Explaining the Appearance of Open-Mouth Operations in the 1990s U.S.

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Abstract: In the 1990s it became apparent that changes in the FOMC's target fed funds rate could be implemented through announcements alone - "open mouth operations" - with no adjustments to reserve supply or the discount rate. This phenomenon could not be explained by standard models of interest-rate control. It also differed from the Fed's experience with interest-rate targeting in the 1970s. I explain the appearance of open-mouth operations in the 1990s as a consequence of the Federal Reserve's longstanding discount-window lending practices, interacting with a decrease after the 1970s in the relative importance of discount borrowing by small banks. Data on discount borrowing by large *versus* small banks in the 1980s-1990s and the 1970s support my explanation.

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In the 1990s Federal Reserve staff found that market overnight rates changed when the Federal Open Market Committee (FOMC) signalled it had changed its target fed funds rate, even if the staff made no adjustment to the supply of high-powered money (or monetary base) through open-market operations. Eventually the volume of bank deposits responded to interest rates through the usual "money demand" channels, and the Fed had to accommodate resulting changes in the quantity of reserves needed to satisfy fractional reserve requirements or clear payments. But these effects appeared only after many weeks (Carpenter and Demiralp, 2008). Until then there was no need to systematically increase (decrease) reserve supply to implement a decrease (increase) in the target. Eventually this phenomenon attracted the attention of academic economists (Taylor, 2001; Friedman and Kuttner, 2011). It became known as "open mouth operations." The appearance of open-mouth operations in the 1990s was a puzzle at the time. By some, it was taken as evidence against conventional views of monetary policy's role in the economy (Thornton, 2004). It remains a puzzle today. It is now understood that, at some frequencies and in certain regulatory settings, changes in a target overnight rate can be implemented without adjustments to high-powered money supply. But the 1990s U.S. does not seem to satisfy those conditions.

At a daily frequency, target changes can be implemented without immediate reserve-supply adjustments in systems where a bank is required to hold a minimum reserve balance on average over a multi-day "maintenance period." A bank meets its requirement at lowest cost by holding more reserves on days within the period when the overnight rate is relatively low. Early in a period, reserve demand depends on the spread between the day's market overnight rate and rates expected to prevail later in the period. As a signalled change in the target changes expected end-of-period rates, it shifts the daily reserve demand curve, changing the market rate resulting from a given supply. A central bank can wait until later in the period to accommodate changes in reserve demand for the maintenance period as a whole (Hamilton, 1996; Furfine, 2000; Demiralp and Jorda, 2002). Maintenance periods have always been a feature of the U.S. system. But they cannot account for the appearance of open-mouth operations.

In the 1990s, target changes were implemented without adjustments to reserve supply *for the maintenance period as a whole* (Friedman and Kuttner, 2011).

For the maintenance period as a whole, the relationship between interest rates and reserve supply should depend on the way the central bank sets two administrative interest rates: the rate paid on excess reserves, and the "penalty" rate charged for short-term credit to cover a shortfall in a bank's reserve account. In recent years, many central banks have adopted "corridor" or "tunnel" systems in which these two rates are automatically set at fixed margins around the target. In corridor systems target changes are implemented without adjustments to maintenance-period reserve supply, because the automatic adjustment in the two administered rates shifts reserve demand up and down with the target (Woodford, 2000; Ennis and Keister, 2008; Friedman and Kuttner, 2011). In the early 1990s New Zealand's central bank had a system which was not obviously a corridor, but operated like one. It set the two administered rates as fixed margins around the market rate for bills. As signalled changes in the overnight-rate target affected expectations of future overnight rates, they affected bill rates, shifted the two administered rates, shifted reserve demand and changed the overnight rate resulting from a given reserve supply (Guthrie and Wright, 2000).

The Federal Reserve began to move toward a corridor in 1999. From October 1999 to March 2000 the Fed operated the "Special Liquidity Facility," which lent freely to financial institutions at a rate set at a fixed margin above the target fed funds rate (Federal Reserve Bank of New York, 2000). In 2003 the Fed introduced "primary credit," loans that covered reserve-account shortfalls at a rate set at a fixed margin above the target (Federal Reserve Board, 2003). In 2008, the Fed began to pay interest on reserves. For some of the period from 2003 to 2008 the Fed was practically operating a corridor system even though it was not yet paying interest on reserves, because the target was about one percent, halfway between the primary credit rate and the zero rate paid on excess reserves (Whitesell, 2006).

Before 1999, however, the Federal Reserve system appeared to embody *no* elements of a corridor. It paid no interest on excess reserves. It provided short-term credit to cover reserve shortfalls through a facility informally known as the "discount window," charging a "discount rate" that was usually set below the target and *held fixed* when the FOMC changed the target. Fed staff rationed discount credit through "administrative control." The most common view of this system at the time (e.g. Federal Reserve System, 1990; Christiano and Eichenbaum, 1992; Hamilton, 1997; Bernanke and Mihov, 1998a) was that administrative control created a nonpecuniary "harassment cost" that increased with the amount a bank borrowed, such that banks' maintenance-period reserve demand increased with the spread between the market overnight rate and the discount rate. Given this demand, the spread between the prevailing market rate and the discount rate was determined by the supply of "nonborrowed reserves." A change in the target could be implemented either by a change in the discount rate, or by the "liquidity effect" of a change in the quantity of nonborrowed reserves supplied through open-market operations. The Fed's earlier experience with interest-rate targeting in the 1970s had been quite consistent with this view. In the 1970s, when Fed policymakers changed the target but not the discount rate, Fed staff adjusted maintenance-period reserve supply. In the 1990s, this was no longer true. *Whether or not* the discount rate was changed along with the target, Fed staff made no systematic adjustments to reserve supply.

Why were open-mouth operations effective in the 1990s U.S.? What was different about the 1970s? In this paper I argue that the appearance of open-mouth operations in the 1990s can be accounted for as the result of a longstanding feature of discount window administration. In both the 1970s and the 1990s, the Fed applied different types of discount credit rationing to large *versus* small banks. The rules applied to small banks, and the consequent relationship between interest rates and small banks' reserve demand, were consistent with the traditional "harassment cost" view. The rules applied to large banks, on the other hand, created a very different relationship between interest rates and large banks' reserve demand which held the potential for open-mouth operations. Large banks were always prohibited from borrowing "continuously," that is for many periods in a row. Thus for a large bank the nonpecuniary cost of discount borrowing was the loss of an option to borrow in the near future. The value of this option depended on expectations of near-future overnight rates. As a signalled change in the target affected these expectations, it affected large banks' nonpecuniary borrowing cost and shifted large banks' reserve demand much as a target change shifted reserve demand in New Zealand or in a corridor system. The relationship between interest rates and total reserve demand depended on the relative importance of large *versus* small banks. In the 1970s, small banks made up a big part of total reserve demand. Thus, the behavior of aggregate reserve quantities appeared consistent with the traditional view, and the Fed adjusted reserve supply around changes in the target. After the 1970s the relative magnitude of small banks' reserve demand diminished, partly because many small banks were closed or merged (Amel and Jacowski, 1989; Berger, Kashyap, and Scalise, 1995). By the 1990s, therefore, target changes could be implemented mainly through open-mouth operations.

My argument that restriction of continuous borrowing links the cost of discount borrowing to expected future market rates is not new. Goodfriend (1983), Van Hoose (1987), Dutkowsky (1993) and Cosimano and Sheehan (1994) all present models that demonstrate this point. Hamdani and Peristiani (1991) and Mitchell and Pearce (1992) note that it applied especially to large banks. But none of these studies recognized that it created the potential for open-mouth operations.

In the first section of the paper, I lay out the puzzle of open-mouth operations. I review Fed rules for reserve accounts and discount lending, and standard models of reserve demand under those rules. I show that target changes were accompanied by obvious changes in reserve supply in the 1970s but not in the 1990s. In the second section I present a model in which large banks face a prohibition on continuous borrowing. In the model, target changes can be implemented largely without adjustments to reserve supply *if* small banks are relatively unimportant. The key magnitude is the response of aggregate small banks' discount borrowing to interest rates. The key definition of a "small" bank is the one applied by Fed staff at the discount window.

In the final section I present evidence this was indeed the mechanism behind the appearance of open-mouth operations. I focus on discount borrowing because I have data on borrowing by banks divided into size classes that are known *a priori* to match discount-window definitions of "large" and "small." The data show that "small" banks' borrowing was always consistent with the traditional harassment-cost model of reserve demand, not only in the 1970s but also in the 1990s, while "large" banks' borrowing was always consistent with the type of reserve-demand behavior that could support open-mouth operations, not only in the 1990s but also in the 1970s. The difference between the eras was the relative importance of small bank borrowing.

1) The puzzle

1.1) Reserve accounts and discount lending in the 1970s and 1990s

In the 1970s the maintenance period was one week long. The required minimum was a bank's "required reserve balance." After the early 1980s the period was two weeks (for banks holding the bulk of reserves); the required minimum was the required reserve *plus* a "required clearing balance."[1] Following most academic literature, I refer to all balances held by financial institutions in their Federal Reserve accounts as "reserves" and to all required balances as "required reserves."[2] "Excess reserves" is reserves *less* required reserves. As the Fed paid no interest on excess reserves, holding them incurred a cost to bank: the market overnight rate. But it also brought a benefit. Some reserve-account transactions were cleared with unpredictable lags. A bank that aimed to end a period with a balance just equal to the required minimum might end up with a shortfall. A bank could not cover a shortfall with market borrowing or securities sales because the Fed closed down the system for interbank funds transfer before

1. In both the 1970s and 1990s carryover rules allowed a bank to substitute a portion of required minimum balances across maintenance periods, under some circumstances. To a limited degree, carryover may have tended to make maintenance-period reserve demand somewhat sensitive to expectations of interest rates in the upcoming period, in the same way that daily reserve demand was sensitive to expected rates at the end of a maintenance period (Tinsley, Farr, Fries, Garrett and Von zur Meulen,1982: 839). Carryover does not constitute an alternative explanation of open mouth operations as it was a feature of both the 1970s and the 1990s.

2. These definitions match Federal Reserve practice. "In its analysis of banks' reserve management strategies..the Federal Reserve focuses informally on required operating balances, which consist of required clearing balances plus required clearing balances" (Meulendyke, 1998: 152). They do *not* match published Federal Reserve figures for total reserves and required reserves, which *exclude* required clearing balances. In both eras all components of required reserves were predetermined for a given period. Required reserves were effectively predetermined even when reserve requirements were "contemporaneous" (as in the 1980s-1990s), because their ultimate determinants - the public's demands for cash and reserveable deposits - responds to interest rates only many weeks' lag (Small and Porter, 1989). A bank could adjust its required clering balance but only after a delay of ten business days - at least one maintenance period (Edwards, 1997). Over the 1990s "sweeps" eliminated many banks' required reserve balances but required clearing balances increased at the same time (Edwards, 1997; Bennett and Peristiani 2001), so daily reserve demand was still strongly affected by maintenance-period requirements (Clouse, 2002: 70).

it finished clearing payments (Federal Reserve Board 1996: 4). Fed officials strongly encouraged a bank to cover any shortfall with a loan from the "discount window" (Meulendyke, 1998: 72-75, 151-52). Thus, the effective cost of a shortfall was the cost of discount credit.

