Do Treasury Bill Futures Rates Satisfy Rational Expectation Properties?

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INTRODUCTION

Recent research concludes that Treasury Bill (T-bill) futures rates provide "a useful measure of the market's expectation of future rates" (Hafer and Hein, 1989, p. 41). They are useful, but are they rational predictions? Consider that the accuracy of no-change predictions is comparable to the accuracy of futures interest rate predictions for the most common one- and two-quarter forecast horizons (Hedge and McDonald, 1986; Hafer, Hein, and MacDonald, 1990). To date, there is no empirical evidence to support the argument that futures rates provide better one- and two-quarter predictions than no-change forecasts. This article shows that these futures market forecasts possess "rational expectations" properties that no-change forecasts do not. Satisfying rational expectations properties is a better criterion to use in judging forecasts of short-term interest rates than are simple accuracy measures.

In recent years, most of the quarterly movement in short-term interest rates has been unpredictable (Fama, 1984a). Suppose that 5% of the movement in T-bill rates for a given test period is anticipated and 95% is unanticipated, and you are asked to compare the two most accurate sets of interest rate forecasts. Both sets forecast 5% of the change. The first correctly forecasts the 5% anticipated change and the second forecasts 5% from the unanticipated component. The first set provides the best ex ante forecasts, while the second is worthless ex ante, but provides the luckiest

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guesses of unanticipated changes ex post. Accuracy measures, such as root mean square error, cannot distinguish skill from luck and would show the forecasts to be equally desirable. Tests of rational expectations, on the other hand, might indicate that the first set of forecasts fully reflects available information, while the second set does not. In this case, judging forecasts by their rational expectations properties would identify the optimal ex ante set of expectations.

Before forecasts can be considered "rational expectations" or rational forecasts, in Muth's (1961) sense, they must meet a rigorous set of standards. They must possess the properties of unbiasedness, efficiency, consistency, and orthogonality of forecast errors to costless information. These standards are difficult to ascertain (Friedman, 1980; Pesando, 1975). This article examines, for one- through four-quarter forecast horizons, whether futures rate predictions and no-change predictions possess these properties.

Being market-determined interest rates, one might expect the empirical evidence to indicate that futures rates are rational expectations. Yet futures rates may reflect several factors besides the market's expectations of delivery-time spot rates. A detailed discussion of these factors is presented in the next section. Conceptually, if the combined influence of these other factors causes today's futures rates to deviate noticeably from expected delivery-time spot rates, futures rates should fail tests of rational expectations. Conversely, if futures rates pass all the tests, they would appear to be not only useful but also rational forecasts of interest rates.

The empirical evidence supports the hypothesis that one- and two-quarters-ahead T-bill futures rates are rational forecasts of delivery-time spot rates. Three-quarters-ahead futures rates fail only 1 of 12 rationality tests at the 5% level. Stringent standards imposed in this study cause one to reject their rationality, but these futures rates possess several desirable properties, and would likely be acceptable forecasts for many purposes. Four-quarters-ahead futures rates fail multiple tests of rationality. The evidence on no-change predictions is consistent across all forecast horizons: no-change predictions fail several tests of rationality.

THE FUTURES CONTRACT

T-bill futures contracts traded on the International Monetary Market (IMM) of the Chicago Mercantile Exchange (CME) call for delivery of 90-day maturity T-bills having a face value of $1 million. It is often assumed that today's futures rate is the market's expectation of the delivery-time spot rate. However, there are several reasons why a futures rate may differ from the market's rational forecast of the spot rate. While these factors may cause a futures rate and expected spot rate to differ, the difference need not imply a bias such that the difference would be systematically positive or negative.

For example, T-bill spot rates are generally considered to be free of default risk, but traders may not view the futures contract, guaranteed by the CME, to be default-risk free (Capozza and Cornell, 1979; Kamara and Lawrence, 1986; Lang and Rasche, 1978; Rendleman and Carabini, 1979). Even if traders question the creditworthiness of the CME, it is not clear how this would affect futures rates, because it is unclear whether the long or short position will be in the money at contract maturity. In short, while default-risk could cause futures rates to deviate from expected spot rates, there is no reason the expected value of this difference should deviate from zero (Viswanath, 1989).

