Announcements and the effectiveness of policy: A view from the U.S. prime rate

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Abstract

Until 1994, the U.S. prime rate was said to be sticky because of its irresponsiveness to short-term interest rates. After the Fed started the practice of announcing its intended funds rate in 1994, however, the prime rate has come to react immediately to shifts in the target rate. This paper attempts to explain how the Fed's policy announcements changed the behavior of the prime rate by using a simple menu cost model. It is shown that an increase in the expected duration of funds rate targets was essential to the improvement in the target rate pass-through.

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1 Introduction

In the 80's and the early 90's, a lot of attention was paid to the prime rate stickiness in the U.S. At that time, the U.S. prime rate was considered to be determined based upon various market interest rates such as the Federal funds rate, CD rates, T-bill rates, etc. Many empirical studies were conducted in an attempt to explain the source of sluggishness in the response of the prime rate to those market interest rates (e.g., Goldberg, 1982, Forbes and Mayne, 1989, Mester and Saunders, 1995).

Since 1994, however, adjustments of the prime rate have been synchronizing with shifts in the Federal funds target.[1] In response to a shift in the target rate, the prime is moved in the same amount within a few days of the corresponding FOMC. This implies that policy effectiveness has greatly improved since 1994 because the prime rate is used as a base rate in many of the loan contracts. The empirical models of the sticky prime rate proposed by the early studies cannot account for such one-to-one correspondence between the prime rate and the target rate. Nevertheless, to the best of my knowledge, almost no formal explanation was given for this phenomenon.[2]

This paper attempts to explain the reason why the prime rate has become "flexible". To this end, we must remember some noticeable changes in the Fed's practice made around 1994. The most obvious institutional change was the start of policy announcements, which was first made at the February 1994 meeting. Prior to that meeting, the FOMC had never disclosed to the public whether the intended federal funds rate was changed or not, and because of this secrecy, the FOMC's intention had sometimes been misperceived by market participants. In any case, the FOMC started announcing changes in the intended funds rate and its rationale after the meeting at which policy actions were implemented. Recently, many studies have investigated the influences of such an institutional change by closely looking at the behavior of market interest rates, such as the T-bill rates and futures rates. For instance, Lange et al. (2003), Poole and Rasche (2003) and Swanson (2006) argue that the predictability of future policy shifts that can be computed from the Federal funds futures or the euro dollar options has been significantly improved since February 1994. Demiralp and Jordà (2004) also provide statistical evidence that there was a structural break in February 1994 in the response of T-bill rates to the Federal funds target. Given the results of these studies, it is natural to infer that the structural change in the behavior of the prime rate that occurred in 1994 bears some relation to the

[1] Throughout the paper, by the "prime rate" we mean the prime rate reported by the Federal Reserve Statistical Release: H.15 Selected Interest Rates. This is the rate posted by a majority of the top 25 (by assets in domestic offices) insured U.S.-chartered commercial banks.

[2] Sellon (2002) argued that the improvement in the response of the prime rate was due to the increased competition for business loans among financial institutions or to the greater transparency of monetary policy. However, his argument is not based on a formal analysis.

start of the Fed's practice of announcing its target.

However, there are several other aspects that should be taken into account aside from the beginning of the policy announcements. The first is that most of the policy shifts before 1994 were decided outside the regularly scheduled FOMC meetings.[3] In fact, prior to 1994, only about 30% of all the policy shifts were made within 7 days of the last scheduled meeting. According to Thornton (2004b), only 27 out of 94 policy changes were made at the regularly scheduled FOMC meetings in the pre-94 period. Second, the average duration of a newly changed target has been considerably increased since 1994. The average number of weeks between policy shifts was 5.8 in the pre-94 period and 13.3 in the post-94 period, as of March 2007. Third, the volatility of the spread between the effective funds rate and the target rate has been significantly reduced since 1994. Although there is some debate as to whether this phenomenon is due to an advancement in the Fed's controllability ("open market operation") or to an "announcement effect" ("open mouth operation"), we should take into account the fact that the volatility of the spread has been largely reduced.[4]

The main findings are as follows. First, the response of the prime rate to the funds rate over the entire sample period can be well captured by a simple menu cost model once the abovementioned differences in the Fed's practice are taken into account. Second, according to stochastic simulations, neither secrecy in the numerical funds rate target nor uncertainty in the timing of policy shifts was a major cause of the prime-rate stickiness before 1994. Third, an increase in the average duration of targets seemed to have the largest influence on the improvement in the response of the prime rate. The simulation shows that if the target rate after the current policy shift is expected to be kept unchanged for a sufficiently long time, then the prime rate will immediately follow the current policy shift. Conversely, if the next policy shift is expected to be carried out in the immediate future, then commercial banks will tend to hold back from reacting to the current policy shift and wait for the next policy shift. Finally, it is shown that the volatility of the effective funds rate had a non-negligible effect on the response of the prime rate. That is, the greater the volatility of the effective rate, the less frequently commercial banks would react to shifts in the target rate.

The rest of the paper is organized as follows. Section 2 briefly reviews the relationship

[3]Throughout the paper, the "pre-1994" period refers to the period from September 27, 1982 to January 31, 1994, and the " post-1994" period is from February 7, 1994 to February 28, 2007. February 7, 1994 is the first Monday since the February 4 meeting. The choice of the starting date of the pre-1994 period follows from Thornton (2005), who argued that the Fed has been virtually targeting the funds rate since September, 1982. In fact, the FF target data before February 1994, which originated with Thornton's (2005) work, is now available from the FRB St. Louis FRED data base.

[4]See, for example, Guthrie and Wright (2000), Demiralp and Jordà (2002), Taylor (2001) and Thornton (2004a).

between the Federal funds rate and the prime rate over the past few decades. The baseline models, called the pre-94 model and the post-94 model, are presented in section 3. Section 4 conducts stochastic simulations, and section 5 attempts to explain the source of the structural change in 1994. Section 6 concludes the paper.

2 The relationship between the prime rate and the Federal funds rate: Comparing the pre- and post 1994 periods

This section summarizes several features of the relationship between the Federal funds rate and the U.S. prime rate in the pre- and post- 1994 periods, respectively. We are focusing on the date February 1994, because many previous studies indicated that it was the special date for the Fed's policymaking. Differences in the Fed's policy practices between the pre and post-1994 periods are also noted.

2.1 The degree of pass-through

Figure 1 shows the paths of the Federal funds rates and the prime rate. The spread between the prime rate and the FF target is also illustrated. It appears that the difference between the prime rate and the FF target had been biased downward until 1994. After 1994, the premium of the prime rate over the FF target has been kept constant at 3%. Figure 2 illustrates daily changes in the FF target and the prime rate, and Figure 3 shows differences in weekly changes between the prime rate and the FF rates. As is clear from these figures, the prime rate has been immediately and almost completely adjusted to shifts in the target rate since February 1994.[5] In other words, the pass-through from the target rate to the prime rate has been almost complete since February 1994. Although small deviations can still be observed even after 1994 in Figure 3, these are merely reflecting short time lags (at most 2 days) between a policy shift and the succeeding prime rate adjustment. This fact can be summarized as follows:

Fact 1 *Shifts in the FF target rate have been almost completely passed through to the prime rate since February 1994.*

Not only has the response of the prime rate to the target rate improved, but the relationship between the effective rate and the prime rate has been more closely correlated since 1994 than before. In fact, the F-test rejects the null hypothesis that the variances of weekly differences between changes in the effective rate and the prime rate are the same between the two periods. The F-value is 7.46 ($p = .000$). The null hypothesis is

[5] The only exception was April 1994, when a .25% increase in the FF target was followed by a .5% increase in the prime rate.

still rejected even if we exclude large fluctuations for which daily deviation of the effective rate from the target is greater than 1%. These simple tests support the view that the relationship between the effective FF rate and the prime rate has become more stable since 1994 compared to the pre-94 period. This implies that the prime rate has been more responsive to the effective rate in the post-94 period than in the pre-94 period.

Fact 2 *The relationship between the effective FF rate and the prime rate after February 1994 is closer than before.*

Next, let us look at the size of the prime rate changes. As can be seen from Figure 2, .5% changes (in absolute value) were more frequently observed than .25% changes in the pre-94 period. Specifically, the ratio of the number of .25% prime rate changes to the total number of changes is only .213, while the ratio of the number of target changes that are less than or equal to .375% to the total number of target changes is .756. This implies that .5% prime shifts were chosen "too often". This phenomenon is quite consistent with what the standard menu cost model suggests.

Fact 3 *During the pre-94 period, the average size of absolute changes in the prime rate was much larger than that of the funds rate target.*

In order to quantify the difference in the response of the prime rate to the Federal funds rate, several statistics are reported in Table 1. All the statistics are calculated from weekly data, where the "week" begins on a Monday and ends on a Friday. $R^T(t)$, $R^F(t)$ and $L(t)$ denote the target FF rate, the effective FF rate and the prime rate, respectively. $\Delta X(t) \equiv X(t) - X(t-1)$ for an arbitrary variable X represents the weekly change in X. Since there are some cases where policy changes were made twice a week, our FF target data is based on the end-of-week data. This implies that two within-week policy changes are treated as a single large change.[6] On the other hand, the weekly effective rate is defined as the average of the five daily effective rates.

The first row of the data shows the probability of perfect pass-through, which is defined as $\text{Prob}(\Delta R^T(t) = \Delta L(t) \mid \Delta R^T(t) \neq 0)$. To be precise, $\Delta R^T(t) = \Delta L(t)$ means that the prime rate is adjusted to a shift in the target rate in the same amount within 7 days of the target change. The second row is the probability that the prime rate responds to a shift in the target rate in the same direction, but not necessarily in the same amount, within 7 days of the corresponding policy shift. This is expressed as $\text{Prob}(\Delta R^T(t)\Delta L(t) > 0 | \Delta R^T(t) \neq 0)$. The third row is the probability that the prime rate is changed at the date when more than 7 days have passed since the last policy change. This can be expressed as $\text{Prob}(\Delta L(t) \neq 0 \mid \Delta R^T(t) = 0)$. The fourth row is the ratio of the total number of prime

[6]Such a treatment is also employed by Hamilton and Jordà (2002), although they defined a week as beginning on a Thursday and ending on a Wednesday.

rate adjustments to the total number of target shifts. In the following, we call this simply the prime-policy ratio. Finally, the last four rows of the table show the mean absolute deviations and the standard deviations of the difference between changes in the FF target and the prime.

2.2 The Fed's policymaking

Now let us turn to the Fed's policymaking. First, let us look at the timing of policy shifts. Figure 4 illustrates the number of policy changes made within 7 days of the last regular FOMC meetings as well as the total number of policy shifts. While the total number of policy shifts before February 1994 was 94 times, only 34 of them were decided within 7 days of the last regular FOMC meeting. Thornton (2004b) also indicated that in the pre-94 period, only 27 out of 94 policy changes were made at the regular FOMC meetings. The rest were made during the 'inter-meeting" periods without notice. Thus, it can be said that the timing of policy shifts was quite irregular before 1994. In contrast, although there are some exceptions, most of the policy shifts after 1994 were made at the regular FOMC meetings. As of March 2007, 45 out of 49 FF target shifts were decided at the scheduled FOMC meetings.[7]

Figure 5 illustrates the hazard rate for policy change, which is defined as follows:

$$\text{hazard rate(x)} \\ = \frac{\text{number of times the target rate had been kept unchanged for x weeks}}{\text{number of times the target rate had been kept unchanged for x weeks or longer}}.$$

Before 1994, the hazard rate takes a value ranging from .1 to .3 in the region where the unchanged periods are less than 9 weeks. Although the hazard rate becomes more volatile as the length of unchanged periods exceeds 9 weeks, this is, at least partially, because the number of samples in such a long-interval area is very small. In fact, as is shown in Figure 5 (c), more than 80% of policy changes were made within 8 weeks of the last policy shift.[8] In the post-1994 period, on the other hand, the hazard rate takes a multimodal form (Figure 5 (b)). This reflects the fact that most of the shifts in the FF target were determined at the scheduled FOMC meetings.

Fact 4 *Timing of policy shifts was much more irregular in the pre-1994 period than in the post-1994 period.*

We should look at another feature from Figure 4. Not only was the timing of the policy shifts staggered, but also the number of policy shifts per annum was much larger

[7]The exceptions are: October 15, 1998 (-.25%), January 3, 2001 (-.5%), April 18, 2001 (-.5%), and September 17, 2001 (-.5%).

[8]The maximum value of the horizontal axis of the figure is determined such that 90% of the total policy changes are illustrated.

in the pre-94 period than in the post-94 period. In fact, the average duration of targets is about 5.8 weeks in the pre-94 period, whereas it is about 13.3 weeks in the post-94 period. Thus, the average duration of targets in the post-94 period is more than twice of that in the pre-94 period.

Fact 5 *The average duration of target rates is 5.8 weeks in the pre-94 period and 13.3 weeks in the post-94 period.*

Before August 1989, the Fed used to choose the size of target-rate increments from a variety of candidates. The size of policy increments in that period varied from .0625% to 1.125%. Since August 1989, however, changes in the FF target have been limited to multiples of .25%. Table 2 summarizes the frequency of each increment size. It is evident from the table that the fraction of .25% and .5% shifts was relatively small in the pre-94 period. Actually, only 55% (52/94) of total policy changes were multiples of .25%. Although this procedural change was made well before 1994, we cannot ignore this feature in considering the determination of the prime rate in the pre-94 period.

