INTEGRATION OF KEY WORLDWIDE MONEY MARKET INTEREST RATES AND THE FEDERAL FUNDS RATE: AN EMPIRICAL INVESTIGATION

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ABSTRACT

This study investigates whether there is an increased integration of U.S. domestic money market interest rates and the Eurodollar market interest rates following two important changes that the U.S Federal Reserve (the Fed) implemented. First, elimination of reserve requirements on Eurodollar bank deposits in the early 1990s. Second, change in the operating procedure for conducting monetary policy in early 1992 from borrowed reserves targeting to federal funds rate targeting. The money market interest rates are three and six month Eurodollar London Interbank Offered Rates (Libor), three and six month U.S. Treasury bill (T-bill) rates, and the effective federal funds rate. Cointegration and error-correction methodology of Johansen and Juselius (1990,1992) is employed for this empirical study. Results indicate that integration of the five interest rates increased following the two changes by the Fed. It is the effective fed funds rate and the three-month T-bill rate that participate in the adjustment process back to their equilibrium path following an external shock to the system. Granger causality tests produced different and somewhat conflicting results when the error-correction model is estimated with and without the federal funds rate in the system. This finding requires further study and investigation.

JEL: C32, C58, E43, G15

KEYWORDS: Libor, Unit Root, Cointegration, Granger Causality

INTRODUCTION

The primary objective of this study is to examine whether there is an increase in the integration of U.S. domestic money market interest rates and the offshore Eurodollar London interbank offered rates (Libor) since 1990 following two important changes made by the U.S. Federal Reserve (the Fed). First, a regulatory change eliminating reserve requirements on Eurodollar liabilities of offshore banks in early 1990, and second, change in the Fed's operating procedure for conducting monetary policy switching from borrowed reserve targeting to federal (fed) funds rate targeting in early February, 1992. The money market interest rates used in this study are the three and six month U. S. Treasury bill (T-bill) rates, effective fed funds rate, and the offshore three and six-month Libor. To my knowledge there is no published study that exclusively investigated the relationship between the domestic and offshore rates after the monetary policy regime change to fed funds targeting in early 1992.

The relationship between U.S. T-bill yields including the effective fed funds rate and the Libor of different maturities is examined employing cointegration and error correction methodology developed by Johansen and Juselius (JJ) (1990, 1992). The choice of methodology to examine the relationships is supported by several similar studies summarized in Hall, Anderson, and Granger (1992).

These money market rates play a very important role in influencing various other interest rates. For instance the three month T-bill rate is a prominent default-risk-free rate in the U.S. and often used as a proxy for a risk-free asset as well as a benchmark lending rate. Likewise, according to some estimates, the value of financial contracts linked to the Libor is over $3 trillion. The Eurodollar market and the fed funds market are located in different places but the currency in both the markets is the U.S. dollar. The volume of transactions in the Eurodollar interbank market is larger than the U.S. fed funds market. Further, according to Baba et al (2009) European banks had substantially increased their U.S. dollar asset positions from about $2 trillion to over $8 trillion by mid-2007. The effective federal funds rate is considered a 'bellwether' rate leading all short-term rates. The effective fed funds rate is the weighted average of the funds rates that prevailed during the day. The weights are the amounts of funds traded at different rates during the day.

During the financial and banking crises in the U.S. from late 2007 to mid-2009 the international money markets, especially, the interbank Eurodollar market, ran into serious trouble due to shortage of U.S. dollars. According to McAndrews et al (2008) the volume of transactions in the interbank market sharply declined and banks reportedly could not borrow funds at the posted rates. These interbank loan rates rose to very high levels, and spreads between the three-month Libor and the effective fed funds rate suddenly jumped to over 90 basis points, from an average of 20 basis points. The increased spread was mainly attributed to increased liquidity and credit risks of banks. Banks sustained huge losses due to the collapse of the mortgage market in the U.S. McAndrews et al (2008) reported that on December 12, 2007, the Fed responded to the shortage of term funds for banks by introducing the 'Term Auction Facility' (TAF) that provided term funding to eligible banks through periodic auctions. According to Taylor and Williams (2008) as many private loans are linked to Libor rates, the sharp increase in these spreads raised the cost of borrowing and interfered with monetary policy. The widening spreads became a major focus of the Federal Reserve which took several actions including the TAF.

The foreign-currency exposures of European banks had grown significantly over the decade preceding the crisis, with dollar exposures accounting for half of the growth in European banks' foreign exposures over the period from 2000 to 2007 (McGuire and von Peter 2009a). European Union, United Kingdom, and Swiss banks' on-balance sheet dollar exposures were estimated to exceed $8 trillion in 2008.While there was severe shortage of term funds for banks, there was a lot of concern about the alleged manipulation of Libor in 2008, and according to the financial press reports several participating banks were accused of conspiring to artificially keep the Libor rates low. If these accusations are proven to be valid, then we cannot expect the key rates to maintain an equilibrium relationship if Libor manipulated rather than market determined.