Other characteristics of the two markets that could produce unbiased differences in rates include differences in transaction costs (Poole, 1978; Rendleman and Carabini, 1979), differences in margin requirements, and differences in liquidity (Puglisi, 1978).

There also exist certain features that may contribute to systematic bias in the difference between futures rates and expected spot rates. Before 1981, an investor had a favorable tax treatment option on a futures position held for more than 6 months (Cornell, 1981; Viswanath, 1989). Depending upon whether the ending futures position was a gain or a loss, the investor could either realize a long-term gain in the futures market that was eligible for favorable capital gains tax treatment or take delivery and realize an ordinary loss in the spot market. This favorable tax effect could bias futures rates downward as a forecast of expected spot rates.

Another aspect that could result in a biased forecast of spot rates is term premia. It is generally agreed that term premia exist in spot T-bill rates and that these premia are time-varying and difficult to predict (Fama, 1984a, 1984b). Term premia must be deducted from forward rates to prevent the latter from systematically overestimating expected spot rates (Fama and Bliss, 1987; Startz, 1982).

MacDonald and Hein (1989) and Hafer, Hein, and MacDonald (1990) conclude that while the Treasury spot rates contain term premia, the futures market does not. Kamara (1988) concludes that the forward-futures spread is due to differences in the structures of the markets, including liquidity risk premia embedded in forward rates. Accordingly, futures rates do not need to be adjusted for term premia in arriving at rational forecasts of future spot rates.

A final biasing factor recognized by Gay and Manaster (1984) and MacDonald and Hein (1989) involves the location, timing, and delivery options contained in the futures contract. However, Gay and Manaster report that they have little or no value. If they have value, they would cause an upward bias in futures rates.

In summary, while a futures rate is often viewed as the market's expectation of the delivery-time spot rate, it may reflect a number of features besides this expectation. If the combination of these aspects is sufficient to cause the futures rate and expected spot rate to differ appreciably, then the futures rate should fail tests of rational expectations. If the combination of these features is nonexistent or trivial, then the futures rate should pass tests of rational expectations.

DATA

Table I illustrates the design of the data. Consider the June 1976 contract that calls for delivery of either the newly issued 13-week T-bill maturing in September 1976, or the original-issue 1-year T-bill maturing in September 1976. The spot 13-week T-bill rate, r_t, is the June 22, 1976 closing average of the bid and ask discount yield on the bill maturing on September 21, 1976. This rate is also the June 1976 no-change forecast of later bill rates. Similarly, settlement rates on June 22, 1976 serve as futures market forecasts of the September 1976, December 1976, March 1977, and June 1977 spot rates.

This study examines the entire history of the IMM futures contract through December 1988. Spot and futures rates are from the *The Wall Street Journal*. The study encompasses 51 one-quarter-ahead forecasts and 48 four-quarters-ahead forecasts, beginning with March 1976 predictions of June 1976 through March 1977 spot rates.

Table I

EXAMPLES OF MARCH 1976 FORECASTS OF JUNE 1976 THROUGH MARCH 1977 SPOT RATES

	Spot Rates Being Forecast				
Forecasts	**March 1976**	**June 1976**	**September 1976**	**December 1976**	**March 1977**
Futures:					
One-quarter-ahead	March 1976 settlement rate on June 1976 T-bill contract.				
Two-quarters-ahead	March 1976 settlement rate on September 1976 T-bill contract.				
Three-quarters-ahead	March 1976 settlement rate on December 1976 T-bill contract.				
Four-quarters-ahead	March 1976 settlement rate on March 1977 T-bill contract.				
No-change:					
One-quarter-ahead	March 1976 spot rate on 3-month T-bill.				
Two-quarters-ahead	March 1976 spot rate on 3-month T-bill.				
Three-quarters-ahead	March 1976 spot rate on 3-month T-bill.				
Four-quarters-ahead	March 1976 spot rate on 3-month T-bill.				

The macroeconomic data used in the tests are from the Federal Reserve Bank of Dallas. The data are described later. West Texas intermediate crude oil prices are from Pennwell Publishing Co.