Fact 6 *In the pre-94 period, only 55% of total policy changes were multiples of .25%.*

Finally, let us look at the spread between the effective rate and the target. Henceforth, we call this simply the *error*. As is well known, the average size of the error is much smaller in the post-94 period than in the pre-94 period. Figure 6 illustrates the weekly errors, defined as the weekly average of the effective rate minus the weekly average of the target. Not surprisingly, the F-test strongly rejects the null hypothesis that the variances of the weekly errors are identical between the two periods. The F-value is 9.30 (p=.000). This result does not change even if we exclude extremely large size errors that are greater than 1%, which were occasionally observed prior to 1994.

Fact 7 *The effective FF rate is more closely correlated to the FF target in the post-94 period than in the pre-94 period.*

3 Baseline Models

The aim of this section is to construct two kinds of baseline models: the post-94 model and the pre-94 model. In these models, we consider a situation in which a representative commercial bank determines the prime rate in accordance with the effective funds rate since the effective rate is the cost of funds. It is assumed that the commercial bank regards the FF target as a stochastic variable. Thus, there is no strategic interaction between the central bank and the commercial bank.

3.1 The post-94 model

3.1.1 Objective function

It is assumed that a representative commercial bank tries to minimize the deviation of the prime rate from the desired level, which is equal to the effective FF rate plus the risk premium. The one-period objective function, which is common to both models, is given by

$$f(R^F(t), L(t), \xi(t)) = -\lambda |(R^F(t) + \varrho)^\gamma - L(t)^\gamma|^\theta - \xi(t)C, \quad \lambda, \theta, \gamma, C > 0, \ \varrho \geq 0$$

In this model, interests are expressed in the gross annual rate. γ denotes an appropriate discounting parameter that converts an annual rate into a weekly rate. C is the fixed adjustment cost and $\xi(t)$ is a dummy variable that takes one if the commercial bank adjusts the prime and zero otherwise. In practice, changing the prime rate entails some pecuniary costs for managerial procedures and notification. In this model, however, the value of C does not necessarily represent pecuniary costs alone, but it also includes non-pecuniary costs such as the customer's objections to a change in the prime.[9] This simple objective function could be justified by the high correlation between the FF rates and the prime rate that has been observed since February 1994. Notice that the objective function involves a deviation of the prime from the *effective* rate, not from the *target* rate. Although the actual prime rate is virtually adjusted in response to the target rate, there is no *a priori* reason that the prime rate automatically reacts to the FF target which is a mere objective of the Fed. It is the effective FF rate that becomes a cost of funds for commercial banks. The observed quick response of the prime rate to the target should be regarded as an outcome of the optimizing behavior of commercial banks rather than as evidence of an exogenous objective that avoids the deviation of the prime from the Fed's target.

In the model, the effective FF rate is defined as the sum of the FF target and the error component:

$$R^F(t) \equiv R^T(t) + e(t),$$

where $e(t)$ is the error at time t. It should be pointed out that, in the presence of fixed costs, the FF target will become a chief determinant of the prime rate since it acts as the core process of the effective rate. For example, suppose that the effective rate deviated from the target to some extent. The commercial bank would not necessarily adjust the prime in response to the effective rate, since it is quite likely that the effective rate in the next period will get closer to the current target rate. If the difference between the effective rate and the prime rate is not so large, it would be optimal for the commercial bank to keep the prime unchanged until the next period. The point is that there is a

[9] Mester and Saunders (1995) provided various reasons for the existence of adjustment costs.

significant difference in the frequency of changes between the effective rate and the target rate.

In this analysis, we treat the risk premium ϱ as a constant. This assumption is fairly reasonable in the post-94 period, but seems questionable in the pre-94 period, because the difference between the prime rate and the target was highly biased. The downward bias illustrated in Figure 1 cannot necessarily be replicated by this model, given our symmetric objective function. Nonetheless, we keep this assumption throughout the analysis because our main interest is not to replicate the *level* of the prime rate, but to replicate the *response* of the prime to a shift in the funds rate. As will be shown, the prime rate responses to the funds rates generated by stochastic simulations fit the data quite well.

3.1.2 Transition of the FF target

It is often said that a key feature of recent monetary policy is that there are few reversals in the direction of policy shifts. To see this, the maximum likelihood (ML) estimate of the meeting-based Markov transition matrix of policy increments is shown in Table 3. As can be seen, the upper-right and lower-left elements of the matrix are all zero. This implies that there has been no case in which consecutive policy meetings made opposite policy shifts. Moreover, it is also evident that the current policy shift has a high positive correlation with the next policy shift.

In this model, the size of the current target increment is treated as a state variable of the bank's optimization problem, for it has useful information on the future course of the target rate and the effective rate. However, if the behavior of the FF target is described by a Markov transition matrix composed only of increments, as in Table 3, then the level of the funds rate will be unbounded and the optimization problem cannot be well specified. To overcome this problem, we employ the pair $(R^T(t), \bar{\Delta}R^T(t))$ as a state, where $\bar{\Delta}R^T(t)$ denotes the change in the target determined at the last policy meeting. That is, the Markov chain used here describes the transition of the pair $(R^T(t), \bar{\Delta}R^T(t)) \equiv \boldsymbol{X}(t)$, not the transition of $\bar{\Delta}R^T(t)$ alone. The size of the next policy shift depends not only on the policy increment determined at the last policy meeting, but also on the current level of the target, in which case the bank's problem can be well defined once we set an upper and a lower bound for R^T.

3.1.3 Model frequency and the timing of policy meetings

Let us turn to the frequency of the model. In practice, there is no doubt that the effective rate moves much more frequently than the target rate. The effective FF rate moves every day while the FF target is changed every 93 days on average. In order to take into account such a non-negligible difference in frequency, we consider a situation where policy meetings are held periodically. In the following we employ weekly frequency, and the interval between policy meetings is set at 6 periods since the regular FOMC meetings are scheduled to be held 8 times per annum.

The reason for the use of weekly frequency is as follows. First, the prime rate has not changed twice a week since September 1982. Second, although a daily frequency model might be worth considering, it will be practically infeasible due to the "curse of dimensionality". In the case of daily frequency, the periodicity of policy meetings necessarily increases from 6 to 42. As a consequence, the number of states to be treated in the discrete-state dynamic programming increases by 7 times. Third, in the case of daily frequency, the error term has a significant serial correlation. This would greatly complicate the analysis, not only because we have to introduce additional state variables, but also because the filtering problem described below becomes a nonstandard one.

Notice that this periodic policy meeting regime does not mean that *changes* in the FF target are periodic, but a *chance* of policy change comes periodically. While the target rate is not allowed to move during inter-meeting periods, the effective rate and the prime rate are allowed to move every period, independently of whether a policy meeting is currently held or not.

3.1.4 Optimization problem

The value function for the bank's optimization problem is given by[10]

$$V(\boldsymbol{X}(t), R^F(t), L(t-1), \tau) = \max\{\, V^c(\boldsymbol{X}(t), R^F(t), \tau),\; V^k(\boldsymbol{X}(t), R^F(t), L(t-1), \tau)\,\},$$

where

$$\begin{aligned}
& V^c(\boldsymbol{X}(t), R^F(t), \tau) \\
= \;& \max_{\hat{L}}\{\, f(R^F(t), \hat{L}, 1) + \delta E_t V(\boldsymbol{X}(t), R^F(t+1), \hat{L}, \tau+1)\,\} \quad \text{if } \tau \in [1, \bar{\tau}-1], \\
= \;& \max_{\hat{L}}\{\, f(R^F(t), \hat{L}, 1) + \delta E_t V(\boldsymbol{X}(t+1), R^F(t+1), \hat{L}, 1)\,\} \quad \text{if } \tau = \bar{\tau},
\end{aligned}$$

and

$$\begin{aligned}
& V^k(\boldsymbol{X}(t), R^F(t), L(t-1), \tau) \\
= \;& f(R^F(t), L(t-1), 0) + \delta E_t V(\boldsymbol{X}(t), R^F(t+1), L(t-1), \tau+1) \quad \text{if } \tau \in [1, \bar{\tau}-1], \\
= \;& f(R^F(t), L(t-1), 0) + \delta E_t V(\boldsymbol{X}(t+1), R^F(t+1), L(t-1), 1) \quad \text{if } \tau = \bar{\tau}.
\end{aligned}$$

$V^c(\cdot)$ and $V^k(\cdot)$ represent the value function when the prime rate is adjusted and kept unchanged, respectively. $\delta \in (0,1)$ is the discount factor and E_t denotes the expectations operator conditional on information available in period t. τ represents the number of weeks

[10] See Bertsekas (2007) for a treatment of a value function that involves periodic states.

that have passed since the last policy meeting, and $\bar{\tau}$ denotes the length of periodicity. This implies that a chance of policy shifts comes every $\bar{\tau}$ weeks. If $t = n\bar{\tau},\ n = 1, 2, \ldots$, then a policy meeting is held at the beginning of period $t+1$. If $t \notin n\bar{\tau},\ n = 1, 2, \ldots$, on the other hand, a policy meeting will never be held at $t+1$, and thereby $\boldsymbol{X}(t+1) = \boldsymbol{X}(t)$.

In order to rewrite the above value function more explicitly by using the transition matrix, let us define some notations here. Let $\Omega^T = \{R^T_1, \ldots, R^T_{n_T}\}$, $D = \{d_1, \ldots, d_{n_d}\}$ and $E = \{e_1, \ldots, e_{n_e}\}$ be the sets of possible values for the FF target, increments of the FF target, and the errors, respectively. Then, $\Omega^F = \{R^T + e | R^T \in \Omega^T, e \in E\} = \{R^F_1, \ldots R^F_{n_f}\}$ turns out to be the set of the effective funds rate, and $\Omega^X = \{(R^T, d) | R^T \in \Omega^T, d \in D, R^T - d \in \Omega^T\} = \{\boldsymbol{X}_1, \ldots, \boldsymbol{X}_{n_x}\}$ denotes the feasible set of the pair $(R^T(t), \bar{\Delta}R^T(t))$ $= \boldsymbol{X}(t)$. The condition $R^T - d \in \Omega^T$ is imposed so as to exclude impossible combinations of $(R^T, \bar{\Delta}R^T)$, such as $(R^T_{min}, .0025)$ or $(R^T_{max}, -.0025)$, where R^T_{min} and R^T_{max} are the lower and upper bounds of the FF target, respectively. $\Omega^L = \{L_1, \ldots, L_{n_L}\}$ denotes the set of possible states for the prime rate.

Let $\boldsymbol{P}(t)$ denote the transition probability matrix of the pair $(R^T(t), \bar{\Delta}R^T(t))$. The (i, j) element of $\boldsymbol{P}(t)$, denoted as $p_{i,j}(t)$, is expressed as

$$\begin{aligned} p_{ij}(t) &= \mathrm{Prob}(\boldsymbol{X}(t+1) = \boldsymbol{X}_j | \boldsymbol{X}(t) = \boldsymbol{X}_i), \quad \text{if } t \in n\bar{\tau}, n = 1, 2, \ldots \\ &= 0 \quad \text{if } i \neq j \text{ and } t \notin n\bar{\tau}, n = 1, 2, \ldots, \\ &= 1 \quad \text{if } i = j \text{ and } t \notin n\bar{\tau}, n = 1, 2, \ldots \end{aligned}$$

This states that if a policy meeting is not going to be held at the beginning of period $t+1$, then the matrix $\boldsymbol{P}(t)$ becomes an identity matrix since the FF target will never be changed.

Let us denote the (j, k) element of the matrix $\boldsymbol{Q}(t)$ as $q_{jk}(t)$, where

$$q_{jk}(t) = \mathrm{Prob}(R^F(t) = R^F_k | \boldsymbol{X}(t) = \boldsymbol{X}_j).$$

This is the conditional probability of the current effective rate given the pair $(R^T(t), \bar{\Delta}R^T(t))$ $= \boldsymbol{X}_j$.[11] Under the assumption that $e(t)$ is i.i.d., each row of $\boldsymbol{Q}(t)$ is fully determined by the probability distribution of $e_i, i = 1, \ldots n_e$, as will be explained below.

With the stationarity conditions $\boldsymbol{P}(t) = \boldsymbol{P}$ and $\boldsymbol{Q}(t) = \boldsymbol{Q}$ for all $t \in n\bar{\tau},\ n = 1, 2, \ldots$, the value function can be rewritten as

$$V(\boldsymbol{X}_i, R^F_u, L_s, \tau) = \max\{\ V^c(\boldsymbol{X}_i, R^F_u, \tau),\ V^k(\boldsymbol{X}_i, R^F_u, L_s, \tau)\ \}, \tag{1}$$

where

$$V^c(\boldsymbol{X}_i, R^F_u, \tau)$$

[11] Although $R^F(t)$ is independent of $\bar{\Delta}R^T(t)$, this expression is used for convenience.

$$= \max_{\hat{L}\in\Omega^L} \{ f(R_u^F, \hat{L}, 1) + \delta \sum_k q_{ik} V(\boldsymbol{X}_i, R_k^F, \hat{L}, \tau+1) \} \quad \text{if } \tau \in [1, \bar{\tau}-1], \quad (2)$$

$$= \max_{\hat{L}\in\Omega^L} \{ f(R_u^F, \hat{L}, 1) + \delta \sum_k \sum_j p_{ij} q_{jk} V(\boldsymbol{X}_j, R_k^F, \hat{L}, 1) \} \quad \text{if } \tau = \bar{\tau}, \quad (3)$$

and

$$V^k(\boldsymbol{X}_i, R_u^F, L_s, \tau)$$
$$= f(R_u^F, L_s, 0) + \delta \sum_k q_{ik} V(\boldsymbol{X}_i, R_k^F, L_s, \tau+1) \quad \text{if } \tau \in [1, \bar{\tau}-1], \quad (4)$$
$$= f(R_u^F, L_s, 0) + \delta \sum_k \sum_j p_{ij} q_{jk} V(\boldsymbol{X}_j, R_k^F, L_s, 1) \quad \text{if } \tau = \bar{\tau}. \quad (5)$$

3.2 The pre-94 model

Let us turn to the model of the pre-94 period. Since we have already explained the basic framework, this section describes how to treat the period-specific features that should be taken into account at this stage. The first feature is the uncertainty in the timing of policy shifts. As is shown in Figure 4, changes in the FF target decided outside the regular FOMC meetings account for more than 60% of total policy shifts carried out during this period. The official schedule of the FOMC meeting makes little sense in this respect, and the periodic-meeting model presented in the previous section will no longer be appropriate. In this section, we instead consider a situation in which the timing of policy shifts is stochastic. Specifically, we treat the FF target as a semi-Markov process, where the interval of time between policy changes has a geometric distribution.

