Information in the U.S. Treasury Term Structure of Interest Rates

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1. Introduction

In 1984, Eugene Fama published two papers in the *Journal of Financial Economics* focusing on the term structure of interest rates. Fama (1984a) studies one- to six-month Treasury bills for the period 1959-1982 to determine the existence of information in the term structure of interest rates. He demonstrates for most forecasting horizons that the current rate is the best forecast of future spot rates. This evidence suggests that there exists more information in the term structure about expected holding period returns than about expected future interest rates. Fama (1984b) examines expected returns on Treasury bills and bond portfolios. In this work, evidence suggests that average holding period returns rise for about eight or nine months and then decline.

In an October 2000 Dimensional Funds Advisors Inc. (DFA) trade document, James Davis provides an update to Fama's 1984 papers by examining Treasury bill data from June 1964 through November 1999. By the time of Davis' work, the Center for Research in Security Prices (CRSP) included information for Treasury bills with maturities up to one year. Consequently, Davis provides results for maturities 11 months ahead instead of only six as reported by Fama (1984a).[1] The results of Davis indicate that the patterns found in Fama (1984a) and Fama (1984b) were still in place for the period June 1964-November 1999 and for two sub-periods, June 1964-July 1982 and August 1982-November 1999.

[1] Fama and Bliss (1987) examine longer term forecast horizons and find they have predictive ability, "... attributing this forecast power to slow mean reversion of the spot rate that only becomes evident over long horizons" (p. 359). Fama (2006) reexamines the Fama and Bliss (1987) result with more recent data and concludes that the forecast power remains, but attributes this forecast power to time-varying mean reversion.

In recent decades, many changes have taken place that suggests these results may no longer hold. For example, the documented shift in U.S. demographics may have altered the average investor's preferred habitat. Poterba (2001) finds correlations between Treasury bill returns, long-term government bond returns, and demographics in the United States. The heightened demand for short-term debt instruments by an aging population might reduce demand for long-term debt instruments, thus changing the information content of the term structure.

Second, given the discoveries in the aforementioned studies, strategies seeking to capitalize on the findings could alter the economic process itself. Dimensional Funds Advisors adopts a "variable maturity" approach developed by Professor Eugene Fama, which uses the current term structure to determine optimal maturities and holding periods. As DFA has grown, and perhaps as many other competing investment managers adopted this approach, the excess returns may have diminished. MacKenzie (2006) calls this effective performativity.

Finally, changes in the Federal Reserve Bank policy could significantly affect the information in the term structure. Arnold and Vrugt (2010) show that monetary policy is the most significant predictor of Treasury bond volatility. Given that mid-2004 began a period of transparency over which the Fed moved the target rate in a very predictable manner, results from previous periods may no longer hold.

In this study, we examine the information in the U.S. Treasury term structure of interest rates and provide two important contributions to the literature. First, we extend the work of Fama (1984a) using constant maturity Treasury (CMT) data and a common curve fitting procedure based on the work of Nelson and Siegel (1987) and Svensson (1995). A curve fitting procedure is required since a complete set of prices for each maturity is not available for CMT data. We find that the essential analytical conclusions remain whether one uses the original Fama

Treasury Bills Term Structure files (Fama data) contained on the CRSP Monthly U.S. Treasury Database, the smoothed Fama data, or the smoothed CMT data.[2] This result is important since the full 12 month Fama data no longer exists after March 31, 2000.[3] Although six-month Fama data does exist after this change, the advantage of CMT data is the ability to analyze beyond six months. Therefore, results for the 12-, 18-, and 24-month are reported here for the first time.

A second and potentially more insightful contribution is found when we extend the time period examined in Fama (1984a) through December 2009. Using data from December 1982 through December 2009, the full period regression results appear to further support the main findings of Fama (1984a). However, an analysis of five-year subperiods reveals a dramatic departure in the nature of the information contained in the U.S. Treasury term structure in recent periods. Specifically, in recent periods, the term structure seems to convey more information about the expected course of interest rates than expected holding period returns. This information-content change occurred prior to the financial crisis and held during the crisis. This shifting of information has important implications for monetary policy, money market fund management, and corporate debt policy. Because the U.S. Treasury term structure is such a vital component of the financial marketplace, this research impacts other areas as well.

2. Data and Curve Fitting Procedure

2.1. Data

The data used in the analysis that follows consist of the CMT data available from the H 15 file produced by the Board of Governors of the Federal Reserve System. We also compare

[2] The smoothed Fama data provides a basis to understand how smoothing may impact the regression results. The CMT data is freely available from the Board of Governors of the Federal Reserve System and is not restricted to the first six months. The data are also available daily, removing the restriction of monthly analysis.

[3] Although March 1, 2001 was the last regularly auctioned one-year U.S. Treasury bill until June 5, 2008, the issuance appeared sporadic between March 2000 and March 2001 with only three bills with maturities greater than 330 days (as reported on CRSP). Thus, the Fama data on CRSP is incomplete after March 2000.

our results with Fama data available on CRSP. Using the curve-fitting method described below, we build a database of monthly discount factors. Our curve-fitting methodology follows Nelson and Siegel (1987) and Willner (1996), which was extended by Svensson (1995). Brooks and Yan (1999) also applied this curve-fitting technique.

The CMT data starts in January 1962, however, three-month and six-month CMT rates were unavailable until January 1982. The one-month CMT rate was not provided until July 2001. Because our focus is on the short end of the term structure, we begin our analysis roughly where Fama (1984a) left off in 1982. The lack of three- and six-month CMT restricts us from conducting CMT analysis prior to 1982. We selected December 1982 as our starting point as it excludes observations from Volcker's M1 experiment from October 1979 through October 1982. This starting point also corresponds with approximately the start of Federal funds rate targeting by the Federal Open Market Committee according to Thornton (2006).[4]

Determining an appropriate notation is fraught with difficult trade-offs and no approach is ideal. We follow the approach taken by Fama (1984a), although an alternative can be found in Fama and Bliss (1987) and Fama (2006). The approach taken here is very detailed at the expense of being a bit more cumbersome. The advantage of our approach is that the calendar time perspective (t) is clearly delineated from the maturity time perspective (τ). The notation used in this paper is summarized here:

τ	denotes maturity time or term to maturity; for example, for zero coupon bond, expressed in fraction of year
t	denotes calendar time, expressed in fraction of year
$r(\tau_j : t_i)$ - τ_j	term yield to maturity, continuously compounded, on a reference bond observed at time t_i
$r(\tau_1 : t_i) = r(t_i)$	one period spot yield to maturity (spot rate), continuously compounded, on a reference bond observed at time t_i

[4] The authors thank an anonymous referee for disentangling several issues related to selection of the appropriate starting date.

$\tilde{h}(\tau_j, \tau_k : t_i + \tau_j - \tau_k)$ - $\tau_j > \tau_k$ holding period rate of return, continuously compounded, τ_j is the term to maturity on the reference bond when purchased, τ_k is the term to maturity on the reference bond when sold, contemplated at time t_i, holding period rate of return realized at point in time $t_i + \tau_j - \tau_k$

$f(\tau_j, \tau_k : t_i)$ - $\tau_j > \tau_k$ forward rate, continuously compounded, where τ_j denotes the final point on the term structure, τ_k denotes the initial point on the term structure, observed at time t_i, $f(\tau_1, \tau_0 : t_i) = r(t_i)$

$\tilde{\Pi}_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau) = f(\tau_j, \tau_{j-1} : t_i) - \tilde{f}(\tau_{j-1}, \tau_{j-2} : t_i + \Delta\tau)$ long position in forward rate contract, expressed in rates

$\tilde{\Pi}_{Short}(\tau_j, \tau_{j-1} : t_i + \Delta\tau) = \tilde{f}(\tau_{j-1}, \tau_{j-2} : t_i + \Delta\tau) - f(\tau_j, \tau_{j-1} : t_i)$ short position in forward rate contract, expressed in rates

Prices or yields are observed at calendar time t and are used to calculate the one period spot rate $r(t_i)$, single period forward rate $f(\tau_j, \tau_{j-1} : t_i)$, and the implied forward-spot differential $f(\tau_j, \tau_{j-1} : t_i) - r(t_i)$. In order to maintain consistency with other variables, period profits $\tilde{\Pi}_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau)$ or $\tilde{\Pi}_{Short}(\tau_j, \tau_{j-1} : t_i + \Delta\tau)$ are expressed in continuously compounded period rates. Finally, at the end of the calendar period $t + (j-1)\Delta t$, the future spot rate $r(t_i + (j-1)\Delta t)$ for the single period $t + j\Delta t$ is observed which is used to calculate the cumulative change in the spot rate $r(t_i + (j-1)\Delta t) - r(t_i)$.

Figure 1, Panel a illustrates the behavior of the Fama smoothed data (FSD) one month spot rate annualized and the smoothed CMT data. Several observations can be made from this graph. First, on average, the spot rates decline over our period of study. Second, the maturity time smoothing technique provides fairly accurate estimates of the one-month spot rates. Finally, comparing the two spot rates there appears to be a significant decrease in variability once the one-month CMT rate becomes available.[5] Hence, we observed some deviation of CMT estimates from Fama estimates prior to July 31, 2001. After this date, the difference is quite small.

Panel b further illustrates the estimation error between Fama smoothed data (FSD) and Fama original data (FOD), as well as that between CMT smoothed data (CMT) and FSD. Clearly, the addition of one-month CMT in 2001 decreased the deviation between CMT and FSD considerably. Therefore, using CMT data after July 31, 2001 is expected to provide similar results to Fama data.

Insert Figure 1 about here

2.2. Curve-Fitting Procedure

After July 31, 2001, CMT data is available for one, three, and six months as well as for one to three, five, seven, ten, 20, and 30 years. Following Fama (1984a) we examine monthly horizons. Hence, a methodology is needed to estimate a monthly CMT curve. Svensson (1995) developed an accurate methodology based on the work of Nelson and Siegel (1987). Steeley (2008) provides a detailed examination of a variety of term structure estimation methods to the U.K. STRIPS market and finds the Nelson and Siegel (1987) method to be extremely robust. We call this approach the LSC model because it estimates for level, slope, and curvature. We use the general form that can be expressed as $r(\tau_j : t_i) = \sum_{n=0}^{N} b_{n,t} C_{j,n}(\tau_j; s_{n-1})$ where $C_{j,0}(\tau_j; s_{-1}) = 1$, $C_{j,1}(\tau_j; s_0) = \frac{\tau_j}{s_1}\left[1 - \exp\left\{-\frac{s_1}{\tau_j}\right\}\right]$, and $C_{j,n}(\tau_j; s_{n-1}) = \frac{\tau_j}{s_{n-1}}\left[1 - \exp\left\{-\frac{s_{n-1}}{\tau_j}\right\}\right] - \exp\left\{-\frac{s_{n-1}}{\tau_j}\right\}$; for $n > 1$, where s_n denotes a scalar that applies various weights to different locations on the term structure. The five-parameter version with fixed scalars 0.25, 0.75, 2.0, and 4.0 is applied for CMT since

[5] Prior to July 31, 2001 the one-month CMT is unavailable. On July 31, 2001 the H 15 file began reporting a one-month CMT "...which the Treasury began calculating when it introduced the 4-week bill." See www.federalreserve.gov/feeds/h15.html.

maturities extend to 30 years. For Fama smoothed data we use the fixed scalars 0.1, 0.2, 0.3, and 0.4 since maturities only extend to six months. A range of scalars was applied with similar results as long as more than two scalars are used.

