Interactions of Spot Foreign Exchange Markets among Taiwan, Hong Kong and Japan: Japanese Forward Premium/Discount as an Information Variable

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ABSTRACT

This study takes the foreign exchange rates of Taiwan, Hong Kong and Japan as the research issue, and utilises the VEC GJR-Asymmetric GARCH model to analyse the interaction among spot exchange rates of these three countries. The empirical results prove that the average returns of all foreign exchange markets have their own- and cross-spillovers, and the volatility of the return rate exists ARCH and /or GARCH effects. In addition, using Japanese forward premium/discount as information variable, empirical results find that Japanese forward premium/discount have important explanatory power for the links of Taiwan, Hong Kong, and Japanese spot exchange rates, and the original volatility spillover effect has disappeared, indicating that Japanese forward premium/discount is indeed an information variable. In terms of the volatility asymmetry effect, the results show that the estimated coefficients of asymmetry in Taiwan and Japan are positively significant, indicating that under the impact of bad news, their own market volatilities will be greater than good news. We also justify that the foreign exchange rates of Taiwan and Hong Kong, Taiwan and Japan, and Hong Kong and Japan are more closely linked to each other in the face of the two major events. The US-China trade war and the COVID-19 outbreak have triggered risk contagion, with a crisis in one country quickly spreading to another, intensifying the link between the foreign exchange markets of Taiwan, Hong Kong, and Japan. Our findings may help investors and policymakers find responses to such foreign exchange market turbulence.

KEYWORDS: *foreign exchange market, forward premium/discount, VEC GJR-asymmetric GARCH model, US-China trade war, COVID-19 pandemic.*

JEL CLASSIFICATION: *F30, G10, G13, G19.*

1. INTRODUCTION

Today, with the rapid development of technology and the intensive development of communication networks, the economic pulses of Taiwan and other countries in the world have been integrated and become globalised. However, there are differences in economic growth rates, interest rates, product price levels, stock market performance, trade conditions, and political situations between Taiwan and other countries. Therefore, the exchange rates of various countries are affected by macroeconomic and international factors, and there are considerable differences and changes. For domestic and foreign investors, because the exchange rate linkage between countries has increased, strategies to avoid exchange rate risks and strengthen investment or trading transactions usually consider the relationship between the exchange rates of countries or holding other countries' currencies. In order to strengthen the effectiveness of Taiwanese or other investors in hedging, price discovery and arbitrage from exchange rate markets, it is necessary to understand the interactions between Taiwan

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and other countries' exchange rates. Therefore, exploring the relationships between Taiwan and other countries' exchange rates has become an important research topic of this study.

According to the latest statistics (2018) from Taiwan's government agency, Japan is still Taiwan's largest importer, and its trade deficit with Japan exceeds US$ 20,750 million. Therefore, the exchange rate interaction between Taiwan and Japan has a profound impact on the profitability of Taiwan importers. In addition, Hong Kong and Mainland China are Taiwan's largest export regions with a value of US$ 180,244.19 million. Therefore, the exchange rate interaction between Taiwan and Japan, or between Taiwan and Hong Kong is also an important indicator for Taiwan exporters to affect their benefits. However, the RMB in mainland China is not a freely convertible currency. If an enterprise opens an account in mainland China, it is easy to buy RMB, but it may not be easy to convert it into foreign currency, and the capital flow is rather inconvenient, which is the potential risk of RMB. Therefore, the target foreign exchange markets selected in this study are the foreign exchange markets in Taiwan, Hong Kong, and Japan.

In addition, this study aims to understand how information intervention in the foreign exchange market will have an interactive impact on the exchange rates of other countries. It uses Japan's forward exchange rate premium/discount $(F_t - S_t)$ as representative variable of the information response. In order to understand whether the interaction between the foreign exchange market returns of these countries and the volatility spillover effect is contagious due to the intervention of the Japanese foreign exchange market, that is, to understand the interaction of the spot exchange rates of these countries, the correlation of the Japanese foreign exchange market can be directly used. This information can predict the causality of the exchange rates of these countries and the rate of return or volatility in the foreign exchange market.

Table 1. Statistics on Foreign Exchange Transactions of the Bank for International Settlements

Foreign exchange turnover by instrument, counterparty and currency in April 2022					
	Total	**Japan**	**Hong Kong**	**Taiwan**	**Other Areas**
Spot transactions	3,002,893	148,722	134,180	151,169	2,568,822
Buy-out and Sell-off forward transactions	1,444,462	62,391	74,606	1,785	1,305,680
Total	4,447,355	211,113	208,786	152,954	3,874,502
percentage	100.00%	4.75%	4.69%	3.44%	87.12%

Source: Bank for International Settlements (BIS), see the website: https://www.bis.org/statistics/rpfx22.htm?m=2677

Note: Total reported transactions in all currencies (daily averages, in millions of US dollars)

Table 1 is taken from the latest statistics of foreign exchange transactions published by the Bank for International Settlements in 2022. It can be seen from the table that the daily average Japanese foreign exchange trading volume accounts for 4.75% of the world's foreign exchange market trading volume, while Hong Kong and Taiwan's foreign exchange trading volume accounted for 4.69% and 3.44 %, respectively. Compared with the foreign exchange markets of Hong Kong and Taiwan, the trading volume of the Japanese foreign exchange market is relatively ahead. Furthermore, foreign exchange transactions will cause relative fluctuations in the spot and forward exchange rates. The Japan's forward exchange rate premium/discount $(F_t - S_t)$ can predict the direction of change in the future spot exchange rate, and also Japan's exchange rate also plays a leading role in currency trends across Asia

(Han, Wang and Xu, 2020). Therefore, in addition to exploring the interaction of Taiwan, Hong Kong, and Japan's spot exchange rates, this study intends to add Japan's forward exchange rate premium/discount $(F_t - S_t)$as an explanatory variable to verify whether Japan's foreign exchange rate premium/discount on Taiwan, Hong Kong and Japan's foreign exchange markets is the information variable and its impacts on Taiwan, Hong Kong, and Japan's spot exchange rates since forward exchange rate premium/discount may indicate the way a market expects the exchange rate to move in the future (Goodhart, et al., 1992; Zivot, 2000; Cho and Chun, 2019).

In view of the early days, the correlation coefficients are generally used to explore the relationship between foreign exchange markets in various countries. However, Fama (1965) proposed the phenomenon of volatility clusters in financial market returns, that is, when time series data has greater volatility, greater volatility usually follows. Conversely, if the time series produces less volatility, it is usually accompanied by less volatility. This situation reflects that past capital returns volatility will affect future volatility. This is different from the traditional calculation assuming that the error term has constant variance. Therefore, Engle (1982) proposed the auto-regressive conditional hydroelectricity (ARCH) model, setting the conditional variance of time series affected by the previous square of its error term. That is, the volatility will be impacted by the past shocks.

Subsequently, Bollerslev (1986) pointed out the generalised autoregressive conditional heteroscedasticity (GARCH) model, and believed that the previous conditional variances should be added to the ARCH model as an explanatory variable. However, the GARCH model takes into account the change of conditional volatility, which only changes with the size of the residual term, and does not change with the sign of the residual term, Thus, the GARCH model cannot reflect that positive and/or negative news have the same predictive power for volatility, resulting in a low predictive power for volatility. In order to accurately assess exchange rate fluctuations, some researchers have developed models that can capture the effects of volatility asymmetry in response to volatility, such as, firstly, Engle and Ng (1993) and, in recent years, Ali (2013), Harvey and Sucarrat (2014), Ajayi and Nageri, (2016), Mouna and Anis (2016), Harvey and Lange (2018), Ma et al. (2020), and Liu et al., (2023) applied EGARCH, AGARCH, NGARCH, VGARCH, TGARCH and GJR-GARCH models, etc., to reflect the impact of good or bad news on exchange rate fluctuations.

