Interbank Payments and the Daily Federal Funds Rate

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Abstract[♦]

This paper develops a model of bank reserve management and federal funds rate determination that incorporates the role of interbank payments. In the model, uncertainty in the receipt of payments generates a precautionary demand for bank reserves as banks face both reserve requirements and penalties for overnight overdrafts. Days with higher payment volume are assumed to create more uncertainty in a bank's reserve account that accentuates this precautionary motive. As a result, upward pressure is placed on the equilibrium funds rate. Implications of the model are then estimated using a panel of large banking institutions. Using the parameter estimates, simulations of the model suggest that patterns in payment activity explain many intra-maintenance period movements in both the level and volatility of the federal funds rate.

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Section 1: Introduction

The federal funds rate, the rate at which financial institutions lend each other reserves overnight, attracts widespread attention, primarily because it reflects the stance of monetary policy (Bernanke and Blinder [1992]). As a popular measure of monetary policy, the funds rate plays a major role in the analysis of the impact of monetary policy (Miron, Romer, and Weil [1993], Bernanke and Mihov [1995]). Such research typically averages the actual federal funds rate over a period of a month or longer to correspond with the frequency of measurements of macro-level data. Some studies, however, have exploited the daily frequency of federal funds rate observations. For example, Rudebusch [1995] uses the daily federal funds rate to investigate puzzles in the term structure of interest rates, Feinman [1993a] relies on daily observations of the rate to estimate the Federal Reserve's daily operating policy, while others have explored apparent anomalies in the level and volatility of the rate itself (Dyl and Hoffmeister [1985], Campbell [1987], Spindt and Hoffmeister [1988], Hamilton [1996]). A greater understanding of the determination of the daily federal funds rate would therefore be useful for these applications as well as others.

As previous research has examined, the federal funds rate is determined in the market for bank reserves (Ho and Saunders [1985]). On a daily basis, the Federal Reserve changes the supply of reserves, based upon forecasts of reserve demand, in an attempt to achieve its target for the federal funds rate (Feinman [1993a]).[1] The observed daily deviations of the funds rate from target underscore the difficulty in accurately predicting reserve demand (Hamilton [1996]). Historically, reserve demand has been driven primarily by reserve requirements (Feinman [1993b], Weiner [1992]). By requiring banks to hold reserves either as vault cash or in an account at the Federal Reserve, a relatively stable demand for reserves could be achieved, making the Fed's goal of setting interest rates more straightforward. The importance of reserve requirements in determining reserve demand has been demonstrated by research documenting that the federal funds rate exhibits different behavior on different days of the reserve maintenance

[1] Some changes in reserve supply are beyond the direct control of the Fed. For instance, payments between commercial banks and the federal government affect reserve supply.

period (Spindt and Hoffmeister [1988], Hamilton [1996]), on reserve settlement days (Dyl and Hoffmeister [1985], Spindt and Hoffmeister [1988], Kopecky and Tucker [1993], Eagle [1995], Griffiths and Winters [1995], Clouse and Dow [1996], Hamilton [1996]), and following changes to reserve requirement accounting conventions (Lasser [1992]).

Over the last several years, however, lower reserve requirements and the introduction of sweep accounts at commercial banks have led to a marked decline in required reserve balances (Sellon and Weiner [1996]), perhaps creating increased uncertainty in reserve demand.[2,3] This has raised concern that the Fed's role of intervening in the reserve market to achieve the goals of monetary policy will become progressively more challenging (Brunner and Lown [1993], Clouse and Elmendorf [1997], Naroff [1997], Koretz [1997], Bennett and Hilton [1997], Hamilton [1997], Seiberg [1997]). Therefore, continued successful implementation of monetary policy relies crucially on understanding how the funds rate obtains each day in an environment where reserve requirements need not be of significant importance. With the exception of Clouse and Elmendorf [1997], however, none of the above research has analyzed the likely impact of a decline in required reserves. Further, none of the above papers has explicitly modeled, in a bank-optimization framework, motivations beyond statutory reserve requirements for holding bank reserves.