2.3. Forward-Spot Differential

Following Fama (1984a, 1984b, and 2006), the forward-spot differential can be expressed as

$$f(\tau_j, \tau_{j-1} : t_i) - r(t_i) = E_{t_i}\left[\tilde{r}(t_i + (j-1)\Delta\tau)\right] - r(t_i)$$
$$+ E_{t_i}\left[R\tilde{P}(\tau_j : t_i + \Delta\tau)\right] + \sum_{k=2}^{j-1}\left\{E_{t_i}\left[R\tilde{P}(\tau_{j-k+1} : t_i + k\Delta\tau) - R\tilde{P}(\tau_{j-k+1} : t_i + (k-1)\Delta\tau)\right]\right\}$$

for all forward rates j, and all time t_i, where E_{t_i} is the conditional expectation operator over time t_i information and $R\tilde{P}(\tau_{j-k+1} : t_i + k\Delta\tau)$ is the return premium defined as the excess holding period rate of return over the current spot rate. The return premium in this context can be viewed as the profits on a portfolio of forward contracts

$$R\tilde{P}(\tau_j : t_i) = \sum_{k=2}^{j} \tilde{\Pi}_{Long}(\tau_k, \tau_{k-1} : t_i + \Delta\tau) = \sum_{k=2}^{j}\left\{f(\tau_k, \tau_{k-1} : t_i) - \tilde{f}(\tau_{k-1}, \tau_{k-2} : t_i + \Delta\tau)\right\}$$

An advantage to this methodology is that the forward-spot differential can be viewed as a combination of information related to the expected change in spot rates and information related to the expected change in the return premium. For a given forward-spot differential, if the expected change in the spot rate increases, then the expected change in the return premium must decrease.

Most studies of the expectations hypothesis of the term structure of interest rates find little empirical support for the theory. Some of the most compelling results include: Shiller, Campbell, and Schoenholtz (1982); Campbell and Shiller (1987); Fama and Bliss (1987); Shiller

(1990); Campbell and Shiller (1991); and Evans and Lewis (1994).[6] The lack of empirical support is generally explained by the expected return premium not being constant. Interestingly, while the findings against the hypothesis for short term rates is quite strong, the literature is still not unanimous regarding its plausibility with respect to long term rates.

Fama (1986) finds that the yield curve for U.S. Treasury bills from six to 12 months has no predictive power for the subsequent six month rate, but does find some predictive power for the CD yield curve from six to 12 months. Fama and Bliss (1987) regress short term rate changes on the linear combinations of two different yield spreads, which they call "forward premia," and find the forecasting power of the term structure to be quite strong for large yield spreads. Campbell and Shiller (1991) reject the expectations hypothesis for all combinations of the short-term and long-term rates when the long-term maturity was less than four years, but reject only once when the long-term maturity was four years or greater.

Cochrane and Piazzesi (2002) study monetary policy shocks, defined from federal funds target movements relative to daily interest rate data, for the period 1984 to 2001. They find long term rates to be a far more effective predictor of Federal Reserve moves than short-term rates. They conclude, "the Fed responds to long-term interest rates, perhaps embodying inflation expectations, and to the slope of the term structure, which forecasts real activity" (p. 95). Heuson and Su (2003) examine the effects of macroeconomic announcements on implied volatilities in the Treasury sector index option market and conclude that implied volatilities are predictable. Wang, Yang, and Simpson (2008) study currency markets and document that futures prices react to both changes in the target rate and the path of the expected rate change.

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[6] For a more exhaustive survey of these rejections, see Cook and Hahn (1990), Brooks and Livingston (1992), and Rudebusch (1994).

3. Empirical Results

Recall one purpose of our study is to extend the time period examined through December 2009 to determine if more recent changes in preferred habitat, effective performativity, or changes in Fed policy have altered the information in the term structure.

3.1. Basic Regressions

Based on the expectations hypothesis, Fama (1984a) estimates the following time series regressions to assess the predictive ability of forward rates:

$$RP(\tau_j : t_i + \Delta\tau) = \alpha_1 + \beta_1\left(f(\tau_j, \tau_{j-1} : t_i) - r(t_i)\right) + \varepsilon_{t+1} \qquad \text{(Regression 1)}$$

$$r(t_i + (j-1)\Delta\tau) - r(t_i) = \alpha_2 + \beta_2\left(f(\tau_j, \tau_{j-1} : t_i) - r(t_i)\right) + \eta_{t+\tau-1} \qquad \text{(Regression 2)}$$

These regressions determine whether the current forward-spot differential $f(\tau_j, \tau_{j-1} : t_i) - r(t_i)$ has power to predict either the return premium $RP(\tau_j : t_i + \Delta\tau)$ or the future change in the one period spot rate $r(t_i + (j-1)\Delta\tau) - r(t_i)$. Results suggesting that β_1 is significantly positive indicate that the forward rate observed at time t contains information regarding the return premium to be observed at time $t_i + \Delta\tau$. Results suggesting that β_2 is significantly positive indicate that the forward rate observed at time t contains information regarding the one period spot rate to be observed at time $t_i + (j-1)\Delta\tau$. β_1 and β_2 are linked based on the covariance between the expected return premium and the expected change in rates. If this covariance is zero and the current expected changes in return premiums are zero, then β_1 and β_2 sum to one. As our results show, the betas often do not sum to one, but are close. Hence, if we observe when one beta is declining over time, then the other beta is typically increasing.

Under the pure expectations hypothesis, forward rates contain no return premiums, and consequently are unbiased predictors of future spot rates. Thus, the expectations hypothesis in its purest form suggests that the slope coefficient in regression 1 be 0.0 and the slope coefficient in regression 2 be 1.0. Alternatively, in the case where the forward rate contains information regarding future spot rates and return premiums do exist, both slope coefficients may be greater than 0.0.

Our investigation first seeks to find out whether significant differences exist between three data sets, the original Fama data set (Fama unsmoothed), a smoothing procedure is applied to the original data set (Fama smoothed), and smoothed rates derived from CMT yields (CMT). Specifically, regressions (1) and (2) are run on monthly continuously compounded forward rates derived from these three datasets from December 1982 to December 2009. The goal is to determine empirically if implied forward rates contain information about return premiums $RP(\tau_j : t_i + \Delta\tau)$ or the future change in the one period spot rate $r(t_i + (j-1)\Delta\tau) - r(t_i)$ in these three datasets.

Although not reported here, we find no significant difference between these three datasets for the full period 1982-2009. These results are available upon request. Interestingly, however, there appear to be some differences in the more recent time period. For example, we examined the last five-year subperiod for each of our three databases. The overall rate volatility is lower for shorter maturities and the pattern is very different from Fama (1984a). The standard deviation of the difference between forward rates and subsequently observed spot rates is lower than the standard deviation of the changes in the spot rates for the same horizon. These results are inconsistent with Fama (1984a), Hamburger and Platt (1975), Fama (1976), and Shiller, Campbell and Schoenholtz (1982). Thus, the more recent period suggests that unadjusted forward rates provide better forecasts of subsequently observed spot rates than the current spot rate, a dramatic change from empirical observations from the past.

Table 1 reports the results for regressions 1 and 2 for the full sample period as well as for five subperiods of five years' duration. Although we follow Fama (1984a) and report the values of β and R^2 for each sample period, we construct all *t*-statistics using robust standard errors. The use of robust standard errors allows us to control for potential heteroskedasticity and serial correlation in the regression residuals. This control is especially important because maturity time smoothing of the data may introduce serial correlation and since regression 2 contains overlapping observations. We report results using Newey-West standard errors with a truncation lag that exceeds the degree of overlap in the data. Results using other truncation windows, such as a flat window, are quite similar and available upon request. The return premium regressions address whether the forward minus spot differential contains information regarding the return premium $\mathrm{RP}(\tau_j : t_i + \Delta\tau)$, and the rate change regressions address whether the forward minus spot differential contains information regarding the subsequent spot rate changes.

Insert Table 1 about here

Table 1 reveals that, over the entire sample period, the CMT smoothed data results in statistically significant beta coefficients for both return premium regressions and rate change regressions. For example, the first entry in Table 1 indicates that, over the full sample period, the value of β_1 for the one-month return premium is 0.44 with a *t*-statistic of 5.51 and R^2 of 0.11. For regression 1, the coefficients generally rise across maturities and all have robust *t*-statistics that are significant at the 5% level. For regression 2, the coefficients are quite stable across the maturities (the range is 0.33 to 0.58) and all are statistically significant at the 5% significance level, except the 18 and 24 month.

The remainder of the table contains the results for five consecutive five-year periods. The key insight is that regression 1 fails to be significant during the December 1989 through

December 1994 period and during the last two subperiods. Most of the point estimates of β_1 are quite close to zero and none are statistically significant at the 5% level. This result is in contrast to the subperiod results for regression 2. Notice that for 2 through 6 months, all but one of the coefficients are significant at the 5% level, and within each subperiod are relatively stable across maturities. For subperiods December 1984-December 1989 and December 1994-December 1999, regression 2 does not result in significant beta coefficients for longer maturities (12, 18, and 24 months).

Notice that the movements in β_1 and β_2 coefficients mirror each other and sum to approximately one. One advantage of the Fama (1984a) methodology is that forward-spot differential can be viewed as a combination of information related to the expected change in spot rates and information related to the expected change in the return premium. Hence β_1 and β_2 are linked based on the covariance between the expected return premium and expected change in rates. If this covariance is zero, and the current expected change in return premiums are zero, then β_1 and β_2 sum to one. As our results show, the betas often do not precisely sum to one, but are close and move in opposite directions toward the end of our sample period.

Also note that the results for the last two subperiods are similar in nature, but the financial market dynamics for these periods were drastically different. In the 99-04 time frame, interest rates fell drastically. In the 04-09 period, interest rates rose predictably and then fell sharply in response to the financial crisis. Yet the information content of the term structure appears similar.