After testing several volatility asymmetry models, this study found that the GJR-Asymmetric GARCH model has a better response, the GJR-GARCH model is applied as the basis for empirical analysis. In addition, if there is a co-integration relationship between variables, it can be known from the representation theorem of Engle and Granger (1987) that there must be a vector error correction model (VECM) corresponding to it. The meaning of the vector error correction model is to add the error correction term (ECT) of the long-run relationship into the vector autoregressive model, which can make the variable deviate from the long-run equilibrium due to external shocks, and then use the error correction term to gradually adjust to the long-run equilibrium. Therefore, the VEC GJR-Asymmetric GARCH model is used to analyse the interaction of spot exchange rates in Taiwan, Hong Kong, and Japan. Furthermore, we incorporate two structural break events (the US-China trade war and the COVID-19 pandemic) into our modelling system for these three foreign exchange markets to examine their impacts on these three markets during the study period.

The remaining of the study is organised as follows. Section 2 reviews the relevant theoretical foundations of this study. Section 3 discusses the empirical results and implications while model setups is also described in this section. Section 4 presents the concluding remarks.

2. THEORETICAL FOUNDATIONS

The relevant theoretical explanations for the model construction and empirical results of this study are as follows:

2.1 Theoretical Foundation of International Indebtedness

Goschen (1901) developed the theory of balance of payments based on the exchange rate theory of Smith (1776) and Ricardo (2004). This theory advocates that if there is a surplus in the balance of payments, the currency will appreciate; if there is a deficit, the currency will weaken. The factors that affect the amount of currency purchases of both sides include: (1) The price of domestic products is expensive or low relative to other countries' products. (2) The real personal income levels of the two nations. In addition, changes in consumption habits, resource endowments or accumulations, technological development, crop harvest conditions, and even strikes, changes in market structure or commercial policies, etc., will also affect the supply and demand of foreign exchange. Secondly, the theory of international balance of payments believes that the difference in short-term interest rates between the two countries will cause international capital movements and affect the supply and demand of foreign exchange. However, in practice, exchange rate changes are not so simple, and raising interest rates does not necessarily produce a net inflow of funds. To be correct, the interest rate that the central bank can adjust is only the nominal interest rate, and countries with higher real interest rates can attract capital inflows and make their currencies appreciate (the so-called real interest rate is the nominal interest rate minus the inflation rate). In short, even if country B adjusts its interest rate higher than that of country A, if the interest earned by depositors cannot offset the asset shrinkage caused by rising prices, the funds will still not flow into country B.

2.2 Theoretical Foundation of Interest Rate Parity (IRP)

The theory of interest rate parity was first proposed by Keynes (1923). This theory believes that the difference in interest rate levels directly affects the flow of short-term capital in the world, causing exchange rate fluctuations. In order to obtain higher returns, investors will shift their funds from countries with lower interest rates to countries with higher interest rates. The inflow of funds will increase the exchange rate of countries with higher interest rates. Keynes's theory explains that the difference in interest rates in the currency market is the same as the relationship between immediate and forward exchange rates. In fact, the derivation process of the forward exchange rate also applied the theory of interest rate parity. If interest rates in the United States are higher than those in Japan, the yen will depreciate against the US dollar, and the extent of the depreciation will be determined by risk-free arbitrage. The future exchange rate will be reflected in the forward exchange rate specified on the day.

The theory of interest rate parity breaks through the scope of the traditional theory of international payments and price levels. It studies exchange rate changes from the perspective of capital flow, laying the foundation for modern exchange rate theory. It can be divided into covered IRP and uncovered IRP, which are expressed in equations (1) and (2) respectively.

$$\gamma_t - \gamma_t^* \cong \pi \tag{1}$$

$$\gamma_t - \gamma_t^* = \frac{F_{t+1}\text{-}S_t}{S_t} = \frac{E_t(S_{t+1})\text{-}S_t}{S_t} \tag{2}$$

where
F_t: The forward exchange rate of period t,
S_t: The spot exchange rate of period t,
γ_t: The domestic interest rate of period t,
γ_t^*: The foreign exchange rate of period t,
π: The forward premium or discount, and
$E_t(S_{t+1})$: The expected value of spot exchange rate at period t+1 formed at period t.

Equation (1) shows that in the case of an effective capital market and no trade barriers, the interest rate gap between the two countries should be equal to the forward premium or discount (π) of the currencies of the two countries. If an imbalance occurs, the exchange rate between the two countries will be re-adjust until it returns to an equilibrium state. Equation (2) shows that under an efficient exchange rate market and rational expectations, the investment behaviour of the exchange rate market will make the interest rate gap between the two countries equal to the expected value of the exchange rate changes between the two countries over a period of time. This also implies that the forward exchange rate is an unbiased estimate of the future spot exchange rate.

2.3 Theoretical Foundation of Purchasing Power Parity (PPP)

Purchasing power parity theory was put forward by Cassel (1916), who pointed out that the exchange rate of the two currencies is mainly determined by the purchasing power of the two currencies. It is divided into absolute purchasing power parity (absolute PPP) and relative purchasing power parity (relative PPP). Absolute purchasing power parity believes that the value of a country's currency and the demand for it are determined by the amount of goods and services that can be purchased in the country per unit of currency, that is, by its purchasing power. Therefore, the exchange rate between the two currencies can be expressed as the ratio of the purchasing power of the two currencies. The size of purchasing power is revealed through the price level. Through this relationship, the increase in domestic prices will mean the depreciation of the domestic currency relative to the foreign currency. Equation (3) is the exchange rate determination method based on absolute purchasing power parity.

$$R = \frac{P}{P^*} \tag{3}$$

where
P: The price of a basket of commodities in the domestic country, denominated in the domestic currency.
P*: The price of a basket of foreign commodities, denominated in foreign currencies.
R: The foreign exchange rate (the domestic country to foreign country).

Relative purchasing power parity theory makes up for some shortcomings of absolute purchasing power parity theory. The main point of view can be expressed simply as follows: The exchange rate levels of the two currencies will be adjusted accordingly according to the difference in inflation rates between the two countries. It means that the relative inflation between the two countries determines the equilibrium exchange rate between the two currencies. For example, if a delicious crab castle is worth US$ 2.00 in the United States and 1.00 Euro in Europe, according to the theory of purchasing power parity, the exchange rate must be US$ 2 to 1 Euro. If the prevailing exchange rate in the market is US$ 1.7 to 1 euro, then the euro is undervalued, and the US dollar is overvalued. This theory assumes that the two currencies will eventually adjust towards a 2:1 relationship.

$$\Delta P_{t+1} - \Delta P^{*}_{t+1} = \frac{E_{t+1} - E_t}{E_t} \quad (4)$$

Where ΔP *and* ΔP^{*} are the price inflation rates at time t+1 for domestic and foreign countries and E is foreign exchange rate. Compared with the absolute purchasing power parity theory, the relative purchasing power parity theory adds the psychological component of anticipation. From the macroeconomic point of view, the purchasing power parity theory reasonably explains the basis for determining exchange rates. Even now, according to the researches of Gil-Alana and Carcel (2020), Boundi-Chraki and Mateo Tomé (2022), and Frömmel et al. (2022), since purchasing power parity theory is an important theme in monetary models of exchange rate determination, many papers on exchange rate in international trade and economy still involve the verification and application of purchasing power parity theory. Although it ignores the impact of other factors such as international capital flows on the exchange rate, the central bank still has an important role in calculating the basic ratio between currencies. Because the difference between the basic exchange rates calculated from purchasing power and the actual market exchange rate can determine the degree of deviation of the foreign exchange rate from the basic exchange rate. It is an important method for predicting long-term exchange rates. This doctrine is still valued by Western economists, and is still a mathematical model widely used to predict exchange rate movements in fundamental analysis.

