COINTEGRATION AND SHORT-RUN DYNAMICS OF U.S. LONG BOND RATE AND INFLATION RATE

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ABSTRACT
According to the Fisher hypothesis the nominal bond interest rate adjusts to changes in the expected rate of inflation. This also implies the efficiency of the financial asset markets. Optimizing behavior of agents in asset markets requires that the nominal yield on bonds and expectations of inflation move in the same direction. The original Fisher hypothesis stipulates a one-to-one relationship between expected rate of inflation and nominal interest rates, unadjusted for taxes. This dynamic relationship between the long-bond yield and expected inflation rate as well as the long-run equilibrium relationship between the two rates, in the presence of the Federal Reserve's close monitoring of the inflation rate, is investigated using the Johansen and Juselius (JJ) (1990, 1995) cointegration and equilibrium error correction methodology. The empirical results of our study strongly indicate that bond rate and consumer inflation rate are cointegrated. Secondly, bond rate is caused by consumer price inflation and consumer inflation is not caused by bond rate. Further, our empirical results support Darby's (1975) finding of 'augmented Fisher effect.' The implication of this finding is that the interest rate, not adjusted for taxes, has to increase by nearly 1.52 when the inflation rate rises by one unit in order to keep the real rate constant.

Key words: degree of integration, unit root, cointegration, erro-correction, Granger causality
JEL Classification: E4 and E5

INTRODUCTION

The forces that produce a long-run equilibrium relationship between two or more variables implies mean reversion and existence of an error correction mechanism. Such a relationship is the relationship between inflation and interest rates.

Earlier studies looked at the 30 year bond rate versus the inflation rate. In this study we consider the yield on 10-year Treasury bond and the long-term expected inflation rate. We investigate this dynamic relationship between the 10-year bond rate and expected inflation rate using the popular cointegration and equilibrium error correction methodology. Studies in the early 1990s by Mishkin (1990a, 1990b, 1991), and Jorian and Mishkin (1991) examined the information content of the long-bond rate in predicting the expected rate of inflation. Their studies reported that the slope of the yield curve contained information for forecasting future long-term inflation expectations, but not for short-term expectations. Blough's (1994) study examined whether the steep yield curve implication of accelerating inflation in near future is valid and found no support for that hypothesis.

The common assumption in many such studies is that the real rate of interest is constant. Some economists, such as, McCullum (1994), Rudebusch (1995), and Mehra (1995) expressed doubt about the assumption and suggested that the predictive content of the slope of the term structure can be influenced by the Federal Reserve (Fed) through its monetary policy actions. Since early 1980s the Fed's monetary policy actions brought the inflation rate down and kept it relatively stable at a low rate. This could not have been achieved if its policy actions did not have an influence on nominal interest rates and/or expected future rates of inflation. In our study, we incorporate some of the methodological aspects proposed in Mehra's paper where this assumption is relaxed.

The state of current knowledge on this issue, at best, is inconclusive as the earlier empirical studies reported mixed results, some in favor and other studies either found little or no evidence for the information content of the long-bond rate for predicting expected inflation rate.

The remainder of this study is organized as follows. In Section 1 we present an overview of the relationship between the two variables expressed as the original Fisher (1930) equation, followed by the time series econometric model used to investigate the dynamic interactions between the variables. The sample period, data, and the estimated results are presented in Section 2. Main conclusions and summary of the study including a comparison of our results with some earlier studies are presented in Section 3.