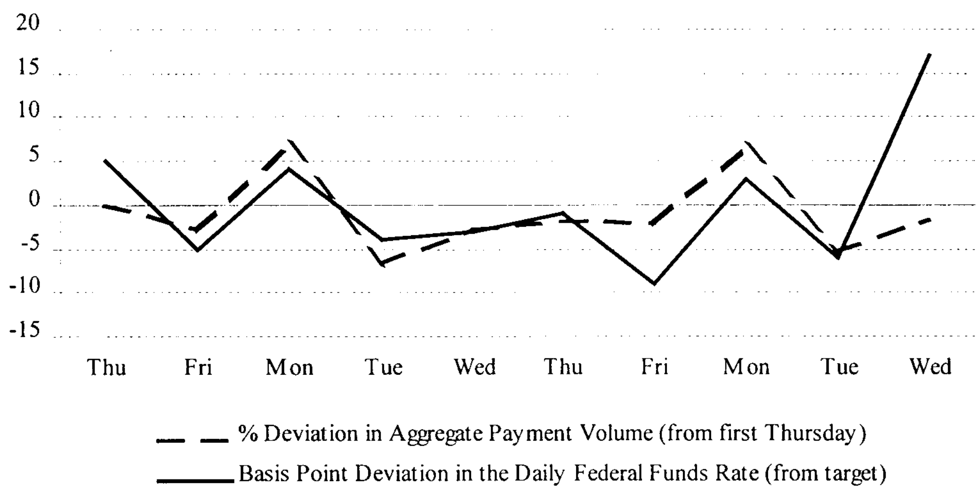
In contrast, this paper argues that interbank payments play a significant role in determining both the level and volatility of the daily federal funds rate. Evidence of the link between payments and the level of the funds rate is illustrated in Figure 1. The figure plots the estimated deviations in the funds rate over the reserve maintenance period estimated by the regression coefficients on the day-of-the-maintenance period dummy variables from a regression of the effective daily federal funds rate on the funds rate target and various calendar variables. The second line on the chart plots the percentage deviation in aggregate payments activity from its position on the first day of the banking system's two-week maintenance period estimated by the regression coefficients on the

[2] The Federal Reserve reduced reserve requirements twice, in 1990 and again in 1992.

[3] Sweep accounts move customer deposits on a daily basis from liabilities against which reserves are required to liabilities that require no reserves.

day-of-the-maintenance period dummy variables from a regression of aggregate payment volume on various calendar variables.[4] As is evident from the figure, movements in the funds rate appear to be highly positively correlated with movements in the volume of interbank payments.

Figure 1: Payment Patterns and Federal Funds Rate Deviations



This paper contributes to both the theoretical and empirical understanding of the determination of the daily funds rate. First, the model developed below gives an economic rationale for the apparent correlation between the level and volatility of the funds rate and bank payment flows. In particular, the model formalizes the interaction between payments activity, reserve balance uncertainty, optimal federal funds market participation, reserve requirements, and the equilibrium daily funds rate. Second, the model can, in an optimization framework, account for many of the observed patterns in the daily federal funds rate as well as the patterns to funds rate volatility. In particular, when interbank payment volume is higher, the federal funds rate tends to be higher and more volatile. Finally, the model's simulations of the federal funds rate's response to payment volume changes are based on parameter values that are estimated directly from a panel dataset.

[4] Reserve maintenance periods are discussed in Section 2.

The remainder of the paper is as follows. Section 2 briefly describes the two sources of reserve demand, namely reserve requirements and the funding of interbank payments. Section 3 develops a model of bank reserve management that generates a theoretical relationship between payment volume and the equilibrium daily federal funds rate. Section 4 structurally estimates the implications of the model using a panel of large banking institutions. The estimates are used to quantify the role that interbank payments play in determining the observed patterns in the level and volatility of the funds rate. Section 5 concludes.

Section 2: The Sources of Demand for Bank Reserves

The most widely recognized source of reserve demand is the existence of statutory reserve requirements.[5] Every two weeks, beginning on a Tuesday and ending on a Monday, depository institutions, hereafter called banks, measure their transaction account balances. The average transaction account balance during this two-week "reserve computation period" are the balances that are subject to reserve requirements. Vault cash and reserves held in accounts at a Federal Reserve Bank that are used to satisfy reserve requirements are averaged over a roughly contemporaneous period beginning two days after the start of the reserve computation period.[6] This second two-week interval, beginning on a Thursday and ending on "Settlement Wednesday," is called the reserve maintenance period. Only on the last two days of the reserve maintenance period will a bank's reserve requirement be known with certainty. Reserves are calculated over all fourteen days of the two-week period.[7] Banks failing to satisfy their reserve requirement are subject to penalties at a rate of 200 basis points above the discount rate.[8]

To date, research on the daily funds rate has generally not focused on the payments motivation for demanding overnight reserves. However, in light of recent

[5] Required reserves may be held in the form of vault cash and reserve balances that do not earn interest. Required clearing balances, which earn credits towards Federal Reserve priced services, are another component of required operating balances.

[6] Reserve requirements also have carryforward provisions whereby banks can smooth reserve surpluses and deficiencies across two reserve maintenance periods. See Feinman [1993b].

