An Empirical Evaluation of Treasury-Bill Futures Market Efficiency: Evidence from Forecast Efficiency Tests

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INTRODUCTION

Many studies of futures market efficiency have used one of two basic methods to examine market efficiency. The first method, widely used to examine the efficiency of commodity futures, is to regress the actual realized delivery-day spot rate against an earlier observed futures price. If the futures market is allocationally efficient (ignoring transaction costs), futures prices should fully and instantaneously reflect all available relevant public information. Assuming rational expectations, the constant and slope term in the preceding regression should not be different from zero and one, respectively. This test of the efficient market hypothesis has the advantage of being simple and having universal appeal in application to all futures market instruments. However, this method can suffer from serious statistical problems as outlined below. Such problems can render the OLS estimation results meaningless.

A second method of testing for futures market efficiency, widely used in examining the efficiency of the Treasury-bill future market, is to compare a futures rate with an arbitrageable alternative rate, such as a forward rate; e.g., Poole (1978), Vignola and Dale (1980), Rendleman and Carabini (1979), and Kawaller and Koch (1984). These studies primarily compare futures and forward rates as a means of testing futures market efficiency. If these two rates are found to be statistically different from one another, then one or both markets is said to be inefficient. Many such studies, but not all, find futures and forward rates are statistically different and conclude that the Treasury-bill futures market is inefficient. This method, however, does not adequately determine which of the two markets is inefficient.

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This article argues that it is impossible to conclude which market is inefficient based simply on the fact that prices in the two markets are different. Established test procedures are more closely examined and criticized and two alternative tests of futures (weak-form) market efficiency are proposed. These methods are based on an evaluation of forecast efficiency and the rational expectations hypothesis. The proposed test procedures do not suffer the problems encountered by the above two methods used to test futures market efficiency. The tests are subsequently implemented using the Treasury-bill futures market.

This article is organized as follows: In the next section, a critical analysis of the two basic methods for examining futures market efficiency is presented. Alternative weak-form efficiency tests are presented and then applied to the Treasury-bill futures market. The tests uncover evidence of inefficiencies in this market early in its development, but little evidence of inefficiencies after 1978 is detected.

TESTING FUTURES MARKET EFFICIENCY: A CRITICAL REVIEW

One popular method used to test the efficiency of the futures market is to estimate the following regression

$$S_T = \alpha + \beta F_{t,T} + e_T \tag{1}$$

where S_T is the actual realized spot price (rate) at time T, (i.e., delivery day of the futures contract), $F_{t,T}$ is the futures price (rate) at time t for delivery at time $T (t < T)$, and e_T is a random disturbance term. The null hypothesis of market efficiency is held to be $\alpha = 0$, $\beta = 1$. Bigman, Goldfarb, and Schechtman (1983) and others have examined the efficiency of commodity futures using this methodology. Empirical estimates of the coefficients often find α to be significantly positive, while β is significantly less than one. For example, estimating eq. (1) using daily Treasury-bill futures contrast rates from 1976 to 1989 yields the following estimates:

$$S_T = \underset{(0.06)}{1.55} + \underset{(0.01)}{0.80} F_{t,T}$$

(where the standard error of the respective coefficient estimates is in parentheses).

Such a finding is suggestive of significant inefficiencies in this market, with a constant term significantly greater than zero and a slope estimate significantly less than units. Futures rates observed at time t appear to be significantly biased forecasts of subsequent spot rates at time T.

This methodology, however, is controversial. For example, Maberly (1985) suggests that this test procedure may be invalid due to the statistical problem of censored data. Maberly argues that the ex-post restrictions on the value of the dependent variable, S_T, will lead to the conclusion that α is positive and β is less than one. For one delivery-day price, S_T, there is an array of forecasts $(F_{t,T}, F_{t+1,T}, F_{t+2,T}, \ldots F_{T,T})$ matching the one observation S_T. According to Maberly, ex post it is known that one of the $F_{i,T}$ values will be the maximum while another value, $F_{j,T}$, will be the minimum. Maberly argues that S_T will be censored as: $F_{\text{MIN},T} \leq S_T \leq F_{\text{MAX},T}$. He concludes that this will censor the random disturbance term e_t and lead to biased coefficient estimates, as suggested above.

