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Abstract

In January 2003, the Federal Reserve introduced primary credit as its main discount window lending program. The primary credit program replaced the adjustment credit program, which, subject to a number of restrictions, had generated a stigma associated with borrowing from the Fed. Eliminating or lessening the stigma of borrowing was viewed as essential for reducing the reluctance to borrow and strengthening the traditional role of the discount window as a safety valve when reserve markets tighten unexpectedly. In this paper we estimate the borrowing function prior to and after the introduction of the new facility and develop a daily model of borrowing. Using this model, we estimate the implicit cost associated with borrowing for the first time in the literature via "indirect inference" a la Gourieroux, Monfort and Renault (1993). Our results suggest that the stigma associated with borrowing from the Fed is significantly reduced in the post 2003 period.

Keywords: Discount Window, Primary Credit, Federal Funds Market

JEL Codes: E40, E58

1. Introduction

In January 2003, the Federal Reserve revised its discount window lending program. The new facility resembled the standing facilities of some central banks that make collateralized loans at above market rates. This facility was intended to improve the working of the discount window which had lost its functionality under the old regime prior to 2003. Before 2003, borrowing from the Fed took place at a rate below the market rate (called the "discount rate"), and Fed officials applied a non-price rationing mechanism by asking detailed questions to potential borrowers about their financial well-being before granting them a loan. Slowly, this administrative process pushed depository institutions away from the discount window because borrowing from the Fed was perceived as a signal of financial weakness by market participants (see e.g. Goodfriend, 1983; Pearce, 1993; Dutkowsky, 1993; Peristiani, 1998; Clouse and Dow, 1999; Furfine, 2003; Dow, 2001; Darrat et al., 2004).

The new borrowing facility was designed to eliminate the reluctance to borrow from the Fed with a new "no questions asked" policy towards eligible borrowers. However, despite the assurance by the Fed that the new facility would eliminate all administrative costs of borrowing, some argued that the stigma could not be eliminated completely. Furfine (2001) looked at the experience of the banking system under the special lending facility before the century date change and argued that despite the removal of all administrative costs on discount window borrowing at that time, depository institutions still remained hesitant to borrow from the Fed. This made him predict that depository institutions would follow a similar attitude towards the new facility after 2003. Furfine (2003) also looked at some

preliminary data on borrowing during the first three months of the new facility and noted that the borrowing behavior was consistent with his predictions from the earlier paper.

Did the experience in the pre-2003 period create a permanent stigma in market psychology which cannot be changed by a new regime? Or did the market participants simply need a little time to warm up to the new regime and they are now using the new facility liberally whenever a need arises? This paper attempts to answer these questions for the first time by analyzing the daily borrowing behavior before and after the establishment of the new facility. In particular, we investigate whether and to what extend the new facility reduced the non-price cost of discount window borrowing. Our results suggest that the stigma is reduced substantially over the three years since the formation of the new facility and the borrowing function is once again operational.

The structure of the paper is as follows. In the next section, we give a historical overview of borrowing from the Fed and provide a perspective on the problem. The third section provides an estimation of the daily borrowing behavior which illustrates the re-appearance of the borrowing function. In the fourth section, we develop and estimate an equilibrium model of the federal funds market. The model explains the adjustments in the borrowing behavior with the changes in the fixed cost of borrowing in the post-2003 period which reinforces our findings in the third section. The fifth section concludes.

2. Discount Window Borrowing: Why is it Important?

Monetary policy in the United States is implemented by setting a target for the interbank overnight borrowing rate (federal funds rate) that is consistent with the Federal Reserve's

ultimate objectives of price stability and sustainable growth. The Federal Reserve pursues these goals operationally through open market operations where the level of reserve balances are adjusted to ensure that overnight interest rates do not deviate from the target. Hence, interest rate stability can be viewed as the first measure to judge the performance of the central bank and establish its credibility.

In implementing open market operations, the Trading Desk forecasts the balance need for each day and injects the necessary amount of reserves to the system. Nevertheless, open market operations alone may not be sufficient to achieve interest rate stability because the Desk may forecast the total need for balances erroneously, or even if there is no shortage of balances in the aggregate level, there may be problems regarding the distribution of these balances within the banking system. The additional tool that the Fed uses to limit interest rate volatility is to provide credit to depository institutions through the discount window. The discount window credit has two main roles: First, it makes additional balances available when the aggregate supply of balances provided through open market operations fall short of demand and hence prevents an excessive tightening of the interbank market. Second, it enables depository institutions that are financially sound but have experienced an unexpected shortage of balances to meet their needs (see Madigan and Nelson, 2002).

Over the last decade, the Desk faced several challenges in achieving its goal of maintaining the funds rate target. The first of these challenges was the decline in required reserve balances. The reduction in required reserve balances reflected official actions and private sector activity. In 1990 and 1992 the Fed reduced reserve requirements on several types

of deposits. Beginning in 1994, depository institutions adopted retail sweeps programs in which funds above a predetermined amount are transferred from a depositor's checking account on which required reserve ratios are positive, to nontransaction accounts, which are not reservable. When required balances are low relative to balances needed for clearing, however, it is more difficult for the Desk to ensure trading at the target because clearing needs are more volatile and less easy to predict. Nevertheless, the Desk was very successful in controlling the volatility in the funds rate in this era by tailoring its actions to adjust to a low reserve balances environment (see Demiralp and Farley, 2005).

Another challenge that the Desk faced more recently is the anticipation effect in the funds market, which was a consequence of the steps taken towards central bank transparency and openness. Achieving the target in the days prior to a well-anticipated policy action still constitutes a challenge to the Desk because it faces a trade-off between maintaining the target before the policy action and generating more interest rate volatility after the action (see Carpenter and Demiralp, 2006b).

A third challenge faced by the Desk, and which is the focus of this paper is the gradual abandonment of the discount window and the disappearance of the sensitivity of borrowing to the interest rate paid for borrowing (i.e. the "borrowing function") over the last two decades. Until 2003, interest rate charged on discount credit (i.e. "discount rate") was set below the federal funds rate. This practice caused significant problems because the incentive for depository institutions to exploit the below-market rate meant that borrowing requests were subject to considerable administration by the Fed. Furthermore, because

depository institutions that borrow from the discount window were expected to seek funds from alternative sources first, those who borrowed from the Fed were perceived by market participants as institutions in financial weakness.[1] This growing reluctance impaired the functioning of the discount window because depository institutions preferred borrowing from the interbank market at high rates rather than going to the discount window. With the loss of the functionality of the discount window as a secondary source of funds, any forecast errors by the Desk in calculating balance needs or a distributional problem were reflected as deviations in the funds rate from the target.[2]

The Federal Reserve's response to this challenge was to make changes to its lending program so that it would be more appealing to depository institutions. To overcome the problems associated with borrowing and to make the discount window operational again, the Federal Reserve introduced a new borrowing facility in 2003. This new facility offered credit to banks in good financial conditions at a rate that is 100 basis points above the FOMC's target federal funds rate ("primary credit rate"). Primary credit is made available to financially sound depository institutions at an above-market rate but with very little administration and no restrictions on the use of the proceeds (see Madigan and Nelson, 2002). Because the interest rate charged on primary credit is above the market price of funds, it replaced the rationing mechanism for obtaining funds from the central bank and eliminated any administrative review by the Fed.

[1] Borrowing information is kept in strictest confidence at the Fed. However, market participants try to infer the borrowing institutions by looking at regional borrowing data from the H.4.1. release.

[2] Carpenter and Demiralp (2006a) estimated that the funds rate deviates from the target about a basis point for each $1 billion forecast error.

