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# INTEREST RATE TARGETING AND THE DYNAMICS OF SHORT-TERM RATES

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## ABSTRACT

We find that in 1989-1996, when U.S. monetary policy tightly targeted overnight fed funds rates, the volatility and persistence of spreads between target and term fed funds levels were larger for longer-maturity loans. We show that such patterns are consistent with an expectational model where target revisions are infrequent and predictable. In our model, the (autoco-) variance of the spreads of term fed funds rates from the target increases with maturity because longer-term rates are more heavily influenced by persistent expectations of future target changes.

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# 1 Introduction

One of the most puzzling pieces of evidence on the term structure of interest rates is the weak link between the slope of the term structure and future changes in interest rates.[1] Mankiw and Miron (1986) relate this evidence to the active targeting of interest rates on the part of the Federal Reserve. They argue that prior to the founding of the Federal Reserve System, the slope of the term structure of interest rates was a fairly accurate predictor of future changes in short-term rates. During this period, interest rates were quickly mean-reverting and highly seasonal, and therefore fairly easy to predict. In contrast, since the Federal Reserve's inception, the stabilization of interest rates was so successful that seasonal effects and volatility were greatly reduced (see also Mankiw, Miron, and Weil (1987)), and interest rates began behaving in a way similar to a random walk.

An important implication of Mankiw and Miron's (1986) analysis is that, by targeting the overnight fed funds rate, the Federal Reserve effectively enjoys a substantial amount of control over term fed fund rates and longer-term yields. Goodfriend (1991) suggests that the targeting of the overnight fed funds rate is implemented with exactly this goal, since longer-term rates are more strongly linked to macroeconomic goals such as unemployment and inflation. The existing literature suggests that a Federal Reserve policy enforcing smooth interest rates is desirable to avoid "whipsawing" the bond market (Goodfriend 1991), to contain the variability of the inflation tax (Barro 1989), and to stabilize the macroeconomy (Mankiw, Miron, and Weil 1987).

This paper documents a new stylized fact concerning the relation between interest rate targeting and the dynamics of short-term rates. We show that during the 1989–1996 period, the Federal Reserve was able to closely target the overnight fed funds rate, and especially to reduce the persistence of its spreads from the target: these spreads average one basis point, and exhibit an autocorrelation of only 0.07, after one day. Still, term fed funds rates of maturity up to three months fluctuated widely and persistently around the target. For example, the volatility of daily spreads of the three-month term fed funds rate from the target is 36 basis point, and the autocorrelation of these spreads after 60 days is still 0.58. Perhaps even more surprising, both the volatility and the persistence of spreads of term fed funds rates from the target is an increasing function of the maturity of the loan. This new stylized fact can be interpreted as evidence that, while central bank intervention is important in determining the shape and position of the term structure, even a tight targeting of the overnight fed funds rate does not mechanically translate into a tight control of longer-term rates.

This feature of the data is somewhat surprising if we take an "expectations-hypothesis view" of the term structure of fed funds rates, whereby term fed funds rates are averages of future expected overnight rates. If future target changes are indeed unpredictable, and since fluctuations of the overnight rate around the target are short-lived, spreads of term fed funds rates from the target should not exhibit much volatility nor persistence. This would be especially true for longer-maturity rates, whose term allows more time for the overnight rate to revert towards the expected future target which, if the target changes were unpredictable, would equal the current target. Hence, the presence of volatile and long-lived spreads of term fed funds rates from the target hints at the predictability of future target changes.

This paper develops a model of the term structure of interest rates which incorporates target-changes predictability and other features of interest rate targeting to replicate the new stylized fact that we document. Our model takes an expectations-hypothesis view of the relation between overnight fed funds rates and interest rates of longer maturity, which is corroborated by empirical evidence; see Balduzzi, Bertola, and Foresi (1996) and Simon (1990). The model incorporates *three* realistic features of interest rate targeting on the part of the Federal Reserve: i) spreads of the overnight fed funds rate from the target, while short-lived, are non-zero; ii) target changes occur infrequently, on a daily time scale; and iii) changes in the target are somewhat predictable. The first two features of interest rate targeting arise because of our analysis of daily data, where the volatility of spreads of the overnight fed funds rate from the target is 40 basis points, and target changes occur, on average, every 37 business days. By comparison, Mankiw and Miron (1986) use observations at the monthly frequency, and do not find it useful to explicitly distinguish between the target, the overnight rate, and other short-term rates. The third feature is consistent with the notion that even if all "adjustment pressures" are released at the time of the target change, immediately after the target change investors start receiving and processing new information to help them predict the *next* target change. This is consistent with evidence that target changes cause large, but less than one-to-one positive changes in longer-term rates (see the empirical results presented in Section 2 of this paper which complement previous findings by Cook and Hahn (1989)).

Given these three features of interest rate targeting, we put forward a model in which the spreads of term fed funds rates from the overnight target are driven by *two* factors: the current spread of the overnight rate from the target, and the expectation of the next target change. The first factor exhibits almost no persistence, and has a loading which *decreases* with the maturity of the loan. The second factor, on the other hand, is highly persistent, because the expectation of the next target change behaves like a random walk between target changes, and has a loading that *increases* with the maturity of the loan. As a result, the persistence of spreads of term fed funds rates from the target increases with the maturity.

The term-structure model that we develop also incorporates the biweekly seasonal pattern in the overnight fed funds rate over the reserve-maintenance period. In fact, we allow intercepts, mean-reversion, and volatility parameters to depend on the day of the maintenance period. This seasonality has been documented and studied by Barren, Slovin, and Shuska (1988), Campbell (1987), and Hamilton (1995), among others. Hamilton (1995) argues that it is likely that the failure of banks to arbitrage out these seasonal patterns over the maintenance period is related to imperfections in the fed funds market, and suggests that these imperfections are essential to the Fed's ability to affect the interest rate on a daily basis.

The model successfully replicates the stylized fact that the (autoco-)variance of the spreads of term fed funds rates from the target increases with maturity, because longer-term rates reflect more heavily persistent expectations of the next target change. Parameter estimates are generally quite precise, and the model cannot be rejected by a standard misspecification test at conventional significance levels. We obtain estimates of the parameters of the overnight-fed-funds-rate process which indicate a statistically significant biweekly seasonal pattern. Consistent with the data, our model implies that little seasonal variability of the overnight fed funds rate should be transmitted to term fed funds rates: biweekly seasonal effects are effectively "averaged out" by investors who form expectations of future overnight fed funds rates over several maintenance periods. We also obtain a realistic estimate of the volatility of the unobservable factor driving interest rates: the expectation of the next target change.

The volatility of the next-target-change expectation is especially interesting from the perspective of monetary policy. It may be viewed as an indicator of how noisy the information-acquisition process is, and of how successful the Federal Reserve is in keeping its intentions secret and preserving a discretionary role for policy. At the same time, however, a high volatility of the next-target-change expectation translates into a loose control on longer-term money-market rates. Hence, a trade-off between secrecy and interest rate control may arise, of which the monetary authorities should be (and probably are) aware. Moreover, the behavior of the fed funds rate around the target, which measures the effectiveness of interest rate targeting, together with the volatility of the next-target-change expectation, which measures the understanding of changes in policy on the part of the market, may provide a useful characterization of a "monetary regime."

This work is related to recent papers which investigate the effects of interest rate targeting on the term structure of interest rates. Balduzzi, Bertola, and Foresi (1996), for example, use a similar term-structure model to extract market expectations of future target changes. They find that investors tend to overestimate the absolute size of target changes, although they correctly assess their direction. Rudebusch (1995) documents the varying predictive ability of the term structure to forecast future changes in short-term rates. He argues that these findings are consistent with the way in which the Federal Reserve controls the overnight fed funds rate, which leads to predictable interest rate movements in the very short run and the very long run, but tends to smooth away predictable movements in the medium run. His term-structure model shares several assumptions with ours, but differs in one crucial respect: it essentially assumes the expected size of the next target change to be solely determined by the last realized target change. Hence, the expectation of the next target change is constant between target changes and, in his model, spreads of short-term rates from the target could not exhibit the volatile and persistent fluctuations that we document in our sample. Jegadeesh and Pennacchi (1996) develop a two-factor model of the term structure of interest rates where the two factors are the level and the central tendency of the instantaneous riskless rate. The central-tendency factor may have the interpretation of a target rate that the Federal Reserve is pursuing in the short or medium run, or a function of the markets' longer-run inflationary expectations, and a Kalman-filter technique is used to estimate this unobservable factor using Eurodollar futures prices. Babbs and Webber (1994), on the other hand, incorporate the features of interest rate targeting in the United Kingdom, and explicitly identify the instantaneous riskless rate with the rate on repurchase agreements of maturity up to 14 days, which is under direct control of the Bank of England.

The paper is organized as follows: Section 2 presents the data, documents the stylized facts, and performs tests of the predictability of target changes. Section 3 develops the term-structure model and studies its implications for the time-series properties of spreads from the target for term fed funds rates of different maturities. Section 4 amends the model to account for the biweekly pattern in the overnight fed funds rate, and estimates and tests the model by generalized method of moments (GMM). Section 5 concludes.

# 2 Data and stylized facts

In this section we describe the data set and we summarize the empirical evidence on interest rate targeting relevant for our study. We also perform tests of the predictability of target changes.

We use daily data for the overnight, target, and term fed funds rates for the period May 18, 1989, to February 29, 1996. The choice of sample period is dictated by data availability,[2] since daily closing-quote series (3:00 pm) for interest rates on overnight, one-, two-, and three-month term fed funds of similar default-risk characteristics are from the Board of Governors, which began collecting this data in May 1989. Target rates, provided by the Federal Reserve Bank of New York, are the Federal Reserve's daily indications of the fed funds target expected to be consistent with the degree of reserve pressure specified by the Federal Open Market Committee.[3] Market holidays are substituted with observations from the last day the market was open, and all interest rates are converted to a continuously compounded basis.

Figure 1 presents the four interest rate series: the overnight fed funds rate and the target (upper panel), and the one-, two-, and three-month term fed funds rates (lower panel). The Figure shows how the overnight fed funds rate, while at times exhibiting wide fluctuations around the target, tends to quickly revert to the target which, in turn, is highly persistent. The Figure shows how the three term fed funds rates move together, with the one-month rate exhibiting higher volatility than the other two rates during periods of high volatility of the overnight rate (December 1990 and November-December 1993). Also, it is apparent that term fed funds rates anticipate changes in the target: they tend to be below the target during periods when the target is falling, and they tend to be above the target when the target is increasing. This evidence corroborates the expectations-hypothesis view of term fed funds rates that we take in our analysis.