An understanding of the relationship among these key market rates and rates targeted by central banks is of great importance for market participants as well as the monetary authorities in implementing monetary policy. To my knowledge, there is no study which examined all the five rates simultaneously. The results of this study provide much needed insight into the interactions between monetary policy and key money market rates in the U.S. and Eurodollar market. The remainder of this paper is organized as follows. The following section contains literature review. Section two presents the data and an overview of the methodology. Section three contains the estimated results and discussion. Section four contains summary and concluding remarks.

LITERATURE REVIEW

The literature on the integration of key domestic and international market interest rates is extensive. This literature review includes a select group of studies widely cited. These studies are divided into two categories. The first category of studies, which I refer to as early studies, mainly focused on testing for causal links among the domestic and foreign interest rates. The second category of studies was mainly interested in testing the 'expectations hypothesis' of the term structure of interest rates, besides examining their short-term dynamics. Expectations hypothesis is that long-term interest rate is the average of the current short-term rates and expected future short-term rates plus a constant term premium.

The following studies by Hartman (1984), Swanson (1987, 1988), Fung and Isberg (1992), Mougoue and Wagster (1997) belong to the first category, that tested for temporal causality between U.S. domestic interest rates Eurodollar rates. All of these studies used U.S. domestic certificate of deposit (CD) rates, weekly or daily frequency, and either one month or three month Eurodollar deposit rates in their studies, except Kaen and Hachey (1983), whose study involves the relationship between Eurodollar rates and the Euro-sterling rates. The sample period of Hartman's (1984) study ranges from 1971-1978, divided into two sub-periods, 1970-1974 and 1975-1978. The study reported unidirectional causality running from the U.S. domestic CD rates to the 3-month Eurodollar rates for the 1970-1974 period, and bidirectional or mutual causality for the 1975-1978 period. Swanson (1987, 1988) used daily CD rates to test for Granger causality for the sample period from mid-1973 to December 1984, split the sample into three sub-periods. For the first sub-period (1974-1980) she reported unidirectional causality (note, Hartman study reported bidirectional causality for this period). And for the sub-period 1981-1982 her study reported bidirectional causality, and for the sub-period 1982-1983 the finding was reverse unidirectional causality, from the Eurodollar rates to the CD rates.

The study by Fung and Isberg (1992) used daily CD rates and employed vector error correction model to test for the causal links for the sample period 1981-1988. For the sub-period 1981-1983 they found unidirectional causality from the U.S. CD rates to the Eurodollar rate. Note, for the same period Swanson study reported reverse unidirectional causality. For the 1984-1988 sub-period they reported bidirectional causality. The study by Mougoue and Wagster (1997) employed daily CD rates and 3-month Eurodollar deposit rates for the sample period from mid-1973 to mid-1993. They argued that the correct way to measure and test for the relationship between the rates should recognize the difference in trading times of these two markets. They did account for this difference in trading times. They divided the sample into three sub-periods, coinciding with the three different monetary policy operating regimes of the U.S. Federal Reserve.

Mougoue and Wagster (1997) identified three different monetary policy regimes the Fed had followed, first, the Fed targeted federal funds rate targeting from July 16, 1973 to October 5, 1979, second, non-borrowed reserve targeting from October 9, 1979 to October 7, 1982, and the third, targeting borrowed reserves from October 8, 1982 to February 7, 1992, in conducting monetary policy. For the three different regimes Mougoue and Wagster (1997) study reported three different causal relations. For the fed funds targeting regime their finding was bidirectional causality, for the non-borrowed reserve targeting causality was reverse unidirectional, from the Eurodollar market to the U.S. domestic market, and for the borrowed reserve targeting causality was unidirectional from the U.S. domestic rates to the Eurodollar rates. The study by Kaen and Hachey (1983) used Eurodollar rates and Euro-sterling rates to test for causality and reported unidirectional causality from the U.S. dollar to the Euro-sterling rate for their entire sample period ranging from 1974 to 1981. We can clearly see the conflicting and contradictory results reported in the above studies. However, one common finding in these studies is that these rates are integrated.

Some of the influential studies in the second category include Engle and Granger (1987), Stock and Watson (1988), Campbell and Shiller (1991), Hall et al (1992), Engsted and Tanggaard (1994), Campbell et al (1997), and Thornton (2002). Empirical support for the 'expectations hypothesis' reported in these studies is generally weak. In spite of that all these studies reported that the U.S. and Eurodollar rates co-move in the long-run. However, there is no agreement as to the causal links between the rates examined.