Figure 1 provides a preliminary look at the data that plots the federal funds rate (FFR) which is a volume-weighted average of the rates that took place in the funds market, federal funds rate target (FFT), the primary credit rate (PRIM) as well as the maximum traded funds rate on a particular day (FF_HIGH). A quick way to assess the performance of the new facility is to check whether the primary credit rate indeed constitutes an upper bound for the funds rate or not. Figure 1 shows that this is not the case because there are days on which the banks preferred borrowing in the funds market and paid a higher rate rather than borrowing from the Fed at the primary credit rate. One should be careful, however, in not drawing quick conclusions based on this figure alone. First of all, this figure does not provide any information about the size of borrowing in the funds market at rates above the primary credit rate, so we cannot determine the size of the "stigma" by looking at the rates alone. Similarly, we cannot infer any information about how much is borrowed from the Fed on those days either. Figure 2 plots the volume of primary credit borrowing on days when the daily high funds rate exceeded the primary credit rate. The figure illustrates that there were sizable amounts of borrowing on these days, with average borrowing close to $944 million. Comparing this number to average borrowing across all days under the new facility, which was only about $56 million, there is clear evidence that market participants used the new facility extensively when the market was tight (about seventeen times more than normal times). In fact, comparing these numbers to the pre-2003 period, average borrowing in that period was $112 million (since 1989) while average borrowing on days when the daily high funds rate was at least 100 basis points above the target was only about $575 million (or about five

times larger than normal times).[3] Naturally, these back of the envelope calculations do not control for other factors that may affect depository institutions' borrowing decisions such as daily liquidity conditions or volatility in the funds market. Controlling for these factors and estimating the borrowing function is the subject of our next section.

3. Estimation of the Daily Borrowing Behavior

A quick look at the data in the previous section points to a revival of the borrowing function. In this section we analyze the determinants of the borrowing behavior empirically and detect any changes that materialize after 2003 consistent with the re-emergence of the borrowing function.

Empirical analysis of the borrowing function go back to Goldfeld and Kane (1966) who noted that borrowing should depend on the spread between the funds rate and the discount rate. As the Fed shifted to a borrowed reserves regime in early 1983 and borrowing became a more important policy tool, more sophisticated estimates of the borrowing relationship were developed where the implicit cost of borrowing was introduced (see Dutkowsky, 1993; Peristiani, 1994). Goodfriend (1983) considered a dynamic framework in which a bank's decision to borrow on a particular day depended on its expected borrowing needs for the rest of the maintenance period. As noted in Dow (2001), however, at the same time that the borrowing function literature developed, banks' attitudes towards the discount window changed. In particular, the crisis in the banking system in late 1980s caused banks to shy away from the discount window for fear of financial weakness. By 1990s, the traditional

[3] These calculations exclude borrowing from the Fed between September 11, 2001 and September 21, 2001 to avoid the temporary hike in borrowing resulting from the terrorist attacks.

borrowing function seemed to disappear (see Pearce, 1993; Dow, 2001). Consequently, the dynamic aspect of borrowing ceased and borrowing reduced down to a static problem.

In estimating the borrowing function, we use daily data on borrowings from the Federal Reserve from 1989 to 2007. Daily frequency is considered for the first time in our paper and it is essential for this framework because it allows us to capture the responses to short-lived changes in the funds rate, which characterizes the nature of static borrowing for our sample period.[4] The sample period starts on July 30, 1998 which corresponds to the switch from contemporaneous reserves accounting (CRA) to lagged reserves accounting (LRA).[5] This starting date underlines the fact that we do not need to worry about any dynamic aspect regarding the daily borrowing behavior. The data from September 11, 2001 through September 21, 2001 are excluded from the analysis because excessive amounts of borrowings in that period were purely driven by the terrorist attacks and do not reflect ordinary circumstances.

Table 1 presents the estimation results. Our dependent variable is the volume of borrowing from the Federal Reserve (in $ millions). In specifying the right hand side variables, we focus on factors that may affect borrowing decisions at the aggregate level. The sample is divided into two periods, before and after 2003 by interactive dummy variables. Rows one through eleven display the results from the first sample period. Following Goldfeld and Kane (1966), the first variable that we consider is the spread between the funds rate and the

[4] Most of the previous studies cited earlier considered a bi-weekly or lower frequency.

[5] Under LRA depository institutions maintain reserve account balances with a Federal Reserve Bank against checking account and other transaction account deposits outstanding two weeks earlier. This system allows depository institutions to know their balance requirements prior to the beginning of the maintenance period.

discount rate (row two). Everything else remaining the same, borrowing from the Fed should be positively related to this spread, indicating that market participants borrow from the discount window when the market tightens. Despite the findings of a significant coefficient for earlier sample periods in the previous literature, the reluctance to borrow from the Fed is the dominant feature in our first sample period, which results in an insignificant coefficient for this spread. This is consistent with the disappearance of the borrowing function as a result of the growing stigma. In contrast, the spread between the funds rate and primary credit rate is positive and highly significant for the second sample (row 13) suggesting that with the switch to the new regime and the reductions in the implicit cost associated with the discount window, borrowing function once again became sensitive to the price of borrowing. Specifically, when the spread between the funds rate and the primary credit rate increases by one basis point, borrowing from the Fed increases by about $8 million on that day.

The next variable captures those instances when the maximum funds rate traded for that day deviated from the target by at least one percentage point. This spread measures the extent to which market participants turn to the new borrowing facility when a need arises in the recent period. Comparing the estimates from pre-2003 period (row 3) with post-2003 (row 14), we see that depository institutions' reliance on the discount window increased more than eight folds on these occasions in the recent sample (from 0.46 to 3.90). This is one of the most interesting result for our purposes because it indicates that when the funds rate exceeds the target by at least a percentage point (so that fed funds rate for that particular trade equals primary credit rate) market participants' borrowing from the Fed increases

substantially, consistent with the decline in the implicit cost of borrowing.

Madigan and Nelson (2002) note that firmness in the federal funds rate at the close of the day may cause some depository institutions to borrow from the Fed because they may not have time to search for trading partners, even though the temporary firmness may not show up in the average funds rate. Rows 4 and 15 check the sensitivity of borrowing to late-day tightness for the two periods. While the coefficient estimates are positive for both periods, they are not statistically significant.

The next four regressors, which can be considered as indicators of daily liquidity conditions in the funds market, are taken from Carpenter and Demiralp (2006a) who studied the daily liquidity effect in this market. Carpenter and Demiralp (2006a) note that tightness in the fed funds market show persistence at a daily frequency. Hence, if the market is tight on a particular day, the Desk usually responds to this tightness by providing more balances on the following day. From the perspective of borrowing, this additional injection of balances may reduce borrowing needs. Rows 5 and 16 show the deviation of the funds rate from the target in the previous day. Indeed, the coefficient estimate is negative for both periods and is significant in the pre-2003 period.

The next variable investigates the relationship between required operating balances and borrowing.[6] Lower levels of operating balances constitute a challenge for the Desk because it is harder to predict clearing related balance needs, and forecast misses are more likely to be reflected in the funds rate because depository institutions have less flexibility in managing

[6] Required operating balances consist of required reserve balances and contractual clearing balances (see Carpenter and Demiralp, 2006a, for detailed descriptions of these magnitures).

their balances across the maintenance period (see Demiralp and Farley, 2005; Carpenter and Demiralp, 2006a). Along the same lines, one would expect a negative relationship between balances and borrowing because when banks hold a lower level of balances, they would be more vulnerable to unexpected withdrawals and hence their need for borrowing would increase. The coefficient is negative and significant in the first sample (row 6) but insignificant in the second sample (row 17). This may reflect better supervision of balance needs by the Desk in the later period, as noted in Pearce (1993) or Demiralp and Farley (2005).

The last day of the maintenance period may also exhibit sensitivity to borrowing because this is a day when the depository institutions' flexibility in meeting their reserve requirements is minimized. In fact, the coefficient estimate is positive and significant for the first sample which suggests that banks are more likely to borrow on the settlement Wednesday to meet their reserve requirements.