3.2. More Specific Regressions

Since regression 2 measures the cumulative change in the one period spot rate from t to $t+\tau+1$, overlapping observations exist in the dependent variable. It is possible that the significantly positive β_2 coefficients for longer maturities in these results are driven only by the significance of one particular maturity contract. To test exactly which forward rates contain information, Fama (1984a) supplements regressions 1 and 2 with the following regressions:

$$\Pi_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau) = \alpha_3 + \beta_3(f(\tau_j, \tau_{j-1} : t_i) - f(\tau_{j-1}, \tau_{j-2} : t_i)) + \varepsilon_{t+1} \quad \text{(Regression 3)}$$

$$r(t_i + (j-1)\Delta\tau) - r(t_i + (j-2)\Delta\tau) = \alpha_4 + \beta_4(f(\tau_j, \tau_{j-1} : t_i) - f(\tau_{j-1}, \tau_{j-2} : t_i)) + \eta_{t+\tau-1} \quad \text{(Regression 4)}$$

These tests provide more precise evidence of exactly where information manifests itself by considering the forecasting power of adjacent maturities.

Regressions 3 and 4 determine whether the current forward rate spread between two adjacent maturity forward rates $f(\tau_j, \tau_{j-1} : t_i) - f(\tau_{j-1}, \tau_{j-2} : t_i)$ has power to predict either the forward contract profits (components of the return premium) $\Pi_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau)$ in regression 3, or the difference in the one month spot rate $r(t_i + (j-1)\Delta\tau) - r(t_i)$ in regression 4. Regression 3 compliments regression 1 by testing whether forward rates are reliable predictors of holding period returns on adjacent maturities.

Regression 4 compliments regression 2 by confining the forecasting power of forward rates on the specific one period change in the spot rate. Fama (1984a) reports coefficients β_3 and β_4 to be positive and less than one, indicating that the forward rate has power to predict both the holding period returns and changes in spot rates. Specifically, he finds for the sample period February 1959-July 1982 that the one-month forward rate has power to predict the spot rate one month ahead. He also finds the relation between forward rates and future holding period returns to be much stronger than the relation between forward rates and spot rates. His regression results indicate that, for his entire same sample period, forward rates are useful predictors of the next holding period return for every maturity.

Table 2 reports the results for regressions 3 and 4 for the full sample period as well as for five subperiods of five years' duration. Again, all *t*-statistics are constructed using robust standard errors to control for heteroskedasticity and serial correlation. The profit regressions address whether the forward rate spread contains information regarding the profit on a forward rate agreement $\Pi_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau)$, while the incremental rate change regressions address whether the forward rate spread contains information regarding the subsequent incremental spot rate changes.

Insert Table 2 about here

The results reported in Table 2 for the full period are similar to Fama (1984a). For regression 3, maturities 2, 3, and 4 months have estimated values of β_3 that are significant at the 1% level. However, the relationship appears to break down for the subperiods. Notice that none of the coefficients are significant for the December 1999-December 2004 or December 2004-December 2009 periods. When we estimate regression 4 over the full sample period, we find that the coefficients are only significant for the first two holding periods. All coefficients for the December 1989-December 1994 period, except month 12, are significant at the 5% level. The first month is significant for all subperiods. The last two subperiods have significance at both the near term and long term, but not the intermediate term. Although not reported here, the results are similar for both Fama smoothed and unsmoothed data.

Note that the predictability of forward rates appears stronger in the 99-04 period when compared with the 04-09 financial crisis period. During the crisis period, the 2nd through 5th incremental forward rates are not significantly different from zero (04-09 period) as they are in the 99-04 period.

Table 3 reports the standard deviations of FRA profits, forward rate spreads, and changes in spot rates. When compared to Fama (1984a), the standard deviations are much lower for this time period. Although not reported here, the Fama smoothed and unsmoothed data provided similar results. Overall, the standard deviations fell over this time period to an unusually low level. Interestingly, during this updated time period, the decreased variability in *ex post* returns (FRA profits) and changes in spot rates are apparently compensated by proportional decreases in the variability of their expected returns. (See Fama (1984a), pages 521-522.)

Insert Table 3 about here

Before turning to selected robustness tests, we again offer several potential explanations for the shifting information content of the U.S. Treasury term structure of interest rates. We leave for further research the task of providing additional evidence related to these and other explanations.

First, the observed shift might be due to changes in investors' preferred habitat, perhaps driven by changing demographics. The heightened demand for short-term debt instruments by a retiring population could have reduced the liquidity demand for long-term debt instruments, thus changing the information content of the term structure.

The observed shift may be due to what MacKenzie (2006) calls "effective performativity." The notion is that learning about an economic process can affect the nature of the process itself. As the excess return of longer-term bonds over the expected future spot rate became better understood, economic agents sought to earn this premium. The act of many agents trying to capitalize on such knowledge, affected everyone's ability to actually earn an excess return. For example, Dimensional Fund Advisors, Inc. (DFA) follows a "variable maturity" approach developed by Professor Eugene Fama in their strategies, using the current term structure to determine optimal maturities and holding periods.[7] As DFA grew and perhaps many other competing investment managers adopted this approach, the excess returns may have diminished.

Finally, the observed shift may be linked to changing Federal Reserve Bank policy. For example, beginning in mid-2004, the published target Federal funds rate increased 17 times in a fairly predictable pattern of 25 basis points from 1.00% to 5.25% by mid-2006. The target federal funds rate then remained at 5.25% for more than one year. Prior to this point in 2004, the next closest predictable trend was 2001 when rates declined from 6.50% to 1.75%; however, the size of the incremental changes varied between 25 and 50 basis points and the timing was less predictable. For example, there were two 50-point decreases in the rate in January 2001.[8] Again, further analysis into these potential explanations is beyond the scope of this paper.

In order to get a better sense of the nature of the shifts, we re-estimate Regressions 1 through 4 using a rolling window analysis and perform tests for the existence of multiple structural breaks.

3.3. Rolling Window Analysis

To better understand when the degradation in the values of the βs begin, we estimate regressions 1 through 4 using a rolling window of 60 observations. Beginning with the December 1982-July 1987 sample period, we estimate regressions 1 through 4 and constructed a ± 2 standard deviation confidence interval for the estimated values of β_i. To correct for heteroskedasticity and serial correlation, the confidence intervals are constructed using robust standard errors. We repeat the procedure eliminating the first observation and updating the last

[7] "To maximize expected returns, we choose shorter maturities in flat or inverted yield curve environments and longer maturities in upward sloped curves. Maturities are shifted in response to changes in the current yield curve. See http://www.dfaus.com/strategies/fixed-income.html. DFA had about $12 billion in fixed income under management as of September 2010.

[8] The authors thank an anonymous referee for the possible connection with target federal funds rates.

by one period. We continued forming 60-period rolling windows through the December 2004-December 2009 period. The point estimates of various β_i and the ± 2 standard deviation confidence bands are shown in Figures 2 though 7. In order to save space, we illustrate the results for only the two-, four-, six-, 12-, 18-, and 24-month maturities. This analysis reveals four key findings.

First, regarding regression 1, for the two-month maturity reported in Figure 2, the estimate of β_1 declines until 1991, remains reasonably stable through 2003, and then begins a steady decline toward zero. From mid-2003 through the end of the sample, it is almost impossible to reject the null hypothesis that $\beta_1 = 0$. Notice that in December 2007, the confidence band expands sharply as a result of several dramatic changes in the term structure partially in response to Federal Open Market Committee announcements related to the ongoing financial crisis. Nevertheless, the point estimates of β_1 remain quite close to zero throughout the end of the sample. Except for the post-December 2007 period, a very similar pattern holds for all of the other maturities. However, because of the large standard errors for this period, it is difficult to interpret the apparent upturn in β_1 for the longer maturities.

For regression 2, the two-month maturity β_2 coefficients rise until 1991 and then are stable until the end of 2002. At that point, the estimate of β_2 slowly increases until a large spike in 2007. Notice that the null hypothesis that $\beta_2 = 0$ is soundly rejected (except for one observation). Perhaps the most interesting result is that the movements in β_1 and β_2 almost mirror each other in that the sum almost always is close to unity. The other maturities all have the property that β_2 rises through 1991 and the property that the coefficient estimates peak in the early 1990s and near the end of the sample period.

Third, by construction, regressions 1 and 3 are necessarily identical for the two-month maturity. It is somewhat surprising to find, however, such a strong relationship between regressions 1 and 3 when we use the four-month maturity. This being said, some care needs to be used in concluding that the two are quite similar since the coefficient estimates from the four month maturity are insignificantly different from zero beginning in mid-1992, with the exception of a few brief periods. However, for the six-month maturity, the coefficient estimates from regression 3 are nearly always insignificantly different from zero. For the longer maturities of 12, 18, and 24, β_3 is sometimes statistically positive. However, after 1995 (except for a brief period around 2003), β_3 is not statistically different from zero.

Finally, the estimates of β_4 are generally quite erratic (notice that the scales used to construct Panel d are smaller than those for Panel b). Nevertheless, in comparing Panels b and d, notice that the shapes of the graphs are quite similar. For the two-, four- and six-month maturities, the estimates of β_4 drop sharply in 1992, but rebound by the end of 1994. Also notice that these maturities exhibit sharp drops at the end of 2007. For the longer maturities of 12, 18, and 24 months, β_4 behavior is very different, rising to statistical significance in the later part of the sample period.

Insert Figure 2-7 about here

3.4. Multiple Structural Breaks

Andrews and Ploeberger (1994) develop a test to estimate a single structural break occurring in the slope coefficient at an unknown date. Consider the regression equation

$$y_t = a + b_j x_t + \varepsilon_t$$

where: $j = 1$ for $t < T_B$, $j = 2$ for $t \geq T_B$, and T_B is the time period at which the break occurs.

Notice that the series follows the process $y_t = a + b_1x_t + \varepsilon_t$ prior to T_B, and follows the process $y_t = a + b_2x_t + \varepsilon_t$ beginning at T_B. As such, there is a structural break in the model such that the coefficients change at T_B. If the break date is known, it is possible to estimate a regression equation through $T_B - 1$ and the other from T_B to the end of the sample. A Chow test for the equivalence of the coefficients (*i.e.*, $b_1 = b_2$) can be conducted using a standard *F*-test. Rejecting the null hypothesis of coefficient stability is equivalent to accepting the alternative of a structural break occurring at T_B. However, if the break date is unknown, a different method is necessary.