3. ESTIMATION RESULTS AND DISCUSSIONS

This study tries to examine the interactions among Taiwan, Hong Kong, and Japanese spot exchange rates, especially including Japanese forward premiums/discounts as an information (intermediary) variable to examine the intervention effect and changes in the interactions between Taiwan, Hong Kong, and Japanese spot exchange rates. The sample period is from January 3, 2009 to December 31, 2022. Before establishing the empirical model, this research first conducts some verification analysis on the series of data to find an appropriate model fit.

3.1 ADF Unit Root Test

Before discussing the co-integration relationship between Taiwan, Hong Kong, and Japanese spot exchange rates, it is necessary to determine whether the integration order among variables is one, that is, the I (1) time series, so unit root test must be performed firstly. This research mainly uses the ADF unit root test method to verify whether a variable is a stationary time series. If the test result has a unit root, it means that the series of the variable is in a non-stationary, and must be converted to a stationary series through differencing, and then continue to verify the stationarity of variable after the differencing. If the existence of a unit root is rejected, the series of this variable can be regarded as I (1) feature. It is necessary to determine the number of lagging periods before performing unit-root test. This is due to the inconsistency of estimation caused by insufficient selection of the number of lagging periods when unit-root test is performed, compared to the problem of insufficient degrees of freedom caused by selecting too long lagging periods serious. Therefore, this study adopts the AIC (Akaike, 1969) to select the optimal number of lagging periods and takes into account the problem of residual term correlation.

Table 2 shows the results of the ADF test for the original, logarithmic and return rates series for spot exchange rates of Taiwan, Hong Kong and Japan, as well as Japanese forward premium/discount. From Table 2, it can be found that the original series of spot exchange rates in the three foreign exchange markets, the series after taking the logarithm, and the series of Japanese forward premium/discount cannot reject the null hypothesis (i.e., there is a unit root), which means that they are all non-stationary series. Next, this study converts the logarithm of the spot exchange rate and the Japanese forward premium/discount data into the return type by the first-order difference.

Table 2. Results of Unit Root Tests for Spot Exchange Rates of Taiwan, Hong Kong and Japan as well as Japanese Forward Premiums/Discounts

Spot Exchange Rates				
		With Intercept Term	**With Intercept and Trend**	**Without Intercept nor Trend**
Original Series	Taiwan	-2.0125[5]	-1.7981[5]	-0.61575[5]
	Hong Kong	-2.1542[7]	-2.1125[7]	0.2321[7]
	Japan	-1.7736[1]	-2.3214[1]	0.1217[1]
Logarithmic Series	Taiwan	-1.2135[5]	-1.8251[5]	-0.6012[5]
	Hong Kong	-2.1123[7]	-2.2261[7]	0.2428[7]
	Japan	-1.7782[1]	-2.2571[1]	0.1625[1]
Return Series	Taiwan	-36.4121***[1]	-36.6712***[1]	-36.2125***[1]
	Hong Kong	-36.0021***[1]	-36.0354***[1]	-36.1178***[1]
	Japan	-35.2402***[1]	-35.0001***[1]	-35.2241***[1]
Japanese Forward Premium/Discount				
Original Series		-0.7021[3]	-2.0184 [3]	0.8921[3]
First Difference		-24.102***[1]	-24.1172***[1]	-24.1130***[1]

Notes: 1. The values in [.] are the most fitting lags determined by the Akaike information criterion (AIC) criterion.
2. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

The ADF unit-root test was performed again, and it was found that the spot exchange rate return series of the Taiwan, Hong Kong and Japan foreign exchange markets and the differenced Japanese forward premium/discount all reject the null hypothesis at the 1% significance level in three unit-root test models. It means that all series of exchange rate returns and the differenced Japanese forward premium/discount have met the characteristics of the stationary series, that is, they all have the same I (0) integration order. We can conclude that unit roots exist in all original series by natural logarithm transformation and these variables are integrated of order one, I (1) process.

3.2 Johansen co-integrated Test and Error Correction Model

According to the above unit-root test results, it can be known that the time series of the spot exchange rates in Taiwan, Hong Kong and Japan after logarithmic transformation are all I (1). They have the same order of integration, and there may be a long-run co-integration relationship between the series. After taking the logarithm of these series, we conduct co-integration analysis on the exchange rates of Taiwan, Hong Kong and Japan. If there is a co-integration relationship, it can be converted into a stationary series from the linear combination of various variables. It is no longer necessary to conduct a co-integration analysis of the differential action on the log-transformed time series to avoid losing the long-run equilibrium relationship due to differences. In this study, Trace and Max-eigenvalue tests proposed by Johansen (1991) are used to determine the number of co-integration vectors, and then maximum likelihood estimation (MLE) is used to estimate the parameters of the co-integration vectors (Johansen and Jusselius, 1990).

Table 3 shows the results of Johansen's co-integration tests (Trace and Maximum Eigenvalue test). Both test results reject the null hypothesis that the number of co-integrating vectors is zero and accept the null hypothesis that the number of co-integrating vectors is 1. This means that there is a long-run co-integration relationship in the time series of the spot exchange rates of Taiwan, Hong Kong and Japan after logarithmic transformation, that is, there is a co-movement or linkage trend. Indicating that long-run equilibrium relationship for multinational investors, if there is a spillover effect between returns in the foreign exchange market, it will increase non-systematic risks and reduce the benefits of diversification of international asset portfolios, so that the effect of risk diversification is relatively small. Following the above, this study uses the MLE method to estimate the parameter value of the co-integration vector. Table 3 also shows the co-integration relationship of Taiwan, Hong Kong and Japan spot exchange rates after taking the logarithm, and an error correction term Z_t can be established as follows:

$$Z_t = \text{tlog}_t + .04131\ \text{jlog}_t - 3.8871\ \text{hlog}_t + 1.5426 \quad (5)$$

Where tlog_t, jlog_t and hlog_t represent the spot exchange rate of Taiwan, Japan, and Hong Kong after the logarithmic transformation at the time t.