PROPERTIES AND TESTS OF RATIONAL EXPECTATIONS

Muth (1961) identifies several necessary properties of "rational expectations." The expectations must be *unbiased,* they must *efficiently* incorporate information included in past observations of the series being predicted, they must be *consistent* in that forecast errors are unrelated to prior forecast revisions, and the forecast errors from rational expectations must be *unrelated* to prior costlessly available information.

Following are descriptions of tests developed to determine whether or not one-through four-quarters-ahead futures market forecasts and no-change forecasts possess these properties of unbiasedness, efficiency, consistency, and orthogonality of error terms. Before forecasts are considered rational expectations, they must pass every test at the 5% level.

Tests of Unbiasedness

Unbiasedness is a key property of rational expectations. Following Friedman (1980) and Theil (1966) among others, T-bill yields are regressed on s-quarters-ahead predictions.

$$r_t = \alpha + \beta r_t^{t-s} + e_{st}$$

Here, r_t is the actual bill rate at time t and r_t^{t-s} is a general term denoting a forecast of r_t made at time $t - s$. For the futures market, r_t^{t-s} is f_t^{t-s}, the s-quarters-ahead futures market rate. For the no-change forecast, r_t^{t-s} is by definition r^{t-s}, the actual bill rate at time $t - s$. The unbiasedness property is examined by the null hypothesis: H_0: $(\alpha, \beta) = (0, 1)$. In addition, for the one-quarter-ahead forecast ($s = 1$) the Durbin–Watson d-statistic must be consistent with the lack of serial correlation. Test results are reported in Table II.

Table II
TESTS OF UNBIASEDNESS: $r_t = \alpha + \beta r_t^{t-s} + e_{st}$

	Futures Forecasts				No-Change Forecasts			
Forecast Horizon	α	β	χ^2	**DW**	α	β	χ^2	**DW**
One-quarter-ahead	1.97	0.76	2.90	2.02	2.25	0.74	7.41[a]	2.37
	(1.32)	(0.18)	(0.234)		(1.14)	(0.16)	(0.025)	
Two-quarters-ahead	2.64	0.67	3.63		3.06	0.65	6.02[a]	
	(1.41)	(0.17)	(0.163)		(1.25)	(0.15)	(0.049)	
Three-quarters-ahead	2.76	0.65	3.08		3.09	0.65	13.64[a]	
	(1.57)	(0.20)	(0.214)		(0.83)	(0.11)	(0.001)	
Four-quarters-ahead	4.27	0.48	5.52[b]		4.51	0.49	16.14[a]	
	(1.95)	(0.22)	(0.063)		(1.18)	(0.13)	(0.001)	

Chi-square value (χ^2) is for the null hypothesis, H_0: $(\alpha, \beta) = (0, 1)$. Significance levels of the statistics are in parentheses below χ^2.

Standard errors are in parentheses below α and β.

[a]Significant at the 5% level.

[b]Significant at the 10% level.

Prior tests of the unbiasedness of futures market forecasts are limited to short forecast horizons, usually 13 weeks or less. The short history of futures markets makes it difficult to study longer forecast horizons. There are not enough nonoverlapping forecasts to accommodate traditional econometric procedures which assume independence of consecutive forecast errors. Observe that consecutive errors in multiperiod-ahead forecasts are not independent. For example, December and March two-quarters-ahead forecast errors reflect unexpected interest rate changes from the end of March through June. Recent econometric advances by Hansen (1982) and White (1980) adjust, respectively, for the autocorrelation induced by overlapping forecasts and the potential for heteroskedastic errors. Hansen's contribution makes it possible to double the forecast horizon without losing half the observations. This makes it feasible to study longer forecast horizons.[1] Empirical tests in this study reflect these econometric advances that were not available to prior studies.[2]

