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International Money Market Integration: An Application of GARCH Model with Consideration of Missing Data

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Abstract

The purpose of this study is to re-examine Taiwan's progress in entering the international financial arena and achievement in the liberalization of the banking industry by implementing a GARCH error correction model incorporating the missing-data effect. The evidence show that the causality relationships with consideration of missing data are drastically different from those without taking into account of them, confirming the existence of the missing- data effect. Bi-directional Granger causality relationships are supported for all pairings of markets when both heteroscedasticity and mis-specification of models are considered. In addition, Taiwan's liberalization of the banking industry is more successful than previously believed, being proved by its long-term co-movements with Singapore and London.

1. INTRODUCTION

World financial markets, including capital and money markets, have become increasingly integrated over the past two decades. This development has been accelerated by the need to establish a 24-hour global market and the ease of political tension between Super Powers. Tremendous opportunities have also been created by this trend for both international investors and borrowers through reduction in capital market imperfections and the flow of capital and information worldwide.

Following the integration trend, many studies have been conducted in the area of offshore money market. These studies, including Hendershott (1967), Kwack (1971), Giddy, Dufey, and Min (1979), Hartman (1984), and Swanson (1987), focused primarily on the relationship between the U.S. and the Eurodollar market. For instance, using a stock adjustment model, Hendershott (1967) concluded that the Eurodollar rate adjusted completely to changes in the U.S. bill rate. Giddy, Dufey, and Min (1979) supported the view that U.S. rates show greater stickiness than Eurodollar rates and the Eurodollar rates respond more efficiently to information. In addition, Swanson (1987) found that the degree of integration between the U.S. domestic market and the Euro market had increased throughout the period studied and that the direct causality was found to be stronger than the reverse causality.

Other studies extended the issue to include more offshore and domestic money markets. Argy and Hodjera (1973) explored financial integration and interest rate linkages in ten industrial countries. Primary findings were that the movement in the Eurodollar rate tended to be dominated by conditions in the U.S. and that the U.S. and Eurodollar markets were highly integrated. Subsequently, Swanson (1988) investigated the relationships between yields on various currency denominated deposits. Results indicated that changes in domestic and offshore yields for the same currency moved closely and primary direction of causality is from the national to the offshore markets. In a recent study, utilizing the error correction model, Lin and Swanson (1993) extended the integration investigation by incorporating the Asiancurrency markets of Singapore and Hong Kong. Their results showed that major domestic markets and included offshore markets are partially segmented and domestic markets are not immune from outside influences.

Over the past decade, establishing Taipei as a regional international financial market has been a "must-be-executed" policy of Taiwan. Supporting actions, including reopening of the forward market, enacting new laws to enhancing banking operating environment, allowing more foreign capital to invest in financial markets, and many others, have been implemented by the government, especially directed by the Central Bank of Taiwan. Another prominent effort is the establishment of the Taipei Offshore Money Market (TOMM) on August 7, 1989.

Since its inception, the TOMM has grown fast. One of the milestones is the completion of synchronous transaction linkages with Singapore, Hong Kong, and Japan. It is believed that this establishment symbols the success of Taiwan in joining the global banking transaction network, implying offshore money market integration between Taiwan and well-developed financial markets. This issue had been examined by Lin and Leu (1994). Their results indicated that three offshore money markets examined (Taipei, Singapore, and London) are not fully integrated. Singapore and the London Eurodollar market have much more integrating relationship (long-term co-movement) than those with Taipei, showing weak evidence of Taiwan's achievement in joining the global banking society.