Table 3. Johansen co-integration Tests

Unrestricted Co-integration Rank Test (trace)			
Hypothesized	Eigenvalue	Trace Statistic	5% Critical Value
None **	0.0312	46.1172	35.1928
At most 1	0.0162	19.1178	20.2618
At most 2	0.0054	4.7124	9.1645
Unrestricted Co-integration Rank Test (maximum eigenvalue)			
Hypothesized	Eigenvalue	Max-Eigen Statistic	5% Critical Value
None **	0.0312	28.1654	22.2996
At most 1	0.0162	14.2292	15.8921
At most 2	0.0054	4.7728	9.1645
Co-integrating Vector Estimates			
tlog_t	jlog_t	hlog_t	c
1.0000	0.4131***	-3.8871***	1.5426
	(0.1269)	(1.2415)	(2.0115)

Note: 1. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
2. ( ) means standard deviation

Now, we further consider adding Japanese forward premium/discount to discuss the interaction and volatility spillover effects of the exchange rates of Taiwan, Hong Kong and Japan. This model regards Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable to discuss the interactions between the spot exchange rates of various countries under the information effect. It is hoped to verify that the $(JER_{f,t}\text{-}JER_{s,t})$ will have a continuous impact on Taiwan, Hong Kong and Japan exchange rate markets, and it is expected that the Japanese forward premium/discount will play the role of the information centre. In the following study, the $(JER_{f,t}\text{-}JER_{s,t})$ will be included in the conditional mean equation and conditional variance equation for discussion. As indicated before, in this study there is a co-integration relationship between variables, Granger's representation theorem shows that there must be a vector error correction (VEC) model corresponding to it, and the meaning of the VEC model is to add the error correction term (ECT) of the long-term relationship to the vector auto-regression in the model. Here, the VEC model of the spot exchange rate with lagging K period for the three countries is constructed in order to avoid spurious regression, the stationary series after first-order difference should be used, that is, the rate of return pattern of foreign exchange should be used in the subsequent studies. Concerning the interrelationships of spot foreign exchange markets among Taiwan, Hong Kong and Japan, the order of VEC model is first chosen by Akaike information criterion (AIC). The best order (lagging periods) that we choose to construct VEC model for detecting the relationships of spot exchange rates among Taiwan, Hong Kong and Japan.

According to the VEC model we set up, we also calculate the standardised residuals, squared standardised residuals, and cross-product of the two standardised squared residuals. The Ljung-Box Q tests (Table 4) about the standardised residuals ($Z_{TER_{s,t}}$, $Z_{HER_{s,t}}$ and $Z_{JER_{s,t}}$) shows that there is no autocorrelation for the standardised residuals but the serial correlation exists in the squared standardised residuals ($Z^2_{TER_{s,t}}$, $Z^2_{HER_{s,t}}$ and $Z^2_{JER_{s,t}}$) and cross-product of the two standardised residuals ($Z_{TER_{s,t}}\ Z_{HER_{s,t}}$, $Z_{TER_{s,t}}\ Z_{JER_{s,t}}$ and $Z_{HER_{s,t}}\ Z_{JER_{s,t}}$), i.e., the presences of ARCH effects in the residuals in our model system.

Table 4. Serial Correlation, ARCH and Asymmetric Effect Tests on Standardised Residuals Terms for the Estimated VEC Models

	Taiwan	Hong Kong	Japan
	$Z_{TER_{s,t}} = \varepsilon_{TER_{s,t}} / \sqrt{var(\varepsilon_{TER_{s,t}})}$	$Z_{HER_{s,t}} = \varepsilon_{HER_{s,t}} / \sqrt{var(\varepsilon_{HER_{s,t}})}$	$Z_{JER_{s,t}} = \varepsilon_{JER_{s,t}} / \sqrt{var(\varepsilon_{JER_{s,t}})}$
Q(5)	4.0151	8.0217	2.5415
Q(10)	9.3718	10.1151	4.0317
	$Z^2_{TER_{s,t}}$	$Z^2_{HER_{s,t}}$	$Z^2_{JER_{s,t}}$
Q(5)	76.1151***	46.2241***	37.3389***
Q(10)	102.1175***	57.2089***	40.1152***
	$Z_{TER_{s,t}}\ Z_{HER_{s,t}}$	$Z_{TER_{s,t}}\ Z_{JER_{s,t}}$	$Z_{HER_{s,t}}\ Z_{JER_{s,t}}$
Q(5)	89.951***	23.545***	46.080***
Q(10)	96.160***	42.726***	54.589***
Asymmetric Effects Test of $Z_{TER_{s,t}}$, $Z_{HER_{s,t}}$ *and* $Z_{JER_{s,t}}$ for VEC Model			
	Taiwan($Z_{TER_{s,t}}$)	Hong Kong($Z_{JER_{s,t}}$)	Japan ($Z_{JER_{s,t}}$)
SBT	3.6172**	3.9712**	3.5015**
NSBT	3.1124***	3.1197***	3.6675***
PSBT	-9.6215***	-10.4475***	9.2141***
JT	61.3394***	70.1182***	50.1195**

Note: 1. $Z_{i,t} = \varepsilon_{i,t} / \sqrt{var\ (\varepsilon_{i,t})}$, $Z_{i_t}^2$ and $Z_{i,t}\ Z_{j,t}$ indicate standardised residuals, squared standardised residuals and cross-product of standardised residuals, respectively.

2. SBT, NSBT, PSBT are tested by t-values, while JT is tested by F-value.

3. *** and ** denote statistically significant at confidence level of 1% and 5%, respectively.

Based on the asymmetric effect test results of the standardised residuals in Table 4, the relevant statistics of sign bias test (SBT), negative sign bias test (NSBT), positive sign bias test (PSBT) and joint test (JT) are statistically significant as the square of the standardised residuals. It can be concluded that these three exchange rate markets do have asymmetric characteristics of volatility, so the GJR-GARCH model will be applied to capture the asymmetric effects. Thus, in this study, the VEC GJR- Asymmetric GARCH is built up for analysing the interrelationships among these three spot foreign exchange markets.

Furthermore, we consider 2 structural break dummies (the US - China trade war (D_{1t}) and COVID-19 pandemic (D_{2t})) in the conditional return, volatility, and co-variance equations for these three foreign exchange markets to examine their impacts on these three markets. From the narrative point of view, the most intense US-China trade relationship began on March 22, 2018, and is therefore identified as the first day of the trade war, which lasted until December 31, 2019 (Xu and Lien, 2020; Zeng et al., 2022). In this study, we used March 11, 2020, the date when the World Health Organisation (WHO) declared the COVID-19 pandemic, as the starting date until December 31, 2020 (Cucinotta and Vanelli, 2020; Kumeka et al., 2022) to represent the COVID-19 pandemic period.

3.3 VEC GJR-Asymmetric GARCH Model Establishment and Estimated Results

3.3.1 VEC GJR-GARCH Model Establishment

The VEC GJR-GARCH model for Taiwan, Hong Kong and Japan spot exchange rate after the inclusion of Japanese forward premium/discount$\left(JER_{f,t}\text{-}JER_{s,t}\right)$ and two structural break dummies (the US -China trade war (D_{1t}) and COVID-19 pandemic (D_{2t})) are as follows:

Conditional Mean Equations

$$TER_{s,t} = u_1 + \gamma_1 Z_{t-1} + \sum_{i=1}^{k} a_{1i} TER_{s,t-i} + \sum_{i=1}^{k} a_{2i} HER_{s,t-i} + \sum_{i=1}^{k} a_{3i} JER_{s,t-i} + h_1\left(JER_{f,t} - JER_{s,t}\right) + g_1 D_{1t} + k_1 D_{2t} + \varepsilon_{TER_{s,t}}$$

$$HER_{s,t} = u_2 + \gamma_2 Z_{t-1} + \sum_{i=1}^{k} b_{1i} TER_{s,t-i} + \sum_{i=1}^{k} b_{2i} HER_{s,t-i} + \sum_{i=1}^{k} b_{3i} JER_{s,t-i} + h_2\left(JER_{f,t} - JER_{s,t}\right) + g_2 D_{1t} + k_2 D_{2t} + \varepsilon_{HER_{s,t}}$$

$$JER_{s,t} = u_3 + \gamma_3 Z_{t-1} + \sum_{i=1}^{k} c_{1i} TER_{s,t-i} + \sum_{i=1}^{k} c_{2i} HER_{s,t-i} + \sum_{i=1}^{k} c_{3i} JER_{s,t-i} + h_3\left(JER_{f,t} - JER_{s,t}\right) + g_3 D_{1t} + k_3 D_{2t} + \varepsilon_{JER_{s,t}} \quad (6)$$