The cost of discount credit was the sum of the below-market discount rate and "nonpecuniary costs" created by "administrative control."[3] Discount window officers wanted to lend only to banks that had no other source of funds. "In judging whether borrowers have pursued all reasonably available alternative sources of funds before turning to the discount window, the Federal Reserve distinguishes between banks with ready access to national money markets, usually large banks, and those that do not have such access, which generally are smaller banks" (Clouse, 1994:967). A small bank was allowed to borrow for many maintenance periods in a row subject to heightened Fed staff oversight of its activities and financial condition. A large bank, on the other hand, was strongly discouraged from borrowing "continuously" - more than one day or maintenance period in a row. These practices were followed as early as the 1950s (McKinney, 1960:104-112), if not earlier (Federal Reserve Board, 1927:4). A Fed press release of 1980 gives an especially detailed description:

> Reserve Bank discount officers monitor the appropriateness of borrowing by institutions using the discount window by collecting timely data on selected assets and liabilities (including net federal funds sales) and by maintaining periodic personal and telephone contracts with officials of the borrowing institutions. (Federal Reserve Board 1980:2).
>
> When an institution's borrowing become excessive relative to borrowing patterns of institutions of similar size, the discount officer presses for additional information to determine whether the borrowing is justified...Standards governing the availability of adjustment [discount] credit will normally vary with the size of the institution...The largest institutions, which have broad access to the money markets for funds and adjust their reserve positions on a daily basis, will normally be expected to borrow only to the next business day. Other large institutions, which have some market access and also closely monitor their reserve positions, will be encouraged not to borrow beyond the end of the current reserve period. Medium-sized and smaller institutions, however, will be able to request advances extending beyond the current reserve period....A borrowing institution with a high frequency record normally would be expected to make arrangements to avoid the window for an extended period. But frequency of borrowing

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3. It was often argued that an additional nonpecuniary cost was a perceived "stigma" of discount borrowing: a fear on the part of banks that borrowing would be observed and taken as a signal that the borrowing bank was in financial distress (Clouse 1994).

will be considered in context with the amounts borrowed. Thus, less importance will be attached to reserve periods in which the amount of borrowing is relatively small (1980:I 3-4).

Reserves supplied through the discount window are "borrowed reserves." The supply of "nonborrowed reserves" - total reserves *less* discount borrowing - is determined mainly by Federal Reserve open-market operations.

1.2) Two eras of interest-rate targeting

The first era of interest-rate targeting began in the early 1970s as the FOMC instructed Fed staff responsible for open-market operations - the "Desk" - to keep nonborrowed reserves at the level that would hold the market fed funds rate in the middle of a target range (Rudebusche, 1995). Changes in the target were not announced but were deliberately signalled to financial market participants, usually through the conspicuous use of certain types of open-market operations (Meulendyke, 1998: 45). This era ended after September 1979. My 1970s samples end then, and begin with January 1975 to avoid maintenance periods affected by financial crises and the 1974 Credit Crunch.[4]

The later era began over the late 1980s as FOMC instructions to the Desk put more and more weight on the "intended" fed funds rate. According to Meulendyke (1998:55), the transition to interest-rate targeting was complete following the stock market crash of October 1987. Hamilton and Jorda date it a bit later, to 1989 (2002:1149). At first, changes in the target were not announced but signalled to market participants as in the 1970s (Federal Reserve Bank of New York, 1992:86-87; Feinman, 1993a: 239-240; Edwards, 1997:862). In February 1994 the FOMC began to announce whether it had changed the target. My "1990s" samples begin with January 1989; beginning with January 1988 or 1990 gave similar results. They end in July 1999, with the last change in the target before the adoption of the Special Liquidity Facility. For most results I exclude four maintenance periods around the end of 1990

4. During these periods discount lending was boosted by lender-of-last resort operations. The crises were the Franklin National Bank failure and the Herstatt crisis, described by Wojnilower (1980, p. 299). Eckstein and Sinai (1986, p. 43) date the 1974 Credit Crunch.

when Fed staff made extraordinary adjustments to nonborrowed reserves to accommodate decreases in reserve requirements.[5]

Figure 1 plots discount and target rates on days ending maintenance periods ("settlement Wednesdays") at a weekly frequency (so for the 1980s-1990s values are the same for two weeks). The discount rate and 1980s-90s targets are taken from the Federal Reserve Bank of New York's website. The 1970s target rate is from Rudebusche (1995a, b). The 1970s sample contains 81 changes in the target series. For 70 of these the discount rate remained fixed through the end of the maintenance period, or longer. The 1980s-1990s sample (excluding the periods around the end of 1990) contains 42 target changes; the discount rate remained fixed through 28. Figure 2 plots maintenance-period average values of the target and market (effective) fed funds rates. Table 1 shows results of regressing changes in the maintenance-period average market rate on changes in the maintenance-period average target, for all periods and for periods when the discount rate was held fixed. Coefficients on the target are close to one for both eras.

In both the 1970s and 1990s, Desk staff understood that substitution of required balances across a maintenance period's days tended to hold the market rate at the perceived target early in the period (Federal Reserve Bank of New York, 1977: 43; Meulendyke 1998:48). Daily open-market operations were guided by a multi-day plan for the maintenance period as a whole, known as the "path," intended to hold the market rate at the target on average through the period's end. The path was usually described in terms of "free reserves" - nonborrowed reserves less required reserves, or equivalently excess reserves less discount borrowing. At a period's outset Fed staff forecast the volume of discount borrowing that would prevail, and the amount of excess reserves banks would desire to hold, *assuming* market rates were equal to the target. Subtracting the conditional forecast for discount borrowing from forecast excess reserves gave the supply of free reserves that should hold the market rate at the target. Adding this

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5. The decreases were phased in over two periods (Federal Reserve Bank of New York, 1991: 72-73; 1992:80-84). I exclude these and those just before and after. Including them in my samples only strengthen the arguments I make below, as it further reduces magnitudes and significance of coefficients when I regress changes in reserve supply on policy rates.

quantity to an estimate of required balances gave the corresponding supply for nonborrowed reserves. The path equated maintenance-period average nonborrowed reserves to this figure (Meek, 1978; Meulendyke, 1998:142-47; Edwards, 1997). Over the course of a period Desk staff might revise the path in response to new information about required reserves, or obvious deviations of borrowing and excess reserves from their initial assumptions. They might also marginally add (drain) reserve supply if they observed fed funds rates persistently above (below) the target (Meulendyke, 1998:147, 177-80). But any predictable patterns were soon incorporated into initial planning. Thus, the relationship between the path for free reserves and policy rates - the target rate and the discount rate - reflected the theory on which Desk staff based their conditional forecasts of banks' desired excess reserves and discount borrowing.

Over the course of the period Fed staff carried out open-market operations to keep nonborrowed reserve supply on the path, given their daily forecasts of other factors affecting reserve supply. Daily free reserve supply could deviate from the path due to mishaps in open-market operations, errors in Fed forecasts of other factors affecting reserve supply, or errors in Fed estimates of current required reserves. Before the FOMC began to announce whether it had changed the target in February 1994, daily reserve supply could also deviate because of signalling operations. But errors or signalling operations in the earlier days of a period could usually be counteracted later in the same period, leaving period- average free reserves close to the path.[6]

1.3) Standard theories of reserve demand

Two theories of reserve demand and discount borrowing were common through the 1970s and the 1990s. I refer to them as the "inventory-theoretic" view and the "borrowing-function" view. Both implied that a change in a target overnight rate had to be implemented either by a change in maintenance-period average free reserve supply, or by a change in the discount rate.

The borrowing function view

6. It was possible to adjust reserve supply without signalling because many types of open-market operations were *not* interpreted as signals (Meulendyke, 1988:13; 1998:45, 47; Federal Reserve Bank of New York, 1992:87).

The borrowing function view was developed by Federal Reserve staff in the 1920s (Riefler, 1930; Burgess, 1936). Through the 1990s it was laid out in Fed publications and academic literature (e.g. Polokoff 1960, Goldfeld and Kane 1966, Peristiani 1991) and framed empirical studies of American data (e.g. Strongin 1995, Hamilton 1997, Bernanke and Mihov 1998a, 1998b). It assumed banks borrowed from the discount window because, up to a point, it was cheaper to borrow from the discount window than in the market - otherwise there would be no discount borrowing at all (Goodfriend and Whelpley, 1993:14; Roth and Siebert, 1983:21,22). To explain why banks borrowed at times when the discount rate exceeded the market fed funds rate, it was argued that transactions costs were higher for market borrowing: net of transactions costs, discount borrowing was still cheaper (Willis, 1967; VanHoose, 1987: 569). Administrative control created costs that increased with the amount a bank borrowed - "higher borrowing increases the likelihood of costly Federal Reserve consultations with bank officials" (Goodfriend and Whelpley, 1993:12). A bank borrowed up to the point where the nonpecuniary cost of borrowing another dollar just equalled the spread between the overnight rate and the discount rate (adjusted for transactions costs). The resulting positive relation between the spread and borrowing was the "borrowing function." The quantity of excess reserves banks desired to hold was believed to be variable, but insensitive to interest rates (Strongin, 1995: 470). Thus, free reserve demand was negatively related to the spread between the market rate and the discount rate, as the flip side of the borrowing function. Given the discount rate, Fed staff could hold the market rate at a target by supplying the right quantity of free reserves. A change in the target could be implemented by a change in free reserve supply, holding the discount rate fixed; or by making an equal change in the discount rate, holding free reserve supply fixed.

To illustrate, consider a simple model in which all banks are identical, a maintenance period is just one day long, and there is no transactions-cost differential. i is the market overnight rate. i^D is the discount rate. R is a bank's free reserve. X is its desired excess reserve. B is its discount borrowing. The marginal nonpecuniary borrowing cost is $\Phi(B)$. The inverse of $\Phi(B)$ is $\Psi(x)$. Arbitrage profit *less* nonpecuniary cost is:

$$V = (i - i^D)\ B - \int_0^B \Phi(B)\ dB \quad where \quad \Phi'(B) > 0\ ,\ \Phi(0) = 0 \tag{1}$$

Maximizing (1) gives discount borrowing per bank:

$$B_{bf} = \Psi(i - i^D) \quad where \quad \Psi'(i - i^D) > 0 \tag{2}$$

(2) is the borrowing function. Free reserve demand is $R_{bf} = X - B_{bf}$. Given free reserve supply per bank R^S, the market overnight rate is:

$$i = i^D + \Phi(X - R^S) \quad where \quad \partial i / \partial R_S = = -1/\Psi'(i - i^D) < 0 \tag{3}$$

An exogenous change in free reserve supply has a "liquidity effect" on the market rate.

i^T is the target fed funds rate . B_{bf}^T is the value of (2) for $i = i^T$. The corresponding free reserve quantity is $R_{bf}^T = X - B_{bf}^T$. The market rate hits the target if $R^S = R_{bf}^T$. Free reserve supply can deviate from R_{bf}^T, causing a market-rate "miss" $e = (i - i^T)$, because of mishaps in open-market operations, errors in Fed staff forecasts of other reserve-supply factors, or errors in estimates of current required reserves. All of these events constitute "reserve supply shocks" ε_S uncorrelated with R_{bf}^T. Reserve supply can also deviate from R_{bf}^T if Fed staff fail to accommodate a fluctuation in R_{bf}^T. Unaccommodated fluctuations in R_{bf}^T due to instability in desired excess reserves are ε_X. Those due to instability in the borrowing function are ε_B . Thus:

$$R_S = R_{bf}^T + \varepsilon_S - \varepsilon_X - \varepsilon_B \tag{4}$$

$$e = i - i^T \approx -1/\Psi'(i^T - i^D)\ (\varepsilon_S - \varepsilon_X - \varepsilon_B\ ) \tag{5}$$

Assuming Fed staff estimates of reserve demand are roughly rational, reserve-supply errors are uncorrelated with changes in policy rates. Thus, regressions of reserve quantities on exogenous changes in policy rates should reveal partial effects of policy rates on B_{bf}^T and R_{bf}^T. These are:

$$\partial R_{bf}^{T}/\partial i^{T} = -\partial R_{bf}^{T}/\partial i^{D} = -\partial B_{bf}^{T}/\partial i^{T} = \partial B_{bf}^{T}/\partial i^{D} = -\Psi'(i^{T} - i^{D}) \quad \textbf{(6)}$$

Note that effects on borrowing are equal in absolute magnitude to effects on reserve supply. This is because free-reserve demand is the flip side of the borrowing function. Also, effects of target changes are equal in magnitude to effects of discount-rate changes. This is because borrowing and free-reserve demand depend on the *spread* between the overnight rate and the discount rate.