[7] Since banks are closed over weekends, Friday values are counted three times. Similarly, business days before one-day holidays within a given maintenance period are counted twice.

declines in required reserve balances, an understanding of the other sources of reserve demand becomes important -- specifically, the use of reserves to facilitate the nearly $2 trillion of large-value payments that are sent and received each day. Banks send and receive these large-value payments as a result of their own business activity and the activity of their customers. Both inflows and outflows of payments over the Federal Reserve's large-value wire transfer system, Fedwire, are reflected immediately as debits or credits to a bank's reserve account. Banks active in the payment system typically send and receive payments whose value is around 30 times greater than the bank's overnight reserve balance, with the most active banks typically having a ratio of payments to balances of nearly 200.[9]

To facilitate an efficient payment system, the Federal Reserve allows banks to maintain negative reserve account balances during the day, charging a rate of 15 basis points for so called "daylight overdrafts" (Richards [1995]). Since this charge is far below the overnight borrowing rate, many banks will typically use daylight overdrafts in addition to their overnight reserves to fund their intraday payments activity. The Federal Reserve, however, expects daylight overdrafts to be repaid in full by the close of Fedwire at 6:30 PM.[10] If a bank has not returned its account balance to a non-negative level, the resulting overnight overdraft is assessed a penalty at a rate of 400 basis points above the federal funds rate for that day. That is, although overdrafts are relatively inexpensive during the day, they are a relatively costly source of overnight funding compared with federal funds. To avoid the penalty for overnight overdrafts, a bank that otherwise would be in overdraft can borrow reserves in the funds market to return its account to a positive balance. Likewise, a bank that has had a large net inflow of payments during the day may find it less necessary to borrow or more likely to lend in the funds market. Therefore, a bank's daily demand for federal funds is likely influenced by its payments activity that day. This idea will be formalized in subsequent sections.

[8] Banks deficient in their clearing account forgo the accrual of earnings credits at the federal funds rate and also face a 200 basis point penalty.

[9] I define "active" banks as those that send and receive 600 or more payments over Fedwire daily, while the "most active" are those sending and receiving at least 7500 payments a day.

[10] In practice, overnight overdraft charges are applied to a bank's closing balance. Closing balances may differ from balances at 6:30 due to items that may be posted to a bank's account after Fedwire closes.

In general, both the two-week cycle and the weekend accounting conventions suggest that the demand for reserves may vary according to the day of the reserve maintenance period. However, as Hamilton [1996] argues, predictable variation in reserve demand due to reserve requirements should not necessarily be reflected in predictable patterns in the funds rate. Because banks face an average reserve requirement, market participants, through arbitrage, should eliminate predictable patterns in the funds rate. That is, a bank that knows that the funds rate will be higher on Monday than Friday should be willing to hold more reserves on Friday and sell more reserves on Monday, implying that the funds rate should follow a martingale within a reserve maintenance period. This paper will argue that one major invalidation of the martingale hypothesis is that banks are severely penalized for having a negative overnight reserve balance, and that this restriction, combined with reserve uncertainty, is sufficient to generate interday patterns in the daily funds rate. In addition, the paper further demonstrates that patterns in interbank payments can explain many of the intra-maintenance-period movement in the level and volatility of the funds rate.

Section 3: The Model

Model Timing:

The model characterizes the reserve management behavior of a commercial bank. For simplicity, the model assumes that the portfolio structure of the bank outside of reserves and federal funds activity can be treated as exogenously given. In particular, the model abstracts from issues such as a bank actively trying to reduce its required reserves. Because bank reserve decisions are driven, in part, by the reserve maintenance period, the model is equivalent to a series of fourteen calendar day (ten business day) models, each independent from one another.[11] Let m index the reserve maintenance period and t index the business day of the maintenance period. Therefore, m goes from 1 to ∞ while t goes from 1 to 10.

[11] I am abstracting from reserve carryforward provisions.

Market Environment:

Banks can participate in the federal funds market on each day indexed by the pair m,t. For simplicity, I assume that any bank i at time m,t can either buy an amount of federal funds B^{D}_{imt} or sell federal funds (negative B^{D}_{imt}) at the same rate of interest i_{mt}. That is, I assume that banks are price-takers. This abstracts from the market-making activity of banks and focuses only on a bank's need to hold an overnight funds position.

Intraday Bank Reserves and the Timing of Bank Decisions and Realizations:

Early Day: At the start of the day, the bank must return the funds that it borrowed from the day before, $B^{D}_{im,t-1}$.[12] Also during the early part of the day, each bank is sending and receiving payments. Let T_{imt} be the total volume of payments sent or received during the day by bank i on day mt. I define the net inflow of payments as χ_{imt}, which accounts for the fact that a bank will typically not have an equal volume of incoming and outgoing payments. The net inflow, χ_{imt}, is assumed to have accumulated before the bank decides on its federal funds activity for the day. For example, a bank that has a large negative value of χ_{imt} is going to be a federal funds borrower that day. Typically, much of a bank's payment flow may be known in advance, and therefore, I consider χ_{imt} to be exogenous.

