INTEREST RATE FUTURES: EVIDENCE ON FORECAST POWER, EXPECTED PREMIUMS, AND THE UNBIASED EXPECTATIONS HYPOTHESIS

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Due to the convergence of the futures contract price to the spot price at delivery, it has been hypothesized that a component of the futures price is the expectation of the spot price on the delivery date. The extent to which a futures contract price reflects unbiased expectations of the spot price on the delivery date, or conversely the extent to which futures contract prices embody systematic expected premiums, affects the cost of using the futures contract in hedging activities.

This study examines the forecast power of interest rate futures contract prices and tests the unbiased expectations hypothesis in the Treasury bill, Eurodollar, and Treasury bond markets. The forecast power and expectational properties of the Eurodollar and Treasury bond contract prices have not appeared in previous literature. Cointegration methodology, which explicitly accounts for the nonstationarity of the data series, is used to test the parameter restrictions implied by the unbiased expectations hypothesis.

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INTRODUCTION

Previous research has investigated the use of Treasury bill futures contract prices as a mechanism to forecast short-term interest rates. Hafer, Hein, and MacDonald (1992) examined the forecast performance of Treasury bill futures contract prices relative to forecasts produced from implied forward rates and analyst's surveys. Compared to these alternative forecast mechanisms Treasury bill futures rates provided superior one quarter forecasts as measured by root mean square, and absolute forecast errors. Cole, Impson, and Reichenstein (1991) found that at the one quarter forecast horizon Treasury bill futures contract rates possess the qualities of rational expectations: unbiasedness, efficiency, consistency, and orthogonality of forecast errors to costless information.

Fama and French (1987) used two regression relationships to assess forecast power and evidence of systematic expected premiums in futures contract prices:

$$\text{BASIS} = F_{t,T} - S_t$$

$$\text{CHANGE} = S_T - S_t$$

$$\text{PREMIUM} = F_{t,T} - S_T$$

$$S_T - S_t = a_1 + b_1[F_{t,T} - S_t] + \mu_1 \tag{1}$$

$$F_{t,T} - S_T = a_2 + b_2[F_{t,T} - S_t] + \mu_2 \tag{2}$$

(1) implies that the change in the spot price from $t - T$, where T is the contract delivery date, is a linear function of the; basis at t; (2) implies that observed premiums are a linear function of the basis. The observed premium, $F_{t,T} - S_T$, is equivalent to the change in the futures price over the horizon $t - T$ since on the delivery date the futures contract price will converge to the spot price, $F_T = S_T$.

Relationship (1) and (2) are not independent. Adding (2) to (1) illustrates the cross equation parameter restrictions which Fama and French refer to as the adding up constraints: $a_1 + a_2 = 0$ and $b_1 + b_2 = 1$. If $F_{t,T}$ contains information useful for forecasting S_T which is not contained in S_t then b_1 will be significantly different from zero. Finding b_1 significantly different from zero would indicate that the futures contract price provides superior forecasts relative to the naive forecast, $E_t(S_T) = S_t$.

Predictable variation in realized premiums, $b_2 > 0$, is consistent with time varying expected premiums, $E_t(F_{t,T} - F_T) \neq 0$; Fama and French (1987). However this test for predictable variation in realized premiums is conditional on the forecast power of the futures contract price. If b_1 is not statistically different from zero then, by construction, b_2 must be significantly different from zero and equal to 1. Hence rejection of a time varying expected premium will be possible if and only if the futures price has forecast power relative to a naive forecast.

UNBIASED EXPECTATIONS HYPOTHESIS

The unbiased expectations hypothesis posits parameter restrictions on the relationship between realized spot prices and futures contract prices. Because these series are found to be nonstationary standard regression based techniques are inappropriate for statistical inference. To test the unbiased expectations hypothesis, one must first test for the existence of a cointegrating relationship between the futures contract price and the realized spot price. The Treasury bill and Eurodollar markets produce evidence consistent with a cointegrating relationship. For these markets, parameter restrictions on the cointegrating relationship are tested to determine consistency with the unbiased expectations hypothesis.