What if the maintenance period is more than one day? In this view that makes no substantial difference to the relation between interest rates and reserve quantities: borrowing, and hence free reserve demand, are still determined by the spread between the market rate and the discount rate as in (2).

The inventory-theoretic view

The inventory-theoretic view focused on banks' use of reserve accounts to clear payments and discount loans to cover reserve-account shortfalls. Given a probability distribution for the net credit to a bank's reserve account in end-of-period settlement, a larger free reserve balance decreases the probability of a shortfall. A bank balances the cost of holding excess reserves against the potential cost of discount borrowing to cover a shortfall. In a corridor system, the cost of discount borrowing is an above-market penalty rate. In inventory-theoretic models of the Fed's pre-1999 regime, it is the below-market discount rate *plus* nonpecuniary cost created by administrative control (Orr and Mellon, 1961; Poole, 1968; Clouse and Dow, 1999). As in the borrowing-function view, free reserve demand is negatively related to the overnight rate, positively related to the discount rate; a change in the target holding the discount rate fixed must be implemented by a change in free reserve supply. But in inventory-theoretic models the determinant of reserve demand is the *ratio* of the overnight rate to the total cost of discount borrowing, not the *spread* between the overnight rate and the discount rate. Thus, the partial effect of an implemented change in the target on free reserves is larger than the partial effect of a change in the discount rate. Also, effects of implemented changes in policy rates on discount borrowing are smaller in magnitude than effects on free reserves.

To illustrate, again assume identical banks and a one-day maintenance period. A random variable δ is the net credit to a bank's reserve account in final settlement, with a minimum value $(-\underline{\delta})$ (there is a limit to possible debits), a p.d.f. $f\{x\}$, c.d.f. $F\{x\}$, the inverse of the c.d.f. $G(x)$, and $H(x) = E[\delta \mid \delta < x]$. Banks know this distribution. In the event that $R+\delta<0$ there is a shortfall in the reserve account and the bank borrows $(-R-\delta)$ from the discount window. Each dollar of borrowing costs i^{D} plus nonpecuniary cost φ. A bank chooses R to minimize:

$$C = iR + (i^{D}+\varphi)\ E[B] \quad where \quad E[B] = \int_{\underline{\delta}}^{-R} (-R-\delta) f\{\delta\} d\delta = F\{-R\}\big(-R - H\{-R\}\big) \tag{7}$$

so its demand for free reserves is:

$$R_{inv} = -G(i/(i^{D}+\varphi)) \quad where \ \ \partial R_{inv}/\partial i = -\frac{1}{i^{D}+\varphi}\ G'(i/(i^{D}+\varphi)) = -\frac{1}{i^{D}+\varphi}\ \frac{1}{f\{-R_{inv}\}} < 0 \tag{8}$$

A bank borrows only in the event of a reserve-account shortfall. The probability of that event is:

$$F\{-R_{inv}\} = i/(i^{D} + \varphi) \tag{9}$$

The expected value of a bank's borrowing, or average borrowing across all banks, is:

$$B_{inv} = \frac{i}{i^{D}+\varphi}\ \Big[G\big(i/(i^{D}+\varphi)\big) - H\big(G(i/(i^{D}+\varphi))\big)\Big] \quad where \ \ \partial B_{inv}/\partial i = -\left(\frac{i}{i^{D}+\varphi}\right)\ \partial R_{inv}/\partial i \tag{10}$$

Given free reserve supply per bank, the market overnight rate is:

$$i = (i^{D}+\varphi) F\{-R_S\} \qquad where \quad \partial i/\partial R_S = -(i^{D}+\varphi)\ f(-R_S) = -\frac{i^{D}+\varphi}{G'(i/(i^{D}+\varphi))} < 0 \tag{11}$$

Again, an exogenous change in free reserve supply affects the market rate. The market rate hits the target if free reserve supply equals R_{inv}^{T} defined by setting $i=i^{T}$ in (8). The corresponding volume of discount borrowing is B_{inv}^{T} defined by (10).

Describing Fed reserve-supply procedures as before, ε_S represents reserve-supply shocks uncorrelated with R^T_{inv}. Unaccommodated disturbances to R^T_{inv} due to instability in the distribution for δ are ε_G. Those due to instability in φ are ε_φ. Thus:

$$R_S = R^T_{inv} + \varepsilon_S - \varepsilon_\varphi - \varepsilon_G \quad \textbf{(12)}$$

$$e = i - i^T \approx -\frac{i^D+\varphi}{G'(i^T/(i^D+\varphi))}(\varepsilon_S - \varepsilon_G - \varepsilon_\varphi) \quad \textbf{(13)}$$

Regressions of reserve quantities on policy rates should reveal their partial effects on R^T_{inv} and B^T_{inv}:

$$\partial R^T_{inv}/\partial i^T = -G'(i^T/(i^D+\varphi)) \ / \ (i^D+\varphi) \quad \textbf{(14)}$$

$$\partial R^T_{inv}/\partial i^D = \frac{i^T}{i^D+\varphi}\left(G'(i^T/(i^D+\varphi)) \ / \ (i^D+\varphi)\right) = -\frac{i^T}{i^D+\varphi}\ \partial R^T_{inv}/\partial i^T < -\partial R^T_{inv}/\partial i^T \quad \textbf{(15)}$$

$$\partial B^T_{inv}/\partial i^T, i^D = -\frac{i^T}{i^D+\varphi}\ \partial R^T_{inv}/\partial i^T, i^D \quad \textbf{(16)}$$

Note that the magnitude of (15) is smaller than (14), and effects on borrowing in (16) are smaller in magnitude than (14) and (15).

If the maintenance period is more than one day, reserve demand and borrowing are governed by the interaction between the reserve requirement that must be met by the end of the period and the requirement to hold a positive or zero balance at the end of each day's settlement. At one extreme, required reserves are very small relative to balances banks would choose to hold anyway to avoid overnight overdrafts: then daily reserve demand is as described above with free reserves practically equal to nonborrowed reserves. At the opposite extreme, if required reserves are very large, on earlier days of a period the market rate remains equal to the rate expected to prevail on the final day; on the final day reserve demand is as described above with required reserves equal to the unsatisfied portion of the multi-day requirement (for examples see Poole, 1968; Ennis and Keister, 2008). Things are more complicated if required reserves are between these extremes, but it generally remains true that changes in the target holding the discount rate fixed require adjustments to free reserve supply; partial effects of discount-rate changes are smaller than partial effects of implemented target changes; and effects on discount borrowing are smaller than effects on free reserves.

1.4 Reserve supply and borrowing in the 1970s and the 1980s-1990s

According to Fed staff accounts, in the 1970s open-market operations were guided by the borrowing-function view. Aggregate borrowing obviously tended to increase with the spread between market overnight rates and the discount rate. When the spread was very wide borrowing exceeded required reserves so that free reserves were negative - in Fed jargon, there were "net borrowed reserves." To hit the fed funds target the Desk "exploited the positive relationship between borrowing and the spread between the funds rate and the discount rate. The relationship was imprecise, but it gave the Desk an idea of how many free or net borrowed reserves were likely to be consistent with the intended funds rate" (Meulendyke, 1988:11). A change in the target relative to the discount rate "meant instructing the Desk to change interest rates by altering the share of the demand for reserves met with nonborrowed reserves"; to decrease the spread, "the Desk used to increase the proportion of reserve demands met with nonborrowed reserves" (141).

When the Fed returned to interest-rate targeting in the late 1980s, Fed publications continued to describe Desk practices in this way (Federal Reserve System, 1990). But the reality was different. In the mid-1980s Fed staff had observed that discount borrowing no longer increased with the spread between the discount rate and market overnight rates: the borrowing function had disappeared (Meulendyke, 1998:54,55; Clouse, 1994). This "complicated the reserve management procedures that depended on a reasonably predictable relationship between borrowing and the spread" (Federal Reserve Bank of New York, 1989:83). Unable to predict this relationship, the Desk did *not* change the planned path for reserve supply in response to a change in the target rate, whether or not there was a change in the discount rate. Market rates nonetheless appeared to follow communicated changes in the target. In the late 1990s, Meulendyke (1998:142) observed that the market overnight rate "has tended to move to the new, preferred level as soon as the banks knew the intended rate, with little or no change in the amount of borrowing allowed for when constructing the path for nonborrowed reserves" (see also Krieger, 2002:74). But staff accounts do not say exactly when the Desk stopped adjusting the path in response to target changes. Was it around February 1994, when the FOMC switched from signalling to open announcement of target changes? Or was it as soon as the Fed returned to interest-rate targeting in the late 1980s, as a consequence of the disappearance of the borrowing function?

To confirm these accounts and establish the timing of the development of open-mouth operations, I examine data from the 1975-79 and 1989-1999 spans described above. For each era, I regress changes in average free reserves and discount borrowing from one maintenance period to the next on changes in maintenance-period average policy rates. Policy rates can be treated as exogenous here because, as Friedman and Kuttner (2011:1380) observe, there is no reason to believe the FOMC changed them in response to other factors causing fluctuations in reserve quantities from one maintenance period to the next. To see whether open-mouth operations were effective prior to February 1994, I examine a sample that starts in 1989 but ends with January 1994. Table 2 presents results. For columns (1) the LHS variable is the change in log discount borrowing from the previous period. For (2) it is the change in free reserves. As I cannot take the log of free reserves (often a negative quantity), I express the change as a fraction of the previous period's nonborrowed reserve quantity. For (3) I express the change in borrowing also as a fraction of nonborrowed reserves, to compare coefficient magnitudes with (2). For (4) and (5), I omit periods when there was a change in the maintenance-period average discount rate, to observe effects of target changes holding the discount rate fixed.

Both the borrowing-function and inventory-theoretic views imply that coefficients on the target change should be positive for discount borrowing, negative for free reserves. The borrowing-function view implies that, within each column, the target-rate coefficient should be about equal in absolute magnitude to the discount-rate coefficient, and that across (2) and (3) or (4) and (5), coefficients should be about equal in magnitude. 1970s results, in panel A, show just these patterns. Coefficients are all significantly different from zero at the one or two percent level. In no case can one reject at the five percent level a hypothesis that corresponding coefficients are equal in magnitude. Panels B) and C) show results from 1989-1999 and 1999-January 1994. None of the estimated coefficients is significantly different from zero at conventional levels; they have the same signs as their 1970s counterparts but are much smaller in magnitude.

Thus, data confirm staff accounts. In the 1970s Desk staff adjusted maintenance-period free reserve supply when the FOMC changed the target-discount rate spread. Relationships between reserves, discount borrowing and policy rates appeared consistent with the borrowing-function view specifically. In the 1990s era Desk staff no longer adjusted reserve supply when the FOMC changed the spread, as borrowing no longer appeared consistent with the borrowing function. This was already true prior to February 1994, while target changes were still being signalled rather than announced.

The last piece of the puzzle is this: though Fed staff were no longer using *intended* reserve-supply adjustments to implement changes in the target, it is clear that *accidental* reserve-supply shocks affected market overnight rates just as predicted by standard views. Recall that, in both the borrowing-function and inventory-theoretic models, reserve-supply errors due to errors in Fed forecasts of reserve-supply factors other than open-market operations (denoted ε_S) cause the market rate to deviate from the target (expressions 5 and 13). In reality, one such factor is the balance of payments into the U.S. Treasury's Federal Reserve accounts (inflows to the accounts drain reserves). Using data from the 1990s, Hamilton (1997) found evidence that errors in Fed staff forecasts of Treasury payments were strongly correlated with fluctuations in market fed funds rates, especially on the last days of maintenance periods. Carpenter and Demiralp (2006) later confirmed Hamilton's results.