Afternoon: Each bank, having observed its value of χ_{imt}, then decides how much it will borrow in the federal funds market, B^{D}_{imt}. Sales of federal funds can simply be considered negative values of B^{D}_{imt}.

End of Day and Closing: After the bank commits to a federal funds transaction B^{D}_{imt}, a shock ε_{imt} occurs to its reserve account. That is, there is uncertainty so that a bank cannot perfectly control its end-of-day reserve position. Since shocks to a bank's closing reserve balance may result from surprises in either incoming or outgoing payments, I assume that the magnitude of uncertainty in a bank's closing reserve account balance is positively related to the overall volume of payments that a bank has transacted that day, T_{imt}. This could be caused by operational glitches, bookkeeping mistakes, or payments expected from a counterparty that fail to arrive before the closing of Fedwire. Mathematically, I assume that ε_{imt} is normally distributed with a standard deviation being a function g, which is everywhere positive and increasing in T_{imt}.

Evolution of Reserve Balances: Defining R_{imt} to be the end-of-day reserve balance of bank i on day mt, the model assumes[13]

$$\begin{aligned} R_{i,m+1,1} &= R_{im,10} + \chi_{i,m+1,1} + B^D_{i,m+1,1} - B^D_{im,10} + \varepsilon_{i,m+1,1}, \ t=1 \\ R_{imt} &= R_{im,t-1} + \chi_{imt} + B^D_{imt} - B^D_{im,t-1} + \varepsilon_{imt}, \ t = 2,\ldots,10 \\ \varepsilon_{imt} &\sim N\left(0,(g(T_{imt}))^2\right) \end{aligned} \quad . \qquad (1)$$

Overnight Overdrafts:

During each day, banks are permitted to hold negative reserve balances. At the end of each business day, however, banks are expected to maintain a non-negative reserve balance. A penalty for negative closing balances, overnight overdrafts, is the key to invalidating the theoretical justification of the funds rate following a martingale process. Banks cannot arbitrage the predictable movements in the federal funds rate within a reserve maintenance period because of penalties for having a negative reserve account balance at the end of any given day. A bank wishes to avoid such a penalty by managing its purchase or sale of federal funds in a way that typically avoids overnight overdrafts.

Dropping the i subscript and defining f as the probability distribution of ε_{imt}, θ as the cost of overnight overdrafts, and $\hat{R}_{mt} = R_{m,t-1} + \chi_t + B^D_{mt} - B^D_{m,t-1}$ as the certain portion of a bank's closing balance, a bank's expected cost of overnight overdrafts can be written for t>1 as

$$\theta \times \left[\int_{-\infty}^{-\hat{R}_{mt}} (\hat{R}_{mt} + \varepsilon_{mt}) f(\varepsilon_{mt}) d\varepsilon_{mt} \right] \qquad (2)$$

[12] For the discussion, I assume that the bank is in the middle of a maintenance period. However, the model will take into account when adjoining business days span two separate maintenance periods.
[13] For tractability, I have assumed that interest paid or received on federal funds activity is insignificant for purposes of reserve management and can be ignored.

where the term in brackets is the expected size of the reserve deficiency and the rate θ is the overdraft charge.[14] Rewriting in terms of a standard cumulative density function Φ and simplifying, the overnight penalties can be written as

$$\theta \times g(T_{mt}) \times \left[\int_{-\infty}^{\frac{-\hat{R}_{mt}}{g(T_{mt})}} \Phi(v) dv \right]. \tag{3}$$

Reserve Requirements:

I model the impact of reserve requirements in a similar way as I model overnight overdraft penalties. Defining

$$\begin{aligned} z_t &= 3 \text{ for } t = 2,7 \\ z_t &= 1 \text{ otherwise} \end{aligned} \tag{4}$$

as the scaling factor that accounts for the fact that reserves count three times over a weekend, a bank's reserves which count towards meeting its reserve requirement are equal to $\sum_{t=1}^{10} z_t R_{imt}$. This quantity is uncertain during each day of the maintenance period, but becomes less uncertain throughout the maintenance period as early reserve shocks are realized. On the last day of the reserve maintenance period, the only unresolved uncertainty is the last day's reserve shock. To maintain symmetry with the overnight overdraft penalties, I assume that a bank faces a cost r for each dollar of reserve deficiency that it has on Settlement Wednesday, t=10. Defining RQR as a bank's required reserve balances (net of applied vault cash and any carryforwards), a bank's expected reserve deficiency charge can be written as

$$r \times \left[\int_{-\infty}^{-\left(\left(\sum_{t=1}^{9} z_t R_{mt}\right) + \hat{R}_{m,10} - RQR_{mt}\right)} \left(\left(\sum_{t=1}^{9} z_t R_{mt}\right) + \hat{R}_{m,10} - RQR_{mt}\right) f(\varepsilon_{m,10}) d\varepsilon_{m,10} \right]. \tag{5}$$

[14] An alternative to running an overnight overdraft would be for the bank to take out a loan from the discount window. The model implicitly assumes that the cost of either action is the same.