Conditional Variance Equations

$$\sigma^2_{TER_{s,t}} = \lambda_1 + \alpha_1 \sigma^2_{TER_{s,t-1}} + \beta_1 \varepsilon^2_{TER_{s,t-1}} + \tau_1 \sigma^2_{HER_{s,t-1}} + \theta_1 \sigma^2_{JER_{s,t-1}} + \phi_1 S_{TER_{s,t-1}} \varepsilon^2_{TER_{s,t-1}} + o_1\left(JER_{f,t} - JER_{s,t}\right) + \nu_1 D_{1t} + \eta_1 D_{2t}$$

$$\sigma^2_{HER_{s,t}} = \lambda_2 + \alpha_2 \sigma^2_{HER_{s,t-1}} + \beta_2 \varepsilon^2_{HER_{s,t-1}} + \tau_2 \sigma^2_{TER_{s,t-1}} + \theta_2 \sigma^2_{JER_{s,t-1}} + \varphi_2 S_{HER_{s,t-1}} \varepsilon^2_{HER_{s,t-1}} + o_2\left(JER_{f,t} - JER_{s,t}\right) + \nu_2 D_{1t} + \eta_2 D_{2t}$$

$$\sigma^2_{JER_{s,t}} = \lambda_3 + \alpha_3 \sigma^2_{JER_{s,t-1}} + \beta_3 \varepsilon^2_{JER_{s,t-1}} + \tau_3 \sigma^2_{TER_{s,t-1}} + \theta_3 \sigma^2_{HER_{s,t-1}} + \phi_3 S_{JER_{s,t-1}} \varepsilon^2_{JER_{s,t-1}}$$

$$+o_3(JER_{f,t} - JER_{s,t}) + \nu_3 D_{1t} + \eta_3 D_{2t} \quad (7)$$

Conditional Co-variance Equations

$$\sigma_{TER,HER,t} = X_1 + \omega_1 \sigma_{TERHER,t-1} + \delta_1 \varepsilon_{TER,t-1}\varepsilon_{HER,t-1} + \pi_1 D_1 + \vartheta_1 D_2$$

$$\sigma_{TER,JER,t} = X_2 + \omega_2 \sigma_{TERJER,t-1} + \delta_2 \varepsilon_{TER,t-1}\varepsilon_{JER,t-1} + \pi_2 D_1 + \vartheta_2 D_2$$

$$\sigma_{HER,JER,t} = X_3 + \omega_3 \sigma_{HERJER,t-1} + \delta_3 \varepsilon_{HER,t-1}\varepsilon_{JER,t-1} + \pi_3 D_1 + \vartheta_3 D_2$$

$$\varepsilon_{ER_{s,t}} = \begin{vmatrix} \varepsilon_{TER_{s,t}} & \varepsilon_{HER_{s,t}} & \varepsilon_{JER_{s,t}} \end{vmatrix} \quad \varepsilon_{ER_{s,t}} \sim N(0\ ,\ \sigma^2_{ER_{s,t}})$$

$$\sigma^2_{ER_{s,t}} = \begin{vmatrix} \sigma_{TERTER} & \sigma_{TERHER} & \sigma_{TERJER} \\ \sigma_{HERTER} & \sigma_{HERHER} & \sigma_{HERJER} \\ \sigma_{JERTER} & \sigma_{JERHER} & \sigma_{JERJER} \end{vmatrix} \quad (8)$$

Related variables and Parameters can be described as follows:

Variables:

$TER_{s,t}$, $HER_{s,t}$, $JER_{s,t}$: Mean returns of the Taiwan, Hong Kong, and Japan's spot exchange rates at time t

Z_{t-1} : Error correction term at time t-1

$(JER_{f,t}\text{-}JER_{s,t})$: Japanese forward premium/discount (as an information variable) at time t

$\varepsilon_{TER_{s,t}}$, $\varepsilon_{HER_{s,t}}$, $\varepsilon_{JER_{s,t}}$: Residual terms of the conditional mean equations of Taiwan, Hong Kong, and Japan's spot exchange rate returns at time t

$\sigma^2_{TER_{s,t}}$, $\sigma^2_{HER_{s,t}}$, $\sigma^2_{JER_{s,t}}$: Conditional variance of Taiwan, Hong Kong, and Japan's spot exchange rate returns at time t

$\sigma_{TER,HER,t}$, $\sigma_{TER,JER,t}$, $\sigma_{HER,JER,t}$: Conditional co-variance between Taiwan-Hong Kong, Taiwan-Japan, and Hong Kong-Japan of exchange rate returns at time t

$S_{mER_{i,t-1}}$: $\begin{cases} 1, & \text{if } \varepsilon_{mER_{s,t-1}} < 0 \text{ bad news} \\ 0, & \text{if } \varepsilon_{mER_{s,t-1}} \geq 0 \text{ good news} \end{cases}$ $m = T, H, J$:

The dummy variable in GJR-GARCH equation

$$D_{1t}: \begin{cases} 1, \text{US} - \text{China trade war period, March 22, 2018 to December 31, 2019} \\ 0, \text{Otherwise} \end{cases}$$

$$D_{2t}: \begin{cases} 1, \text{COVID} - 19 \text{ pandemic period, March 11, 2020} - \text{December 31,2020} \\ 0, \text{Otherwise} \end{cases}$$

Parameters:

u_1, u_2, u_3: Constant terms in conditional mean equations of the three foreign exchange markets.

$\gamma_1, \gamma_2, \gamma_3$: Measuring the adjustment speed toward the long-term equilibrium relationship of the exchange rate returns in three foreign exchange markets.

a_{1i}, a_{2i}, a_{3i} : Measuring whether Hong Kong's foreign exchange rate returns have own-spillover effects and cross-spillover effects from other two countries.

b_{1i}, b_{2i}, b_{3i} : Measuring whether Taiwan's foreign exchange rate returns have own-spillover effects and cross-spillover effects from other two countries.

c_{1i}, c_{2i}, c_{3i} : Measuring whether Japan's foreign exchange rate returns have own-spillover effects and cross-spillover effects from other two countries.

h_1, h_2, h_3 : The spillover effect of Japanese forward premium/discount on Taiwan, Hong Kong, and Japan's foreign exchange markets.

$\lambda_1, \lambda_2, \lambda_3$: Constant terms of the conditional variation equations of the three foreign exchange markets.

$\alpha_1, \alpha_2, \alpha_3$: Measuring whether the conditional variance of the exchange rate return has the GARCH effect in the three foreign exchange markets.

$\beta_1, \beta_2, \beta_3$: Measuring whether the conditional variance of the exchange rate return has the ARCH effect in the three foreign exchange markets.

τ_1, θ_1 : Measuring the volatility spillover effects from Hong Kong and Japan to Taiwan.

τ_2, θ_2 : Measuring the volatility spillover effects from Japan and Taiwan to Hong Kong.

τ_3, θ_3 : Measuring the volatility spillover effects from Taiwan and Hong Kong to Japan.

$\varphi_1, \varphi_2, \varphi_3$: Measuring the asymmetry effects of the three foreign exchange markets themselves.

o_1, o_2, o_3 : The spillover effect of the Japanese forward premium/discount on the foreign exchange markets of Taiwan, Hong Kong and Japan.

χ_1, χ_2, χ_3: Constant terms of conditional co-variance equations in three foreign exchange markets.