Daily borrowing may also be affected by special pressure days. Special pressure days are defined as days on which payment flows are heavy, which are characterized by higher uncertainty about those flows. These conditions elevate payment-related demands for end-of-day balances at the Federal Reserve and put an upward pressure on the funds rate. Borrowing is significantly less on special pressure days in the second sample (row 19), likely reflecting the Desk's ample provision of reserves on these days (see Demiralp and Farley, 2005).[7]

The next variable aims to capture borrowing due to technical difficulties regarding the

[7] Special pressure days are: month-ends, quarter-ends, and year-ends, first day of a month, first and last days of a quarter, and first day of a year, 15th of a month, the day before and the day after a holiday.

transfer of funds across depository institutions through the "Fedwire" system. Fedwire is the Federal Reserve's facility for the electronic transfer of funds between institutions with accounts at Federal Reserve Banks which opens and closes at set times. When there is an operating problem at the Federal Reserve or a Fedwire participant, the Fedwire can be extended upon request by depository institutions.[8] Our results indicate that on days when there were Fedwire extensions borrowing from the Fed was significanlty higher on average in the post-2003 period (row 20).

Days of higher intraday volatility also trigger more borrowing in the second sample (row 21) likely because higher intraday volatility may reflect higher turmoil and hence less availability of funds in the fed funds market.[9] In order to investigate this issue in more detail, we consider those factors that contibuted to the decline in fed funds volatility in late 1990s (see Demiralp and Farley; 2005). These factors, such as improvements in internal information systems (including those that track the balance in a bank's Federal Reserve account), banking industry consolidation, or adjustments to the Desk's reaction function, could reduce the need for borrowing because volatility is negatively related to the size of borrowing, at least in the second sample. One cannot quantify these factors precisely. However, the discussion in Demiralp and Farley (2005) points to a gradual improvement in these factors which we can be captured by a time trend. Rows 11 and 23 show that the time trend is not significant in either sample, perhaps due to the present set of control variables which may also pick up

[8] We would like to thank Beth Klee for generously providing us with this data.

[9] Intraday volatility is a volume-weighted measure of standard deviation based on total brokered funds rate transactions on a given day.

the gradual improvements over time. In an alternative specification (not shown) we interact the time trend with the cost of borrowing to test whether there is a gradual increase in the stigma of borrowing in the pre-2003 sample or a gradual decline in the stigma of borrowing in the post-2003 sample. One can argue that the sensitivity of borrowing to the interest rate spread may increase gradually over the second sample as the market participants adjust to the new regime and the implicit cost of borrowing declines steadily. While the argument is highly plausible, the coefficients associated with the interactive time trend turn out to be insignificant.[10]

Overall, the results in this section provide strong support for the argument that the borrowing function re-emerged after 2003, consistent with the decline in the implicit cost of borrowing in that period. The next section develops a model of borrowing and investigates these issues in more detail.

4. A Model of Borrowing

In this section, we develop a model of borrowing that explains the re-emergence of the borrowing function with the reductions in the implicit costs of borrowing. We model an equilibrium model of the funds market similar to Clouse and Dow (1999) that includes bank-specific reserve shocks for the market as well as for discount window borrowing. We specify both fixed and variable costs for banks going to the discount window. Because of the fixed cost, some banks go the discount window while others borrow from the funds market to avoid

[10] One might note that our specification suffers from an omitted variables bias because Federal Reserve's forecast errors in providing the daily liquidity to the system are not included in our specification. When this variable was added to our specification it was found to be insignificant, as confirmed by the Federal Reserve staff. Hence, an omitted variable bias is not an issue for our analysis.

a daily overdraft. Estimation of our model captures the changes in depository institutions perceptions towards the new borrowing facility and explains the behavior of borrowing as well as the decline in the volatility of the funds rate in the recent era.

In a typical simple model of the funds rate (see Poole, 1968) the supply of funds is determined by the Federal Reserve, subject to exogenous shocks, while the demand for funds is determined by reserve requirements and excess reserves which are used as a buffer to avoid an unexpected withdrawal. In this basic set up, a bank chooses a level of reserves while facing an uncertain flow of funds represented by a mean zero shock. The decision variable is the level of excess reserves, R, which has an opportunity cost r (the funds rate). There is a penalty rate if the bank does not meet its requirement.

Recently, Clouse and Dow (1999) made several modifications to the basic static model. First, they introduced two periods with information being revealed in the second period. Second, they added a fixed penalty in addition to a variable penalty for banks that have insufficient reserves, and third, they introduced bank-specific as well as system-wide shocks. The two period structure allowed the second period funds rate to depend on actual reserves rather than targeted reserves which increases fed funds volatility and resembles real data. The fixed cost allowed the funds rate to exceed the penalty rate, since firms with small deficiencies prefer to borrow at a higher rate rather than pay the fixed cost. Finally, aggregate shocks allowed the system to be short on reserves on occasion while individual shocks generate trade in the funds market.

In this paper, our main focus is the changes in the fixed cost of borrowing after 2003,

that is after the disappearance of the borrowing function. Hence, our model follows the static model of Clouse and Dow (1999) and ignores any dynamic aspects. In addition to Clouse and Dow, however, we simulate the model to explore the changes in the fixed cost of borrowing empirically. To that end, we make some simplifications to the model.

We consider a simple framework where bank i's goal is to keep its daily reserves holdings at a level L. Daily reserve balances do vary over the course of the maintenance period (see Carpenter and Demiralp, 2006b). However, from the borrowing viewpoint, a bank's decision to borrow from the Fed is a static decision based on the liquidity conditions on each day. Therefore, we do not differentiate across the days of the maintenance period to simplify the analysis.

Banks' balance holdings follow a stochastic process. During the day, there are aggregate and individual shocks to the average level of reserve balances, $\bar{R}$, which sets the end of day balance of bank i equal to:

$$R_i = \bar{R} + U + V_i, \tag{1}$$

where U is an aggregate shock and V_i is an individual shock with uniform distributions such that:

$$\begin{aligned} U &\backsim U\left[-X_U, +X_U\right], \\ V_i &\backsim U\left[-X_V, +X_V\right]. \end{aligned} \tag{2}$$

Hence, the individual bank becomes a lender in the funds market if $R_i > L$ and demands funds if $R_i < L$.

Banks that are short of reserves have two options: they either choose to borrow from the funds market or they borrow from the Federal Reserve. If the bank chooses to borrow Q dollars from the funds market, the cost per dollar is the market interest rate, r. Alternatively, if the bank borrows Q dollars from the Federal Reserve, the cost per dollar is the discount rate (or the primary credit rate after 2003), r_f, plus a fixed cost c. Thus, total cost per dollar is $r_f + \frac{c}{Q}$. Because of the fixed cost, partial borrowing from the Federal Reserve is not optimal and a bank either prefers to borrow entirely from the Federal Reserve or from the funds market. Specifically, banks with larger reserve shortages are more likely to borrow from the Federal Reserve because total cost per dollar decreases as borrowing increases.

In addition to borrowings from the Federal Reserve that are driven by market conditions, there are also borrowings due to technical difficulties such as network problems which force banks to borrow from the Fed regardless of market conditions. In order to capture this type of borrowing, we assume that a random fraction, p, of the banks will face a technical problem in the system where p has a uniform distribution: $p \backsim U[0, F]$.

We assume that there is a continuum of banks, indexed from 0 to 1. Thus there are an infinite number of banks with zero individual measure whose measure integrates to 1. Indexing is done according to reserve balance levels such that a bank with the lowest level of reserve balances is indexed to 0 and the one with the highest level of reserve balances is indexed to 1. Figure 3 shows the distribution of these banks according to their balance

levels. Accordingly, those with reserve balances higher than L supply funds in the fed funds market, where the total supply is the area of the triangle on the right. Meanwhile, those with balances lower than L demand funds. There is a threshold level T such that banks with reserve shortages greater than T go to the discount window. Hence, the area of the trapezoid shows the demand for funds from the Fed, while the triangle adjacent to the trapezoid shows the demand for funds from the market. In the figure, we omit one dimension of the model, which is borrowing from the Fed due to technical difficulties. The actual demand from the market is the area of the triangle on the left times $(1 - p)$.