In the real world, when examining information transmission or integration of two financial markets, one often confronts with the problem of missing data due to different time zones and diverse market operating times. If data which are missing occur on both markets, then it creates no problem since one can just delete these missing observations on both markets. For instance, records of asset prices usually do not contain data of Sunday since no market trades on this. However, it is quite frequent that one market is operating while the counterpart market is closed due to particular holidays in that country.[1] Under this circumstance, one typically deletes the missing points of one market as well as the informative data from the other.[2] In other words, lack of price information in one market on some dates would tempt researchers to throw out useful information of corresponding calendar dates in the counterpart market. This missing-data effect is magnified if models of autoregressive nature, such as Granger and Sims models and error correction model which were utilized widely in previous integration studies, are employed.[3]

The purpose of this study is to re-examine Taiwan's progress in entering the international financial arena and achievement in the liberalization of the banking industry by implementing a GARCH (Generalized Autoregressive Conditional Heteroscedasticity) error correction model incorporating this missing-data effect. The evidence show that the causality relationships with consideration of missing data are drastically different from those without taking into account of them, confirming the existence of the missing-data effect.

The remaining of this paper is grouped into four sections. The next section demonstrates algebraically the impact of the missing-data effect. Section two provides the testing procedures of the conventional models and of the GARCH error correction model. Section three describes the data utilized and reports the empirical results. Finally, concluding remarks and implications are discussed.

2. MISSING-DATA EFFECT

Detecting lead-lag relationship between two variables typically uses the Granger causality test. However, as discussed above, the missing data in one market on some dates might tempt researchers to delete data points of corresponding calendar dates of another, and thus throw out useful information. The impact of this effect is magnified in an autoregressive model such as the Granger causality or Sims test. To illustrate, assume that a true underlying yield relationship of two financial markets is AR(1), then a Granger causality test could be implemented as

$$Y_t = a_0 + a_1 Y_{t-1} + b_1 X_{t-1} + e_t \tag{1}$$

Assume that one observation of Y is missing on a particular day, $t-1$, then, the true model at day t becomes

$$Y_t = a_0 + a_1(missing) + b_1 X_{t-1} + e_t \tag{2}$$

If one deletes this missing point, Y_{t-1}, as well as X_{t-1}, then the following match is created

$$Y_t = a_0^* + a_1^* Y_{t-2} + b_1^* X_{t-2} + e_t^* \tag{3}$$

which is a misspecified estimation model since the correct relationship between Y_t and Y_{t-1} and X_{t-2} is

$$\begin{aligned} Y_t &= a_0 + a_1 Y_{t-1} + b_1 X_{t-1} + e_t \\ &= a_0 + a_1(a_0 + a_1 Y_{t-2} + b_1 X_{t-2} + e_{t-1}) + b_1 X_{t-1} + e_t \\ &= (a_0 + a_1 a_0) + a_1^2 Y_{t-2} + a_1 b_1 X_{t-2} + w_t \end{aligned} \tag{4}$$

where e_t^* in Equation (3) is equal to $w_t = b_1 X_{t-1} + a_1 e_{t-1} + e_t$.

Equations (3) and (4) illustrate the potential impact from missing data on an autoregressive model when estimated by OLS. That is, the true model is Equation (4) but Equation (3) is used erroneously. Since $E(X_{t-2}, w_t)$ in Equation (4) is probably not equal to zero owing to the correlation between X_{t-1} and X_{t-2}, the OLS estimations in Equation (3) are thus biased. In addition, note that residuals, e_t, in Equation (1) are white noise, but residuals of Equation (3), e_t^*, become serially correlated and possibly display conditional heteroscedasticity. Thus, mis-specification arising from the missing data renders OLS estimators both biased and inefficient. The GARCH-miss model considered shortly can overcome both problems successfully and simultaneously.

3. ESTIMATION METHODS

Three estimation methods are introduced in order to make a comparison with the GARCH-miss model. The OLS method, which is used by Lin and Leu (1994), is employed first. Since the residuals exhibit conditional heteroscedasticity, the generalized method of moments is applied next to take the heteroscedasticity into account. Further, the GARCH model, an alternative method to remedy the heteroscedasticity, is utilized to investigate the sensitivity. Finally, the GARCH-miss model is introduced.

