INTERNATIONAL EVIDENCE OF SPILLOVER EFFECTS OF DEPOSIT RATES: A MULTIVARIATE GARCH MODEL

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ABSTRACT

This paper uses the multivariate GARCH methodology to investigate spillover effects of deposit rates and its volatility among the United States, Japan and German. Empirical results show that multivariate GARCH (1,1) is appropriate and the deposit rate of one country is affected by the domestic long-term government bond yield and money market rate. We find at the mean level, the deposit rate transmission is from Japan to Germany, the United States to Germany and Germany to Japan. At the volatility level, deposit rate volatility spillover is from Germany to Japan, from the United Sates to Japan, and from Germany to the United States. Our findings contribute to the deposit rate literature of transmission and spillover effect.

JEL: G15; G21

KEYWORDS: Deposit Rate; Multivariate GARCH; Transmission; Spillover; Mean; Volatility

INTRODUCTION

In the past three decades, world financial markets have achieved a greater degree of integration, and barriers to the flow of capital have been reduced. Consistent with this development, interest rates became more synchronized across financial markets, and the issue of interest rate transmission and volatility spillover has sparked worldwide interest among international traders, investors, governments and academics. Interest rates and its volatility (risk) can be transmitted through two channels: first, international traders and investors manage their financial risk exposure and change trading strategies in respond to interest rate movements of major economies. Second, governments usually take actions to prevent capital outflow or maintain stability of their financial systems relative to the change of interest rates by other countries.

Research suggests that there are international linkages of interest rates among financial markets. Kirchgassner and Wolter(1987, 1993), Karfakis and Moschos (1990) and Fung and Lo (1995) examine international interest rate transmission primarily on conditional mean values, and find strong contemporaneous correlations and/or transmission of various interest rates. Interest rate transmission exists not only at the mean level but also in volatility (risk). Researchers employ the autoregressive conditional heteroscedasticity (ARCH) type model to examine interest rate transmission and volatility spillover, because interest rate risk is time dependent and its variance changes over time (Choi et al., 1992; Song, 1994 and Flannery et al., 1997). Generalized ARCH (GARCH) framework, which allows past conditional variances to appear in the current conditional variance equation, is used in the presence of heteroscedastic and leptokurtic residuals and time-changing conditional variances. Using a multivariate GARCH model, Fung, Jang and Lee (1997), Kearney and Patton (2000) and Laopodis (2002) demonstrate that international interest rate volatility spillover exists.

The main purpose of this paper is to employ the multivariate GARCH methodology to investigate spillover effects of deposit rates and its volatility among the United States, Japan and German. The sample period is from 1982 to 2003. Our sample begins in 1982 because the United States began to follow a new monetary policy since October 1982, i.e., the Fed targeted borrowed reserves. We use the sample until 2003 for empirical examination to exclude effects of recent years' financial crisis during the late 2000, and to exclude the effect of a very volatile exchange rate between Yen and US dollar in the same period. We find the deposit rate transmission is from Japan to Germany, the United States to Germany and Germany to Japan at the mean level. Deposit rate volatility spillover is from Germany to Japan, from the United Sates to Japan, and from Germany to the United States at the volatility level.

This paper has three contributions. First, by analyzing the deposit rate transmission in mean value and volatility, this paper provides a complete framework of information flow of deposit rates between three markets. The major advantage of the multivariate GARCH framework is its ability to examine all three markets simultaneously, assuming spillovers are realized in a process of global shocks that affects all financial markets in the system.

Second, the study on the interest rate transmission between USA, Japan and Germany remains a rarity. While several papers examine the spillover effects among the European Monetary System (EMS) and/or the United States and Japan (Levin, 1974; Karfakis and Moschos, 1990; Katsimbris and Miller, 1993; Fung et al., 1997 and Laopodis, 2000, 2002). These three countries have strong economies, and their banking systems are different from each other. Germany plays a leading role in the EMS (Kearney and Patton 2000). The German banking system consists of three pillars: public sector banks, cooperatives and commercial banks. A large majority of German banks are universal banks. They are not merely financial conglomerates, but rather accommodate almost all divisions within a single institution. Elyasiani and Mansur (2003) point out that the Japanese banking system is a thin firewall system, within which traditional banking and other operations are still separated to some degree. They also document that the U.S. banking system is categorized as a thick firewall system and it is the most restrictive of three banking systems. Since deposit rates within a certain banking system will respond differently to various shocks, our examination of interest rate transmission and spillover effects between the tripolar systems becomes important.

The third contribution rests with the analysis of deposit rates. Deposit rate transmission and spillover effects are generally overlooked in previous literature. The effects of a high deposit rate are two-fold. When one country increase deposit rates to attract foreign funds, on one hand, other countries may raise their deposit rates to prevent capital outflow and a consequent loss of foreign exchange reserves. In this way, there will be deposit rate transmissions. On the other hand, to generate an economic return, banks with higher deposit rate have to make higher-risk, higher-yield loans, fee-based services, and off-balance sheet activities. Depositors may realize that they have to undertake higher risks in return for higher rates and therefore they would not switch their funds to the country with higher rates. If this is the case, other countries do not need to raise deposit rate to prevent capital outflow. There will be no deposit rate transmission.

The rest of this paper is organized as follows. In section 2, the literature on interest rate spillover is reviewed. Section 3 presents the model and methodology. Section 4 introduces the data and hypotheses, and section 5 discusses the empirical result. Section 6 presents the conclusion.