Tests of Efficiency

Rational forecasts efficiently incorporate the information contained in the historical T-bill series. If the bill rate follows a given autoregressive representation, then rational expectations of that rate must share the same autoregressive pattern. To test the efficiency of futures rates, the paired regressions are estimated as done in Friedman (1980) and Pesando (1975)

$$r_t = \alpha_o + \sum_{j=s}^{s+3} \alpha_j r_{t-j} + e_{st}$$

and

$$f_t^{t-s} = \alpha'_o + \sum_{j=s}^{s+3} \alpha'_j r_{t-j} + e'_{st}$$

The null hypothesis of efficiency is: H_0: $\alpha_j = \alpha'_j$ for $j = 0, s, s+1, s+2, s+3$. For the no-change forecast, the paired regressions are estimated

$$r_t = \alpha_o + \sum_{j=s+1}^{s+4} \alpha_j r_{t-j} + e_{st}$$

and

$$r_{t-s} = \alpha'_o + \sum_{j=s+1}^{s+4} \alpha'_j r_{t-j} + e'_{st}$$

and test the null hypothesis H_0: $\alpha_j = \alpha'_j$ for $j = 0, s+1, s+2, s+3, s+4$. The lag length is set at four quarterly observations to reflect any seasonal pattern that

[1]Economists traditionally forecast macroeconomic variables on a quarterly basis. Economic literature includes six surveys that request forecasts of U.S. or Canadian interest rates (Goldsmith–Nagan letter, *Institutional Investor, The Wall Street Journal,* and three analyzed in Pesando and Plourde, 1988). Each one requests one- and/or two-quarter forecasts. The widespread adoption of these horizons in business publications strongly suggests that they are the forecast horizons of most interest.

[2]The General Methods of Moments (GMM) estimators calculate a corrected covariance matrix in the overlapping sample case. The GMM estimator assumes that the exogenous variables are stationary, ergodic, continuously measurable, and that the relevant matrices are full rank. See assumptions 3.1 to 3.6 in Hansen (1982).

might exist, while minimizing the loss of degrees of freedom. Test results are reported in Table III.[3]

Tests of Consistency

Rational expectations must revise forecasts to reflect new information in a consistent manner. Statistically, forecast errors must be unrelated to prior forecast revisions. Tests of the consistency of forecasts in this context are provided by regressing forecast errors on prior forecast revisions.

$$r_t - r_t^{t-s} = \alpha + \beta(r_t^{t-s} - r_t^{t-s-q}) + e_{st}$$

where q can be 1, 2, or 3 for $s = 1$ (i.e., one-quarter-ahead forecasts), 1 or 2 for $s = 2$, and 1 for $s = 3$. For futures market and no-change forecasts, r_t^{t-s} is f_t^{t-s} and r_{t-s}, respectively. The null hypothesis of consistency is H_0: $(\alpha, \beta) = (0, 0)$. Test results are reported in Table IV.

Tests of Orthogonality of Errors

A key property of a rational forecast is that it must fully reflect all costless information at the time of the forecast. If futures market or no-change forecasts are rational expectations, prediction errors should show no significant relation to prior values of macroeconomic variables. Consider a situation where forecast errors are significantly associated with prior macroeconomic information. This implies that the forecasts are not rational in that they could have been improved by considering the information.

Table III
CHI-SQUARE STATISTICS FOR TESTS OF EFFICIENCY

Forecast Horizon	Futures Forecasts (χ^2)	No-Change Forecasts (χ^2)
One-quarter-ahead	2.28	12.43[a]
	(0.810)	(0.029)
Two-quarters-ahead	4.01	13.80[a]
	(0.548)	(0.017)
Three-quarters-ahead	1.43	16.40[a]
	(0.921)	(0.006)
Four-quarters-ahead	17.88[a]	32.19[a]
	(0.003)	(0.001)

Significance levels are in parentheses.
[a]Significant at the 5% level.

[3]The efficiency tests are multiple regression tests. Following the advice of Stephen Brown and utilizing the Regression Analysis Time Series Package, the maximum moving-average order, L, of OLS residuals and the product of the residuals and the regressors are estimated first. Next, the products of the OLS residuals and the regressors are formed into Hansen's S_w matrix with lag windows of the form $[L + 1 - |k|/(L + 1)]^\theta$, where $k = -L, -L + 1, \ldots, L$. For futures forecasts, $L = n - 1$, and for no-change forecasts, $L = n$. (Using $n - 1$ for no-change forecasts did not affect the conclusions). The default value of θ is zero; however, the matrix may not be positive definite. In these cases, θ is increased in increments of 0.25 until the matrix becomes positive definite.