Andrews and Ploeberger (1994) show that it is possible to search for the break date by performing a Chow test for every possible break date. To ensure that there are an adequate number of observations in regression, it is standard to use only the values of T_B within the middle 90% of the sample. If a break actually is present in the data, the value of T_B producing the best fit is a consistent estimate of the actual break date. The null hypothesis of structural stability is tested against the alternative hypothesis of a one-time structural break using the Andrews and Ploeberger (1994) supremum *F*-test. Bai and Perron (2003) generalize this methodology to allow for *m* structural breaks. To be consistent with Bai and Perron (2003), we allow for a maximum of five breaks with the restriction of each having the duration of at least one year. We follow the recommended procedure and test the null hypothesis of no breaks against the alternative hypothesis of the maximum number of breaks (i.e., five breaks). If the null hypothesis is rejected, we select the number of breaks using the BIC.

For each maturity, column 2 of Table 4 reports the sample values of the supremum *F*-test for the null hypothesis of coefficient stability versus the alternative hypothesis of five breaks. Interestingly, for both regressions 1 and 3 we can always reject the null hypothesis of no structural change using Bai and Perron's (2003) 99% critical value. Column 3 of the table reports the number of breaks (b) selected by the BIC, column 4 reports the estimated break dates, and column 5 reports the BIC for no breaks and for the estimated number of breaks. Since the BIC is expressed in logarithms, the more negative the BIC, the better the fit of the model. As indicated in the table, when we apply the Bai and Perron (2003) methodology to regression 1 for the two month maturity, we find three breaks occurring in July 1984, October 1987, and November 2007. The sample value of F-value for the null of zero versus five breaks is 9.85; this value is significant at any conventional significance level. Moreover, the BIC indicates that the fit of the three-break model is superior to that of a model assuming coefficient stability. Although three breaks might seem excessive, notice that the estimated values of β_1 shown in Panel a of Figure 2 decay slowly. As is well known, the Bai-Perron procedure mimics smooth changes with a succession of sharp breaks (as in a step function).

The key feature of the table is that all maturities for both regressions are found to have multiple structural breaks indicating smooth structural change. Although there are some idiosyncratic dates, notice that the selected breaks seem to cluster around the mid-1984 to mid-1987 period and around the end of the sample. Without a formal causal analysis, we cannot hope to pinpoint the underlying reasons for the changes. The task is complicated by the fact that the evolution of the slope coefficients is smooth, rather than sharp. However, as suggested by an anonymous referee, it possible to surmise that the first cluster is associated with the turmoil caused by the failure of Continental Illinois and with the October 1987 market crash. For a detailed analysis of the Continental Illinois Bank failure and the regulatory agencies' decision in May 1984 to insure all deposits, see O'Hara and Shaw (1990). It also seems likely that breaks near the end of the sample are associated with the financial crisis of 2007.

Perhaps the most interesting result is not reported in the table. We found little evidence of breaks in regressions 2 and 4 for any holding period exceeding two. The point is the marginal regressions display a great amount of stability. In contrast, there is strong evidence that the coefficients of regressions 1 and 3 have significantly changed from the early portions of the sample.

Insert Table 4 about here

4. Conclusion

We use CMT yields and a smoothing procedure to assess information in the U.S. Treasury term structure of interest rates. The results presented suggest that forward rates have power to forecast spot rates but not return premiums for recent periods of U.S. Treasury market activity. The forecasting of spot rates appears significant for both the near and long maturities for the most recent 10-year period examined. Most important perhaps is the finding that β_1 and β_2 coefficients actually move in opposite directions during this later time period. These results contrast with the findings of earlier studies of the term structure, which document that forward rates have power to predict U.S. Treasury bill return premiums for an earlier time period.

Our research is important for at least two reasons. First, it provides an update of important term structure research. More importantly, since CMT data is available for longer maturities than U.S. Treasury bills and is available on a daily basis, our study lays the groundwork for investigating the information contained in longer maturity forward rates as well as in holding periods shorter than one month.

References

Arnold, I., and E. Vrugt, 2010. Treasury bond volatility and uncertainty about monetary policy, *The Financial Review* 45, 707-728.

Andrews, D. and W. Ploeberger, 1994. Optimal tests when a nuisance parameter is present only under the alternative, *Econometrica* 62, 1383-1414.

Bai, J. and P. Perron, 2003. Computation and analysis of multiple structural change models, *Journal of Applied Econometrics* 18, 1-22.

Brooks, R. and M. Livingston, 1992. The difference between the local and unbiased expectations hypothesis, *Review of Quantitative Finance and Accounting* 2, 377-389.

Brooks, R. and D. Yan, 1999. London inter-bank offer rate (LIBOR) versus treasury rate: Evidences from the Parsimonious Term Structure Model, *Journal of Fixed Income* 9, 71-83.

Campbell, J. and R. Shiller, 1987. Cointegration and tests of present value models, *Journal of Political Economy* 95, 1062-1088.

Campbell, J. and R. Shiller, 1991. Yield spreads and interest rates movements: A bird's eye view, *Review of Economic Studies* 58, 495-514.

Cochrane, J. and M. Piazzesi, 2002. Asset prices and monetary policy: The Fed and interest rates – a high-frequency identification, *AEA Papers and Proceedings* 92, 90-95.

Cook, T. and T. Hahn, 1990. Interest rate expectations and the slope of the money market yield curve, *Economic Review* 76, 3-26.

Davis, J., 2000. The information in the term structure: An update, Dimensional Fund Advisors Inc., http://www.dfauk.com/library/articles/information_term_structure/.

Evans, M. and K. Lewis, 1994. Do stationary risk premia explain it all? Evidence of the term structure, *Journal of Monetary Economics* 33, 285-318.

Fama, E., 1976. Forward rates as predictors of future spot rates, *Journal of Financial Economics* 3, 361-377.

Fama, E. 1984a. The information in the term structure, *Journal of Financial Economics* 13, 509-528.

Fama, E., 1984b. Term premiums in bond returns, *Journal of Financial Economics* 13, 529-546.

Fama, E., 1986. Term premiums and default premiums in money markets, *Journal of Financial Economics* 17, 175-196.

Fama, E., 2006. The behavior of interest rates, *Review of Financial Studies* 19, 359-379.

Fama, E. and R. Bliss, 1987. The information in long maturity forward rates, *American Economic Review* 77, 680-692.

Hamburger, M. and E. Platt, 1975. The expectations hypothesis and the efficiency of the treasury bill market, *Review of Economics and Statistics* 57, 190-199.

Heuson, A. and T. Su, 2003. Intra-day behavior of treasury sector index option implied volatilities around macroeconomic announcements, *The Financial Review* 38, 161-177.

MacKenzie, D., 2006. An engine, not a camera how financial models shape markets, *The MIT Press*, Cambridge, MA.

Nelson, C. and A. Siegel, 1987. Parsimonious modeling of yield curves, *Journal of Business* 60, 473-489.

O'Hara, M. and W. Shaw, 1990. Deposit insurance and wealth effects: The value of being 'too big to fail', *Journal of Finance* 45, 1587-1600.

Poterba, J., 2001. Demographic structure and asset returns, *Review of Economics and Statistics* 83, 565-584.

Rudebusch, G., 1994. Federal reserve interest rate targeting and the term structure, *Manuscript. Board of Governors of the Federal Reserve System*.

Shiller, R., J. Campbell, and K. Schoenholtz, 1982. Forward rates and future policy: Interpreting the term structure of interest rates, *Brookings Papers on Economic Activity* 1, 173-217.

Shiller, R., 1990. "The term structure of interest rates, B. Friedman and F. Hahn (eds.). *Handbook of Monetary Economics*, North-Holland, Amsterdam.

Steeley, J., 2008. Testing term structure estimation methods: Evidence from the UK STRIPs market." *Journal of Money, Credit and Banking* 40, 1489-1512.

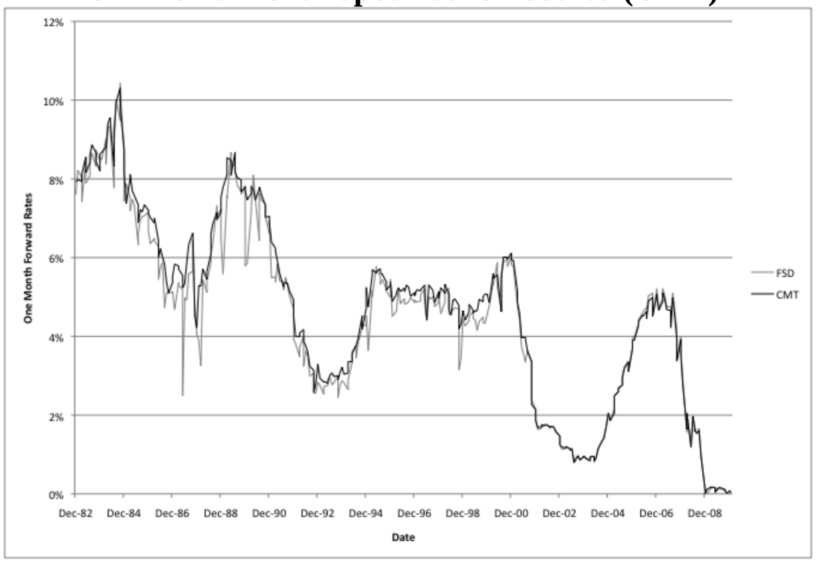
Svensson, L.E.O., 1995. "Estimating forward interest rates with the extended Nelson & Siegel method, Institute for International Economic Studies, Stockholm University, Reprint Series, No. 543 from Quarterly Review (Swedish Central Bank) No. 3, 1995.

Thornton, D., 2006. When did the FOMC begin targeting the federal funds rate? What the verbatim transcripts tell us, *Journal of Money, Credit and Banking* 38, 2039-2071.

Willner, R., 1996. A new tool for portfolio managers: Level, slope, and curvature durations, *Journal of Fixed Income* 6, 48-59.

Wang, T., J. Yang, and M.W. Simpson, 2008. U.S. monetary policy surprises and currency futures markets: A new look, *The Financial Review* 43, 509-541.