2) An explanation

In this section, I propose an explanation of the development of open-mouth operations that is consistent with liquidity effects from accidental reserve supply shocks, the disappearance of the borrowing function and the apparent consistency of reserve quantities with the borrowing-function view in the 1970s. I propose that the borrowing-function model was a good description of bank behavior all along, even through the 1990s, but only for *small* banks. Large banks' behavior was always different, in two ways. First, it was always more consistent with the inventory-theoretic view. In both the 1970s and the 1990s large banks cleared payments through their reserve accounts, while many small banks did not (they cleared through accounts held in larger "correspondent" banks [Knight, 1970; Osterberg and Thompson, 1999]). As early as the 1920s it was observed that large banks borrowed from the discount window mainly to cover unforseeable reserve shortfalls, while small banks borrowed to arbitrage against the discount rate.[7]

More importantly, large banks faced a different form of discount-window administrative control. Recall large banks were discouraged from borrowing "continuously." Their nonpecuniary borrowing cost was the loss of an option to borrow in the near future. The value of this option depended on expectations of near-future overnight rates, which were guided by signalled changes in the target. As these affected large banks' nonpecuniary borrowing cost they shifted large banks' reserve demand much as a target change shifts reserve demand in a corridor system. For the same reason, signalled target changes shifted the relationship between the current overnight rate and large banks' discount borrowing.

Taking large and small banks together, the relationship between interest rates and *total* reserve quantities depended on the relative magnitude of small banks' borrowing. In the 1970s, the effect of a change in the target-discount spread on small banks' borrowing was substantial relative to other factors causing variations in total borrowing. That is why total borrowing appeared consistent with the borrowing function view. In the 1990s, small banks' borrowing still responded to the spread. But the magnitude of their aggregate response was no longer substantial relative to total borrowing. That is why

7. Riefler (1930) observed that banks outside money-market centers borrowed from the discount window for long periods to fund loans to customers, while "larger city member banks" borrowed only for a few days when "unforeseen demands have reduced their reserves below requirements" (p. 31). In 1931 Fed officials testified that "borrowing to profit by the difference between rates of rediscount and the lending rates to the market" was "confined principally to country banks" (United States Senate 1931, Appendix Part 6:790, 792). In the 1970s, Stigum (1978:201) observed that "larger banks" borrow "because they experience, due to an unexpected occurrence, difficulty in settling on a Wednesday." In data from 1987 through 1993, Clouse (1994:968) found that large banks tended to borrow at times when banks were subject to unforseeable reserve shortfalls; small banks' borrowing did not show this pattern.

total borrowing no longer appeared consistent with a borrowing function. When Fed staff stopped adjusting reserve supply to changes in the target-discount spread, the market rate nonetheless followed signalled changes in the target because of the effect of expected future overnight rates on large banks' reserve demand.

Importantly, there are *a priori* reasons to believe the relative magnitude of small banks' discount borrowing declined greatly after the 1970s. Starting in the early 1980s, many small banks were closed or merged. Relatively small banks' share of total bank assets and liabilities fell sharply (Amel and Jacowski, 1989; Berger, Kashyap, and Scalise, 1995). In 1989 many remaining small banks joined the Federal Home Loan Bank system (Federal Home Loan Bank of San Francisco, 2002) and thereby lost regular access to discount credit.[8]

In the remainder of this section, I present a model to illustrate my argument. The model shows that the effect of signalled (or announced) changes in the target on large banks' nonpecuniary borrowing cost can be strong enough to make open-mouth operations effective, while accidental reserve-supply shocks still affect market rates. The model also lays out implications for the behavior of discount borrowing by large *versus* small banks which I will test in the following section.

2.1) Model

There are two types of bank, "large" and "small." A small bank follows the borrowing-function model with free reserve demand R_{bf} and borrowing B_{bf}, and R_{bf}^{T}, B_{bf}^{T} for $i = i^{T}$.

A large bank uses its reserve account to clear payments as in the inventory-theoretic model above, but subject to a constraint on continuous discount borrowing. The specific assumptions I make about this constraint keep this model as close as possible to a standard inventory-theoretic model. A large bank that borrows may lose access to the discount window for one period. Matching the policy that "less importance will be attached to reserve periods in which the amount of borrowing is relatively

8. The Fed did not ordinarily lend to FHLB members on the grounds that FHLB advances, which have no effect on reserve supply or discount borrowing, were a substitute source of funding (Meulendyke, 1998: 153).

small" (Federal Reserve Board, 1980: I 4), a bank is more likely to lose access the more it borrows: if it borrows B dollars, it loses access with probability πB. (π must be scaled so that $\pi B \leq 1$ within the realized range of borrowing.) A bank without discount-window access this period holds a free reserve balance equal to $\underline{\delta}$, large enough to cover the largest possible net debit, because the penalty for running an uncovered reserve deficiency is very high. A large bank *with* access can hold a smaller balance $R < \underline{\delta}$, choosing R to minimize the expected present value, across present and all future periods, of the sum of the costs of discount borrowing and opportunity costs of holding excess reserves. This is equivalent to minimizing (7) with the nonpecuniary borrowing cost is defined to be:

$$\varphi = \pi \ \tfrac{1}{1+i} \ E\Big[i_{+1}\underline{\delta} - \big(i_{+1} R_{+1} + (i_{+1}^{D} + \varphi_{+1}) B_{+1} \big) \Big] \qquad \textbf{(17)}$$

The subscript *+1* denotes a variable in the upcoming period. φ incorporates the value of the option to borrow in the upcoming period, that is to say, the option to hold a free reserve smaller than $\underline{\delta}$. Given φ, reserve demand and average borrowing for large banks with window access this period are R_{inv} and B_{inv} from (8) and (10), and R_{inv}^{T}, B_{inv}^{T} for $i = i^{T}$. The fraction of large banks with window access this period is $\alpha = 1 - \alpha_{-1} \pi B_{inv_{-1}}$. Across *all* large banks average borrowing is $B_{large} = \alpha B_{inv}$ and free reserve demand is $R_{large} = (1 - \alpha)\underline{\delta} + \alpha R_{inv}$. The supply of free reserves per bank that holds the market overnight rate at the target is $R_{S}^{T} = s R_{bf}^{T} + (1 - s) R_{large}^{T}$, where $R_{large}^{T} = (1 - \alpha)\underline{\delta} + \alpha R_{inv}^{T}$ and s is the fraction of small banks.

Market participants expect the market rate to equal the target plus a mean-zero miss e. With that, substituting (8) and (10) into (17) gives:

$$\varphi = \pi \ \tfrac{1}{1+i} \ E\Big[\ (i_{+1}^{T} + e_{+1}) \ \big(\underline{\delta} \ + \ H(-G((i_{+1}^{T} + e_{+1})/(i_{+1}^{D} + \varphi_{+1})) \ \big) \ \Big] \qquad \textbf{(18)}$$

For realistic values of the overnight rate, *1/(1+i)* is practically equal to one. A large bank's nonpecuniary borrowing cost φ is effectively determined by expectations of the policy rates that will prevail in the upcoming period and, through φ_{t+1}, in subsequent periods. An increase in the expected value of the upcoming period's target raises φ as it raises the value of the option to hold a smaller free reserve. An increase in the expected discount rate decreases φ.

An accidental reserve-supply shock ε_S has no effect on expected future interest rates (assuming it is not confused with a signal of a change in the target). Thus, it is unrelated to φ. It has a negative liquidity effect on the market rate just as in standard models:

$$\partial i/\partial\varepsilon_S \;\approx\; -1/\left(s\frac{1}{\Psi'(i^T - i^D)} \;+\; (1-s)\,\alpha\frac{G'\!\left(i^T/(i^D+\varphi^T)\right)}{(i^D+\varphi^T)} \right) \;<\; 0 \qquad \textbf{(19)}$$

The relation between reserve supply and the target is different. Across maintenance periods, current policy rates may be correlated with policy rates expected to prevail in the upcoming period, hence with φ. (Also, α depends on lagged large bank borrowing.) Allowing for this:

$$\partial R^T_{large}/\partial i^T = -\,\alpha Z_1\frac{G'(i^T/(i^D+\varphi))}{i^D+\varphi}\;\left(1 - \frac{i^T}{i^D+\varphi}\;\partial\varphi/\partial i^T\right) \qquad \textbf{(20)}$$

$$\partial R^T_{large}/\partial i^D = \alpha Z_1\frac{i^T}{i^D+\varphi}\;\frac{G'(i^T/(i^D+\varphi))}{i^D+\varphi}\;\left(1 + \partial\varphi/\partial i^D\right)$$

$$where\quad 1-\pi(\underline{\delta}-R^T_{inv})\;\frac{1}{1+\pi B^T_{inv}}\;\frac{i^T}{i^D+\varphi}\;\le\; Z_1\;\le 1$$

(Z_1 accounts for the eventual effect of a change in lagged borrowing on α. Z_1 is equal to one immediately after a change in a policy rate, and converges to the smaller value over time.) To the degree that the current target (discount) rate is positively correlated with the expected target (discount) rate for the upcoming period, then $\partial\varphi/\partial i^T>0$ ($\partial\varphi/\partial i^D<0$). This tends to weaken the relationship between implemented changes in policy rates and the quantity of free reserves demanded by large banks.

The correlations between current policy rates and φ that hold on average across periods in an era depend on market participants' beliefs about dynamics of the target and the target-discount rate spread. Any assumptions here would be debatable, especially for the 1990s which was marked by rapidly evolving Fed practices on policy "transparency" and changes in the relation between expected and realized target rates (Swanson, 2006). In both the 1970s and the 1990s, changes in the target-discount spread were almost unpredictable (Thornton, 1998). But it is easy to show that, under plausible conditions, correlations between policy rates and φ may be such that R^T_{large} is practically unrelated to the current level of i^T.

In many macroeconomic models the Fed's target fed funds rate has a long-run steady-state value (typically the sum of a desired inflation rate and the natural rate of interest) and deviations from this value are approximately AR(1) (typically as a result of an interest-rate rule or central-bank preference function interacting with AR(1) shocks to spending or inflation). Suppose market participants believe these conditions hold and the serial correlation coefficient ρ is very close to one, which is certainly realistic at a maintenance-period frequency. Suppose they also believe there is a LRSS discount rate. Then one can take linear approximations around a nonstochastic long-run steady state in the usual way to roughly quantify relationships between current policy rates and reserve quantities. Denoting LRSS values as $\bar{x}$ the LRSS frequency of discount borrowing by large banks is:

$$\bar{\alpha}\; F\{-\bar{R}_{inv}\} = \frac{1}{1+\pi\,\bar{B}_{inv}}\;\frac{\bar{i}^{\,T}}{\bar{i}^{\,D}+\bar{\varphi}} \quad where \quad \bar{\alpha} = 1\,/\,(1+\pi\,\bar{B}_{inv}) \tag{21}$$

Cosimano and Sheehan (1994, Table 1) report that over 1984-1990, around the appearance of open-mouth operations, a typical bank in the relatively large "weekly reporters" category borrowed in about three percent of the maintenance periods. On this basis, 0.03 would be a reasonable value for (21).