SECTION 1: OVERVIEW OF THE FISHER HYPOTHESIS AND THE EMPIRICAL MODEL

The Original Fisher equation, (1.1) below, relates the nominal long-bond interest rate (i_t) to expectations of inflation (p_t^e) and the real rate of interest (r_t), over the maturity of the bond.

$$\mathbf{i_t = r_t + p_t^e} \qquad (1.1)$$

where, i_t is the nominal long-bond interest rate over its maturity, r_t is the real rate of interest over the same period, and p_t^e is the expected rate of inflation corresponding to the bond maturity period. The original Fisher hypothesis stipulates a one-to-one relationship between expected rate of inflation and nominal interest rates, unadjusted for taxes. Fisher's implicit assumption in (1.1) is that i_t and p_t^e are integrated of the same order and are also co-integrated, while r_t , the real rate of interest, is assumed to be stationary. If i_t and p_t^e time series are integrated of the same order, and if r_t is stationary, the Fisher equation can be regarded as a long-run equilibrium relationship between the expected inflation rate and the nominal interest rate. However, if r_t is not stationary, then changes in r_t will be a source of change in both the expected inflation rate and the nominal interest rate.

The Fisher equation has been tested extensively in the literature with mixed empirical results. Evidence in some of the studies rejected the strict Fisher effect, but found less than complete adjustment of nominal interest rate to changes in inflation rate. For instance, Darby (1975), Feldstein (1976), and Tanzi (1976), in their empirical studies had found that nominal long-bond rate, in the absence of tax adjustment, must change by more than the change in the expected rate of inflation, after tax, for the real rate to be invariant. Darby's (1975) study suggested that nominal rate, unadjusted for taxes, should change between 1.3 to 1.5 times the change in the expected rate of inflation, a sort of 'augmented Fisher effect'.

Studies by McDonald and Murphy (1989), Mishkin (1992), Wallace and Warner (1993), Phylaktis and Blake (1993), and Evans and Lewis (1995) supported the general view that changes in nominal long-bond rate reflect fluctuations in expected inflation, but not to the extent of the full one-to-one Fisher effect. Fisher's own study (1930) did not find a one-to-one relationship between changes in inflation and the changes in the nominal interest rates. Fisher attributed the lack of the strict one-to-one relationship to some type of 'money illusion'.

Engsted (1995) investigated whether the spread between long-tern interest rate and one-period inflation rate is helpful in forecasting future one-period inflation rate. The reported results of Engsted's study did not find strong support for the hypothesis in the case of the U.S. although the results for other countries, included in the study, strongly validated the hypothesis.

According to Engle and Granger (1987), if two time series are integrated of the same order and also found to be co-integrated, the appropriate procedure to model the series is the equilibrium error correction model. This finding of less than full adjustment of nominal interest rates in some studies, mentioned above, is largely attributed to the downward bias of the coefficient estimates caused by inadequate modeling or misspecification of the stochastic features of the data generating process, and to the sensitivity of the estimated results to the selection of the sample period and the country concerned (Widemann 1997). Widemann questioned whether this relationship should be tested as a long-run equilibrium or co-integration relationship, or should it be tested within a threshold co-integration framework? According to Widemann, it is not clear whether inflation and nominal interest rates are integrated of the same order. His results, when tested within the threshold co-integration, perfectly supported the full Fisher hypothesis.

We will revisit the issue without the assumption that the real rate of interest is stationary, and employing the vector error correction (VEC) methodology suggested by Johansen and Juselius.

SECTION 2: THE EMPIRICAL MODEL

Following the advances in time series econometrics during late 1980s and early 1990s economists reopened the question of the implied Fisher hypothesis of the relationship between expected inflation and the nominal interest rates.

We will revisit this empirical question using a different but longer sample period, and by employing co-integration and vector error correction estimation procedure. We will compare our empirical results with the earlier studies in the next section. Given the inconclusive nature of this relationship, and the mixed results reported in earlier studies, we believe our study will make a good contribution toward resolving this issue.

The long-run equilibrium relationship between changes in nominal interest rates and expected inflation is examined employing the Johansen and Juselius (JJ) (1990, 1995), maximum likelihood estimation procedure. If two or more time series share a common stochastic trend, then, the series are co-integrated. The presence of co-integration relation forms the basis of the VEC specification.