The second feature is that the FF target was never announced immediately after each FOMC meeting. Before February 1994, it was necessary for market participants to infer the target rate. It is probable that such convention had a serious influence on the determination of the prime rate. In the following, we take into account this possibility by expressing the FF target as a hidden (semi-)Markov process. In this environment, the commercial bank attempts to estimate the FF target from both the current effective rate and the past target rate.

3.2.1 Transition matrix and the timing of policy shifts

In the pre-94 model, it is assumed that the target FF rate is changed with probability α at the beginning of each period. For simplicity, we assume that the probability of a target shift is constant and independent of the time that has passed since the last policy change. The actual distribution of policy-shift intervals is shown in Figure 5 (c). The figure also illustrates the geometric distribution with parameter $\alpha = 1/5.81$, the reciprocal of the average number of weeks between two consecutive FF target changes during the pre-94 period. Notice that the assumption of constant policy-shift probability requires both (i) the distribution of policy intervals to be approximated as a geometric distribution and (ii) the hazard rates to be constant. As was previously discussed, the actual hazard rate appears to be volatile in the long-interval area. However, it would be fair to say that the number of samples used, especially in the long-interval area, is too small to form a definitive judgment about the constancy of the probability.

Although a meeting-based transition matrix is used in the post-94 model, such specification cannot be applied here. We instead employ a policy-shift-based transition matrix. Here, the (i, j) element of $\tilde{\boldsymbol{P}}$, $\tilde{p}_{ij}$, denotes the conditional probability of state transition from $\tilde{\boldsymbol{X}}(t) = \boldsymbol{X}_i$ to $\tilde{\boldsymbol{X}}(t+1) = \boldsymbol{X}_j$ *given that* a policy change occurred at the beginning of period $t+1$, where $\tilde{\boldsymbol{X}}(t) \equiv (R^T(t), \tilde{\Delta} R^T(t))$. $\tilde{\Delta} R^T(t)$ denotes the last policy increment.[12] Note that the diagonal elements of $\tilde{\boldsymbol{P}}$ are all zero by definition.

However, the choice of increment state is a little more complicated than in the case of the post-94 model, because the frequencies of some of the increment sizes are too low. If all the increment sizes were used as states, the accuracy of the transition matrix would be questionable. To overcome this low-frequency problem, we take the following strategies: first, increments of very low frequency are incorporated into the nearest state that is a member of $\tilde{d} = \{-.005, -.0025, -.00125, \ -.000625, .000625, \ .00125, .001875, .0025, .005\}$. Second, in addition to the 1982-1994 data, the data for 1974-1979 are also included in constructing the transition matrix. It should be pointed out that the behavior of the FF target during the 1974-1979 period has general similarities with that of the 1982-1994 period: policy changes were not limited to multiples of .25%, policy shifts were carried out in inter-meeting periods without notice, and market participants often misunderstood the true target rate.[13] One major difference is, on the other hand, that the spread between the effective rate and the target rate was significantly smaller in the 1974-1979 period than in the 1982-1994 period. However, since we use only the target rate data here, such a difference does not matter. The obtained shift-based transition matrix is shown in Table 4. The FF target data from September 1974 to August 1979 follow from Rudebusch (1995).

3.2.2 Partial observability of the FF target and the optimization problem

In investigating the pre-94 period, it is natural to consider a situation where the commercial bank needs to estimate the FF target using observable variables. Here, it is assumed that the FF target is revealed at the end of each period, and thus the bank sets the prime by reference to the current effective FF rate and the past FF target.[14] Specifically, the

[12] A notation with tilde in the pre-94 model corresponds to the notation without tilde in the post-94 model.

[13] See Rudebusch (1995).

[14] In practice, inter-meeting policy changes were recorded in the minutes of the next scheduled meeting, which would be made public a few days after the succeeding meeting. See Bomfim and Reinhart (2000)

current state is now given by the combination $(\tilde{\boldsymbol{X}}(t-1), R^F(t), L(t-1))$. The sequence of events is summarized as follows: at the beginning of period t, $R^T(t)$ and $R^F(t)$ are determined, and the commercial bank adjusts the prime or decides to keep it unchanged after observing $R^F(t)$. $R^T(t)$ is observed at the end of period t.[15]

The value function is given as

$$\tilde{V}(\tilde{\boldsymbol{X}}(t-1), R^F(t), L(t-1)) = \max\{\,\tilde{V}^c(\tilde{\boldsymbol{X}}(t-1), R^F(t)),\ \tilde{V}^k(\tilde{\boldsymbol{X}}(t-1), R^F(t), L(t-1))\,\},$$

where

$$\begin{aligned}
&\tilde{V}^c(\tilde{\boldsymbol{X}}(t-1), R^F(t)) \\
&= \max_{\tilde{L}\in\Omega^L}\{\, f(R^F(t), \tilde{L}, 1) + \delta E_t \tilde{V}(\tilde{\boldsymbol{X}}(t), R^F(t+1), \tilde{L})\,\}, \qquad (6)\\
&\tilde{V}^k(\tilde{\boldsymbol{X}}(t-1), R^F(t), L(t-1)) \\
&= f(R^F(t), L(t-1), 0) + \delta E_t \tilde{V}(\tilde{\boldsymbol{X}}(t), R^F(t+1), L(t-1)). \qquad (7)
\end{aligned}$$

To solve the problem numerically, we need to have a conditional probability distribution of $(\tilde{\boldsymbol{X}}(t), R^F(t+1))$.

As a first step of optimization, the commercial bank must estimate the current FF target using the observation $(\tilde{\boldsymbol{X}}(t-1), R^F(t))$. The probability distribution of $\tilde{\boldsymbol{X}}(t)$ conditional on $(\tilde{\boldsymbol{X}}(t-1), R^F(t)) = (\tilde{\boldsymbol{X}}_h, R^F_j)$ is expressed by the vector $\boldsymbol{\rho}_{h,j}$, where the i-th element of $\boldsymbol{\rho}_{h,j}$ is given by $\mathrm{Prob}(\tilde{\boldsymbol{X}}(t) = \tilde{\boldsymbol{X}}_i \,|\, \tilde{\boldsymbol{X}}(t-1) = \tilde{\boldsymbol{X}}_h, R^F(t) = R^F_j)$. It follows from Bayes' law that

$$\boldsymbol{\rho}_{h,j} = \frac{\boldsymbol{\varphi}_{h,j}}{\alpha\sum_{s=1}^{\tilde{n}_x}\tilde{p}_{hs}\tilde{q}_{sj} + (1-\alpha)\tilde{q}_{hj}}, \quad \text{where} \quad \boldsymbol{\varphi}_{h,j} = \begin{pmatrix} \alpha\tilde{p}_{h1}\tilde{q}_{1j} \\ \vdots \\ \alpha\tilde{p}_{h(h-1)}\tilde{q}_{(h-1)j} \\ (1-\alpha)\tilde{q}_{hj} \\ \alpha\tilde{p}_{h(h+1)}\tilde{q}_{(h+1)j} \\ \vdots \\ \alpha\tilde{p}_{h\tilde{n}_x}\tilde{q}_{\tilde{n}_x j} \end{pmatrix}. \qquad (8)$$

The denominator of (8) is equal to $\mathrm{Prob}(\tilde{\boldsymbol{X}}(t-1) = \tilde{\boldsymbol{X}}_h, R^F(t) = R^F_j)$. The first and second terms correspond to the case where the FF target is changed and kept unchanged, respectively.

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for details.

[15] It is theoretically possible to consider a situation where the FF target is never revealed, in which case the model is generically called the partially observable Markov decision process (POMDP). However, in such a case, too many states would arise to solve the optimization problem numerically. In the case of POMDP, the prior distribution of $\tilde{\boldsymbol{X}}$ has to be included as additional states, which would immediately give rise to the problem of the "curse of dimensionality". This is, to the best of my knowledge, the main reason why POMDP has rarely been used in economics. See Monahan (1982) for a survey of POMDP.

We can now express the distribution of $(\tilde{\boldsymbol{X}}(t), R^F(t+1))$ by using $\boldsymbol{\rho}_{h,j}$. Let $\rho_{h,j}(i)$ denote the i-th element of the vector $\boldsymbol{\rho}_{h,j}$. It follows from (8) that

$$\begin{aligned} &\text{Prob}(\tilde{\boldsymbol{X}}(t) = \tilde{\boldsymbol{X}}_i,\ R^F(t+1) = R^F_k \mid \tilde{\boldsymbol{X}}(t-1) = \tilde{\boldsymbol{X}}_h,\ R^F(t) = R^F_j) \\ &= \alpha\rho_{h,j}(i)(\ \tilde{p}_{i1}\tilde{q}_{1k} + \tilde{p}_{i2}\tilde{q}_{2k} + \ldots + \tilde{p}_{i\tilde{n}_x}\tilde{q}_{\tilde{n}_x k}\ ) + (1-\alpha)\rho_{h,j}(i)\tilde{q}_{ik}. \end{aligned} \tag{9}$$

The first term corresponds to the case where the target is changed at the beginning of period $t+1$, while the second represents the case of no policy shift. At this stage, it is useful to define the matrix $\boldsymbol{\mathcal{P}}_{h,j}$ as follows:

$$\boldsymbol{\mathcal{P}}_{h,j} \equiv \alpha(\boldsymbol{\rho}_{h,j}\mathbf{1}')\Box\tilde{\boldsymbol{P}}\tilde{\boldsymbol{Q}} + (1-\alpha)(\boldsymbol{\rho}_{h,j}\mathbf{1}')\Box\tilde{\boldsymbol{Q}}, \tag{10}$$

where $\mathbf{1}$ is the $\tilde{n}_x$ by 1 vector of ones, and $\Box$ denotes congruent (element-by-element) multiplication. It can be easily shown that the (i,k) element of $\boldsymbol{\mathcal{P}}_{h,j}$, denoted by $\boldsymbol{\mathcal{P}}_{h,j}(i,k)$, is identical to (9).

Consequently, the optimization problem can be rewritten as

$$\tilde{V}(\tilde{\boldsymbol{X}}_h, R^F_j, L_s) = \max\{\ \tilde{V}^c(\tilde{\boldsymbol{X}}_h, R^F_j),\ \tilde{V}^k(\tilde{\boldsymbol{X}}_h, R^F_j, L_s)\ \}, \tag{11}$$

where

$$\tilde{V}^c(\tilde{\boldsymbol{X}}_h, R^F_j) = \max_{\tilde{L}\in\Omega^L}\{\ f(R^F_j, \tilde{L}, 1) + \delta\sum_k\sum_i \boldsymbol{\mathcal{P}}_{h,j}(i,k)\tilde{V}(\tilde{\boldsymbol{X}}_i, R^F_k, \tilde{L})\ \}, \tag{12}$$

$$\tilde{V}^k(\tilde{\boldsymbol{X}}_h, R^F_j, L_s) = f(R^F_j, L_s, 0) + \delta\sum_k\sum_i \boldsymbol{\mathcal{P}}_{h,j}(i,k)\tilde{V}(\tilde{\boldsymbol{X}}_i, R^F_k, L_s). \tag{13}$$

4 Stochastic simulation

This section conducts stochastic simulations and evaluates the goodness of fit of the model. Before proceeding, baseline parameters and the methodology for the specification of adjustment costs, transition matrices and the distribution of errors are explained in turn.

4.1 Baseline parameters and methodology

4.1.1 Grids

All the variables of this model are treated as discrete-state variables. The possible states of the FF target are: $\{R^T \,|\, 1.01 \le R^T \le 1.08,\ R^T = 1.01 + .0025n,\ n \in \boldsymbol{N}\}$ for the post-94 model and $\{R^T \,|\, 1.01 \le R^T \le 1.08,\ R^T = 1.01 + .000625n,\ n \in \boldsymbol{N}\}$ for the pre-94 model.[16] As for errors: $\{e \mid -.005 \le e \le .005,\ e = -.005 + .000625n,\ n \in \boldsymbol{N}\}$. Accordingly, the states of the effective rate are: $\{R^F \mid 1.005 \le R^F \le 1.085,\ R^F = 1.005 + .000625n,$

[16] $\boldsymbol{N}$ denotes the set of natural numbers that includes 0.