LITERATURE REVIEW

Recent studies have found that interest rate risk is time dependent (Engle, et al., 1987; Grier and Perry, 1993; Choi et al., 1992; Song, 1994; Wetmore and Brick, 1994; Flannery et al., 1997 and Elayasiani and Mansur, 1998). Researchers use the multivariate GARCH model to examine the spillover effects of variables with time-varying conditional variances as well as covariance. For example, Bollerslev (1990) employed a multivariate GARCH model with constant conditional correlation to illustrate the change of five nominal European U.S. dollar exchange rates after the inception of the European Monetary System

(EMS). He finds that conditional volatility is lower and the coherence among exchange rates is higher in the post-EMS period. Hu, Jiang and Tsoukalas (2004) applied a multivariate GARCH (1,1) model to examine the impact of two events (establishment of the EMS and the ratification of the Basle-Nyborg agreement) on the exchange rates of all European Union currencies. They document that volatility of log returns of European currencies generally decreased after such events, i.e. such two events helped to stabilize the European currencies.

The issue of volatility spillover of economic variables is an important but relatively new topic, and papers in this area are limited. Ross (1989) found that information transmission speed is more relevant to the conditional variance of an asset's price changes, i.e., volatility is more important in analyzing such spillover effects than the mean value. Kearney and Patton (2000) construct a set of 3-, 4- and 5-variable multivariate GARCH models to illustrate the volatility spillover effects of exchange rates in the EMS system. Their model is a little different from what Bollerslev (1990) used. In Bollerslev's model, the correlation is constant, while Kearney et al. (2000) allows the correlation to change over time. Using the BEKK parameterization of the multivariate GARCH model, they find the German mark plays a leading role in transmission of volatility. Elyasiani and Mansur (2003) employ the bivariate GARCH methodology to investigate spillover effects of interest rates and its volatility among the banking sectors of the United States and Japan, and the United States and Germany. By estimating two sets of bivariate models, they demonstrate that bank returns are sensitive to exchange rates and interest rates, and bank stock volatilities are interdependent in the three countries. They also find the United States plays a dominant position in the interest rate volatility transmission.

Several other papers employ the multivariate GARCH model to examine interest rate transmission and volatility spillover. Fung, Jang and Lee (1997) examine interest rate transmission between domestic and offshore (Eurodollar) markets. Their major findings reveal that international interest rate transmission exists, in terms of both mean and volatility, between domestic and offshore markets. Their results also show that interest rate transmission at the mean level is rapid, and the volatility spillover process from the offshore market to U.S. market lasts longer than from U.S. market to offshore market. Their findings indicate the domestic U.S. market is more important than the Eurodollar market in terms of volatility transmission. Laopodis (2000, 2002) uses a multivariate vector moving average exponential GARCH (MVMA-EGARCH) model to examine the long-term interest rate spillover mechanism among eight countries. He finds that financial markets are strongly linked in terms of volatility since 1990, and such volatility spillover will affect the monetary policy in all markets.

Above papers indicate that interest rate transmission exists both at the mean level and volatility level. Since interest rate risk is time changing, ARCH-type framework is appropriate to analyze this issue. Detailed information about multivariate GARCH model will be discussed in next secession.

METHODOLOGY

Previous studies have found the traditional assumptions of constant variance of innovations are inappropriate for studying stock prices, interest rates and other macroeconomic variables. Fama (1965) recognized that uncertainty of speculative prices, measured by the variance and covariances, is changing over time. Campbell, Lo and Mackinlay (1997, P.481) argues that "it is both logically inconsistent and statistically inefficient to use volatility measures that are based on the assumption of constant volatility over some periods when the resulting series move through time". One tool to model time-changing variances is ARCH-type model introduced by Engle (1982) and generalized by Bollerslev (1986). In this kind of framework, the current conditional variances are affected by past conditional variances. Since the introduction of ARCH model, many research papers have applied this modeling strategy to examine financial time series data. Akgiray (1989), Engle, Lilien and Robins (1987) and Grier and Perry (1993) all find that ARCH-type model is appropriate to analyze stock return and interest rates.

To model deposit rate transmission among three countries, a multivariate GARCH model is called for. This study models the mean value (first moment) following Bollerslev's (1990) method, i.e., the log difference.

$$R_{i,t} = \log\left(\frac{d_{i,t}}{d_{i,t-1}}\right)$$

where:

$R_{i,t}$: the log difference of deposit rate of country i between time t-1 and time t

$d_{i,t}, d_{i,t-1}$: the deposit rate of country i at time t and time t-1

i: Germany, Japan and the United States

The multivariate GARCH (1,1) model here is similar to that introduced by Bollerslev (1990). The conditional variance can change over time, but the correlation remains constant. The model can be expressed in the following equations:

$$R_{1,t} = \beta_{10} + \beta_{11}R_{1,t-1} + \beta_{12}R_{2,t} + \beta_{13}R_{2,t-1} + \beta_{14}R_{3,t} + \beta_{15}R_{3,t-1} + \beta_{16}BY_{1,t} + \beta_{17}BY_{1,t-1} + \beta_{18}MM_{1,t} + \beta_{19}MM_{1,t-1} + \varepsilon_{1,t} \quad (1)$$

$$R_{2,t} = \beta_{20} + \beta_{21}R_{2,t-1} + \beta_{22}R_{1,t} + \beta_{23}R_{1,t-1} + \beta_{24}R_{3,t} + \beta_{25}R_{3,t-1} + \beta_{26}BY_{2,t} + \beta_{27}BY_{2,t-1} + \beta_{28}MM_{2,t} + \beta_{29}MM_{2,t-1} + \varepsilon_{2,t} \quad (2)$$

$$R_{3,t} = \beta_{30} + \beta_{31}R_{3,t-1} + \beta_{32}R_{1,t} + \beta_{33}R_{1,t-1} + \beta_{34}R_{2,t} + \beta_{35}R_{2,t-1} + \beta_{36}BY_{3,t} + \beta_{37}BY_{3,t-1} + \beta_{38}MM_{3,t} + \beta_{39}MM_{3,t-1} + \varepsilon_{3,t} \quad (3)$$