The general form of the time series model underlying our empirical estimation can be stated as a k^{th}-order Gaussian vector autoregressive (VAR) model for X as:

$$X_t = \mu + \sum_{i=1}^{k} A_i X_{t-i} + \varepsilon_t \qquad (2.1)$$

where, X_t is a *n x1* column vector of observations on the variables of the model, μ is a vector of constants, A_i are *n x n* matrices of autoregressive coefficients (that do not contain any zero elements), ε_t is a vector of *n* non-observable random errors usually assumed to be contemporaneously correlated but not autocorrelated, and k is the number of lags on the variables in the system.

If the variables in X_t are integrated of, say, order one, I(1), and are also found to be co-integrated, that co-integration restriction has to be incorporated in the VAR in (2.1). The Granger Representation Theorem (Engle and Granger, 1987) states that variables, individually driven by permanent shocks, are co-integrated if and only if there exists a vector error correction representation of the time series data. A VAR model, with this restriction embedded, is referred to as the vector error-correction (VEC) model. Variables in the model enter the equation in their first differences, and the error correction terms are added to the model. The VEC has co-integration relation built into the specification so that it restricts the long-run behavior of the endogenous variables to converge to their long-run relationship while allowing for short-run dynamics. Deviations from long-run equilibrium are corrected through a series of partial short-run adjustments.

The VEC representation of the VAR in (2.1), following JJ is:

$$\Delta X_t = \mu + \sum_{i=1}^{k} \Gamma_i \Delta X_{t-i} + \Pi X_{t-1} + \xi_t \qquad (2.2)$$

where X_t is a $nx1$ vector of I(1) variables. Γ_i is a $n \times n$ matrix of coefficients of the short-run dynamic effects, Π is a $n \times n$ matrix of coefficients of long run effects, and ξ_t is a vector white noise process.

If the rank of Π in (2.2) is r, where $r \preccurlyeq n$-1, then Π can be decomposed into two nxr matrices, α and β, such that $\Pi = \alpha\beta'$. The matrix β is the co-integrating matrix of r co-integrating vectors, $\beta_1, \beta_2, \ldots, \beta_r$. The β vectors represent estimates of the long-run co-integrating relationship among the variables in the system. The error correction terms, $\beta' X_{t-1}$, are the mean-reverting weighted sums of co-integrating vectors. The matrix α is the matrix of error correction coefficients, the so called 'speed of adjustment' coefficients that measure the speed at which the variables adjust to their long-run equilibrium values. If the rank of Π in (2.2) is found to be $r \preccurlyeq n$-1, the above model can be expressed in the first differences of X_t, augmented by the error correction terms, $\alpha\beta' X_{t-1}$, as shown below:

$$\Delta X_t = \mu + \sum \Gamma_i \Delta X_{t-i} + \alpha\beta' X_{t-1} + \xi_t \quad (2.3)$$

The JJ technique provides maximum likelihood estimates of α and β'. In our model, X_t is a 3x1 vector consisting of long bond rate, inflation, and fed funds rate, (first differences) in their natural logs. The co-integrating relationship, r, is determined by the trace eigen value statistic and the maximum eigenvalue statistic of the stochastic matrix and the maximum likelihood estimates of the cointegrating vectors (β) in the equation (2.3) above.

The estimated model is a three variable VEC, and the variables are the 10-year Treasury long-bond rate, CPI inflation rate, and the effective federal funds rate.

SECTION 3: SAMPLE DATA, MODEL ESTIMATION, AND RESULTS

Monthly data from 1954.08 to 2004.08, on all the variables, namely, the 10-year bond constant maturity rate, the actual consumer inflation rate (CPI, all urban consumers), and the effective monthly federal funds rate, are obtained from the website of the Federal Reserve Bank of St. Louis (Fred II data base).