Most recent studies include Clinebell et al (2000), Sarno and Thornton (2003), and Zhou (2007). Clinebell et al (2000) went a step further besides testing whether the financial markets integration increased and examined the changing monetary policy regimes and its impact on Granger causality. That is whether the conflicting results were due to changes in the Fed's monetary policy targets. The study found strong financial market integration under fed funds rate targeting phase relative to the non-borrowed reserve targeting. Their findings were contradicted by the results reported in the Sarno and Thornton (2003) study. Employing a non-linear error-correction model they reported no change in long-run equilibrium relationship and short-run dynamics between the interest rates irrespective of different monetary policy regimes. The study by Zhou (2007) differs from the earlier studies in one respect, namely, in the selection of interest rates. Zhou(2007) chose the federal funds rate and the Eurodollar rates of different maturities. The cointegration tests conducted in this study are bi-variate, not multivariate, even though the number of rates involved are four. Each pair of interest rates are reported to be cointegrated. The interesting aspect of this study is the results of the error-correction model. Specifically, it is the federal funds rate that plays a major role in the adjustment process of the system when it is out of equilibrium following a shock. This is also one of the key findings of this study.

This study differs from the earlier studies, reviewed above, in three important ways. First, this study explicitly includes the effective fed funds rate along with three and six-month Libor and the two domestic three and six-month T-bill rates. One or two of earlier studies included the fed funds target rate, which is not the interbank lending rate, but it is the Federal Reserve's monetary policy target rate. Second, the sample period in this study is the longest, from January 6, 1986 to September 14, 2009, close to 6,000 daily observations. Time series models estimated using high frequency data as well as a long time periods are expected to perform well in providing more reliable cointegrating rank and coefficient estimates. Finally, this study estimated multivariate cointegration models rather than bi-variate cointegration model as many of the earlier studies. As such, there is very little discussion on the number of identified cointegrating vectors, perhaps, the focus of those studies was testing for the causal linkages between the market interest rates. This study fills the gap by emphasizing the long-run equilibrium relationship rather than just testing for temporal Granger causality. The results of this study provide much needed insight into the interactions between monetary policy and key money market rates in the U.S. and Eurodollar market. The results of this study provide a better understanding of the interactions between monetary policy and key money market rates.

METHODOLOGY

Data

The sample data are the three and six month daily (5-day week) three and six-month T-bill yields, three and six month Eurodollar Libor interbank lending rate, and the effective federal funds rates, for the periods January 6, 1986 to September 14, 2009. The Eurodollar rates are computed by Thomason Reuters for the British Bankers Association. A department of the British Bankers Association (BBA) averages the inter-bank interest rates being offered by its membership. Libor is calculated for periods as short as overnight and as long as one year. Libor daily data series are from the BBA (www.bba.org.uk). The three and six month T-bill rates are the secondary market rates data, and are from the Federal Reserve Bank of St. Louis website (www.stlouisfed.org).

Summary statistics of the five interest rate series are presented in Table 1. The first four moments of the five money market interest rates are provided in Table 1. The effective federal funds rate for the sample period averaged about 44 basis points over 3-month T-bill rate and about 27 basis points over the average 6-month T-bill rate. Average effective fed funds rate is below the 3-month and 6-month Eurodollar rates by 38 and almost 50 basis points, respectively. One explanation for the fed funds rate being higher than the U.S T-bill rates is that the two markets are partially segmented according to Campbell et al (1997). This is contrary to the belief that the fed funds rate affects all other short-term interest rates. Another explanation may be due to the fact that the T-bill rates have no liquidity risk and are default risk free, and may have some tax advantages while fed funds rate is not free of default and liquidity risks, according to Sarno and Thornton(2003). Based on the standard deviations of the rates, the fed funds rate is slightly more variable than the T-bill and the Eurodollar rates. The third and fourth moments show positive skewness and high kurtosis, which is an indication that the underlying distributions of these rates are non-normal. This is confirmed by the Jarque-Bera test for normality (bottom row of Table 1).

Table 1: Summary Statistics: *tb3m, tb6m, lbr3, lbr6m, and ffr*

	tbm3m	*tb6m*	*lbr3m*	*lbr6m*	*Ffr*
Mean	5.3150	5.4848	6.1454	6.2359	5.7581
Median	5.1800	5.3300	5.9375	5.9883	5.5700
Maximum	9.0900	9.1200	10.625	11.000	16.170
Minimum	2.6100	2.7500	3.1250	3.1250	2.5800
Std. Dev.	1.4253	1.3757	1.6352	1.6201	1.7672
Skewness	0.3047	0.2150	0.2194	0.2335	0.3529
Kurtosis	2.7232	2.6859	2.7038	2.7462	3.0938
Jarque-Bera	70.9281	44.9055	44.3878	44.7289	80.2814
Probability	0.0000	0.0000	0.0000	0.0000	0.0000

The first four moments of the five money market sample interest rate series are provided in Table 1. The average effective federal funds rate for the sample period was 44 basis points over the mean 3-month T-bill rate and 27 basis points over the mean 6-month T-bill rate. The mean federal funds rate is below 38 basis points of 3-month average Libor and nearly 50 basis points below 6-month Libor. The rates exhibit positive skewness and a relatively high kurtosis. The distribution of the market interest rates appears to be non-normal.

