RESEARCH PAPER

THE SHORT END OF THE FORWARD CURVE AND ASYMMETRIC CAT'S TAIL CONVERGENCE

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Federal Reserve Bank of New York
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ABSTRACT

How is the term structure able to predict future interest rates several months in the future and why is it so steep at the short end? Recent empirical work shows that rates of mean reversion are too slow to help predict short rates or to account for the curve's steepness. We propose that short term interest rates are predictable because Federal Reserve actions are predictable. In particular, our estimates suggest that the market anticipates the Fed's monetary stance twelve months in advance. Moreover, forward rates contain more information when the Fed is expected to tighten than when it is expected to ease. When the market anticipates a tightening, expectations about rising short rates drive movements in near term forward rates. When the market anticipates an easing, the term premia drives movements in forward curves. This asymmetry in the behavior of forward rates with regard to future monetary policy stance explains the forward curve's typically humped shape. We argue that a rapid convergence to a Fed target when a tightening is anticipated but not when an easing is anticipated generates an average forward curve that is steep at the short end.

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The Short End of the Forward Curve and Asymmetric Cat's Tail Convergence

Eli M. Remolona, Joseph Dziwura, and Irene Pedraza[1]

1. Introduction

Reconciling equilibrium models of the term structure with the empirical behavior of interest rates is a task that continues to challenge economists. Equilibrium models, such as those by Vasicek (1977) and Cox, Ingersoll, and Ross (1985), specify a short rate that reverts toward a long-run mean. However, in empirical studies the short rate is often seen as having a unit root, and in practice market participants routinely calibrate their yield curve models to reflect a short rate that behaves as a random walk. Even when mean reversion is detected, it appears to be too slow to account for the curvature of the yield curve or to be of much help for predicting short rates in the near future.

Nonetheless there seem to be enough regularities in the short rate's movements to allow the market to anticipate it a few months in advance. Fama (1984) and Mishkin (1988) have demonstrated that the short end of the

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[1] We thank Ben Bernanke, James Hamilton, and our colleagues at the New York Fed. The views expressed are our own and are not necessarily shared by the Federal Reserve Bank of New York or the Federal Reserve System.

forward curve helps predict changes in short rates over the near term. Rudebusch (1995) suggests that such short rates are predictable in the United States because of "Fed smoothing," in which the Federal Open Market Committee (FOMC) so loathes reversing itself that it adjusts its fed funds target in measured steps. Indeed some market participants liken the Fed's conduct to cutting a cat's tail, with the Fed not knowing exactly how much to cut and therefore cutting a little at a time. Hence, instead of a short rate that reverts toward a long-run mean, the hypothesis is that the short rate converges toward a near-term Fed target. Such convergence may account for the shape of the yield curve at the short end, while mean reversion may account for the curve's shape at the long end.

How well can the market in fact anticipate monetary stance? Using daily data, Rudebusch finds that a change in the fed funds target is likely to be followed by another change in the same direction for the first five weeks but that a change in the opposite direction is just as likely beyond five weeks. Market participants, however, seem able to predict short rate movements well more than five weeks in advance. With monthly data, Mishkin finds that in the 1980s forward rates helped predict one-month rates as many as three months ahead. Market participants, after all, have access to other relevant information besides the direction of the last target change and the time since the last change. Data on inflation rates, for example, may help them anticipate target changes well beyond a five-week horizon.

We estimate a probit model for the future stance of monetary policy by conditioning on lagged inflation rates and the spread between the corresponding forward rate and the current short rate as well as on Rudebusch's variables, the direction of the last change in the fed funds target and the time since that change. We find that Rudebusch's variables are most helpful within the two-month time horizon but beyond this horizon inflation rates and forward rates begin to acquire predictive power. Our results suggest that monetary stance can be anticipated even twelve months in advance.

In what way does the anticipation of monetary stance help in the prediction of short rates in the future? We extend the work of Fama and Mishkin by taking account of the market's anticipation of monetary stance. We find that the informational content of the forward curve at the short end depends significantly on the perceived likelihood of the Fed's tightening or easing. Forward rates contain more information when the Fed is expected to tighten than when it is expected to ease. When the market anticipates a tightening, expectations about rising short rates seem to drive movements in near-term forward rates. When the market anticipates an easing, the term premium seems to drive movements in forward rates.

The apparent asymmetry in the behavior of forward rates with regard to future monetary stance may explain the forward curve's typically humped shape. The hump seems to stem from the tendency of the curve to be relatively steep at the short end and relatively flat at the long end. Empirical estimates, however, suggest rates of mean reversion that are too slow to account for the curve's steepness. A rapid convergence to a Fed target when a tightening is anticipated but not when an easing is anticipated would be one way to generate an average forward curve that is steep at the short end.

In the next section, we present a preliminary analysis of our data on short rates and examine the extent to which the short rate's behavior can explain the shape of the forward curve. In Section 3, we estimate the extent to which market participants can anticipate the stance of monetary policy. In Section 4 we measure the amount of information about future short rates contained in forward rates of varying maturities, distinguishing between periods of anticipated tightening and anticipated easing. In Section 5, we test the hypothesis that short-term changes in short rates are driven by a process of convergence to a Fed target.

2. Mean reversion versus unit roots

2.1 An equilibrium model with mean reversion

A short rate that follows a mean reverting process is appealing for two reasons. First, the process places variance bounds on interest rates, specifically preventing interest rates from becoming negative. Second, the process helps reproduce the typical humped shape of the yield curve. Empirically, however, such mean reversion has been hard to establish. Our view is that mean reversion becomes important only over the very long run. In the short run, the short rate's behavior is dominated by expectations that arise from anticipations about the monetary stance.

We start with the simplest possible equilibrium model with mean reversion in the short rate. The model is based closely on Backus, Foresi, and Zin (1994). A single state variable is the source of uncertainty in the model. The evolution of the state variable x_t is described by the equation

$$x_{t+1} = \theta x_t + (1 - \theta)\delta + u_{t+1} \qquad \textbf{(1)}$$

where x_t reverts to a mean given by δ at the rate $1 - \theta$ each period. If $\theta = 1$, we would have a unit root process. In period $t + 1$, a shock u_{t+1} with mean zero and variance σ^2 perturbs the state variable.

To price financial assets, we relate the state variable to a discount factor k_{t+1}, which is also called the pricing kernel:[2]

$$-\log k_{t+1} = x_t + \lambda u_{t+1} \tag{2}$$

In a more general equilibrium model, the pricing kernel k_{t+1} would be the intertemporal marginal rate of substitution of the representative agent. The factor λ represents the market price of risk, and an absence of arbitrage opportunities is assured when this price is fixed across all financial assets.

We can now price bonds of varying maturities by relying on the recursive equation

$$b_t^{n+1} = E_t(k_{t+1} b_{t+1}^n) \tag{3}$$

where $b_t^0 = 1$ by construction. The short rate process can then be derived by noting that $b_t^1 = E_t k_{t+1}$ and

$$r_t = -\log b_t^1 = x_t - \frac{\lambda^2 \sigma^2}{2} \tag{4}$$

Defining the unconditional mean of the short rate as

$$E(r_t) = \delta - \frac{\lambda^2 (\sigma^2)}{2} \equiv \mu \tag{5}$$

we can then write the short rate process as

$$r_{t+1} = (1-\theta)\mu + \theta r_t + u_{t+1} \tag{6}$$

which then gives us a process with mean reversion.