The first step in the estimation process is determining the order of integration of the individual time series of the system, long-bond rate (**i_t**), inflation rate (p^e_t), and the federal funds rate (FFR). Unit root tests are performed on each of the time series using the augmented Dicky-Fuller (ADF) (1979) test following the lag structure suggested by the Akaike Information Criterion (AIC). First, we tested the series in their levels (**i_t**) and (**p^e_t**) and (FFR) then in their first differences. The critical values used for the tests are the McKinnon (1991) critical values. Test results, presented in Table 1, indicate that the null hypothesis that the series in levels contain one unit root could not be rejected for all the three series. Then, unit root tests are performed on the first differences of series $\Delta \mathbf{i_t}$, $\Delta \mathbf{p^e_t}$ and ΔFFR. The null hypothesis of a unit root could be rejected for each of the time series in their first differences at 1% level of significance. As each of the series is found to be stationary in their first differences no further tests are performed. Our results perfectly agree with the earlier studies as far as the degree of integration of the three time series is concerned.

The second step involves testing the three time series for cointegration. The cointegration test procedure employed is the JJ procedure that uses the maximum likelihood method. The cointegration tests assumed linear deterministic trends in the series and used lag intervals 1 to 8 as suggested by the AIC for appropriate lag lengths. The results of cointegration tests are presented in table 2. In both the cases the trace test (which tests the null hypothesis of n cointegrating relations against k cointegrating relations, where k is the number of endogenous variables, for n = 0, 1,…k, indicates two cointegrating vectors at 1% level of significance. The maximum eigenvalue test (tests the null of r cointegrating relations against the alternative of n+1cointegrating relations) results indicated two cointegrating equation at the 1% level of significance.

Table 1: Augmented Dickey-Fuller (ADF) Unit Root Tests (1954.07-2004-08.)

Time Series	Lags (AIC criterion)	Test Statistic	Probability[1]
ltbr	3	-2.1651	0.2195
Δltbr	2	-3.3194	0.0000
lp_te	12	-0.8753	0.7959
Δp_t^e (inflation rate)	11	-3.3194	0.0104
lFFR (Fed Funds Rate)	2	-0.8019	0.8175
Δlffr	2	-13.5900	0.0000

1. MacKinnon (1996) one-sided p-values.

The normalized cointegrating coefficients, in table 2 for the logs of long-bond rate and inflation indicate a more than a one-to-one relationship between nominal interest rate and inflation (p^e_t). Our results are close to the results suggested by Darby (1975) between 1.3 and 1.5 rather than the results reported in Mehra. Our cointegration test results are consistent with the findings of most the earlier studies.

Table 2: Cointegration Test Results: *ltbr, lp^e_t* ,and *lffr*. Sample: 1954:07 to 2009:12.

Assumptions: intercept and trend in cointegrating equation and intercept in VAR.						
Hypo.: # of CEs	Trace statistic	5% critical value	Probability[1]	Max. Eigen Stat.	5% critical value	Probalility[1]
None	43.8219	35.0109	0.0045	37.7635	24.2520	0.0005
At most 1 CE	6.0584	18.3977	0.8643	5.4176	17.1477	0.8694
Trace statistic and Max Eigen value statistic indicate one cointegrating equation at the 5% level of significance.						
1. MacKinnon-Haug-Michelis (1999) p-values						
Normalized cointegrating equation (normalized on long-bond yield). Standard errors in parentheses.						
ltbr	***lp^e***	***lffr***				
1.0000	- 1.5201	- 0.1567				
	(0.4505)	(0.0576)				

The final step is the estimation of the three variable VEC model, equation (2.3). The equations include first differences of the 10-year bond rate, inflation, and the federal funds rate. Inflation and the federal funds rate are expected to capture the impact of monetary policy on the bond rate. The lag lengths for the series in the system are determined according to the AIC. The optimal lag lengths are one to four periods for the VEC model using the 10-year bond rate as the dependent variable. Estimated results are presented in Table 3.