Model

The relationship between T-bill yields (*tb3m* and *tb6m*) and Libor *(lbrm3m* and *lbrm6m)* and effective federal funds rate (*ffr*) is studied within the framework of cointegration and error-correction methodology employing the JJ procedure and the error correction model for examining the short-run dynamics. JJ methodology uses an asymptotically fully efficient maximum likelihood technique for the estimation of cointegrating vectors.

The general form of the time series model underlying the empirical estimation is stated as a *k*-order Gaussian vector autoregressive (VAR) model for *X* as:

$$X_t = \mu + \sum_{i=1}^{k} A_i X_{t-i} + \varepsilon_t \tag{1}$$

where, X_t is a $n \times 1$ column vector of observations on the variables of the model, μ is a vector of constants, A_i are $n \times n$ 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 cointegrated, that cointegration restriction has to be incorporated in the VAR in (1). The Granger Representation Theorem (Engle and Granger, 1987) states that variables, individually driven by permanent shocks are cointegrated 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 VEC model enter the equation in their first differences, and the error correction terms are added to the model. The VEC has cointegration 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 per unit of time.

The VEC representation of the VAR in (1), following JJ is:

$$\Delta X_t = \mu + \sum_{i=1}^{k} \Gamma_i \Delta X_{t-i} + \Pi X_{t-1} + \xi_t \tag{2}$$

where X_t is a $n\times1$ 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 equation (2) is r, where $r \preccurlyeq n$-1, then Π can be decomposed into two $n\times r$ matrices, α and β, such that $\Pi = \alpha\beta'$. The matrix β is the cointegrating matrix of r cointegrating vectors, $\beta_1, \beta_2, \ldots, \beta_r$. The β vector represents the estimate of the long-run cointegrating relationship among the variables in the system. The error-correction terms, $\beta' X_{t-1}$, are the mean-reverting weighted sums of cointegrating 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 equation (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:

$$\Delta X_t = \mu + \sum \Gamma_i \Delta X_{t-i} + \alpha\beta' X_{t-1} + \xi_t \tag{3}$$

The JJ technique provides maximum likelihood estimates of α and β'. In our model, X_t is a 2×1 vector consisting of T-bill yields, two Libor, and fed funds rate of different maturities. The cointegrating relationship, r, is determined by the trace eigenvalue statistic and the maximum eigenvalue statistic of the stochastic matrix and the maximum likelihood estimates of the cointegrating vectors (β) in equation (3).

The standard estimation process has three-steps. First, unit root tests of each of the interest rate series in levels for their degree of integration. If two or more time series are integrated of the same order and are found to be cointegrated, then, according to the Granger Representation theorem (Engle-Granger, 1987), there must be 'Granger causation' at least in one direction. Further, such cointegrated series must be modeled within an 'error correction' framework as per Engle and Granger (1987). If the interest rate time series are found to be integrated of the same order in the first step, then, in the second step we have to test for cointegration of the time series to see if there is a long-run equilibrium relationship between the variables concerned. If cointegration is found in the levels of the series, then, the interest rate series should be modeled in the framework of vector error correction procedure described in (3). In all of the above estimation procedures, we use the Schwarz (1978) information criterion (SIC) to determine the lag structure for the unit root tests, cointegration tests, and for estimating the vector error-correction model.

The initial step in the estimation involves the determination of the time series proprieties of each variable individually by conducting two of the popular unit root tests, namely, the augmented Dicky Fuller (ADF) (1979), and the KPSS (Kwiatkowski, Phillips, Schmidt, and Shin, (1992) test. For the KPSS unit root tests the Bartlett kernel spectral estimation and Newey-West (1994) bandwidth selection methods were used. The ADF test involves running one of the following regressions:

$$Y_t = \alpha X_{t-1} + \Sigma d_i \Delta X_{t-I} \tag{4}$$

$$Y_t = \mu + \alpha X_{t-1} + \Sigma d_i \Delta X_{t-I} \tag{5}$$

$$Y_t = \mu + \beta T + \alpha X_{t-1} + \Sigma d_i \Delta X_{t-I} \tag{6}$$

The KPSS test differs from the ADF unit root test. In the KPSS test, each e series, X_t, is assumed to be trend- stationary under the null hypothesis. The KPSS statistic is based on the residuals from the OLS regression of X_t on the exogenous variables, X_t: ($X_t = Z_t'\delta + u_t$). The null hypothesis is different for the ADF and KPSS tests. The null hypothesis for the ADF test is H_0: I(1), but for the KPSS test is H_0: I(0).