$$h_{11,t} = \alpha_{10} + \alpha_{11}h_{11,t-1} + \alpha_{12}\varepsilon^2_{1,t-1} + \alpha_{13}VOL_{2,t-1} + \alpha_{14}VOL_{3,t-1} \quad (4)$$

$$h_{22,t} = \alpha_{20} + \alpha_{21}h_{22,t-1} + \alpha_{22}\varepsilon^2_{2,t-1} + \alpha_{23}VOL_{1,t-1} + \alpha_{24}VOL_{3,t-1} \quad (5)$$

$$h_{33,t} = \alpha_{30} + \alpha_{31}h_{33,t-1} + \alpha_{32}\varepsilon^2_{3,t-1} + \alpha_{33}VOL_{1,t-1} + \alpha_{34}VOL_{2,t-1} \quad (6)$$

$$h_{12,t} = \rho_{12}\sqrt{h_{11}h_{22}} \quad (7)$$

$$h_{13,t} = \rho_{13}\sqrt{h_{11}h_{33}} \quad (8)$$

$$h_{23,t} = \rho_{23}\sqrt{h_{22}h_{33}} \quad (9)$$

$$\varepsilon_{i,t} \mid \Omega_{t-1} \cdots N(0, h_{ii,t})$$

In this model, country 1 = Germany, 2 = Japan, 3 = the United States.

$BY_{i,t} = \log\left(\frac{BYR_{i,t}}{BYR_{i,t-1}}\right)$, $BYR_{i,t}$ is the long-term government bond yield rate.

$MM_{i,t} = \log\left(\frac{MMR_{i,t}}{MMR_{i,t-1}}\right)$, $MMR_{i,t}$ is the money market rate.

The variable $VOL_{i,t-1}$ is the lagged conditional variance from the log difference of deposit rates, and it is calculated as a proxy for deposit rate volatility. Following Elyasiani and Mansur (1998), it is generated from a GARCH (1,1) process. Given past information set Ω_{t-1}, random error term $\varepsilon_{i,t}$ is normally distributed with conditional mean zero and time varying conditional covariance matrix H_t.

In the mean equations (equation 1 to 3), the change (log difference) of deposit rate $(R_{i,t})$ is a function of its own lag ($R_{i,t-1}$), the change of domestic money market rate ($MM_{i,t}$) and long-term bond yield ($BY_{i,t}$), and the change of deposit rates of other two countries. Lagged changes of the domestic money market rate and long-term bond yield are added to the mean function, since the money market rate and bond yield of the last period may affect current deposit rates. We also add lagged changes of other two countries' deposit rate to the mean function, to check whether the deposit rate transmission is contemporaneously or has one lag.

Elyasiani and Mansur (2003) found that transmission of risk can occur through interest rate volatility. They add the interest rate volatility variable to the volatility equation, and find risk transmissions from the United States to Germany and Japan. Thus, inclusion of deposit rate volatility in the volatility equations is important. To check for volatility spillover among three countries, we add conditional volatilities ($VOL_{i,t-1}$) of the other two countries in the volatility equations. Therefore, the deposit rate can be transmitted both in the mean level ($R_{i,t}, R_{i,t-1}$) and in volatility ($VOL_{i,t-1}$).

DATA AND HYPOTHESES

Our data consist of deposit rates, money market rates, and long-term bond yields all at monthly basis obtained from International Financial Statistics (IFS). The conditional variances of log difference of deposit rates which are generated from GARCH (1,1) acts as a proxy for deposit rate volatility. The sample period is from January, 1982 to June, 2003. This period is of major research importance, not only because EMS became stronger in this period, but also because the United States began to follow a new monetary policy. From October 1982 the Fed targeted borrowed reserves. Considering excluding the effect of recent years' financial crisis during the late 2000 on spillover effects, and a very volatile exchange rate between Yen and US dollar in the same period, we use the sample until 2003 for empirical examination.

Before we use the multivariate GARCH model to fit the deposit rate data, we must check whether such a framework is appropriate. Table 1 reports sample statistics of deposit rate data, including mean, variance, skewness, kurtosis and other test statistics. From Table 1, the skewness and kurtosis of three countries are all significantly different from zero, which indicates that we cannot accept the null hypothesis of normal distribution. Jarque-Bera statistics are also used to test the normality of the data. The Jarque-Bera statistics are large and p-values are close to zero, therefore, we conclude that these three time series cannot be approximated by the normal distribution.

The Ljung-Box Q-Statistics reject the white noise hypothesis for Germany and Japan, but not for the United States. The LM (χ^2) statistics is used to test for ARCH effects in the error terms for each log difference of deposit rate time series. Following Ender (2003), we first run an ARCH (3) model. The test statistic for the null hypothesis of no ARCH effect is TR^2, which is distributed as χ^2_3 (i.e. "3" is the number of lags). From Table 1, the null hypothesis of no ARCH effects is rejected for Japan and the United States. In other words, Japan and the United States exhibit ARCH (3) effects in their error terms.

Table 1: Sample Statistics: Change (Log Difference) of Monthly Deposit Rate

	Germany	Japan	United States
NO. of Observations	257	257	257
mean	-0.0066	-0.0152	-0.0103
variance	0.0016	0.0339	0.0030
skewness	-0.3307**	-0.8083***	-0.8814***
kurtosis	2.827***	20.693***	2.385***
Jarque-Bera	90.232***	4,613.1***	94.166***
LM(χ^2)	0.4821	10.006**	24.390***
Q(8)	15.762**	23.496***	7.782
Q(16)	27.644**	65.629***	13.086
Q(24)	51.078***	91.919***	16.785

*This table reports the summary statistics of the entire sample. Our data consist of monthly deposit rate, money market rate and long-term bond yield obtained from International Financial Statistics (IFS). The sample period is from January, 1982 to June, 2003. In the table, ** and *** represent significance at 5% and 1% levels, respectively.*

Above analyses suggest the data are nonlinear and the conditional variances are time-varying. LM test also suggests ARCH effects in the log difference of deposit rate time series. Therefore, we conclude the ARCH-type model is an appropriate framework to analyze the deposit rate series of these three countries.