Elam and Dixon (1988) agree that the regression-based statistical method for testing market efficiency is flawed. They suggest that the reason one generally finds $\alpha > 0$ and $\beta < 1$ is due to the use of ordinary least squares (OLS) on a model with a lagged dependent variable, which they argue is close to the relationship estimated. They assume that $F_{t,T} = E[S_T] = S_t$, where S_t is the current spot rate at time t. Substituting S_t for $F_{t,T}$ in eq. (1) essentially yields a regression with lagged dependent variables. Elam and

Dixon argue that the bias is a result of the correlation between the independent variable and previous values of the disturbance term. They support this notion with a Monte Carlo study.[1]

Hein, Ma, and MacDonald (1990) further point out that overlapping data are a major concern when the forecast horizon (days until the expiration of the futures contract) exceeds the futures contract cycle. Under the assumptions of Elam and Dixon, they show that the overlapping data problem generally leads to a rejection of the unbiased hypothesis, often falsely suggesting market inefficiencies.

Given the numerous statistical problems plaguing this methodology, the interpretation of findings from such tests is not readily apparent. It is only natural that the investigators have looked for other means of testing market efficiency. A second popular method for evaluating futures market efficiency is to compare futures rates with a substitute such as forward rates. In the Treasury-bill market, investigators have generally found forward rates and futures rates to be significantly different from one another. Some researchers attribute this systematic differential to transactions costs involved in arbitraging the differences; e.g., Poole (1978), Vignola and Dale (1980), MacDonald and Hein (1989). Kawaller and Koch (1984) also argue that market participants cannot arbitrage differences between futures and forward rates because of significant costs associated with short selling cash Treasury-bills. They suggest that investors must use the Treasury-bill repurchase agreement market, in contrast to cost-free short selling. In this setting Kawaller and Koch conclude that the futures market is efficient.

On the other hand, Elton, Gruber, and Rentzler (1984) conclude that transaction costs can not explain the apparent differences in the two rates when properly sampled. They find evidence of arbitrageable opportunities that can be profitably exploited between these two markets. Studies such as Elton, Gruber, and Rentzler, which conclude from this evidence that the futures market is inefficient, have ruled out, a priori, the possibility that the forward market is the observationally "inefficient" market.

Recent evidence suggests that the Treasury-bill cash market may not behave as the pure expectation theory of the term structure would suggest. For example, many studies have found evidence of a time varying term premium in the Treasury-bill market; e.g., Fama (1976); Friedman (1979); Rowe, Lawler, and Cook (1986); and MacDonald and Hein (1989). Yet, the empirical studies examining the efficiency of the Treasury-bill futures market make no allowance for a (e.g., Elton, Gruber, and Rentzler) time varying term premium in the forward rate. Moreover, evidence that the futures rates is a more accurate predictor of future spot rates, as reported in Kamara and Lawrence (1985), Hedge and McDonald (1986), and MacDonald and Hein (1989), is consistent with the existence of a term premium in the forward rate.

At a minimum, previous research indicates that the inequality found between the Treasury-bill futures and forward rates may be due to peculiarities in the forward market, not necessarily the futures market. If one were to use the futures rate as the "correct" rate in previous studies, one would conclude that the forward market is the "inefficient" market.

[1]Dwyer et al. (1989) also provide evidence in a slightly different setting that the slope parameter estimate will be biased downward, with excessive false rejection of the rational expectation hypothesis, due to nonstationarity problems. Shen and Wang (1990) also suggest that the estimates of (1) will be biased due to nonstationarity of the spot and futures prices.

TESTING FORECASTING EFFICIENCY

The Nordhaus Test Procedure

Alternative forecast efficiency tests are described and explored in this section. The first set of tests are based on the work of Nordhaus (1987) who introduced the concept of forecast efficiency, based on rational expectations. Using Nordhaus' terminology, the futures market can be viewed as a "fixed-event forecast," rather than a "fixed-horizon forecast." In other words, daily futures market prices (rates) can be viewed as representing the market's forecast of prices (rates) for a *fixed* delivery day in the future, based on currently available information. For any one specific contract, the "event" is the delivery day price and this event is fixed in time. Daily futures prices of the nearby futures contract, for example, can be taken to represent multiple forecasts of the spot price on delivery day. This forecast setting is very different from the more traditional forecast in which forecasters are given a fixed horizon, such as one-quarter, over which they are required to forecast.