The effective federal funds rate, r, is determined by the market equilibrium when the total supply of funds is equal to the total demand for funds. In modeling the borrowing behavior, our focus is on days of market tightness because these are the days on which borrowing from the Fed are more likely, while days of market softness are almost always cleared in the funds market unless there is a technical problem. For that reason and without loss of generality, if the supply is larger than the demand, we simply set the funds rate (r) equal to the marginal benefit of holding balances (γ) as in Clouse and Dow (1999) and do not deal with the market softness that would result as a consequence of the market surplus. Hence, a bank can offer reserves in the funds market if the market rate is greater than γ.[11]

At the end of each day, total supply of funds available in the funds market is determined by the area of the triangle on the right in Figure 3 (labeled as "supply funds"). Total demand for funds has two components. It can be met in the funds market ("borrow from market")

[11] In the estimation of the model, we set γ equal to the federal funds rate target.

or it can be met at the discount window ("borrow from Federal Reserve"). Total supply of funds in the funds market ("supply funds") is at least as big as the size of total borrowing in the funds market ("borrow from market"). When the total demand for funds exceeds the total supply, the market equilibrium occurs on the vertical segment of the supply curve. Meanwhile, the demand for funds is represented by the regular downwards sloping demand curve. Recall that if a bank borrows Q dollars from the Federal Reserve, total cost per dollar is given by . There is a threshold such that a bank borrows from the Federal Reserve if and only if it needs more than T dollars ($Q > T$), where T is determined as the level for which the cost of borrowing from the Fed is equal to the cost of borrowing from the market: $r = \frac{c}{T} + r_f$. Hence, the threshold is equal to $T = \frac{c}{r - r_f}$ and the demand from the market (labeled as "borrow from market" in Figure 3), is proportional to the square of T.

Supply and demand in the federal funds market calculated in this manner is illustrated in Figure 4 for a day with market tightness where demand exceeds supply.[12] If the fixed cost of borrowing (c) has indeed declined in the post-2003 period, then the demand curve would shift left since T^2 gets smaller. As a result, the interval in which the funds rate could deviate from the target declines from |AC| to |AB|.[13] That is, if the fixed cost of borrowing declines in the period after 2003, then, everything else remaining the same, this implies a decline in the volatility of the funds rate in this period and an increase in the sensitivity of

[12] In Figure 4, the mirrored "L" shape of the supply curve reflects our simplifying assumption that the marginal benefit of holding balances (γ) is identical across banks. In real life γ differs across depository institutions which gives the positive slope to the supply curve. In the figure, on a day without market tightness the demand and supply curves intersect in the horizontal section of the supply curve, such that the funds rate is equal to the target.

[13] Recall that γ= target rate.

Fed borrowing to the funds rate. This implied change in volatility and the revival of the borrowing function allows us to identify the size of the implicit cost before and after 2003.

The discussion in the previous paragraph points to a decline in the funds rate volatility as a result of a reduction in the implicit cost of borrowing. As we have discussed in the earlier section, however, the decline in feds funds volatility is also influenced by certain other developments over time which might be prominent over our sample period. To capture such changes, at least partially, we allow the distributions of U and V_i to get wider or narrower in a linear fashion over time. That is we let:

$$\begin{aligned} X_U &= A + \frac{Dt}{1000}, \\ X_V &= B + \frac{Et}{1000}, \end{aligned} \tag{3}$$

(where X_U and X_V are defined as in equation 2).

To identify the potential decrease in the stigma associated with discount window borrowing, we consider the following specification for the implicit borrowing cost c:

$$\begin{aligned} c &= c_1, \text{ prior to 2003,} \\ c &= c_2, \text{ after 2003.} \end{aligned}$$

In order to estimate our model, we use "Indirect Inference" (henceforth II) which can be considered as a more generalized form of the Method of Simulated Moments. II uses the estimates of an auxiliary model (rather than moments) to compare the actual and the simulated data. Because we can think of the moments of the data as the parameters of a simplified auxiliary model, Method of Simulated Moments can be considered as a special case of II. Note that an auxiliary model does not need to be "correct" for II to give consistent results. So long as the selected auxiliary model summarizes the data well, the estimates of the actual model will be consistent and asymptotically normal (for more details on II, see Gourieroux, Monfort and Renault, 1993; Smith, 1993).

We contemplate a simplified version of the borrowing function that we have estimated in the previous section as the auxiliary model. We need to simplify the borrowing function because it is not possible simulate most of the explanatory variables that we have considered in the previous section. The auxiliary borrowing function summarizes how borrowing from the Fed changed over time and after the policy change in 2003 through a simple OLS regression. In addition to the OLS estimates, we use the mean and the variances of borrowing and the spread between the funds rate and the target as part of the auxiliary model. The estimation strategy is to find the parameters that will make the simulations of the model and the actual data look as similar as possible when looked through the auxiliary model's OLS estimates and moments. Specifically, our auxiliary model is:

$$
\begin{aligned}
\zeta_t &= \beta_1 + \beta_2 \tilde{r} + \beta_3 \frac{t}{100} + \beta_4 \frac{t}{100} \tilde{r}_t + \beta_5 D^{2003} \tilde{r}_t + \varepsilon_t \qquad (4) \\
\beta_6 &= \frac{1}{T} \sum \zeta_t,\ \beta_7 = \frac{1}{T} \sum \tilde{r}_t, \\
\beta_8 &= \frac{1}{T} \sum (\zeta_t - \beta_6)^2,\ \beta_9 = \frac{1}{T} \sum (\tilde{r}_t - \beta_7)^2, \\
\beta &= [\beta_1\ \beta_2\ ...\ \beta_9]'.
\end{aligned}
$$

where $\tilde{r}_t$ is the spread between the funds rate and the funds rate target, t the time trend, ζ_t is the amount of borrowing from the Fed normalized by required operating balances, D^{2003} is a dummy for days after the policy change and ε_t is an iid random shock, and T is the sample size.

Let $\hat{\beta}$ be an OLS estimate of β from the actual data and $\tilde{\beta}$ be an estimate of β from the simulated data. We pick the model's parameters $[A\ B\ c_1\ c_2\ D\ E\ F]$ such that $\left(\hat{\beta} - \tilde{\beta}\right) W \left(\hat{\beta} - \tilde{\beta}\right)'$ is minimized, where W is the weighting matrix.

In estimating the model, we set the average level of reserve balances $\bar{R}$, equal to 1 and the threshold level, L equal to zero since they are not identified by our model. Furthermore, we exclude those days when the daily high rate exceeded the target rate by more than 25% to obtain a more realistic distribution for the shocks in the model.[14]

The first two panels of Table 2 present the OLS estimates of the auxiliary model parameters using the actual as well as the simulated data along with the mean and the variance

[14] We end up with 2159 days, 1052 days prior to the policy change in 2003 and 1107 days thereafter. We simulate 20 data sets in the estimation process, thus we have 2159x20=43180 days for the simulated data.

of borrowing and $\tilde{r}_t$. Comparing the second and the fourth columns in the first panel, we note that the auxiliary model's estimates from the simulated data and the actual data are pretty close to each other since the algorithm minimizes the distance between those two estimates. However, they are not identical since the auxiliary model has more parameters than the true underlying model. As shown in the last row, borrowing responsiveness to the interest rate spread ($\tilde{r}_t$) increases significantly after the policy change in 2003 similar to our finding in the previous section.[15] The second panel provides a similar comparison between the moments generated by the simulated data (column 2) and those computed from the actual data (column 4). Similar to the first panel, the two sets of statistics display a strong resemblance.