Two suppositions form the unbiased expectations hypothesis: the price of a futures contract equals the expected spot market price on the contract delivery date, and the expectation of the spot price is formed rationally. The first supposition suggests parameter restrictions $a_3 = 0$, $b_3 = 1$ in (3).

$$F_{t,T} = a_3 + b_3(E_t(S_T)) \tag{3}$$

Because expectations are not directly measurable, realized spot prices are substituted in (3). In this manner the assumption of rational expectations is imposed on the empirical analysis. Equation (4) is the empirical relationship used to test the unbiased expectations hypothesis in this study.

$$F_{t,T} = a_4 + b_4(S_T) \tag{4}$$

A test of the unbiased expectations hypothesis is of both theoretical and practical significance. The condition of a non-zero expected premium (i.e., normal backwardation $a_4 < 0$, or contango, $a_4 > 0$) increases the cost of hedging. The possibility of non-zero expected premiums is posited due to the need to compensate speculators for the risk of net long or net short positions when hedgers are net short or net long. If hedgers are paying speculators a risk premium, this would imply that they realize consistent losses on the futures leg of their hedged positions.

DATA

The data for this study match the delivery date spot price of the underlying interest rate instrument with the futures contract price measured one quarter prior to the delivery date. All delivery dates through December 1992 for the Treasury bill, Eurodollar, and Treasury bond contracts are used to construct the sample. Each of these contracts offers a March, June, September, December delivery cycle. Terms of the Eurodollar contract allow identification of the exact delivery date; two London business days before the third Wednesday of the delivery month. Terms of the Treasury bill contract call for delivery in a 3-day delivery period beginning on the date when the newly auctioned Treasury bill aligns with the previously issued one year bill having 91 days until maturity. Terms of the Treasury bond contract call for delivery in the delivery month before the last business day of the delivery month. Treasury bill and Eurodollar spot prices are measured on the delivery day (first delivery date in the case of Treasury bills) for each contract delivery period. The asked discount rate for Treasury bills and the average of the range reported for three-month London Eurodollars are collected from the *Wall Street Journal*. These values are subtracted from 100 to form a "price" measure consistent with the International Monetary Market (IMM) index value quoted for the Treasury bill and Eurodollar futures contracts. Two spot price measures are considered for the Treasury bond contract; the asked price of the cheapest to deliver Treasury bond (TBONDA) on the first day of the delivery month and futures contract price (TBONDB) of the expiring futures contract on the first day of the delivery month.[1] The Treasury bond sample contains 61 observations starting with the December 1977 contract, the Treasury bill sample contains 68 observations beginning with the March 1976 contract, and the Eurodollar sample contains 44 observations beginning with the March 1982 contract.

Fama and French (1987) examined the metals contracts: gold, platinum, silver, and copper; commodities with high market value to storage cost ratios like the financial instruments considered in this study. No evidence of forecast power was found for the metals contracts. Fama and French attributed this to the small basis variance of these contracts relative to the variances of the realized premium and spot price change. The financial contracts considered in this study exhibit greater basis

[1]The spot price of the cheapest to deliver bond is divided by the CBOT conversion factor. This effectively produces the price at which the cheapest to deliver bond would product an 8% yield to maturity. The futures contract calls for the delivery of a standardized 8% coupon bond.

variability relative to the variability of realized premiums and spot price changes. Therefore, it is less likely that finding no forecast power for the financial futures prices is a statistical artifact caused by small variation in BASIS relative to variation in CHANGE and PREMIUM.

Let σ_B, σ_C, and σ_P, be the standard deviations of BASIS, CHANGE, and PREMIUM. Table IA lists the standard deviations of the basis for the financial futures contracts and the ratios: σ_C/σ_B and σ_P/σ_B. The largest ratio σ_C/σ_B occurs for the Treasury bond (BONDB) contract, 8.92, the smallest for the (EUROS) Eurodollar contract, 2.30. Fama and French found that the ratio σ_C/σ_B for the silver, gold, platinum, and copper futures contracts were 37.0, 21.8, 7.4, and 4.8. Similar comparisons of the ratio σ_P/σ_B indicate the variability of basis relative to variability in realized premiums is generally greater in financials than metals.