The time-series properties of term fed funds rates in levels and in spreads from the target are further documented by Figure 2. The upper panel of Figure 2 displays the autocovariance functions of the four fed funds rates, in levels. The ranking of the four autocovariance functions is opposite to that of the maturities of the four loans: the volatility and persistence of fed funds rates decreases as the maturity of the loan increases. The lower panel of Figure 2 displays the autocovariance functions of the four fed funds rates, in spreads from the target. Overnight spreads are quite volatile around the target, but short-lived, and exhibit a strong biweekly seasonal pattern. One-, two-, and three-month spreads are also quite volatile and long-lived, but volatility and persistence *increase* with maturity, and they exhibit no biweekly seasonal pattern.

The biweekly seasonal pattern (and absence thereof) of the spreads of fed funds rates from the target is further documented in Figure 3, which displays the means (upper two panels) and volatilities (lower two panels) of the spreads according to the day of the maintenance period. We find that the mean spread of the overnight rate follows a decreasing pattern over the two weeks, to spike up on the last day (Wednesday). The volatility of the spread of the overnight rate decreases over the first half of the maintenance period, while it increases over the second half. The means and volatilities of spreads of term fed funds rates, on the other hand, exhibit hardly any seasonal pattern.

The statistical properties of the target and of the four fed funds rates are also documented in Table 1. Panel A demonstrates how the volatility of term fed funds rates decreases with the maturity of the instrument. Panel B presents the statistical properties of the *spreads* of the four fed funds rates from the target and highlights several stylized facts. First, all four fed funds rates are, on average, very close to the target: the average spread from the target goes from a minimum of minus one basis point (overnight) to a maximum of 6.7 basis points (three-month). Second, as already documented in Figure 2, both the volatility and the persistence of the spreads increase with the maturity. Third, there is significant excess kurtosis, especially in the spreads of the overnight and one-month rate.

In Table 2 we regress changes in term fed funds rates on changes in the target, only for days on which the target change is implemented. The Table shows how changes in the target significantly affect term fed funds rates, although in less than a one-to-one fashion:

the largest slope coefficient is 0.345, for the one-month rate. Hence, we may conclude that target changes are at least partially anticipated by term fed funds rates before they are implemented. This result is similar and complements the evidence reported by Cook and Hahn (1989) for Treasury bill and bond rates, during the 1974–1979 period.[4]

# 3 Interest rate targeting and the term structure

This Section formulates an expectations-hypothesis model of the term structure of interest rates which may account for the stylized evidence discussed above.

## 3.1 A term-structure model

We model the fluctuations of the overnight rate around the target as reverting towards a zero mean

$$r_t - \bar{r}_t = (1 - k)(r_{t-1} - \bar{r}_{t-1}) + \epsilon_t, \qquad (1)$$

where $\epsilon_t$ is a white-noise error with standard spread $\sigma_\epsilon$, and $0 < k < 1$ is a given constant. The overnight rate is more tightly targeted the higher the mean-reversion parameter $k$ and the smaller $\sigma_\epsilon$. While this assumption is shared by the papers by Balduzzi, Bertola, and Foresi (1996), and Rudebusch (1995), a natural alternative to the specification in (1) would be to assume that $r$ fluctuates freely in a neighborhood of $\bar{r}$, but that the Federal Reserve intervenes when the distance of $r$ from the target is too large. This would lead to reflecting barriers of the kind modeled in the "target zones" literature on exchange rates. This alternative specification is not chosen here for two reasons: first, the large positive and negative "spikes" in the overnight fed funds rate (see Figure 1) are inconsistent with the presence of enforced barriers (unless the bands are extremely wide); second, the presence of reflecting barriers would lead to a long-run stationary behavior similar to that captured by the autoregressive process in (1).

To explain the behavior of the target, we argue the following: Target changes are not influenced by the temporary spreads of the overnight rate from the target. Moreover, the Federal Reserve typically revises the target by small increments, so as not to "whipsaw" the market; see Goodfriend (1991). When a sizable change in the target is required, several small changes in the same direction are implemented. This gives rise to positive serial correlation in target changes that we model as follows:

$$\Delta \bar{r}_{N_t} = \rho \; \Delta \bar{r}_{N_t - 1} + \xi_{N_t}, \tag{2}$$

where $N_t$ denotes the number of target changes between time zero and time $t$, $0 < \rho < 1$ regulates the serial correlation in target changes, and $\xi_{N_t}$ is a mean-zero, serially uncorrelated error independent of $\epsilon_t$. The absence of an intercept term in (2) implies that the unconditional average of target changes has mean zero; also, *at the time* of a target change the market expects the *next* target change to equal $\rho \Delta \bar{r}_{N_t}$. Although actual target changes take place in *discrete* amounts (Rudebusch (1995) explicitly accounts for this feature, assuming a discrete-value distribution for target changes), typically a multiple of (about) 12.5 basis points,[5] *expected* future target changes are a weighted average of these multiples, and hence the expectations generated by the model (2) are not inconsistent with this institutional feature.[6] We denote by $z_t$ the time-$t$ market expectation of the *next* target change, formed at the *end* of day $t$. Two features of this expectation are worth noting:

First, $z_t$ is the expectation of the next target change as it is formed by the market, and not necessarily a *rational expectation.* In other words, there may be systematic discrepancies between the $z_t$ process and the process governing actual target changes. In fact, the Fed may not follow a stable policy, or it may hide the one it follows to surprise the market. As a result, the process of target changes may be changing over time, requiring potentially endless learning on the part of the market. The present paper focuses on the dynamic behavior of interest rate spreads irrespective of the way the market forms expectations, and does not investigate the rationality of these expectations.

Second, $z_t$ is the expectation of the next target change *irrespective* of when the change will be implemented. In other words, we assume that the market expects the same policy change whether it is implemented tomorrow or several days from now. Hence, the time elapsed since the last target change affects neither the realization of a target change, nor the expectation $z_t$ (in this respect, the market expectation is assumed to be consistent with the realizations). This hypothesis is made for analytical tractability, and it is consistent with the empirical evidence of Table 3, Panel A, where we regress the absolute size of a target change on the length of the time interval since the last target change. The table shows that the effect is not significant.[7]

As to the behavior of $z_t$ over time, we argue the following. *Between* target changes, the expectation of the next target change is revised according to the daily flow of new information, and behaves like a random walk. This behavior is consistent with the market updating its expectation of a next target change whose size also changes from day to day in an unpredictable fashion.[8]

*On the day* of a target change the expectation $z_t$ relates to the realized target change through the parameter $\rho$. We formalize this behavior as follows

$$z_t = \begin{cases} z_{t-1} + \zeta_t, & \text{if there is no target change at } t, \\ \rho \Delta \bar{r}_t + \zeta_t, & \text{if there is a target change at } t, \end{cases}$$

where $\zeta_t$ is a mean-zero serially uncorrelated error, independent from $\epsilon_t$, with volatility $\sigma_\zeta$. This error term captures the notion that immediately after a target change the market accumulates information on the next one, and is consistent with the timing of our data, which are 3:00 pm closing quotes.[9]

Our assumptions on the behavior of $z_t$ are quite realistic and to be contrasted with the model of Rudebusch (1995), where, at each point in time, the expectation of the next target change *only* depends on the value of the last target-change realization and on the time elapsed since the last change. Since most of the variability in the daily probabilities of target changes disappears after a few weeks, the expected value of the next target change is essentially constant (and close to zero) thereafter. As it will be clear from the ensuing analysis, this feature crucially sets his framework apart from ours. Indeed, it prevents his model from generating the volatile and persistent spreads of term fed finds rates from the target that we document in our sample.

The probability $\nu$ of a target change taking place on any given day is assumed to be constant. Hence, the probability distribution of the number of target changes $n$ over $s$ periods is given by

$$\begin{pmatrix} s \\ n \end{pmatrix} \nu^n (1-\nu)^{s-n}, \; s \geq n.$$

While the main appeal of a constant daily rate of target changes is its analytical convenience, it is consistent with the evidence presented in Table 3, Panel B, which reports the statistic of a Kolmogorov-Smirnov test of the hypothesis that the length of the no-target-change spells is drawn from a binomial distribution with constant parameter $\nu$.[10] The null hypothesis cannot be rejected at the 5% nor at the 10% level. This result is also consistent with Rudebusch

(1995) who finds that for the 1974–1987 period, the daily probabilities of target changes exhibit most of their variability during the first seven days from the last change, and are essentially constant after 24 days. As a further test of our assumption, we run a regression of the length of time since the last target change on the absolute size of the last change; see Table 3, Panel C. This test wants to determine whether a large target change makes a new target change soon after more or less likely. Again, we find no significant effect.

Finally, we assume that the interest rate of maturity $\tau$, $R(\tau)$ satisfies

$$R_t(\tau) = \sum_{s=0}^{\tau-1} \frac{E_t(r_{t+s})}{\tau}, \; \tau \geq 1, \tag{3}$$

a pure-expectations hypothesis model of the term structure of interest rates. One implication of the model in (3) is that the spread between a short-term rate and the overnight fed funds rate should predict future changes of the overnight rate. This implication is corroborated by the empirical findings of Simon (1990), who considers the three-month Treasury bill rate and daily data for the 1972–1987 period. It is also corroborated by Balduzzi, Bertola, and Foresi (1996), who consider the three-month term fed funds rate and daily data for the 1987–1990 period. Note that we could augment the expectations-hypothesis formulation in (3) with a constant maturity-specific term premium, and the time-series behavior of term fed funds rates implied by our model would not be at all affected. On the other hand, the presence of time-varying term premia would indeed change our analysis. We do not include them for two main reasons. First, in our empirical applications we consider term fed funds rates of maturity up to three months, for which term premia should be "small." Second, we show that expectational effect alone can account for the stylized facts in the data, with no need to introduce *ad hoc* time-varying premia.