$\omega_1, \omega_2, \omega_3$: Measuring whether the conditional co-variance has the own-spillover effect.

$\delta_1, \delta_2, \delta_3$: Measuring whether the conditional co-variance affected by the cross-term residuals.

g_1, g_2, g_3 : Measuring the effect of the US-China trade war in the mean equations for each foreign exchange market.

k_1, k_2, k_3 : Measuring the effect of the COVID-19 pandemic in the mean equations for each foreign exchange market.

ν_1, ν_2, ν_3 : Measuring the effect of the China-US trade war in the variance equations for each foreign exchange market.

η_1, η_2, η_3 : Measuring the effect of the COVID-19 pandemic on the variance equations for each foreign exchange market.

π_1, π_2, π_3 : Measuring the effect of the US-China trade war in the co-variance equations for each foreign exchange market.

$\vartheta_1, \vartheta_2, \vartheta_3$: Measuring the effect of the COVID-19 pandemic in the co-variance equations for each foreign exchange market.

3.3.2 Empirical Evidences and Analysis

As indicated before, concerning the interrelationships of spot foreign exchange markets among Taiwan, Hong Kong and Japan, the order of VEC model is first chosen by AIC. The best order (lagging periods) that we choose to construct the VEC model for detecting the relationships of spot exchange rates among Taiwan, Hong Kong and Japan is 8.

To obtain the effectively empirical results, this study uses the BHHH estimation method (quasi-maximum likelihood estimation (QMLE)) proposed by Berndt, Hall, Hall, and Hausman (1974) to estimate the multivariate model of these three foreign exchange markets. The calculation of the BHHH estimation method uses an iterative process to estimate each parameter and assign its tolerance level until the final estimate converges within the error range. However, when using the BHHH estimation method to estimate the parameters, the initial value of the operation must first be given. Since a good initial value has a dominant influence on the model convergence, the SIMPLEX estimation method is used to calculate the initial value of the parameter and then put it into the model to perform BHHH estimation method to quickly achieve convergence.

(1) Estimation Results of Conditional Mean Equations

Based on the parameter estimation results of the spot exchange rate conditional mean equation in Taiwan, Hong Kong, and Japan (Table 5), the main discussions is in terms of three effects, including own-mean return spillovers, cross-mean return spillovers and dynamic adjustment effects from short-run disequilibrium to long-run equilibrium.

A. Own-Mean Exchange Rate Return Spillovers

According to Table 5, under a significant level of 5%, Taiwan's spot exchange rate return is significantly affected by its own spot exchange rate return at the lagging period 1 and 5 based on the significantly estimated coefficients (a_{11} and a_{15}); Hong Kong's spot exchange rate of return is affected by its own spot exchange rate return at the lagging period 1, 2, 3, 5 and 8 based on the significantly estimated coefficients ($b_{21}, b_{22}, b_{23}, b_{25}$ and b_{28}) ; Japanese spot exchange rate return is affected by its own spot exchange rate return at lagging period 2 based on the significantly estimated coefficients (c_{32}). It shows that the exchange rates of Taiwan, Hong Kong and Japan all have own-spillover effects. Investors can use their past spot exchange rates to predict future exchange rates. Compared to the model that does not include the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$)as an information variable, we find that Taiwan, Hong Kong, and Japan all have a slight reduction in the own-spillover effect of the exchange rate for each country. It is obvious that the Japanese forward premium/discount has a certain information effect though the estimated coefficients (h_1, h_3)of ($JER_{f,t}$-$JER_{s,t}$) are also significant while h_2 is not. The main reasons will be discussed later.

Table 5. Parameter Estimation Results of the Conditional Mean Equation for the Exchange Rate Returns of Taiwan, Hong Kong, and Japan

Taiwan	Coeff.	t-value	Hong Kong	Coeff.	t-value	Japan	Coeff.	t - value
u_1	-0.0069	-0.3115	u_2	-0.0151	-0.0711	u_3	-0.0312	-1.9921
γ_1	-0.0415***	-4.2261	γ_2	-0.0171**	-2.3031	γ_3	-0.0099**	2.0115
a_{11}	-0.1926**	-2.2273	b_{11}	0.0039**	2.0011	c_{11}	0.0301	0.4115
a_{12}	-0.0415	-0.0712	b_{12}	-0.0571	-1.9012	c_{12}	-0.0310	-0.3643

Taiwan	Coeff.	t-value	Hong Kong	Coeff.	t-value	Japan	Coeff.	t - value
a_{13}	-0.0101	-0.1202	b_{13}	-0.2011	-0.8015	c_{13}	-0.0091	-0.1426
a_{14}	0.0411	0.0788	b_{14}	-0.4246	-1.7112	c_{14}	0.0412	0.4048
a_{15}	0.1120***	2.8182	b_{15}	0.0208**	2.3035	c_{15}	0.1426	1.9250
a_{16}	0.0501	0.1015	b_{16}	0.1624	0.4110	c_{16}	-0.0264	-0.2340
a_{17}	0.0880	0.1821	b_{17}	0.0721	0.2426	c_{17}	0.1628**	2.2101
a_{18}	0.0182	0.4045	b_{18}	0.0541	0.1418	c_{18}	-0.0926	-1.2151
a_{21}	0.0041***	3.0151	b_{21}	0.0312***	2.6026	c_{21}	-0.0302	-0.0414
a_{22}	0.2526	0.8869	b_{22}	-0.1126***	-3.0011	c_{22}	0.9012	0.1326
a_{23}	0.1871	1.1125	b_{23}	0.0389**	2.0454	c_{23}	-0.6555	1.1172
a_{24}	0.0415	0.3936	b_{24}	0.2829	1.7171	c_{24}	0.6624	0.9090
a_{25}	-0.2626	-0.3945	b_{25}	-0.0611**	-2.2345	c_{25}	-0.7117	-0.9366
a_{26}	-0.3371	-0.5053	b_{26}	0.5051	1.8826	c_{26}	0.4226	0.6024
a_{27}	-0.3882	1.3362	b_{27}	0.5454	1.0775	c_{27}	-0.2328	-0.3839
a_{28}	0.5015	0.8080	b_{28}	-0.1126***	-2.9115	c_{28}	0.7726	1.3131
a_{31}	0.1526**	2.3011	b_{31}	-0.2391	-0.2020	c_{31}	-0.0099	-0.2247
a_{32}	0.0411	0.1415	b_{32}	-0.0471	-0.0678	c_{32}	0.0228**	2.0345
a_{33}	0.0201	0.1617	b_{33}	0.2262	0.3039	c_{33}	0.1325	1.3690
a_{34}	0.0224	0.2629	b_{34}	0.0554	0.4421	c_{34}	0.0145	0.3536
a_{35}	-0.0627	-1.1526	b_{35}	0.0041	0.6010	c_{35}	0.1436	1.3305
a_{36}	0.0321	1.3325	b_{36}	0.4338	-0.5512	c_{36}	-0.0316	-1.2525
a_{37}	0.0512	0.1565	b_{37}	0.0771	1.1415	c_{37}	-0.2032	-1.3445
a_{38}	-0.1445	-0.2728	b_{38}	-0.1451	-1.551	c_{38}	0.0335	1.7228
h_1	-0.0091**	2.0345	h_2	0.0162	0.0832	h_3	0.0203**	2.1154
	-0.1126**	-1.9901	g_2	-0.2538***	-3.4168		-0.1045**	-2.0291
	-0.1871**	-2.4057	k_1	-0.3001**	-2.8977		-0.1301***	-2.5881

Note: *** and ** denote statistically significant at 1% and 5% level, respectively.