$n \in \boldsymbol{N}\}$. As for the prime rate: $\{L \mid 1+\varrho \leq L \leq 1.09+\varrho,\, L = 1+\varrho+.0025n,\, n \in \boldsymbol{N}\}$. The premium ϱ is set at .03. Finally, the grids of target-rate increments and periodicity are: $d = \{-.005, -.0025, 0, .0025, .005\}$ and $\tau = \{1, 2, \ldots, 6\}$ for the post-94 period and $\tilde{d}$ $= \{-.005, -.0025, -.00125, -.000625, .000625, .00125, .001875, .0025, .005\}$ for the pre-94 period. It follows that the numbers of possible states of $\boldsymbol{X}(t)$ and $\tilde{\boldsymbol{X}}(t)$ are 139 and 984, respectively. Actually, the total number of state combinations we have to calculate amounts to 493728 for the post-94 model and 982424 for the pre-94 model.

4.1.2 Adjustment costs: C and λ

One of the complex issues in conducting simulation is the determination of the size of adjustment cost C. In this model, C represents not only pecuniary costs, but also non-pecuniary costs such as the customer's objections to changes in the prime. Thus, the value of C is unobservable by nature. However, even if the value of C were obtained from the data, λ would still have to be determined. What we really need is the value of C/λ. In order to determine C/λ, we take the following steps:

1. Provide the parameter values except for C.
2. Choose the value of C.
3. Solve the post-94 model by value iteration.
4. By conducting stochastic simulations, calculate the standard deviation of $\Delta R^T(t) - \Delta L(t)$.
5. Iterate steps 2 - 4 until C attains the minimum standard deviation.

The use of the standard deviation of $\Delta R^T(t) - \Delta L(t)$ as the criterion would be justified by the fact that a shift in the target rate has been passed through to the prime rate almost completely since February 1994. Since the actual value of $std(\Delta R^T(t) - \Delta L(t))$ is very close to zero (in fact, 0.01) in the post-94 period, choosing the adjustment cost that attains the lowest standard deviation is reasonable.[17] At this point, it should be emphasized that a smaller (larger) adjustment cost does not necessarily lead to a higher (lower) degree of FF target pass-through. This is because the objective function is defined by the spread between the prime rate and the *effective* rate. It is possible that the target rate tends to exhibit a lower (higher) correlation with the prime rate as the adjustment cost becomes smaller (larger). For example, in the extreme case of $C = 0$, the correlation between the effective rate and the prime becomes almost complete, and thereby the FF target plays no role. If C is extremely large, on the other hand, the degree of FF target

[17] The golden search algorithm is used to obtain C. The golden search is a derivative-free algorithm that gives a local maximum. See Miranda and Fackler (2002) for details.

pass-through would also be quite low since the adjustment cost would turn out to be too large for the bank to frequently adjust the prime. Intuitively, the adjustment cost that attains the maximum degree of FF target pass-through will lie between these two extremes. In the case of moderate adjustment costs, the prime rate tends to follow the FF target most often since the target rate plays a role as the core process of the effective rate. Unless practical pricing technology was dramatically improved in February 1994, which seems improbable, it is reasonable to use the obtained value of C in the pre-94 model as well. This enables us to focus only on changes that do not stem from the difference in adjustment costs.

4.1.3 Transition matrices: $\boldsymbol{P}$ and $\tilde{\boldsymbol{P}}$

Next, let us turn to the construction of $\boldsymbol{P}$ and $\tilde{\boldsymbol{P}}$. As shown in Tables 3 and 4, the ML estimates of the transition matrix of policy increments can be easily obtained. However, when it comes to the transition of the pair $(R^T(t), \bar{\Delta}R^T(t))$ or $(R^T(t), \tilde{\Delta}R^T(t))$, the ML method cannot be applied since the sample is too small. Therefore, we assume that the transition of the target rate follows the increment-based transition matrix if $R^T(t) \in \Omega^T_{int}$, where $\Omega^T_{int} \equiv [R^T_{min} - d_{min}, R^T_{max} - d_{max}]$. If $R^T(t) \in \Omega^T_{int}$, neither the upper nor the lower bound is currently binding. If $R^T(t) \notin \Omega^T_{int}$, on the other hand, there arises a possibility that either the upper or the lower bound for the target rate will be violated in the next period. In the latter case, zero probabilities are assigned to such impossible state transitions, and then the removed probabilities are allocated to the nearest state. In other words, as long as $R^T(t) \in \Omega^T_{int}$, transition of the target rate is independent of its level, and thereby the transitions of $\boldsymbol{X}(t)$ are fully described by the simple increment-based transition matrix. If $R^T(t) \notin \Omega^T_{int}$, then the transition probabilities depend on the level of $R^T(t)$.

4.1.4 The effective FF rate and the distribution of errors: $\boldsymbol{Q}$ and $\tilde{\boldsymbol{Q}}$

The FF error is assumed to be i.i.d. in both models. Let $F(\cdot)$ denote the probability function (p.f.) of errors, and let $\{\hat{e}_1, \ldots, \hat{e}_{n_{es}}\}$ be the sample of weekly errors, where n_{es} denotes the sample size. The p.f. $F(\cdot)$ is computed as follows:

$$
\begin{aligned}
F(e_m) &= \frac{\#\text{ elements in } \Xi_m}{n_{es}}, \\
\text{where} \quad \Xi_m &= \left\{\hat{e} \mid \hat{e} \in \left[-.01, \frac{e_1 + e_2}{2}\right)\right\} \quad \text{if } m = 1 \\
&= \left\{\hat{e} \mid \hat{e} \in \left[\frac{e_{m-1} + e_m}{2}, \frac{e_m + e_{m+1}}{2}\right)\right\} \quad \text{if } m = [2, (n_e + 1)/2) \\
&= \left\{\hat{e} \mid \hat{e} \in \left[\frac{e_{\frac{n_e-1}{2}} + e_{\frac{n_e+1}{2}}}{2}, \frac{e_{\frac{n_e+1}{2}} + e_{\frac{n_e+3}{2}}}{2}\right]\right\} \quad \text{if } m = \frac{n_e + 1}{2}
\end{aligned}
$$

$$= \left\{ \hat{e} \mid \hat{e} \in \left(\frac{e_{m-1}+e_m}{2}, \frac{e_m+e_{m+1}}{2} \right] \right\} \quad \text{if } m = [(n_e+3)/2, n_e-1]$$

$$= \left\{ \hat{e} \mid \hat{e} \in \left(\frac{e_{n_e-1}+e_{n_e}}{2}, .01 \right] \right\} \quad \text{if } m = n_e.$$

In order to eliminate exceptionally large fluctuations, daily errors larger than 1% are precluded. The obtained p.f. is depicted in Figure 7.

Let $\boldsymbol{X}_j^1$ denote the level of the FF target corresponding to $\boldsymbol{X}_j$, and define $e_{j,k} \equiv R_k^F - \boldsymbol{X}_j^1$. It follows that

$$\begin{aligned} q_{jk} &= \text{Prob}(R^F(t) = R_k^F \mid \boldsymbol{X}(t) = \boldsymbol{X}_j) \\ &= \text{Prob}(R^F(t) = \boldsymbol{X}_j^1 + e_{j,k} \mid \boldsymbol{X}(t) = \boldsymbol{X}_j) \\ &= \text{Prob}(e(t) = e_{j,k}) \\ &= F(e_{j,k}), \end{aligned}$$

for $j = 1, \ldots, n_x$, $k = 1, \ldots, n_f$. Thus, the matrix $\boldsymbol{Q}$ can be constructed solely by the p.f. $F(\cdot)$. The same procedure is applied to the matrix $\tilde{\boldsymbol{Q}}$. Figure 8 illustrates sample paths for the target and the effective rates.

4.2 Basic Results

Now let us look at the simulation results under the baseline models. In order to check the sensitivity of the specification of objective function, the results under $\theta = 1, 2, 3$ are presented, which respectively corresponds to the case of a linear, a quadratic, and a cubic objective function. The discount parameter, γ, is set at 7/360, and $\delta = .96^{\gamma}$. For comparison, Figure 9 illustrates the actual behavior of $|\Delta R^i(t) - \Delta L(t)|$, $i = F, T$. For the property of the actual data to be consistent with the simulated data, daily errors greater than 1% are precluded, as was done in the derivation of $F(\cdot)$ and $\tilde{F}(\cdot)$.

Table 5 shows the statistics obtained from the actual and simulated data, and Figure 10 illustrates the simulated paths of $|\Delta R^i(t) - \Delta L(t)|$, $i = F, T$, under the baseline post-94 model.[18] First of all, it should be pointed out that the simulated probability of perfect pass-through is very close to 1 in all cases. This reflects the fact that the prime rate is adjusted in response to the target rate rather than the effective rate. As expected, the prime rate immediately responds to the target rate in the presence of certain adjustment costs, although the target rate itself does not matter to the bank's loss *prima facie*. In this model, the commercial bank knows that fluctuations in the effective rate during inter-meeting weeks are only transitory, whereas shifts in the target rate are highly persistent. Reacting to the target rate trades off between the cost of adjusting the prime and the

[18] The length of simulated periods is 580 and initial 100 periods are discarded. This is repeated 1000 times, so the sample size amounts to 480000.

cost of deviating the prime from the desired level. Such bank's behavior can also be confirmed by the fact that the mean absolute deviation and the standard deviation of $\Delta R^T(t) - \Delta L(t)$ are much smaller than that of $\Delta R^F(t) - \Delta L(t)$, which is consistent with the data. Table 5 also shows that the probability of same-direction change is almost equal to the probability of perfect pass-through, while the probability of prime shift in a no-policy week is very close to zero. This implies that the size of a prime rate adjustment is identical to the corresponding policy increment in most of the cases, which can also be confirmed by the fraction of .25% changes. Overall, it could be said that the post-94 model can well replicate the key characteristics of the actual prime rate both qualitatively and quantitatively. These results are quite robust to the specification of the objective function.

Let us turn to the pre-94 model. The former part of Table 6 shows the statistics, and the simulated absolute differences are illustrated in Figure 11. It turns out that the pass-through is far from complete in this model. The probability of perfect pass-through is less than 10% in all cases, while the probability of same-direction change is much higher. On the other hand, the frequency of prime adjustments made in the inter-meeting periods is greatly increased compared to the post-94 model. This is, at least partially, attributable to the partial observability of the target rate. Since the commercial bank is uncertain about the timing of policy shifts, it cannot distinguish a transitory shift in the effective rate from a persistent shift in the target rate. In addition, it turns out that the fraction of .25% prime shifts is too small. This clearly reflects the fact that the frequency of prime changes is less than that of target changes. It should also be pointed out that although the effective rate has an informational value in this environment, the correlation between the prime rate and the effective rate is also weakened compared to the post-94 model.

Roughly speaking, both of the baseline models can well replicate the actual data. However, at this stage, we have no idea what the major cause of the prime stickiness is. We cannot affirm that the partial observability of the target is the sole reason for the stickiness. As discussed in section 2, there are other candidates: uncertainty in the timing of policy shifts, the average duration of target rates, and the size of errors. We shall attempt to make explicit the relative importance of these "destabilizing factors" in turn.

5 What explains the prime rate stickiness?

5.1 Partial observability of the FF target

First of all, let us examine the influence of the partial observability of the FF target. To this end we use the pre-94 model, assuming that the FF target is completely observable.[19]

[19] Geraats (2002) calls this situation "policy transparency".

Specifically, we modify the pre-94 model by replacing the state $\tilde{\boldsymbol{X}}(t-1)$ with $\tilde{\boldsymbol{X}}(t)$. Any other specifications are kept unchanged.

The simulation results are shown in the latter part of Table 6 and Figures 11 (c) (d). Table 6 states that although the probability of perfect pass-through and the probability of same-direction changes are larger under policy transparency than under partial observability, the extent of improvement is limited, and the degree of pass-through is still far from complete. On the contrary, the prime-policy ratio is decreased in the case of $\theta = 2, 3$. The response of the prime rate to the effective rate is not significantly improved, judging from the result that the mean absolute deviation and the standard deviation are virtually unchanged. This can also be confirmed by Figure 11.

According to the simulation results, we cannot explain the source of prime-rate stickiness solely by the existence of the partial observability of the FF target. Although it is probable that partial observability is one of the several sources of prime rate stickiness, it may not have played a major role. Interestingly, it turns out that some of the simulated statistics seem to better fit the actual data under policy transparency than under partial observability. In other words, the introduction of the partial observability of the target rate might make the prime rate "too sticky". Of course, this is not positive evidence that the FF target was completely observable before February 1994, but the goodness of fit of the model strongly suggests that partial observability per se is not the main cause of the prime stickiness. This is consistent with the view that the Fed's policy changes since the late 80's had been fully understood by market participants (e.g., Meulendyke, 1998, Poole et al., 2002).

5.2 Uncertainty in the timing of policy changes

The next possibility we will consider is uncertainty in the timing of policy changes. As already discussed, the formal schedule of the FOMC meetings in the pre-94 period did not provide accurate information regarding the timing of policy shifts. There was a positive probability of policy shift all the time. This is in clear contrast to the post-94 period, when policy shifts were made basically at the scheduled meetings. It is probable that such uncertainty had some influences on the behavior of commercial banks.

To see the pure effects of random policy changes, a modified version of the post-94 model is employed. Here, the state variable τ is dropped, and a policy meeting is assumed to be held at the beginning of each period with probability 1/6. The probability of a policy meeting is set at 1/6 so as to keep the average length of the intervals between policy meetings unchanged. Thus, the only departure from the baseline model is that the commercial bank now faces a positive probability of policy shift all the time. This modification allows us to examine the pure effects of random policy meeting without affecting any other aspects.

The results are shown in Table 7 and Figure 12. Table 7 shows that the response of the prime rate becomes less flexible under random meeting than under periodic meeting. The probability of perfect pass-through is now slightly less than .9, and so is the probability of same-direction changes. However, the other statistics are roughly the same as in the case of the baseline model. For example, the prime-policy ratio is still above .97, and the mean absolute deviation and the standard deviations are almost unchanged. It could be said that the timing uncertainty itself would have had little influence on the prime rate behavior. This can also be confirmed by Figure 12. These simulation results do not depend on the specification of the objective function.