For the ADF test the correct specification of the equation is determined based on the data generating process (DGP). If it is determined that the DGP is a random walk without a drift and a mean, then the unit root test is based on equation (4). If the DGP is a random walk with a drift and zero mean, then we have to use equation (5). Equation (6) is appropriate if the series has a non-zero drift and non-zero mean.

RESULTS AND DISCUSSION

The unit root test results for each series, in log levels and in log first differences, are presented in Table 2. The ADF tests, involving each of the time series in log levels, the null of 'unit root,' [H_0: I(1)], could not be rejected, while the null of 'no unit root' [H_0 : I(0)], for the KPSS test was rejected. Then, the series are tested in their log first differences. In all the cases, the ADF test rejected the null of 'unit root,' in log first differences, and in the KPSS tests, the null of 'no unit root' could not be rejected in log first differences of the series (note, the null of the KPSS test is the opposite of ADF test). According to the ADF tests, the five time series are stationary in their log first differences. The KPSS test results confirm the ADF test conclusion. The finding that each one of the interest rates is I(1) is consistent with the results of the studies by Stock and Watson (1988, 1999).

Since the unit root tests indicated that each of the interest rate series is integrated of the same order, I(1), we conducted the cointegration tests on the series employing the JJ procedure. Three multivariate cointegration tests of the interest rates are performed. First, a cointegrating rank test among all the five market interest rate series: *ltb3m*, *ltb6m*, *llbr3m*, *llbr6m, and lffr*. Then, a cointegration test among the four series: *ltb3m*, *ltb6m*, *llbr3m*,and *llbr6m.* Finally, a cointegration test between *ltb3m*, *ltb6m*, and *lffr,* the U.S.domestic interest rates. All cointegration tests are performed in log levels of the interest rate series and the equations are normalized on the *ltb3m.* Test results are presented in Table 3, panels (a), (b) and (c), respectively. In the case of the five interest rate series, panel (a) of Table 3, the trace test identified two cointegrating vectors but the maximum eigenvalue tests identified three cointegrating vectors. Since there is no agreement between the trace and maximum eigenvalue tests, I followed the convention of choosing the trace test results of two cointegrating vectors as more appropriate. Among the five interest rate series I conclude that there are two cointegrating vectors. For the four interest rate series without the fed funds rate, panel (b), Table 3, both trace and maximum eigenvalue tests identified two cointegrating vectors. For the three U.S. domestic rates, panel (c), Table 3, both the trace and maximum eigenvalue tests indicated one cointegrating vector. Tests of residuals from the estimated cointegrating equations indicate that the residuals are stationary in all cases. However, we cannot conclude that the estimated coefficients of the cointegrating equations are structural parameters.

Results of the cointegration test between *ltb3m*, *ltb6m*, and *lffr* , bottom part of panel (c) of Table 3, indicate one cointegrating vector. There is no one-to-one relationship between *ltb3m* and *lffr*. The finding of two cointegrating vectors in the bottom panel (a) of Table 3 imply that there are two ways the five interest rate series can be stable and two ways the series can deviate from each other. In general, more cointegrating vectors means more ways the system will be stable. So, there is strong evidence that the two money markets are more integrated during the sample period for this study. Studies in the late 1980s and early 1990s reported one cointegrating vector between fed funds rate and the T-bill rates, between three month T-bill rate and three month Libor, and between one month CD rate and the three month Libor deposit rate. The studies by Clinebell et al (2000) and Sarno and Thornton (2003) also reported one cointegrating vector. However, Clinebell et al (2000) did report any increased integration of the two markets. Their conclusion is exclusively based on no finding of mutual causation between T-bill rates and Libor. Clinebell et al (2000) state that 'increased integration and more rapid movement of dollar flows should promote bi-directional Granger causality between T-bills and LIBOR'.

The study by Zhou (2007) used bivariate cointegration tests among three different sets of interest series and reported one cointegrating vector in all the three cases. There can only be one cointegrating vector between two variables integrated of the same order, say, I(1). The finding of two cointegrating vectors among the five interest rate series in this study is a strong indication that integration of U.S. domestic and

Eurodollar market rates has substantially increased during the sample period under investigation. Since we cannot directly infer that the increased integration is due to the elimination of reserve requirements on Eurodollar deposits in 1990 and also due to the switch to fed funds rate targeting in the conduct of monetary policy by the Fed in 1992. However, the increased integration of the two markets may be in large part attributed to the two changes, the regulatory and monetary policy operating procedure.