3.1 Conventional OLS Error Correction Model

The causality models such as Granger, Sims, and error correction models are the popular ones used in previous market integration studies Among them, the error correction model which combines the cointegration concept and an autoregressive modelling had been proved to be more effective.[4] The first step of this approach is to examine if included series are stationary with the same order of integration (unit root test) by using the augmented Dickey-Fuller stationarity test. In the ADF test, the first difference of the variable is regressed on a time trend, on its own level lagged one period, and on lagged first differences of the variable.

$$\Delta Y_t = \alpha_0 + \alpha_1 TD + \alpha_2 Y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta Y_{t-i} + e_t \tag{5}$$

where TD is the time trend variable and p is chosen so that the residuals are white noise. If Y_t contains a unit root, the estimated coefficient, α_2, should be zero, suggesting non-stationary. The conventional t test statistic for α_2 is used and the critical values can be obtained from Fuller (1976).

If two series, X_t and Y_t, are non-stationary with the same integration order and a vector of d can be found such that a linear combination, $Y_t - dX_t = U_t$, is stationary, then X_t and Y_t are said to be cointegrated and this linear combination is termed the cointegrating equation. A cointegrating equation implies a long-run relationship between the two series. One widely used method of detecting cointegration is to employ the augmented Dickey-Fuller cointegration test which is implemented as:

$$\Delta U_t = -\beta_0 U_{t-1} + \beta_1 \Delta U_{t-1} + \cdots + \beta_k \Delta U_{t-k} + e_t \tag{6}$$

The test statistic is the t calculated value for β_0 and critical values are from Engle and Yoo (1987). A large t value will support the existence of cointegration.

If X_t and Y_t are proved to be cointegrated with a cointegrating vector of d, then they can be expressed as an error correction model (ECM).

$$\Delta Y_t = \theta_0 + \theta_1 U_{t-1} + \sum_{j=1}^{n1} c_i \Delta Y_{t-i} + \sum_{j=1}^{n2} f_j \Delta X_{t-j} + \varepsilon_t \tag{7}$$

Equation (7), usually estimated by conventional OLS, provides a basis for the testing of money market integration. A yield series of a market, Y, could be affected by a yield series from another market, X_t, through two channels.

The conventional way of explaining Granger causality is the past changes of X_t causing a significant move in Y_t if some of f_js are statistically significant. A second avenue of impact is through the lagged residual term (error correction term) from the cointegrating equation. If the coefficient of the error correction term is significant, then a diverging Y_{t-1} from X_{t-1} will drive Y_t to move closer to X_t, displaying a correction from past disequilibrium.

3.2 Generalized Method of Moments

As discussed earlier, autoregressive models with missing data could create possibly the heteroscedasticity problem. In order to avoid negative impact caused by heteroscedasticity, White's (1980) heteroscedasticity- correction method is employed to yield a consistent covariance matrix estimator. Since it is a special case of Hansen's (1982) generalized method of moments, the estimator here will be referred as GMM for simplicity.

If Equation (7) is further presented in matrix notions, then

$$\Gamma = ZB + \eta \tag{8}$$

where Z is the matrix for T observations of regressors and Γ is the corresponding dependent variable. Hansen (1982) proved that the estimator of B based on OLS is still consistent but its variance-covariance matrix needs to be modified. The asymptotic distribution of B is then

$$T^{1/2}(\hat{B} - B) \sim N(O, \Sigma) \tag{9}$$

where

$$\Sigma = (M_{zz} W^{-1} M_{zz})^{-1} \tag{10}$$

and $M_{zz} = \lim(Z'Z/T)$ and $W = \lim(Z'\eta\eta' Z/T)$. Although W is unknown, it would not cause a serious problem. The asymptotic distribution of $\hat{B}$ would remain unaffected if W is replaced by a consistent estimate which is

$$\hat{W} = T^{-1} \sum_{t=1}^{T} \sum_{t=-m}^{m} Z_t' \hat{\eta}_t \hat{\eta}_{t-k} Z_{t-k} \tag{11}$$

where Z_t is the tth row of Z and $\hat{\eta}$ is the consistent estimate of η. OLS disturbances from Equation (8) are substituted into Equation (11) to obtain a consistent estimate of $\hat{W}$, which is then placed back to Equation (10). Restrictions on $B = B_0$ can be tested by the conventional Wald test with a test statistic of