The integrand represents the overall reserve position of a bank. It consists of the accumulated reserve position going into the last day of the maintenance period plus the certain part of the last day reserve position less the bank's required reserves for the period. The deficiency is integrated over the values of $\varepsilon_{m,10}$ that would make the bank fail its reserve requirement.[15] Once again, simplifying the expected reserve deficiency charge in terms of a standard normal variable, the charge for failing reserve requirements can be expressed by

$$r \times g(T_{m,10}) \times \int_{-\infty}^{\frac{-\left(\left(\sum_{t=1}^{9} z_t R_{mt}\right) + \hat{R}_{m,10} - RQR_{mt}\right)}{g(T_{m,10})}} \Phi(v)\,dv \;. \tag{6}$$

Bank Objective Function:

A representative bank is assumed to minimize the expected discounted costs of its reserve management activities, plus costs incurred from overnight overdraft penalties and failing reserve requirements. Since the time periods being modeled are 24-hour periods, it is unlikely that banks discount day-to-day operations in the standard sense. However, the model aims to capture potential deviations from the maintenance period optimization by allowing banks to weight the costs occurring on different days. The daily weighting factor, defined by δ, allows banks to be more concerned about the current day's outcome than would be implied by strict rational expectations. That is, a bank solves

$$\underset{\{B_{mt}^{D}\}}{Min}\; E\sum_{m=1}^{\infty}\sum_{t=1}^{10}\delta^{10m+t}\left(z_t\left[i_{mt}B_{mt}^{D} + \theta g(T_{mt})\int_{-\infty}^{\frac{-\hat{R}_{m,t}}{g(T_{mt})}}\Phi(v)\,dv\right] + \left[rg(T_{m,10})\times\int_{-\infty}^{\frac{-\left(\left(\sum_{t=1}^{9} z_t R_{mt}\right)+\hat{R}_{m,10}-RQR_{mt}\right)}{g(T_{m,10})}}\Phi(v)\,dv\right]\right) \tag{7}$$

subject to (1). Equation (7) accounts for the fact that interest and overdraft penalties accrue for z_t days.[16]

[15] The model does not distinguish between required reserves and required clearing balances. Failing either requirement either implicitly or explicitly costs the bank an amount equal to 200 basis points over either the funds rate or the discount rate.

[16] Although left to the discretion of the Federal Reserve Bank maintaining the account, I have assumed for tractability that overnight overdraft penalties would be weighted by z.

Let a bank's optimal choice of federal funds borrowing be denoted by the series $\{B^{*D}_{mt}\}$. For any of the first nine days of the maintenance period, consider a small deviation from this optimal plan that involves the bank borrowing $(B^{*D}_{mt} + \omega/z_t)$ at time t, and borrowing $(B^{*D}_{m,t+1} - \omega/z_{t+1})$ at time $t+1$. This change leaves both the reserve position $R^*_{m,t+2}$ as well as the accumulated reserve position $R_{mt} + R_{m,t+1}$ unchanged at time $t+2$. That is, $R_{m,t+2} = R^*_{m,t+2}$ and $R_{mt} + R_{m,t+1} = R^*_{mt} + R^*_{m,t+1}$. For the original path of federal funds rate borrowing $\{B^{*D}_{mt}\}$ to be optimal, the bank's optimal choice of ω must be zero. Analysis of this deviation yields the first order condition

$$\left[i_{mt} - \theta\Phi\left(\frac{-\hat{R}_{m,t}}{g(T_{mt})} \right) \right] = \delta E\left(i_{m,t+1} + \theta\Phi\left(\frac{-\hat{R}_{m,t+1}}{g(T_{m,t+1})} \right) \right) \tag{8}$$

Intuitively, a bank should be indifferent to shifting a dollar of borrowing from one day to the next within a maintenance period. Note that in the absence of overnight overdraft penalties, the federal funds rate follows a martingale within a maintenance period.

For the last day of the maintenance period, a bank can consider increasing its borrowing on that day. This has no repercussions for the following period's accumulated reserves since the following day begins a new maintenance period. For day 10 of the maintenance period, therefore, the first order condition is

$$i_{m,10} - \theta\Phi\left(\frac{-\hat{R}_{m,10}}{g(T_{m,10})} \right) - r\Phi\left(\frac{-\left(\left(\sum_{t=1}^{9} z_t R_{mt} \right) + \hat{R}_{m,10} - RQR_m \right)}{g(T_{m,10})} \right) = 0 \tag{9}$$

Intuitively, this says that on the final day of the maintenance period, the bank simply chooses its federal funds borrowing to equate the marginal cost of borrowing to the sum of the marginal savings of expected overnight overdraft penalties and reserve requirement deficiency penalties.