Four categories of hypotheses are tested in this paper.

1. Whether the basic multivariate GARCH (1,1) model is appropriate:

The basic multivariate GARCH model is appropriate:
H_1: $\beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{16} = \beta_{17} = \beta_{18} = \beta_{19} = \beta_{21} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = \beta_{26} = \beta_{27} = \beta_{28} = \beta_{29} = \beta_{31} = \beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = \beta_{36} = \beta_{37} = \beta_{38} = \beta_{39} = \alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{14} = \alpha_{21} = \alpha_{22} = \alpha_{23} = \alpha_{24} = \alpha_{31} = \alpha_{32} = \alpha_{33} = \alpha_{34} = 0$

The variance is constant for Germany, Japan and the United States, respectively:
H_2: $\alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{14} = 0$; H_3: $\alpha_{21} = \alpha_{22} = \alpha_{23} = \alpha_{24} = 0$; H_4: $\alpha_{31} = \alpha_{32} = \alpha_{33} = \alpha_{34} = 0$

2. The domestic macroeconomic factors have effects on determining the deposit rate:

A. Long-term government bond yield:

Domestic long-term government bond yield has no effect on the deposit rate:
H_5: $\beta_{16} = \beta_{17} = \beta_{26} = \beta_{27} = \beta_{36} = \beta_{37} = 0$

Domestic long-term government bond yield has no effect on the deposit rate of Germany, Japan and the United States, respectively:

H_6: $\beta_{16} = \beta_{17} = 0$; H_7: $\beta_{26} = \beta_{27} = 0$; H_8: $\beta_{36} = \beta_{37} = 0$

B. Money market rate:

Domestic money market rate has no effect on the deposit rate:
H_9: $\beta_{18} = \beta_{19} = \beta_{28} = \beta_{29} = \beta_{38} = \beta_{39} = 0$

Domestic money market rate has no effect on the deposit rate of Germany, Japan and the United States, respectively:

H_{10}: $\beta_{18} = \beta_{19} = 0$; H_{11}: $\beta_{28} = \beta_{29} = 0$; H_{12}: $\beta_{38} = \beta_{39} = 0$

3. Log difference of deposit rate is transmitted at the mean level:

There are no spillover effects in the mean level among Germany, Japan and the United States:
H_{13}: $\beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = \beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = 0$

There is no spillover effect in the mean level from Japan to Germany:
H_{14}: $\beta_{12} = \beta_{13} = 0$

There is no spillover effect in the mean level from the United States to Germany:
H_{15}: $\beta_{14} = \beta_{15} = 0$

There is no spillover effect in the mean level from Germany to Japan:
H_{16}: $\beta_{22} = \beta_{23} = 0$

There is no spillover effect in the mean level from the United States to Japan:
H_{17}: $\beta_{24} = \beta_{25} = 0$

There is no spillover effect in the mean level from Germany to the United States:
H_{18}: $\beta_{32} = \beta_{33} = 0$

There is no spillover effect in the mean level from Japan to the United States:
H_{19}: $\beta_{34} = \beta_{35} = 0$

There are no spillover effects in the mean level from Japan and the United States to Germany:
H_{20}: $\beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = 0$

There are no spillover effects in the mean level from Germany and the United States to Japan:
H_{21}: $\beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = 0$

There are no spillover effects in the mean level from Japan and Germany to the United States:
H_{22}: $\beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = 0$

4. There are deposit rate volatility spillover effects:

There is no deposit rate volatility spillover among Germany, Japan and the United States:
H_{23}: $\alpha_{13} = \alpha_{14} = \alpha_{23} = \alpha_{24} = \alpha_{33} = \alpha_{34} = 0$

There is no deposit rate volatility spillover from Germany to Japan and the United States:
H_{24}: $\alpha_{23} = \alpha_{33} = 0$

There is no deposit rate volatility spillover from Japan to Germany and the United States:
H_{25}: $\alpha_{13} = \alpha_{34} = 0$

There is no deposit rate volatility spillover from the United States to Germany and Japan:
H_{26}: $\alpha_{14} = \alpha_{24} = 0$

There is no deposit rate volatility spillover from Japan to Germany:
H_{27}: $\alpha_{13} = 0$

There is no deposit rate volatility spillover from the United States to Germany:
H_{28}: $\alpha_{14} = 0$

There is no deposit rate volatility spillover from Germany to Japan:
H_{29}: $\alpha_{23} = 0$

There is no deposit rate volatility spillover from the United States to Japan:
H_{30}: $\alpha_{24} = 0$

There is no deposit rate volatility spillover from Germany to the United States:
H_{31}: $\alpha_{33} = 0$

There is no deposit rate volatility spillover from Japan to the United States:
H_{32}: $\alpha_{34} = 0$

RESULTS AND DISCUSSION

In this paper, a 3-variable multivariate GARCH (1,1) model is estimated using the Brendt-Hall-Hall-Hausman algorithm. The parameter estimates of the multivariate GARCH model are presented in Table 2. Table 3 reports the testing results (chi-square statistics and t-test statistics) of hypotheses described above. Our major empirical findings are mainly in following three categories: whether the multivariate GARCH model is appropriate, deposit rate transmission in terms of mean and deposit rate transmission in terms of volatility.