5.3 Distribution of errors

This section examines the role of errors. As illustrated in Figures 6 and 7, the volatility of errors are significantly smaller in the post-94 period than in the pre-94 period. To investigate the influence of the change in the volatility of errors, we replace the post-94's error distribution, F, with the pre-94's distribution, $\tilde{F}$. It can be expected that the commercial bank's incentive to follow the target rate would be reduced compared to the baseline model, simply because the current target rate will be less correlated to the effective rate.

Table 8 and Figure 13 show the results. It turns out that the degree of pass-through from the target rate to the prime rate is largely deteriorated. The probability of perfect pass-through takes values ranging from .54 to .66, and the probability of same-direction changes is around .7. On the other hand, the prime-policy ratio will require some explanation. The prime-policy ratio is significantly less than one when $\theta = 1, 2$ and more than one when $\theta = 3$. It should be noted that the presence of large errors has two effects. First, even in the period when the target rate is moved, in some cases a lower one-period loss can be achieved by keeping the prime rate unchanged rather than by following the target. Suppose that the target rate is shifted from 5% to 5.25% in period t, while the effective rate at t is 5%. In this case, as long as the prime rate was 8% (5% plus risk premium) in period $t-1$, the optimal strategy is to keep the prime unchanged until period $t+1$. If the prime rate is adjusted in period $t+1$, then the frequency of prime-rate changes could be the same as that of the target rate. However, the result states that this is not necessarily the case. In fact, if the effective rate is kept at 5% or lower for several more periods, then there would be a point in time when it is optimal to wait until the next meeting.[20] This is why the prime-policy ratio is lowest when $\theta = 1$, where the objective function takes a "risk-neutral" form. The second effect is that as the effective rate becomes more volatile, the one-period loss of keeping the prime unchanged is more likely to be too costly. This implies that the commercial bank is prone to adjust the prime rate in response to

[20]This mechanism is the main topic of the next section.

the effective rate, not the target rate. The simulation results implies that this effect is dominant when $\theta = 3$, where the objective function takes a "risk-averse" form.

Although the commercial bank is prone to react to the effective rate, this does not necessarily mean that the correlation between the prime rate and the effective rate is improved. The table shows that the mean absolute deviation and the standard deviation between the prime rate and the effective rate are both deteriorated. It is true that the prime rate is adjusted to the effective rate more frequently in this modified model than in the baseline model, but the enlarged volatility of the effective rate more than offsets such an effect.

Consequently, it is reasonable to consider that one of the reasons for the improvement in the target rate pass-through achieved in 1994 is the reduction in the volatility of errors. In the post-94 period, there is less need to follow the effective rate because the deviations of the effective rate from the target are usually small. Reduced volatility of errors has contributed to making the relationship between the prime rate and the funds rate more stable.

5.4 The average duration of targets

Finally, let us consider the possibility that an increase in the average duration of target rates has altered the response of the prime rate. Recall that the periodicity $\bar{\tau}$ in the post-94 model represents the length of interval between policy *meetings*, not policy *changes*. Therefore, it is not correct to regard $\bar{\tau}$ as the duration of policy changes. In the post-94 model, the average duration of policy changes is much longer than $\bar{\tau}$ since the transition matrix includes the state of $\bar{\Delta}R^T(t) = 0$. In order to compare the periodic policy-meeting regime with the stochastic policy-shift regime, the average interval of time between policy changes must be equated with each other. According to the simulation, the average duration of targets is 5.57 weeks if $\bar{\tau}$ was set at 2 in place of 6. This is fairly close to the baseline value of α^{-1}.

The results are reported in Table 9. Although the statistics are not so drastically altered when $\bar{\tau} = 4$ and $\theta = 1$, they are greatly changed in all cases if the periodicity reduces to 2. This deterioration in the degree of pass-through can also be confirmed by Figure 14. The table states that the degree of pass-through under $\bar{\tau} = 2$ is even worse than in the case where the pre-94's error distribution is used. For example, the probability of perfect pass-through under $\bar{\tau} = 2$ is now less than half of that under the baseline model, and the probability of same-direction changes is only around .6. Moreover, the fraction of .25% prime adjustment is greatly reduced and takes a value that is about a half or less than a half of the fraction of small policy shifts, which is quite consistent with the pre-94 data. Thus, it can be considered that an increase in the average duration of targets played a major role in the improvement in the target rate pass-through.

An intuition is as follows. Suppose that a policy shift occurred at the beginning of the current period. If the current target rate is expected to be kept unchanged for a sufficiently long time, the bank immediately reacts to the target shift because the bank can continue to offer the desirable prime rate for a long time by paying the adjustment costs only in the current period. On the other hand, if the current target rate is expected to be readjusted in the near future, then the bank is inclined to wait for the next policy change in order to avoid paying the adjustment costs several times over the next few periods. In the latter case, it would become optimal for the bank to adjust the prime to a large amount in response to the next target shift. Or, in the case where the succeeding policy changes are expected to be carried out very soon, the probability that the target rate will be back to the previous level in the sufficiently near future might not be zero. This is why the average duration of a newly adjusted target rate greatly affects the behavior of the prime rate.

5.5 Discussion: The role of policy announcements

As was previously shown, the fundamental cause of the improvement in the prime rate response turned out to be an increase in the average duration of targets. Neither the partial observability of the target nor the uncertainty in the timing of policy changes had a significant influence on the determination of the prime rate. However, this does not mean that the Fed's disclosure practice beginning in February 1994 had no effect on the prime rate. Given the drastic change in the prime rate response that occurred in 1994, it is rather natural to regard it as having some relation to the Fed's disclosure policy. In the following, We discuss some possible ways in which the start of the Fed's policy announcements changed the behavior of the prime rate.

The first and most evident outcome of the policy announcement practice is that the explicit FF target rate has come to be known to market participants. As discussed above, however, the observability of the target rate per se did not seem to have a significant influence. It is now widely recognized that the market has understood the Fed's intended funds rate since 1989. Second, there is a possibility that the spread between the effective rate and the target rate has been significantly reduced due to the "announcement effect", although this effect is still controversial among some researchers.[21] If the announcement effect was a major cause of a reduction in the volatility of the effective funds rate, then it could be said that the start of the policy announcement practice has indirectly improved the response of the prime.

Finally, the practice of target rate announcement might have increased the expected

[21] For example, Guthrie and Wright (2000) and Demiralp and Jordà (2002) support the presence of the announcement effect, while Thornton (2004a) argues that there is no irrefutable evidence for such an effect.

duration of targets. This effect could occur through several channels. Firstly, as many studies have indicated, market participants have come to better anticipate future policy changes after the Fed's announcement practice started. In particular, Demiralp and Jordà (2004) point out that the *timing* of future policy shifts has also been better anticipated since February 1994, because market participants understood that most of the policy changes would be made at the regularly scheduled meetings. Such a reduction in timing uncertainty would have enlarged the expected duration of targets by reducing the probability of inter-meeting policy shifts. However, recall that our analysis suggested that timing uncertainty itself played a limited role. Although a reduction in timing uncertainty would have led to an increase in the expected duration of targets, it is a change in the expected duration that would have ultimately affected the prime rate. It is interesting to note that shifts in the prime rate have come to synchronize exactly with policy shifts since May 1994, not since February 1994. It would have taken three months (three FOMC meetings) until the market could have confirmed that there would be no inter-meeting policy changes. The second possibility is that the market considered that the practice of policy announcement itself would prohibit the Fed from changing the target rate very often. It is natural that frequent policy changes would have been taken by the market as generating political pressures. As Thornton (2004b) thoroughly argued, the tendency to avoid political pressures would be a major reason why the Fed had kept its intended funds rates secret for such a long time. Third, the market might have known that the Fed would avoid frequent policy changes since it might be perceived by market participants as an alteration to the previous policies, which would undermine the credibility of the current policy.

The verification of the abovementioned possibilities are beyond the scope of this paper. However, it can be said that the practice of policy announcement was not a sufficient condition but a necessary one for the improvement in the response of the prime rate to the funds rate target. Without an increase in the average duration of targets, the start of policy announcements could not have improved the target rate pass-through.

6 Conclusion

This paper has investigated the source of the 1994 structural break in the relationship between the Federal funds rate and the prime rate. To this end, We have constructed two baseline models: the pre-94 model and the post-94 model. Stochastic simulations were conducted in order to examine the extent to which each of the period-specific features was responsible for the behavior of the prime rate.

The main findings can be summarized as follows. First, partial observability of the intended funds rate itself is not a major cause of prime-rate stickiness. Actually, it was shown that some of the data can be better replicated under policy transparency than under partial observability. Second, introducing uncertainty in the timing of policy changes does not largely deteriorate the degree of pass-through. It is not uncertainty in the timing of policy changes, but the average duration of targets that matters the most to the response of the prime rate. This is because if the target rate is expected to be readjusted in the near future, commercial banks are inclined to hold back from adjusting the prime rate until the upcoming policy change. Therefore, in order to have commercial banks respond promptly to a policy change, the expected duration of targets has to be sufficiently long. Quantitatively, this effect seems to have the largest impact on the degree of pass-through. Third, the volatility of the effective rate has the second largest influence on the behavior of the prime rate. The reason is twofold: on the one hand, if the effective rate is sufficiently close to the current prime rate, it is better for commercial banks to keep the prime rate unchanged, at least until the next period. Since the absolute deviation of the effective rate from the target rate often reached .25% or more prior to 1994, this mechanism might have had a non-negligible influence in the pre-94 period. On the other hand, large fluctuations in the effective rate will cause the cost of funds to fluctuate. In the face of a large deviation, it would be better for risk-averse commercial banks to immediately adjust the prime in response to the effective rate. This also deteriorates the degree of target rate pass-through.

Over the past several years, a lot of studies have been made on the issue of how central banks should communicate with the markets (e.g., Morris and Shin, 2002, Woodford, 2005, Walsh, 2008). However, little attention has been paid to the issue of how often central banks should change their policy rates. One exception is the work by Fukuda (2007), who argues that central banks change their policy rates only infrequently since a shift in the policy rate itself would create further uncertainty. The results of this paper provided an alternative rationale for central banks' infrequent policy changes, which have been widely observed in industrialized countries. Given that recent central banks often make the decision to "do-nothing", the issue of policy shift frequency should receive much attention in future research.

References

[1] Bertsekas, D. P. (2007) *Dynamic Programming and Optimal Control vol. 2, 3rd ed.* Athena Scientific.

[2] Bomfim, A. N., Reinhart, V. R. (2000) Making news: Financial market effects of Federal Reserve disclosure practices. Federal Reserve Board.

[3] Demiralp, S., Jordà, Ò. (2002) The announcement effect: Evidence from open market desk data. Federal Reserve Bank of New York *Economic Policy Review*, 29-48.

[4] Demiralp, S., Jordà, Ò. (2004) The response of term rates to Fed announcements. *Journal of Money, Credit, and Banking* 36, no.3, 387-405.

[5] Forbes, S. M., Mayne, L. S. (1989), A friction model of the prime. *Journal of Banking and Finance* 13, 127-135.

[6] Fukuda, S. (2007) Infrequent changes of policy target: Stop-go monetary policy under Knightian uncertainty. Manuscript, University of Tokyo.

[7] Geraats, P. M. (2002) Central bank transparency. *Economic Journal* 112, F532-565.

[8] Goldberg, M. A. (1982) The pricing of the prime rate. *Journal of Banking and Finance* 6, 277-96.

[9] Guthrie, G., Wright, J. (2000) Open mouth operations. *Journal of Monetary Economics* 46, 489-516.

[10] Hamilton, J. D., Jordà, Ò. (2002) A model of the Federal funds rate target. *Journal of Political Economy* 110, 1135-1167.

[11] Lange, J., Sack, B., Whitesell, W. (2003) Anticipations of monetary policy in financial markets. *Journal of Money, Credit, and Banking* 35, no.6, 889-909.

[12] Mester, L., Saunders, A. (1995), When does the prime rate change? *Journal of Banking and Finance* 19, 743-64.

[13] Meulendyke, A-M. (1998) *U.S. Monetary Policy and Financial Markets.* New York: Federal Reserve Bank of New York.

[14] Miranda, M. J., Fackler, P. L. (2002) *Applied Computational Economics and Finance*, MIT press.

[15] Monahan, G. E. (1982) A survey of partially observable Markov decision processes: Theory, models, and algorithms. *Management Science* 28, 1-16.

[16] Morris, S. and Shin, S. H. (2002) Social value of public information. *American Economic Review* 92, 1521-34.

[17] Poole, W., Rasche, R. H. (2003) The impact of changes in FOMC disclosure practices on the transparency of monetary policy: Are markets and the FOMC better "Synched"? Federal Reserve Bank of St. Louis *Review*.

[18] Poole, W., Rasche, R. H., Thornton, D. L. (2002) Market anticipations of monetary policy actions. Federal Reserve Bank of St. Louis *Review*.

[19] Rudebusch, G. D. (1995), Federal Reserve interest rate targeting, rational expectations, and the term structure. *Journal of Monetary Economics* 35, 245-74.

[20] Sellon, G. H. Jr. (2002) The changing U.S. financial system: some implications for the monetary transmission mechanism. Federal Reserve Bank of Kansas City *Economic Review*, first quarter 5-35.

[21] Swanson, E. T. (2006) Have increases in Federal Reserve transparency improved private sector interest rate forecasts? *Journal of Money, Credit, and Banking* 38, no.3, 791-819.