Consider an innovation to the target that is not expected to affect the path of the discount rate. The effect on R^T_{large} is approximately:

$$\partial R^T_{large}/\partial i^T \approx -Z_2\Big(G'(\bar{i}^{\,T}/(\bar{i}^{\,D}+\varphi))/(\bar{i}^{\,D}+\bar{\varphi})\Big)\bar{\alpha} Z_1 \quad where\;\; Z_2 = \frac{1}{1/\rho+\pi\bar{B}_{inv}}\;\frac{\bar{i}^{\,T}}{\bar{i}^{\,D}+\bar{\varphi}}\;\frac{\bar{i}^{\,D}+(1-\rho)\bar{\varphi}}{\rho\,\bar{i}^{\,T}} < 1 \tag{22}$$

Z_2 is the degree to which the correlation between i^T and φ diminishes the magnitude of the relationship between i^T and R^T_{large}.[9] If φ were unrelated to i^T as in a standard inventory theoretic model, Z_2 would

9. (22) is derived from (18) and (8) on the condtion that $\partial\varphi_{+1}/\partial\varphi = \rho$, using $\partial H(G(i/(i^D+\varphi)))/\partial i = B_{inv}((i^D+\varphi)/i^2)$.

be equal to one. Here, for ρ very close to to one, an upper bound for Z_2 is (21), the large-bank borrowing frequency, so a plausible value for Z_2 would be less than 0.03: that is, the magnitude is diminished by about 97 percent. The observable relationship may be further diminished and even *reversed in sign* if market participants believe a target change is likely to be followed up in the near future with a discount-rate adjustment. For example, suppose a target change creates a probability ω that an equal change in the discount rate will occur in the period after next, after which the discount rate would converge to the long-run steady state at the same rate as the target. Then:

$$\frac{\partial R_{large}}{\partial i^{T}} \approx -(Z_2 - Z_3)\left(G'(\bar{i}^{T}/(\bar{i}^{D}+\varphi))\ /\ (\bar{i}^{D}+\bar{\varphi})\right)Z_1 \quad where\ Z_3 = \omega\frac{\bar{i}^{T}}{\bar{i}^{D}+\bar{\varphi}}\ \frac{(\pi\bar{B}_{inv})^2}{1+\rho\pi\bar{B}_{inv}} \tag{23}$$

Depending on the value of ω it is possible that $Z_2 - Z_3 < 0$: a higher value of the target could actually be associated with an increase (decrease) in the quantity of free reserves demanded by large banks.

One should not put too much weight on these calibrations. They depend on assumptions I made merely for simplicity about the specific nature of the constraint on large banks' continuous borrowing. But they do show it is plausible that the quantity of free reserves demanded by large banks could be practically unrelated to the level of the target. Similar arguments hold for the discount rate.

The relationship between R^{T}_{large} and policy rates actually prevailing in a sample of periods can be inferred from the behavior of large banks' borrowing in that sample. As in the standard inventory-theoretic model borrowing reflects the quantity demanded of free reserves :

$$\partial B^{T}_{large}/\partial i^{T,D} = -Z_4\frac{i^{T}}{i^{D}+\varphi}\ \partial R^{T}_{large}/\partial i^{T,D} \quad where\ (1-\alpha\pi)/[1-\alpha\pi\frac{i^{T}}{i^{D}+\varphi}(\underline{\delta}-R^{T}_{inv})] \le Z_4 \le 1 \tag{24}$$

(Z_4 accounts for the eventual effect of a change in lagged borrowing on α; it is equal to one immediately after a change in a policy rate and converges to the smaller value over time.) If implemented policy rates are uncorrelated with R^{T}_{large}, policy rates will also be uncorrelated with large banks' discount borrowing.

Suppose large banks' free reserve demand and borrowing are indeed unrelated to policy rates across periods. The apparent relation between policy rates and *total* borrowing would then depend on the relative importance of small banks' borrowing. If one regressed log total borrowing on the target and the discount rate as for Table 2, estimated coefficients would tend to equal those for small banks weighted by the share of small banks in total borrowing. The coefficients' statistical significance would depend on this magnitude relative to variations in total borrowing due to other factors.

I hypothesize that the relative magnitude of the response of aggregate small banks' borrowing to changes in the spread was large in the 1970s, small by the late 1980s. That accounts for the disappearance of the borrowing function, and for the disappearance of a relation between policy rates and free reserves through the response of Fed staff to the disappearance of the borrowing function. The market rate would still tend to follow the target across periods due to the relationship between current policy rates and φ. There would be some shortfall of the market rate from differences in the target, because reserve supply would fail to accommodate the relationship between small banks' reserve demand and the target-discount spread. But the shortfall might not be noticable. The size of the shortfall, like the appearance of the borrowing function, depends on the relative importance of small banks' borrowing. The average magnitude of the shortfall immediately around changes in the target (that is holding α fixed) would be:

$$\partial e/\partial i^{T} \approx -\frac{\partial R_{bf}^{T}/\partial(i-i^{D})}{\partial R_{bf}^{T}/\partial(i-i^{D}) + \frac{1-s}{s}\partial R_{inv}\partial i|_{\partial\varphi=0}} = -\frac{Z_5}{Z_5+Z_6 Z_7^{-1}} \quad \textbf{(25)}$$

$$where\ \ Z_5 = sn\partial B_{bf}^{T}/\partial(i^{T}-i^{D}) \qquad Z_6 = (1-s)n\partial B_{large}/\partial i|_{\partial\varphi=0} \qquad Z_7 = \frac{i^{T}}{i^{D}+\varphi}$$

where *n* is the number of small banks. Z_5 is the effect of the target-discount spread on aggregate small-bank reserve demand. As small banks follow the borrowing-function model, this is equal in magnitude to the effect on their discount borrowing. $Z_5+Z_6Z_7^{-1}$ is the effect of an exogenous change in the market rate, holding φ fixed, on the total quantity demanded of free reserves. Large banks follow a version of the inventory-theoretic model, so the effect on *their* reserve demand $Z_6 Z_7^{-1}$ is equal to the effect on their discount borrowing Z_6 multiplied by the inverse ratio of the target to large banks' total cost of discount borrowing Z_7. If Z_5 is relatively small, so is the shortfall. Importantly, this conclusion does not depend on my specific assumptions about the constraint on large banks' continuous borrowing. (25) holds as long as small banks follow the borrowing function model, while implemented changes in the target are unrelated to the quantity of free reserves demanded by large banks.

Testable implications

In both the 1970s and the 1990s, the spread between the target and the discount rate should be positively related to borrowing by banks that were treated as "small" at the discount window, unrelated to borrowing by banks that were treated as "large." In a regression of aggregate borrowing on the target-discount spread, the estimated coefficient should depend on the type of bank included in the aggregate. For an aggregate of "small" banks the coefficient should be positive. For an aggregate of "large" banks, the coefficient should not be significantly different from zero.

Another difference between small and large banks should appear if one adds to the right-hand side of the regression the spread between the *market* rate and the target, that is the miss *e*. Misses reflect either reserve-supply shocks, or unaccommodated disturbances to reserve demand on the part of small or large banks. For small banks the estimated coefficient on the miss should be *less than or equal to* the coefficient on the target-discount spread. For large banks, the estimated coefficient on the miss should be positive, *greater* than the zero coefficient on the target-discount spread.

Large banks' coefficient on the miss should be positive because most possible causes of misses are equivalent to an exogenous change in the overnight rate holding φ fixed: their causes are uncorrelated with disturbances to large banks' relation between interest rates and borrowing. An exception is unaccommodated disturbances to φ (which affect the market rate but not large bank borrowing). Denoting the resulting disturbances to reserve demand by ε_φ as in expression (12), the partial correlation between large-bank borrowing and the market-target spread should be about :

$$0 \leq \left(1 - \sigma_{e,\varphi}/\sigma_e^2\right) \bar{\alpha} \left(\frac{i^T}{i^D+\varphi}\right)\left(\frac{G'(i^T/(i^D+\varphi))}{i^D+\varphi}\right) = \left(1 - \sigma_{e,\varphi}/\sigma_e^2\right) \partial B_{large}/\partial i|_{\partial\varphi=0} \qquad \textbf{(26)}$$

where σ_e^2 is the variance of the miss e and $\sigma_{e,\varphi}$, is the covariance of e and ε_φ.

Small banks' coefficient on the miss can be less than their target-discount coefficient because one possible cause of misses is unaccommodated disturbances to small banks' borrowing function. Denoting these reserve-demand disturbances by ε_B as in (4), the partial correlation between small-bank borrowing and the market-target spread should be about:

$$0 \leq \left(1 - \sigma_{B,e}/\sigma_e^2\right) \Psi'(i^T - i^D) \leq \partial B_{bf}^T/\partial(i^T - i^D) \qquad \textbf{(27)}$$

where $\sigma_{B,e}$ is the covariance of the miss and ε_B.

3. Evidence

In this section of the paper I examine data on discount borrowing by banks aggregated into size classes that can be assumed *a priori* to correspond to the standards of "large" and "small" applied at the discount window. Results are consistent with my explanation of open-mouth operations. Borrowing by banks in small classes was positively related to the target-discount spread in the 1990s as well as the 1970s. Borrowing by banks in large classes was not. The two eras differed in the relative magnitude of the spread's effect on borrowing for the aggregate of banks that displayed "small bank" behavior. This was much greater in the 1970s. Finally, I use estimated relations between borrowing and interest rates to project the shortfall of the market rate from differences in the target across periods that would result if Fed staff failed to adjust reserve supply to accommodate small banks' demand. For the 1990s era the shortfall is miniscule: about two-tenths of a basis point for a one percent difference in the target.

3.1. Borrowing by large and small banks in the 1990s

Many Fed publications over the years stated that the Fed had different discount-window rules for large and small banks. But the 1980 press release referred to earlier gave unusually specific information about the Fed's standards of "large" and "small." To clarify the relationship between bank size and what Fed officials would accept as appropriate use of discount credit, the release gave figures on past borrowing for banks divided into four size classes, by volume of domestic deposits. In January 1981, Fed staff began to produce a regular internal report, for their own use, that recorded weekly borrowing by banks in exactly the same four classes, which I refer to as Large, Medium-large, Medium-small and Small.[10] The reports were never published but are available from the Federal Reserve Board. I was provided with data through December 1998. I do not claim the groupings in these data *exactly* match distinctions applied at the discount window. The Fed did not adjust the size cut-offs in response to general changes in deposits per bank, so their correspondence with discount-window standards must have drifted. But given the original purpose of the figures it is reasonable to assume *a priori* that a bank receiving "small bank" treatment was more likely to fall into a smaller class in these data. Unfortunately, the figures cannot be matched with data on other reserve quantities so I cannot calculate free or nonborrowed reserves for banks in the same classes.

I regress log maintenance-period borrowing by banks in each class, and total borrowing by all classes, on maintenance-period average values of the spread between the target and the discount rate, and the spread between the market rate and the target - the miss. I use levels rather than first differences because, while the two smaller classes showed borrowing in every period, the two larger classes do not (consistent with the inventory-theoretic model, which predicts that the occurrence of borrowing depends on the realization of payments shocks). The specification is Tobit for the two larger classes, OLS for the two smaller. Banks were reclassified in January and June of each year, so I add a set of dummies that take values of one beginning in the first maintenance periods of January or June, which also control for any time trends in borrowing. I do not report their estimated coefficients. As a group they were highly

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10. "Large" banks had $3 billion or more in domestic deposits; "medium-large" had between $1 billion and $2 billion; "medium-small" between $200 million and $1 billion; "small" less than $200 million.

significant.[11] For each class, I test the hypothesis that the market-target coefficient is less than or equal to the target-discount coefficient.

My explanation of open-mouth operations implies that results for a smaller class should be closer to the borrowing-function model: a positive coefficient on the target-discount spread, a coefficient on the market-target spread that is less than or equal to the target-discount coefficient. For a larger class, coefficients should be closer to my "large bank" model: zero for the target-discount spread, positive for the market-target spread. The hypothesis that the market-target coefficient is less than or equal to the target-discount coefficient should be rejected for a "large" bank class, accepted for a "small" bank class.