The forecast efficiency tests suggested by Nordhaus presume a fixed-event setting and are most appropriate when applied to the behavior of futures prices. Two tests of weak-form forecast efficiency are proposed by Nordhaus. Forecast efficiency, according to Nordhaus, requires:

$$E[\gamma_{t,T}|\gamma_{t-1,T}, \gamma_{t-2,T}, \ldots \gamma_{1,T}] = 0 \qquad \text{for all } t \tag{2}$$

$$E[\varepsilon_{t,T}|\gamma_{t,T}, \gamma_{t-1,T}, \ldots \gamma_{1,T}] = 0 \qquad \text{for all } t \tag{3}$$

where $\varepsilon_{t,T} = F_{t,T} - S_T$, the forecast error from the future market, at time t; $F_{t,T}$ is the futures rate at t for delivery at T and S_T is the spot rate at delivery; and $\gamma_{t,T} = F_{t,T} - F_{t-1,T}$, the period-by-period revision in the futures rate forecast for delivery day T.

The system of equations in (2) requires that the forecast revisions by serially uncorrelated with temporally preceding forecast revisions. That is, knowing earlier price revisions should not aid in predicting today's price change. Tests based on eq. (2) have been widely applied to stock price behavior, but the test procedure has not been applied to the Treasury-bill futures prices. The system of equations in (3) requires that the forecast error at time t be independent of all earlier forecast revisions.

Equations (2) and (3) have strong intuitive appeal. If the forecast revisions, $\gamma_{t,T}$, are serially correlated, in violation of (2), this provides evidence that futures market participants are either too slow or too quick to change their views about the future course of the economy. Tversky and Kahneman (1981) suggest that "anchoring" frequently occurs, where people tend to hold on too long to a particular view of the future. Nordhaus (1987) examined the correlation in forecast revisions for a number of different macroeconomic forecasts and finds overwhelming evidence of *positive* correlation in forecast revisions, suggesting a tendency to smooth forecasts which is consistent with the anchoring hypothesis. In this regard, Nordhaus generally rejects the notion of weak-form forecast efficiency for the forecasts he considered. The evidence provided by Nordhaus suggests that forecasters do not revise their forecasts quickly enough to reflect new information.

Additionally, if the forecast error is related to past forecast revisions, in violation of (3), the evidence suggests an over- or under-reaction (depending on the sign of the correlation) of expectations to new information. For example, if the forecast error is negatively related to past forecast revisions, there is evidence that the futures market overreacts to new information. Subsequent forecast errors could be reduced by eliminating such over-reaction. Alternatively, a positive relationship would suggest an under-reaction to news, again suggesting simple procedures to reduce forecast errors. Nordhaus finds evidence of a strong positive correlation between forecast errors and earlier revisions in the forecasts for the fixed-event macroeconomic forecasts he considered.

The test proposed by Nordhaus can be used to consider the forecast efficiency of the futures market. Two assumptions are necessary for this extension. First, as in the Nordhaus development, it is assumed that all forecasts are rational, reflecting all available information. Second, it is assumed that the futures market is efficient, such that futures rates reflect these rational expectations. In this vein, the question addressed is whether information in the past behavior of futures rates can be used to yield increased futures trading profits. These tests, then, represent a joint test of rational expectations and futures market efficiency.

The Arrow Test Procedure

A test suggested by Arrow (1982) is used as well in this examination of the Treasury-bill futures market. Arrow states that: "One standard implication of rationality . . . is that the price of a security on futures contract at any moment is an unbiased prediction of the price at a future moment . . . . This implies that the price change from the present to the future is uncorrelated with the current price . . . . For if it were not true, the individual observing the correlation could use the information to forecast the price change and therefore increase his or her wealth" [Arrow (1982, p. 3)]. Arrow's description of rationality and efficiency suggests another test of futures market efficiency. In particular, this test requires the regression of day-to-day change in futures rate $(F_{t,T} - F_{t-1,T})$ on yesterday's futures rate (F_{t-1}, T):

$$F_{t,T} - F_{t-1,T} = \alpha + \beta F_{t-1,T} + \varepsilon_t \tag{4}$$

According to Arrow, the null hypothesis of market efficiency implies an absence of any correlation in the two variables; i.e., $\beta = 0$. The price change should be independent of today's price. This regression is estimated in a fixed-event setting.