Under these assumptions, we are able to obtain closed-form analytical solutions for yields of different maturity where interest rates are linear in the three factors: the current target, $\bar{r}_t$, the current spread of the overnight rate from the target, $r_t - \bar{r}_t$, and the current expectation of the next target change, $z_t$; similar multi-factor yield-curve models are obtained by Babbs and Webber (1994) and Jegadeesh and Pennacchi (1995). These solutions are quite convenient, in that they lend themselves to empirical estimation, and allow us to obtain, also in closed-form, the implied time-series properties of term fed funds rates.[11] Specifically, we have

$$R_t(\tau) = \bar{r}_t + L_{r_t - \bar{r}_t}(\tau)\,(r_t - \bar{r}_t) + L_{z_t}(\tau) z_t, \; \tau \geq 1, \tag{4}$$

with factor loadings

$$L_{r_t-\bar{r}_t}(\tau) \equiv \frac{1-(1-k)^\tau}{k\tau}, \ \tau \geq 1, \tag{5}$$

and

$$L_{z_t}(\tau) \equiv \begin{cases} 0, \ \tau = 1 \\ \frac{1}{\tau}\sum_{s=1}^{\tau-1}\left[\sum_{n=1}^{s}\begin{pmatrix} s \\ n \end{pmatrix}\nu^n(1-\nu)^{s-n}\frac{1-\rho^n}{1-\rho}\right], \ \tau > 1. \end{cases} \tag{6}$$

These factor loadings are calculated as follows: First, we obtain

$$E_t(r_{t+s} - \bar{r}_{t+s}) = (r_t - \bar{r}_t)(1-k)^s, \ s \geq 0$$

and the loading on $r_t - \bar{r}_t$ is given by equation (5).

Second, for any $t+s \geq t$ we have the definitional relation

$$E_t(r_{t+s}|N_{t+s}) \equiv \begin{cases} \bar{r}_t + E_t(r_{t+s} - \bar{r}_t), \ N_{t+s} = N_t, \\ \bar{r}_t + E_t\left[\sum_{j=1}^{N_{t+s}-N_t}\Delta\bar{r}_{N_t+j} + (r_{t+s} - \bar{r}_{t+s})\Big| N_{t+s} > N_t\right], \ N_{t+s} > N_t, \end{cases} \tag{7}$$

where $N_{t+s}$ is the number of target changes between time zero and time $t+s$ and $\Delta\bar{r}_{N_t+j}$ is the $j$-th target change after time $t$. Since target changes occur with fixed daily probability $\nu$, and their timing is independent of $z_t$, we can condition on their total number $N_{t+s} > N_t$ and calculate the relevant expectations using probabilities based on the known (binomial) form of the distribution of $N_{t+s}$:

$$EE_t\left(\sum_{j=1}^{N_{t+s}-N_t}\Delta\bar{r}_{N_t+j}\middle| N_{t+s} > N_t\right) = \sum_{n=1}^{s}\begin{pmatrix} s \\ n \end{pmatrix}\nu^n(1-\nu)^{s-n}\, E_t\left(\sum_{j=1}^{n}\Delta\bar{r}_{N_t+j}\middle| N_{t+s} = N_t + n\right),$$

where $N_{t+s} > N_t$. Applying the law of iterated expectations to equation (2), the expected size of the $(N_t+j)$-th target-change realization is

$$E_t(\Delta\bar{r}_{N_t+j}\,|\, n \geq j \geq 1) = \rho^{j-1}z_t,$$

hence

$$\begin{aligned} E_t\left(\sum_{j=1}^{N_{t+s}-N_t}\Delta\bar{r}_{N_t+j}\middle| N_{t+s} = N_t + n\right) &= \sum_{n=1}^{s}\begin{pmatrix} s \\ n \end{pmatrix}\nu^n(1-\nu)^{s-n}\sum_{j=1}^{n}\rho^{j-1}z_t \\ &= z_t\sum_{n=1}^{s}\begin{pmatrix} s \\ n \end{pmatrix}\nu^n(1-\nu)^{s-n}\frac{1-\rho^n}{1-\rho}, \quad s \geq 1. \end{aligned} \tag{8}$$

Substituting (8) in (7), we find that

$$E_t(\bar{r}_{t+s}) - \bar{r}_t = z_t \left[ \sum_{n=1}^{s} \binom{s}{n} \nu^n (1-\nu)^{s-n} \frac{1-\rho^n}{1-\rho} \right], \quad s \geq 1.$$

Averaging this expression over the horizon relevant to an instrument of maturity $\tau$ yields the factor loading on the next target-change expectation $z_t$ in equation (6).

The factor loadings (6) and (5) depend on the features of interest rate targeting. An increase in targeting intensity affects $L_{r_t - \bar{r}_t}(\tau)$ negatively: as $k$ increases, the overnight rate reverts more quickly to the target, making current spreads less relevant for future overnight rates, and hence for current short-term rates as well. Crucial to our main point, the longer the maturity, the *smaller* the factor loading $L_{r_t - \bar{r}_t}(\tau)$. The factor loading $L_{z_t}(\tau)$ increases when target changes become more frequent (higher $\nu$), and hence future target changes are more likely. More persistence in target changes (higher $\rho$) increases $L_{z_t}(\tau)$: current expectations of the next target change have higher "information content" as to the subsequent ones. Unlike the loading for overnight spreads $L_{r_t - \bar{r}_t}(\tau)$, $L_{z_t}(\tau)$ is *increasing in* $\tau$*:* the longer the maturity, the higher the chance that the target will change before the instrument matures, and the more relevant the current expectation $z_t$ in determining average overnight rates before maturity. This feature is crucial for our model to replicate the ranking of autocovariance functions observed in Figure 2.

## 3.2 Time-series properties of spreads from the target

We now investigate the time-series properties of the spreads of term fed funds rates from the target as implied by our term-structure model.

If contemporaneous and lagged overnight spreads do not influence the Federal Reserve's decision to revise the target, they should also be irrelevant to market participants' revision of $z_t$, the expectation of the next target change. Thus, the assumed orthogonality of the two processes $\Delta \bar{r}_t$ and $r_t - \bar{r}_t$ implies that $z_t$ is orthogonal to $r_t - \bar{r}_t$. Based on equation (4) we can then write the *autocovariance* function of the maturity-$\tau$ rate spread, $\text{Cov}\left[R_{t+s}(\tau) - \bar{r}_{t+s}, R_t(\tau) - \bar{r}_t\right]$. We have

$$\begin{aligned} &\text{Cov}\left[R_{t+s}(\tau) - \bar{r}_{t+s}, R_t(\tau) - \bar{r}_t\right] \\ &= L_{r_t - \bar{r}_t}(\tau)^2 \text{Cov}(r_{t+s} - \bar{r}_{t+s}, r_t - \bar{r}_t) + L_{z_t}(\tau)^2 \text{Cov}(z_{t+s}, z_t). \end{aligned} \quad (9)$$

As we discussed above, longer-maturity spreads attach a larger weight to $z_t$. Hence, they inherit the time series properties of $z_t$ to a larger extent than shorter-maturity rates.

For given factor loadings, $L_{z_t}(\tau)$ and $L_{r_t-\bar{r}_t}(\tau)$, the autocovariance functions in (9) depend on the autocovariances of $z_t$ and $r_t - \bar{r}_t$ which we calculate as follows. The autocovariance of $r_t - \bar{r}_t$ is simply that of an AR(1) process,

$$\mathrm{Cov}(r_{t+s} - \bar{r}_{t+s}, r_t - \bar{r}_t) = \frac{(1-k)^s \sigma_\epsilon^2}{1-(1-k)^2}, \tag{10}$$

which decreases with the targeting intensity $k$ at any number of lags.

To calculate the autocovariance of $z_t$, first consider the case of $\rho = 0$, that is, no autocorrelation in target changes:

$$z_{t+s} = \begin{cases} z_t + \sum_{j=1}^{s} \zeta_{t+j}, & \text{if there is no target change at } t, \\ \sum_{j=0}^{s} \zeta_{t+j}, & \text{if there is a target change at } t, \end{cases}$$

where $\zeta_t$ denotes a serially independent mean-zero error, with constant volatility $\sigma_\zeta$. The unconditional autocovariance of $z_t$ is, by the law of total probabilities, $\mathrm{Cov}(z_{t+s}, z_t) = (1-\nu)^s \mathrm{Var}(z_t)$. To calculate $\mathrm{Var}(z_t)$, note that the innovations $\zeta_t$ are serially independent and accumulate only from the time of the *last* target change. Conditional on the last target change having occurred at time $t^*$, $\mathrm{Var}(z_t | \text{last target change at } t^*) = (t - t^* + 1)\sigma_\zeta^2$, and therefore the unconditional variance is $\mathrm{Var}(z_t) = \sum_{s=0}^{\infty} \nu(1-\nu)^s (s+1)\sigma_\zeta^2 = (1/\nu)\sigma_\zeta^2$.

When target changes are autocorrelated, the expectation series $z_t$ takes such autocorrelation into account:

$$z_{t+s} = \begin{cases} z_t + \sum_{j=1}^{s} \zeta_{t+j}, & \text{if there is no target change at } t, \\ \rho(z_{t-1} + \eta_t) + \sum_{j=0}^{s} \zeta_{t+j}, & \text{if there is a target change at } t, \end{cases}$$

where $\eta_t$ is an expectational error defined as $\eta_t \equiv \Delta \bar{r}_t - z_{t-1}$ which is realized only when a target change is implemented.

Iterating the law of motion of $z_t$ backwards and using the law of total probabilities, we obtain the unconditional autocovariance of $z_t$:

$$\mathrm{Cov}(z_{t+s}, z_t) = \sum_{n=0}^{s} \binom{s}{n} \nu^n (1-\nu)^{s-n} \rho^n \mathrm{Var}(z_t),$$

where $\mathrm{Var}(z_t)$ is given by

$$\mathrm{Var}(z_t) \quad = \quad \rho^2 \mathrm{Var}(z_t) + \rho^2 \mathrm{Var}(\eta_t) + \mathrm{Var}\left(\sum_{n=0}^{s} \zeta_{t+n}\right)$$

$$= \rho^2 \mathrm{Var}(z_t) + \rho^2 \sigma_\eta^2 + \sum_{s=0}^{\infty} \nu(1-\nu)^s (s+1)\sigma_\zeta^2 = \frac{\rho^2\sigma_\eta^2 + \sigma_\zeta^2/\nu}{1-\rho^2},$$

and thus

$$\mathrm{Cov}(z_{t+s}, z_t) = \sum_{n=0}^{s} \binom{s}{n} \nu^n (1-\nu)^{s-n} \rho^n \frac{\rho^2\sigma_\eta^2 + \sigma_\zeta^2/\nu}{1-\rho^2}, \tag{11}$$

where $\sigma_\eta$ denotes the volatility of $\eta_t$.