Panel a: Fama One Month Spot Rate Smoothed (FSD) and CMT One-Month Spot Rate Smoothed (CMT)



Panel b: Error in Estimating One-Month Spot Rate

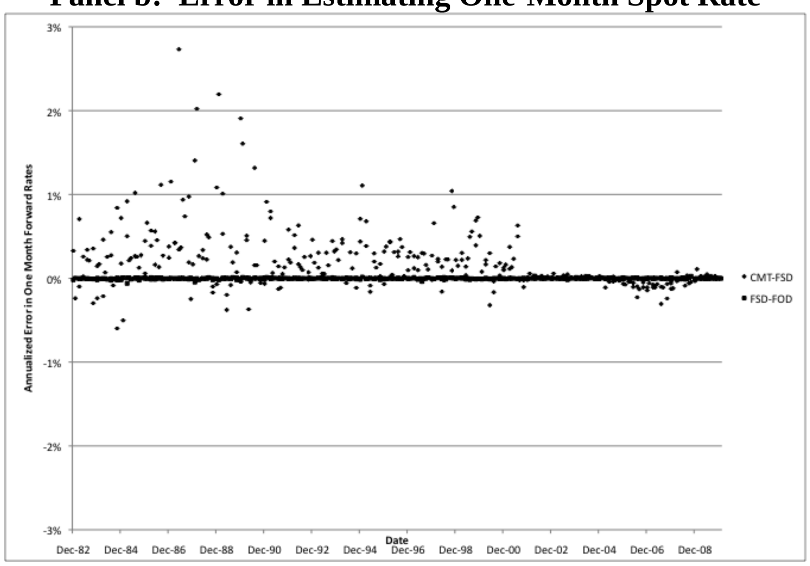


Figure 1.
Comparison of Data

Panel a illustrates the behavior of the smoothed Fama one-month spot rate annualized and the smoothed CMT data. Panel b reports the estimation error between Fama smoothed data (FSD) and Fama original data (FOD), as well as CMT smoothed data (CMT) and FSD. Fama Data is from the Fama Treasury Bills Term Structure files contained on the CRSP Monthly U.S. Treasury Database. CMT is the constant maturity Treasury data available from the H 15 file produced by the Board of Governors of the Federal Reserve System. Data smoothing is based on level, slope, and curvature following Nelson and Siegel (1987).