$$Wald = (\hat{B} - B_0)/\hat{W}^{-1}(\hat{B} - B_0)$$

3.3 GARCH Model Without Missing Observations

The motivation of using GARCH modelling is similar to that of GMM, that is, residuals are possibly heteroscedasticity. However, the GARCH model is more appealing than GMM in that it specifies an explicit conditional error function and incorporates this function into estimation. If this specification is correct, the GARCH estimation is much more efficient than that of OLS. Based on GARCH (1,1), the error terms of Equation (7) can be specified as

$$\varepsilon_t|\Omega_{t-1} \sim N(o, h_t) \tag{12}$$

$$h_t = d_0 + d_1\varepsilon_{t-1}^2 + d_2 h_{t-1} \tag{13}$$

where h_t is the conditional variance and Ω_{t-1} is the information set up to $t-1$. The likelihood estimate is

$$L = \sum_{i=1}^{T} L_t \tag{14}$$

and

$$L_t = -\frac{1}{2}\ln h_t - \frac{\varepsilon_{t-1}^2}{2h_t} \tag{15}$$

where T is the sample size. The algorithm of Berndt et al. (1974) is used numerically to obtain the estimates by maximizing the likelihood function.

3.4 GARCH Model with Missing Data

The EM algorithm, proposed by Dempster et al. (1974), is the standard method to deal with missing data problem. The EM algorithm includes two steps. The first step, called the E-step, is to set up an expected likelihood function to replace the conventional likelihood function, which is incomplete due to the missing data. Maximizing this expected likelihood function is the second step, also called the M-step. The estimates are obtained after implementing the M-step and the by-product of new expected value of missing data is thus yielded. The expected value of the missing data are then substituted back into the expected likelihood function. The M-step then again maximizes this new expected likelihood function. The procedure repeats until the estimates converge.

Though EM algorithm is originally designed to solve the missing data problem, the application of the algorithm to the GARCH model is not trivial. For instance, when ε_t is missing, the first step of the conventional EM algorithm is to derive the expected value of ε_t^{*2} as follows:

$$\begin{aligned} E(\varepsilon_t^{*2}|\Omega_{t-1}) &= E(Y_t - a_0 - a_1 Y_{t-1}^* - b_1 X_{t-1}|\Omega_{t-1})^2 \\ &= (Y_t - a_0 - a_1 E(Y_{t-1}^*|\Omega_{t-1}) - b_1 X_{t-1})^2 \\ &\quad + Var(Y_t - a_0 - a_1 Y_{t-1}^* - b_1 X_{t-1}|\Omega_{t-1}) \end{aligned} \tag{16}$$

where asterisk * denotes the missing variables. Equation (16) consists of two terms. The first term is related to the mean where missing Y_{t-1} is replaced by its expected value. The second term is the calculation of the expected variance which is inflated because of measurement error arising from missing data. However, this standard derivation to solve missing data problem is challengeable. Since EM approach utilizes both the past and future information and GARCH contains only conditional precise information, direct application of EM to GARCH, when missing data exist, is impossible. Trevor (1994), thus, suggests a pseudo-EM algorithm which can successfully overcome this weakness.[5]

Assume that GARCH (1,1) follows the same pattern as Equations (12) and (13) and thus unobservable ε_t^{*2} can be expressed as

$$E(\varepsilon_{t-1}^2|\Omega_{t-1}, \varepsilon_{t-1} \in \Omega_{t-1}) = E(\varepsilon_{t-1}^2|\Omega_{t-2}) = h_{t-1}$$

Thus, the expectation of ε_t^{*2} is simply expressed as its conditional expectation rather than is separated into two components as shown in Equation (16). Accordingly, the expected conditional variance can be shown as

$$\begin{aligned} h_t &= d_0 + d_1 E(\varepsilon_{t-1}^{*2}|\Omega_{t-1}, \varepsilon_{t-1} \in \Omega_{t-1}) + d_2 h_{t-1} \\ &= d_0 + d_1 h_{t-1} + d_2 h_{t-1} \end{aligned} \tag{17}$$