Defining DAY10 to be equal to 1 on the last day of the maintenance period and 0 otherwise, (8) and (9) can be estimated simultaneously by the equation

$$\delta\left(i_{m,t+1}-\theta\Phi\left(\frac{-\hat{R}_{m,t+1}}{g(T_{m,t+1})}\right)\right)\times(1-DAY10)$$
$$=\left[i_{mt}-\theta\Phi\left(\frac{-\hat{R}_{mt}}{g(T_{mt})}\right)-DAY10\times r\Phi\left(\frac{-\left(\left(\sum_{t=1}^{9}z_t R_{mt}\right)+\hat{R}_{m,10}-RQR_{mt}\right)}{g(T_{m,10})}\right)\right]+\tau_{mt} \tag{10}$$

where $\tau_{mt}=(1-DAY10)\times\mu_1+\ DAY10\times\mu_2\ +\kappa_{mt}$, and κ_{mt} is an expectation error at time mt.[17] Note that the incorporation of the time invariant specification errors μ_1 and μ_2 explicitly allows for the possibility that settlement day errors to the model's assumed behavior may differ from errors occurring on the first nine days of a maintenance period.

Section 4: Data, Estimation, and Results

The interest rate used for the estimation was the effective federal funds rate, which is a volume weighted average of federal funds transactions for the given day. This rate best measures the rate that banks trading in federal funds would likely pay on a given day. Because the effective rate weights across transactions, the impact of intraday variation in market liquidity is minimized. That is, the end-of-day market thinness and corresponding rate spikes that have been documented in the literature would not, in general, influence the effective rate.[18]

The sample of banks in this study consists of all depository institutions with accounts at a Federal Reserve Bank that have a daily average of at least 300 account debits and 300 account credits resulting from transfers over Fedwire for the time period beginning on May 27, 1993 and ending on May 7, 1997.[19] The starting date coincides

[17] Technically, the expectation errors are only present during the first nine days of the maintenance period.
[18] The estimation was also calculated using the closing rate, which although adding numerous outliers to the sample, did not change the qualitative nature of the results that follow.
[19] As outliers may present a problem for the nonlinear analysis, I eliminated observations that had a ratio of closing balance to payment volume of either less than 0 or greater than 100000. This eliminated approximately 1% of the sample.

with the creation of the *Daylight Overdraft Report Pricing System* (DORPS), which is used by the Federal Reserve Banks to monitor a bank's compliance with payment system risk policies such as daylight overdraft caps.[20] This confidential database was the source for daily payment volumes and daily closing reserve balances. The measure of transactions used in the estimation was the total dollar value of a bank's credits and debits due to Fedwire funds transfers for a given day.[21] As bank reserves are continuously changing, I do not attempt to estimate the bank's reserve balance before its end of day shock, but simply replace $\hat{R}$ with the bank's closing reserve balance for that day, R.

A bank's required reserve balance was constructed from the Federal Reserve's *Report of Transaction Accounts.* This series contains information on all balance sheet items necessary to measure compliance with reserve requirements. Since the reserve balance measures are only counting reserves held in an account with the Fed, my required reserve measure was constructed accounting for applied vault cash, required clearing balances, and carryforward provisions for each bank during each maintenance period. Therefore, the measure of required reserves being used is actually a measure of required operating balances held in a bank's Fed account.[22]

I modeled the relationship between uncertainty and payment volume as a linear function. That is, $g(T_{imt}) = \alpha T_{imt}$. I also restrict the model to conform to statutory requirements. Specifically, prior to April 1, 1994, the penalty for overnight overdrafts was a flat rate of 10%. After this date, the penalty was set at 4% over the federal funds rate. Therefore, I restrict the value of the overnight overdraft penalty, θ, to be either .10 or $(i_t + .04)$. The value of the reserve requirement penalty, r, is set to $(i_t + .02)$.

To control for possible cross-sectional heterogeneity that is correlated with payment activity, the sample was separated into size categories based upon the number of payments made on an average day.[23] Summary statistics for the sample are given in

[20] DORPS calculates the Federal Reserve account balance of each institution on a minute-by-minute basis in addition to keeping daily totals for the number and value of wire transfers.

[21] Although included in this measure, payments associated with federal funds activity do not appear to be driving the patterns in overall payment volume.

[22] Required reserve balances are likely the source for marginal changes to a bank's total reserves, and therefore are most likely the most relevant in determining the funds rate.