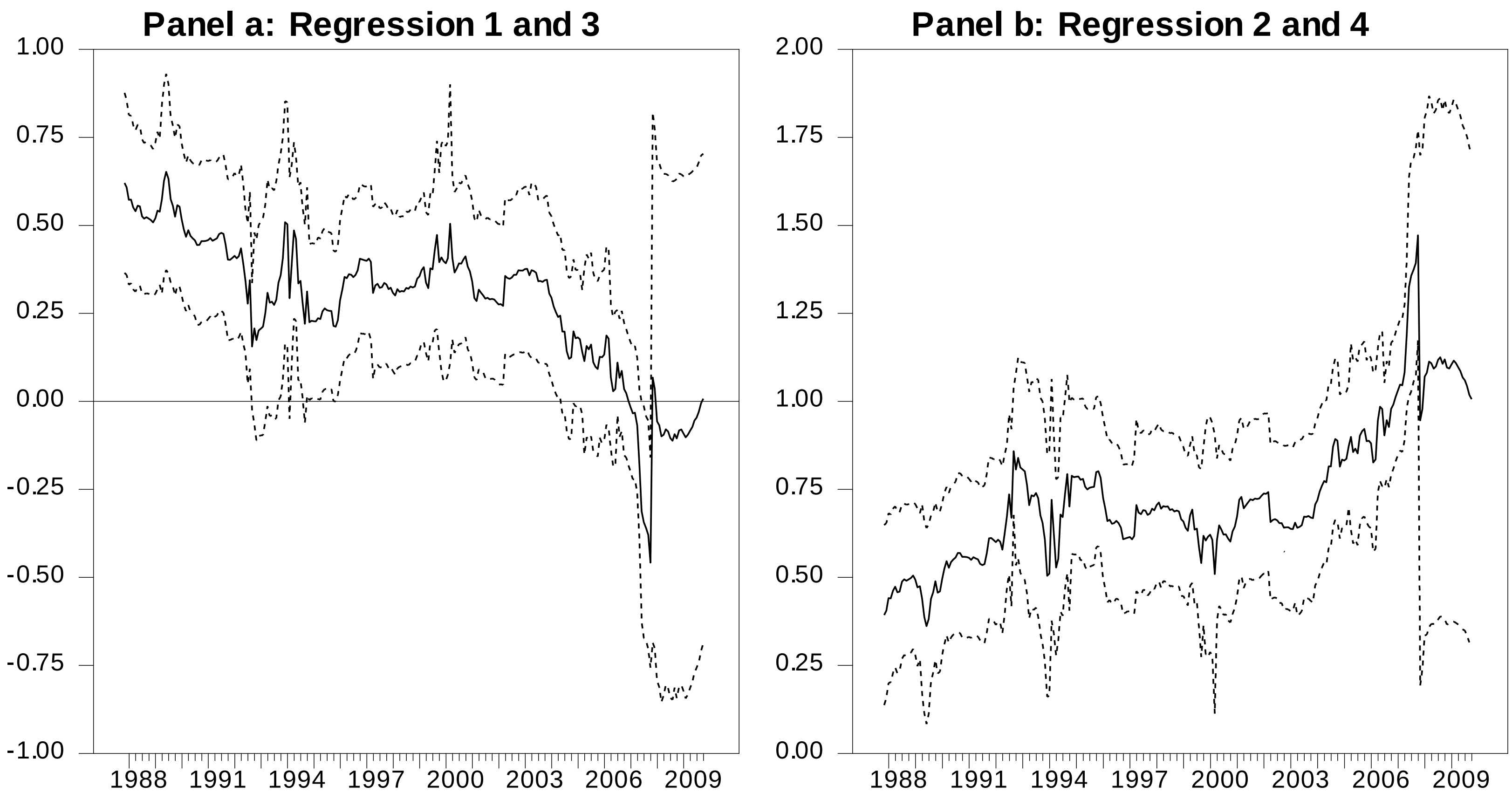


Figure 2.
Two-Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

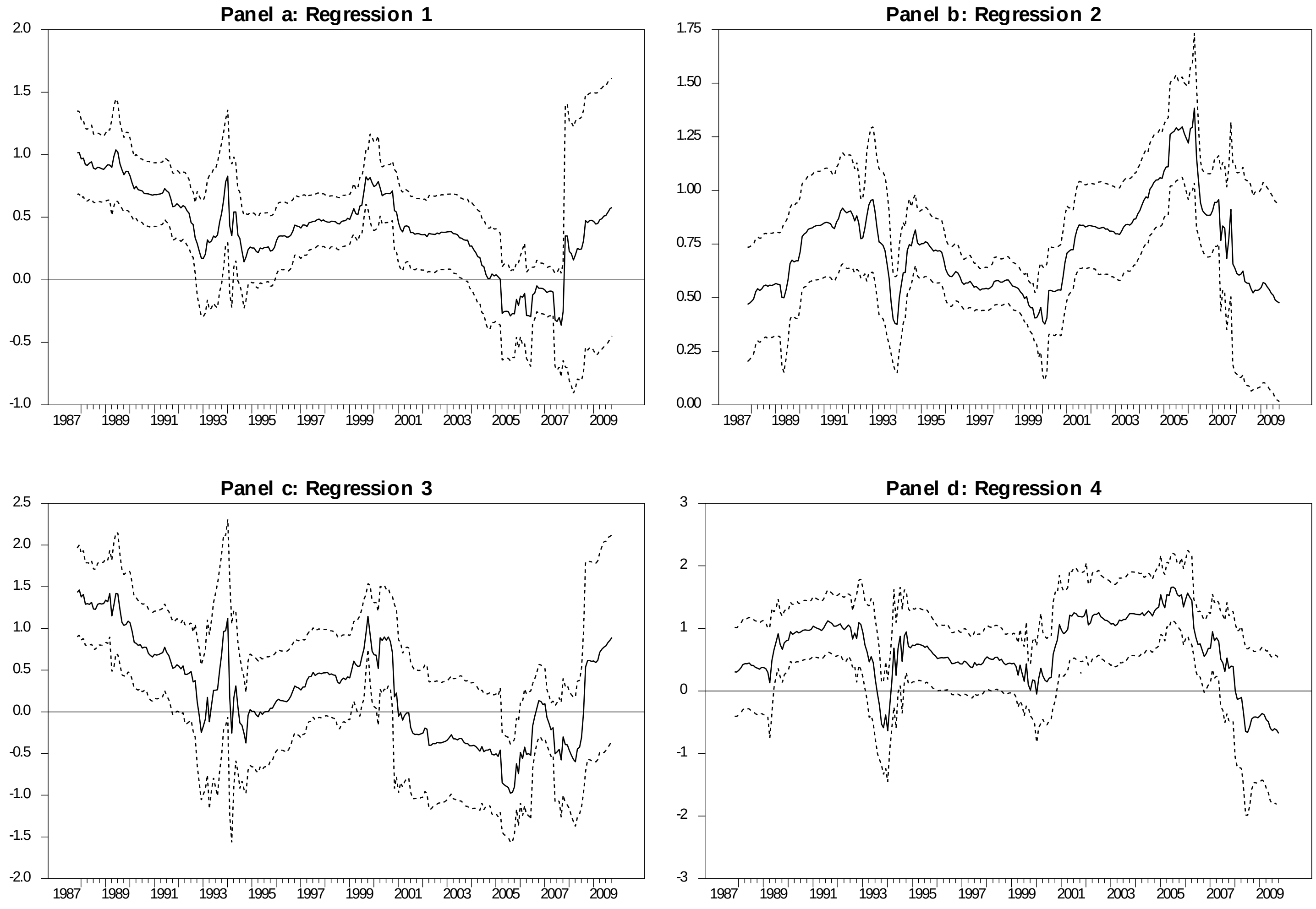


Figure 3.
Four-Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

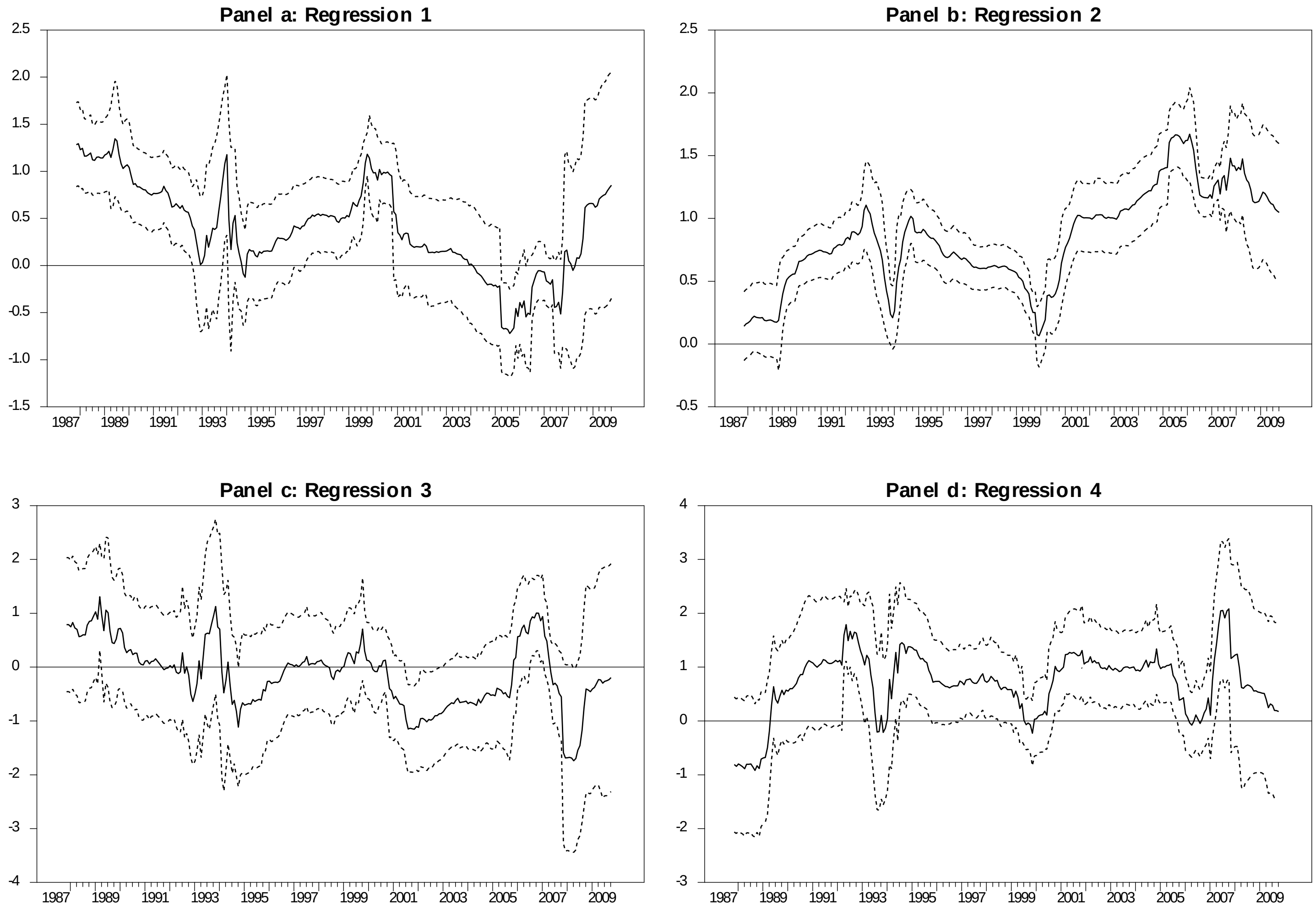


Figure 4.
Six-Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

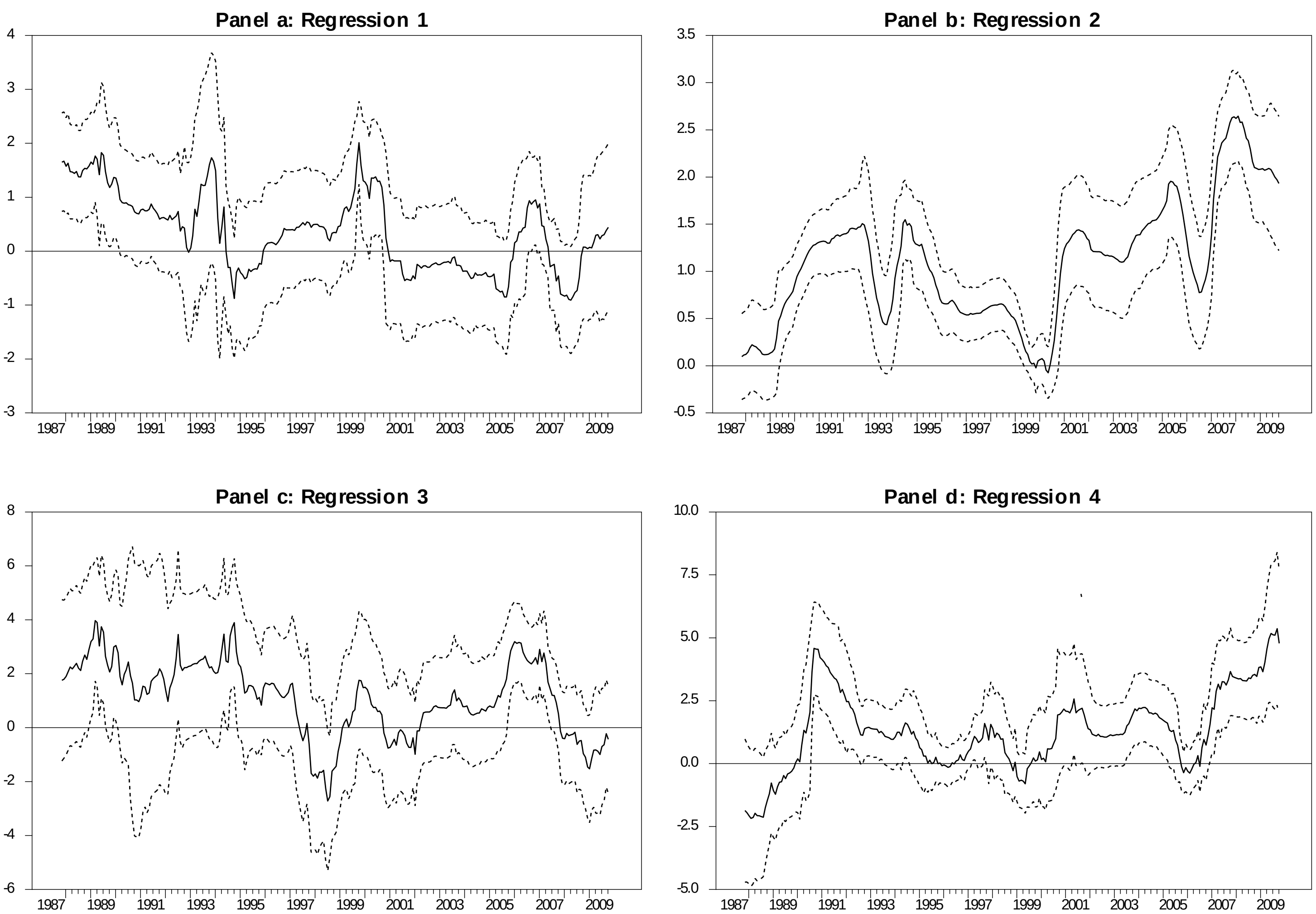


Figure 5.
Twelve-Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

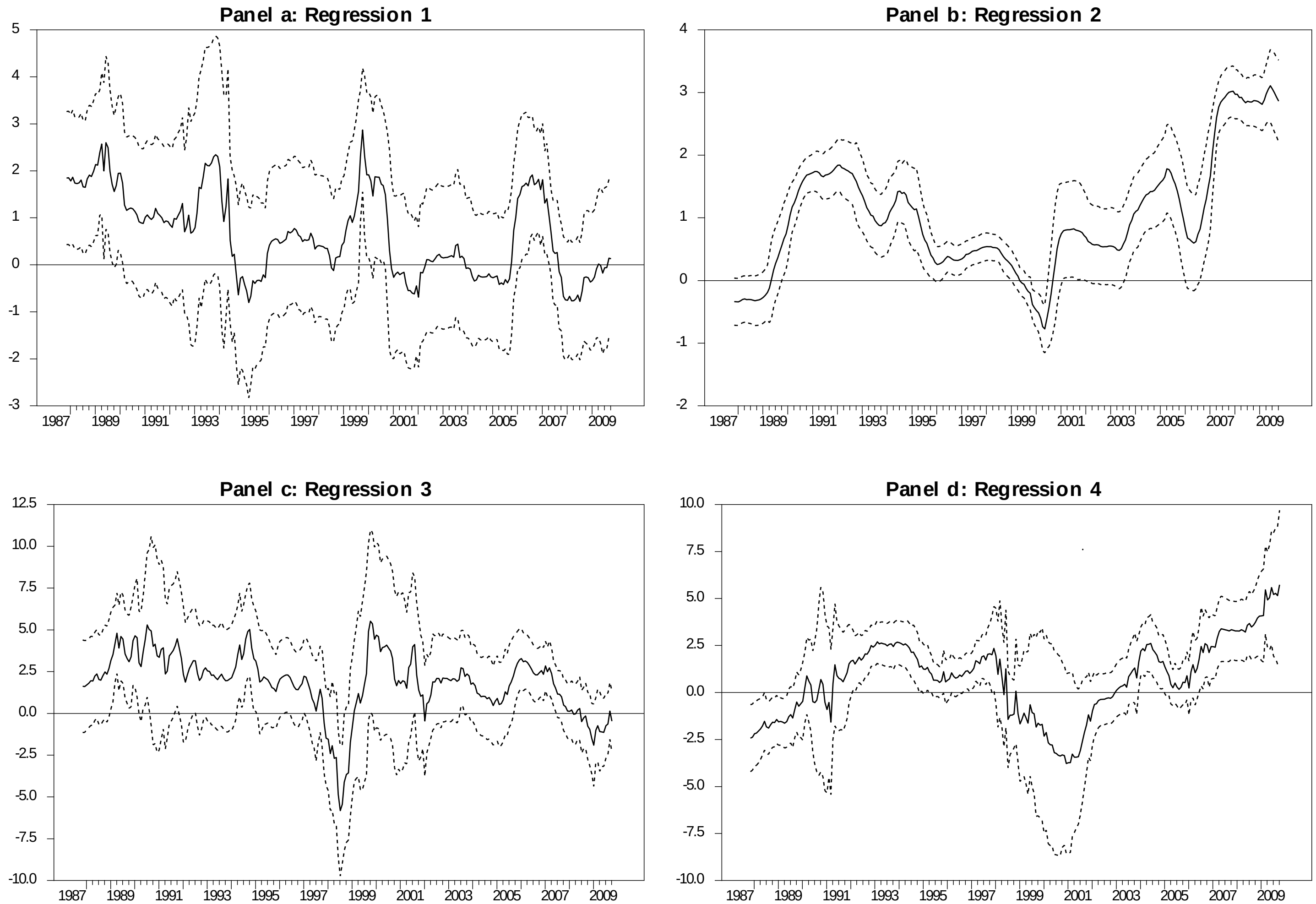


Figure 6.
Eighteen-Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

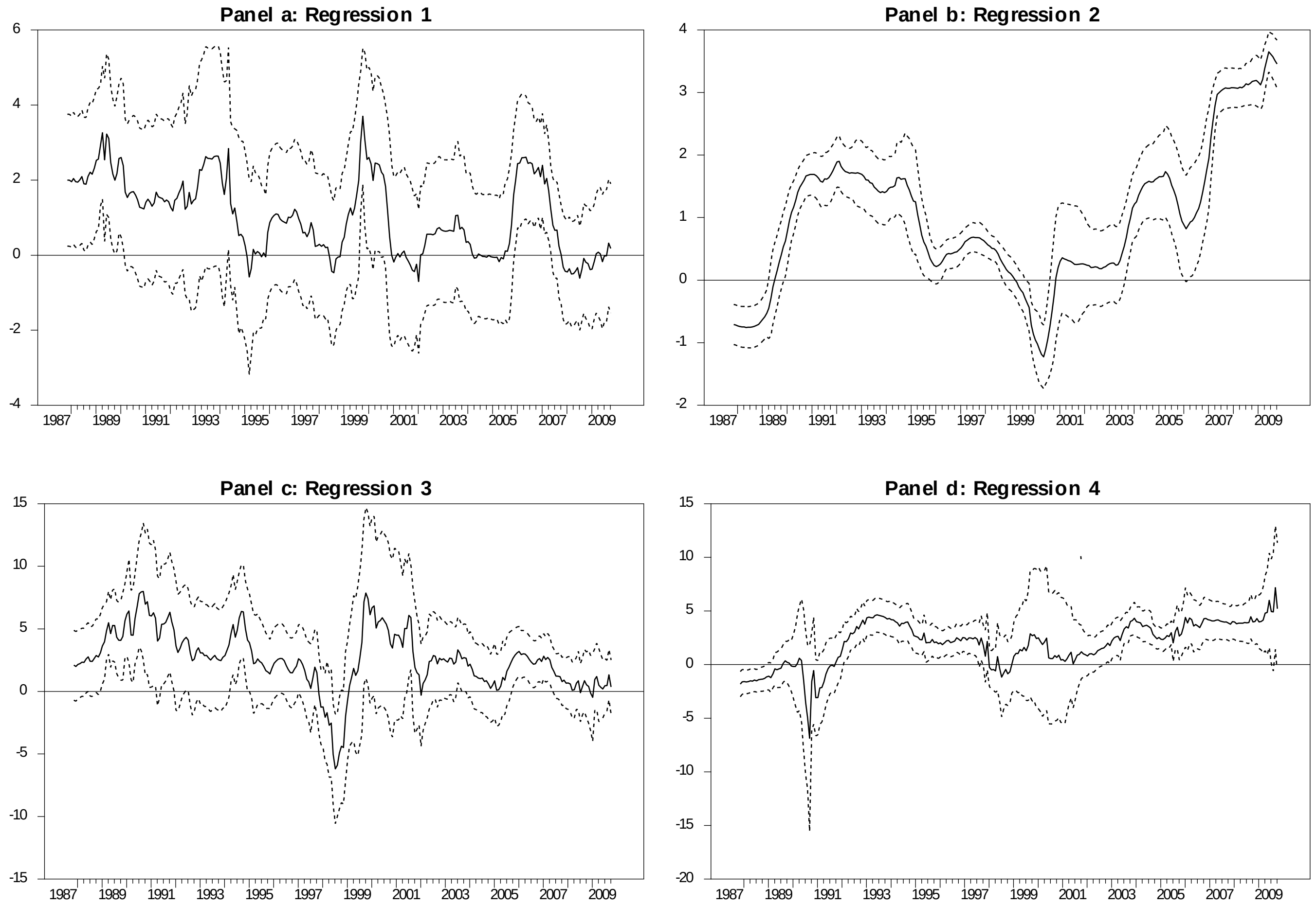


Figure 7.
Twenty-four Month Maturity Slope Coefficient and Two Standard Deviation Confidence Interval for Regressions 1 to 4

Table 1

CMT Smoothed

Regression of the return premium, $RP(\tau_j : t_i + \Delta\tau)$, and the change in the spot rate, $r(t_i + (j-1)\Delta\tau) - r(t_i)$, on the forward rate minus the current spot rate, $f(\tau_j, \tau_{j-1} : t_i) - r(t_i)$.

$$RP(\tau_j : t_i + \Delta\tau) = \alpha_1 + \beta_1 \left(f(\tau_j, \tau_{j-1} : t_i) - r(t_i) \right) + \varepsilon_{t+1}$$

$$r(t_i + (j-1)\Delta\tau) - r(t_i) = \alpha_2 + \beta_2 \left(f(\tau_j, \tau_{j-1} : t_i) - r(t_i) \right) + \eta_{t+\tau-1}$$

Table 1 reports the results for regression 1 and 2 for the full sample period as well as for five subperiods. The number in parentheses below β is its *t*-statistic. * indicates significant at the 5% level (±1.959964), ** indicates significant at the 2.5% level (±2.241403), and *** indicates significant at the 1% level (±2.575829).

	12/82-12/09 N = 325		12/84-12/89 N = 60		12/89-12/94 N = 60		12/94-12/99 N = 60		12/99-12/04 N = 60		12/04-12/09 N = 60	
Dependent	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2
$RP(2 : t_i + \Delta\tau)$	0.44***	0.11	0.52***	0.14	0.31	0.06	0.39**	0.11	0.12	0.01	0.00	0.00
	(5.51)		(3.83)		(1.79)		(2.52)		(0.90)		(0.00)	
$RP(3 : t_i + \Delta\tau)$	0.58***	0.15	0.68***	0.19	0.27	0.04	0.58***	0.23	0.08	0.00	0.29	0.02
	(6.36)		(4.81)		(1.64)		(4.01)		(0.46)		(0.61)	
$RP(4 : t_i + \Delta\tau)$	0.69***	0.15	0.83***	0.19	0.17	0.01	0.78***	0.32	0.00	0.00	0.57	0.04
	(6.09)		(4.94)		(1.02)		(5.47)		(-0.01)		(0.99)	
$RP(5 : t_i + \Delta\tau)$	0.75***	0.13	0.94***	0.17	0.02	0.00	0.98***	0.35	-0.11	0.00	0.76	0.05
	(5.27)		(4.42)		(0.13)		(7.14)		(-0.35)		(1.21)	
$RP(6 : t_i + \Delta\tau)$	0.77***	0.10	1.01***	0.14	-0.14	0.00	1.16***	0.35	-0.22	0.01	0.84	0.04
	(4.38)		(3.79)		(-0.67)		(8.83)		(-0.58)		(1.21)	