Note that ε_t is not observable when either Y_{t-i} or X_{t-i} is missing (i=0,1 in the illustrated model of Equation (1)). Similarly, the log likelihood term could be computed in the same manner above.

$$L_t = -\frac{1}{2}\ln h_t - \frac{\varepsilon_t^2}{2h_t} \quad \text{if } \varepsilon_t \text{ is observable}$$

$$L_t = -\frac{1}{2}\ln h_t - \frac{h_t}{2h_t} \quad \text{if } \varepsilon_t \text{ is not observable}$$

4. EMPIRICAL TESTS

Three offshore money markets, Taipei, Singapore, and London, are included in the following tests.[6] Daily observations of U.S. dollar denominated overnight yields during the period May 19, 1993 through November 2, 1994 are collected from Taipei Forex Inc., totally 350 observations.

Table 1 sets forth the results of the ADF stationarity tests. Very consistently, all overnight yield series are nonstationary in levels, but statistically significant at the 1% level after being differenced once. Thus, all series fulfill the necessary condition for further examination of cointegration.

Table 1

Results of Augmented Dickey-Fuller Stationarity Tests

$\Delta Y_t = \alpha_0 + \alpha_1 T + \alpha_2 Y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta Y_{t-i} + e_t$

Variables (Overnight Yield)	t Test Statistic of α_2^a			
	Level	Lag	1st-Diff.	Lag
Taipei	-1.74	4	-13.59**	3
Singapore	-1.22	4	-12.86**	3
London	-2.41	3	-8.57**	5

a: Critical values are from Fuller (1976).

**: significant at the 1% level

Results of the ADF cointegration tests are shown on Table 2. Test statistics are all significant at the 1% level for all pairings, confirming the existence of cointegrating relationships.[7,8,9]

Table 2

Results of Augmented Dickey-Fuller Cointegration Tests

$$\Delta U_t = -\beta_0 U_{t-1} + \beta_1 \Delta U_{t-1} + \cdots + \beta_k \Delta U_{t-k} + e_t$$

Variable Pairing		t Test Statistic	Lag^b
Dep.V.	Indep.V.	of β_0^a	Length
Taiwan	London	-10.88**	1
London	Singapore	-10.10**	1
Singapore	Taiwan	-5.88**	4

a: Critical values are from Engle and Yoo (1987).

b: The number of lags needed to induce white noise in residual series ın the ADF test.

**: significant at the 1% level

Table 3 reports the results of OLS error correction models without considering the impact from missing data and heteroscedasticity. Four lags are implemented in all models.[10] Only a pair of markets, Singapore and London, shows the existence of Granger causality relationship running from London to Singapore with a coefficient of 2.44 significant at 5%. Strong error correction terms are found for four out of the six market pairings. Very interestingly, neither causality relationship nor correction for past disequilibrium is shown for the pair of Taiwan and Singapore. When considering two impact channels together, only two pairings are significant, Taiwan to London and Singapore to London. These causality relationships are somehow different from those obtained by Lin and Leu (1994) where they reported bi-directional causality for all pairings except that of Taiwan and Singapore.

In order to avoid heteroscedasticity possibly induced by autoregressive modelling, the error correction model is further estimated by implementing the GMM procedure recommended by Hansen (1982). Results are presented on Table 4. No Granger causality is found in all pairs. When considering both causality avenues, the results are different from those reported on Table 3 in that an additional causal relationship, running from Singapore to Taiwan, is identified. Error correction terms also show discrepancies. None of those significant on Table 3 shows sign of existence on Table 4. However, Taiwan reveals the tendency to follow Singapore's movements with an error correction coefficient of 2.32.