B. Cross-Mean Exchange Rate Return Spillovers

As shown in Table 5, under a significant level of 5%, Taiwan's spot exchange rate return is significantly affected by Hong Kong's spot exchange rate return at the lagging period 1and Japan's spot exchange rate of return at the lagging period 1 based on the significantly estimated coefficients (a_{21} and a_{31}); Hong Kong's spot exchange rate of return is affected by Taiwan's spot exchange rate of return at the lagging period 1 and 5 based on the significantly estimated coefficients (b_{11} and b_{15}); Japanese spot exchange rate return is affected by Taiwan's exchange rate return at lagging period 7 based on the significantly estimated coefficients (c_{17}). Based on the above results, it can be found that the spot exchange rates of Taiwan and Japan have a two-way causal relationship, while the spot exchange rates of Taiwan and Hong Kong have a two-way causal relationship. Compared with the model that does not include the Japanese forward premium/discount($JER_{f,t}$-$JER_{s,t}$)as an information variable, we find that Taiwan's spot exchange rate of return was affected by Japan's spot exchange rate at the lagging period 1, and it also increased the impact of Hong Kong's spot exchange rate at the lagging period 1. It seems that there is a phenomenon of noise. The spot exchange rate returns of Hong Kong and Japan all reduce the impacts of Taiwan's spot exchange rate at their lagging periods. The Japanese forward premium/discount can still be thought of as a representative variable of the information response to exchange rate changes among these three markets.

It should be noted that the part of the information spillover effect (h_1)of the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$) does not have the ability to explain Hong Kong's spot exchange rate at a significant level of 5%. It is speculated that the Hong Kong currency management authority strictly implements the linked exchange rate system. However, the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$)has a significant explanatory ability for Taiwan and Japan's spot exchange rate market at a significant level of 5%, and the estimated coefficients are h_1 and h_3, respectively.The estimated coefficient of Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$) to Taiwan's spot exchange rate is significantly negative, which means that when Japan's foreign currency exchange rate is at a discount (the forward exchange rate < the spot exchange rate means that Japan's spot exchange rate is expected to appreciate), it will depreciate Taiwan's spot exchange rate. The reason may be that Japan is Taiwan's largest importer. When Japan's spot exchange rate is expected to appreciate, Taiwan's need for imports will accelerate the exchange rate against the Japanese yen, resulting in a depreciation of the new Taiwan dollar's spot exchange rate. The estimated coefficient of the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$) to Japan's spot exchange rate is significantly positive, indicating that when Japan's foreign currency exchange rate is at a discount, it will cause Japan's spot exchange rate to appreciate. The cause may be anticipated changes in psychology. Because what investors are most concerned about is not the current exchange rate, but the gain or loss of the future exchange rate return, so when the Japanese exchange rate is expected to appreciate, investors will buy Japanese Yen at the expected moment to avoid future exchange losses. However, the expectation (i.e., the appreciation of the Japanese currency) has been fulfilled, and vice versa. According to the above results, it can be found that the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$) have information effects on the changes in the spot exchange rates of Taiwan and Japan. It seems that the Japanese forward premium/discount ($JER_{f,t}$-$JER_{s,t}$) plays the role of an information centre for Taiwan and Hong Kong.

C. Dynamic Adjustment Effects from Short-run Disequilibrium to Long-run Equilibrium

As indicated in Table 5, the corresponding coefficients (γ_1, γ_2 and γ_3) of error correction term Z_{t-1},i.e., the short-run disequilibrium adjustment coefficients, are negative and significant at a confidence level of 5%. This means that when the exchange rates of Taiwan, Hong Kong and Japan deviate from the long-term equilibrium due to short-run external shock, they can all be adjusted back to the long-run equilibrium through the error correction term or so-called co-integration relationships with these three spot exchange rates. It is confirmed that the spot exchange rate returns of these foreign exchange markets have a co-movement trend. Comparing the size of the adjustment coefficients ($\gamma_1 = -0.0415$, $\gamma_2 = -0.0171$ and $\gamma_3 = -0.0099$) of the three foreign exchange markets during the estimation period and taking the absolute value, we can find that the adjustment coefficient of the Japan exchange market is the smallest, which means that when the Japan's foreign exchange market is deviating from long-run equilibrium relationship due to unexpected impacts, the Japan's foreign exchange market can then adjust to the original long-run equilibrium situation faster in comparison with the Taiwan, Hong Kong's foreign exchange markets. This would imply that the Japan's foreign exchange rate plays the dominant role in affecting the other markets.

D. Effects of the US-China Trade War (D_{1t}) and COVID-19 Pandemic (D_{2t}) Outbreaks on Spot Exchange Rate Returns

Regarding the effects of dummy variables (D_{1t} and D_{2t}) estimated in the conditional mean equation. The impact effects ($k_1 = -0.1126, k_2 = -0.2743$ and $k_3 = -0.1045;\ g_1 = -0.1871$, $g_2 = -0.3236$ *and* $g_3 = -0.1045$) of the US-China trade war (D_{1t}) and COVID-19 pandemic (D_{2t}) outbreaks on the exchange rate returns of Taiwan, Hong Kong and Japan markets are negative and statistically significant at confidence level 1% (Table 5), indicating that the US-China trade war and the spread of COVID-19 creates a significant negative shock on spot exchange rate returns. The main reasons may be that the uncertainties or risks surrounding the US-China trade war (D_{1t}) and the outbreak of the COVID-19 pandemic(D_{2t}) events lead to lower returns on domestic goods and services, especially the related financial asset transactions. It has led investors to withdraw their capitals or funds from the domestic markets, exacerbating capital outflows and downward pressure on the economy, and the exchange rates in the foreign exchange markets of Taiwan, Hong Kong and Japan depreciated. That is to say, the foreign exchange markets of Taiwan, Hong Kong and Japan have experienced currency depreciation during the period of the US-China trade war and the outbreak of COVID-19. Also, Hong Kong's spot exchange rate depreciation was more affected by these two events than Taiwan and Japan markets.

(2) Estimation Results of Conditional Variance Equations

As shown in Table 6, the parameter estimation results of the conditional variance equation for the spot exchange rate returns of Taiwan, Hong Kong and Japan, the main discussions are in terms of four effects, including own-market volatility effects (GARCH effects), unexpected shocks on volatility (ARCH effects), asymmetric effects of own-market volatility and cross-market volatility spillover effects.

A. Own-Market Volatility Effects (GARCH effects)

As indicated in Table 6, we find that the conditional variance of Taiwan, Hong Kong and Japan spot exchange rate returns will be affected by their own prior-period conditional variance at the lagging period 1 since their estimated coefficients (α_1, α_2 and α_3)are positively significant at 5% significant level. It indicates that Taiwan, Hong Kong and Japan's spot exchange rate volatility all have obvious own- market volatility (GARCH) effects. That is to say, the current volatilities of the Taiwan, Hong Kong and Japan can be predicted by their own prior volatilities. Among them, Japan's

Table 6. Parameter Estimation Results of the Conditional Variance Equation for the Exchange Rate Returns of Taiwan, Hong Kong and Japan

Taiwan	Coeff.	t-value	Hong Kong	Coeff.	t-value	Japan	Coeff.	t -value
χ_1	0.0211	0.0575	χ_2	2.09e-06	0.0042	χ_3	0.00013	0.0625
α_1	0.3321**	2.6231	α_2	0.4416**	2.3571	α_3	0.5154***	5.1125
β_1	0.2282***	2.5454	β_2	0.3539**	2.1151	β_3	0.3526**	2.0314
φ_1	0.2131**	2.2271	φ_2	0.1557	0.3515	φ_3	0.0145***	2.7151
τ_1	-0.4567	1.2562	τ_2	-0.0329	0.1029	τ_3	-0.0125	-0.0389
θ_1	0.2620	0.8877	θ_2	0.0339	0.0678	θ_3	0.0145	0.0210

Taiwan	Coeff.	t-value	Hong Kong	Coeff.	t-value	Japan	Coeff.	t -value
o_1	0.0205***	2.0145	o_2	4.05e-05	0.0026	o_3	-0.0107***	8.5725
ν_1	0.2962***	3.0175	ν_2	0.5712***	4.0159	ν_3	0.2865***	3.0416
η_1	0.3321**	2.0521	η_2	0.6078 ***	2.1982	η_3	0.3066***	2.2147

Note: *** and ** denote statistically significant at 1% and 5% level, respectively.