The reported results include the coefficients of the normalized cointegration equation (the first step of the JJ procedure). Second part of the output in table 3 contains results from the second step VAR (in first differences), including the error correction terms estimated from the first step that are referred to as Coint.Eq.1 and Coint.Eq.2 in Table 3, and also the coefficient values of the lagged variables along with the t-statistics (asymptotic standard errors, corrected for degrees of freedom are not reported for want of space in the table, and are available from the authors). At the bottom of the output the standard statistics, log likelihood values, and the values of the Akaike and Schwarz criteria are reported.

The key aspects of interest for this study are the coefficients of the normalized cointegration equations, the coefficients of the error correction terms and the lagged values of the variables presented in Table 3. The Fisher hypothesis of a one-to-one relationship is however not validated by the coefficients of the normalized cointegration equations, because the coefficient of inflation is 1.52 as reported in Table-2.

Granger-causality:

The coefficients of the error-correction terms (Coint Eq.1 in table3) associated with the 10-year bond rate and inflation rate equations of the VEC along with the coefficients of the lagged variables and the appropriate response of the dependent variable in the VEC contain information for drawing inferences regarding the direction of Granger-causality. If the coefficients of the error correction terms are statistically significant in both the equations, and if the coefficients of the lagged variables in both the equations are jointly and significantly different from zero, the inference is that Granger-causality runs in both the directions. But if the coefficient of the error correction term in one of the equations is statistically significant, and if the coefficients of the lagged variable are significantly different from zero in that equation and not in the other equation, it implies, Granger-causation in one direction from the statistically significant variable to the other. The reported values in table 3 of the VEC estimates provide strong support for Granger-causality running from inflation to bond rate and not the other way around, because the t-statistic associated with the error correction term, in Coint.Eq1 Δ *ltbr,* column 2, is statistically significant, while the t-statistic reported for the Δlp^e_t is not statistically significant. Also, in the Δ*ltbr* equation the coefficients of the lagged $\Delta l\ p^e_t$ are significantly different from zero while the coefficients of the lagged Δ *ltbr* in Δlp^e_t equation are not significantly different from zero at the 5% level. So, the inference is that consumer inflation causes bond rate. This result is not in agreement with Mehra's findings.

Response of the Dependent Variable to Shocks:

Another important aspect that needs to be examined is the response of the dependent variable to shocks in order to restore equilibrium. Response of the dependent variable to the error correction information is generally evaluated based on available theoretical information concerning the variables.

Given a one unit positive shock to the bond rate from the error (ε_{pt}), the vector will be pushed above its equilibrium level. The adjustment back to equilibrium requires that the nominal 10-year bond interest rate and inflation rates move in the appropriate direction to restore equilibrium. According to the reported results in table 3, only the inflation rate responds to the shock. It is the gradual decline in the inflation rate that will eliminate the positive value to restore equilibrium.