FORECAST POWER AND SYSTEMATIC RISK PREMIUMS

Relationships (1) and (2) are estimated evidence for forecast power and time varying expected premiums embedded in interest rate futures contract prices. Dickey–Fuller test statistics appear in Table IB and are provided as a check of the stationarity of the series used in the estimation of relationships (1) and (2). For all series, except BASIS for the Treasury bond contract, the null hypothesis of nonstationarity can be rejected at

TABLE IA

Sample Standard Deviations

	OBS.	σB	$\sigma C/\sigma B$	$\sigma P/\sigma B$
TBONDA	60	0.82	6.81	6.90
TBONDB	60	0.62	8.91	9.03
TBILLS	67	0.60	3.01	3.03
EUROS	43	0.43	2.30	2.48

TABLE IB

Dicky–Fuller Test Statistics

	BASIS	*CHANGE*	*PREMIUM*
TBONDA	−2.72	−8.62[a]	−8.12[a]
TBONDB	1.87	−8.63[a]	−8.22[a]
TBILLS	5.09[a]	−10.91[a]	−9.55[a]
EUROS	−4.98[a]	5.52[a]	−5.12[a]

[a]Reject null hypothesis of unit-root process at the 5% confidence level.

the 5% confidence level. This implies that CHANGE and PREMIUM, the dependent variables in eqs. (1) and (2), have finite variance which is a requirement of the maximum likelihood regression model.

Table II presents maximum likelihood parameter estimates of eqs. (1) and (2). A first-order autoregressive process in the residuals is assumed. T-statistics for the estimated coefficients of b_1 and b_2, the coefficients of determination of the estimated relationships, and Durbin–Watson statistics are also provided. Estimates of intercept terms a_1 and a_2 are not significantly different from zero for any of the interest rate contracts and are not included in Table II.

The estimated value of b_1 is not statistically significant for any of the interest rate futures contracts. This evidence is inconsistent with Treasury bond, Treasury bill, and Eurodollar futures contract prices providing forecast power relative to a naive forecast. The positive signs and statistical significance of the estimated values of b_2 reported in Table II are not reliable evidence of systematic expected premiums given the conclusion of no forecast power. In this circumstance these tests for systematic expected premiums have no power to reject the null hypothesis.

JOHANSEN'S PROCEDURE FOR TESTING PARAMETER RESTRICTIONS IN A COINTEGRATED SYSTEM

Before proceeding with the cointegration tests it is necessary to establish the nonstationarity of the data. Dickey–Fuller and augmented Dickey–Fuller tests are used to test the null hypothesis of nonstationarity for the prices and first differences of prices. The augmented Dickey–Fuller test statistics reported in Table III are calculated assuming a fourth-order process. Rows entitled DTBONDA, DTBONDB, etc. contain test statistics for first-differenced series. The test statistics reported are consistent with first-order, unit root, processes for every

TABLE II

Price Change and Premium Regression Results Three-Month Horizon

	b_1	b_2	$t(b_1)$	$t(b_2)$	R_12	R_22	DW
TBONDA	0.59	1.59	−0.72	1.95	0.02	0.06	1.99
TBONDB	−1.28	2.28[a]	−1.24	2.20	0.04	0.08	2.00
TBILLS	0.23	0.77[a]	0.71	2.36	0.10	0.11	2.22
EUROS	0.11	0.89[a]	0.30	2.41	0.02	0.16	1.98

[a]Significant at the 5% confidence level.

TABLE III
Dickey–Fuller and Augmented Dickey–Fuller Test Statistics for Spot and Futures Markets

	Spot		*Futures*	
	DF	*ADF(4)*	*DF*	*ADF(4)*
TBONDA	−1.55	−1.52	1.57	−1.55
TBONDB	−1.59	1.54		
TBILLS	−2.54	−1.35	−2.30	−1.34
EUROS	−2.11	−0.34	−1.32	−0.27
DTBONDA	−8.62[a]	−3.04[a]	−8.55[a]	−2.94[a]
DTBONDB	−8.63[a]	−3.00[a]		
DTBILLS	−10.91[a]	−3.07[a]	−11.25[a]	−3.16[a]
DEUROS	5.52[a]	2.99[a]	−6.27[a]	−3.19[a]

[a]Reject null hypothesis of unit root process at the 5% confidence level.

price series tested. The null hypothesis of nonstationarity cannot be rejected for any of the series, the null hypothesis can be rejected for every first-differenced series.