The third panel of Table 2 exhibits the parameter estimates of the true underlying model and their standard errors. The most interesting parameters for our purposes are displayed in the first two rows. Notice that the implicit fixed cost of borrowing declines about 75 percent (from 0.035 to 0.009) after the policy change in 2003. This is a strong evidence that the Fed's new policy was indeed successful in reducing the stigma associated with discount window borrowing. In addition to estimating the fixed cost of borrowing from the discount window, we are also interested in determining whether this implicit cost exhibits any gradual changes over time. In particular, one may expect a gradual decline in the implicit cost of borrowing in the post-2003 period, due to the market's slow adjustment to the new regime. In order to

[15] Note that the parameter estimates are bound to be different between the models estimated in the previous section and the auxiliary model estimated in this section due to the normalization of the dependent variable in the latter model as well as the omitted variables that cannot be simulated by the auxiliary model.

address this issue, we experimented with an alternative model which allows a time trend in the implicit cost of borrowing prior to and after 2003 (not shown). However, the trend terms associated with the implicit cost of borrowing were not significant in either sample. This finding suggests that there may not be a gradual adjustment to the new regime in the second sample, similar to our finding in the previous section. We believe that our results in both sections may be driven by the fact that we do not have a sufficient number of observations to identify such a time trend.[16]

The third row shows that the aggregate reserve shock U changes between -1.1 and +1.1 in the beginning of the sample, while the bank specific reserve shock varies between -0.36 and 0.36 initially (row 4). Rows 5 and 6 show that there is a significant time trend in the support of the uniform distributions of these shocks. For example, substituting the estimates for D and E in equation 3, U varies between -1.09 and +1.09 while V_i varies between -1.14 and +1.14 in 2007. Comparing these ranges to those in the beginning of the sample, we note that the aggregate reserve shock exhibits a negative trend while the bank specific shock exhibits a positive trend. The mild negative time trend in the aggregate shock, U, could reflect improvements in the Desk's reserve management ability over time as we noted in the previous section.

The last row shows that the estimated ratio of banks that incur a technical problem, and thus are forced to borrow from Fed rather than the market, vary from 0 to 0.032, indicating

[16] We have experimented with different combinations of auxiliary model specifications and borrowing cost structures, including an alternative Method of Simulated Moments estimation to check the robustness of our results. Our qualitative findings remain unchanged under alternative specifications. The results from these experiments are available from the authors upon request.

that not more than 3.2% of the banks are affected by this type of a problem at a given point in time.

In order to evaluate how the data generating process of the original data compares to that generated by the model, Figures 5a-c plot the actual as well as the simulated data on borrowing, the difference between daily high funds rate and the target rate ($\tilde{r}_t$), and the covariance between borrowing and $\tilde{r}_t$. The data is plotted as a 100 day moving average in each figure. The policy change in 2003 corresponds approximately to $t = 1050$. It is clear from these figures that the model is able to match the data generating processes reasonably well for these random variables. Hence, we are confident in our model's conclusion that there was a significant decline in the implicit cost of borrowing in the post 2003 period. Combined with our results from the previous section, our analysis confirms that the hesitance to borrow from the Fed declined substantially under the new facility.

5. Conclusions

In the summer of 2007, financial markets were hit by a liquidity crisis triggered by the subprime-mortgage market's collapse. Because market participants avoided lending to each other, increasing the size of open market operations was not a sufficient tool to ease liquidity constraints and stabilize the level of the funds rate at the target level. The Federal Reserve responded to this situation by reducing the primary credit rate by 50 basis points on August 17. The action was aimed at restoring the normal functioning of disrupted credit markets. The money market as well as the rest of financial markets took this action as a very positive move. Even though the new primary credit rate was still above the effective funds rate,

credit markets, especially the ones where banks lend to each other were noted to be relaxed while the stock market which seemed in a state of panic on August 16th, recovered some of its losses. There was not a notable increase in discount window borrowing in the weeks following the action because the federal funds rate still remained below the primary credit rate. However, the outlook changed in the week before September FOMC meeting when the anticipated rate cut put downwards pressures on the funds rate (see Carpenter and Demiralp, 2006b). The Desk tightened liquidity conditions in the funds market to offset these pressures and maintain the current target. In the absence of sufficient liquidity in the funds market, some market participants were unable to borrow at rates below the primary credit rate. Consequently, discount window borrowing surged to more than $7.1 billion that week, which was the highest level since the day after the Sept. 11, 2001, terrorist attacks. All along, the market's interpretation and the reaction to Fed's moves were highly consistent with the findings in our paper that the new discount window is now completely functional and market participants turn to this window whenever they exhaust other cheaper alternatives.

Naturally, the reluctance to borrow from the discount window cannot be eliminated completely. This is because institutions who borrow from the window are the ones who cannot borrow from others at cheaper rates in the funds market. Depsitory institutions are therefore worried that if their identity becomes known, it can make counterparties skittish or hurt their share prices. The Federal Reserve cannot do much about reducing this type of a reluctance other than assuring the market participants that the information is confidential. However, it can and it did reduce the stigma that was attributable to the Fed's administrative

policy and restrictions as we documented in this paper.

The Federal Reserve's experience sets a good example for other countries that are planning to consider changes in their operational procedures. In particular, having a credible history and a transparent communications policy enables a central bank to interact with market participants about a new regime relatively easily and allows a far more efficient functioning of the markets.

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Table 1: Estimation Results for the Borrowing Function (1998-2007)

	Independent Variable	Coefficient	Std. Error
1.	$1-D^{2003}$	1342.05**	551.42
2.	$(FFR_t - DR_t)\times 100\times(1-D^{2003})$	0.91	0.75
3.	$(FF\_HIGH_t - FFT_t)\times 100\times(1-D^{2003})\times D^{Spread}$	0.46**	0.16
4.	$(FF\_CLOSE_t - FFT_t)\times 100\times(1-D^{2003})$	0.23	0.20
5.	$(FFR_{t-1} - FFT_{t-1})\times 100\times(1-D^{2003})$	-1.46**	0.49
6.	$\log(ROB)\times(1-D^{2003})$	-141.46**	56.96
7.	$D^{Last\ day\ of\ maintenance\ period}\times(1-D^{2003})$	85.67**	37.76
8.	$D^{Special\ day}\times(1-D^{2003})$	-9.35	10.75
9.	$D^{Fedwire}\times(1-D^{2003})$	29.31	18.42
10.	$FF\_Vol_t\times(1-D^{2003})$	81.02	93.42
11.	$T\times(1-D^{2003})$	1.50	2.64
12.	D^{2003}	1101.67	806.57
13.	$(FFR_t - PRIM_t)\times 100\times D^{2003}$	8.19**	3.91
14.	$(FF\_HIGH_t - FFT_t)\times 100\times D^{2003}\times D^{Spread}$	3.90**	0.95
15.	$(FF\_CLOSE_t - FFT_t)\times 100\times D^{2003}$	0.05	0.40
16.	$(FFR_{t-1} - FFT_{t-1})\times 100\times D^{2003}$	-2.78	1.72
17.	$\log(ROB)\times D^{2003}$	-27.36	59.74
18.	$D^{Last\ day\ of\ maintenance\ period}\times D^{2003}$	33.03	37.75
19.	$D^{Special\ day}\times D^{2003}$	-51.34*	26.82
20.	$D^{Fedwire}\times D^{2003}$	38.64*	23.04
22.	$FF\_Vol_t\times D^{2003}$	766.05**	385.46
23.	$T\times D^{2003}$	-5.07	4.39
24.	R-squared	0.28	

*/** indicates significance at 90 percent and 95 percent level of confidence respectively.

where

D^{2003}	Dummy variable for the period after January 6, 2003
$Borrowing_{t-1}$	Aggregate borrowing on day t-1
FFR_t	Average federal funds rate on day t
FFT_t	Federal funds rate target on day t
DR_t	Discount rate on day t
$PRIM_t$	Primary credit rate on day t
FF_HIGH_t	Maximum funds rate traded on day t
D^{Spread}	Dummy variable for days when $FF\_HIGH_t - FFT_t > 1$
FF_CLOSE_t	Federal funds rate at the close of the day

$\log(ROB)$	Logarithm of required operating balances
$D^{Last\ day\ of\ maintenance\ period}$	Dummy variable for the last day of the maintenance period
FF_Vol_t	Intraday fed funds rate volatility on day t
$D^{Special\ day}$	Dummy variable for special pressure days
$D^{Fedwire}$	Dummy variable for Fedwire extensions
T	Time trend

Table 2: Indirect Inference and Auxiliary Model Estimations

PANEL 1: AUXILIARY OLS REGRESSION				
	Actual Data		***Simulated Data***	
	Coefficient	Std. Err.	Coefficient	Std. Err.
Constant	0.5269**	0.0728	0.5793**	0.0310
$\tilde{r}$	0.3463**	0.0538	0.3352**	0.0231
(1/100) × t	-0.0465**	0.006	-0.0253**	0.0024
(1/100) × t × $\tilde{r}$	0.0547**	0.0126	0.0799**	0.0045
D^{2003} × $\tilde{r}$	1.0017**	0.2369	0.7674**	0.0792

PANEL 2: MOMENTS		
	Actual Data	***Simulated Data***
Mean(ζ)	0.451	0.5057
Mean($\tilde{r}$)	0.3907	0.1857
Var(ζ)	2.9255	1.4759
Var($\tilde{r}$)	0.8864	1.0602

PANEL 3: INDIRECT INFERENCE ESTIMATION		
	Coefficient	Std. Err.
c_1	0.035**	0.0006
c_2	0.0089**	0.0002
A	1.1**	0.0002
B	0.3553**	0.0037
D	-0.004**	0.0002
E	0.3921**	0.0077
F	0.0321**	0.0007

*/** indicates significance at 90 percent and 95 percent level of confidence respectively.