Table 2: Coefficient Values of Multivariate GARCH (1,1) Model

$$R_{1,t} = 0.0004 - 0.017\, R_{1,t-1} - 0.009\, R_{2,t} + 0.019\, R_{2,t-1} - 0.089\, R_{3,t} + 0.117\, R_{3,t-1} + 0.137\, BY_{1,t} + 0.105\, BY_{1,t-1} + 0.417\, MM_{1,t} + 0.411\, MM_{1,t-1} \quad (1)$$

(0.308) (-0.293) (-1.008) (1.888)* (-3.297)*** (4.628)*** (3.124)*** (2.212)** (14.228)*** (9.478)***

$$R_{2,t} = 0.0005 - 0.032\, R_{2,t-1} - 0.039\, R_{1,t} - 0.106\, R_{1,t-1} - 0.013\, R_{3,t} + 0.012\, R_{3,t-1} + 0.131\, BY_{2,t} + 0.097\, BY_{2,t-1} + 0.421\, MM_{2,t} + 0.128\, MM_{2,t-1} \quad (2)$$

(0.349) (-0.664) (-0.657) (-1.932)* (-0.304) (0.291) (6.643)*** (6.148)*** (26.573)*** (4.194)***

$$R_{3,t} = 0.001 - 0.064\, R_{3,t-1} - 0.024\, R_{1,t} - 0.069\, R_{1,t-1} - 0.008\, R_{2,t} + 0.007\, R_{2,t-1} + 0.352\, BY_{3,t} + 0.025\, BY_{3,t-1} + 0.587\, MM_{3,t} + 0.292\, MM_{3,t-1} \quad (3)$$

(0.449) (-0.705) (-0.395) (-1.054) (-0.504) (0.449) (5.574)*** (0.356) (14.481)*** (3.589)***

$$H_{11} = 0.0001 + 0.289\, h_{11,t-1} + 0.480\, \varepsilon^2_{1,t-1} - 0.00002\, VOL_{2,t-1} + 0.00001\, VOL_{3,t-1} \quad (4)$$

(1.794)* (1.878)* (3.507)*** (-1.287) (0.774)

$$H_{22} = 0.0004 + 0.066\, h_{22,t-1} + 3.398\, \varepsilon^2_{2,t-1} + 0.00009\, VOL_{1,t-1} - 0.00008\, VOL_{3,t-1} \quad (5)$$

(1.292) (2.097)** (5.820)*** (1.862)* (-2.634)***

$$H_{33} = 0.0002 + 0.196\, h_{33,t-1} + 0.339\, \varepsilon^2_{3,t-1} + 0.00010\, VOL_{2,t-1} - 0.00006\, VOL_{3,t-1} \quad (6)$$

(1.316) (0.924) (2.712)*** (1.925)* (-1.636)

*This table presents the parameter estimates of the multivariate GARCH model. The model can be expressed in equations (1)-(6). $R_{i,t}$ is the return on deposit rate of country i. $BY_{i,t}$ is the long-term government bond yield rate of country i. $MM_{i,t}$ is the money market rate of country i. $VOL_{i,t}$ is the deposit rate volatility of country i. Deposit rate volatility is measured by the conditional variances of log difference of deposit rates which are generated from GARCH (1,1). i = 1 is Germany, i = 2 is Japan, i = 3 is the United States. T-values are in the brackets. *, ** and *** represent significance at 10%, 5% and 1%, respectively.*

The results from Table 2 demonstrate the multivariate GARCH approach in determining the relationship of deposit rates among Germany, Japan and the United States is appropriate. From the volatility equations (equation 4-6), the ARCH and GARCH parameters are all significant (α_{11} is significant at 10% level, α_{21} is significant at 5% level, α_{12}, α_{22} and α_{32} are significant at 1% level) except α_{31}. In Table 3, four hypotheses regarding the appropriateness of the model are tested: the model follows a multivariate GARCH specification (H_1), and constant variances for three countries, respectively (H_2, H_3 and H_4). The results of likelihood ratio test from Table 3 reject the null hypotheses of H_2, H_3 and H_4, which indicates that

GARCH errors exist and the restricted model should be rejected. The testing results also reject the null hypothesis of H_1, therefore, the multivariate GARCH specification is appropriate for three log difference of deposit rate time series.

The mean equations (equation 1-3) include two macroeconomic factors (log difference of long-term bond yield rate and money market rate) and one lag of these two factors. From Table 2, log differences of domestic bond yield rates and money market rates have positive and statistically significant effects on the log difference of deposit rates of three countries, respectively (β_{i6}, $\beta_{i8}>0$, i=1,2,3). One lag of log difference of money market rates also has positive and significant effects on the log difference of deposit rate ($\beta_{i9}>0$, i=1, 2, 3). The estimated coefficients of one lag of log difference of long-term bond yield rate are statistically significant only for Germany and Japan (β_{17}, β_{27}), but not for the United States (β_{37}). Therefore, we expect that domestic long-term bond yield rates exert a more rapid effect on deposit rates in the United States than in Germany and Japan. This finding is not surprising, since the financial market is more developed in the United States and the information transmission process in the United States will need a shorter period.

The hypotheses regarding domestic long-term bond yield and money market rates include: H_5 is a test of joint zero domestic long-term government bond yield effect for all three countries; H_6, H_7 and H_8 are tests of zero domestic long-term government bond yield effect for each country; in the same way, H_9 is a test of joint zero domestic money market rate effect for all three countries; and H_{10}, H_{11} and H_{12} are tests of zero domestic money market rate effect for each country, respectively.

The results from Table 3 are consistent with the t-test results from Table 2. All null hypotheses of H_6 – H_{12} are rejected by the data. We conclude the domestic long-term bond yield rate and money market rate play positive and statistically significant effects on determining domestic deposit rate for Germany, Japan and the United States, respectively.