$RP(12 : t_i + \Delta\tau)$	0.71*	0.03	1.15***	0.05	-0.91	0.04	1.98***	0.23	-0.45	0.02	0.41	0.00
	(2.02)		(3.05)		(-1.85)		(7.28)		(-1.18)		(0.54)	
$RP(18 : t_i + \Delta\tau)$	0.88*	0.03	1.52***	0.05	-0.67	0.01	2.83***	0.19	-0.29	0.00	0.09	0.00
	(2.05)		(3.13)		(-0.60)		(5.24)		(-0.43)		(0.14)	
$RP(24 : t_i + \Delta\tau)$	1.07**	0.03	1.95***	0.05	0.48	0.00	3.65***	0.17	-0.10	0.00	0.13	0.00
	(2.35)		(3.46)		(0.31)		(4.56)		(-0.12)		(0.23)	
$r(t_i + \Delta\tau) - r(t_i)$	0.56***	0.16	0.48***	0.13	0.69***	0.24	0.61***	0.24	0.88***	0.39	1.00***	0.22
	(6.94)		(3.57)		(4.06)		(3.97)		(6.72)		(2.51)	
$r(t_i + 2\Delta\tau) - r(t_i)$	0.58***	0.21	0.64***	0.24	0.80***	0.37	0.51***	0.27	0.92***	0.50	0.90***	0.21
	(7.54)		(4.68)		(6.53)		(5.28)		(9.51)		(4.67)	
$r(t_i + 3\Delta\tau) - r(t_i)$	0.52***	0.18	0.66***	0.27	0.81***	0.38	0.40***	0.22	1.04***	0.56	0.47	0.06
	(5.31)		(3.62)		(9.16)		(4.69)		(7.67)		(1.93)	
$r(t_i + 4\Delta\tau) - r(t_i)$	0.50***	0.16	0.62***	0.23	0.93***	0.42	0.24**	0.10	1.22***	0.61	0.78***	0.12
	(3.78)		(3.49)		(8.32)		(2.43)		(6.34)		(2.81)	
$r(t_i + 5\Delta\tau) - r(t_i)$	0.46***	0.13	0.53***	0.18	0.98***	0.40	0.24**	0.09	1.26***	0.58	1.03***	0.17
	(2.59)		(2.99)		(7.67)		(2.42)		(5.68)		(2.58)	
$r(t_i + 11\Delta\tau) - r(t_i)$	0.60*	0.13	0.70	0.20	1.46***	0.35	0.01	0.00	1.53***	0.46	1.91***	0.37
	(1.90)		(1.86)		(6.32)		(0.12)		(5.52)		(3.38)	
$r(t_i + 17\Delta\tau) - r(t_i)$	0.43	0.06	0.54	0.10	1.34**	0.17	-0.23	0.06	1.41***	0.28	2.84***	0.57
	(1.14)		(0.91)		(2.37)		(-1.08)		(4.08)		(4.43)	
$r(t_i + 23\Delta\tau) - r(t_i)$	0.33	0.04	0.38	0.05	1.59*	0.18	-0.46	0.14	1.55***	0.27	3.43***	0.76
	(0.83)		(0.66)		(2.14)		(-1.28)		(3.94)		(11.25)	

Table 2
CMT Smoothed
Regression of the contract profit, $\Pi_{Long}(\tau_j,\tau_{j-1}:t_i+\Delta\tau)$, and the change in the spot rate, $r(t_i+(j-1)\Delta\tau)-r(t_i+(j-2)\Delta\tau)$, on the forward rate spread, $f(\tau_j,\tau_{j-1}:t_i)-f(\tau_{j-1},\tau_{j-2}:t_i)$.

$$\Pi_{Long}(\tau_j,\tau_{j-1}:t_i+\Delta\tau)=\alpha_3+\beta_3\big(f(\tau_j,\tau_{j-1}:t_i)-f(\tau_{j-1},\tau_{j-2}:t_i)\big)+\varepsilon_{t+1}$$

$$r(t_i+(j-1)\Delta\tau)-r(t_i+(j-2)\Delta\tau)=\alpha_4+\beta_4\big(f(\tau_j,\tau_{j-1}:t_i)-f(\tau_{j-1},\tau_{j-2}:t_i)\big)+\eta_{t+\tau-1}$$

Table 2 reports the results for regression 3 and 4 for the full sample period as well as for five subperiods. The number in parentheses below β is its *t*-statistic. * indicates significant at the 5% level (±1.959964), ** indicates significant at the 2.5% level (±2.241403), and *** indicates significant at the 1% level (±2.575829).