[22] Taylor, J. B. (2001) Expectations, open market operations, and changes in the Federal funds rate. Federal Reserve Bank of St. Louis *Review*.

[23] Thornton, D. L. (2004a) The Fed and short-term rates: Is it open market operations, open mouth operations or interest rate smoothing? *Journal of Banking and Finance* 28, 475-98.

[24] Thornton, D. L. (2004b) When did the FOMC begin targeting the Federal Funds rate? What the verbatim transcripts tell us. Federal Reserve Bank of St. Louis, Working Paper 2004-015B.

[25] Thornton, D. L. (2005) A new Federal Funds rate target series: September 27, 1982 - December 31, 1993. Federal Reserve Bank of St. Louis, Working Paper 2005-032A.

[26] Walsh, C. E. (2008) Announcements and the role of policy guidance. Forthcoming in Federal Reserve Bank of St. Louis *Review*.

[27] Woodford, M. (2005) Central bank communications and policy effectiveness. In *The Greenspan Era: Lessons for the Future*, Kansas City Federal Reserve Bank of Kansas City.

Table 1: Data description

	Sep 1982 - Jan 1994	Feb 1994 - Feb 2007
perfect pass-through[a)]	.107	.979
same-direction change[a)]	.333	1
no-policy week[a)]	.038	0
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	.522	1
frac. $\lvert\Delta R^T(t)\rvert \in (0, .00375]$	.756	.714
frac. $\lvert\Delta L(t)\rvert = .0025$	.213	.694
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	.054	.000
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$[b)]	.163	.071
$std(\Delta R^T(t) - \Delta L(t))$	.152	.010
$std(\Delta R^F(t) - \Delta L(t))$[b)]	.225	.114

Note: $\Delta R^T(t)$, $\Delta R^F(t)$ and $\Delta L^T(t)$ denote weekly changes in the FF target, the effective FF rate and the prime rate, respectively. Large fluctuations in the effective rate such that daily deviation of the effective rate from the target rate is more than 1% are excluded.

[a)] Policy changes for which the last or the next policy shift was carried out within one week are excluded.

[b)] Based on weekly average.

Table 2: Frequency of increments

Size (bp)	6.25	12.5	18.75	25	31.25	37.5	43.75	50	56.25	75	112.5
Increase											
Sep 82 - Jan 94	9	9	6	8	2	0	2	3	0	0	1
Feb 94 - Feb 07	0	0	0	25	0	0	0	4	0	1	0
decrease											
Sep 82 - Jan 94	2	3	1	26	1	1	0	15	1	0	0
Feb 94 - Feb 07	0	0	0	10	0	0	0	9	0	0	0

Table 3: Meeting-based transition probability matrix: post-94

	-50	-25	0	25	50
-50	.667	.222	.111	0	0
	(6)	(2)	(1)	(0)	(0)
-25	0	.4	.6	0	0
	(0)	(4)	(6)	(0)	(0)
0	.044	.059	.75	.103	.044
	(3)	(4)	(51)	(7)	(3)
25	0	0	.2	.72	.08
	(0)	(0)	(5)	(18)	(2)
50	0	0	1	0	0
	(0)	(0)	(1)	(0)	(0)

Note: Actual counts are in parentheses.

Table 4: Increment-based transition probability matrix: pre-94

	-50	-25	-12.5	-6.25	6.25	12.5	18.75	25	50
-50	.316	.368	.053	.053	.105	.105	0	0	0
	(6)	(7)	(1)	(1)	(2)	(2)	(0)	(0)	(0)
-25	.205	.682	.091	0	0	.023	0	0	0
	(9)	(30)	(4)	(0)	(0)	(1)	(0)	(0)	(0)
-12.5	0	.211	.421	.105	.053	.105	0	.053	.053
	(0)	(4)	(8)	(2)	(1)	(2)	(0)	(1)	(1)
-6.25	0	0	.286	.143	.286	.143	0	.143	0
	(0)	(0)	(2)	(1)	(2)	(1)	(0)	(1)	(0)
6.25	.214	.071	.071	.143	.214	0	.143	.143	0
	(3)	(1)	(1)	(2)	(3)	(0)	(2)	(2)	(0)
12.5	0	.044	0	.044	.044	.348	.044	.348	.130
	(0)	(1)	(0)	(1)	(1)	(8)	(1)	(8)	(3)
18.75	0	.091	.091	0	.273	.091	.182	.091	.182
	(0)	(1)	(1)	(0)	(3)	(1)	(2)	(1)	(2)
25	0	.036	.036	0	0	.321	.179	.393	.036
	(0)	(1)	(1)	(0)	(0)	(9)	(5)	(11)	(1)
50	0	0	0	0	.250	0	.125	.500	.125
	(0)	(0)	(0)	(0)	(2)	(0)	(1)	(4)	(1)

Note: Actual counts are in parentheses.

Table 5: Baseline results: Post-94 model

	post-94	$\theta = 1$	$\theta = 2$	$\theta = 3$
perfect pass-through	**.979**	.956	.951	.945
same-direction change	**1**	.956	.952	.951
no-policy week	**0**	.003	.003	.003
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	**1**	1.000	1.000	1.002
frac. $\lvert\Delta R^T(t)\rvert = .0025$	**.714**	.706	.718	.714
frac. $\lvert\Delta L(t)\rvert = .0025$	**.694**	.706	.716	.707
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	**.000**	.001	.002	.002
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$	**.071**	.072	.072	.071
$std(\Delta R^T(t) - \Delta L(t))$	**.010**	.020	.022	.024
$std(\Delta R^F(t) - \Delta L(t))$	**.114**	.110	.111	.110

Table 6: Pre-94 model: observable and unobservable cases

		unobservable			observable		
	pre-94	$\theta = 1$	$\theta = 2$	$\theta = 3$	$\theta = 1$	$\theta = 2$	$\theta = 3$
perfect pass-through	**.107**	.033	.062	.092	.117	.125	.129
same-direction change	**.333**	.144	.190	.242	.323	.324	.327
no-policy week	**.038**	.059	.070	.090	.026	.035	.057
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	**.522**	.428	.531	.684	.447	.495	.605
frac. $\lvert\Delta R^T(t)\rvert \in (0, .00375]$	**.756**	.881	.881	.881	.881	.879	.879
frac. $\lvert\Delta L(t)\rvert = .0025$	**.213**	.304	.400	.449	.401	.460	.474
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	**.054**	.055	.055	.059	.035	.036	.043
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$	**.163**	.188	.178	.166	.177	.174	.167
$std(\Delta R^T(t) - \Delta L(t))$	**.152**	.139	.137	.144	.098	.098	.114
$std(\Delta R^F(t) - \Delta L(t))$	**.225**	.247	.233	.216	.234	.229	.218

Table 7: A modified post-94 model: timing uncertainty

	post-94	pre-94	$\theta = 1$	$\theta = 2$	$\theta = 3$
perfect pass-through	**.979**	**.107**	.859	.858	.820
same-direction change	**1**	**.333**	.877	.878	.845
no-policy week	**0**	**.038**	.007	.007	.009
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	**1**	**.522**	.981	.980	.978
frac. $\lvert\Delta R^T(t)\rvert \in (0, .00375]$	**.714**	**.756**	.726	.712	.712
frac. $\lvert\Delta L(t)\rvert = .0025$	**.694**	**.213**	.705	.687	.681
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	**.000**	**.054**	.004	.004	.005
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$	**.071**	**.163**	.072	.072	.073
$std(\Delta R^T(t) - \Delta L(t))$	**.010**	**.152**	.033	.032	.036
$std(\Delta R^F(t) - \Delta L(t))$	**.114**	**.225**	.111	.111	.111

Table 8: A modified post-94 model: the pre-94 errors

	post-94	pre-94	$\theta = 1$	$\theta = 2$	$\theta = 3$
perfect pass-through	**.979**	**.107**	.660	.647	.542
same-direction change	**1**	**.333**	.754	.714	.623
no-policy week	**0**	**.038**	.012	.015	.026
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	**1**	**.522**	.935	.947	1.020
frac. $\lvert\Delta R^T(t)\rvert \in (0, .00375]$	**.714**	**.756**	.716	.713	.718
frac. $\lvert\Delta L(t)\rvert = .0025$	**.694**	**.213**	.577	.572	.560
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	**.000**	**.054**	.009	.011	.016
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$	**.071**	**.163**	.173	.172	.170
$std(\Delta R^T(t) - \Delta L(t))$	**.010**	**.152**	.055	.062	.076
$std(\Delta R^F(t) - \Delta L(t))$	**.114**	**.225**	.230	.229	.225

Table 9: A modified post-94 model: smaller periodicity

	post-94	pre-94		$\bar{\tau}=4$			$\bar{\tau}=2$	
			$\theta=1$	$\theta=2$	$\theta=3$	$\theta=1$	$\theta=2$	$\theta=3$
perfect pass-through	**.979**	**.107**	.923	.796	.612	.381	.325	.179
same-direction change	**1**	**.333**	.946	.860	.736	.633	.598	.510
no-policy week	**0**	**.038**	.003	.007	.012	.023	.027	.036
$\frac{\text{\# prime shifts}}{\text{\# policy shifts}}$	**1**	**.522**	.978	.926	.958	.737	.722	.675
frac. $\lvert\Delta R^T(t)\rvert \in (0, .00375]$	**.714**	**.756**	.709	.712	.711	.704	.707	.704
frac. $\lvert\Delta L(t)\rvert = .0025$	**.694**	**.213**	.678	.604	.479	.358	.329	.266
$mean(\lvert\Delta R^T(t) - \Delta L(t)\rvert)$	**.000**	**.054**	.003	.007	.013	.037	.041	.051
$mean(\lvert\Delta R^F(t) - \Delta L(t)\rvert)$	**.071**	**.163**	.072	.074	.078	.095	.096	.103
$std(\Delta R^T(t) - \Delta L(t))$	**.010**	**.152**	.028	.046	.063	.107	.113	.128
$std(\Delta R^F(t) - \Delta L(t))$	**.114**	**.225**	.111	.113	.118	.144	.145	.153
Ave. policy-shift intervals	13.33	5.81		10.92			5.57	