The above short rate process implies that forward rates are

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[2] The term "pricing kernel" is due to Sargent (1987).

$$f_t^n = (1-\theta^n)\mu + \theta^n r_t + \left(\lambda^2 - \left(\lambda + \frac{1-\theta^n}{1-\theta}\right)^2\right)\frac{\sigma^2}{2} \qquad \textbf{(7)}$$

The first two terms represent the expected future spot rate n periods ahead and the last term is a risk premium that arises from Jensen's inequality when taking expectations of logarithms. If the short rate followed a unit root process, we would have $\theta = 1$, and with L'Hospital's rule $(1 - \theta^n)/(1 - \theta)$ reduces to n, so that forward rates are given by

$$f_t^n = r_t + \left(\lambda^2 - (\lambda + n)^2\right)\frac{\sigma^2}{2} \qquad \textbf{(8)}$$

which corresponds to Ho and Lee's (1986) model of the term structure, one of the most popular models used in the fixed-income market.

2.2 *Unit roots and a preliminary look at the data*

In one of the most careful empirical efforts to date, Chan, Karolyi, Longstaff, and Sanders (1992) employ Generalized Method of Moments to examine monthly data on one-month Treasury bill rates over the period from June 1964 to December 1989. The data do not provide precise estimates of the drift in the short rate process, and Chan et al. are unable to reject the hypothesis that the short rate follows a random walk. The study assumes a single regime. At the same time, the study implicitly assumes that the long-run mean to which the short rate would revert is the sample mean of the short rate. Even with a sample period covering 307 months, the sample mean may be different from the mean perceived by the market, a mean that is not only unobservable but may actually change over time.

Our own look at the data, shown in Chart 1, suggests that the level of the short rate is very persistent. Indeed basic statistical tests suggest that it is nonstationary while its change is stationary. The data are based on end of month continuously compounded spot rates for U.S. Treasury bills. The summary statistics are shown in Table 1 for the period January 1977 through December 1993 and two subperiods, June 1973 through September 1979, and March 1984 through December 1993. The data are from Data Resources Inc. (DRI). As shown in Table 1, the autocorrelations of the one month spot rate, r_t, for all the periods are large at short lags, but decay slowly at higher lags. The pattern suggests that the month-to-month levels of the one-month spot rate are highly correlated, suggesting nonstationarity. The month-to-month changes in the spot rate show little autocorrelation and appear to be stationary.

The results of formal stationarity tests, the augmented Dickey-Fuller (ADF) tests, are reported below for three lags. Results using other lags are similar. These results support the conclusions above. The ADF test statistics do not reject the null hypothesis of non-stationarity of levels for the full period and the subperiods. However, the test results reject the null hypothesis for the first differenced data, indicating that the spot rates are integrated of order 1.

Augmented Dicky-Fuller Test Results

Variable	Test Statistic
June 1973-December 1993	
r_t	-2.07
$r_{t+1}-r_t$	-9.77
June 1973-September 1979	
r_t	-0.18
$r_{t+1}-r_t$	-3.80
March 1984-December 1993	
r_t	-1.14
$r_{t+1}-r_t$	-6.89

From Table 1 we see that μ, from equation (6), is equal to 6.74 for the full sample period; for the two subperiods, June 1973 through September 1979, and March 1984 through December 1993, μ is 6.46 and 5.60, respectively. The standard deviations vary substantially from the full sample period to the subperiods. The mean reversion parameter is the first autocorrelation of the short rate. In Table 1 the first autocorrelations are all quite high suggesting that the spot rate has a slow mean reverting tendency. This indicates a high degree of persistence but less than a random walk. For the full period the mean reverting parameter is 0.94. The mean reversion parameter is substantially higher in the March 1984 through December 1993 period, 0.95, than the June 1973 through September 1979 period, 0.89.

These results are consistent with those obtained by Campbell and Shiller (1987) and Shea (1988). The data suggest that changes in the spot rate are not predictable from their past values. As a result, any evidence that suggests that the forward rates have information about future changes in spot rates would suggest that the market uses information other than just the time series of short rates.

In practice, market participants have ignored equilibrium models with mean reversion. Instead they rely on models that assume unit roots, such as Ho and Lee (1986) and Black, Derman and Toy (1990). Market participants implement their models by calibrating the drift term in the short rate process to be consistent with the yield curve at each moment in time. Such a modeling approach would seem to be effective if there were frequent changes in regimes that implied changes in the short rate process.

Using equation (7) and the parameter estimates from Table 1 along with an estimate of the price risk λ, we can derive a theoretical forward curve. We choose λ to approximate the average slope of the sample forward curve. In effect, we force the theoretical forward curve to look like the sample curve, given the other parameter estimates from Table 1.

The sample forward curve data are derived from monthly estimates of annualized continuously-compounded zero-coupon U.S. government bond yields constructed from a yield curve model.[3] Because of data limitations we spliced together the data for the forward rates from two different sources. For the June 1973 through March 1990 period the forward rates were derived from zero-coupon yields supplied by McCulloch and Kwon (1993); from April 1990 through December 1993 the forward rates were derived from zero-coupon yields from an estimated yield curve model.[4] Since the zero-coupon yields for both data sets are estimated using cubic splines they form a smooth continuous series at periods where they overlap.

For the sample period March 1984 through December 1989, and using $\lambda = -750$, we get a theoretical forward curve similar to the sample curve at the short end, but substantially different at the long end. The opposite is true for the June 1973 through September 1979 period as shown in Chart 2. When λ is more negative the curve is steeper and when λ is less negative the curve is flatter. As a result we can get a theoretical model that is fairly close to the sample data at the short end or a theoretical model that is fairly close to the sample data at the long end but not both simultaneously.

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[3]The yield curve model used in this paper creates a zero curve that relates the prices of securities at particular points in time to their future coupon payments in a cross-sectional cubic spline estimation procedure. The zero curves produce relatively stable forward rates particularly at the short-end of the curve.

[4]See, Fisher, Nychka, and Zervos for the details of the procedure.

Again it is worth noting that when $\theta = 1$, from equations (6) and (7), the short rate process follows a random walk. But even if we believe in mean reversion, the estimates of the autocorrelations from Table 1 suggest that θ is not substantially different from one. As long as θ is close to one, the theoretical forward curve becomes very flat, which tends not to be consistent with observed forward curves.

3. Predictability of monetary stance

3.1 Asymmetric transition probabilities for the monetary stance

One cannot help but be impressed by the predictability of monetary policy actions. Rudebusch (1995), for example, obtaining data from the Federal Reserve Bank of New York Open Market Trading Desk, has pointed out that from 1973 to 1992, a change in the Federal funds target rate was followed by another change in the same direction 84 percent of the time. The data yields a time series with precise dates of Federal Reserve policy moves as presented in Charts 3a and 3b. From March 1988 to May 1989, the Fed raised the funds target 18 times in a row, then reduced it 24 times in a row until September 1992. Rudebusch calls the phenomenon "Fed smoothing," while some market participants call it "cutting a cat's tail." Meulendyke (1990) attributes the phenomenon to the notion that the Federal Open Market Committee (FOMC) tightens in measured steps, because it loathes reversing itself if it tightens too much. When the FOMC doesn't know how much to cut of a cat's tail, it cuts a little at a time.