	12/82-12/09 N = 325		12/84-12/89 N = 60		12/89-12/94 N = 60		12/94-12/99 N = 60		12/99-12/04 N = 60		12/04-12/09 N = 60	
Dependent	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2
$\Pi_{Long}(2,1:t_i+\Delta\tau)$	0.44***	0.11	0.52***	0.14	0.31	0.06	0.39**	0.11	0.12	0.01	0.00	0.00
	(5.51)		(3.83)		(1.79)		(2.52)		(0.90)		(0.00)	
$\Pi_{Long}(3,2:t_i+\Delta\tau)$	0.74***	0.15	0.91***	0.19	0.12	0.00	0.86***	0.33	-0.06	0.00	0.79	0.06
	(6.04)		(4.86)		(0.63)		(6.12)		(-0.22)		(1.22)	
$\Pi_{Long}(4,3:t_i+\Delta\tau)$	0.70***	0.06	1.02***	0.09	-0.39	0.02	1.12***	0.22	-0.47	0.04	0.87	0.03
	(3.33)		(3.00)		(-1.25)		(4.67)		(-1.04)		(1.03)	
$\Pi_{Long}(5,4:t_i+\Delta\tau)$	0.45	0.02	0.67	0.02	-0.88*	0.06	0.89	0.09	-0.63	0.04	0.15	0.00
	(1.61)		(1.46)		(-2.07)		(1.64)		(-1.09)		(0.11)	
$\Pi_{Long}(6,5:t_i+\Delta\tau)$	0.33	0.01	0.41	0.01	-1.14*	0.07	0.68	0.04	-0.51	0.02	-0.23	0.00
	(1.03)		(0.86)		(-2.00)		(1.13)		(-0.76)		(-0.15)	
$\Pi_{Long}(12,11:t_i+\Delta\tau)$	0.95	0.02	2.00**	0.04	3.83***	0.09	1.70	0.02	0.60	0.01	-0.49	0.00
	(1.74)		(2.53)		(2.97)		(1.64)		(0.43)		(-0.40)	
$\Pi_{Long}(18,17:t_i+\Delta\tau)$	1.22*	0.02	2.99***	0.06	4.92***	0.16	5.41*	0.06	0.66	0.00	-0.56	0.00
	(2.13)		(3.75)		(4.18)		(2.11)		(0.41)		(-0.53)	
$\Pi_{Long}(24,23:t_i+\Delta\tau)$	1.47**	0.03	3.95***	0.08	6.22***	0.16	7.73**	0.08	0.45	0.00	0.22	0.00
	(2.41)		(3.88)		(4.81)		(2.31)		(0.34)		(0.26)	
$r(t_i+\Delta\tau)-r(t_i)$	0.56***	0.16	0.48***	0.13	0.69***	0.24	0.61***	0.24	0.88***	0.39	1.00**	0.22
	(6.94)		(3.57)		(4.06)		(3.97)		(6.72)		(2.51)	
$r(t_i+2\Delta\tau)-r(t_i+\Delta\tau)$	0.60***	0.07	0.85***	0.13	1.01***	0.18	0.27	0.02	1.01***	0.19	0.60	0.02
	(4.43)		(2.64)		(4.76)		(1.83)		(4.78)		(1.07)	
$r(t_i+3\Delta\tau)-r(t_i+2\Delta\tau)$	0.35	0.01	0.64	0.03	0.92***	0.09	-0.01	0.00	1.25***	0.14	-0.71	0.01
	(1.72)		(1.74)		(3.68)		(-0.06)		(4.34)		(-1.02)	
$r(t_i+4\Delta\tau)-r(t_i+3\Delta\tau)$	0.27	0.01	0.17	0.00	1.44***	0.14	0.05	0.00	1.07**	0.08	0.68	0.01
	(0.86)		(0.35)		(4.36)		(0.26)		(2.45)		(1.25)	
$r(t_i+5\Delta\tau)-r(t_i+4\Delta\tau)$	0.27	0.01	0.17	0.00	1.44***	0.14	0.05	0.00	1.07**	0.08	0.68	0.01
	(0.85)		(0.35)		(4.36)		(0.26)		(2.45)		(1.25)	
$r(t_i+11\Delta\tau)-r(t_i+10\Delta\tau)$	0.44	0.01	-0.38	0.00	1.22	0.01	0.03	0.00	1.90	0.10	4.71***	0.09
	(0.90)		(-0.29)		(0.93)		(0.04)		(1.65)		(2.74)	
$r(t_i+17\Delta\tau)-r(t_i+16\Delta\tau)$	0.25	0.00	-0.60	0.00	1.67*	0.03	-1.72	0.01	1.55	0.06	5.64***	0.06
	(0.51)		(-0.57)		(1.98)		(-0.96)		(1.70)		(3.66)	
$r(t_i+23\Delta\tau)-r(t_i+22\Delta\tau)$	0.51	0.01	0.06	0.00	3.45***	0.11	2.54	0.01	2.46***	0.13	5.05***	0.03
	(0.87)		(0.05)		(3.59)		(1.02)		(5.21)		(2.63)	

Table 3
CMT Smoothed
Standard deviations of adjacent maturity return spreads, $\Pi_{Long}(\tau_j, \tau_{j-1} : t_i + \Delta\tau)$, forward rate spreads, $f(\tau_j, \tau_{j-1} : t_i) - f(\tau_{j-1}, \tau_{j-2} : t_i)$, and the change in the spot rate, $r(t_i + \Delta\tau) - r(t_i)$;

Table 3 provides standard deviations of FRA profits, forward rate spreads, and changes in spot rates. Fama Data is from the Fama Treasury Bills Term Structure files contained on the CRSP Monthly U.S. Treasury Database. CMT is the constant maturity Treasury data available from the H 15 file produced by the Board of Governors of the Federal Reserve System. Data smoothing is based on level, slope, and curvature following Nelson and Siegel (1987).

Variable	12/82-12/09 N = 325	12/84-12/89 N = 60	12/89-12/94 N = 60	12/94-12/99 N = 60	12/99-12/04 N = 60	12/04-12/09 N = 60
$\Pi_{Long}(2,1 : t_i + \Delta\tau)$	0.00029	0.00036	0.00020	0.00021	0.00020	0.00029
$\Pi_{Long}(3,2 : t_i + \Delta\tau)$	0.00025	0.00031	0.00018	0.00015	0.00016	0.00027
$\Pi_{Long}(4,3 : t_i + \Delta\tau)$	0.00027	0.00034	0.00020	0.00016	0.00018	0.00028
$\Pi_{Long}(5,4 : t_i + \Delta\tau)$	0.00029	0.00035	0.00022	0.00018	0.00020	0.00028
$\Pi_{Long}(6,5 : t_i + \Delta\tau)$	0.00029	0.00036	0.00023	0.00019	0.00021	0.00026
$\Pi_{Long}(12,11 : t_i + \Delta\tau)$	0.00032	0.00039	0.00030	0.00026	0.00029	0.00024
$\Pi_{Long}(18,17 : t_i + \Delta\tau)$	0.00035	0.00042	0.00032	0.00029	0.00034	0.00026
$\Pi_{Long}(24,23 : t_i + \Delta\tau)$	0.00037	0.00046	0.00034	0.00030	0.00037	0.00029
$f(2,1 : t_i) - r(t_i)$	0.00021	0.00026	0.00015	0.00018	0.00018	0.00016
$f(3,2 : t_i) - f(2,1 : t_i)$	0.00013	0.00015	0.00010	0.00010	0.00011	0.00008
$f(4,3 : t_i) - f(3,2 : t_i)$	0.00010	0.00010	0.00008	0.00007	0.00007	0.00006
$f(5,4 : t_i) - f(4,3 : t_i)$	0.00008	0.00008	0.00006	0.00006	0.00007	0.00005
$f(6,5 : t_i) - f(5,4 : t_i)$	0.00008	0.00007	0.00005	0.00006	0.00006	0.00005
$f(12,11 : t_i) - f(11,10 : t_i)$	0.00005	0.00004	0.00002	0.00002	0.00004	0.00003
$f(18,17 : t_i) - f(17,16 : t_i)$	0.00004	0.00003	0.00003	0.00001	0.00003	0.00003
$f(24,23 : t_i) - f(23,22 : t_i)$	0.00004	0.00003	0.00002	0.00001	0.00002	0.00002
$r(t_i + \Delta\tau) - r(t_i)$	0.00030	0.00036	0.00022	0.00022	0.00025	0.00033

Table 4
Estimated Number of Breaks and Break Dates

Table 4 reports the estimated number of breaks, the estimated break dates, the *F*-test for the null hypothesis of *b* versus *b-1* breaks, and the sample *BIC* values for *b-1* and *b* breaks. Since the BIC is expressed in logarithms, the smaller the BIC, the better the fit of the model. There were no significant breaks found for Regressions 2 and 4 for any holding period exceeding two, suggesting the marginal regressions display a great amount of stability.

Maturity	*F*(5)	Breaks	Dates	*BIC(0) / BIC(b)*	
			Regression 1		
2 month	9.85	3	1984:07 1987:10 2007:11	-16.39	-16.45
3 month	13.50	3	1984:07 1987:10 2007:11	-15.29	-15.40
4 month	14.56	4	1984:07 1987:09 2000:05 2007:09	-14.55	-14.67
5 month	13.77	5	1984:07 1987:09 1989:02 1992:08 2007:09	-13.98	-14.05
6 month	12.83	5	1984:07 1986:07 1989:02 1992:08 2007:09	-13.46	-13.55
12 month	9.55	5	1984:05 1986:07 1989:02 1992:08 2008:05	-11.76	-11.80
18 month	9.86	5	1984:05 1986:07 1989:02 1992:08 1994:11	-10.74	-10.80
24 month	9.42	5	1984:05 1987:07 1989:02 1993:07 1994:11	-10.01	-10.06
			Regression 3		
2 month	9.85	3	1984:07 1987:10 2007:11	-16.39	-16.45
3 month	9.58	5	1984:07 1987:09 2000:05 2007:09 2008:10	-16.70	-16.81
4 month	9.82	5	1984:04 1988:01 1989:02 1992:08 2007:08	-16.46	-16.51
5 month	10.93	4	1984:04 1985:05 2004:07 2008:05	-16.33	-16.40
6 month	12.30	4	1984:04 1985:05 2004:07 2008:05	-16.29	-16.38
12 month	10.04	5	1984:05 1986:07 1987:07 1993:08 1994:11	-16.17	-16.23
18 month	8.69	3	1984:05 1986:07 1987:08	-15.96	-16.00
24 month	7.95	3	1984:05 1986:07 1987:08	-15.80	-15.84