Note that a higher correlation in target changes ($\rho$) increases the volatility and persistence of $z_t$. On the other hand, when target changes become more frequent (higher $\nu$) the volatility and average persistence of $z_t$ *decreases*: a higher number of target changes means that $z_t$ is more often reset close to $\Delta\bar{r}_t$, which in turn reverts to zero across target-change events (see equation (2)). Moreover, the parameters characterizing the information-acquisition process also affect the time-series properties of $z_t$. A higher variance of $\zeta_t$ increases the variance and the persistence of $z_t$. As the market's expectations on the next target change become less accurate (higher $\sigma_\eta$), the variability and persistence of $z_t$ also increases.

Substituting (11) and (10) into (9) yields an explicit expression for the theoretical autocovariance function of spreads from the target.

# 4 Empirical analysis

This section extends the model illustrated above to account for the marked biweekly pattern in the overnight fed funds rate. We then estimate and test the amended model by GMM.

## 4.1 A term-structure model with biweekly effects

The autocovariance functions of Figure 2 and the statistics in Figure 3 show a marked biweekly pattern in overnight spreads. Hence, we proceed to incorporate such biweekly effects into our term-structure model. While the relevance of maintenance-period seasonalities in the overnight fed funds rate is well known (see, for example, Barret, Slovin, and Sushka 1988, Campbell 1987, and Hamilton 1995) this is, to our knowledge, the first attempt at explicitly incorporating such effects in a term structure model. We modify equation (1) and assume

$$r_t - \bar{r}_t = d_t + (1-k_t)(r_{t-1} - \bar{r}_{t-1} - d_{t-1}) + \epsilon_t, \tag{1'}$$

where $d_t = d_{t+10}$ is a time-varying intercept which captures changes in the average spread of the overnight rate from the target over the maintenance period. Similarly, we allow for a time-varying mean-reversion parameter $k_t = k_{t+10}$ and a time-varying volatility $\sigma_{\epsilon,t+10} = \sigma_{\epsilon t}$.

Some care is needed in the treatment of weekends. There are no market quotes for overnight rates during the weekend: the probability of a target change on Saturday or Sunday is nil and thus expectations of target levels prevailing for interest rates quoted on Friday are appropriate also for the (shadow) interest rate of Saturday and Sunday. For other holidays in the sample we proceed "as if" a target change were possible during any non-weekend day.

Interest rates are then given by

$$R_t(\tau) = \bar{r}_t + L_{r_t-\bar{r}_t}(\tau)\,(r_t - \bar{r}_t - d_t) + L_{z_t}(\tau) z_t + L_{d_t}(\tau),\ \tau = 30, 60, 91. \tag{4'}$$

Since Friday-overnight rates regulate contracts which mature on Monday and because of the biweekly effect in the mean reversion, the loading $L_{r_t-\bar{r}_t}(\tau)$ is given by

$$L_{r_t-\bar{r}_t}(\tau) \equiv \frac{1}{\tau}\left[1 + 2F_t + \sum_{s=1}^{\hat{\tau}-1}(1 + 2F_{t+s})\prod_{j=1}^{s}(1 - k_{t+j})\right],\ \tau \geq 1, \tag{5'}$$

where $F_t$ is a dummy variable which equals one on Fridays and zero otherwise, and, consistent with practice,

$$\hat{\tau} = \begin{cases} \tau - 2 \times \text{number of weekends}, & \text{if the contract expires on a business day;} \\ \tau + 1 - 2 \times \text{number of weekends}, & \text{if the contract expires on a Sunday;} \\ \tau + 2 - 2 \times \text{number of weekends}, & \text{if the contract expires on a Saturday;} \end{cases}$$

where "number of weekends" denotes the number of weekends within the time to maturity of the loan. The loading $L_{z_t}(\tau)$ now equals

$$L_{z_t}(\tau) \equiv \frac{1}{\tau}\sum_{s=1}^{\hat{\tau}-1}(1 + 2F_{t+s})\left[\sum_{n=1}^{s}\binom{s}{n}\nu^n(1-\nu)^{s-n}\frac{1-\rho^n}{1-\rho}\right], \tau \geq 1. \tag{6'}$$

Finally the loading $L_{d_t}(\tau)$ is given by

$$L_{d_t}(\tau) \equiv \frac{1}{\tau}\left[\sum_{s=0}^{\hat{\tau}-1}(1 + 2F_{t+s})d_{t+s}\right],\ \tau \geq 1.$$

Note that the three loadings are calculated dividing the sum of $\hat{\tau}$ terms by $\tau$, the stated maturity. This is consistent with practice, where the quoted yield is adjusted to account for the actual maturity of the loan.

## 4.2 Autocovariances and biweekly effects

When biweekly effects are explicitly accounted for, some modifications to our discussion of the time-series properties of interest rates are needed. Let $t_i$ denote an observation on the $i$-th day of the maintenance period. Using the autoregressive process in equation (1′), the autocovariance of $r_{t_i} - \bar{r}_{t_i} - d_{t_i}$ is given by

$$\text{Cov}_{t_i}(r_{t_i+s} - \bar{r}_{t_i+s} - d_{t_i+s}, r_{t_i} - \bar{r}_{t_i} - d_{t_i}) = \prod_{j=1}^{s}(1 - k_{t_i+j})\text{Var}_{t_i}(r_{t_i} - \bar{r}_{t_i} - d_{t_i}),\ i = 1, 2, \ldots 10.$$

We can now calculate the autocovariance of a maturity-$\tau$ spread:

$$\begin{aligned}\text{Cov}_t(R_{t+s}(\tau) - \bar{r}_{t+s}, R_t(\tau) - \bar{r}_t) &= EE_{t_i}[(R_{t_i+s}(\tau) - \bar{r}_{t_i+s})(R_{t_i}(\tau) - \bar{r}_{t_i})] \\ &\quad -E(R_{t+s}(\tau) - \bar{r}_{t+s})E(R_t(\tau) - \bar{r}_t). \qquad (12)\end{aligned}$$

Using equation (4′), and the fact that the processes $r_t - \bar{r}_t - d_t$ and $z_t$ have zero mean and are independent from each other, the conditional expectation in the first term on the right-hand-side of (12) equals

$$\begin{aligned}&E_{t_i}[(R_{t_i+s}(\tau) - \bar{r}_{t_i+s})(R_{t_i}(\tau) - \bar{r}_{t_i})] \\ = \ &L_{r_{t_i+s} - \bar{r}_{t_i+s}}(\tau)L_{r_{t_i} - \bar{r}_{t_i}}(\tau)\text{Cov}_{t_i}(r_{t_i+s} - \bar{r}_{t_i+s} - d_{t_i+s}, r_{t_i} - \bar{r}_{t_i} - d_{t_i}) \\ &+L_{z_{t_i+s}}(\tau)L_{z_{t_i}}(\tau)\text{Cov}(z_{t+s}, z_t) + L_{d_{t_i+s}}(\tau)L_{d_{t_i}}(\tau),\end{aligned}$$

whereas the second term equals $-[E(L_{d_t}(\tau))]^2$. Note that in taking this last expectation, as when we apply the law of iterated expectations in equation (12), there is no element of randomness, and we simply compute the arithmetic average over the ten days of the maintenance period.

## 4.3 Estimation and testing

We now compare the implications of our model with the data in the "metric" of the autocovariance functions. We estimate the parameters of the model by GMM. The use of the GMM estimation technique is quite natural in our context, since we want to compare the theoretical moments (autocovariances) implied by our model to the sample ones. Also, estimation by GMM does not require explicit distributional assumptions, and it is robust to departures from normality which are quite likely, given the pronounced excess kurtosis of the fed funds rates spreads from the target (see Table 1). We impose the vector of moment conditions $E(e_t) = 0$, where

$$\begin{aligned}
e_{1-10} &= (r_{t_i} - \bar{r}_{t_i}) - d_{t_i} - (1 - k_{t_i})(r_{t_i-1} - \bar{r}_{t_i-1} - d_{t_i-1}) \\
e_{11-20} &= [(r_{t_i} - \bar{r}_{t_i}) - d_{t_i} - (1 - k_{t_i})(r_{t_i-1} - \bar{r}_{t_i-1} - d_{t_i-1})](r_{t_i-1} - \bar{r}_{t_i-1} - d_{t_i-1}) \\
e_{21-30} &= [(r_{t_i} - \bar{r}_{t_i}) - d_{t_i}]^2 - \sigma^2_{r_{t_i} - \bar{r}_{t_i}} \\
e_{31} &= (\bar{r}_{t^*} - \bar{r}_{t^*-1}) - \rho(\bar{r}_{t^*-1} - \bar{r}_{t^*-2}) \\
e_{32} &= I_{\bar{r}_t - \bar{r}_{t-1}} - \nu \\
e_{33} &= [(r_t - \bar{r}_t) - E_t(r_t - \bar{r}_t)]^2 - \text{Autocov}(r_t - \bar{r}_t; 0) \\
e_{34} &= [(r_t - \bar{r}_t) - E_t(r_{t-60} - \bar{r}_{t-60})]^2 - \text{Autocov}(r_t - \bar{r}_t; 60) \\
e_{35-37} &= [(R_t(\tau) - \bar{r}_t) - E_t(R_t(\tau) - \bar{r}_t)]^2 - \text{Autocov}(R_t(\tau) - \bar{r}_t; 0) \\
e_{38-40} &= [(R_t(\tau) - \bar{r}_t) - E_t(R_{t-60}(\tau) - \bar{r}_{t-60})]^2 - \text{Autocov}(R_t(\tau) - \bar{r}_t; 60),
\end{aligned}$$

for $i = 1,..,10$ and $\tau = 30, 60, 90$. $\sigma_{r_{t_i} - \bar{r}_{t_i}} = \sqrt{\text{Var}_{t_i}(r_{t_i} - \bar{r}_{t_i} - d_{t_i})} = \sqrt{\text{Var}_{t_i}(r_{t_i} - \bar{r}_{t_i})}$ is the volatility of the $i$-th day overnight spread, $t^*$ denotes the time when a target change is implemented, $I_{\bar{r}_t - \bar{r}_{t-1}}$ is an indicator function equal to one when $\bar{r}_t - \bar{r}_{t-1} \neq 0$, and zero otherwise, and Autocov$(.; s)$ denotes the appropriate theoretical autocovariance function of order $s$. Note that we estimate 33 parameters. 30 parameters characterize the stochastic process for $r_t - \bar{r}_t$ (see equation (1)): ten intercepts $d_{t_i}$, ten mean-reversion parameters $k_{t_i}$, and ten volatilities $\sigma_{r_{t_i} - \bar{r}_{t_i}}$. Two parameters characterize the target-change process: the daily frequency $\nu$ and the correlation coefficient $\rho$. One parameter characterizes the behavior of the expectational variable $z_t$: the unconditional volatility of $z_t$, $\sigma_z = \sqrt{\text{Var}(z_t)}$.[12] Given the 40 moment conditions above, we have seven overidentifying restrictions that we test following Hansen (1982).[13]

Parameter estimates are reported in Table 4. Panel A presents estimates of the time-varying parameters with bi-weekly periodicity. Panel B presents the estimates of the constant parameters, and the statistic of the test of the overidentifying restrictions. Note that our parameter estimates are obtained using the information from the actual realizations of overnight fed funds rates and target changes, as well as the additional information contained in the time-series properties of the three term fed funds rates. The use of the associated twin set of moment restrictions results in high precision, and most of our parameter estimates are statistically significant, which is relatively unusual in empirical studies of the term structure.