Rudebusch finds that the probability of a tightening following a tightening is statistically equivalent to the probability of an easing following an easing and the predictability of a policy move depends on the period of time since the last move. However, Rudebusch looks only at the overnight fed funds rate using daily data. When we look at longer horizons, an asymmetry emerges. As shown below, the probability of a tightening in the current month followed by a tightening one month ahead is within two standard deviations of the probability of an ease in the current month followed by another ease one month later. But the probability of a tightening in the current month followed by a tightening four months later is not within two standard deviations of the probability of an ease in the current period followed by an ease four months ahead.

A. Probability of a policy stance followed by the same stance: 1 month ahead

	Jun 1973 - Sept 1979	Mar 1984 - Dec 1993
Probability of Tight	88 %	87 %
Probability of Ease	82 %	91 %
Standard Deviation	0.057	0.042

B. Probability of a policy stance followed by the same stance: 4 months ahead

	Jun 1973 - Sept 1979	Mar 1984 - Dec 1993
Probability of Tight	71 %	62 %
Probability of Ease	53 %	75 %
Standard Deviation	0.057	0.042

This asymmetry in the transition probabilities implies that market participants may behave differently when they anticipate a tightening than when they anticipate an easing; and this behavior may be used in observing the shape of the forward curve.

3.2 Predicting the monetary stance

We specify a probit model to produce the perceived probabilities of the future monetary stance. This model is

$$P(Tight_{t+n}) = f(\alpha_0 + \alpha_1\ TAU_t + \alpha_2\ RUD_{t-1}) \qquad \textbf{(9)}$$

where $Tight_{t+n}$ is a dummy variable that equals 1 if we are in a tightening period n months ahead and equals 0 otherwise as defined by Rudebusch's data, and TAU and RUD are the time since the last target change and the direction of the last target change, respectively.

In general, in addition to the Rudebusch variables a model predicting the stance of monetary policy should include such known variables as inflation rates and forward rates. Specifically, the probit model would be

$$\begin{aligned} P(Tight_{t+n}) = f(&\alpha_0 + \alpha_1\ TAU_t + \alpha_2\ RUD_{t-1} \\ &+ \alpha_3\ FORW_t + \alpha_4 \sum a_i\ INFL_{t-i}) \end{aligned} \qquad \textbf{(10)}$$

where the new variables FORW and INFL are the spread between the forward rate and the one month spot rate for n months ahead, and the core inflation rate lagged 1 to 4 months, respectively.

The results of the Rudebusch model (RUD), equation (9), and the alternative model (ALT), equation (10), are reported in Tables 2a and 2b for two periods: June 1973 through September 1979 and March 1984 through December 1993. Looking at the percent of correct cases the ALT model tends to perform better than the RUD model particularly looking more than 3 or 4 months ahead. This is expected given that Rudebusch has found that the informational content of past Fed behavior can be used to predict a monetary stance up to five weeks ahead. In the March 1984 through December 1993 period the FORW and INFL variables are significant at the long end. Finally, the goodness of fit measure, the log-likelihood index (LL), is higher for the

ALT model in every case for both sample periods except for n=3 in the March 1994 through December 1993 period where they are the same.

The performance of the ALT model relative to the RUD model makes sense given the market's knowledge of the Fed's concern about inflation. This result suggests that the market's success with predicting short rates in the near future may be owed partly to the market's ability to anticipate monetary stance. In the following section, we model interest rate behavior using the ALT model, using it to distinguish between periods of anticipated tightening and periods of anticipated easing.

4. An asymmetry in the forward curve's information

To be clear about what we mean by the forward curve's information, we start with a basic analytical framework. Suppose the change in the short rate between time t and time $t+n$ can be divided into two components

$$r = \eta + \epsilon \qquad \textbf{(11)}$$

where $r = r_{t+n} - r_t$, η is a time varying component observed by rational market participants but not directly by the researcher, and ϵ is white noise. Let η and ϵ have zero means and η have variance σ_η^2.

EXAMPLE: If the market's observations of η were based entirely on mean reversion, we would have $\eta = \alpha(\mu - r_t)$ where μ represents the long run mean and α the rate of reversion to the mean over n periods. Clearly the slower the reversion rate α, the less predictable changes in the short rate would be from its current value alone.

In general, rational market participants will ensure that the corresponding forward rate reflects η so that

$$f = \eta + \rho \tag{12}$$

where $f = f_t^n - r_t$ and ρ is a time varying term premium with variance σ_ρ^2. For convenience we assume that ρ, ϵ, and η are uncorrelated.

Regressing r on f gives us a sense of the information content of forward rates by giving us a sense of the importance of η. The regression equation has the form

$$r = a + bf + u \tag{13}$$

where u is an error term. The constant a will be an estimate of the average term premium. More important, the coefficient b gives us a measure of how much information the forward rate contains. Specifically, the coefficient measures the importance of movements in the expectations component relative to movements in the forward rate. More precisely,

$$plim\ b = \frac{\sigma_\eta^2}{\sigma_\eta^2 + \sigma_\rho^2} \tag{14}$$

Equation (13) is essentially the one estimated by Fama and Mishkin, and their estimates of b for their 1980s sample tend to be in the range of 0.5 to 0.6 for horizons as long as three months, which means that movements in market expectations tend to account for about half to three fifths of the movements in the forward rate. The R^2 statistics of the regressions measure the extent to which changes in expectations correspond to actual changes in the short rate. Mishkin's regressions yield R^2 statistics ranging from 0.26 for the one-month horizon to 0.17 for the three-month horizon.

Stambaugh (1988) and Backus and Zin (1994) conclude that you need at least two factors to explain the forward curve. We think a good second factor would be the anticipated stance of monetary policy. To account for this anticipation, we add more structure to the model by specifying two states so that

$$r = \begin{cases} \eta^1 + \epsilon^1 & \text{for } s = 1 \\ \eta^0 + \epsilon^0 & \text{for } s = 0 \end{cases} \tag{15}$$

where $s = 1$ signifies a state of tightening at $t + n$ and $s = 0$ a state of easing. We can then imagine a regression equation for each state:

$$r = \begin{cases} a^1 + b^1 f + u^1 & \text{for } s = 1 \\ a^0 + b^0 f + u^0 & \text{for } s = 0. \end{cases} \tag{16}$$

We gain from the added structure if in fact the coefficients were different between the two states, that is, if movements in expectations were relatively more important for one state than the other or if the average term premium were different. The slope coefficients in particular have the property

$$plim\ b^{i} = \frac{\sigma^2_{\eta^i}}{\sigma^2_{\eta^i} + \sigma^2_{\rho^i}} \tag{17}$$

where $i = 1, 0$.

Market participants will at time t not be certain about the state s for time $t + n$, so they will form the forward rate by assessing probabilities for the states, say p and $1 - p$ for $s = 1$ and $s = 0$ respectively. In general these probabilities will vary over time. If we had good estimates of p our regression equation would be

$$r = a + pb^1f + (1 - p)b^0f + u \tag{18}$$

where $a = pa^1 + (1 - p)a^0$ and $u = pu^1 + (1 - p)u^0$. We could also estimate a rearranged version

$$r = a^0 + (a^1 - a^0)p + b^0f + (b^1 - b^0)\,p\,f + u. \tag{19}$$

which would allow us to test more directly for a difference in the coefficients by including our probability estimate and the product of that probability and the forward rate spread as additional explanatory variables.

Tables 3a and 3b report our regression estimates. For the 1970s sample period, the regressions do not seem to perform very well, whether or not we take into account the anticipation of monetary stance. Fama and Mishkin themselves found that their regressions tended to provide significant estimates for sample periods in the 1980s rather than for the 1970s.