The Data

Daily Treasury-bill futures closing rates from the inception of the Treasury-bill futures market, January 6, 1976 through December 31, 1988, are used to implement the tests described above. The data are first divided into 52 different contracts, each with a different delivery date. Each contract is interpreted as a fixed event. The first contract began trading on January 6, 1976 and was delivered on March 17, 1976. The second contract began trading on January 6, 1976 and delivered on June 23, 1976. As the strength and depth of the Treasury-bill futures market developed, contracts were traded for more than one year. However, since many investors argue that the liquidity is thin and trading sometimes infrequent beyond one year in the Treasury-bill futures market, only the final one year's worth of daily trading data for each contract are considered. Because of the overlap of dates for the four contracts in each year, only evidence for the contracts that deliver in the month of December is reported. All tests are run for contracts delivering in March, June, and September as well, but are not reported here because the results do not substantially differ from those that deliver in December. These results are available from the authors.

Nordhaus Test Results

The first of the two relationships proposed by Nordhaus, eq. (2), can be applied and tested using T-bill futures data by examining the autocorrelation in forecast revisions (day-to-day changes in T-bill rates). In Table I, the first six autocorrelation coefficient estimates for the forecast revision ($\gamma_{t,T}$, futures rate change from $t - 1$ to t) are presented separately for each December-delivery contract. This represents a test of relationship (2). The relationship states that if expectations are rational and the market is efficient, forecast revisions should show no serial correlation. Coefficient estimates exceeding 0.12 in absolute value (close to 5% significance level for large samples) are highlighted in Table I. The column labeled ρ_1 provides the autocorrelation coefficient for first-order autocorrelation, while columns for ρ_2, ρ_3, ρ_4, ρ_5, and ρ_6 provide the autocorrelation coefficients for the higher order lags. The Ljung–Box statistic, χ^2_6, tests the null hypothesis of no autocorrelation for all six lags jointly. The statistic is reported in the fourth column of Table I and the respective probability value in the fifth column.

As shown in Table I, significant autocorrelation in forecast revisions exists for some contracts. The autocorrelation in forecast revisions is especially noticeable in the early stages of the Treasury-bill futures contract. The Ljung–Box statistics rejects the hypothesis of no autocorrelation for the first three December contracts.[2] In particular, "anchoring" appears to have occurred in 1976 and again in 1978, as there is general evidence of significant, positive autocorrelation in these cases. This indicates that forecasts are not being revised as quickly as they should be. Once a forecast is revised upward, it is likely to be followed by another similar upward revision in the forecast. This evidence is similar to that found by Nordhaus for his survey forecasting evaluation. Interestingly, the significant autocorrelation coefficients in 1977 are primarily negative, suggesting an over-reaction of the forecast revision process after two or three days.

Beyond the first three years of the futures market, however, there is little evidence of significant autocorrelation in the forecast revisions. While there are sporadic, significant autocorrelation coefficients after 1978, the Ljung–Box statistic rejects the joint hypothesis of no autocorrelation through lag six only for 1987. Thus, after the beginning of 1979, there is very little evidence of market inefficiency in the Treasury-bill futures market, at least using Nordhaus' revision autocorrelation test. This evidence is very much consistent with Kamara's (1990) evidence that the Treasury-bill futures market forecast accuracy improved significantly as the market became more liquid a few years after its establishment.

One possible limitation of this test is the use of closing prices bouncing from bid price on one day to ask price the next. Roll (1984) argues that the use of closing prices might lead to negative serial correlation due to the fact that closing prices may randomly fluctuate about bid and ask prices. Roll (1984) and Fama (1965) both suggest, however, that the arrival of new information in a market setting overwhelms any small, observed, negative, serial correlation. As such, the problem outlined by Roll appears to be primarily significant in a small sample setting. The large samples used here dictate that the arrival of new information, day-to-day, dominates the bid–ask sampling problem in observed

[2]Evidence (not reported) of significant autocorrelation in forecast revisions is found also for contracts delivering in September, 1976; June, 1977; September, 1977; and June, 1978. These results are available from the authors.