Table 3: Testing Results

Hypotheses	Results
1. The basic multivariate GARCH (1,1) model is appropriate:	
The basic multivariate GARCH model is appropriate: H_1: $\beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{16} = \beta_{17} = \beta_{18} = \beta_{19} = \beta_{21} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = \beta_{26} = \beta_{27} = \beta_{28} = \beta_{29} = \beta_{31} = \beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = \beta_{36} = \beta_{37} = \beta_{38} = \beta_{39} = \alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{14} = \alpha_{21} = \alpha_{22} = \alpha_{23} = \alpha_{24} = \alpha_{31} = \alpha_{32} = \alpha_{33} = \alpha_{34} = 0$	$\chi^2_{39} = 5{,}775.7^{***}$
The variance is constant for Germany, Japan and the United States, respectively: H_2: $\alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{14} = 0$	$\chi^2_4 = 36.658^{***}$
H_3: $\alpha_{21} = \alpha_{22} = \alpha_{23} = \alpha_{24} = 0$	$\chi^2_4 = 164.44^{***}$
H_4: $\alpha_{31} = \alpha_{32} = \alpha_{33} = \alpha_{34} = 0$	$\chi^2_4 = 39.476^{***}$
2. The domestic macroeconomic factors have effects on determining the deposit rate:	
A. Long-term government bond yield:	
Domestic long-term government bond yield has no effect on the deposit rate: H_5: $\beta_{16} = \beta_{17} = \beta_{26} = \beta_{27} = \beta_{36} = \beta_{37} = 0$	$\chi^2_6 = 170.29^{***}$
Domestic long-term government bond yield has no effect on the deposit rate of Germany, Japan and the United States, respectively: H_6: $\beta_{16} = \beta_{17} = 0$	$\chi^2_2 = 20.041^{***}$
H_7: $\beta_{26} = \beta_{27} = 0$	$\chi^2_2 = 93.265^{***}$
H_8: $\beta_{36} = \beta_{37} = 0$	$\chi^2_2 = 42.828^{***}$
B. Money market rate:	
Domestic money market rate has no effect on the deposit rate: H_9: $\beta_{18} = \beta_{19} = \beta_{28} = \beta_{29} = \beta_{38} = \beta_{39} = 0$	$\chi^2_6 = 1{,}488.3^{***}$

Domestic money market rate has no effect on the deposit rate of Germany, Japan and the United States, respectively: H_{10}: $\beta_{18} = \beta_{19} = 0$	$\chi_2^2 = 301.44$***
H_{11}: $\beta_{28} = \beta_{29} = 0$	$\chi_2^2 = 745.21$***
H_{12}: $\beta_{38} = \beta_{39} = 0$	$\chi_2^2 = 257.65$***
3. Log difference of deposit rate is transmitted at the mean level:	
There are no spillover effects in the mean level among Germany, Japan and the United States: H_{13}: $\beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = \beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = 0$	$\chi_{12}^2 = 41.657$***
There is no spillover effect in the mean level from Japan to Germany: H_{14}: $\beta_{12} = \beta_{13} = 0$	$\chi_2^2 = 5.446$*
There is no spillover effect in the mean level from the United States to Germany: H_{15}: $\beta_{14} = \beta_{15} = 0$	$\chi_2^2 = 22.488$***
There is no spillover effect in the mean level from Germany to Japan: H_{16}: $\beta_{22} = \beta_{23} = 0$	$\chi_2^2 = 7.708$**
There is no spillover effect in the mean level from the United States to Japan: H_{17}: $\beta_{24} = \beta_{25} = 0$	$\chi_2^2 = 0.148$
There is no spillover effect in the mean level from Germany to the United States: H_{18}: $\beta_{32} = \beta_{33} = 0$	$\chi_2^2 = 2.177$
There is no spillover effect in the mean level from Japan to the United States: H_{19}: $\beta_{34} = \beta_{35} = 0$	$\chi_2^2 = 0.529$
There are no spillover effects in the mean level from Japan and the United States to Germany: H_{20}: $\beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = 0$	$\chi_4^2 = 25.910$***
There are no spillover effects in the mean level from Germany and the United States to Japan: H_{21}: $\beta_{22} = \beta_{23} = \beta_{24} = \beta_{25} = 0$	$\chi_4^2 = 7.804$*
There are no spillover effects in the mean level from Japan and Germany to the United States: H_{22}: $\beta_{32} = \beta_{33} = \beta_{34} = \beta_{35} = 0$	$\chi_4^2 = 2.606$
4. There are deposit rate volatility spillover effects:	
There is no deposit rate volatility spillover among Germany, Japan and the United States: H_{23}: $\alpha_{13} = \alpha_{14} = \alpha_{23} = \alpha_{24} = \alpha_{33} = \alpha_{34} = 0$	$\chi_6^2 = 13.143$**
There is no deposit rate volatility spillover from Germany to Japan and the United States: H_{24}: $\alpha_{23} = \alpha_{33} = 0$	$\chi_2^2 = 7.086$**
There is no deposit rate volatility spillover from Japan to Germany and the United States: H_{25}: $\alpha_{13} = \alpha_{34} = 0$	$\chi_2^2 = 4.308$
There is no deposit rate volatility spillover from the United States to Germany and Japan: H_{26}: $\alpha_{14} = \alpha_{24} = 0$	$\chi_2^2 = 7.722$**
There is no deposit rate volatility spillover from Japan to Germany: H_{27}: $\alpha_{13} = 0$	T-stat = -1.287
There is no deposit rate volatility spillover from the United States to Germany: H_{28}: $\alpha_{14} = 0$	T-stat = 0.774
There is no deposit rate volatility spillover from Germany to Japan: H_{29}: $\alpha_{23} = 0$	T-stat = 1.862*
There is no deposit rate volatility spillover from the United States to Japan: H_{30}: $\alpha_{24} = 0$	T-stat = -2.634***
There is no deposit rate volatility spillover from Germany to the United States: H_{31}: $\alpha_{33} = 0$	T-stat = 1.925*
There is no deposit rate volatility spillover from Japan to the United States: H_{32}: $\alpha_{34} = 0$	T-stat = -1.636