Our regressions for the 1980s sample period take advantage of somewhat more data than Fama or Mishkin had while still offering results consistent with theirs. Without taking account of the anticipation of monetary stance, the 1980s regressions suggest that expectations explain a significant part of the movements of forward rates, with slope coefficients ranging from 0.55 for the two-month horizon to 0.34 for the twelve-month horizon. The availability of more data seems to have allowed significant coefficients for longer horizons than before.

When we take account of the anticipation of monetary stance for the 1980s sample period, the results are striking. For the market's perceived probability of a tightening we use the predicted values from the probit model for different future horizons. The R^2 statistics improve significantly. At the four-month horizon, for example, R^2 rises to 0.26 from 0.17 once the anticipation of monetary stance is taken into account. More important, the slope coefficients attached to the forward rates suggest a significant difference between the two states at least for the two-month to four-month horizons. Within the four-month horizon, the slope coefficients associated with a tightening are significantly different from zero and in fact not significantly different from one. At the same time, the slope coefficients associated with the anticipation of easing are not significantly different from zero. This means that when the Fed is expected to tighten, expectations of rising rates drive much if not all the movements in forward rates. But when the Fed is expected to ease, the term premium drives movements in forward rates.

Beyond the four-month horizon the probability variable by itself begins to contribute significantly to predictive power, suggesting that the average term premium tends to become smaller when a tightening is anticipated relative to when an easing is anticipated. Moreover, the gap between term premia in the two states apparently widens with maturity as indicated by the larger and larger coefficients.

The apparent asymmetry in the information content of forward rates with respect to the anticipated monetary stance helps explain the steepness of the forward curve at the short end. When the Fed is expected to tighten, such as after the tightening in November 1994, expectations of higher rates cause the curve to steepen. But when the Fed is expected to ease, such as after the easing in July 1992, movements in expectations give way to movements in term premia and it is then ambiguous whether the forward curve will flatten as illustrated in Chart 4. On the average the forward curve will thus be steep at the short end.

5. Cat's tail convergence

Can the hypothesis of cat's tail convergence provide a better explanation of one-period movements in the short rate compared to the mean reversion hypothesis? Previous efforts to test for mean reversion relied on an equation like

$$r_{t+1} - r_t = (1 - \theta)(\mu - r_t) + u_{t+1} \qquad \textbf{(20)}$$

where μ is the long run mean and the results tended to indicate a rate of reversion that was too slow to correspond to the shape of the forward curve. Our analogous cat's tail convergence equation has the form

$$r_{t+1} - r_t = \phi[E_t(r^T_{t+k}) - r_t] + v_{t+1} \qquad \textbf{(21)}$$

where we replace the long run mean with an expected short rate consistent with an ultimate Fed target k months in the future and ϕ is the rate of convergence to the expected target.

We estimate **(21)** in two ways, one combining periods of both anticipated tightening and anticipated easing and one with just periods of anticipated tightening. To distinguish between the two types of periods, we set a threshold probability of 0.5 and use our probit estimates. For the expected target we use instrumental variables to predict the realized short rate in the future consistent with our forward rate regressions given by **(19)**. In this case, the instruments are the appropriate forward rate, the current short rate, and the probability of a tightening.

Table 4 reports our regression results. As before, the convergence equations perform better for the sample period in the 1980s. In this latter period, the estimated rates of convergence are generally significantly different from zero. For the sample combining periods of anticipated tightenings and easings, the estimated rates range from 0.72 for the two-month horizon to 0.36 for the three-month horizon. When we limit our sample to periods of anticipated tightening, the estimated convergence rates become larger but are significant only for horizons no longer than four months. An interpretation of these results is that convergence to a Fed target is more rapid during periods when a tightening is anticipated than during periods when an easing is anticipated. These results again would support our explanation of why the forward curve tends to be so steep at the short end.

6. Conclusion

Market participants can apparently anticipate monetary stance several months into the future. When they anticipate a tightening, expectations about rising rates drive movements in forward rates. When they anticipate an easing, however, movements in the term premia drive movements in forward rates.

This apparent asymmetry in the behavior of forward rates may explain the forward curve's typically humped shape. The hump seems to stem from the tendency of the curve to be relatively steep at the short end and relatively flat at the long end. Empirical estimates, however, suggest rates of mean reversion that are too slow to account for the curve's steepness. A rapid convergence to a Fed target when a tightening is anticipated but not when an easing is anticipated would be one way to generate an average forward curve that is steep at the short end.

This hypothesis of cat's tail convergence also suggests a simple measure of monetary stance. This measure would be the slope of the forward curve at the short end, a measure of how much the FOMC would tighten as perceived by the market. Estrella and Mishkin (1995) find that central banks can flatten the yield curve by raising the short rate. Our results suggest that the relevant short rate may not be just a single short rate but a target rate sometime in the near future to which the short rate is expected to converge

The asymmetry in forward rate movements may also help explain why De Long and Summers (1988) find that contractionary monetary policy has substantially more effect on real output than does expansionary monetary policy. When the Fed tightens by raising its target for the overnight fed funds rate, the market would anticipate further tightening leading to an ultimate fed funds target. These expectations would raise interest rates of maturities of as long as four months and thus significantly affect the real economy. When the Fed begins to ease, however, expectations about future rates do not seem to move as much so that the effect on the economy is more limited.

