., and E. Klee.* 2011. "The Mechanics of a Graceful Exit: Interest on Reserves and Segmentation in the Federal Funds Market." *JOURNAL OF MONETARY ECONOMICS* 58, no. 5 (July): 415-31.
- Bech, M. L., C. Preisig, and K. Soramäki.* 2008. "Global Trends in Large-Value Payments." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 14, no. 2 (September): 59-81.
- Bech, M. L., and K. Soramäki.* 2001. "Gridlock Resolution in Interbank Payment Systems." Bank of Finland *DISCUSSION PAPERS*, no. 9.
- Becher, C., M. Galbiati, and M. Tudela.* 2008. "The Timing and Funding of CHAPS Sterling Payments." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 14, no. 2 (September): 113-33.
- Board of Governors of the Federal Reserve System.* 2001. "Policy Statement on Payments System Risk." *FEDERAL REGISTER* 66, no. 240: 64419-33. Docket nos. R-1107, R-1108, R-1109, and R-1110.
- . 2003. "Expansion of the Operating Hours for the On-Line Fedwire Funds Service." *FEDERAL REGISTER* 68, no. 101: 28826-8.
- . 2004. "Policy Statement on Payments System Risk." *FEDERAL REGISTER* 69, no. 187: 57917-31. Docket no. OP-1182. Available at <http://www.federalreserve.gov/BoardDocs/Press/other/2004/20040923/attachment.pdf>.
- Bowman, D., E. Gagnon, and M. Leahy.* 2010. "Interest on Excess Reserves as a Monetary Policy Instrument: The Experience of Foreign Central Banks." Board of Governors of the Federal Reserve System *INTERNATIONAL FINANCE DISCUSSION PAPERS*, no. 996, March.
- Brunnermeier, M. K., and L. H. Pedersen.* 2009. "Market Liquidity and Funding Liquidity." *REVIEW OF FINANCIAL STUDIES* 22, no. 6 (June): 2201-38.
- Cecchetti, S. G., and P. Disyatat.* 2010. "Central Bank Tools and Liquidity Shortages." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 16, no. 1 (August): 29-42.
- Coleman, S. P.* 2002. "The Evolution of the Federal Reserve's Intraday Credit Policies." Federal Reserve *BULLETIN*, February: 67-84.
- Copeland, A., A. Martin, and M. W. Walker.* 2010. "The Tri-Party Repo Market before the 2010 Reforms." Federal Reserve Bank of New York *STAFF REPORTS*, no. 477, November.
- Federal Reserve Banks.* 2006. "Funds Transfers through the Fedwire Funds Service." Federal Reserve Financial Services Operating Circular no. 6, September. Available at <http://www.frbservices.org/OperatingCirculars/pdf/Oc6.pdf>.

REFERENCES (CONTINUED)

- Fleming, M. J.* 2003. "Measuring Treasury Market Liquidity." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 9, no. 3 (September): 83-108.
- Furfine, C. H.* 2000. "Interbank Payments and the Daily Federal Funds Rate." *JOURNAL OF MONETARY ECONOMICS* 46, no. 2 (October): 535-53.
- Garbade, K. D., and W. L. Silber.* 1979. "The Payment System and Domestic Exchange Rates: Technological versus Institutional Change." *JOURNAL OF MONETARY ECONOMICS* 5, no. 1 (January): 1-22.
- Gilbert, A. M., D. Hunt, and K. C. Winch.* 1997. "Creating an Integrated Payment System: The Evolution of Fedwire." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 13, no. 2 (July): 1-7.
- Hilton, S.* 2005. "Trends in Federal Funds Rate Volatility." Federal Reserve Bank of New York *CURRENT ISSUES IN ECONOMICS AND FINANCE* 11, no. 7 (July).
- Keister, T., A. Martin, and J. McAndrews.* 2008. "Divorcing Money from Monetary Policy." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 14, no. 2 (September): 41-56.
- Martin, A.* 2004. "Optimal Pricing of Intraday Liquidity." *JOURNAL OF MONETARY ECONOMICS* 51, no. 2 (March): 401-24.
- Martin, A., and J. McAndrews.* 2008. "Liquidity-Saving Mechanisms." *JOURNAL OF MONETARY ECONOMICS* 55, no. 3 (April): 554-67.
- . 2010. "Should There Be Intraday Money Markets?" *CONTEMPORARY ECONOMIC POLICY* 28, no. 1 (January): 110-22.
- McAndrews, J.* 2006. "Alternative Arrangements for the Distribution of Intraday Liquidity." Federal Reserve Bank of New York *CURRENT ISSUES IN ECONOMICS AND FINANCE* 12, no. 3 (April).
- McAndrews, J. J., and S. M. Potter.* 2002. "Liquidity Effects of the Events of September 11, 2001." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 8, no. 2 (November): 59-79.
- McAndrews, J., and S. Rajan.* 2000. "The Timing and Funding of Fedwire Funds Transfers." Federal Reserve Bank of New York *ECONOMIC POLICY REVIEW* 6, no. 2 (July): 17-32.
- Mills, Jr., D. C., and T. D. Nesmith.* 2008. "Risk and Concentration in Payment and Securities Settlement Systems." *JOURNAL OF MONETARY ECONOMICS* 55, no. 3 (April): 542-53.
- Newey, W. K., and K. D. West.* 1987. "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix." *ECONOMETRICA* 55, no. 3 (May): 703-8.
- Payments Risk Committee and Wholesale Customer Advisory Group.* 2007. "Report of the Joint Task Force on the PSR Policy Consultation Paper." Available at http://www.newyorkfed.org/prc/prc_wcag_tf_report.pdf.
- Reserve Bank of New Zealand.* 2006. "Reform of the Reserve Bank of New Zealand's Liquidity Management Operations." June.
- Senior Supervisors Group.* 2009. "Risk Management Lessons from the Global Banking Crisis of 2008." October 21. Available at http://www.newyorkfed.org/newsevents/news_archive/banking/2009/SSG_report.pdf.

The views expressed are those of the authors and do not necessarily reflect the position of the Bank for International Settlements, the Federal Reserve Bank of New York, or the Federal Reserve System. The Federal Reserve Bank of New York provides no warranty, express or implied, as to the accuracy, timeliness, completeness, merchantability, or fitness for any particular purpose of any information contained in documents produced and provided by the Federal Reserve Bank of New York in any form or manner whatsoever.