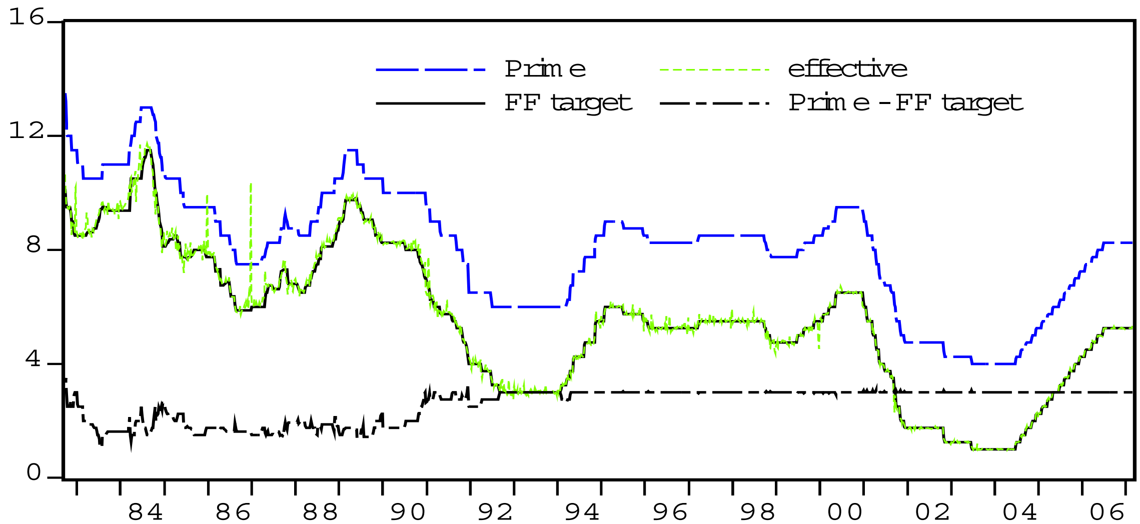

Figure 1: The Prime rate and the Federal funds rates

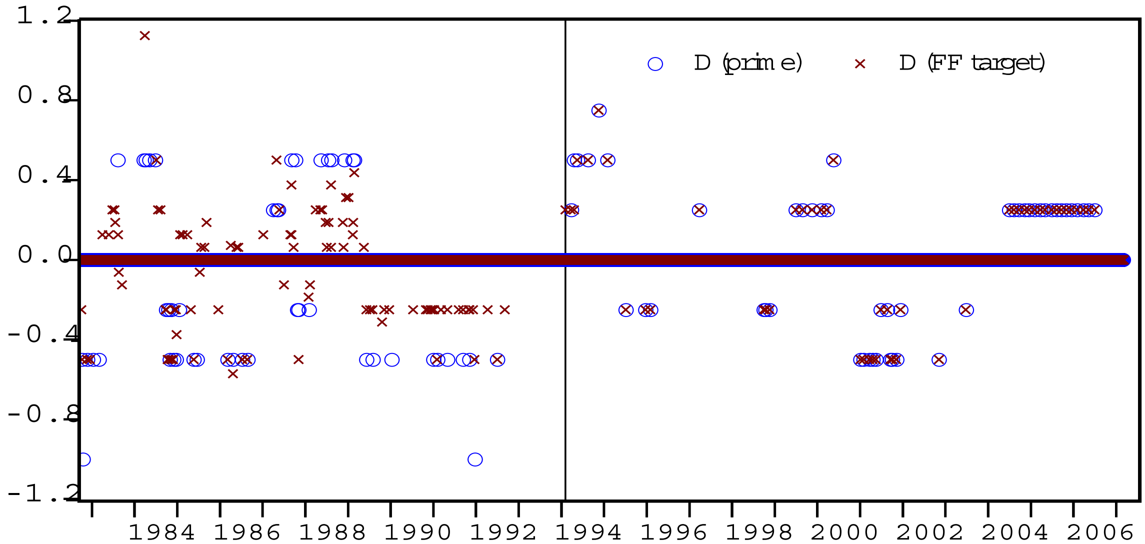

Figure 2: Daily changes in the prime rate and the funds rate target

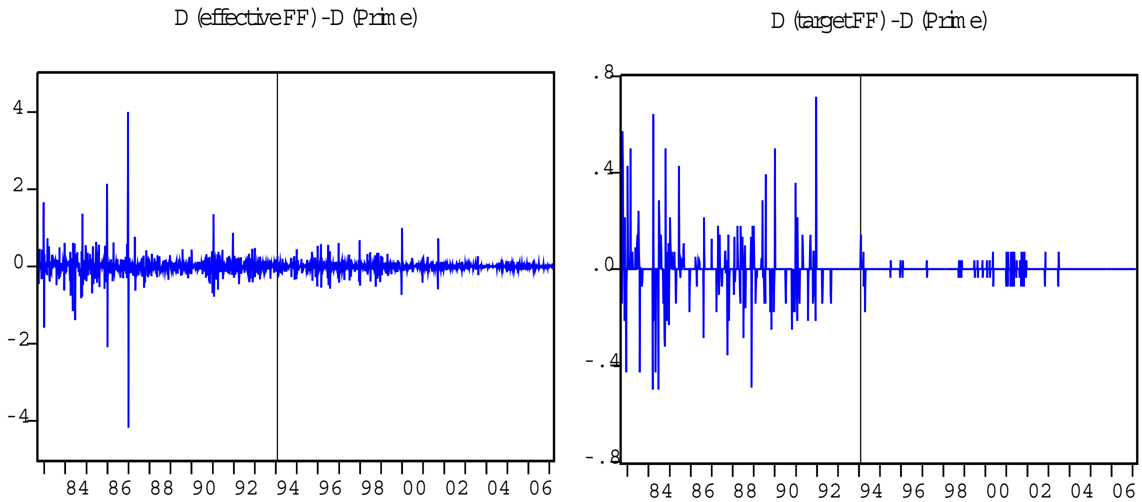

Figure 3: Difference between weekly changes in the prime rate and the Federal funds rate