Table I

NORDHAUS TEST OF FORECAST EFFICIENCY: AUTOCORRELATIONS OF FORECAST REVISIONS ($F_{t,T} - F_{t-1,T}$)

Contract Number	Correlation Coefficients								
	χ^2_6	*p*-value	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	Obs.
1 Jan. 6, 1976–Dec. 22, 1976	12.71[a]	0.048	0.077	0.003	0.023	**0.183**	−0.058	−0.094	237
2 Dec. 23, 1976–Dec. 21, 1977	17.09[a]	0.009	0.080	**−0.143**	**−0.124**	0.088	**0.140**	−0.006	241
3 Dec. 22, 1977–Dec. 20, 1978	34.20[a]	0.000	**0.184**	**0.159**	−0.083	−0.045	**−0.241**	−0.115	240
4 Dec. 21, 1978–Dec. 19, 1979	5.71	0.456	0.077	0.081	−0.009	−0.065	−0.067	−0.042	243
5 Dec. 20, 1979–Dec. 17, 1980	5.78	0.448	0.048	−0.058	0.109	0.071	0.033	0.002	240
6 Dec. 18, 1980–Dec. 23, 1981	2.07	0.914	0.008	0.029	−0.033	0.013	0.070	−0.032	247
7 Dec. 24, 1981–Dec. 22, 1982	6.56	0.363	−0.028	0.076	−0.076	−0.098	−0.024	0.062	243
8 Dec. 23, 1982–Dec. 21, 1983	4.04	0.672	0.041	0.035	0.005	−0.012	−0.045	−0.104	245
9 Dec. 22, 1983–Dec. 19, 1984	11.35	0.078	**0.191**	0.010	0.000	0.020	−0.063	−0.072	243
10 Dec. 20, 1984–Dec. 18, 1985	10.70	0.098	0.020	0.067	−0.053	−0.003	**−0.183**	−0.048	240
11 Dec. 19, 1985–Dec. 17, 1986	9.27	0.159	0.032	0.074	0.073	−0.101	0.096	0.081	239
12 Dec. 18, 1986–Dec. 16, 1987	17.73[a]	0.007	**0.215**	0.097	−0.116	−0.022	−0.032	0.035	243
13 Dec. 17, 1987–Dec. 14, 1988	7.32	0.292	0.010	−0.072	−0.002	0.096	−0.058	0.107	243

[a] Indicates significance at the 5% level.

Boldface entries indicate correlation coefficient values in excess of 0.12 in absolute value.

autocorrelation. Thus, it is felt that the results here are not significantly affected by the use of closing prices. Moreover, these results suggest positive, not negative, correlation.[3]

Nordhaus Test Results: The Fixed-Horizon Test

Relationship (3) above requires that a given forecast error be independent of previously observed changes or revisions in the forecast. Empirical tests of the second Nordhaus relationship can be performed by examining the relationship between forecast errors and previous revisions. However, there are serious statistical problems with applying this procedure to the futures markets in a fixed-event setting. The problem concerns the statistical properties of eq. (3) and the methods required to test its validity. Note that eq. (3) suffers from an overlapping data problem in a fixed-event framework. Consider the futures rate today, $F_{t,T}$, which is a n-period forecast for delivery n days ahead, S_T. The forecast error from the next day, $\varepsilon_{t+1} = F_{t+1} - S_T$, is based on an $n - 1$ period ahead forecast $F_{t+1,T}$. The period $t + 1$ through T, however, is common to both ε_t and ε_{t+1}. Daily forecast errors of the same event will overlap and be correlated, because all forecast errors reflect information that occurs on the same delivery day. Since the overlapping period is not constant (as in a fixed-horizon framework) standard methods used to correct for overlapping data are not appropriate in this fixed-event setting.

The test is better examined in a fixed-horizon setting to mitigate concern about overlapping data problems. A number of different forecast horizons are considered and each is examined for independence of today's forecast error and earlier forecast revision. For a fixed horizon, there is only one observation per futures contrast. In Table II, correlation coefficients between the futures forecast error and the earlier forecast revisions error are reported. Following Nordhaus, we examine the correlation between the futures market forecast error for fixed horizon and the cumulative forecast revision known to have occurred previously are examined.

From the evidence in Table II, there is no indication that previous price changes provide useful information in reducing today's forecast error. In no case reported is the evidence inconsistent with the independence of these two variables. As such, there is no evidence based on this test to suggest market inefficiencies. These findings are in sharp contrast to those of Nordhaus, who found evidence of significant positive correlation between forecast errors and earlier forecast revisions. Nordhaus concluded that the forecasts he examined were inefficient. No such evidence of correlation for the Treasury-bill futures market is found here.