Table 2: Augmented Dickey-Fuller & KPSS Unit Root Tests

	ADF Test[1]		KPSS Test[2]	
Variable	Test Statistic in levels[2]	Test Statistic in first diff	LM Test Stat in levels	LM Test Stat in first diff
ltb3m	-1.1367	-20.288***	4.1011	0.2914***
ltb6m	0.5242	-4.6543***	4.2729	0.5434***
llbor3m	-0.9965	-61.757***	4.3312	0.5264***
llbor6m	-0.2018	-25.934***	4.3312	0.3401***
Lffr	-1.0489	-31.989***	4.7371	0.3553***

*The equation estimated is $Y_t = \mu + \alpha X_{t-1} + \Sigma\delta_i \Delta X_{t-i}$ for the ADF test. ADF and KPSS unit rate test results indicate that all the interest rate series in their log levels are I(1), and are stationary in their log first differences. [1] 1 % critical value for ADF test with intercept is -3.4313, 5% critical value with intercept is -2.8618, 1%. Critical value with intercept and trend it is -3.9595, and for 5% it is -3.4105. [2] 1% critical value for KPSS LM statistic with intercept is 0.739 and 5% value is 0.463, and with intercept and trend the critical values are 0.216 and 0.146, respectively. *** indicates significance at 1% level.*

In the four variable system of *ltb3m*, *ltb6m*, *llb3m*, and *llb6m*, shown in column (b) of Table 3, the maximum number of cointegrating vectors is three. The finding of two cointegration vectors means that there are two ways these rates can be stable. In the case of one cointegrating vector among *ltb3m*, *ltb6m*, and *lffr*, displayed in column (c), there is only one way the system is stable.

The time period from late 2007 to late 2009 is characterized by severe financial crisis in the U.S. During that period there were accusations that the Libor was being manipulated by some of the large participating banks in the Eurodollar market. I used the time period from January 2, 2007 to September 14, 2009 to test whether the accusation of manipulation of Libor had any impact on the cointegrating relationship among the five interest rates. The estimated results indicated two cointegrating vectors among the five interest rate series. For want of space the results are not presented in this paper but are available to anyone interested in these results. However, as the sample period of less than three years is too short to estimate a cointegrating relationship I do not want to conclude that the U.S. financial crisis did not disrupted the degree of integration of the two markets. Instead, I would prefer to examine this issue when the sample period is over five or six years.

For examining the short-run dynamics of the interest rates, two VEC models (equation 3) are estimated, one with all the five rates in their log first differences, and the other with the four money market interest rates (i.e. without the *lffr*) in their log first differences. Based on the estimated results of the VEC models presented in Table 4, panels (a) and (b), we can draw some key inferences about the adjustment mechanism of the interest rates to their long run equilibrium path following an external shock to the system of interest rates.

The magnitudes and signs of the estimated error-correction coefficients reported in panels (a) and (b) of Table 4 provide information as to how the equilibrium is restored, the direction and magnitude, following an external shock. Results in panel (a) of Table 4 show that the error-correction coefficients of two equations, Δ*lffr* and Δ*ltb3m*, are statistically significant. However, the error correction coefficients in the remaining equations are not statistically significant at the conventional levels, which implies that *ltb3m* and *lffr do* participate in the adjustment process, but their participation is not statistically significant.

Table 3: Cointegration Test Results

	Panel (a)	Panel (b)	Panel (c)
H_0: $r = 0$, $H_a = 1$			
Trace statistic	893.66***	866.50***	252.05***
Critical Value	85.336	61.195	41.195
Max. Eigen Stat	786.91***	778.52***	234.69***
Critical Value	40.295	33.733	27.068
H_0: $r \leq 1$, $H_a = 2$			
Trace statistic	106.75***	87.981***	17.353
Critical Value	61.267	41.195	25.078
Max. Eigen Stat.	77.029***	74.405***	15.329
Critical Value	33.733	27.068	20.161
H_0: $r \leq 2$, $H_a = 3$			
Trace statistic	29.717	13.576	
Critical Value	41.195	25.078	
Max. Eigen Stat.	27.067***	12.268	
Critical Value	15.759	20.161	
Lags	15	15	15

Normalized cointegrating equations. Normalized on ltb3m

	Panel (a)	**Panel (b)**	**Panel (c)**
ltb3m	1.0000	1.0000	1.0000
ltb6m	-1.0622***	-1.0658***	1.0527***
	(0.01372)	(0.0138)	(0.0121)
llbr3m	-0.7239***	-0.7171***	
	(0.0397)	(0.0384)	
llbr6m	0.7688***	0.7653***	
	(0.0405)	(0.0398)	
Lffr	-0.0013		0.0293**
	(0.0049)		(00112)
Constant	0.0419	0.0429	0.1619
	(0.0111)	(0.0093)	(0.0207)
Log likelihood	76,056.44	65,475.04	33,726.65