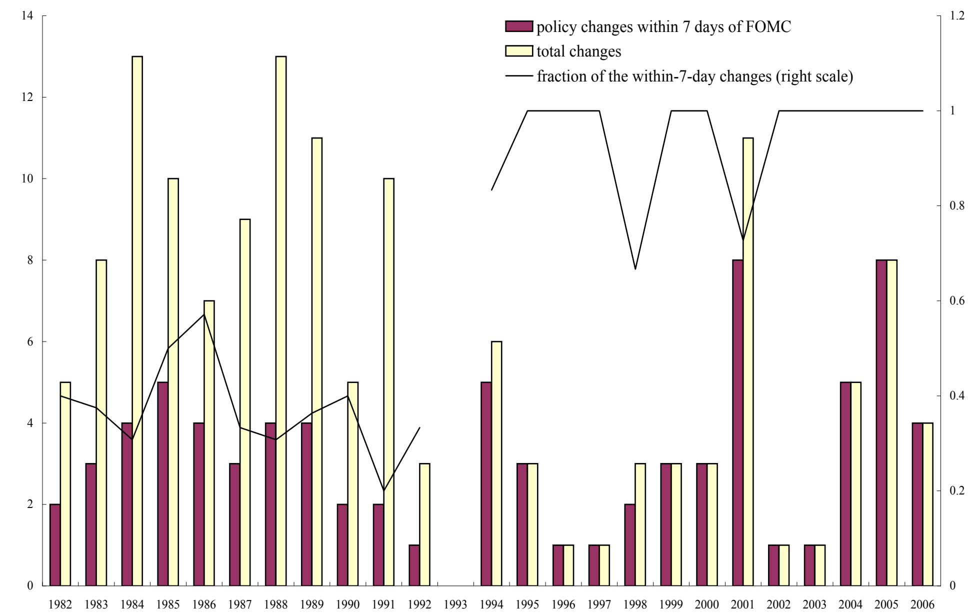

Figure 4: Timing and the frequency of policy changes

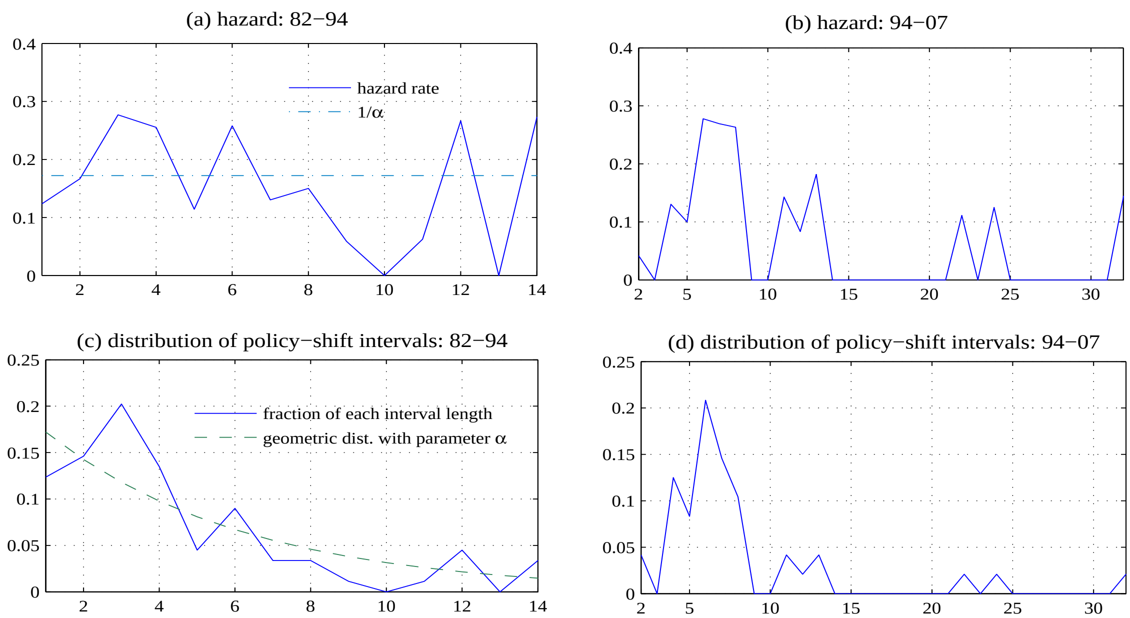

Figure 5: Distribution of policy-shift intervals and the hazard rate

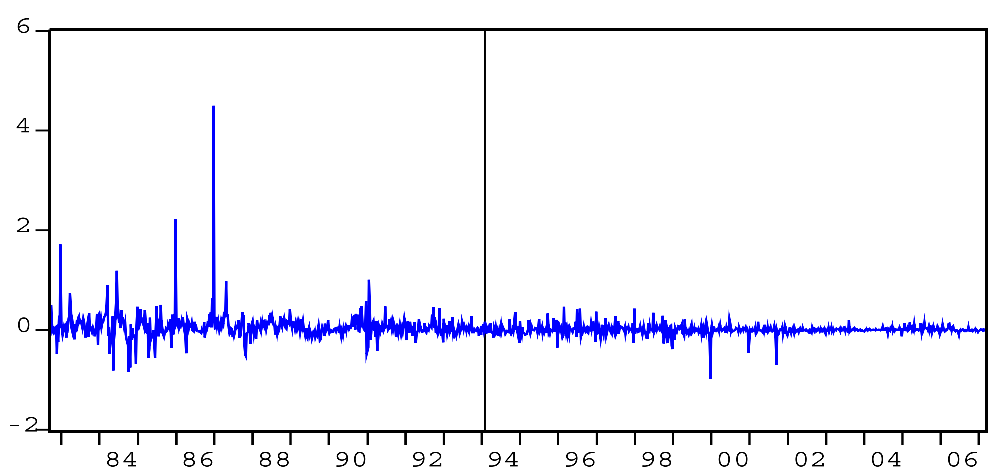

Figure 6: Deviation of the effective funds rate from the intended rate

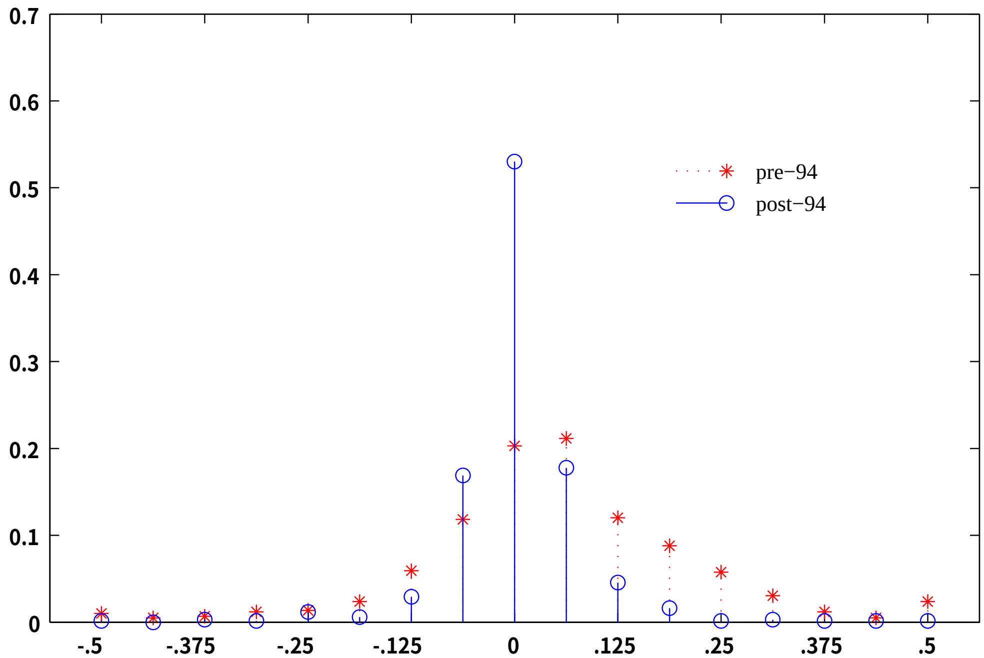

Figure 7: Distribution of errors

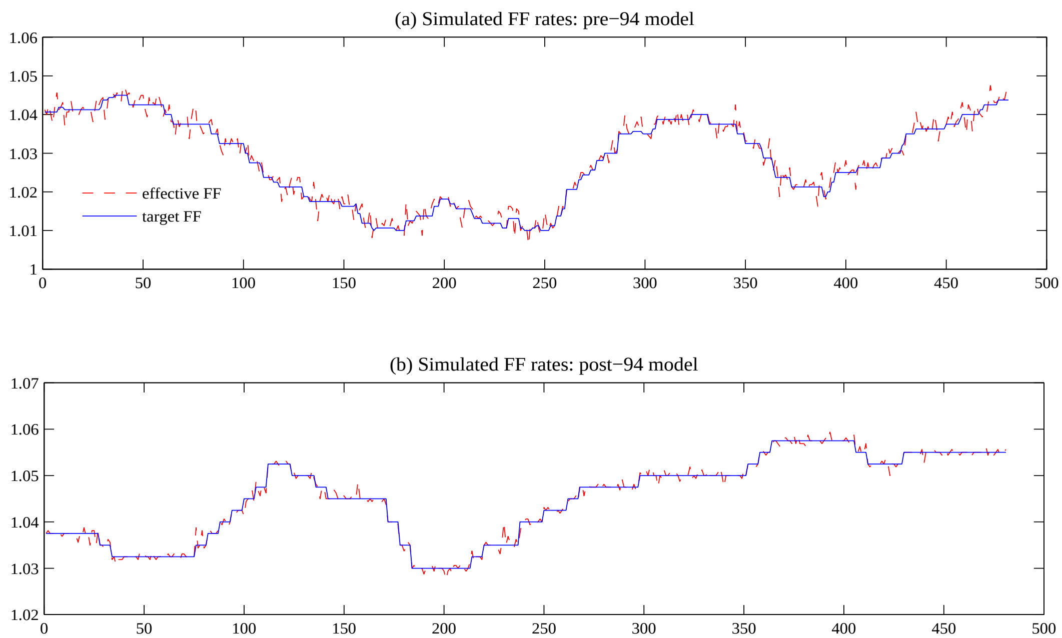

Figure 8: Example paths of simulated Federal funds rates

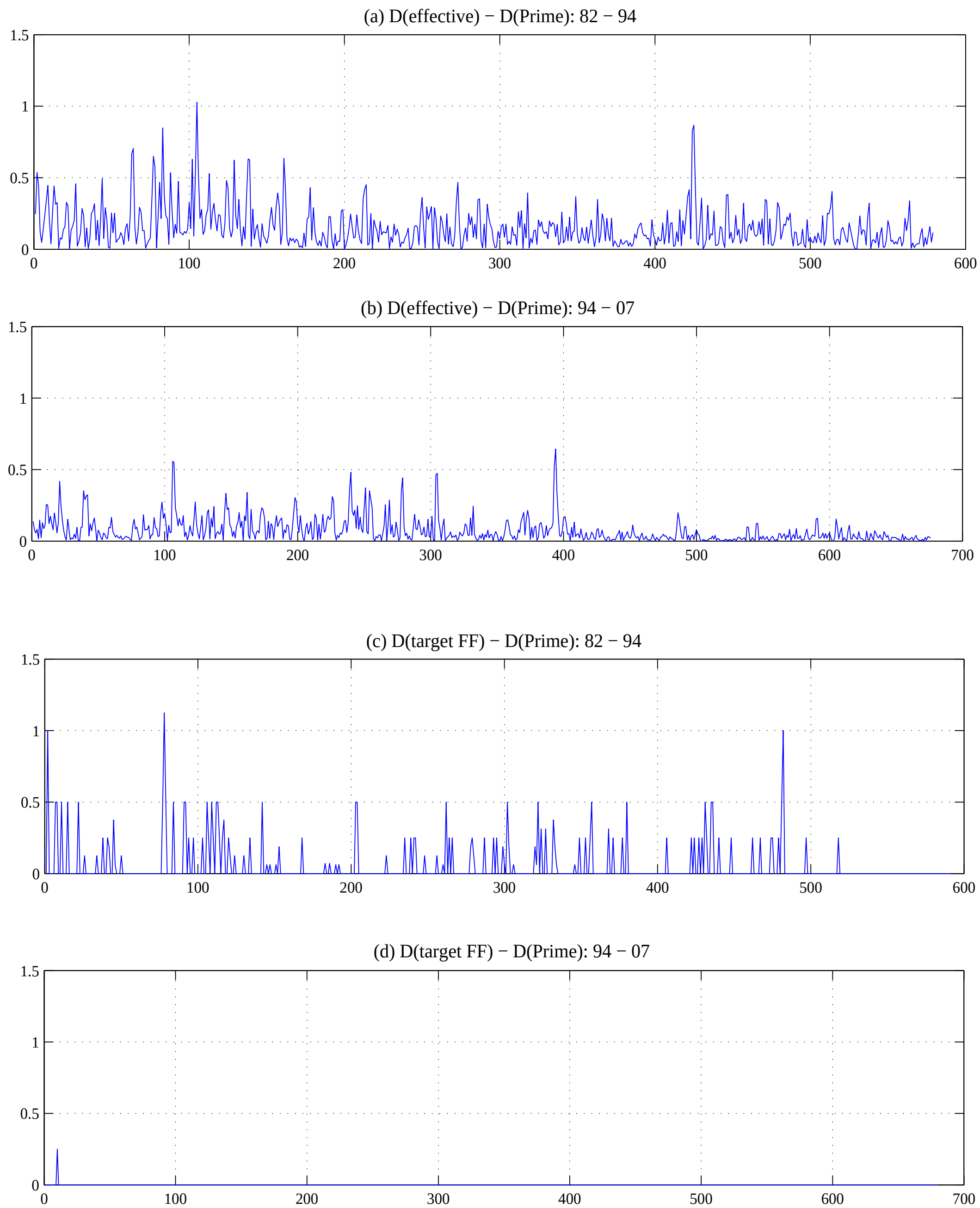

Figure 9: Actual absolute deviations

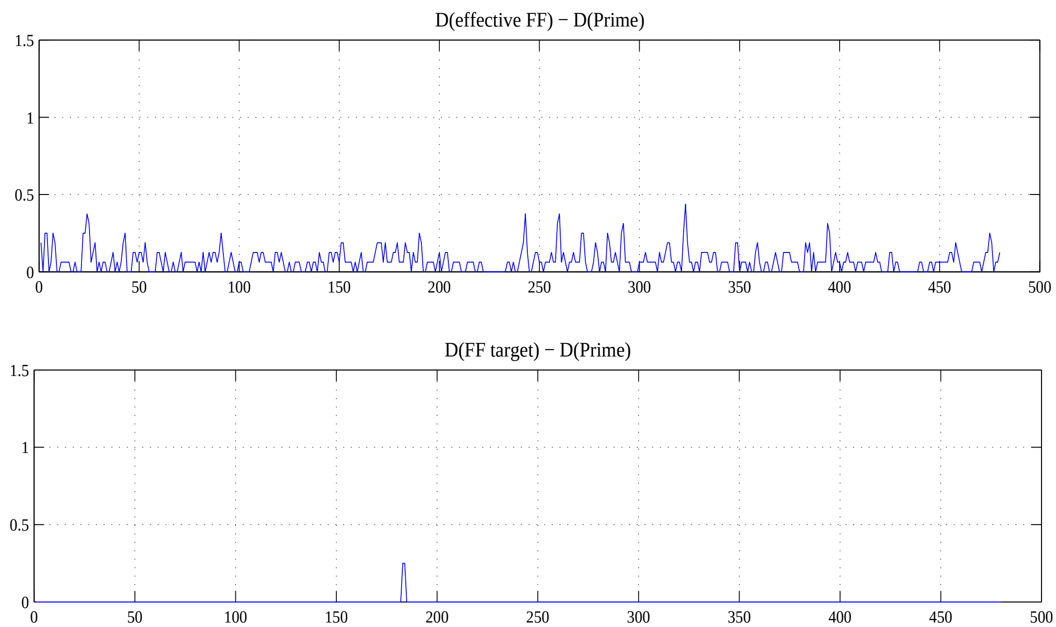

Figure 10: Absolute deviations under the baseline post-94 model

Figure 11: Absolute deviations under the pre-94 model

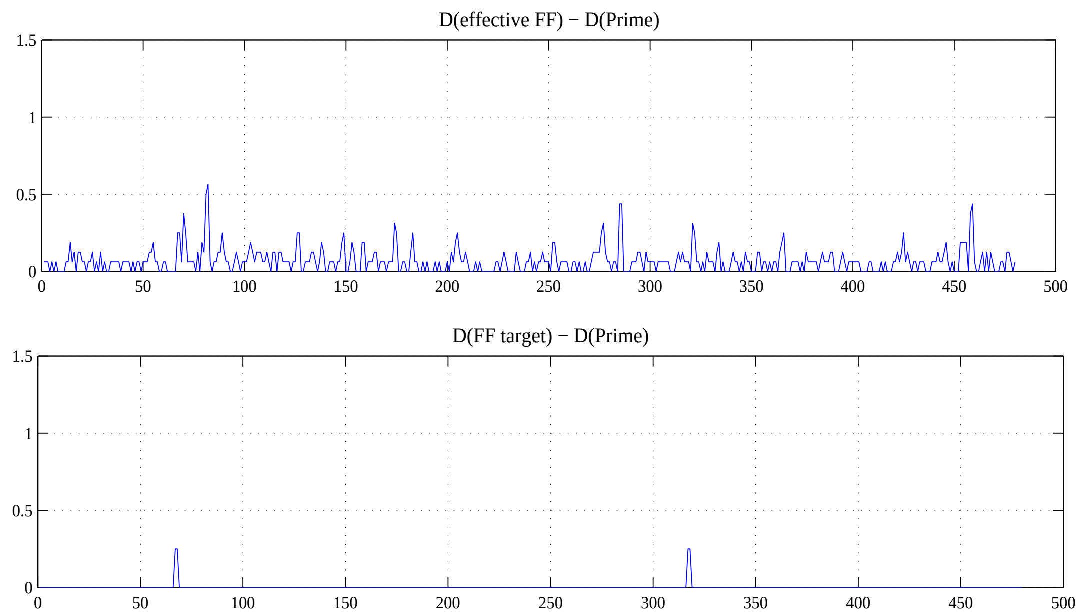

Figure 12: Absolute deviations under a modified post-94 model: timing uncertainty

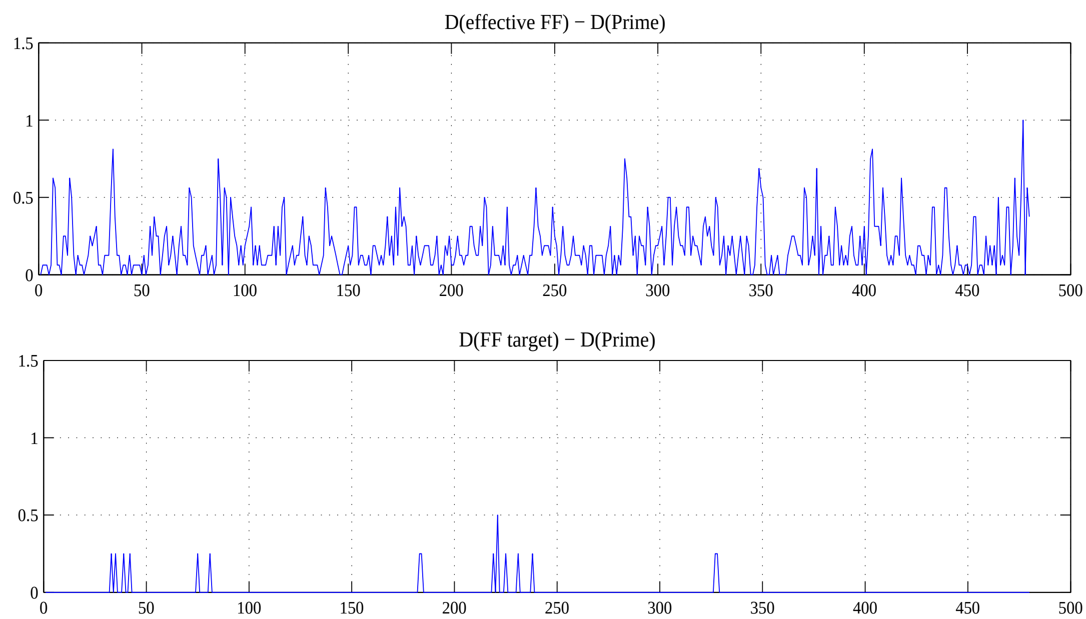

Figure 13: Absolute deviations under a modified post-94 model: pre-94 errors

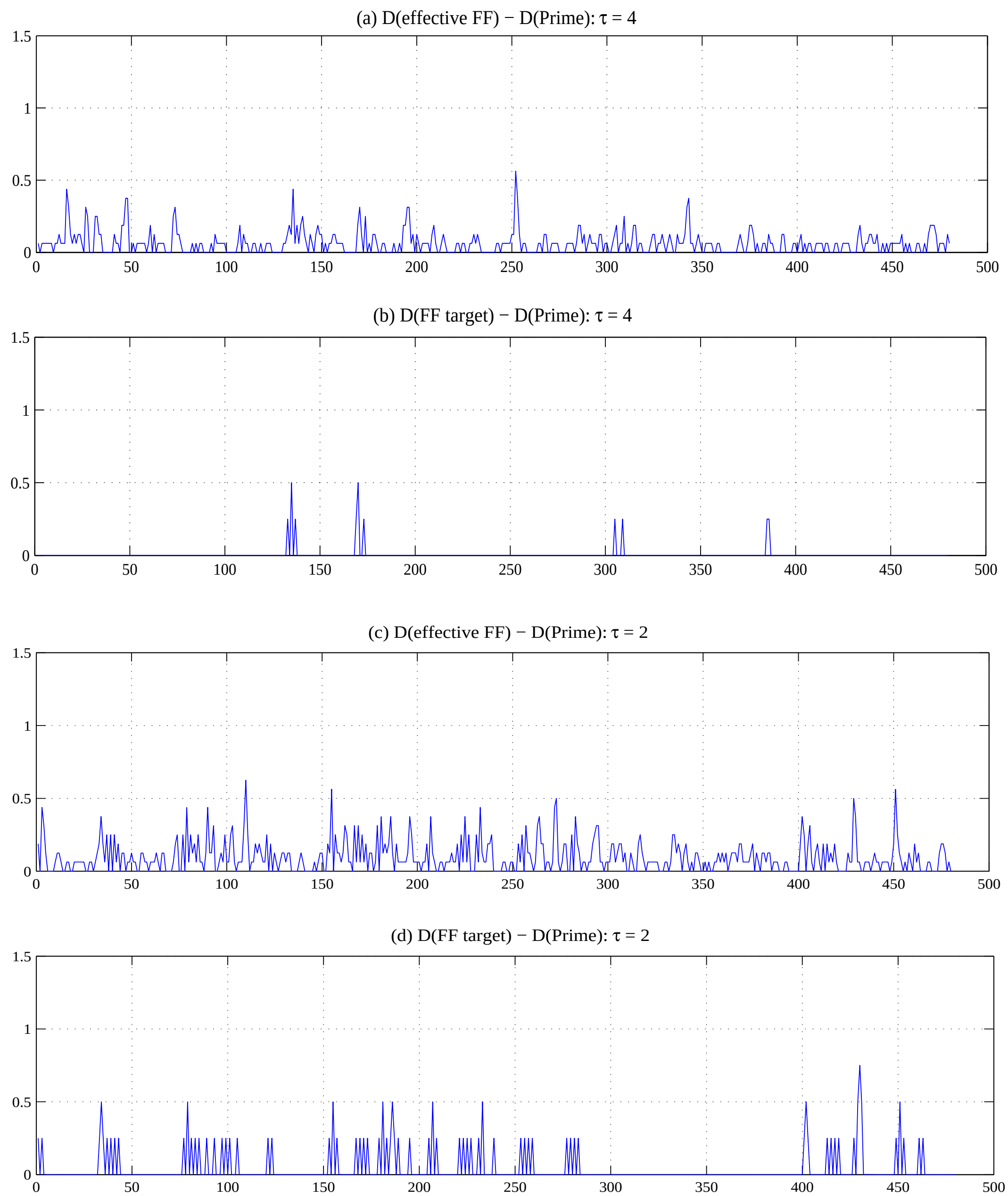

Figure 14: Absolute deviations under a modified post-94 model: smaller periodicity