Table 3

Estimation of Error Correction Models

Based on Conventional OLS

$$\Delta Y_t = \theta_0 + \theta_1 U_{t-1} + \sum_{i=1}^{n1} c_i \Delta Y_{t-i} + \sum_{j=1}^{n2} f_j \Delta X_{t-j} + \varepsilon_t$$

Dependence	Independence	Test Statistics for H_0:		
Variable	Variable	$\theta_1 = 0^a$	$f_j = 0^b$	$f_j = \theta_1 = 0^c$
Taiwan	London	-1.81*	2.28	1.85
London	Taiwan	-3.46**	1.94	3.36**
Taiwan	Singapore	0.85	0.27	0.61
Singapore	Taiwan	-0.05	0.23	0.19
London	Singapore	-3.43**	2.09	3.76**
Singapore	London	-1.74*	2.44*	2.00

a: t test for $H_0: \theta_1 = 0$, b: F test for $H_0: f_{j=0}, \forall j$

c: F test for $H_0: f_j = \theta_1 = 0, \forall j$

**: significant at the 1% level

*: significant at the 5% level

Table 4

Estimation of Error Correction Models Using

The Generalized Method of Moments

Dependence	Independence	Test Statistics for H_0:		
Variable	Variable	$\theta_1 = 0^a$	$f_j = 0^b$	$f_j = \theta_1 = 0^c$
Taiwan	London	-0.94	6.76	6.77
London	Taiwan	-1.81*	3.13	35.90**
Taiwan	Singapore	2.32*	2.23	18.12**
Singapore	Taiwan	-0.14	2.69	2.76
London	Singapore	-2.05*	2.27	37.50**
Singapore	London	-1.04	4.21	4.22

a: t test b: x^2 test (Wald test) for $H_0: f_j = 0, \forall j$

c: x^2 test (Wald test) $H_0: f_j = \theta_1 = 0, \forall j$

**: significant at the 1% level

*: significant at the 5% level

Table 5 reports the evidence of GARCH testing without considering the missing-data effect. In all pairings, the coefficients of lagged squared residuals, d_1, are highly significant, indicating the existence of ARCH characteristic. Furthermore, with the exception of the pair of London and Singapore, coefficients d_2s are also significant. The results of error correction term and causality relationship are identical to those reported on Table 4.

Table 5
Estimation of Error Correction Models
with Implementation of GARCH Model Without Missing Data

Dependence	Independence	Test Statistics for H_0:				
Variable	Variable	$\theta_1 = 0^a$	$d_1 = 0^a$	$d_2 = 0^a$	$f_j = 0^b$	$f_j = \theta_1 = 0^c$
Taiwan	London	0.47	2.73**	2.00*	7.41	7.41
London	Taiwan	-4.52**	4.18**	3.01**	3.30	83.39**
Taiwan	Singapore	3.32**	2.23*	1.76*	2.56	21.54**
Singapore	Taiwan	0.92	3.28**	2.94**	4.55	4.94
London	Singapore	-4.78**	2.35**	1.63	2.95	69.87**
Singapore	London	-0.27	3.11**	2.76**	5.91	5.91

a: t test b: x^2 test (Wald test) for $H_0 : f_j = 0, \forall j$

c: x^2 test (Wald test) for $H_0 : f_{j=0}, \forall j$

**: significant at the 1% level

*: significant at the 5% level

Table 6 shows the missing observation counts when markets are paired with each other.[11] The pair of Taiwan and Singapore shows 10 missing points, equivalent to 2.86% of the total number, 350. The missing counts for pairings of Taiwan and Singapore with London are much higher, 19 and 17, respectively.[12] As discussed previously, missing data could cause serious problem if autoregressive models are used for estimation. For instance, the missing data percentage for the market pair of Taiwan and London is 5.43%. If the ECM model is implemented with 4 lags, then the impact could be magnified to more than 20% of data. Consequently, it is necessary to estimate the ECM by taking into account of this effect.

The estimation results of GARCH with missing data adjustments are presented on Table 7. Table 7 shows a dramatically different picture from previous Tables. Based on x^2 tests for $f_{j=0}$, the hypotheses of bi-directional causality cannot be rejected in all instances. By taking the long-turn adjustment and causal relationship together, all pairings are significant at the 1% level, implying both short- and long-term relationships among these three offshore money markets.

Table 6
Missing Observations Counts for Different Market Pairings

Market Pairing	Counts	Percentage[a]
Taiwan – Singapore	10	2.86%
Taiwan – London	19	5.43%
London – Singapore	17	4.86%

a: The total number of observation is 350.