Table 3 shows results from the 1990s data. For panel A), the sample included all maintenance periods from January 1989 through December 1998. (Excluding maintenance periods around the reserve-requirement change in December 1990 made little difference here.) For panel B) the sample ends with Jamuary 1994. In both samples, Large and Medium-large classes show the patterns predicted for "large" banks: coefficients on the the target-discount spread are not significantly different from zero; coefficients on the market-target spread are positive and significantly different from zero; one rejects the hypothesis that the market-target coefficient is smaller. For the Medium-small and Small classes, patterns match the borrowing-function model: coefficients on the target-discount spread are positive and significantly different from zero; coefficients on the market-discount spread are about equal to the target-discount coefficients; one fails to reject the hypothesis that the market-target coefficient is smaller.

For total borrowing the coefficient on the target-discount spread is not significantly different from zero. Like the results in Table 2, this appears inconsistent with the borrowing-function model. But it is now clear that behavior of banks in the two smaller classes *was* consistent with the borrowing-function model in the 1990s. The bottom rows of Table 3 give average values across maintenance

11. Adding lagged borrowing to the right-hand side made little difference to the values of the interest-rate coefficients, and coefficients on lagged borrowing were not generally significantly different from zero at conventional levels. This is not inconsistent with a negative structural relation between lagged borrowing and current borrowing because, as Peristiani (1994:184) notes, there may be serial correlation in unobservable determinants of borrowing.

periods of each class's share in total borrowing, and the ratio of its borrowing to nonborrowed reserves. The two smaller classes' combined share in total borrowing, about 40 percent, was evidently not enough to create an obvious relationship between the target-discount spread and total borrowing.

3.2 Borrowing by large and small banks in the 1970s

1970s data that appear most comparable to the post-1981 data are in Fed publications that give borrowing in each maintenance period by "large banks in New York," "large banks in Chicago," "Other large banks," and "All other banks."[12] In the 1970s, large New York and large Chicago banks were referred to together as "money market banks." I combine these two groups into one, Large New York and Chicago. I refer to the other groups as Medium and Small. Figure 3 charts the percent of discount borrowing by banks in each class, annually, in these data and in the post-1981 data. The data set covering the 1970s does not overlap the post-1981 data (it ends with October 1979) so there is no way to know exactly how the 1970s classes correspond to the post-1981 classes. But comparing the last years of the 1970s data with the first years of the post-1981 data, it appears that the 1970s Medium class included some banks that would be classed as Medium-large, and some that would be classed as Medium-small, in the post-1981 data. From Table 3's results, one might expect the 1970s Medium class to be a mix of "large" and "small" banks.

As before, I regress log borrowing on the maintenance-period average target-discount spread and the miss, using Tobit for the two larger classes which show no borrowing in some periods (again, consistent with the inventory-theoretic model). The 1970s data, unlike those for the 1980s-1990s, give required reserve balances by size class. I add them to the right-hand side because Fed staff have often argued that required balance levels affect free reserve demand (Federal Reserve Bank of New York 1985, p. 44; Feinman, 1993b, p. 582; Meulendyke, 1998, p. 144) and growth in required balances may be affected by market interest rates (at least in the long run). Unfortunately I have been unable to

12. A bank in the last category held less than $400 million in net demand deposits (reported demand deposits less demand deposits due from other banks) (Federal Reserve Board, 1972:628)

determine the points in time at which banks were reclassified. To control for at least some effects of reclassification as well as long-term trends in borrowing I add cubic time terms.

My argument's implications for 1970s data are unfortunately muddied by possible measurement error in the target rate series. Though Rudebusche's series is the best for the era, he cautions that "the exact date that the Desk began to enforce the new target could have been a day or two sooner or later than the one that I have designated" (1995a:252). That could have a substantial effect on maintenance period average values especially in the 1970s, when periods were just one week long. Measurement error in the target series should have little effect on results for a small bank class, because that class' coefficients on the true market-target spread and the true miss should both be positive, of similar magnitude. But results for a large-bank class should be strongly affected: the estimated coefficient on the market-target spread should be biassed toward zero; the estimated coefficient on the target-discount spread should be biassed *above* zero.[13] Results for a large class should still be different from small banks': for large banks *only* the estimated coefficient on the market-target spread can be greater than the coefficient on the target-discount spread. But otherwise the measurement error blurs the contrast between predicted patterns for large and small classes.

For a cleaner test I examine an edited sample of the 1970s data in which the biasses affecting large banks' coefficients should be less of a problem. As most errors in the target series may be within a few days around an indicated change in the target, I exclude maintenance periods containing the date of an indicated target change. The positive bias on large banks' target-discount coefficient can also be alleviated by focusing on a sample in which changes in the discount rate are more strongly correlated with changes in the true target-discount spread, that is discount-rate changes *not* likely to be coincident

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13. To see this, let $\tilde{i}^{\,T}$ denote the target rate series and u denote the measurement error so that $\tilde{i}=i^{\,T}+u$. The true relationship between borrowing and interest rates is $B=\beta_1(i-i^{\,T})+\beta_2(i^{\,T}-i^{\,D})$ or $B=\beta_1(i-\tilde{i}^{\,T})+\beta_2(\tilde{i}^{\,T}-i^{\,D})+(\beta_1-\beta_2)u$ where for small banks $\beta_2\geq\beta_1>0$ and for large banks $\beta_1>0,\ \beta_2=0$. In my regressions u is an omitted variable. This does not much affect results for small banks as long as for them $\beta_1\approx\beta_2$. For large banks, however, the omitted variable is negatively correlated with the *measured* miss $i-\tilde{i}^{\,T}=(i-i^{\,T})-u$, biassing that coefficient down, and positively correlated with the measured target-discount spread $\tilde{i}^{\,T}-i^{\,D}=(i^{\,T}-i^{\,D})+u$, biassing that coefficient up.

with changes in the true target. According to Cook and Hahn (1988), in the 1970s discount-rate changes that were coincident with changes in the target were accompanied by an announcement that the discount-rate change had been spurred by macroeconomic conditions; other discount-rate changes were announced to be mere “realignments” to market rates. The discount-rate changes which were most likely coincident with target changes were confined to the earliest (before mid-March 1975) and latest (after December 1977) portions of the 1970s era.[14] Thus, I exclude these earliest and latest portions of the era from the edited sample. The edited sample still contains more than fifty changes in the target rate series and five changes in the discount rate.[15] If my argument is correct, for a small class coefficients from the edited sample should be similar to those from the full sample. For a large bank class, the edited sample should give results more like those for large banks in the 1990s.

Table 4 shows results. They are as predicted. For Small both samples give coefficients on the target-discount spread are positive, significantly different from zero and coefficients on the market-target spread that are positive but smaller in magnitude; one accepts the hypothesis that the market-target coefficients are smaller. For Large New York and Chicago, the samples give different results. The target-discount coefficient is positive and significantly different from zero in the full sample, but not in the edited sample. Even in the full sample, the estimated market-target coefficient is larger than the target-discount coefficient; one rejects the hypothesis that the market-target coefficient is smaller than the target-discount coefficient. Results for Medium are one what one expect if the class contained a mix of “small” and “large” banks. Total borrowing gives a positive coefficient on the target-discount spread, significant at the one percent level, even in the edited sample. But this reflects the behavior of the Small and Medium classes only. Their combined borrowing share was 80 percent, twice the share of the classes displaying “small”-bank behavior in the 1990s.

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14. These are referred to as "Type 2" and "Type 3" in Cook and Hahn’s (1988) Table 1.

15. Across four of the these discount-rate changes, there was no change in the target series (the sole exception occurred in the period ending 11/24/1976). In the 1970s sample prior to mid-March 1975, all changes in the discount rate were coincident with changes in the target series (in the same direction but not necessarily of the same magnitude). In the sample after December 1977, eight out of ten discount-rate changes were coincident with changes in the target series.

3.3 Shortfalls of the market rate from the target

Expression (25) describes the market-rate shortfall from the target that should occur if Fed reserve-supply procedures fail to accommodate the effect of a change in the target-discount spread on the quantity of free reserves demanded by small banks. (25) can be re-expressed in terms of estimated relationships between interest rates and discount borrowing by banks in size classes. Let B_j denote aggregate borrowing in class *j,* with classes numbered from one to *k.* B_{largej} is borrowing by large banks in a class. Then:

$$\partial e/\partial i^{T} \approx -\frac{\sum_{j=1}^{k} Z_{8j}\frac{B_j}{NBR}}{\sum_{j=1}^{k}\left(Z_{8j} + Z_{9j}Z_7^{-1}\right)\frac{B_j}{NBR}} \quad where\ Z_{8j}=\partial LnB_j/\partial(i^{T}-i^{D}) \quad Z_{9j}=\partial LnB_{invj}/\partial i|_{\partial\varphi=0}\frac{B_{largej}}{B_j} \tag{28}$$

$\sum_{j=1}^{k} Z_{8j}(B_j/NBR)$ is the effect of a change in the target-discount spread on total small-bank borrowing, expressed as a fraction of nonborrowed reserves. Z_{8j} is the effect of the spread on borrowing by banks in class *j* due to the small banks in the class. For a class containing only small banks or a mix of small and large, Z_{8j} should be about equal to the estimated coefficient on the target-discount spread. $Z_{8j}=0$ for a class containing only large banks. $Z_{8j}+Z_{9j}Z_7^{-1}$ is the effect of an exogenous change in the market rate on a class's quantity demanded of free reserves holding fixed large banks' nonpecuniary borrowing cost. Z_{9j} is the effect of such a change in the market rate on borrowing by large banks in the class. For a class containing only small banks, $Z_{9j}=0$. For a class containing only large banks Z_{9j} should be greater than or equal to the magnitude of the estimated coefficient on the market-target spread (see expression 26). Z_7, from (25), is the ratio of the target to large banks' cost of discount borrowing, including nonpecuniary cost. From (21), Z_7 should be about equal to the frequency of borrowing by large banks, divided by the usual fraction of large banks that have not been barred from the discount window due to recent borrowing.

I use estimated coefficients on the target-discount spread and average borrowing/nonborrowed reserve ratios in Tables 3 and 4 to project $\sum_{j=1}^{k} Z_{8j}(B_j/NBR)$ for each era. If my approach is correct, the projected value for the 1970s should be close in magnitude to estimated coefficients on policy-rate changes for the 1970s in Table 2, columns (3) and (4). The projected value for the 1990s should be much smaller than for the 1970s. Making appropriate assumptions about Z_7, I go on to project the market-rate shortfall $\partial e/\partial i^T$. If my explanation of open-mouth operations in the 1990s is correct, the projected shortfall for the 1990s should be very small, arguably small enough to escape the notice of Fed staff at the time and to be undetectable in data.

The first row of Table 5 shows projected $\sum_{j=1}^{k} Z_{8j}(B_j/NBR)$. For the 1970s I assume there were no small banks in the Large New York and Chicago class, use borrowing-nonborrowed ratios from the full sample and estimated coefficients from the edited sample. (Full-sample coefficients gave about the same result.) The result implies a one percentage point increase in the target-discount spread would increase small bank borrowing, and decrease the total quantity demanded of free reserves, by about 2.8 percent of nonborrowed reserves. That is quite close to the magnitude of coefficients in Table 2. For the 1990s, I assume there were no small banks in the Large and Medium-Large classes, use estimated coefficients and borrowing-nonborrowed ratios from the full sample. The result is much smaller than for the 1970s, less than a tenth of a percent of nonborrowed reserves.

To project $\partial e/\partial i^T$ for the 1990s, I assume there were no small banks in the Large and Medium-Large classes. I set Z_{9j} for those classes equal to their estimated coefficients on the market-target spread, which should tend to give a value for $\partial e/\partial i^T$ greater than or equal to the true value. To further ensure that my value for $\partial e/\partial i^T$ is if anything an overestimate I set Z_7 at an implausibly large value. Recall a plausible value for large-bank borrowing frequency is 0.03 (based on Cosimano and Sheehan (1994, Table 1). I set $Z_7 = 0.10$ which means I am assuming about two-thirds of large banks were usually barred from the discount window in a period due to past borrowing, even though only three percent of large banks borrow in an average period. The resulting value for $\partial e/\partial i^T$, in the second row of Table 5, is indeed very small. It implies that the shortfall in the market rate from a one percentage point difference in the target would have been about two tenths of a basis point.