The time varying intercepts $d_{t_i} = d_{t_i+10}$, which capture changes in the average spread between the overnight rate $r_t$ and the target $\bar{r}_t$ over the maintenance period, suggest that the overnight rate has been fairly "close" to the target in our sample: the average $d_{t_i}$ is less than one basis point (in absolute value). Also, the biweekly pattern is evident, with the largest average spread from the target on the Wednesday ending the maintenance period (19 basis points). The mean-reversion parameters for the $i$-th day of the maintenance period, $k_{t_i} = k_{t_i+10}$, confirm that interest rate targeting during our sample was quite effective. The average $k_{t_i}$ equals 0.55, which means that over half of the spread of the spread from the mean, $d_{t_i}$, on any given day, was "reabsorbed" by the next day. The time-varying volatilities $\sigma_{r_{t_i}-\bar{r}_{t_i}}$ indicate the exceptional volatility of the overnight fed funds rate at the beginning and at the end of the maintenance period.

We also report estimates of the measure of serial correlation in target changes, $\rho$, and of the probability of a target change taking place on any given day, $\nu$. The estimate of $\rho$ confirms the visual evidence of Figure 1, Panel A, that there is substantial persistence in target changes: target changes are not likely to be soon reversed. The estimate of $\nu$ is consistent with the actual infrequency of target changes, at a daily time scale.

The estimate of the volatility of $z_t$, $\sigma_z$, can be better interpreted if we make explicit assumptions on either one of the two parameters $\sigma_\zeta$ and $\sigma_\eta$. For example, we can assume that on the day before a target change the next day's target change is perfectly predicted and $\eta_{t^*} = 0$. The implied volatility of the day-to-day revisions of $z_t$, $\zeta_t$, is given by $\sigma_\zeta = \sqrt{\nu(1-\rho^2)\sigma_z^2} = 0.008$ (0.8 basis points), which is quite realistic in light of target changes whose size is typically (about) 12.5 or 25 basis points.

Finally, we report the $\chi^2$ statistic for the test of the seven overidentifying restrictions. The test fails to reject the null at conventional significance levels. This is evidence that the restrictions imposed by our term-structure model on the interaction between overnight-rate, target-change, and term-fed-funds dynamics are not at odds with the data.

Further evidence of the satisfactory performance of the model is provided by Figure 4, which presents the theoretical autocovariance functions for overnight and short-term spreads calculated using the estimates reported in Table 4. Comparison of Figures 2 and 4 shows that our model successfully replicates the ranking, and broadly reproduces the shape of the autocovariance functions of the data. Also, our model successfully replicates the biweekly seasonal patterns in the autocovariances of overnight spreads and the absence of such patterns in the longer-maturity spreads.

Our empirical results can be compared with the findings of other papers which use similar term structure models to infer implications for the dynamics of interest rates. Jegadeesh and Pennacchi (1995), for example, estimate their two-factor term structure model using monthly Eurodollars futures data for the period April 1982 to October 1995. They compare the spot rates implied by their model to actual spot rates, in a spirit very similar to our comparison of theoretical and sample autocovariances. They find that their model replicates quite well the behavior of the levels of short-term spot rates. Also, Babbs and Webber (1994) calibrate their term structure model based on LIBOR data, and perform simulation exercises. Their model mimics quite well the average ratio of day-to-day changes in various maturities of LIBOR to changes in the rate targeted by the Bank of England, for the 1987–1991 period. Hence, it appears that term structure models which allow the "central tendency" of short-term rates (a short-run rest level, such as the fed funds rate target) to change over time capture some essential features of the data.[14]

# 5 Conclusions

Mankiw and Miron (1986) observe that the manner in which central banks target short-term interest rates makes interest rate changes virtually unpredictable. Therefore, only slight fluctuations in term premiums could cause the rejection of the expectations hypothesis. One implication of the lack of predictability of the shorter-term rates, is that spreads of longer-term rates from the current target should only reflect term premia. This paper shows that during the 1989-96 period, when the Federal Reserve actively targeted the overnight fed funds rate, term fed funds rates displayed volatile and persistent spreads from the target. Perhaps most surprisingly, we document that the volatility and persistence of such spreads increase with the maturity of the loan. We present a model of the term structure of interest rates consistent with expectational effects resulting from two realistic features of the Federal Reserve daily targeting operations: the infrequency and partial predictability of target changes. The implications of the model for the dynamics of term fed funds rates spreads are quite consistent with the data.

Our analysis has several implications for policy. First, the new stylized fact that we document can be interpreted as evidence that even a tight targeting of the overnight fed funds rate does not mechanically translate into a tight control of longer-term rates. In fact, the market is aware that the current target may be changed, and this expectation, whether accurate or not, causes variability in longer-term rates. Second, our estimate of the volatility of the next-target-change expectation provides a direct measurement of how the market receives and processes information relevant for future changes in monetary policy. This information is relevant even (and possibly more) if the market entertains incorrect expectations of future policy changes. Third, while the Federal Reserve may be able to affect interest rates by "surprising" the market with unexpected target changes, it may also induce unwanted volatility in short-term rates as the market tries to process noisy information, and updates a (possibly wrong) expectation of future policy changes. Fourth, the behavior of the overnight fed funds rate and of the next-target-change expectation provide a useful characterization of a monetary regime, intended as the set of rules followed by the monetary authority as well as its understanding (or misunderstanding) on the part of the market.

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**Table 1.** Summary Statistics

**Panel A.**

**Overnight, Target, and Term Fed Funds Rates, Levels**

| Fed Funds Rate | Mean | Volatility | $\gamma_1$ | $\gamma_2$ |
|---|---|---|---|---|
| Overnight | 5.183 | 1.873 | 0.466 | −0.823 |
| | (0.224) | (0.415) | (0.161) | (0.278) |
| Target | 5.193 | 1.816 | 0.414 | −0.983 |
| | (0.222) | (0.404) | (0.166) | (0.248) |
| 1-Month | 5.180 | 1.800 | 0.412 | −0.976 |
| | (0.220) | (0.391) | (0.165) | (0.256) |
| 2-Month | 5.244 | 1.735 | 0.356 | −1.028 |
| | (0.212) | (0.357) | (0.164) | (0.230) |
| 3-Month | 5.261 | 1.689 | 0.315 | −1.075 |
| | (0.206) | (0.330) | (0.166) | (0.206) |

**Panel B.**

**Overnight and Term Fed Funds Rates, Spreads from Target**

| Fed Funds Rate | Mean | Volatility | $\rho_{30}$ | $\rho_{60}$ | $\gamma_1$ | $\gamma_2$ |
|---|---|---|---|---|---|---|
| Overnight | −0.010 | 0.398 | 0.027 | 0.016 | 0.405 | 39.045 |
| | (0.012) | (0.050) | (0.014) | (0.020) | (1.706) | (7.785) |
| 1-Month | −0.013 | 0.214 | 0.145 | 0.171 | 4.354 | 38.851 |
| | (0.019) | (0.017) | (0.061) | (0.108) | (0.992) | (12.479) |
| 2-Month | 0.050 | 0.293 | 0.396 | 0.308 | 1.321 | 3.858 |
| | (0.030) | (0.016) | (0.103) | (0.087) | (0.316) | (1.370) |
| 3-Month | 0.067 | 0.359 | 0.613 | 0.579 | 0.842 | 1.265 |
| | (0.040) | (0.023) | (0.089) | (0.083) | (0.228) | (0.649) |

NOTE: This table reports summary statistics for the overnight, target, and term fed funds rates. The data are continuously-compounded rates over the period May 18, 1989 to February 29, 1996. Statistics were estimated by the Generalized Method of Moments (GMM). Mean is the sample mean, Volatility the sample standard spread, $\gamma_1$ an estimate of the skewness measure, and $\gamma_2$ an estimate of the kurtosis measure. The skewness and kurtosis measures are defined, specifically, in terms of central moments of order $j$, $u_j$: $\gamma_1 = u_3/u_2^{3/2}$ and $\gamma_2 = u_4/u_2^2 - 3$. Both are zero for normal random variables. $\rho_{30}$ and $\rho_{60}$ denote the autocorrelations after 30 and 60 business days, respectively. Standard errors, reported in parentheses below the point estimates, are robust to conditional heteroskedasticity, and allow errors to exhibit serial correlation of moving average-form up to 25 lags.