Table 7
Estimation of Error Correction Models
with Implementation of GARCH Model Considering Missing Data

Dependence	Independence	Test Statistics for H_0:				
Variable	Variable	$\theta_1 = 0^a$	$d_1 = 0^a$	$d_2 = 0^a$	$f_j = 0^b$	$f_j = \theta_1 = 0^c$
Taiwan	London	-0.46	5.69**	5.28**	37.99**	38.35**
London	Taiwan	-0.92	1.51	10.90**	119.27**	121.16**
Taiwan	Singapore	6.40**	1.33	6.26**	63.17**	96.04**
Singapore	Taiwan	-3.44**	4.87**	5.97**	118.43**	135.83**
London	Singapore	-2.04*	5.58**	5.56**	27.91**	56.78**
Singapore	London	1.56	6.69**	4.76**	51.64**	54.23**

a: t test b: x^2 test (Wald test) for $H_0 : f_j = 0, \forall j$

c: x^2 test (Wald test) for $H_0 : f_j = 0, \forall j$

**: significant at the 1% level

*: significant at the 5% level

5. CONCLUSION AND IMPLICATIONS

The purpose of this study is to re-examine Taiwan's progress in entering the international financial arena and achievement in the liberalization of the banking industry by implementing a GARCH error correction model incorporating the missing-data effect. In addition, several methods, including conventional OLS, generalized method of moments, and GARCH without missing values, are included to help understand the impact of missing-data.

Based on the cointegration tests, long-term equilibrium relationships are existing among three offshore markets. This finding is inharmonious with that reported by earlier studies where the market pair of Taiwan and Singapore does not show cointegrating relationship. This discrepancy could be due to the use of data set. Previous studies utilized a much shorter data period, May 19, 1993 to February 28, 1994. This paper utilizes a data set covering a longer period (180 observations vs. 350 observations), thus, it is more likely to capture the underlying long-term relationship.

In terms of the causality relationship, conventional OLS error correction model shows less evidence of existence. After adjustments for potential heteroscedasticity, more causal relationships are identified, however, still not complete through all three markets. Bi-directional causality relationships are confirmed for all pairings of markets when both heteroscedasticity and mis-specification of models are considered. Therefore, a much more strong linkage is found among these three offshore markets.

The implications of this study are threefold. First of all, Taiwan's liberalization of the banking industry is more successful than previously believed, being proved by the long-term comovements with Singapore and London. Second, since bi-directional causality relationships are shown, these examined offshore money market are still partially segmented. However, Taiwan's degree of integration with major financial market has increased. It is a encouraging evidence to Taiwan's government policy-makers. Third, missing data, to some extent, do have impact on estimated results, especially autoregressive models.

Endnotes

1. A good example of this would be the Chinese New Year which is based on the lunar calendar and normally would be observed in January or February. For this, some Asian financial markets will be closed for three to five days, such as Taiwan, Singapore and Hong Kong. However, western financial markets do not recognize and celebrate this occasion.
2. This deletion treatment has been used in earlier money market integration studies including Lin and Swanson (1993, 1995) and Lin and Leu (1994).
3. The missing-data effect on autoregressive models will be elaborate algebraically in the next section.
4. See Lin and Swanson (1993) and Lin and Leu (1994) for details of this application and modelling.
5. Trevor (1994), however, did not show that the pseudo-EM has the same property of increasing likelihood value as that of EM.
6. Although Taiwan had established transaction linkages with Hong Kong and Tokyo, data for these two markets are not available.
7. Critics have argued that the ADF cointegration test may lead to a conclusion of over-identifying cointegrating vectors; that is, accept cointegration too often. The results are further checked by applying the Johansen MLE cointegration test (see Johansen and Juselius, 1990). The Johansen test statistics are 44.09 for the pairing of Taiwan and London, 42.22 for London and Singapore, and 37.61 for Singapore and Taiwan. They are all significant at the 1% level, confirming the results of the ADF tests.
8. Based on Table 2, all pairs of markets reject the null hypothesis of no cointegrating vector, implying that each pair of markets shares one long -term relationship. This further suggests that a cointegration test of including all three markets should leave two cointegrating vectors with one coefficient

close to zero. The Johansen test with three variables are employed and the results confirm with this expectation.