Where

ζ	Normalized borrowing from the Fed
$\tilde{r}$	Daily high funds rate minus the target rate
T	Time trend
D^{2003}	Dummy variable for the period after January 6, 2003
c_1	Implicit cost prior to 2003
c_2	Implicit cost after 2003
A	Interval parameter for the aggregate shock
B	Interval parameter for the bank specific shock
D	Time trend parameter for the aggregate shock
E	Time trend parameter for the bank specific shock
F	Interval parameter for the probability of a technical problem

Figure 1: Primary Credit Rate and Daily High Federal Funds Rate

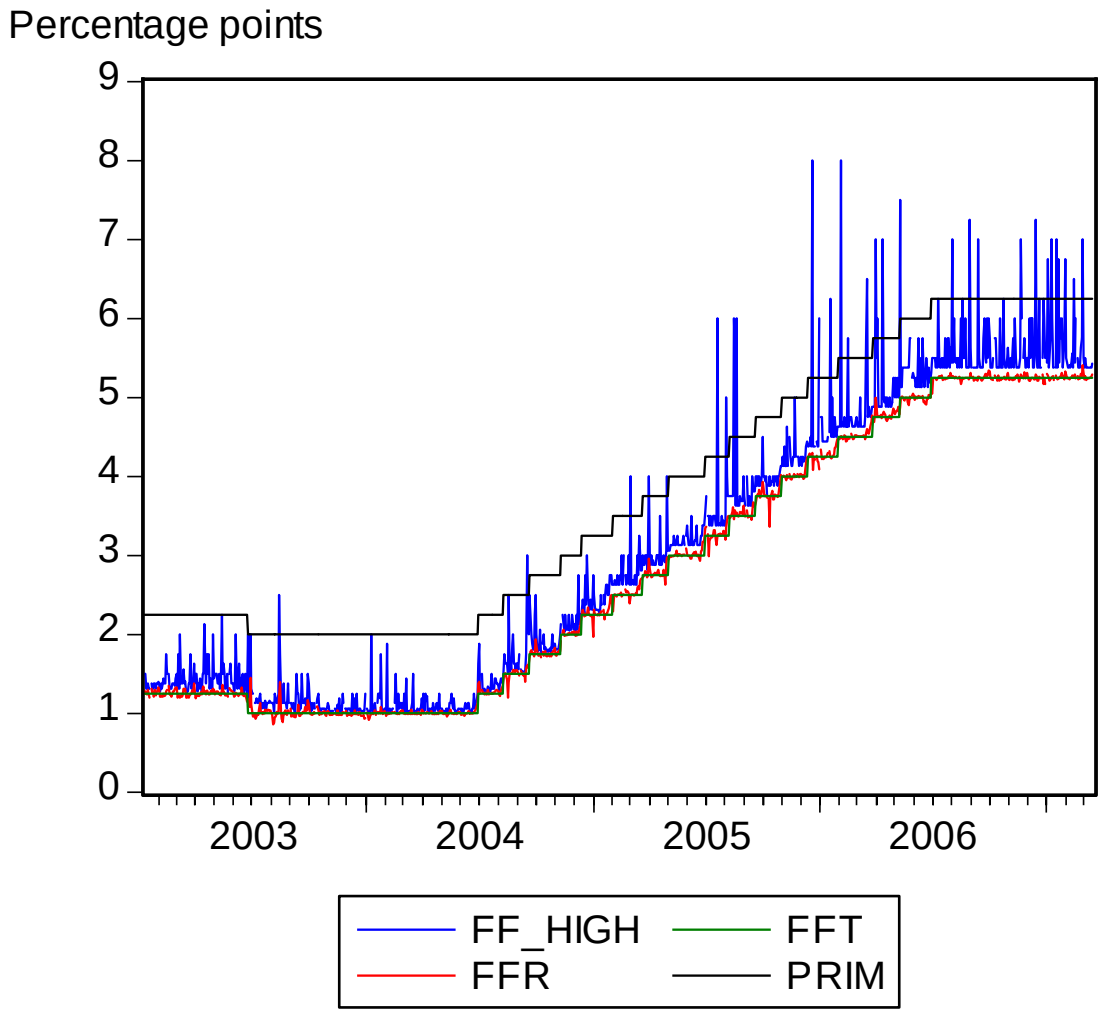


Figure 2: Discount Window Borrowing on Days on which Daily High Funds Rate Exceeded Primary Credit Rate