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Chart 1

One Month Interest Rates

June 1973-March 1995

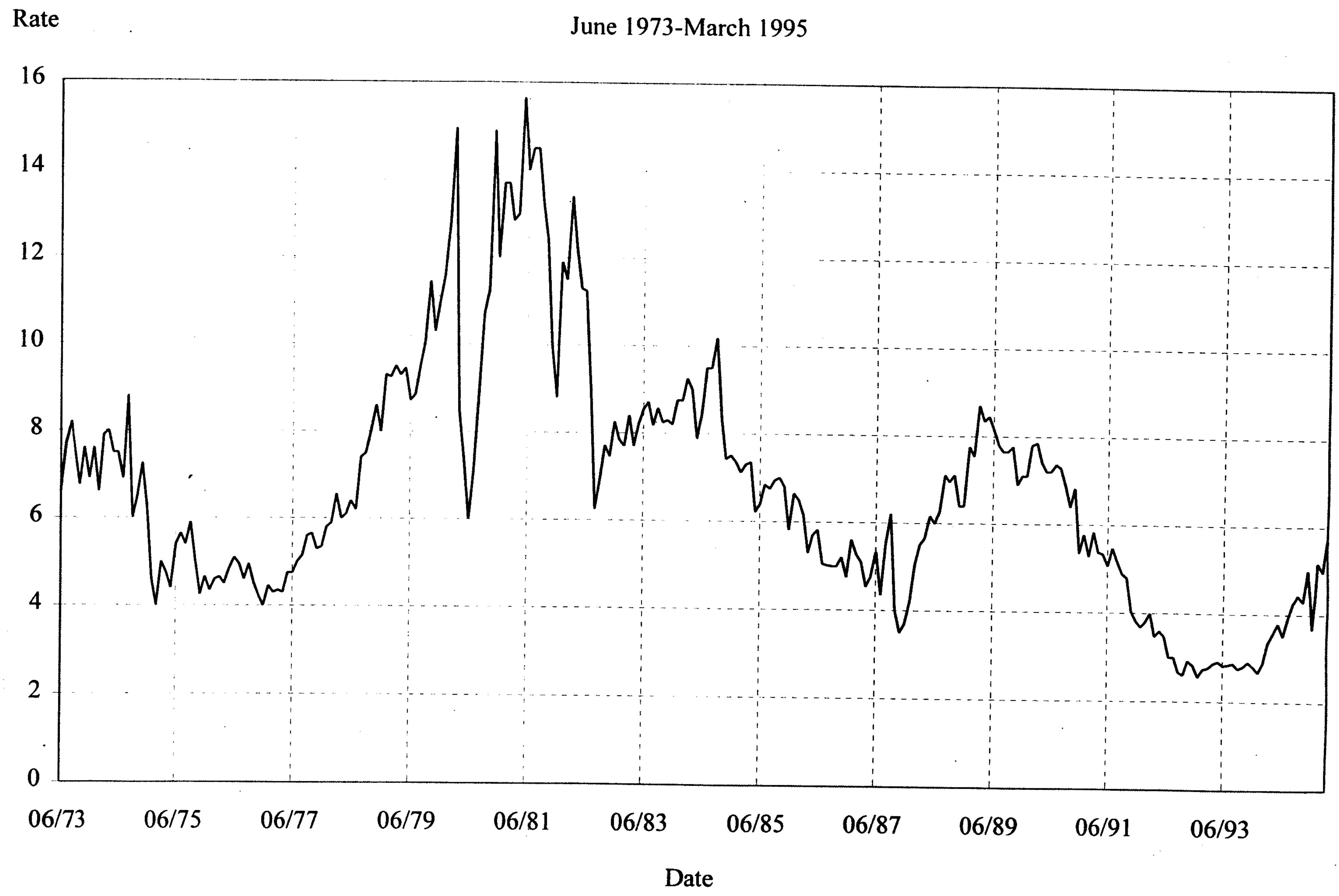

Table 1

Summary Statistics
Monthly Continuously Compounded Treasury Yields

Means, Standard Deviations, and Autocorrelations

Variable	Mean	Standard Deviation	Autocorrelations ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	ρ_9	ρ_{10}	ρ_{11}	ρ_{12}
June 1973 - December 1993														
r_t	6.74	2.71	.94	.90	.86	.82	.80	.78	.77	.76	.74	.71	.69	.65
$r_{t+1} - r_t$	0.00	0.92	-.15	.04	-.06	-.15	-.05	.00	-.12	.21	-.01	-.01	.07	.00
June 1973 - September 1979														
r_t	6.46	1.88	.89	.84	.76	.71	.65	.60	.58	.53	.47	.41	.36	.29
$r_{t+1} - r_t$	0.06	0.72	-.32	.00	.04	.07	.06	-.29	.22	.00	.05	-.10	.11	.08
March 1984 - December 1993														
r_t	5.60	1.89	.95	.91	.87	.84	.81	.78	.74	.69	.63	.59	.56	.52
$r_{t+1} - r_t$	-0.02	0.56	-.19	-.01	-.06	-.06	.05	.10	.09	.03	-.09	-.09	.09	.12

Note: r_t is the end-of-month continuously compounded Treasury bill rate.