*Table 3 reports the testing results (chi-square statistics and t-test statistics) of hypotheses. *, ** and *** represent significance at 10%, 5% and 1%, respectively.*

To test for deposit rate transmission effects in the first moment (the mean), the deposit rates of other two countries are included in the mean equations (equation 1-3) of the multivariate GARCH (1,1) model. Because there may be lags in the transmission process, we also add one lag of the log difference of deposit rates in the mean functions. In Table 3, the likelihood ratio testing result for hypothesis H_{13} indicates there are deposit rate transmission effects in the mean level among Germany, Japan and the United States. Hypotheses $H_{14} – H_{19}$ test the unidirectional transmission effects within the three countries. The likelihood ratio testing results from Table 3 are consistent with the t-test results from Table 2, i.e., changes of deposit rate in Japan positively affect the deposit rate in Germany ($\beta_{13}>0$), and changes of deposit rate in Germany have a statistically significant negative effect on the deposit rate of Japan ($\beta_{23}<0$). It seems that with the increase of deposit rates in Japan, Germany banks have to bid up its deposit rates to prevent capital outflow. But as the deposit rate in Germany increase, the deposit rate of Japan does not correspondingly increase. One explanation is that Germany depositors understand the higher risk they are accepting for higher return. Thus, they switch their funds to safe banks in Japan. The suppliers of capital increase in Japan, and the deposit rate decrease. Another explanation may be some barriers or transfer costs in Japan that make transferring capital to Germany undesirable.

There exists one lag of the deposit rate transmission from Japan to Germany and from Germany to Japan (β_{13} and β_{23} are statistically significant, but β_{12} and β_{22} are not). This finding is consistent with Fung and Lo (1995). They found interest rate transmission at the mean level is rapid, and it takes weeks to complete the transmission process. Current and one lag of deposit rates of the United States both affect the deposit rate of Germany. Information from the United States is transmitted faster.

The test results of hypotheses $H_{20} – H_{22}$ show there are deposit rate transmissions from Japan and the United States to Germany, and from Germany and the United States to Japan, but the log difference of deposit rate of the United States is not affected by that of the other two countries in the mean level. Consistent with the findings above, there are deposit rate transmissions within three countries, and it seems that the deposit rate of United States is independent of the other two, in terms of the deposit rate transmission.

Although the spillover effects of interest rate volatility are important and necessary, there are only few papers examining this topic. For example, Elyasiani and Mansur (1998) investigate the effect of interest rate volatility on the bank stock return using a GARCH-M model. Another research of Elyasiani and Mansur (2003) examine the spillover effects of interest rate volatility among the banking sectors using two bivariate GARCH model. Fung et al. (1997) have found that the international interest rate transmission is more pervasive in terms of the volatility than in terms of the mean.

From the testing result of hypothesis H_{23}, we know that there are deposit rate volatility spillover effects among Germany, Japan and the United States. To find the direction and magnitude of the transmission, we conduct the hypotheses testing with null hypotheses $H_{24} – H_{32}$. According to the results of hypotheses $H_{24} – H_{26}$, we find that the deposit rate volatility generated in Germany will be transmitted to Japan and the United States, and that generated in the United States will also be transmitted to Germany and Japan. But a Japanese shock will not be transmitted to Germany and the United States. When examining the direction of the transmission ($H_{27} – H_{32}$), we find that deposit rate spillover is from Germany to Japan, from the United States to Japan, and from Germany to the United States. It seems that the deposit rate of Germany is independent of the deposit rate of Japan and the United States in terms of volatility spillover effects. This finding is inconsistent with the result from Laopodis (2000) who found that Japanese interest rate shocks impact the interest rate of 7 countries, including Germany and the United States, and the United States rate does not seem to generate volatility in the Japanese interest rate. The inconsistency exists because their framework includes eight countries, and their sample includes different data.

Based on the directions of deposit rate volatility spillover, it seems the Germany economy is somewhat in the leading position. This finding is explainable regarding the sample period of this paper: 1982–2003. In this period, the European Monetary System (EMS) became greatly integrated. Monetary policy within the EMS became closely coordinated and more influential in the world. As the strongest economy in this system, the Germany economy is the representative and its deposit rate risk has a strong effect on the other countries. Another scenario may be that German banks can offer more diversified products in a universal banking system, which helps to prevent deposit rate risk exposure from other countries. This finding is inconsistent with Elyasiani and Mansur (2003). They found the United States plays a leadership role. The difference exists because they examine interest rate volatility spillover effects on bank stock returns, and we investigate the deposit rate spillover effects between three countries. On the other hand, we use a multivariate GARCH framework, and they use two bivariate GARCH models.

It is interesting that the increased deposit rate volatility in the United States can moderate the volatility in Japan. One explanation may be the existence of U.S. branches of Japanese parent banks. When the deposit rate volatility increases in the United States, these banks know the risk first. The information will be transmitted to their Japanese parent banks immediately. The Japanese parent banks take steps to reduce their risk exposure. Other banks in Japan will mimic their actions. Thus, the total deposit rate volatility in Japan will be moderated. At the same time, when deposit rate volatility in the United States increases, risk-averse depositors of U.S. banks will put their money in Japanese banks. With more customers and more safe funds, the deposit rate volatility in Japan will be somewhat lower.

CONCLUDING COMMENTS

This paper examines spillover effects of deposit rates among Germany, Japan and the United States. This issue is of major importance because the financial market has become more integrated in the recent three decades. In a generalized framework, we also investigate whether deposit rates are affected by macroeconomic variables. The empirical findings indicate that deposit rates are sensitive to such macroeconomic variables as money market rate and long-term government bond yield.