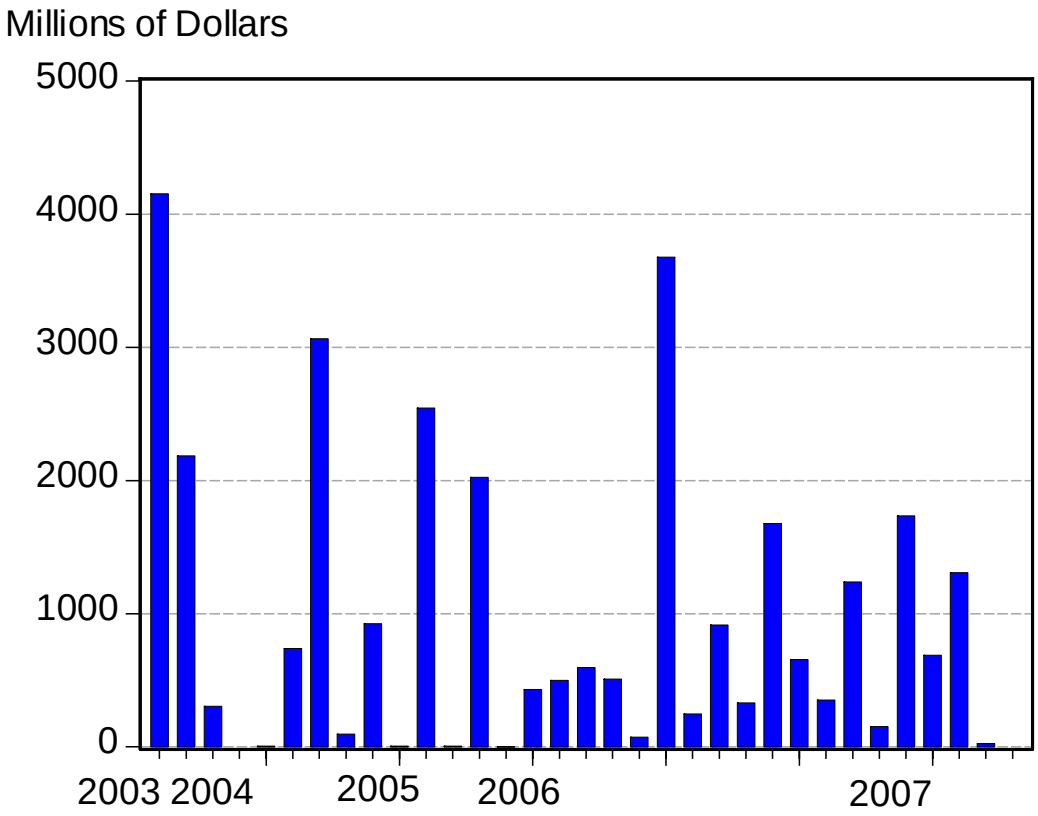


Figure 3: Distribution of Banks and their Reserves

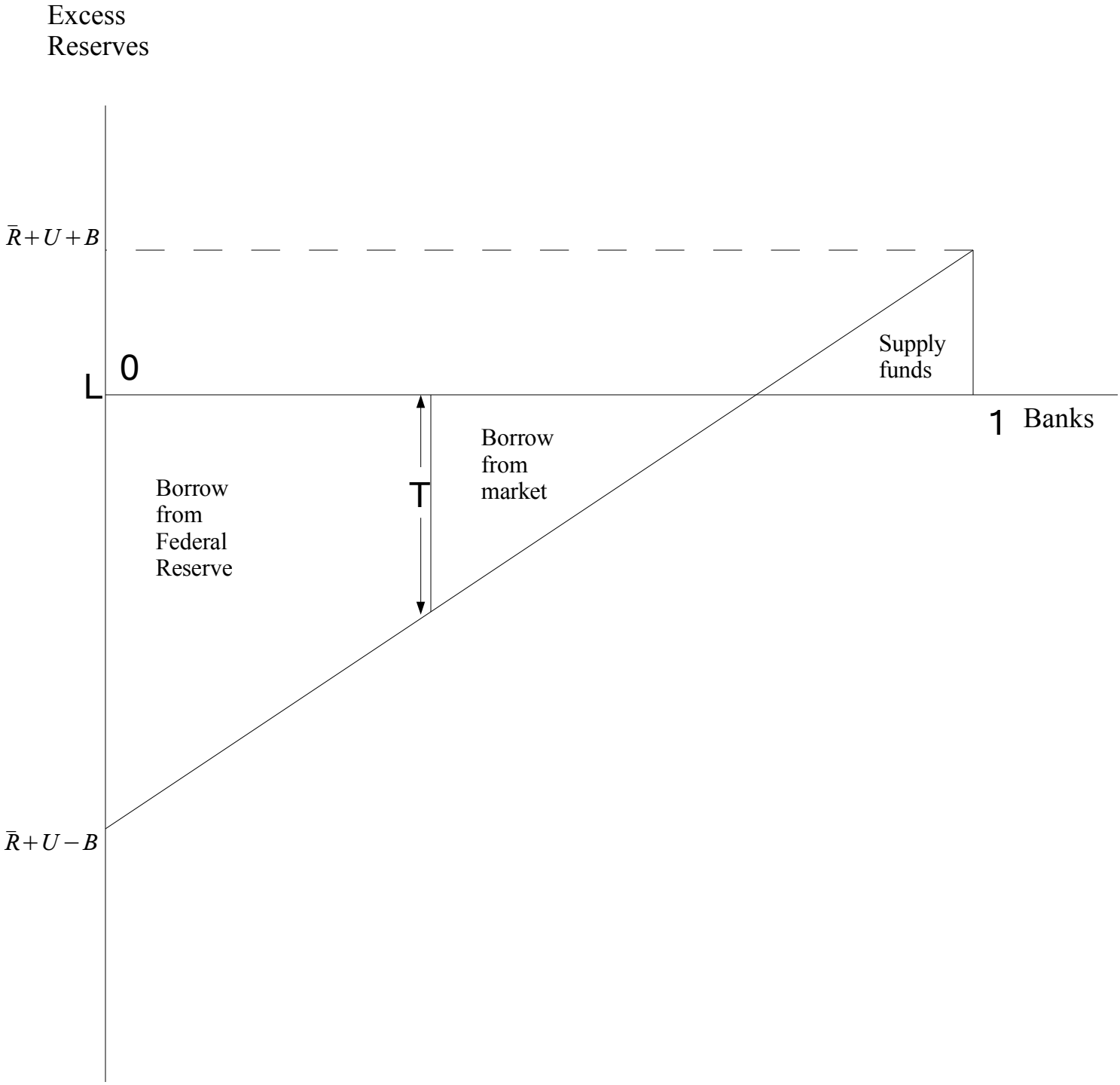
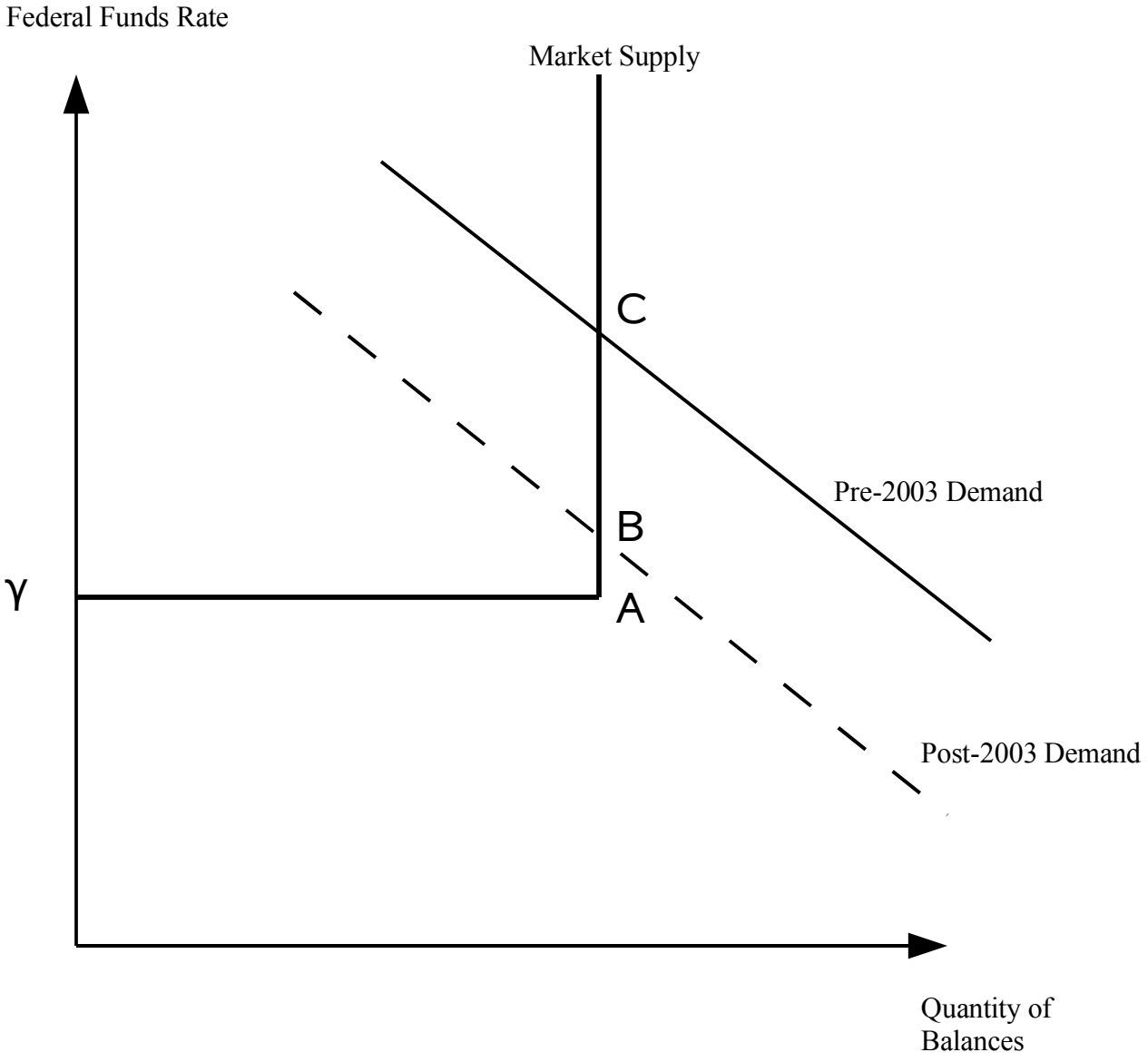
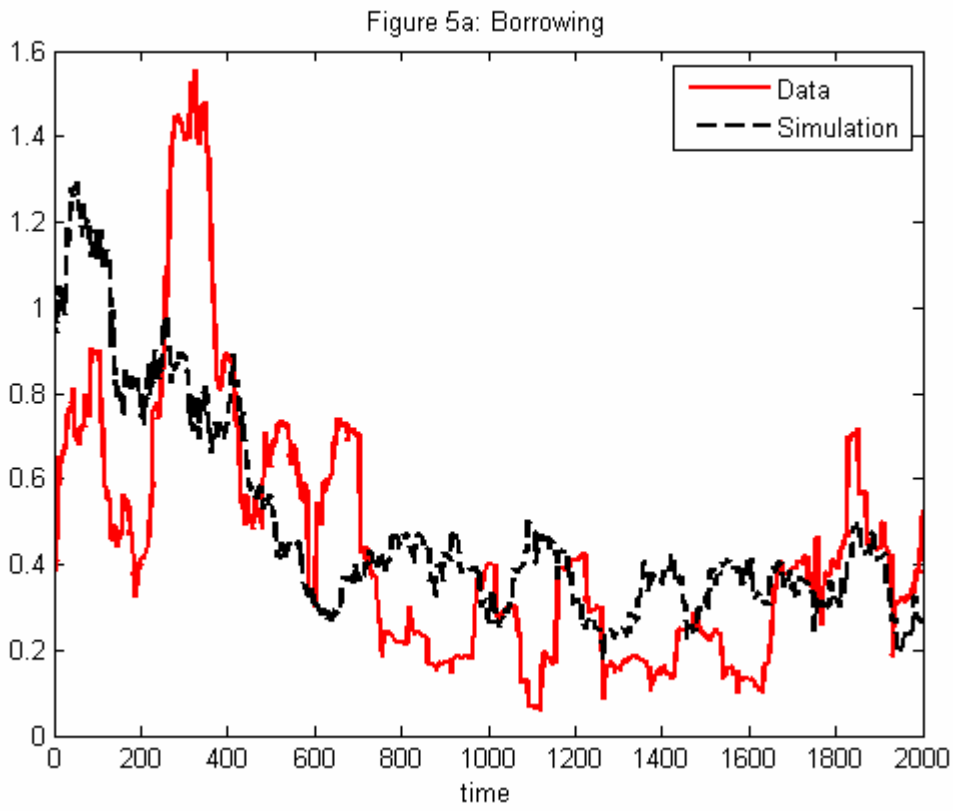
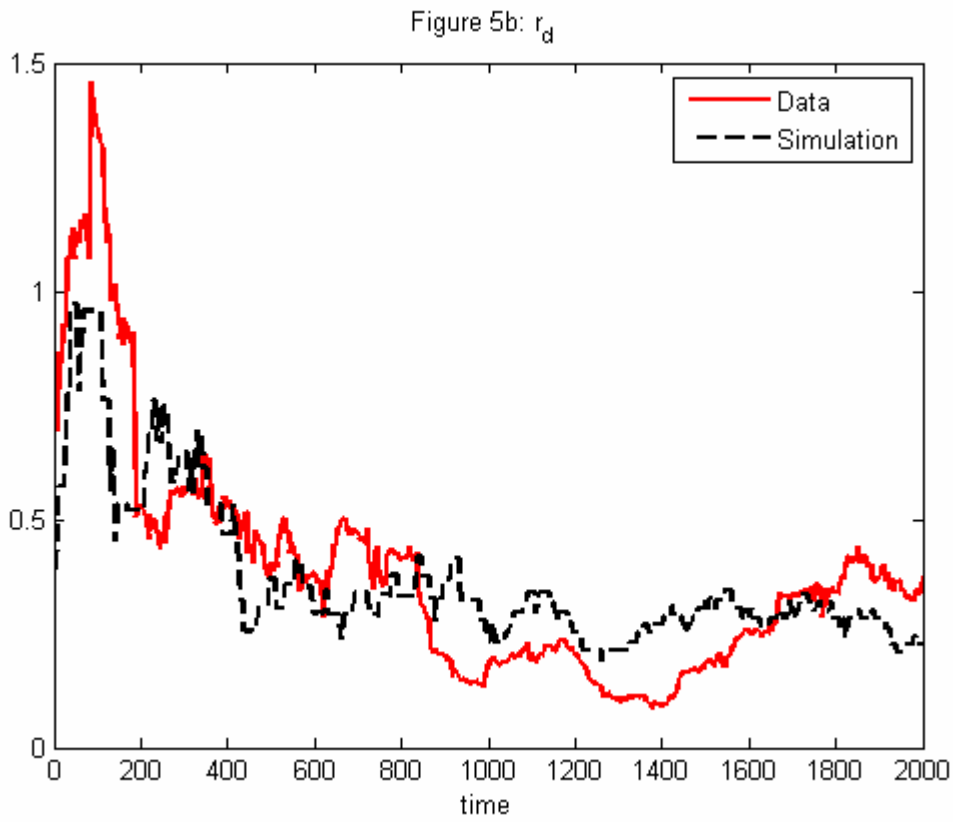