Chart 2

Theoretical and Average Forward Curves

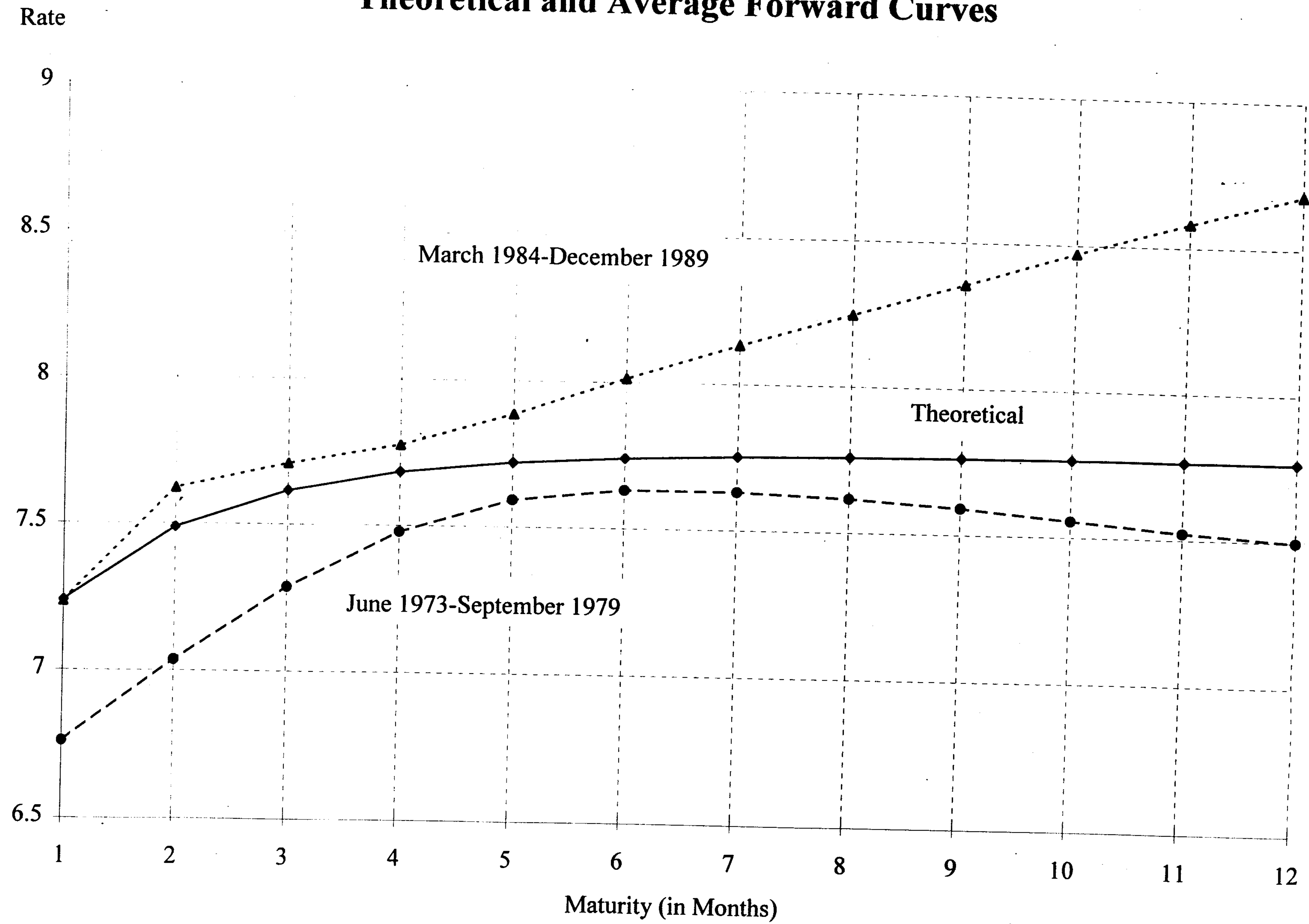

Chart 3a

Fed Funds Targets

March 1973-September 1979

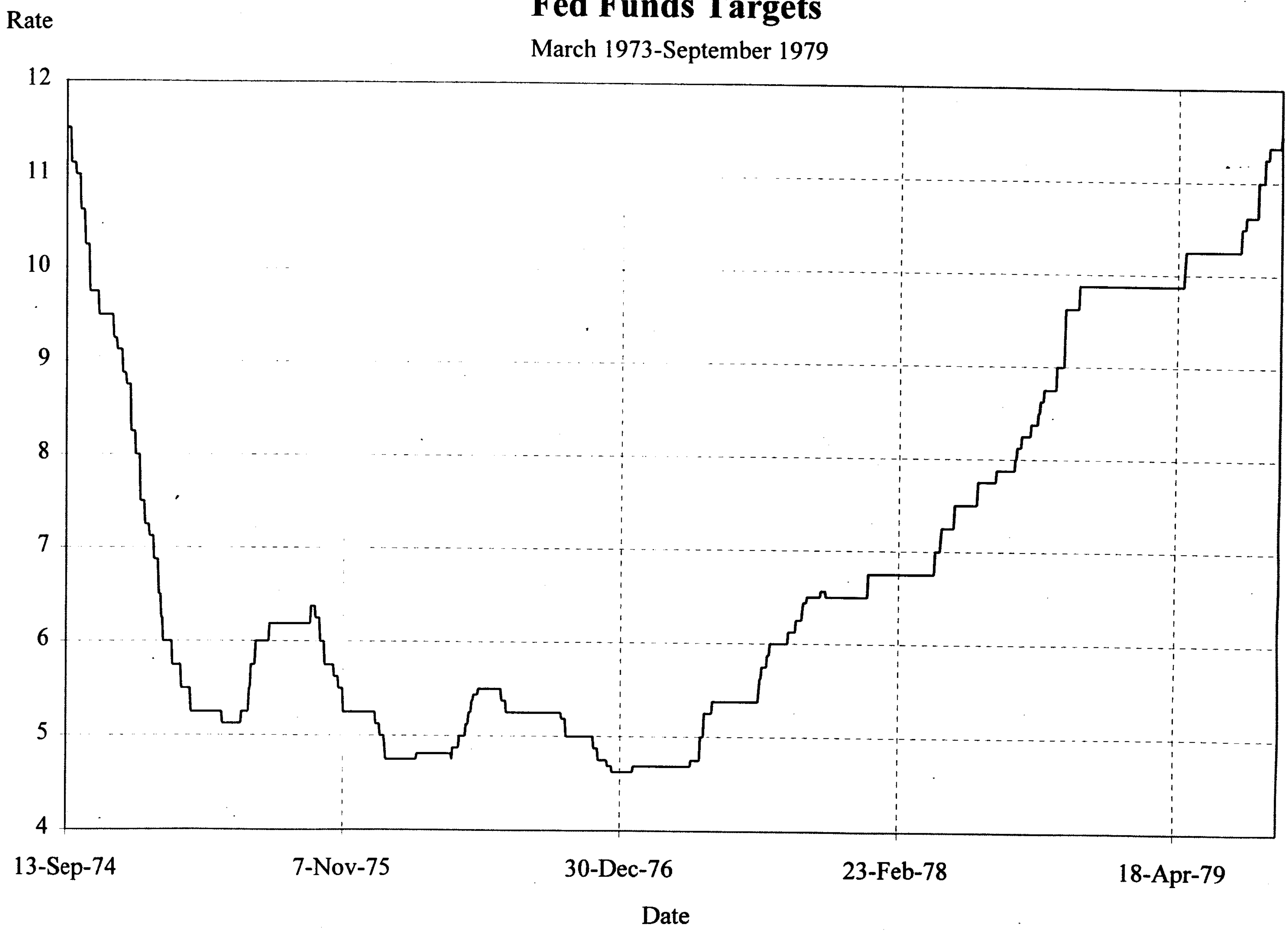

Chart 3b

Fed Funds Targets

March 1984-March1995

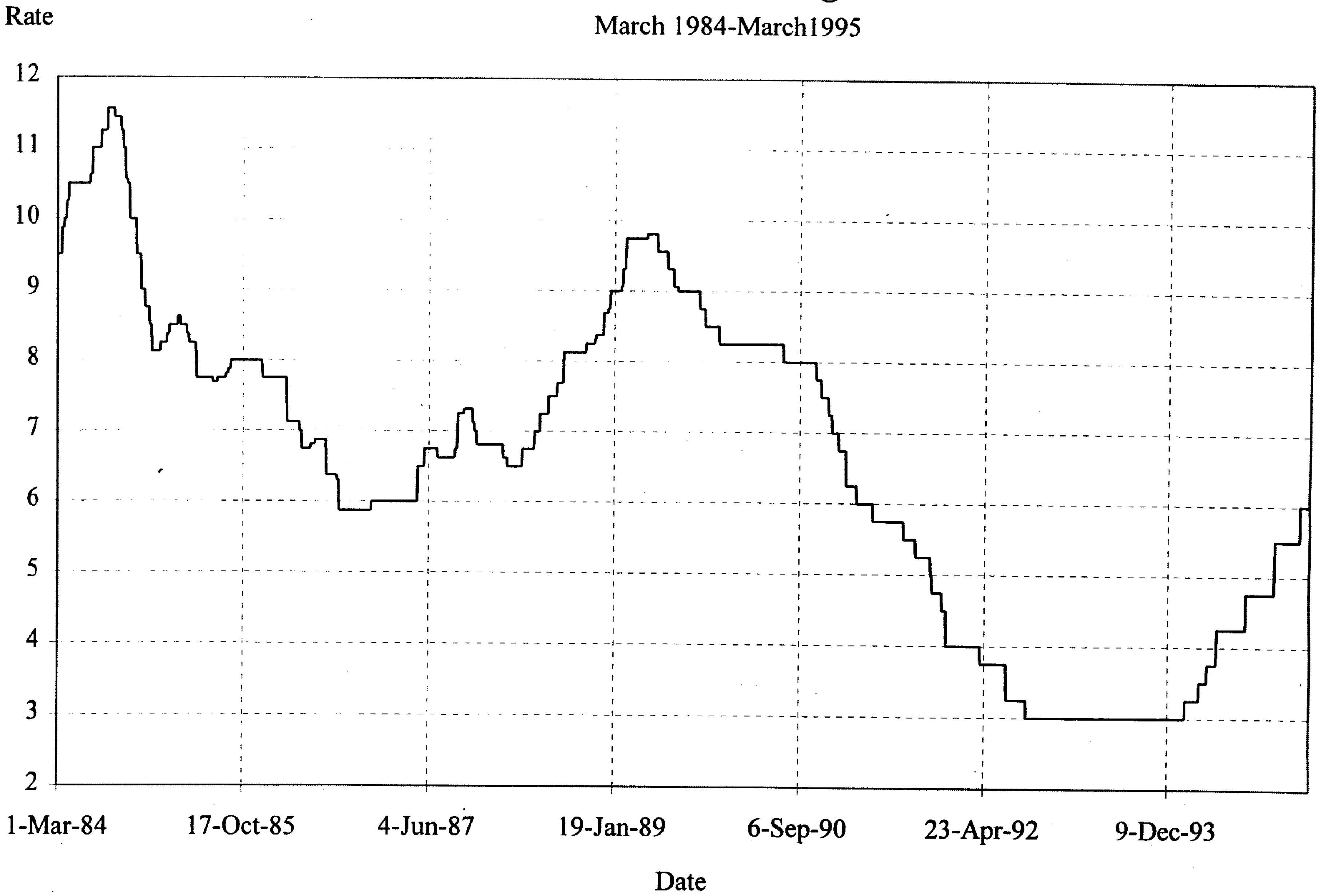

Table 2a

Probit Model Predicting Federal Reserve Behavior
June 1973 - September 1979

$$\text{RUD: } P(\text{Tight}_{t+n}) = f(\alpha_0 + \alpha_1 \text{TAU}_t + \alpha_2 \text{RUD}_{t-1})$$
$$\text{ALT: } P(\text{Tight}_{t+n}) = f(\alpha_0 + \alpha_1 \text{TAU}_t + \alpha_2 \text{RUD}_{t-1} + \alpha_3 \text{FORW}_t + \alpha_4 \textstyle\sum a_i \text{INFL}_{-i})$$