As a final point of comparison, I project what the shortfall in the market rate would have been in the 1970s given the same value for Z_7 if the Fed had relied on open-mouth operations in that era. I assume there were no large banks in the Small class. I do not know the share of large bank borrowing in the Medium class so I perform the calculation for two extreme values. For (a), I set $Z_{8j}+Z_{9j}Z_7^{-1}$ at the value appropriate for a class containing only small banks; for (b), I set $Z_{8j}+Z_{9j}Z_7^{-1}$ at the value appropriate for a class containing only large banks. The resulting shortfalls are larger than the estimates for the 1990s, but still not large: about six to eight basis points for a one percent difference in the target.

4. Conclusion

The phenomenon of open mouth operations appeared as the Fed returned to interest-rate targeting at the end of the 1980s, prior to 1994 when the FOMC began to openly announce changes in the fed funds target. It reflected a change in Fed staff procedures. In the 1970s era of interest-rate targeting, Fed staff had adjusted maintenence-period reserve supply when the FOMC changed the spread between the target and the discount rate, in accordance with a theory of reserve demand supported by the obvious "borrowing function" relationship between the spread and discount borrowing. By the late 1980s the borrowing function was no longer apparent, so Fed staff ceased adjusting reserve supply accordingly. I have shown that small banks' discount borrowing actually remained consistent with the borrowing-function model through the 1990s, while large banks' discount borrowing was *never* consistent with the borrowing-function model, even in the 1970s. Large banks' behavior was instead always consistent with a model in which their nonpecuniary cost of discount borrowing was the loss of an option to borrow again in the near future so that large banks' nonpecuniary borrowing cost was affected by signalled changes in the target, creating the potential for open mouth operations. The main difference between the 1970s and the 1990s was in the relative importance of small banks.

For simplicity, I have ignored a number of other possible contributors to the development of open mouth operations which I view as consistent with my essential argument. Perhaps target changes were signalled more effectively in the later era, even prior to 1994. Perhaps some types of banks that had been treated as small in the earlier era were treated as large in the later era. Perhaps the parameters of small banks' nonpecuniary borrowing cost function changed between the eras so that a small bank's borrowing became less sensitive to the market-target spread. Also for simplicity, my model depicted a bright line distinction between small and large banks. The transition from harassment cost to prohibition of continuous borrowing may have been more gradually related to bank size. There is a lot more to be said about daily reserve demand, effects of anticipated changes in the target, and carryover between maintenance periods. Here it may be important to account for financial-market imperfections that limit banks' ability to arbitrage required balances across days (Hamilton, 1996).

My story has necessarily been concerned with minutiae of Federal Reserve history, but it may nonetheless be of general interest. Too many economists still believe that the view of interest-rate determination associated with the phrase "liquidity preference" implies a central bank must initiate a desired change in overnight rates by adjusting the high-powered money supply through open-market operations. Assuming the Fed sticks with a corridor (or similar) system in the future, economists will come to understand this is no longer the case. But they may expect to see such a relationship in earlier eras and be puzzled when they fail to find it in data from the 1990s. I have presented a solution to the puzzle that is consistent with liquidity preference and shown how it relates to long-established models of monetary policy implementation.

Figure 1

Target fed funds and discount rates
Values on days ending maintenance periods (plotted weekly)
January 1975 - September 1979 / January 1989 - July 1999

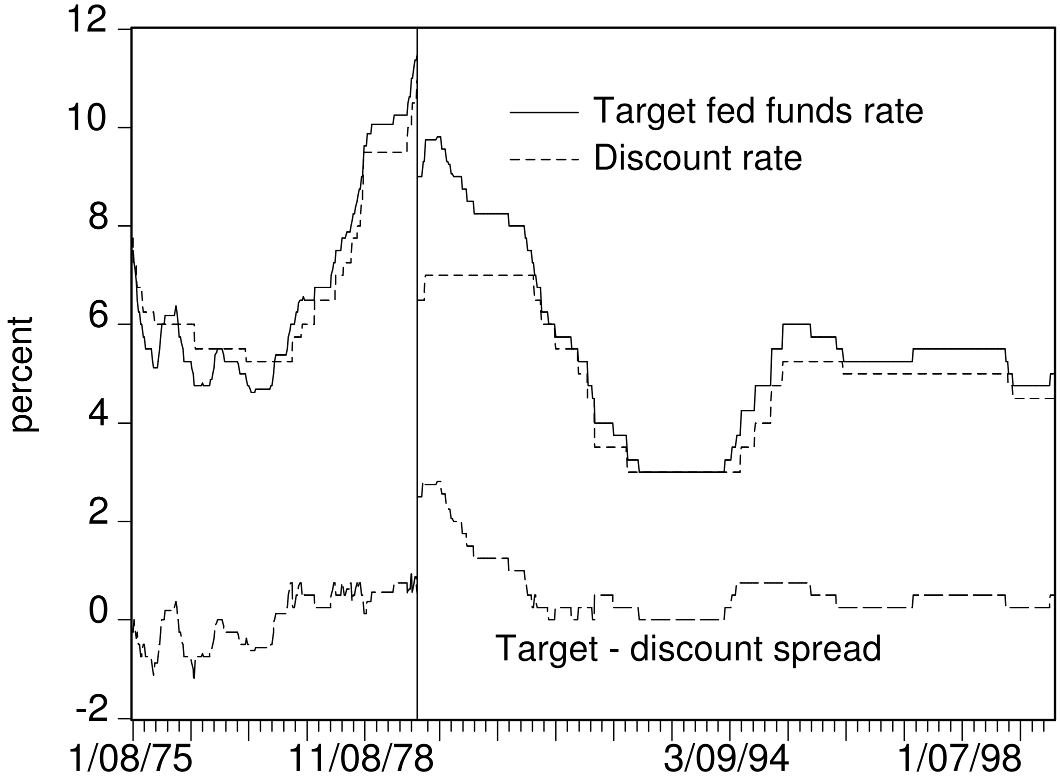

Figure 2

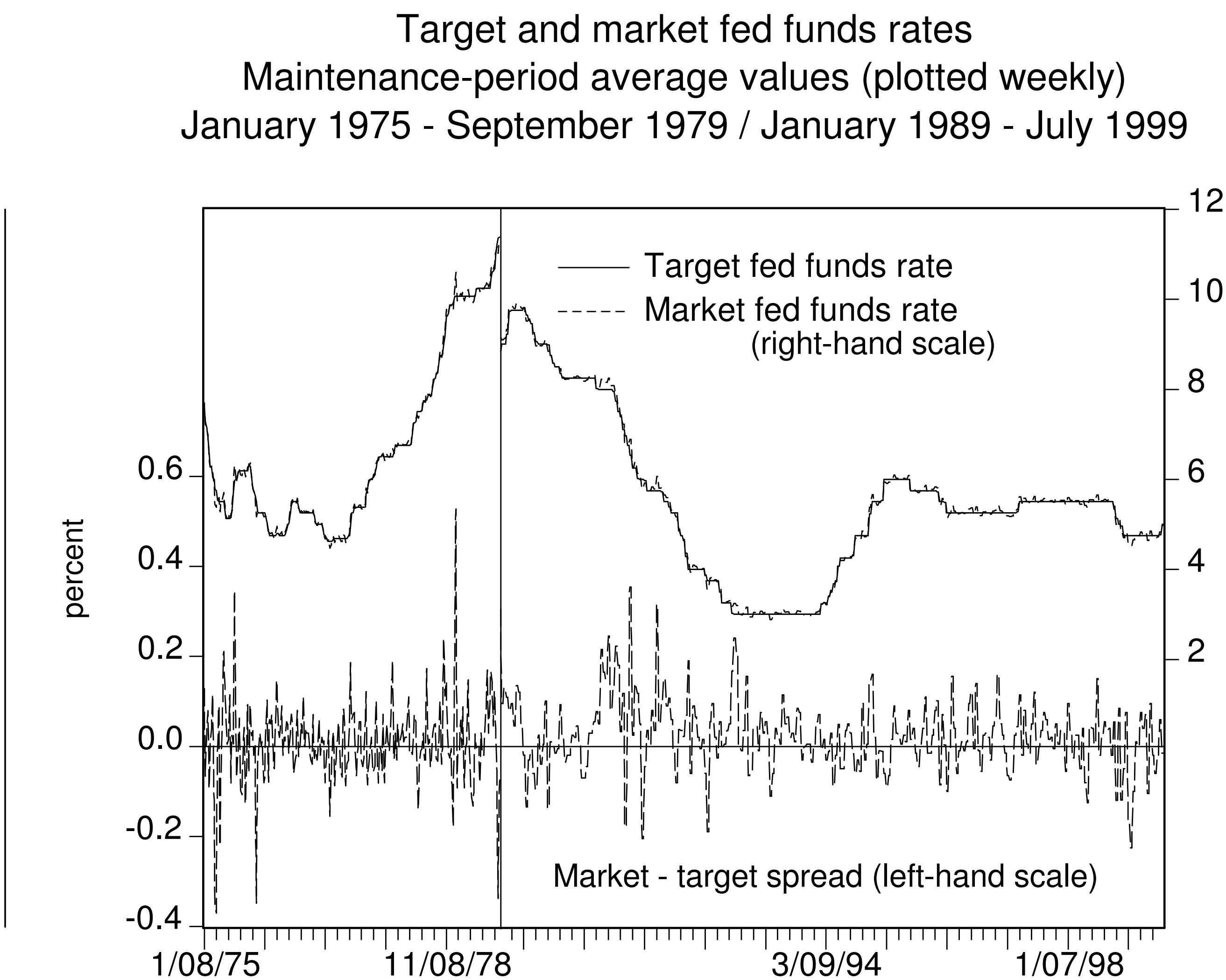
Target and market fed funds rates
Maintenance-period average values (plotted weekly)
January 1975 - September 1979 / January 1989 - July 1999
Target fed funds rate
Market fed funds rate
(right-hand scale)
Market - target spread (left-hand scale)
percent
0.6
0.4
0.2
0.0
-0.2
-0.4
12
10
8
6
4
2
1/08/75
11/08/78
3/09/94
1/07/98