[23] Various permutations of size categories were examined, with negligible changes in the results.

Table 1. As the table indicates, banks that send and receive a greater number of payments also tend to have large required reserve balances. This is because these banks are typically larger, and also because banks active in the payment system are more likely to establish clearing accounts with the Federal Reserve. Such clearing balances are part of a bank's required reserve balance. The table also indicates that payment volume is quite high relative to reserve balances. The banks most active in the payment system have a median ratio of payment value to required reserve balances of 180.58.

Table 1: Summary Statistics

	Number of Transactions on Average			
	600-1500	1500-3000	1500-7500	Over 7500
Number of Banks	58	28	18	12
Number of Observations	49561	24923	16058	11339
Median Daily Payment Value (Millions)	1490	3980	9820	61900
Median Required Reserve Balances (Millions)	59.4	88.2	182	317
Median Payments to Closing Balance Ratio	28.98	53.83	57.80	180.58

I estimate equation (10) using nonlinear least squares. Parameter estimates are given in Table 2. Reported standard errors have been adjusted for potential autocorrelation and heteroskedasticity using the method of Newey and West [1987]. One thing to notice about the parameter estimates is that the estimated value for δ varies between .87 and .95. This estimate is consistently and significantly below 1, indicating that banks neither act as if they minimize daily costs, nor do they act as if they minimize maintenance period costs. Banks seem to be interested in returns over a maintenance period, yet place a higher weight on the current day's reserve position. The second result from the estimates is the value of the parameter α. The estimated value of between .00005 and .00076 suggests that for every million dollars of Fedwire funds transactions that a bank processes, a bank's end-of-day reserve uncertainty increases by between 50 and 760 dollars. The typical bank in the most active category processes approximately

$62 billion a day in Fedwire funds transactions, leading to an estimated reserve uncertainty of approximately $10 million.

Table 2: Parameter Estimates

	Banks with 600-1500 Funds Transfers on Average	Banks with 1500-3000 Funds Transfers on Average	Banks with 3000-7500 Funds Transfers on Average	Banks with Over 7500 Funds Transfers on Average
δ maintenance period weighting parameter	.952 (.002)	.918 (.003)	.877 (.006)	.923 (.005)
α sensitivity of uncertainty to payments parameter	.501 e – 04 (.402 e – 05)	.275 e – 03 (.147 e – 04)	.765 e – 03 (.406 e – 04)	.167 e – 03 (.798 e – 05)
μ_1 constant term, non-settlement days	.583 e – 05 (.202 e – 06)	.978 e – 05 (.423 e – 06)	.146 e – 04 (.794 e – 06)	.880 e – 05 (.699 e – 06)
μ_2 constant term, settlement days	-.410 e – 04 (.163 e – 05)	-.379 e – 04 (.223 e – 05)	-.352 e – 04 (.261 e – 05)	-.524 e – 04 (.308 e – 05)

Payments and the Level of the Federal Funds Rate:

These parameter estimates can be used as a foundation for simulating the impact of payment volume on the daily federal funds rate. For the results presented, I have simulated the model's implications assuming that the aggregate banking system observes equation (10), that the parameters have the values corresponding to the last column in Table 2, and that payments follow their actual path.[24,25,26] Table 3 presents the baseline results from the model. The first column lists the maintenance period pattern in the federal funds rate assuming a target rate of 5.00%. This pattern is estimated from the data. The second column lists the difference between the actual rate and the target rate.

24 The results are qualitatively similar with parameter values from the other columns.

25 Payments patterns were estimated from a fixed-effect regression of payment volume on its own lag, a variety of calendar-effect variables, and dummy variables representing the days of the maintenance period.

26 The model generated unnaturally high interest rates for the day before settlement day that was traced to the value of δ. For the simulation results, the value of δ was restricted to equal .8.

The third and fourth columns in the table list the actual and assumed pattern in reserves. The actual path was estimated from the same panel of banks used to estimate the model. The assumed pattern was chosen to match the simulated path of the federal funds rate to the actual path. Although the model can replicate the path of the funds rate exactly, it must assume a different and more volatile path for reserves than what is actually observed.