n (Months Ahead)	Model	α_0	α_1	α_2	α_3	α_4	Percent Correct	LL
2	RUD	.23 (.21)	.04 (.03)	.42 (.38)	--	--	67%	.53
	ALT	1.09 (.71)	.07 (.04)	.15 (.40)	.05 (.40)	-.17 (.09)	65	.55
3	RUD	-.08 (.22)	.03 (.03)	.22 (.37)	--	--	61	.51
	ALT	1.41 (.73)	.05 (.04)	-.01 (.40)	-.18 (.37)	-.16 (.09)	68	.53
4	RUD	.07 (.22)	.02 (.03)	-.02 (.37)	--	--	58	.51
	ALT	2.16* (.79)	.04 (.04)	-.23 (.42)	-.43 (.36)	-.19* (.09)	57	.54
5	RUD	.07 (.22)	.00 (.03)	.17 (.37)	--	--	58	.50
	ALT	2.01* (.75)	.04 (.04)	-.24 (.44)	-.01(.30)	-.24* (.09)	64	.54
6	RUD	.08 (.22)	-.02 (.03)	.30 (.37)	--	--	64	.51
	ALT	2.04* (.72)	.02 (.04)	-.08 (.45)	.04 (.27)	-.25* (.09)	75	.60
9	RUD	.02 (.22)	-.09* (.04)	.92* (.39)	--	--	68	.53
	ALT	.56 (.63)	-.05 (.04)	.72 (.46)	.37 (.20)	-.15 (.08)	71	.57
12	RUD	-.19 (.22)	-.15* (.04)	1.59* (.43)	--	--	71	.57
	ALT	-.65 (.86)	-.08 (.05)	1.19* (.48)	.64* (.22)	-.07 (.09)	81	.62

Notes: * Significant at the 5 percent level. Numbers in parentheses are standard errors. LL is the log likelihood index. TAU is the duration of Federal Reserve action. RUD is tightening or easing as defined by Rudebusch (1995). FORW is the spread between the forward rate and the spot rate for the appropriate n. INFl is inflation with 1 to 4 lags.

Table 2b

Probit Model Predicting Federal Reserve Behavior

March 1984 - December 1993

$$\text{RUD: } P(\text{Tight}_{t+n}) = f(\alpha_0 + \alpha_1 \text{TAU}_t + \alpha_2 \text{RUD}_{t-1})$$

$$\text{ALT: } P(\text{Tight}_{t+n}) = f(\alpha_0 + \alpha_1 \text{TAU}_t + \alpha_2 \text{RUD}_{t-1} + \alpha_3 \text{FORW}_t + \alpha_4 \textstyle\sum a_i \text{INFL}_{-i})$$

n (Months Ahead)	Model	α_0	α_1	α_2	α_3	α_4	Percent Correct	LL
2	RUD	-.90* (.16)	.08 (.05)	.73* (.35)	--	--	77%	.59
	ALT	-1.28 (.78)	.07 (.05)	.95* (.39)	.17 (.22)	.03 (.19)	77	.61
3	RUD	-.72* (.15)	.08 (.05)	.28 (.35)	--	--	74	.56
	ALT	-1.22 (.71)	.08 (.05)	.20 (.38)	.24 (.19)	.07 (.17)	69	.56
4	RUD	-.60* (.15)	.05 (.05)	.10 (.35)	--	--	66	.54
	ALT	-.60 (.69)	.07 (.05)	-.26 (.40)	-.40* (.18)	-.07 (.17)	69	.56
5	RUD	-.71* (.15)	-.08 (.05)	.99* (.35)	--	--	69	.56
	ALT	.42 (.73)	-.04 (.06)	.60 (.39)	.51* (.18)	-.40* (.19)	75	.59
6	RUD	-.74* (.16)	-.11* (.06)	1.30* (.36)	--	--	73	.57
	ALT	1.37 (.79)	-.08 (.06)	1.09* (.41)	.49* (.18)	-.67* (.21)	75	.61
9	RUD	-.47* (.15)	-.15* (.07)	.91* (.36)	--	--	69	.54
	ALT	1.45 (.79)	-.13 (.08)	.84 (.44)	.66* (.18)	-.74* (.21)	76	.61
12	RUD	-.34*(.14)	-.14* (.07)	.50 (.36)	--	--	65	.53
	ALT	.83 (.70)	-.11 (.08)	.15 (.41)	.43* (.14)	-.47* (.18)	64	.57

Notes: * Significant at the 5 percent level. Numbers in parentheses are standard errors. LL is the log likelihood index. TAU is the duration of Federal Reserve action. RUD is tightening or easing as defined by Rudebusch (1995). FORW is the spread between the forward rate and the spot rate for the appropriate n. INFl is inflation with 1 to 4 lags.

Table 3a

Information in Forward Curve Regressions
June 1973 - September 1979

$$FM: r_{t+n} - r_t = \beta_0 + \beta_2(f_t^n - r_t) + \epsilon_{t+n}$$
$$ALT: r_{t+n} - r_t = \beta_0 + \beta_1 \rho_t^n + \beta_2(f_t^n - r_t) + \beta_3 \rho_t^n (f_t^n - r_t) + \epsilon_{t+n}$$

n(Months Ahead)	Model	β_0		β_1		β_2		β_3		$\bar{R}^2$	F
2	FM	-0.05	(0.17)	-	-	0.20	(0.19)	-	-	0.00	7.12*
	ALT	-0.41	(0.96)	0.44	(1.45)	-0.38	(0.71)	1.23	(1.08)	0.09	
3	FM	-0.11	(0.28)	-	-	0.24	(0.28)	-	-	0.00	12.71*
	ALT	-1.82	(1.50)	2.17	(2.25)	0.40	(1.05)	0.46	(1.69)	0.15	
4	FM	0.11	(0.31)	-	-	0.07	(0.26)	-	-	0.01	2.25*
	ALT	-1.22	(1.28)	1.39	(1.72)	0.26	(0.65)	0.40	(0.93)	0.04	
5	FM	0.40	(0.35)	-	-	-0.10	(0.26)	-	-	0.01	0.73
	ALT	-0.21	(1.12)	0.71	(1.70)	-0.25	(0.50)	0.50	(0.82)	0.02	
6	FM	0.54	(0.39)	-	-	-0.13	(0.26)	-	-	0.01	-0.72
	ALT	0.44	(1.40)	-0.01	(2.11)	-0.46	(0.59)	0.70	(0.96)	0.00	
9	FM	0.24	(0.38)	-	-	0.11	(0.22)	-	-	0.00	0.00
	ALT	0.14	(0.88)	0.28	(1.90)	-0.44	(0.41)	0.78	(0.91)	0.00	
12	FM	-0.30	(0.35)	-	-	0.59*	(0.19)	-	-	0.10	
	ALT	-0.95	(0.51)	3.93	(2.29)	0.69	(0.36)	-1.59	(0.84)	0.14	3.35*

Notes: * Significant at the 5 percent level. Newey-West corrected standard errors in parentheses. r is the one month rate at time t and f is the forward rate at time t, n months ahead.