Estimated system of equations: $X_t = \mu + \Sigma A_i X_{t-} + \epsilon_t$ *Upper half of the Table 3, Panels (a), (b), and (c) contain hypotheses tests of three cointegrationg equations. In Panels (a) and (b) the inference is two cointegrating vectors and one in Panel (c). Panels (a), (b), and (c) in the lower part of Table 3 contain the normalized cointegrating vectors. Standard errors are in parentheses.* ***, ** *Significance at 1% and 5% levels.*

The magnitude of the error-correction coefficient of Δ*lffr* is much larger, over four times larger, than the coefficient of Δ*ltb3m*. Following a positive shock the system is pushed above its equilibrium path. Both *lffr* and *ltb3m* react to gradually restore long-run equilibrium relationship between these rates. The negative signs of the error-correction coefficients indicate the direction of that adjustment to equilibrium. Additionally, it appears that the fed funds rate, the focus of monetary policy, reacts significantly in restoring equilibrium. This finding is consistent with the reported results of the studies by Sarno et al (2003) and Zhou (2007). According to Sarno et al (2003) study, 'the more surprising result was the finding that that the fed funds rate adjusts more rapidly than the three-month T-bill rate'. Likewise, the study by Zhou (2007), that examined the dynamic relationship between the fed funds rate and the Eurodollar rate, reported that, in the post-1994 period the fed fund rate bears the burden of the adjustment toward equilibrium. In general, the belief is that the fed funds rate is the bellwether rate and all other short-term rates follow it. That general belief appears to be in contrast with the findings of this study and also the studies by Sarno et al (2003) and Zhou (2007).

Table 4: VECM Estimated Results

Panel (a)	$\Delta lffr$	$\Delta ltb3m$	$\Delta ltb6m$	$\Delta llbr3m$	$\Delta llbr6m$
Error-correction Coeff. (λ_i)	-0.0867***	0.0095***	-0.0038	0.0034	0.0012
	(-8.1021)	(0.0035)	(1.5746)	(1.2029)	(0.4032)
Sums of lagged first differences: $\Sigma\Delta lffr_{t-i}$		0.0544***	0.0019	-0.0763	-0.0082
		(3.9040)	(0.8990)	(-1.0971)	(1.5244)
Sums of lagged first differences: $\Sigma\Delta ltb3m_{t-i}$	0.0204		-0.0109	0.1996***	0.2133***
	(0.3980)		(0.8674)	(7.5241)	(7.2210)
Sums of lagged first differences : $\Sigma\Delta ltb6m_{t-i}$	0.0876	0.1031		0.1363	-0.0534
	(1.2247)	(1.4321)		(1.4926)	(-0.9327)
Sums of lagged first differences: $\Sigma\Delta llbr3m_{t-i}$	0.1196	-0.1273	0.0326		-0.1358***
	(1.6542)	(1.4634)	(1.2237)		(-2.9050)
Sums of lagged first differences: $\Sigma\Delta llbr6m_{t-i}$	0.9463	0.0671	-0.0295	0.3068	
	(1.1223)	(1.6454)	(1.2895)	(1.0722)	
Panel (b)					
Error-correction Coeff. (λ_i)		-0.1367***	-0.0123***	-0.0048***	-0.0041***
		(-16.797)	(-4.4635)	(-3.5403)	(-2.5986)
Sums of lagged first differences: $\Sigma\Delta ltb3m_{t-i}$			-0.1006***	0.3670	0.0741
			(2.6524)	(2.6948)	(1.0212)
Sums of lagged first differences: $\Sigma\Delta ltb6m_{t-i}$		0.0625***		-0.0480	-0.0044
		(3.5424)		(-1.0145)	(-0.0875)
Sums of lagged first differences : $\Sigma\Delta llbr3m_{t-i}$		0.0329***	-0.0143		-0.0585***
		(3.6687)	(-2.1580)		(-2.5431)
Sums of lagged first differences: $\Sigma\Delta llbr6m_{t-i}$		0.0303	-0.0009	0.4552***	
		(0.9009)	(-1.1057)	(4.7224)	

This table shows VECM Estimated Results. III indicates significance at the one percent level.

The short-run dynamics can be inferred from the reported coefficients of the sums of the log differenced and lagged variables in each equation. The reported results in Table 4 panel (a) in the $\Delta ltb3m$ equation, the coefficient of $\Sigma\Delta lffr_{t-i}$ is statistically significant while the coefficient of $\Sigma\Delta ltb3m_{t-i}$ is not significant in the $\Delta lffr$ equation. The inference is that Granger causality runs from the federal funds rate to the three-month T-bill rate. Next, one-way Granger causation can be inferred in the short-run between three-month T-bill rate to both three-month and six-month Libor, because in the two equations, $\Delta llbr3m$ and $\Delta llbr6m$, the coefficients of $\Sigma\Delta ltb3m_{t-i}$, are significant, columns 5 and 6, panel (a). Finally, none of the variables is causally linked to the six-month T-bill rate because none of coefficients in that equation is statistically significant.