Table 3: VEC Estimation Results. 1954.10-2004.08

Vector Error Correction Estimates Variables: t-statistics [ ]			
Error Correction:	Δltbr	Δlp^e_t	Δlffr
Coffficient (λ_i)	- 0.0203	0.0007	0.0415
	[- 2,8483]	[1.5323]	[2.0256]
$\Delta ltbr_{t-1}$	0.2935	0.0034	0.5640
	[7.1767]	[1.3351]	[5.1290]
$\Delta ltbr_{t-2}$	-0.2543	0.0067	-0.0753
	[-5.9386]	[0.2537]	[-0.6536]
$\Delta ltbr_{t-3}$	0.1118	0.0017	0.4471
	[2.5444]	[0.6178]	[3.7819]
Δltb_{t-4}	-0.0149	-0.0003	0.0961
	[-0.3367]	[-0.1256]	[0.8049]
$\Delta ltbr_{t-5}$	-0.0612	0.0004	0.0454
	[-1.3742]	[0.1579]	[0.3793]
$\Delta ltbr_{t-6}$	-0.0184	-0.0077	-0.2907
	[-0.4151]	[-2.8282]	[-2.4368]
$\Delta ltbr_{t-7}$	-0.0170	-0.0005	0.0269
	[-0.3911]	[-0.1918]	[0.2311]
$\Delta ltbr_{t-8}$	0.0537	-0.0005	-0.2324
	[1.2804]	[-0.2072]	[-2.0596
Δlp^e_{t-1}	2.9683	0.3946	5.4166
	[4.5527]	[9.7789]	[3.0888]
Δlp^e_{t-2}	-1.0228	0.0558	-5.1102
	[-1.5477]	[1.2854]	[-2.7079]
Δlp^e_{t-3}	-0.8711	-0.0248	-3.0897
	[-1.2379]	[-0.5707]	[-1.6326]
Δlp^e_{t-4}	0.4531	0.0914	-2.2289
	[0.6448]	[2.3010]	[-1.1795]
Δlp^e_{t-5}	-0.0749	0.0418	0.8425
	[-0.1067]	[0.9630]	[0.4459]
Δlp^e_{t-6}	0.0228	0.0662	-3.0687
	[0.0324]	[1.6201]	[-1.6213]
Δlp^e_{t-7}	0.6478	0.1107	3.4576
	[0.9148]	[2.6525]	[1.8515]
Δlp^e_{t-8}	-0.0291	0.0629	-0.6162
	[-0.0436]	[1.5234]	[-0.3435]
$\Delta lffr_{t-1}$	0.0365	0.0015	0.0989
	[2.8336]	[1.5748]	[2.8041]

$\Delta lffr_{t-2}$	0.0093	0.0005	0.0782
	[0.6107]	[0.5264]	[1.9020]
$\Delta lffr_{t-3}$	-0.0175	0.0004	0.0965
	[-1.1486]	[0.4867]	[2.4354]
$\Delta lffr_{t-4}$	0.0084	0.0005	-0.0325
	[0.5560]	[0.4935]	[-0.7964]
ΔFFR_{t-5}	-0.0264	0.0013	-0.0219
	[-1.7441]	[1.4124]	[-0.5386]
$\Delta lffr_{t-6}$	-0.0189	0.0008	0.0671
	[-1.2638]	[0.0939]	[1.7674]
$\Delta lffr_{t-7}$	-0.0179	0.0005	0.0746
	[-1.2099]	[0.5441]	[1.9687]
$\Delta lffr_{t-8}$	0.0030	-0.0006	0.0862
	[0.2069]	[-0.0728]	[2,2173]
C	-.0062	0.0006	0.0115
	[-2.6341]	[3.6893]	[1.4642]
R-squared	0.1948	0.46767	0.1855
Adj.R-squared	0.1629	0.4466	0.1533
S.E. equation	0.2609	0.0025	0.1022
F-statistic	7.4873	22.7397	6.7067
Log Likelihood	4898.561		
Akaike Infor. Criterion	-14.6653		
Schwarz Criterion	- 14.1120		

SUMMARY AND CONCLUSIONS

The present study has shown the following three points.

1. Price level and the long-bond rate are cointegrated
2. The relationship between the two is not bidirectional but it is unidirectional. The direction is not from the bond rate to the price level. The direction is from the inflation rate to the rate of interest (VECM result).
3. The adjustment of the interest rate is 52% more than the change in the inflation rate to keep the real interest rate the same.
4. Although not reported, long-bond rate and the federal funds rate are not cointegrated.

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Appendix

Variable	Horizon (months)	Long bond rate	Inflation rate	Fed Funds rate
Long Bond Rate	1	100.00	0.00	0.00
	6	93.68	5.87	0.45
	12	89.31	9.98	0.71
	24	81.88	17.03	1.09
Expected Inflation	1	2.31	97.61	0.00
	6	8.38	88.29	3.33
	12	9.72	86.40	3.88
	24	10.54	85.24	4.22
Fed Funds Rate	1	8.57	0.00	91.43
	6	23.37	1.71	74.92
	12	23.17	3.19	73.64
	24	22.76	6.00	71.24

Note: Entries in columns 3, 4, and 5 are the percentages of forecast error variances accounted for by the variable listed in column 1.