Table 3b

Information in Forward Curve Regressions

June 1984 - March 1995

$$\text{F-M: } r_{t+n} - r_t = \beta_0 + \beta_2(f_t^n - r_t) + \epsilon_{t+n}$$
$$\text{ALT: } r_{t+n} - r_t = \beta_0 + \beta_1 \rho_t^n + \beta_2(f_t^n - r_t) + \beta_3 \rho_t^n (f_t^n - r_t) + \epsilon_{t+n}$$

n(Months Ahead)	Model	β_0	β_1	β_2	β_3	$\bar{R}^2$	F
2	FM	-0.59* (0.09)	- -	0.55* (0.08)	- -	0.23	
	ALT	-0.29* (0.11)	-0.54 (0.31)	0.12 (0.13)	0.87* (0.25)	0.27	6.96*
3	FM	-0.64* (0.10)	- -	0.53* (0.10)	- -	0.19	
	ALT	-0.16 (0.16)	-0.88 (0.47)	-0.22 (0.21)	1.51* (0.36)	0.27	13.81*
4	FM	-0.70* (0.10)	- -	0.52* (0.16)	- -	0.17	
	ALT	-0.70* (0.20)	1.64 (0.93)	-0.38 (0.29)	1.06* (0.43)	0.26	15.20*
5	FM	-0.74* (0.13)	- -	0.46* (0.13)	- -	0.14	
	ALT	-1.02* (0.21)	1.85* (0.65)	0.37 (0.27)	-0.32 (0.46)	0.19	7.65*
6	FM	-0.82* (0.16)	- -	0.44* (0.15)	- -	0.12	
	ALT	-1.34* (0.22)	2.19* (0.62)	0.71* (0.26)	-0.88 (0.44)	0.19	10.63*
9	FM	-1.14* (0.25)	- -	0.49* (0.18)	- -	0.11	
	ALT	-1.49* (0.30)	2.27* (0.79)	-0.37 (0.46)	0.40 (0.29)	0.18	10.24*
12	FM	-1.09* (0.29)	- -	0.34* (0.17)	- -	0.04	
	ALT	-2.21* (0.42)	4.96* (1.22)	0.40 (0.34)	-0.91 (0.64)	0.15	15.14*

Notes: * Significant at the 5 percent level. Newey-West corrected standard errors in parentheses. r is the one month rate at time t and f is the forward rate at time t, n months ahead.

Chart 4

Forward Curves Shortly Following Fed Action

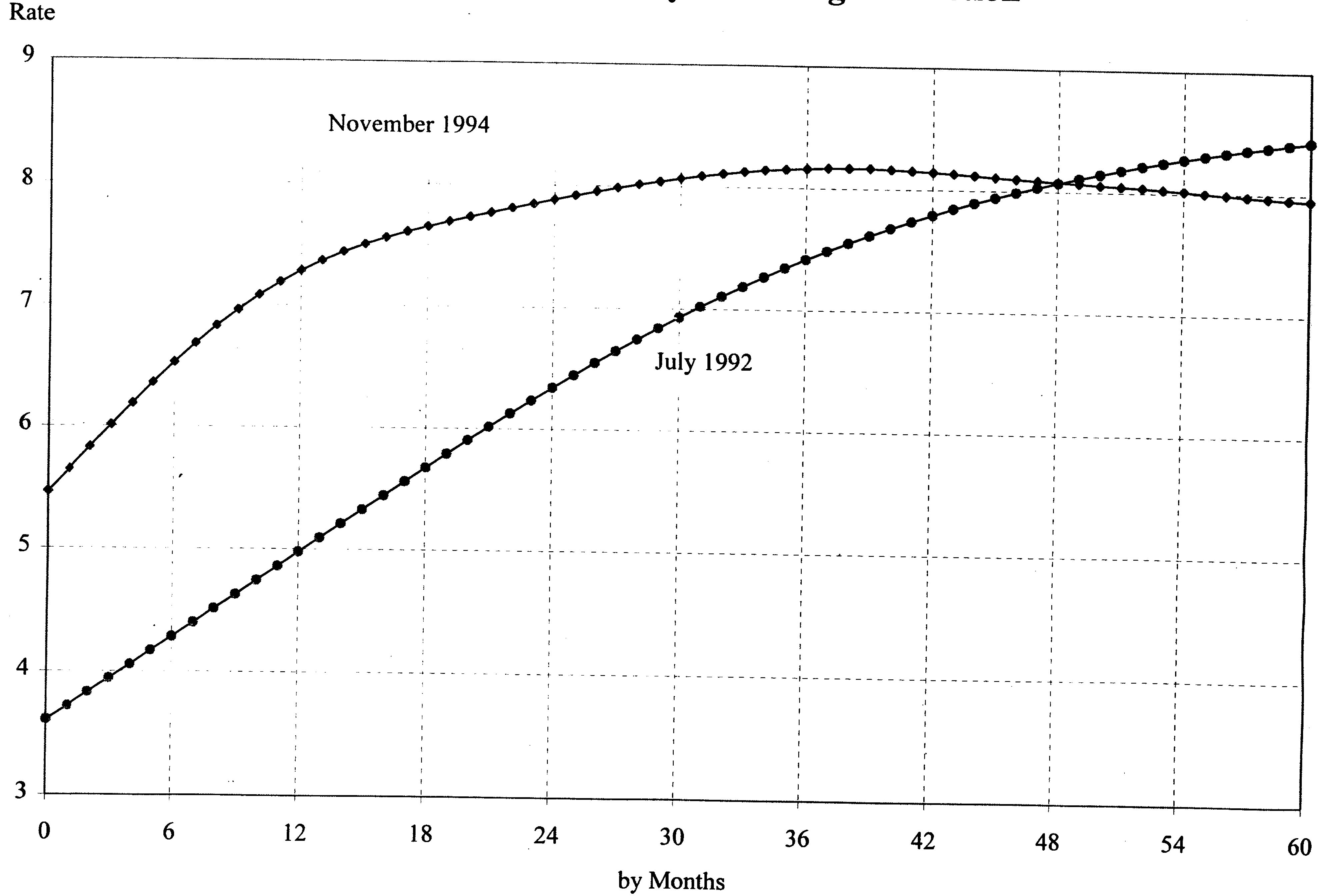

Table 4

Rates of Convergence to Expected Fed Target

$$r_{t+1} - r_t = \beta_0 + \beta_1(r_{t+k} - r_t) + \epsilon_{t+1}$$

Instruments: ρ_t^k, $(f_t^k - r_t)$, $\rho_t^k(f_t^k - r_t)$

Time Period	Maturity k	Tightenings and Easings β_1	Tightenings Only β_1
June 1973-September 1979	2	1.02* (0.38)	1.06* (0.39)
	3	0.63* (0.25)	0.99 (0.60)
	4	0.73* (0.28)	0.26 (0.41)
	5	0.30 (0.21)	-0.60 (0.75)
	6	0.16 (0.23)	0.59 (0.40)
March 1984-March 1995	2	0.72* (0.11)	0.71* (0.18)
	3	0.53* (0.10)	0.70* (0.20)
	4	0.37* (0.10)	0.48* (0.18)
	5	0.39* (0.11)	0.70 (0.52)
	6	0.36* (0.10)	1.06 (1.06)

Notes: * Significant at the 5 percent level. Standard errors in parentheses. r is the one month rate at time t and f is the forward rate at time t, k months ahead.