Table IV
CHI-SQUARE STATISTICS FOR TESTS OF CONSISTENCY:
$(r_t - r_t^{t-s}) = \alpha + \beta(r_t^{t-s} - r_t^{t-s-q}) + e_{st}$

Forecast Horizon	q	Futures Forecasts	χ^2	No-Change Forecasts	χ^2
One-quarter-ahead	1	F_t^{t-1}	2.07 (0.356)	r_{t-1}	8.70[a] (0.013)
One-quarter-ahead	2	F_t^{t-1}	2.35 (0.310)	r_{t-1}	8.97[a] (0.011)
One-quarter-ahead	3	F_t^{t-1}	0.71 (0.701)	r_{t-1}	0.91 (0.634)
Two-quarters-ahead	1	F_t^{t-2}	3.51 (0.173)	r_{t-2}	6.69[a] (0.035)
Two-quarters-ahead	2	F_t^{t-2}	1.03 (0.598)	r_{t-2}	1.53 (0.464)
Three-quarters-ahead	1	F_t^{t-3}	4.87 (0.088)[b]	r_{t-3}	4.11 (0.128)

Chi-square statistics are for the null hypothesis, H_0: $(\alpha, \beta) = (0, 1)$.
Significance levels are in parentheses.
[a]Significant at the 5% level.
[b]Significant at the 10% level.

The tests regress ex post forecast errors on the most recent observation of a macroeconomic variable, x_{t-s}

$$r_t - r_t^{t-s} = \alpha + \beta X_{t-s} + e_{st}$$

The null hypothesis is H_0: $\alpha_o = \alpha_s = 0$.

The economic variables examined in these tests include all variables considered by Friedman (1980) plus some additional variables. They include the unemployment rate (UN), the growth in industrial production as measured by the Industrial Production Index (IP), the inflation rate as measured by the Consumer Price Index (INF), the change in inflation rate (ΔINF), the growth rate in the M1 money supply (MG), the growth rate in the adjusted monetary base (BG), the change in the 3-month T-bill rate (ΔTB), the price of West Texas crude oil (OIL), and the federal deficit (GOV).

It is important to use observations on variables that are publicly available at the time of the forecasts. To this end, observations from the second month in a quarter are used for the following: unemployment rate, IPI, CPI, M1, monetary base, and price of West Texas crude oil. The federal deficit from the prior quarter is considered the most recent observation. Test results are reported in Table V.

ANALYSIS OF EMPIRICAL RESULTS

One-Quarter-Ahead Forecasts

Futures market forecasts pass all 15 tests of rationality at the 5% level. These results strongly support the argument that the futures rate is a rational expectation of the one-quarter-ahead spot rate.

The null hypothesis of unbiasedness is easily supported and the Durbin–Watson d-statistic shows no evidence of serially correlated errors. Results of the efficiency test support the hypothesis that futures rates reflect any autoregressive process inherent in the spot rate. Consistency tests support the hypothesis that forecast errors are unrelated to prior futures market forecast revisions. The nine orthogonality-of-errors regressions imply that futures rates fully reflect the information in common macroeconomic series. In short, the one-quarter-ahead futures rate is not only "use-

Table V
CHI-SQUARE STATISTICS FOR TEST OF ORTHOGONALITY OF ERRORS
(FORECAST HORIZON IN QUARTERS):
$r_t - r_t^{t-s} = \alpha + \beta X_{t-s} + e_{st}$

	Futures Forecasts				No-Change Forecasts			
Ind. Var.	One	Two	Three	Four	One	Two	Three	Four
UN	2.06	2.52	2.96	3.45	0.41	0.96	1.13	1.27
IP	0.85	0.27	0.26	0.52	1.05	0.28	0.21	0.07
INF	1.68	5.62[b]	7.52[a]	8.27[a]	0.05	1.34	1.52	1.15
ΔINF	1.36	0.65	0.82	1.85	1.11	1.18	0.91	0.08
MG	0.08	0.27	0.42	2.18	0.08	0.41	1.48	0.19
BG	0.13	3.43	3.27	2.57	0.04	1.43	2.22	1.87
ΔTB	0.96	1.31	0.30	0.79	8.32[a]	6.69[a]	4.26	5.12[b]
OIL	0.26	0.22	2.77	0.32	2.33	2.51	4.06	4.30
GOV	2.39	4.11	4.40	4.00	0.08	0.45	1.12	1.29

Chi-square characteristics are for the null hypothesis, H_0: $(\alpha, \beta) = (0, 0)$.
[a]Significant at the 5% level.
[b]Significant at the 10% level.

ful" (Hafer and Hein, 1989), but it also appears to be a rational expectation of the spot rate.