Now, let us take a look at the reported results of the error-correction model in panel (b) of Table 4. This model is estimated without the fed funds rate as part of the system. These results are different compared to the reported results in panel (a) of Table 4. First, in panel (a), only the three-month T-bill rate and fed funds rate participate in the adjustment process when the system is out of equilibrium, whereas the results in panel (b) of Table 4 imply that all the four market rates participate significantly in the adjustment process. Secondly, the short-run dynamics among the variables also differ from the results in panel (a) of Table 4. First, in the $\Delta ltb3m$ equation six-month T-bill rate along with the three-month Libor rate cause the three-month T-bill rate. And the three-month T-bill rate causes the three-month Libor. Further, three-month Libor and six-month Libor are mutually causal. In sum, three-month T-bill rate and three-month Libor are mutually causal, three-month T-bill rate and six-month T-bill rate are mutually causal, and the three-month and six-month Libor are mutually causal. These results are not consistent with the results reported in panel (a) of Table 4. The key difference between the two estimated results is the finding of mutual causation among the four rates. The interpretation of the finding of causality running both directions is not very clear. Some of the studies reviewed above argued that a finding of mutual causation of these rates would imply increased integration of the two markets. Results of this study, reported in

Table 4 panel (b) do indicate mutual causation of these rates. If it is assumed that a finding of mutual causation is evidence of increased integration then, this study supports that contention. Instead of basing the inference of increased market integration on a finding of mutual causation of variables, I would argue that the real support for increased market integration has to be based on the number of ways a system can be stable, that is, the number of cointegrating vectors in the system. More ways a system is be stable, that is, the more cointegrating vectors there are, the more integrated the system is. Dickey et al (1991) argued that cointegrating vectors can be thought of as representing constraints that an economic system imposes on the movement or co-movement of the variables in the system in the long-run. Dickey et al (1991) further assert that the more cointegrating vectors there are the more stable the system. Other things being the same, it is desirable for an economic system to be stationary in as many directions as possible. In this paper the inference of increased integration of the markets is based on the finding of two cointegrating vectors among the five interest rate series.

Further, there is some controversy regarding the interpretation of the finding of mutual causation between variables. Economists Hess and Schweitzer (2000) raised objection to the interpretation of mutual causation as the two variables concerned cause each other. They argued that two variables may 'Granger-cause one another', in which case one can conclude only that both economic series are determined simultaneously; hence, a researcher cannot conclude that one series has an independent causal effect on the other'. A second interpretation may be that the two variables involved are caused by a third variable.

The finding of conflicting causal linkages in this study may be due to the omission of the fed funds rate in the estimated results of the VEC model presented in Table 4 panel (b). Perhaps, the fed funds rate is an essential part of the system. However, this issue needs further investigation and will be explored in more detail in future research.

CONCLUDING REMARKS

This empirical study tests whether there is an increase in the degree of integration among the U.S. effective fed funds rate, three and six-month T-bill rates and three and six-month Libor following two key changes. First, in 1990s the Fed dropped the reserve requirement on Eurodollar bank deposits. Second, the Fed switched from borrowed reserve targeting to targeting fed funds rates in conducting monetary policy. To examine this aspect, multivariate cointegrating equations are estimated to test for long-run equilibrium relationship among these rates, and for the short-run dynamics among these rates, two VEC models are estimated. The data used in this study are daily (5-day) series, and the sample period ranges from January 6, 1986 to September 14, 2009. Each of the interest rate series is tested for the degree of integration using ADF and KPSS tests. All the five series in log levels are found to be I(1). The series are stationary in their log first differences. As all the rates are integrated on the same order multivariate JJ cointegration tests are conducted. The tests identified two cointegrating vectors among the U.S. domestic and offshore Libor rates, which implies that the degree of integration among these rates has increased since the 1990s. No published study reported more than one cointegrating relationship between the U.S. domestic rates and the Eurodollar rates. The inference of increased integration between the U.S. domestic and offshore Eurodollar markets is based more on the finding of two cointegration vectors rather than the finding of mutual causation of the interest rates involved. If mutual causation is accepted as proof of increased integration, then, that finding of mutual causation in this study, should reinforce increased integration. One important policy implication of increased integration is that U.S. monetary policy, fed funds targeting, can be expected to be more effective in closely linked markets.

In order to examine the short run dynamics among the key interest rates two VEC models are estimated, one with all the five interest rates and the other without the fed funds rate. The results of the two VEC models are different. This is somewhat intriguing as there is little agreement between the estimated results of the two VEC models. For instance temporal Granger causality runs from the three-month T-bill rate to the three-month Libor in the VEC model with the fed funds rate included in the system. The results of the VEC model estimated without the fed funds rate showed bi-directional Granger causality between the three-month T-bill rate and the three-month Libor. These conflicting results will be further investigated as part of further research of this paper.

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