Arrow Test Results

The test procedure suggested by Arrow is well-suited for a fixed-event setting. Changes in futures rates are regressed on the previous days futures price. These results are reported in Table III. The results are reported separately for each of the different December contracts.[4] These "Arrow test" regressions are tested for homoskedastic residual error variance. Heteroskedasticity is found to exist in most contracts; t-values, arrived at by using White's (1980) heteroskedastic-consistent covariance matrix procedure, are reported.

[3]The effect of bid–ask bounce is far more apparent in an examination of intraday, trade-by-trade, data. There significant negative first order autocorrelation in forecast revisions is found which suggests the arrival of new information over such short intervals is not great enough to overcome the effect of bid–ask bounce. These results are available from the authors.

[4]The regressions are run for all 52 contracts. Generally, the results are quite similar to those reported.

Table II

CORRELATION COEFFICIENTS OF: $S_{t+n} - F_t$ ON $\sum_{i=0}^{n} (F_{t-i} - F_{t-i-1})$

(FORECAST ERRORS ON CUMULATIVE PERCENT REVISIONS)

Daily Data		
# of Days Until Delivery	Correlation Coefficient	# of Obs.
1	−0.1863 (0.186)	52
2	−0.0642 (0.651)	52
8	0.0528 (0.710)	52
15	−0.1482 (0.295)	52
22	−0.1913 (0.174)	52
29	0.0016 (0.991)	52
43	−0.1245 (0.379)	52
57	−0.1084 (0.444)	52
85	0.1704 (0.232)	51
92	0.1201 (0.397)	52
120	0.0484 (0.733)	52
148	−0.0127 (0.929)	52
176	0.1937 (0.170)	52
204	0.0923 (0.515)	52
232	0.1138 (0.422)	52
260	−0.0617 (0.667)	51
288	−0.0209 (0.883)	52
309	−0.1010 (0.476)	52
330	−0.0570 (0.6881)	52
351	−0.0285 (0.846)	49

Values in parentheses are p-values for hypothesis that the observed correlation is zero.

Table III
ARROW'S TEST: ARE CHANGES IN FUTURES RATES INDEPENDENT OF CURRENT LEVELS?
MODEL: $F_{t,T}-\mathrm{Fut}_{t-1,T}=\alpha+\beta F_{t-1}+\varepsilon_t$

Contract Number	$\hat{\alpha}$/ (t-Statistic)	$\hat{\beta}$/ (t-Statistic)	R^2/SE	F-Value Prob-F	DW	Obs.
1 Jan. 6, 1976–Dec. 22, 1976	−0.0209	0.0023	−0.0037	0.121	1.84	237
	−0.638	0.398	0.090	0.728		
2 Dec. 23, 1976–Dec. 21, 1977	0.3718[a]	−0.0594[a]	0.0333	9.275[a]	1.80	241
	2.817	−2.805	0.093	0.003		
3 Dec. 22, 1977–Dec. 20, 1978	0.0440	−0.0050	−0.0032	0.236	1.61	240
	0.391	−0.342	0.079	0.628		
4 Dec. 21, 1978–Dec. 19, 1979	0.0057	0.0005	−0.0041	0.003	1.84	243
	0.045	0.036	0.161	0.958		
5 Dec. 20, 1979–Dec. 17, 1980	−0.0379	0.0059	−0.0021	0.493	1.92	240
	−0.416	0.646	0.285	0.483		
6 Dec. 18, 1980–Dec. 23, 1981	0.3198	−0.0254	0.0094	3.327	1.93	247
	1.912	−1.916	0.286	0.069		
7 Dec. 24, 1981–Dec. 22, 1982	−0.0299	0.0006	−0.0041	0.009	2.06	243
	−0.436	0.101	0.208	0.924		
8 Dec. 23, 1982–Dec. 21, 1983	0.2149	−0.0237	0.0000	3.302	1.90	245
	1.700	−1.696	0.094	0.070		
9 Dec. 22, 1983–Dec. 19, 1984	−0.0911	0.0078	0.0026	1.636	1.64	243
	−1.258	1.102	0.094	0.202		
10 Dec. 20, 1984–Dec. 18, 1985	0.0592	−0.0084	0.0048	2.149	1.96	240
	1.243	−1.405	0.096	0.144		
11 Dec. 19, 1985–Dec. 17, 1986	0.0745[a]	−0.0139[a]	0.0128	4.077[a]	1.94	239
	2.009	−2.177	0.080	0.045		
12 Dec. 18, 1986–Dec. 16, 1987	0.1373	−0.0218	0.0083	3.020	1.56	243
	1.200	−1.130	0.128	0.084		
13 Dec. 17, 1987–Dec. 14, 1988	0.0052	−0.0004	−0.0041	0.002	1.97	243
	0.077	−0.046	0.073	0.962		