A time series process is said to be integrated of the dth-order, $I(d)$, if dth-order differencing produces stationarity. For example, a random walk, $I(1)$, would be stationary, $I(0)$, after first differencing. A cointegrating relationship between $I(1)$ variables exists if a linear combination of the variables is itself $I(0)$. The economic concept of a long-run equilibrium relationship can be used to give meaning to the existence of a cointegrating relationship. Two variables linked by a long-run equilibrium relationship will move in tandem through time. Economic forces serve to eliminate temporary displacements from the long run equilibrium relationship.

Define $z_{t,T}$ to be the displacement from the equilibrium relationship:

$$z_{t,T} = -F_{t,T} + a_5 + b_5(S_T) \tag{5}$$

Then if $z_{t,T} \sim I(0)$, (5) describes a cointegrating relationship operating on the levels $F_{t,T}$ and S_T. The quantity, $z_{t,T}$, is the displacement from the equilibrium relationship at time t. In a cointegrated system this quantity affects subsequent changes in the levels of $F_{t,T}$ and S_T through an error-correction process, Engle and Granger (1987). The parameter vector $(-1, a_5, b_5)$ is called the cointegrating vector.

Non-stationarity of $F_{t,T}$ and S_T prevents the use of standard regression tests of parameter estimates of the cointegrating relationship and examination of first differenced data will not provide direct evidence on the underlying equilibrium relationship. Johansen (1988, 1991) and Johansen and Juselius (1990) developed a methodology for testing the existence of a cointegrating relationship, estimating the parameters of the cointegrating vector, and testing parameter restrictions on the cointegrating vector. A brief summary of the maximum likelihood estimation and testing procedures is given. The reader should consult Johansen (1988) or Johansen and Juselius (1990) for further details. Krehbiel and Adkins (1993) apply the Johnansen methodology to test the parameter restrictions of the unbiased expectations hypothesis in the metals futures markets.

Let $X_t = (F_{t,T}, S_T)$ and define υ to be the difference operator. The general form of a kth order vector autoregression for the realized spot and futures price series is:

$$\upsilon X_t = \Gamma_1 \upsilon X_{t-1} + \Gamma_2 \upsilon X_{t-2} + \ldots + \Gamma_{k-1} \upsilon X_{t-k+1} + \Pi X_{t-k} + \mu + v_t \tag{6}$$

where μ is a 2×1 vector of constants and v_t is a multivariate normal white noise process with mean 0 and finite covariance matrix. Johansen and Juselius (1990) showed that the coefficient matrix Π contains the essential information about the relationship between $F_{t,T}$ and S_T. The number of equilibrating relationships is equal to the rank of Π: if rank(Π) = 2, then $F_{t,T}$ and S_T are jointly stationary; if rank(Π) = 1, then $F_{t,T}$ and S_T are not stationary, but *are* cointegrated; if rank(Π) = 0, then $F_{t,T}$ and S_T are not cointegrated and the relationship between the two time series can only be examined using first differenced data.

A cointegrating relationship in the system $(F_{t,T}, S_T)$ implies that there are $2 \times r$ matrices α and β such that $\Pi = \alpha\beta'$ and rank(Π) = $r = 1$. The matrix β represents the cointegrating vector(s) and α a matrix of weights. Thus cointegration produces a set of nonlinear cross equation constraints on the parameters of the unrestricted vector autoregression, eq. (6). Parameter restriction tests on the matrix β are accomplished by forming likelihood ratio statistics from restricted and unrestricted model estimations. The asymptotic distribution of the likelihood ratio test statistic is chi-square with degrees of freedom equal to the number of assumed parameter restrictions in the null hypothesis.

Implementation of Johansen's procedure requires that several decisions be made before estimating the parameters of the vector process. First, the lag length k is an unknown parameter and must be estimated.

The usual practice is to begin with a maximum possible lag length and to use one of the many model selection rules to reduce the dimension of the parameter space. The maximum possible lag length is set here at 4 and the "optimal lag" is selected using Schwarz's (1978) criterion. For each market the optimal lag selected is $k = 2$.