**Table 2.** Effect of Target Changes on Term Fed Funds Rates

| Maturity | $a_\tau$ | $b_\tau$ | adj.$R^2$ | S.E.R. | D.W. |
|---|---|---|---|---|---|
| 1-Month | −0.019 | 0.345 | 0.499 | 0.098 | 1.443 |
| | (0.017) | (0.056) | | | |
| 2-Month | −0.081 | 0.190 | 0.543 | 0.109 | 2.509 |
| | (0.019) | (0.062) | | | |
| 3-Month | −0.039 | 0.300 | 0.323 | 0.157 | 1.511 |
| | (0.022) | (0.069) | | | |

NOTE: We estimate the regression model

$$\Delta R_{t^*}(\tau) = a_\tau + b_\tau \Delta \bar{r}_{t^*} + \text{error}_{t^*}, \ \tau = 30, 60, 90,$$

where $\Delta$ denotes daily changes, $t^*$ a day when a target change occurs, $R_{t^*}(\tau)$ the term funds rate of maturity $\tau$, and $\bar{r}_t$ the target fed funds rate. The sample includes 34 changes in the fed funds rate target, $\Delta \bar{r}_{t^*}$, over the period May 18, 1989 to February 29, 1996. Standard errors, reported in parentheses below the point estimates, are robust to conditional heteroskedasticity. The last three columns report the adjusted R−square (adj.$R^2$), the standard error of the regression (S.E.R.), and the Durbin-Watson statistic (D.W.).

**Table 3.** Target Change Process

**Panel A.**

$|\Delta\bar{r}_{N_t}| = a + b \times (\text{no-target-change spell})_{N_t} + \text{error}_{N_t}$

| $a$ | $b$ | adj.$R^2$ | S.E.R. | D.W. |
|---|---|---|---|---|
| 0.314 | −0.000112 | 0.839 | 0.138 | 1.534 |
| (0.026) | (0.000160) | | | |

**Panel B.**

Kolmogorov-Smirnov test

| statistic | p-value |
|---|---|
| 0.573 | 0.102 |

**Panel C.**

$(\text{no-target-change spell})_{N_t} = a + b|\Delta\bar{r}_{N_t-1}| + \text{error}_{N_t}$

| $a$ | $b$ | adj.$R^2$ | S.E.R. | D.W. |
|---|---|---|---|---|
| 44.642 | 25.141 | 0.376 | 66.282 | 1.940 |
| (23.842) | (44.848) | | | |

NOTE: Panel A of this table reports the OLS estimates of the regression model

$$|\Delta\bar{r}_{N_t}| = a + b \times (\text{no-target-change spell})_{N_t} + \text{error}_{N_t},$$

where $\Delta$ denotes daily changes, $\bar{r}_{N_t}$ the target fed funds rate on the day of the $N_t$-th change, and
$(\text{no-target-change spell})_{N_t}$ denotes the length of the time period between the $(N_t - 1)$-th and the $N_t$-th target change. Panel B of this table reports the statistic of the Kolmogorov-Smirnov test that target changes take place with constant probability $\nu$, with the associated p-value. Panel C of this table reports the OLS estimates of the regression model

$$(\text{no-target-change spell})_{N_t} = a + b|\Delta\bar{r}_{N_t-1}| + \text{error}_{N_t}.$$

The sample includes 34 changes in the fed funds rate target, $\Delta\bar{r}_t$, over the period May 18, 1989 to February 29, 1996. In Panels A and C, standard errors are reported in parentheses below the point estimates, and are robust to conditional heteroskedasticity. The last three columns of Panels A and C report the adjusted R−square (adj.$R^2$), the standard error of the regression (S.E.R.), and the Durbin-Watson statistic (D.W.).

**Table 4.** Estimation and Testing of the Model

**Panel A.**

**Time-Varying Parameters**

| Day | $d_{t_i}$ | $k_{t_i}$ | $\sigma_{r_{t_i}-\bar{r}_{t_i}}$ |
|---|---|---|---|
| 1 | 0.121 | 0.751 | 0.360 |
| | (0.036) | (0.061) | (0.055) |
| 2 | −0.005 | 0.335 | 0.332 |
| | (0.052) | (0.165) | (0.069) |
| 3 | 0.042 | 0.365 | 0.256 |
| | (0.028) | (0.056) | (0.038) |
| 4 | −0.059 | 0.746 | 0.199 |
| | (0.028) | (0.205) | (0.035) |
| 5 | −0.058 | 0.606 | 0.134 |
| | (0.020) | (0.352) | (0.012) |
| 6 | 0.021 | 0.487 | 0.339 |
| | (0.016) | (0.399) | (0.091) |
| 7 | −0.126 | 0.955 | 0.313 |
| | (0.013) | (0.207) | (0.069) |
| 8 | −0.055 | 0.046 | 0.443 |
| | (0.028) | (0.229) | (0.165) |
| 9 | −0.100 | 0.435 | 0.412 |
| | (0.030) | (0.099) | (0.089) |
| 10 | 0.190 | 0.829 | 0.754 |
| | (0.044) | (0.131) | (0.084) |

**Panel B.**

**Constant Parameters and Test Statistic**

| $\rho$ | $\nu$ | $\sigma_z$ | $\chi^2$ |
|---|---|---|---|
| 0.643 | 0.017 | 0.905 | 9.031 |
| (0.104) | (0.002) | (0.162) | (7) |

NOTE: Panel A reports the estimates of the parameters of the stochastic process of the deviations of the overnight fed funds rate from the target: the intercepts $d_{t_i}$, the mean-reversion parameters $k_{t_i}$, and the volatilities $\sigma_{r_{t_i}-\bar{r}_{t_i}}$. Panel B reports estimates of the target-change frequency $\nu$, the target-change correlation coefficient $\rho$, the unconditional volatility of $z_t$, $\sigma_z$, and the $\chi^2$ statistic of the test of the overidentifying restrictions. The estimates are obtained by Generalized Method of Moments (GMM). Standard errors, reported in parentheses below the point estimates, are robust to conditional heteroskedasticity, and allow errors to exhibit serial correlation of moving average-form up to 25 lags. The degrees of freedom for the $\chi^2$ statistic are shown in parenthesis below the statistic.