Figure 3

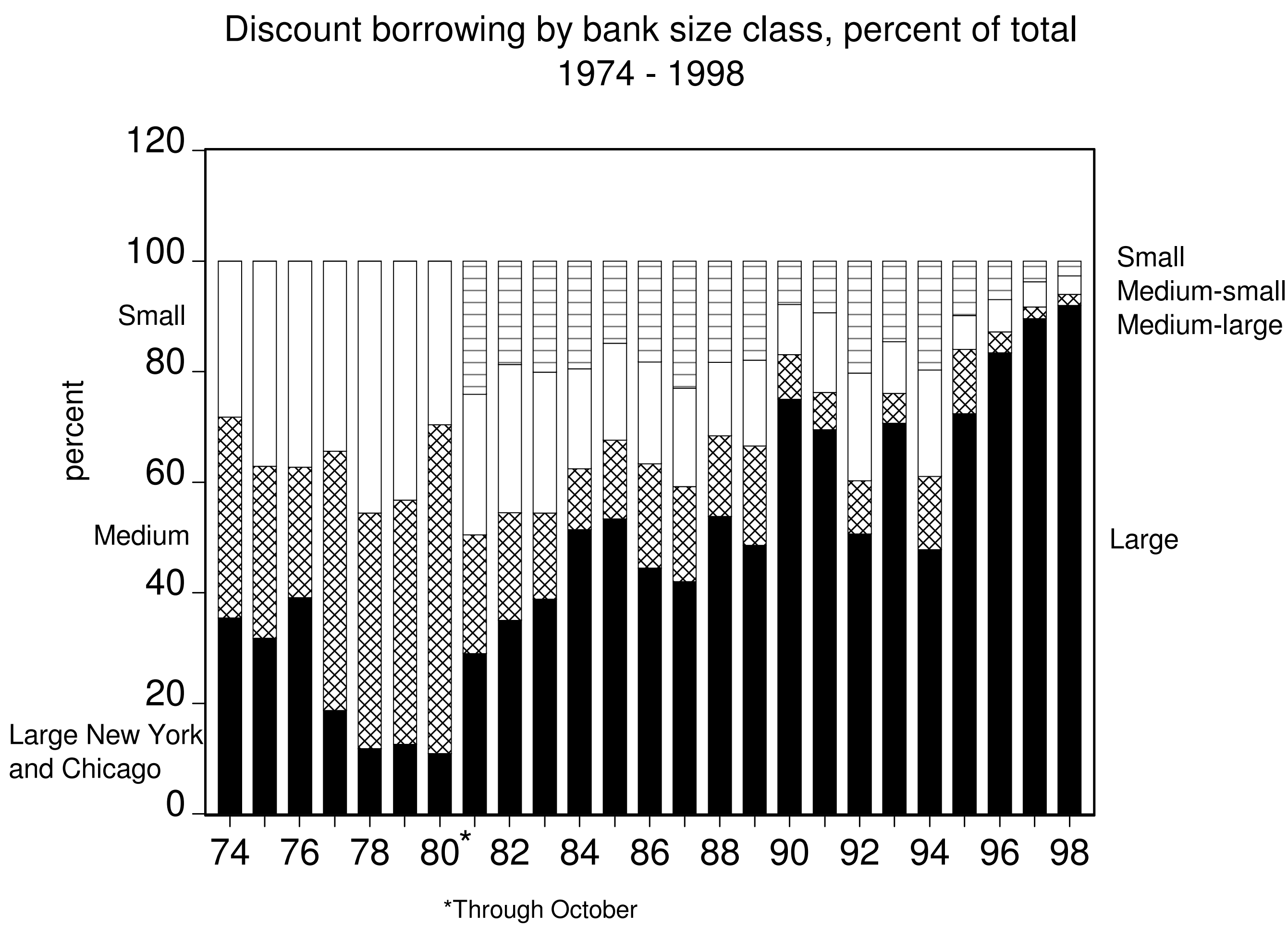
Discount borrowing by bank size class, percent of total
1974 - 1998
percent
120
100
80
60
40
20
0
Small
Medium
Large New York
and Chicago
Small
Medium-small
Medium-large
Large
74
76
78
80*
82
84
86
88
90
92
94
96
98
*Through October

Table 1 Changes in target and market fed funds rates 1975-1979, 1989-1999
i : market fed funds rate (effective rate)
i^T: target (intended) fed funds rate
i^D discount rate

Specification: $\Delta i = Constant + \beta \Delta i_T$

Coefficient
[standard error]
p-value

	All periods		Periods when i^D held fixed	
	1970s[1]	1980s-90s[2]	1970s[1]	1980s-90s[2]
	(1)	(2)	(1)	(2)
N. obs.	245	272	211	244
Coefficient on Δi^T	1.03	0.97	0.95	0.97
	[0.07]	[0.05]	[0.09]	[0.09]
	0.00	*0.00*	*0.00*	*0.00*
R^2	0.47	0.55	0.34	0.34

Maintenance periods in sample (dates are last day of maintenance period):
[1] 1/15/1975 - 9/19/1979
[2] 1/11/1989 - 12/12/1990 2/6/1991-7/14/1999

Table 2 Changes in free reserves, discount borrowing and policy rates
R: Free reserves *B:* Discount borrowing *NBR:* Nonborrowed reserves

Coefficient
[robust (White) standard error]
p-value

	A)January 1975 - September 1979[1]					B)January 1989 - July 1999[2]					C)January 1989 - January 1994[3]				
				$\Delta i^D = 0$					$\Delta i^D = 0$					$\Delta i^D = 0$	
LHS var.	$\Delta Ln(B)$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$	$\Delta Ln(B)$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$	$\Delta Ln(B)$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$	$\frac{\Delta R}{NBR}$	$\frac{\Delta B}{NBR}$
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
N. obs.	245	245	245	211	211	272	272	272	244	244	130	130	130	116	116
Δi^T	2.56	-0.026	0.031	-0.023	0.028	1.24	-0.015	0.009	-0.017	0.006	0.64	-0.008	0.009	-0.002	0.004
	[0.44]	[0.010]	[0.007]	[0.010]	[0.007]	[0.98]	[0.011]	[0.005]	[0.012]	[0.005]	[1.22]	[0.013]	[0.007]	[0.013]	[0.007]
	0.00	*0.01*	*0.00*	*0.02*	*0.00*	*0.21*	*0.18*	*0.08*	*0.16*	*0.28*	*0.60*	*0.53*	*0.21*	*0.90*	*0.59*
Δi^D	-2.10	0.031	-0.033			-1.43	0.014	-0.008			-0.63	0.002	-0.006		
	[0.42]	[0.010]	[0.007]			[1.091]	[0.015]	[0.007]			[1.40]	[0.020]	[0.009]		
	0.00	*0.00*	*0.00*			*0.19*	*0.34*	*0.24*			*0.65*	*0.93*	*0.51*		
R^2	0.11	0.05	0.13	0.03	0.07	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00
N. Δi^T's[4]	81	81	81	69	69	42	42	42	28	28	27	27	27	20	20

Maintenance periods in sample (dates are last day of maintenance period):
[1] 1/15/1975 - 9/19/1979
[2] 1/11/1989 - 12/12/1990 2/6/1991-7/14/1999
[3] 1/11/1989 - 12/12/1990 2/6/1991-2/2/1994
[4] Number of times the target was changed within the sample

Sources for 1970s: Federal Reserve Board of Governors (1976, 1977, 1978, 1979) and various issues of Federal Reserve Bulletin. Discount borrowing is "Total borrowings at Federal Reserve Banks" minus "Seasonal" borrowing.
Sources for 1980s-1990s: Federal Reserve Board website, H3 and H.4.1 historical data, NSA. Free reserves includes float adjustment.

Table 3
Discount borrowing by bank size class, January 1989 - December 1998
Coefficient
[robust (White) standard error]
p-value

A) January 1989 - December 1998 (261 obs.)

	Large*	Medium-large*	Medium-small	Small	All
$(i^T - i^D)$	-1.32	0.88	0.97	0.80	0.56
target - discount	[1.39]	[1.02]	[0.35]	[0.18]	[0.37]
	0.34	*0.39*	*0.01*	*0.00*	*0.14*
$(i - i^T)$	8.05	6.57	0.70	0.84	3.74
market - target	[3.07]	[2.52]	[0.78]	[0.52]	[0.87]
	0.01	*0.01*	*0.37*	*0.11*	*0.00*
$\beta_{i-i^T} \leq \beta_{i^T-i^D}$? (p-value)	*0.00*	*0.01*	*0.37*	*0.47*	*0.00*
R^2	0.23	0.27	0.57	0.75	0.33
Borrowing, % of					
total borrowing	50	10	19	22	100
nonborrowed reserves[1]	0.29	0.03	0.04	0.04	0.40

B) January 1989 - January 1994 (133 obs.)

	Large*	Medium-large*	Medium-small	Small	All
$(i^T - i^D)$	-0.68	0.76	1.14	0.91	0.52
target - discount	[1.52]	[0.86]	[0.83]	[0.19]	[0.45]
	0.65	*0.37*	*0.00*	*0.00*	*0.25*
$(i - i^T)$	8.25	5.41	1.15	1.00	3.35
market - target	[3.71]	[2.51]	[0.81]	[0.54]	[1.02]
	0.03	*0.03*	*0.16*	*0.07*	*0.00*
$\beta_{i-i^T} \leq \beta_{i^T-i^D}$? (p-value)	*0.01*	*0.03*	*0.49*	*0.43*	*0.00*
R^2	0.16	0.29	0.50	0.67	0.40
Borrowing, % of					
total borrowing	41	12	23	23	100
nonborrowed reserves[1]	0.29	0.04	0.06	0.06	0.45

*Tobit

[1] Including required clearing balances

Table 4
Discount borrowing by bank size class, January 1975 - September 1979
Coefficient
[robust standard error]
p-value

	Full sample (246 obs.) Large NY and Chicago*	Full sample Medium*	Full sample Small	Full sample All	Edited sample (78 obs.) Large NY and Chicago*	Edited sample Medium*	Edited sample Small	Edited sample All
$(i^T - i^D)$	2.18	2.76	1.76	2.02	0.99	2.39	1.68	1.73
	[0.61]	[0.24]	[0.10]	[0.13]	[0.93]	[0.49]	[0.17]	[0.22]
	0.00	*0.00*	*0.00*	*0.00*	*0.29*	*0.00*	*0.00*	*0.00*
$(i - i^T)$	5.96	3.04	0.87	1.80	13.71	5.83	1.10	3.60
	[1.80]	[0.88]	[0.31]	[0.45]	[4.19]	[2.30]	[0.86]	[1.12]
	0.00	*0.00*	*0.01*	*0.00*	*0.00*	*0.01*	*0.21*	*0.00*
$\beta_{i-T} \le \beta_{T-D}$? (p-value)	*0.03*	*0.30*	*1.00*	*0.32*	0.00	0.06	1.00	0.05
$Ln(RB)$	4.52	3.79	4.97	2.82	-7.72	0.61	5.89	5.96
	[3.44]	[2.44]	[2.27]	[1.32]	[10.27]	[13.02]	[6.35]	[4.11]
	0.19	*0.12*	*0.03*	*0.03*	*0.45*	*0.96*	*0.36*	*0.15*
$Ln(RB(-1))$	-4.41	0.44	1.98	1.05	8.12	7.72	1.62	4.98
	[3.47]	[0.50]	[2.23]	[1.29]	[9.75]	[12.37]	[5.44]	[3.90]
	0.20	*0.39*	*0.37*	*0.42*	*0.41*	*0.53*	*0.77*	*0.21*
Time	-0.002	-0.380	-0.043	-0.027	-0.053	0.009	-0.011	-0.011
	[0.028]	[0.011]	[0.004]	[0.008]	[0.070]	[0.037]	[0.018]	[0.024]
	0.95	*0.00*	*0.00*	*0.00*	*0.45*	*0.80*	*0.54*	*0.65*
$Time^2/100$	0.070	0.032	0.034	0.024	0.006	0.074	0.009	0.010
	[0.251]	[0.010]	[0.004]	[0.006]	[0.011]	[0.037]	[0.027]	[0.031]
	0.79	*0.01*	*0.00*	*0.00*	*0.58*	*0.80*	*0.72*	*0.75*
$Time^3/$	0.030	0.008	-0.008	-0.006	0.015	0.028	0.098	0.001
10,000	[0.062]	[0.003]	[0.001]	[0.001]	[0.048]	[0.028]	[0.124]	[0.014]
	0.65	*0.00*	*0.00*	*0.00*	*0.75*	*0.33*	*0.43*	*0.93*
R^2	0.21	0.76	0.91	0.84	0.24	0.59	0.82	0.70
Borrowing, % of								
total borrowing	20	33	48	100	28	27	45	100
nonborrowed reserves	0.26	0.68	0.70	1.64	0.18	0.26	0.26	0.70

*Tobit
Source: Federal Reserve Board of Governors (1976, 1977, 1978, 1979) RB is "required" minus "currency and coin."

Table 5

	1970s	1990s
$\sum_{j=1}^{k} Z_{8j}(B_j/NBR)$	2.86 percent	0.07 percent
$\partial e/\partial i^{T}$	(a) 0.075 (b) 0.059	0.002

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