Results of the Johansen test for number of cointegrating relationships in the data are presented in Table IV. The first set of tests help establish whether $F_{t,T}$ and S_t are cointegrated. Here tests are performed to determine the rank of Π which is referred to as r. At a 5% confidence level there is evidence of one cointegrating vector in the Treasury bill and Eurodollar markets. There is no evidence of a cointegrating relationship in the Treasury bond market at the 5% confidence level for either definition of the realized spot Treasury bond price. The Treasury bond futures contract grants valuable delivery options to the short position in the contract. The value of these options is expected to systematically bias the contract price downwards from the expected spot price.[2] Additionally,

TABLE IV

Johansen Tests for Number of Cointegrating Vectors

Hypothesis		*Test Statistics*				*Critical Values*	
Ho:	Ha:	TBONDA	TBONDB	TBILLS	EUROS	95%	90%
$r = 0$	$r = 1$	12.06	8.19	23.75[a]	22.61[a]	15.67	13.75
$r = 1$	$r = 2$	1.92	2.05	0.78	8.95[b]	9.24	7.52
$r < 1$	$r \geq 1$	13.98	10.24	24.53[a]	31.56[a]	19.96	17.85

[a]Reject null hypothesis at 5% confidence level.
[b]Reject null hypothesis at 10% confidence level.
Critical Values from *Microfit 3.0*, Pesaran and Pesaran (1991).

[2]Traders options in the Treasury bond contract: (a) Quality option. The short trader may select from a group of approximately 20 Treasury bonds to deliver into the Treasury bond contract. (b) Timing option. The short trader may select the date on which the three-day delivery process will begin. The first allowable position day will be a trading day in the month preceding the delivery month. (c) Wildcard option. The settlement price on the position day is used to determine the invoice amount at delivery. The delivery follows the position day by two business days. Under the rules of the CBOT, the settlement price is determined at 2:00 PM and the short trader has until 8 PM to notify the exchange of the intention to delivery. The wildcard option is actually a sequence of put options which can be exercised in the 2 PM–8 PM window each trading day from the first to the last position day. The last position day is the third to the last business day of the delivery month. The short trader has a quality option imbedded in the wild card option. The short trader has until 5:00 PM on the notice of intention day, the day following the position day to announce which bond will be delivered into the contract. (d) End-of-month option. The eighth-to-last business day of the delivery month is the last day of trading for the Treasury bond futures contract. The settlement price on this day will be used to determine the invoice amount on all deliveries which take place after this date. All open positions must be settled through physical delivery before the last business day of the delivery month.

because the value of the delivery options are dependent upon the futures contract price, the constant parameter assumption of the cointegrating relationship is more likely to be rejected for the Treasury bond market.

ANALYSIS OF COINTEGRATING RELATIONSHIPS

Maximum likelihood estimates of the parameters of the cointegrating vectors and likelihood ratio test statistics for the parameter restrictions are reported in Table V. Because no evidence of a cointegrating relationship is detected for the Treasury bond market, only parameter estimates and test statistics for the Treasury bill and Eurodollar markets are reported in Table V.

The evidence presented in Table V for Treasury bills is consistent with the findings of Cole, Impson, and Reichenstein (1991). None of the parameter restrictions implied by the unbiased expectations hypothesis can be rejected for this sample at the 5% confidence level. In contrast, each of the parameter restrictions implied by the unbiased expectations hypothesis can be rejected for the Eurodollar futures contract.[3]

Estimates of the parameters of the cointegrating relationship between Eurodollar futures and realized spot prices are consistent with the Eurodollar futures price providing a downward biased estimate of the Eurodollar price, $S_T = 100 - r_T$. Consequently the Eurodollar futures rate provides an upward biased estimate of the realized Eurodollar rate. The size of the bias is proportional to the level of the Eurodollar rate. A Eurodollar rate of 3.00 will produce a negative bias, $(F_{t,T} - S_T)$, of 11 basis points. A Eurodollar rate of 13.00 will produce a negative bias of approximately 100 basis points.

TABLE V
Unbiased Expectations Parameter Restriction
Tests for Treasury Bill and Eurodollar Futures

	a_5	b_5	$Ho{:}a_5 = 0$	$Ho{:}b_5 = 1$	*Joint*
TBILLS	−1.04	0.99	0.06	0.07	0.64
EUROS	8.84	1.09	4.23[a]	4.15[a]	5.18[a]

[a]Reject null hypothesis at 5% confidence level.