Table 3: Model Simulations – Federal Funds Rate Level

	Actual Federal Funds Rate (Assuming 5.00 % Target Rate)	Basis Point Difference from Target	Actual Reserve Balances (Percentage Deviation from First Monday)	Assumed Reserve Balances (Percentage Deviation from First Monday)	Federal Funds Rate Simulated with Constant Payment Volume	Basis Point Difference from Target
Thursday	5.05 %	5	-1.7 %	-19.6 %	5.10 %	10
Friday	4.95 %	-5	-11.2 %	-14.4 %	4.91 %	-9
Monday	5.04 %	4	0.0 %	0.0 %	5.02 %	2
Tuesday	4.96 %	-4	-3.9 %	-27.1 %	5.06 %	6
Wednesday	4.97 %	-3	-15.2 %	9.4 %	5.02 %	2
Thursday	4.99 %	-1	-3.2 %	-28.7 %	5.04 %	4
Friday	4.91 %	-9	0.2 %	25.5 %	4.80 %	-20
Monday	5.03 %	3	12.7 %	-18.8 %	4.92 %	-8
Tuesday	4.94 %	-6	-13.5 %	-0.9 %	4.98 %	-2
Wednesday	5.17 %	17	-13.0 %	-15.6 %	5.18 %	18

The final two columns of Table 3 present the simulated path of the federal funds rate if payment activity is held constant across days. Comparing columns 2 and 6 presents evidence that payments activity is partially responsible for the observed interest rate behavior. For instance, the most noticeable pattern in the federal funds rate besides the settlement day spike is the fluctuating behavior on the second Monday and Tuesday. In reality, the funds rate tends to first rise on the second Monday, then fall noticeably on the second Tuesday, before spiking on settlement day. When payments are held constant, this fluctuating behavior disappears. In particular, on the second Monday, the federal funds rate is simulated to be 11 basis points below where it actually is on Monday. This is likely attributable to the fact that the second Monday of the maintenance period is also the busiest payments day of the period (see Figure 1). Lower than average payment volume also appears responsible for the decline in the funds rate on the middle Tuesday, Wednesday, and Thursday. Finally, the results suggest that the behavior of the funds rate on settlement day does not appear to be significantly influenced by payments activity.

Payments and the Volatility of the Federal Funds Rate:

The model can also be used to investigate volatility in the federal funds rate. That is, although payments activity has predictable movements, it also is uncertain. To investigate the impact of payments uncertainty, I have simulated the model with random payments levels that match the pattern of uncertainty estimated from the data.[27] The simulations were run 250 times and the standard deviation of the funds rate was calculated for each day of the maintenance period. This exercise was repeated 50 times to get a measure of the spread of the estimates. These results are shown in Table 4. In general, the model generates volatility in the funds rate quite similar to the volatility that is observed in the actual data. The model tends to over-predict volatility in the earlier days of the maintenance period. The model, however, does replicate some key features of the data. For example, the model accurately predicts an increase in funds rate volatility on the heavier payment days (Mondays), a U-shaped pattern in volatility between the first and second Mondays, and a marked decline in volatility relative to adjoining days on the second Tuesday. Finally, the model captures the large increase in funds rate volatility on settlement day.

[27] The pattern of uncertainty in payments activity was taken as the standard deviation of the percentage deviation of payments volume from its predicted level in a fixed-effects regression of payment volume on its own lag, calendar variables, and dummy variables for the days of the maintenance period. This was estimated using the most active payments sample that was also the sample used for the other simulation results. These values were then scaled down to better match the actual volatility in the data as initial estimates generated excessive volatility.

Table 4: Simulations -- Federal Funds Rate Volatility

	Actual Federal Funds Rate Volatility (Basis Points)[28]	Simulated Funds Rate Volatility – Current Reserve Requirements Average Over 250 Simulations (Basis Points - 50 Repetitions)		
		Min	Mean	Max
Thursday	11.9	20.2	22.3	24.1
Friday	11.4	20.7	22.6	24.3
Monday	14.0	21.3	23.3	25.5
Tuesday	10.8	10.5	12.2	13.5
Wednesday	8.1	13.5	14.8	16.7
Thursday	13.4	16.5	17.7	19.4
Friday	17.3	15.4	17.0	18.1
Monday	25.5	21.4	23.6	25.5
Tuesday	15.7	14.2	15.5	17.2
Wednesday	39.9	37.5	40.9	46.2

Section 5: Conclusion

This paper formalized the relationship between bank payment activity and the federal funds rate. In the model developed, uncertainty in bank reserve balances was an increasing function of payment volume. On busier days, therefore, banks desired to hold a larger cushion of reserves to protect against penalties for overnight overdrafts. In equilibrium, this generated a positive relationship between payment volume and the federal funds rate. The implications of the model were estimated using a panel dataset of depository institutions that are very active in the payment system. Simulating the model using parameter values estimated from the data suggest that maintenance-period patterns in the federal funds rate can be partially explained by patterns that occur in bank payment activity. Although changes in the supply of reserves could conceivably offset the predictable portion of funds rate movements caused by payments patterns, the results

[28] This was calculated as the standard deviation in the daily funds rate from its predicted value in a regression of the effective rate on its own lag, the target rate, calendar variables, and dummy variables for the days of the maintenance period.

suggest that at least in part, this is not done. The results further demonstrated that patterns in payments' volume and volatility can largely explain maintenance period volatility.

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