Figure 4: Federal Funds Market

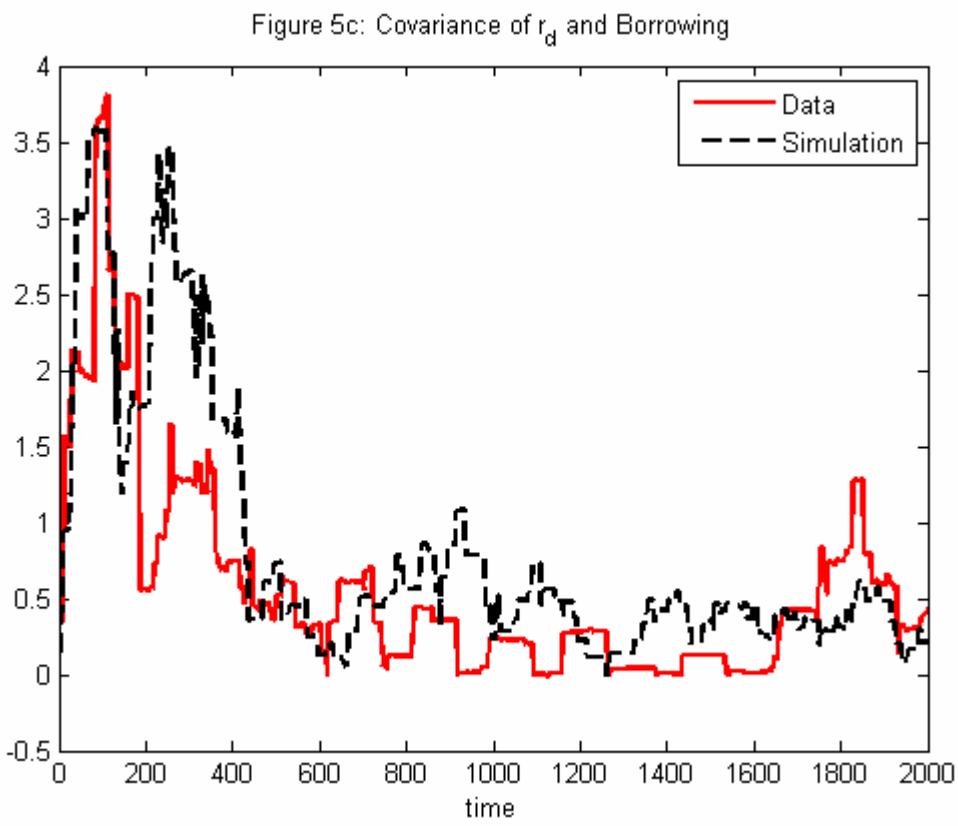




(*) Borrowing: Normalized daily borrowing from Fed.



(*) r_d: Daily high funds rate minus target rate.



(*) Covariance between daily high funds rate minus target rate and normalized borrowing from Fed.