**Figure 1.A.** Fed Funds Rates and Target

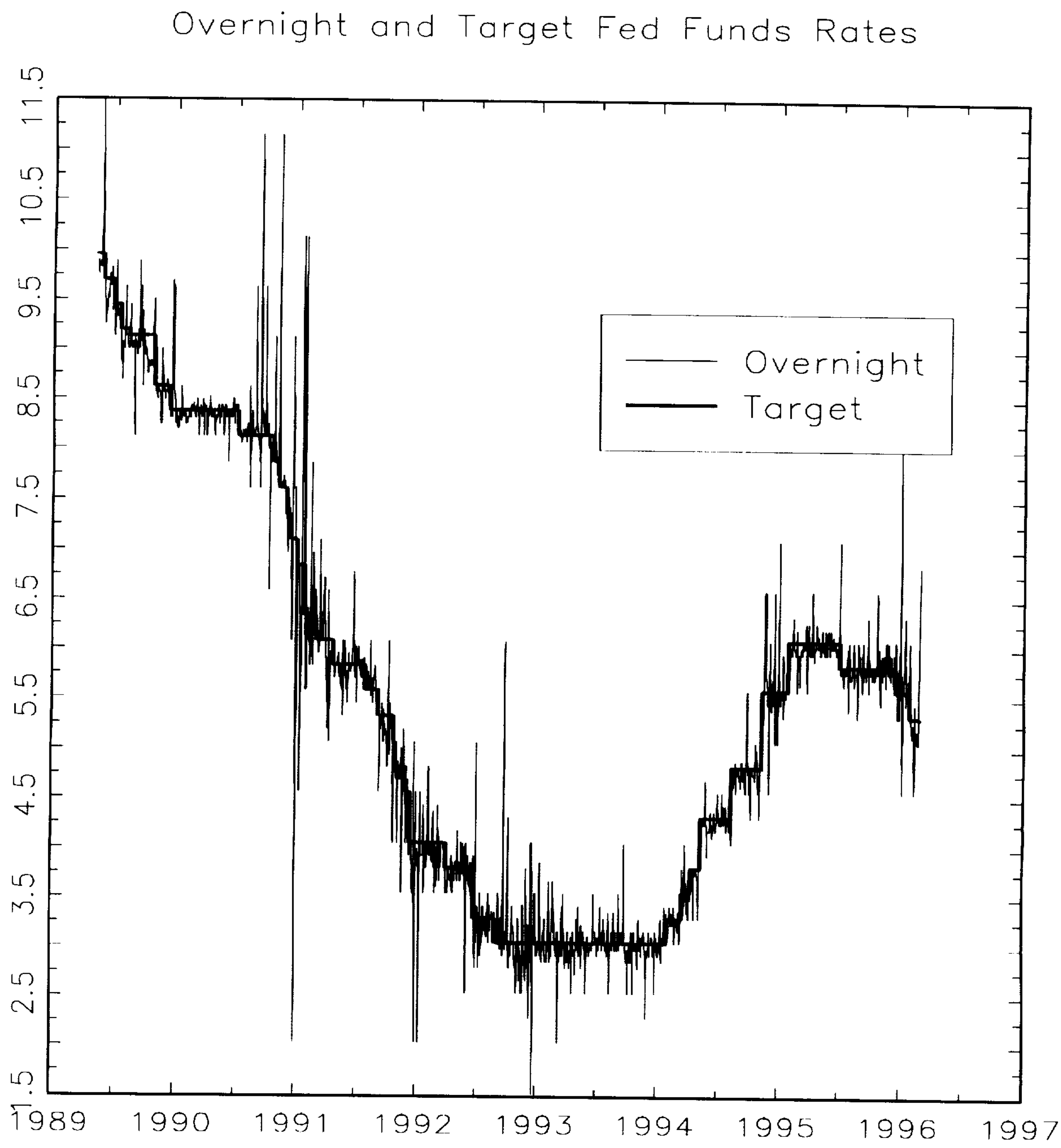


**Figure 1.B.** Fed Funds Rates and Target

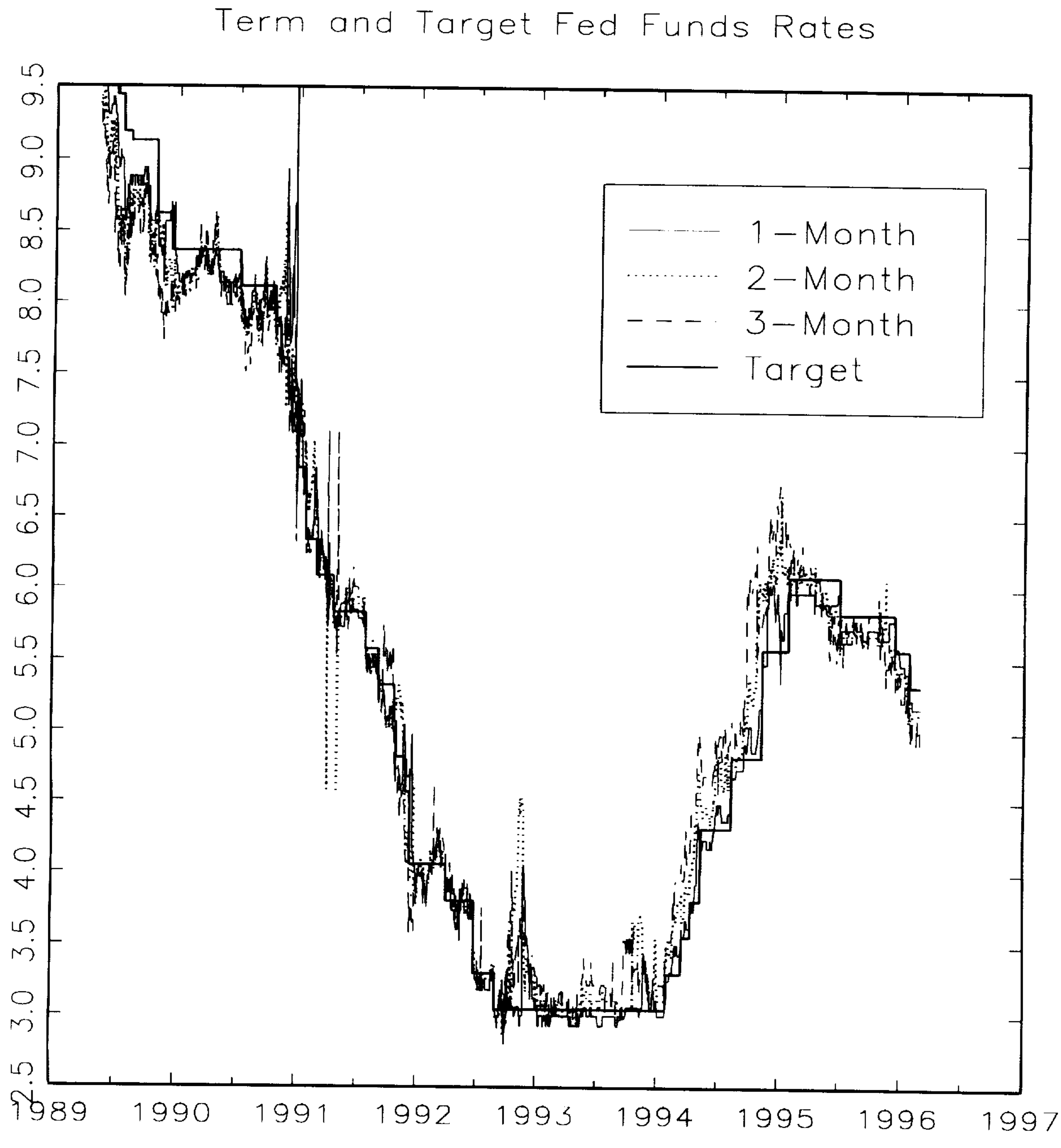
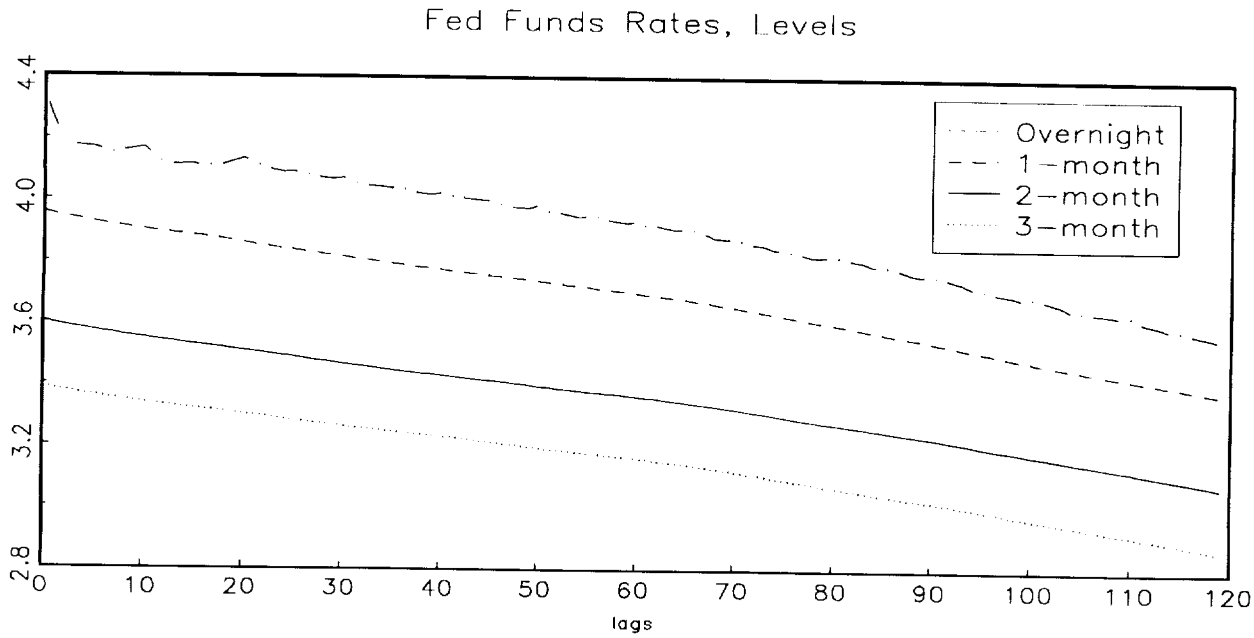