[a] Indicates significance at the 5% level.

Once again there appears to be some evidence contrary to the joint hypothesis of rational expectations and market efficiency in the early stages of development in the Treasury-bill futures market. In particular, the joint hypothesis of no association is rejected at the 5% level for the December, 1977 contract. In this case the intercept term is estimated to be significantly positive and the slope coefficient significantly less than zero. The results of the regression suggest that there is some mean reversion tendency for futures rates during this period. When the futures rate is relatively low, futures rates are likely to rise tomorrow. On the other hand, when the futures rate is relatively high, futures rates are likely to fall the next day. While not indicative of exactly the same problem uncovered with the Nordhaus tests, the Arrow test results also suggest sluggishness of futures rates in the earlier life of the Treasury-bill futures contract.

After 1978, however, there is little evidence inconsistent with the Arrow hypothesis. Only in 1986 is the joint hypothesis of a zero intercept and zero slope coefficient rejected at the 5% level. Again, the rejection occurs because of a positive intercept and negative slope coefficient. Thus, there is evidence of a mean revision tendency in 1986 similar to that found for 1977.[5]

CONCLUSIONS

The test procedures proposed here have general advantages over other methods used to date. First, they do not suffer from the serious statistical problems found to exist with some earlier methods. Second, they do not rely on an alternative market rate, which itself may be flawed, as a basis for comparison. Generally, little evidence inconsistent with the joint hypothesis of weak-form Treasury-bill futures market efficiency and rational expectations is uncovered after 1978. Significant autocorrelation in the daily revision of futures rates is generally absent, and the daily revision in futures rates is found to be independent of earlier observed rate levels, after a brief learning and/or development period. Such observations generally hold for the turbulent interest rate environment from 1979 through 1982. No evidence of inefficiencies is uncovered in this period.

The evidence found in this article appears to be in contrast to earlier empirical work on the Treasury-bill futures market. Much of the literature concludes this market is inefficient. The tests presented here, though, consider only weak-form efficiency while some other tests reported consider semi-strong or strong forms of market efficiency. The findings of this investigation, however, suggest the Treasury-bill futures market may not be as inefficient as once presumed. Many of the earlier tests which have considered stronger forms of market efficiency, for example, have presumed that forward rates are an unflawed measures of market expectations—a hypothesis with little support in the Treasury-bill market.

One final caveat is in order. This study should not lead one to conclude that the Treasury-bill futures market necessarily provides "optimal" forecasts. It does seem, however, that these forecasts are not so flawed as to cause serious problems. While the "optimality" issue is not examined directly in this study, there is a growing literature which suggests that the Treasury-bill futures market is as an "optimal" forecasting vehicle [see, e.g., Cole et al. (1991); Hafer et al. (1992); Kamara (1990); MacDonald and Hein (1989)].

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[5]In addition to the use of daily futures rates, the behavior of intraday T-bill prices are examined. With the exception of the evidence reported in Table I, the examination of intraday data, as opposed to daily data, does not materially affect the central conclusions. A general independence of forecast errors from earlier observed revisions is found and subsequent price changes are found generally to be independent of the one-period previously observed price. However, as indicated earlier, significant negative autocorrelation is found in the forecast revisions, the analog of Table I, when intraday data are used. It is felt that this autocorrelation is due to the Roll (1984) "bid–ask bounce" in quoted futures prices. There did not, however, appear to be a consistent pattern in the autocorrelation. This problem seems to be much more prevalent for transaction to transaction data, as opposed to the daily data set. Therefore, it is felt that the Treasury-bill market exhibits no serious forecast inefficiencies.

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