9. These evidence are different from those reported by Lin and Leu (1994) where no cointegration relationship was observed for the pair of Taiwan and Singapore in three different yield series (overnight, one-week, and one-month).
10. Four lags plus the level is equivalent to one week. Previous studies have shown that the offshore money market is rather volatile and efficient and all information should be reflected within a week.
11. For every market pairing, when the information is missing in either of the two markets, it is counted as missing. If data are missing in both markets, we delete the data and do not refer them as missing.
12. Taiwan and Singapore are in the same time zone and both are affected by the same cultural history. Thus, it is no doubt that both countries have similar holidays.

References

1. Argy, Victor and Zoran Hodjera, 1973, Financial Integration and Interest Rate Linkages in Industrial Countries 1958-71, International Monetary Fund Staff Papers 20, 1–77.
2. Berndt, E.R., B.H. Hall, R.E. Hall, and J.A. Hausman, 1974, Estimation and Inference in Nonlinear Structural Models, Annuals of Economics and Social Measurement 3, 653–655.
3. Dempster, A.P., N.M. Laird, and D.B. Rubin, 1977, Maximum Likelihood from Incomplete Data via the EM Algorithm, Journal of the Royal Statistical Society Serial 39, 1–38.
4. Engle, Robert F. and Byung Sam Yoo, 1987, Forecasting and Testing in Co-integrated Systems, Journal of Econometrics 35, 143–59.
5. Fuller, Wayne A., 1976, Introduction to Statistical Time Series, (John Wiley & Sons, New York).
6. Giddy, Ian H., Gunter Dufey and Sangkee Min, 1979, Interest Rates in the U.S. and Eurodollar Markets, Weltwirtschaftliches Archiv 115, 51–67.
7. Hansen, L.P., 1982, Large Sample Properties of Generalized Method of Moments Estimators, Econometrica 50, 1029–1054.
8. Hartman, David G., 1984, The International Financial Market and US Interest Rate, Journal of International Money and Finance 3, 91–103.
9. Hendershott, Patric H., 1967, The Structure of International Interest Rates The U.S. Treasury Bill Rate and the Eurodollar Deposit Rate, Journal of Finance 22, 455–65.
10. Johansen, Soren and Katarina Juselius, 1990, Maximum Likelihood Estimation and Inference on Cointegration - with Applications to the Demand for Money, Oxford Bulletin of Economics and Statistics 52, 169–210.
11. ______, 1992, Testing Structural Hypotheses in a Multivariate Cointegration Analysis of the PPP and the UIP for UK, Journal of Econometrics 53, 211–44.
12. Kwack, Sung Y., 1971, The Structure of International Interest Rates: An Extension of Hendershott's Tests, Journal of Finance 26, 897–900.

13. Lin, Antsong and Shirley Leu, 1994, Offshore Money Market Integration – Evidence of the U.S. Dollar Yields in Taiwan, Singapore, and the United Kingdom, Sun Yat-Sen Management Review 2, 1-13.
14. Lin, Antsong and Peggy E. Swanson, 1993, Measuring Global Money Market Interrelationships: An Investigation of Five Major World Currencies, Journal of Banking and Finance 17, 609–28.
15. ——, 1995, Emerging Capital Markets: Asiancurrency Markets and Global Money Market Integration, Journal of International Finance, forthcoming.
16. Swanson, Peggy E., 1987, Capital Market Integration over the Past Decade: The Case of the US Dollar, Journal of International Money and Finance 6, 215–25.
17. ——, 1988, Interrelationships Among Domestic and Eurocurrency Deposit Yields: A Focus on the U.S. Dollar, The Financial Review 23, 81–94.
18. Trevor, R., 1994, GARCH with Missing Observations, manuscript, University of New South Wales.
19. White, H., 1980, A Heteroscedasticity-Consistent Estimator and A Direct Test for Heteroscedasticity, Econometrica 48, 817–838.