Using a multivariate GARCH (1,1) model, we examine deposit rate transmission and deposit rate volatility spillover. At the mean level, deposit rate transmission is from Japan and the United States to Germany and from Germany to Japan. There are bidirectional transmissions between Japan and Germany. The deposit rate of United States is not affected by the other two countries. In terms of deposit rate transmission at the mean level, no country is exogenous and no country plays a leading role. At the volatility level, the spillover is from Germany to Japan, from the United States to Japan, and from Germany to the United States. Increased deposit rate volatility moderates the volatility in the United States, and the increased deposit rate volatility in Germany generates increased volatility in Japan and the United States, but vice verse does not exist. Therefore, in terms of the deposit rate volatility spillover effects, Germany is exogenous and independent of the deposit rates of Japan and the United States. This finding is inconsistent with the results in terms of the mean transmission.

Our results suggest inconsistent deposit rate spillover effects at the mean level and at the volatility level. The limitation and future research should examine the underlying reason of this inconsistence and further work on related empirical examinations.

REFERENCES

Akgiray, V., (1989), Conditional Heteroscedasticity in Time Series of Stock Returns: Evidence and Forecasts. *Journal of Business*, 62, 55-80.

Bollerslev, T., (1986), Generalized Autoregressive Conditional Heteroskedasticity. *Journal of Econometrics*, 31, 307-327.

Bollerslev, T., (1990), Modelling the Coherence in Short-Run Nominal Exchange Rates: a Multivariate Generalized ARCH Model. *Review of Economics and Statistics*, 72, 498-505.

Campbel, J.Y., Lo, A.W. and MacKinlay, A.C., (1997), The Econometrics of Financial Markets. *Princeton University Press.*

Choi, J., Elyasiani, E. and Kopecky K.J., (1992), The Sensitivity of Bank Stock Returns to Market, Interest and Exchange Rate Risk. *Journal of Banking and Finance*, 16, 983-1004.

Elyasiani, E. and Mansur, I., (1998), Sensitivity of the Bank Stock Returns Distribution to Changes in the Level and Volatility of Interest rate: a GARCH-M Model. *Journal of Banking and Finance*, 22, 535-563.

Elyasiani, E. and Mansur, I., (2003), International Spillover of Risk and Return among Major Banking Institutions: a Bivariate GARCH Model. *Journal of Accounting, Auditing and Finance*, 18, 303-302.

Engle, R.F., (1982), Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica*, 50, 987-1007.

Engle, R.F., Lilien, D.M. and Robins, R.P., (1987), Estimating Time Varying Risk Premia in the Term Structure: the ARCH-M Model. *Econometrica*, 55, 391-407.

Fama, E.F., (1965), The Behavior of Stock Market Prices. *Journal of Business*, 38, 34-105.

Flannery, M.J., Hameed, A.S. and Harjes, R.H., (1997), Asset Pricing, Time-Varying Risk Premia and Interest Rate Risk. *Journal of Banking and Finance*, 21, 315-335.

Fung, H.G., Jang, H. and Lee, W., (1997), International Interest Rate Transmission and Volatility Spillover. *International Review of Economics and Finance*, 6, 67-75.

Fung, H.G. and Lo, W.C., (1995), An Empirical examination of the Ex Ante Interest Rate transmission. *Financial Review*, 30, 175-192.

Grier, K.B. and Perry, M.J, (1993), The Effect of Money Shocks on Interest Rates in the Presence of Conditional Heteroskedasticity. *Journal of Finance*, 48, 1445-1455.

Hu, M.Y., Jiang, C.X. and Tsoukalas, C., (2004), The Volatility Impact of the European Monetary System on Member and Non-Member Currencies. *Applied Financial Economics*, 14, 313-325.

Karfakis, C.J., and Moschos, D.M., (1990), Interest Rate Linkages within the European Monetary System: a time series analysis. *Journal of Money, Credit and Banking*, 22, 388-394.

Katsimbris, G.M., and Miller, S.M., (1993), Interest Rate Linkages within the European Monetary System: Further Analysis. *Journal of Money, Credit and Banking*, 25, 771-779.

Kearney, C., and Patton, A.J., (2000), Multivariate GARCH Modeling of Exchange Rate Volatility Transmission in the European Monetary System. *The Financial Review*, 41, 29-48.

Kirchgassner, G. and Wolters, J., (1987), US-European Interest Rate Linkage: a Time Series Analysis for West Germany, Switzerland and the United States. *Review of Economics and Statistics*, 69, 675-684.

Kirchgassner, G. and Wolters, J., (1993), Does the DM Dominate the Euro Market? An Empirical Investigation. *Review of Economics and Statistics*, 75, 773-778.

Laopodis, N.T., (2000), Monetary Policy Implications of Volatility Linkages among Long-Term Interest Rates. *Journal of Economics and Finance,* 24, 160-177.

Laopodis, N.T., (2002), Volatility Linkages among Interest Rates: Implications for Global Monetary Policy. *International Journal of Finance and Economics,* 7, 215-233.

Levin, J.H., (1974), The Eurodollar Market and the International Transmission of Interest Rates. *Canadian Journal of Economics*, 7, 205-224.

Ross, S., (1989), Information and Volatility: the No-arbitrage Martingale Approach Timing and Resolution Irrelevancy. *Journal of Finance,* 44, 1–17.

Song, F.M., (1994), A Two-Factor ARCH Model for Deposit-Institution Stock Returns. *Journal of Money, Credit and Banking*, 26, 323-340.

Wetmore, J.L. and Brick, J.R., (1994), Commercial Bank Risk: Market, Interest Rate, and Foreign Exchange. *Journal of Financial Research,* 17, 585–596.

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