No-change forecasts fail 5 of 15 tests of rationality at the 5% level. They are biased, inefficient, and inconsistent, and fail to incorporate fully the information in prior quarter's change in the T-bill series.

Two-Quarters-Ahead Forecasts

Futures market forecasts pass all 13 tests at the 5% level. The forecast errors are unbiased, efficient, consistent, and the forecast errors are unrelated to macroeconomic series at the 5% level. These forecasts pass the strong burden-of-proof conditions, and are considered rational expectations.

No-change forecasts fail 4 of the 13 tests at the 5% level. These forecasts are biased, inefficient, and inconsistent, and forecast errors are associated with the prior quarter's change in the T-bill rate. The evidence strongly rejects the hypothesis that no-change forecasts are rational expectations of two-quarters-ahead spot rates.

Three-Quarters-Ahead Forecasts

The results for three-quarters-ahead futures market forecasts are mixed. Forecast errors are significantly associated with the inflation rate at the 5% level and prior forecast revisions at the 10% level. The burden-of-proof in this study requires forecasts to pass every test at the 5% level. This conservative stance forces rejection of the rationality of these futures market forecasts.

However, futures forecasts pass 11 of 12 tests at the 5% level and 10 of 12 at the 10% level. One cannot rule out the possibility that the test rejections occur by chance alone.[4] The forecasts possess the properties of unbiasedness and efficiency.

[4]The probability, based on the binomial distribution, of at least one (two) failure(s) in 12 occurring by chance at the 5% (10%) level is 46% (34%).

In the absence of an obviously better three-quarters-ahead forecast, some individuals may prefer to emphasize these positive results and the possibility that this futures rate may be a rational expectation of the spot rate.[5] Business should find this futures rate to be useful for proforma purposes, or as a forecast of short-term interest rate changes.

No-change predictions fail unbiasedness and efficiency tests at beyond the 1% level. Although these no-change forecasts pass the consistency and orthogonality of errors tests, they do not possess all the properties required of rational expectations.

Four-Quarters-Ahead Forecasts

The results reject the rationality of both futures market and no-change forecasts. Futures market forecasts fail 2 of 11 tests at the 5% level. It is not clear that they possess any properties of rational expectations. There are no consistency tests for four-quarters-ahead forecasts, and they fail efficiency, orthogonality, and unbiasedness tests at the 0.3%, 1.6%, and 6.3% levels, respectively. The thin volume of trading in the four-quarters-ahead contract and, possibly, the test design may account for its lack of rationality. The vast majority of trading occurs on the earlier contracts. Furthermore, the test design uses the settlement rate on a day shortly after the contract becomes available for trading. The trading on the unseasoned contract may be insufficient to ensure that these futures rates possess desirable forecast properties.

No-change predictions fail unbiasedness and efficiency tests at the 0.1% level. They are not rational forecasts of spot rates.

SUMMARY AND CONCLUSIONS

This study examines whether one- through four-quarters-ahead T-bill futures rate predictions and no-change predictions are rational expectations or rational predictions of future spot interest rates. It is the first study to examine whether these forecasts possess the rational expectation properties of unbiasedness, efficiency, consistency, and orthogonality of errors to costlessly available information.

The results imply that futures rates provide rational one- and two-quarters-ahead forecasts of future spot rates. These are the forecast horizons that seem to be of most interest to the public. It is not clear whether three-quarters-ahead futures rates should be considered rational forecasts of later spot rates; they fail 1 of 12 tests at the 5% level. The results reject the rationality of four-quarters-ahead futures forecasts.

In contrast, the results strongly reject the rationality of no-change predictions for all forecast horizons. This is the first empirical evidence that futures interest rate predictions are significantly better than no-change predictions.

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[5]The rationality of three-quarters-ahead futures forecasts is rejected in the post-1981 period, which implies that the lack of rationality is not due to the change in tax structure for futures contracts.

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