[3]Using rates rather than prices does not affect test outcomes for the Treasury bill market. However, the power of the parameter restriction tests is reduced by re-scaling of the Eurodollar data. The hypotheses $a_4 = 0$ and the joint hypothesis, $a_4 = 0$ and $b_4 = 1$ are rejected at the 10% confidence level using this data definition.

Daigler and Nurawan (1990), Cole and Reichenstein (1993) found evidence consistent with a structural change in the process generating Eurodollar futures prices. They found that prior to the third quarter of 1986, the Eurodollar futures contract provided upward biased forecasts of realized Eurodollar rates; post third quarter 1986, the process generating Eurodollar futures prices was consistent with the unbiased expectations hypothesis.

The Eurodollar sample size, 44, is insufficient to allow parameter restriction tests on subsets of the sample. Therefore, the methodology is modified to test the hypotheses in the presence of a structural break. Tests are performed for a unit root in the presence of a structural break, Perron (1989), and a dummy variable is incorporated in the vector autoregression model corresponding to the proposed 1986.3 structural break [e.g., Krehbiel and Adkins (1993)]. These test results are consistent with those already presented.[4]

CONCLUSIONS

Regression relationships suggested by Fama and French (1987) are estimated to test the forecast power of futures contract prices and evidence of systematic expected premiums. Relative to the contemporaneous spot market price, futures contract prices are found to provide no additional information relevant for forecasting the realized spot price. Consequently, the regression based tests for predictable variation in realized premiums produces no reliable evidence of systematic expected premiums in Treasury bill, Eurodollar, and Treasury bond contract prices.

Each of the price series used in this study is found to be non-stationary based on Dickey–Fuller and augmented Dickey–Fuller tests. The maximum likelihood estimation procedure developed by Johansen

[4]Unit root test statistics augmented for the presence of a one time shift in both the futures and spot Eurodollar price series. The null hypothesis is non-stationarity.

	Test Statistic	Critical Value (5%)
Futures	−1.687	−3.72
Spot	−2.572	−3.72

Likelihood ratio test statistics from vector autoregression model augmented to include a one-time structural shift in third quarter 1986.

Null Hypothesis	Test Statistic
$a_4 = 0$	4.61[a]
$b_4 = 1$	20.83[a]
$a_4 = 0$ and $b_4 = 1$	20.99[a]

[a]reject null hypothesis at 5% level

is used to test for the existence of a cointegrating relationship between price series and for the estimation and parameter restriction tests for the two markets for which evidence of a cointegrating relationship is found. Evidence of one cointegrating relationship between futures contract prices and the realized spot price are found for the Treasury bill and Eurodollar markets. Cointegrating relationships between futures and realized spot prices are consistent with a linear relationship between futures and expected delivery period spot prices.

Neither definition of the realized spot price in the Treasury bond market produces evidence of a cointegrating relationship with the Treasury bond contract price one quarter prior to the delivery month. This finding might be attributable to the valuable delivery options contained in the Treasury bond futures contract.

The unbiased expectations hypothesis posits parameter restrictions on the equilibrium relationship between futures contract and expected delivery period spot prices. Using realized spot prices for unobservable expectations, parameter restriction tests in the Treasury bill and Eurodollar markets produce contrasting results. For the Treasury bill market no parameter restrictions implied by the hypothesis can be rejected; for the Eurodollar market, all parameter restrictions implied by the hypothesis are rejected. The estimated coefficients in the Eurodollar market indicate that the Eurodollar futures price, IMM index, one quarter prior to the contract delivery date is a downward biased forecast of the realized spot "price," $100 - r_T$. Consequently, the Eurodollar contract rate is an upward biased estimate of the Eurodollar rate on the contract delivery date.

The results of parameter restriction tests are consistent with expected premiums in the Eurodollar futures contract price. The parameter values estimated for the cointegrating relationship between futures and realized spot prices suggest that speculators who take a long position in the Eurodollar contract can expect to earn a risk premium for their exposure to fluctuations in the Eurodollar rate.

In the presence of a cointegrating relationship, the precision of estimated parameter values in unrestricted vector autoregressions can be improved by imposing the nonlinear cross equation parameter restrictions implied by the error correction process. The extent to which the nonlinear cross equation parameter restrictions improve vector autoregression forecasts of Treasury bill and Eurodollar rates is a question for further research.

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