**Figure 2.** Fed Funds Rates, Autocovariance Functions



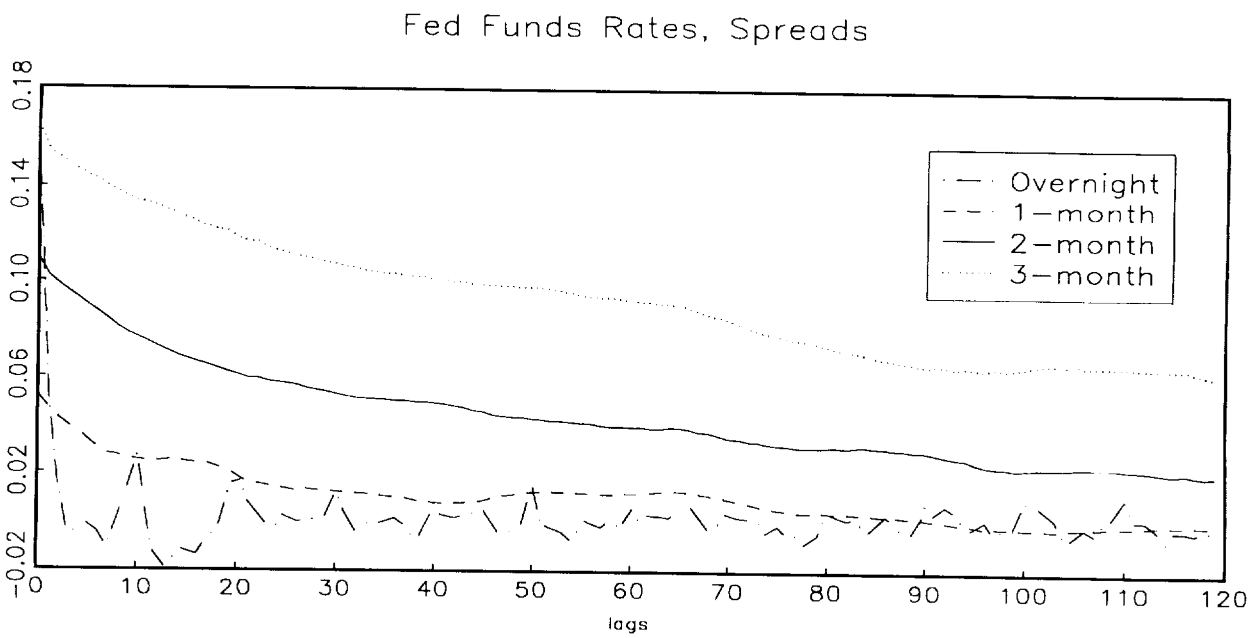



**Figure 3.** Spreads of Fed Funds Rates from Target, Seasonal Effects

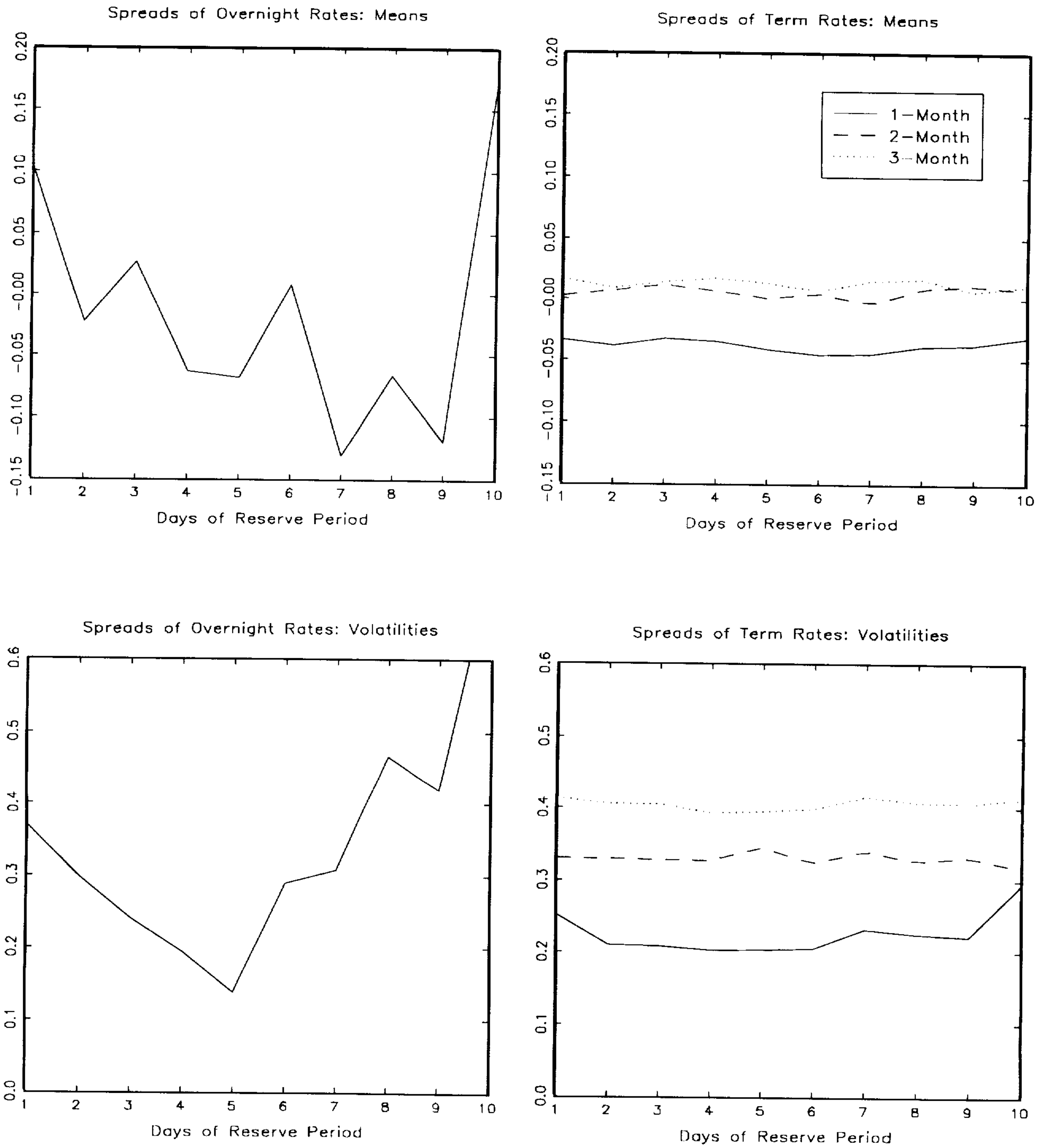
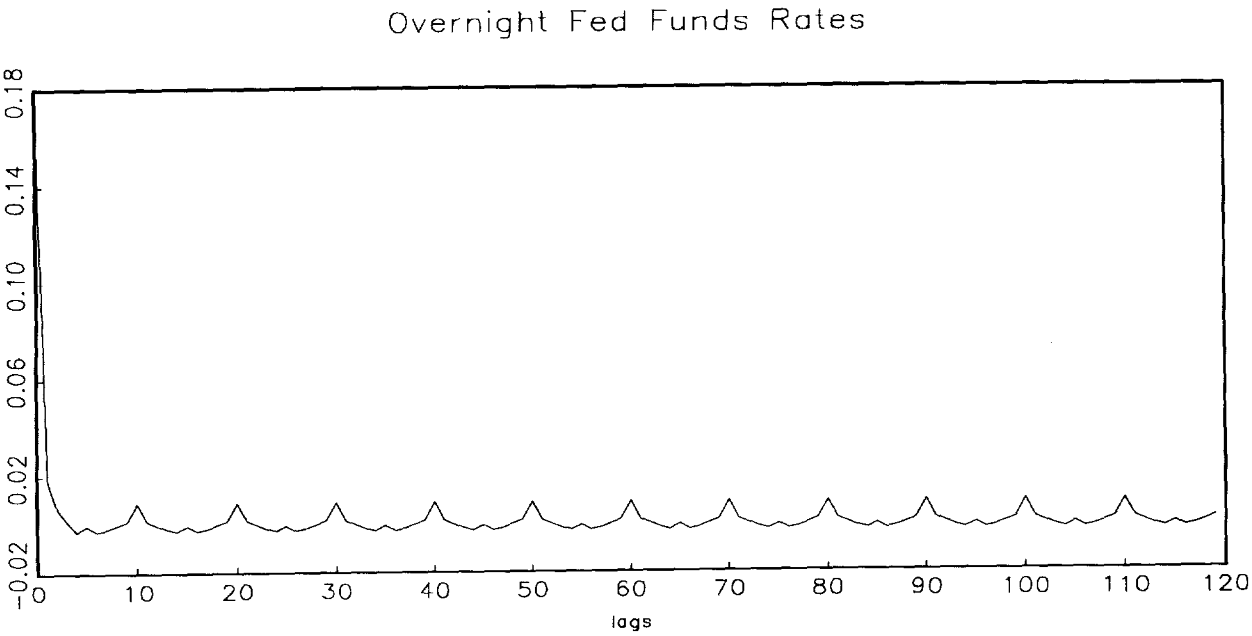
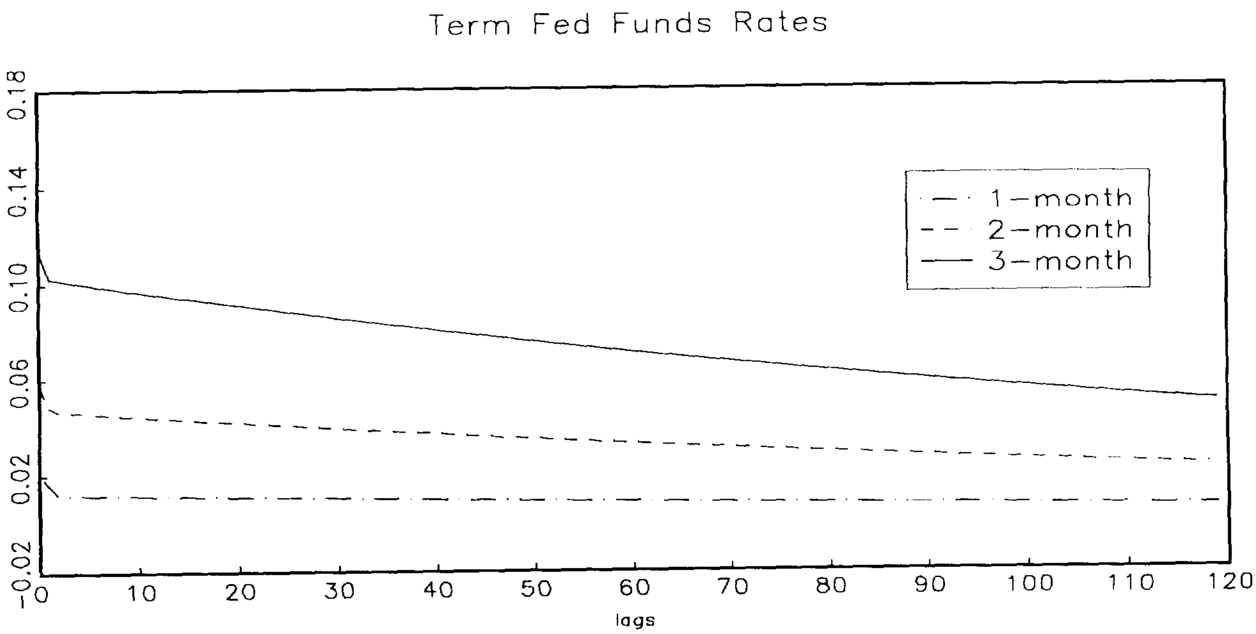


**Figure 4.** Theoretical Autocovariance Functions



**Footnotes**

1. See Campbell (1995), Campbell, Lo, and MacKinlay (1996), Melino (1988), and Shiller (1990) for useful reviews of these issues.

2. It is also convenient though, since the related paper by Rudebusch (1995) considers data for the 1974–1987 period. Hence, we provide evidence for a new sample. Moreover, Rudebusch's empirical analysis only considers the behavior of the overnight fed funds rate and the target, whereas ours extends to term fed funds rates.

3. Further details on the institutional features of interest rate targeting can be found in Meulendyke (1990).

4. See also Balduzzi, Green, and Elton (1996) who document the effects of target-change suprises on the price of the three-month Treasury bill, using intraday data for the 1991–1995 period.

5. The approximation arises because we quote rates on a continuously compounded basis, rather than on a bank discount basis.

6. For example, assume that target changes may only take the two values $\delta(>0)$ and $-\delta$. Also, assume that the probability of observing two target changes in the same direction is constant, and given by $\pi$. At the time of a target change $\Delta\bar{r}_{N_t} = \pm\delta$ the expectation of the next target change is given by $(2\pi - 1)\Delta\bar{r}_{N_t}$. As long as target changes in the same direction as the last one are more likely than changes in the opposite direction, $0.5 < \pi < 1$ and $0 < 2\pi - 1 < 1$. Hence, the serial correlation coefficient $\rho$ in equation (2) can be reinterpreted in terms of probabilities of a discrete-value distribution, much like the one postulated in Rudebusch (1995); in our example $\rho = 2\pi - 1$.

7. Also, a similar assumption is also made in Rudebusch (1995), where the absolute size of target changes is always drawn from the same distribution, irrespective of the time elapsed since the last change.

8. We may think that the policymaker also updates the estimate of the needed change in the target according to the news received.

9. Specifically, until February 1994, target changes were communicated to the market through the trading activity of the New York Fed, and hence around 11:30 am, when the first daily trades are implemented. Beginning with the target change of February 2, 1994, changes in monetary policy have been officially communicated to the market on the (last) day of the meeting of the Federal Open Market Committee during which the decision was made, at about 2:15 pm (with the exception of the two target changes of February 2, 1994 and August 16, 1994, when the news release was made at 11:30 am and 1:29 pm, respectively).

10. See, for example, Spanos (1987), p.229, for an illustration of this test.

11. Rudebusch (1995), on the other hand, relies on Monte Carlo integration to calculate the yield curve implied by his assumptions on the overnight fed funds rate, and his exercises are limited to simulations.

12. In fact, the parameters $\sigma_\zeta$ and $\sigma_\eta$ cannot be separately identified, and our algorithm optimizes with respect to $\sigma_z = \sqrt{(\rho^2\sigma_\eta^2 + \sigma_\zeta^2/\nu)/(1-\rho^2)}$.

13. Estimation and testing is performed assuming a moving-average structure in the errors $e_t$ of order 25. We also experimented with different-order correlation structures, with essentially the same results.

14. In fact, Jegadeesh and Pennacchi (1996) reject the restriction of a constant central tendency at the one-percent level. This result is consistent with the findings of Balduzzi, Das, and Foresi (1996), who show that models of the short-term rate with a time-varying central tendency perform better than models which assume the central tendency to be constant, in capturing variations of short-term rates.