GARCH effect has the greatest of them, that is, compared with the other two foreign exchange markets, the Japanese spot exchange rate market has more risk adjustments. In addition, compared with the model that does not include the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable, the own-market volatility effects of Taiwan, Hong Kong and Japan's exchange rates all have a decreasing trend. The Japanese forward premium/discount$(JER_{f,t}\text{-}JER_{s,t})$ can still be thought as an information variable.

B. Unexpected Shocks on Return Volatility (ARCH effects)

Based on Table 6, we find that the conditional variance of Taiwan, Hong Kong and Japan's spot exchange rate returns are affected by their unexpected shocks at the previous period 1 since their estimated coefficients(β_1, β_2 and β_3)are positively significant at 5% significant level. That is, the Taiwan, Hong Kong and Japan's spot exchange rate returns will all fluctuate due to unexpected shocks, and there is a clear ARCH effect. Compared with the model that does not include the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable, it can be found that the unexpected shocks on volatility (ARCH effects) is significant at 5% significant level. Especially, the estimated coefficient (β_3) has dropped significantly. Therefore, the Japanese forward premium/discount have considerable explanatory power for the volatility of the Japanese spot exchange rate market under considering the unexpected shocks on volatility (ARCH effects).

C. Asymmetric Effects of Own-Market Volatility

The asymmetric effects of bad news and good news are estimated and shown in Table 6. The estimated asymmetry coefficients (φ_1, φ_3) of the forex markets in Taiwan and Japan are positive and significant at the level of 1%. There is an asymmetric effect on the volatility of returns in these two markets. This confirms that unexpected negative shocks (bad news) have a bigger impact on volatility than unexpected positive shocks (good news). In general, any bad news like COVID-19 or any other external shocks such as US-China trade war has the ability to create more volatility in these markets as compared to good news. However, the volatility asymmetric coefficient (φ_2) of the Hong Kong foreign exchange market is positive but not significant, thus the volatility asymmetric effect caused by bad or good news on the Hong Kong foreign exchange market does not exist. The reason may be that the Hong Kong currency management authority strictly implements the linked exchange rate system, investors may follow the system to operate their foreign exchange and have more symmetric information. Furthermore, compared with the model that does not include the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable, the estimated asymmetric coefficients of Taiwan, Hong Kong and Japan's exchange rates all have a decreasing trend. The Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ can still be thought of as an information variable.

D. Cross-Market Volatility Spillover Effects

According to Table 6, it can be found that the cross-market volatility spillover effects for each country have no longer existed since all estimated volatility spillover coefficients ((τ_1, θ_1),

(τ_2, θ_2) and (τ_2, θ_2)) are not statistically significant. This shows that after the inclusion of the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ and compared with the model that did not include $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable, the original cross-market spillover effects have disappeared. It shows that Japan is indeed the information centre, and the co-movement effects of Taiwan, Hong Kong and Japan spot exchange rates should be caused by the Japanese forward premium/discount. That is to say, Japanese forward premium /discount $(JER_{f,t}\text{-}JER_{s,t})$ plays an intermediary role that causes the cross-market volatility spillovers of the Taiwan, Hong Kong and Japanese foreign exchange markets and has information-transmission effect or contagion effect. Investors may suggest to use the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ to achieve the purpose of hedging the exchange rates of Taiwan, Hong Kong and Japan.

E. Effects of the US-China Trade War (D_{1t}) and COVID-19 Pandemic (D_{2t}) Outbreaks on Spot Exchange Rate Return Volatility

Regarding the effects of dummy variables (D_{1t} and D_{2t}) estimated in the conditional variance equation. The impact effects ($\nu_1 = 0.2962, \nu_2 = 0.5712$ and $\nu_3 = 0.2865$; $\eta_1 = 0.3321$, $\eta_2 = 0.6078$ *and* $\eta_3 = 0.3066$) of the US-China trade war (D_{1t}) and COVID-19 pandemic (D_{2t}) outbreaks on the exchange rate return volatility of Taiwan, Hong Kong and Japan markets are positive and statistically significant at the 1% level (Table 6). It shows that when these two events occur, the return volatility of the three foreign exchange markets increases, indicating that the three currencies did experience large fluctuations during the outbreak of these two events. The returns from the COVID-19 pandemic are more volatile than the US-China trade war. The impact effects on spot exchange rate return volatility in Taiwan and Japan are less than Hong Kong when these two events occur. The reason may be that the early control measures in Taiwan and Japan were strong, and the US-China trade war incident and the spread of the COVID-19 epidemic were in a timely manner resisted without causing drastic fluctuations. As indicated above, since Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$have considerable explanatory power and informational effect, which reflect the return volatilities of the Taiwan, Hong Kong and Japanese spot exchange rate markets for considering the unexpected shocks or structural change from the US-China trade war and COVID-19 pandemic outbreaks. Financial investors may also suggest to apply the Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ to achieve the purpose of hedging the exchange rates of Taiwan, Hong Kong and Japan.

(3) Estimation Results of Conditional Co-variance Equations

As can be seen from Table 7, the estimated coefficients of conditional covariance of spot exchange rate returns between Taiwan and Hong Kong, Taiwan and Japan, Hong Kong and Japan (ω_1, ω_2 and ω_3) are significantly affected by their own conditional covariance at the 5% significance level in the past period. It shows that the conditional covariance between Taiwan and Hong Kong, Taiwan and Japan, Hong Kong and Japan has auto-covariance effect. The changes of spot exchange rate returns between the two markets are interrelated and influence each other. In addition, the conditional covariance between Hong Kong and Japan spot exchange rate returns can be predicted through the their residual cross-term ($\varepsilon_{HER,t-1}\varepsilon_{JER,t-1}$) since the estimated coefficient (δ_3, 0.5415) is significant at 1% significant level. That is, when new information or unexpected shock is added, the interactions between Hong Kong and Japan foreign exchange markets will increase.

Table 7. Parameter Estimation Results of the Conditional Co-variance Equation for the Exchange Rate Returns of Taiwan, Hong Kong and Japan

Taiwan-Hong Kong	Coeff.	t-value	Taiwan-Japan	Coeff.	t-value	Hong Kong-Japan	Coeff.	t -value
χ_1	5.25e-06	0.1771	χ_2	4.85e-07	0.0332	χ_3	9.72e-.6	0.0063
ω_1	0.0244***	14.5531	ω_2	0.3005***	12.7151	ω_3	0.4015**	2.6115
δ_1	0.2710	0.8088	δ_2	-0.3571	-0.0445	δ_3	0.5415***	2.7181
	0.2862**	2.0185		0.3279***	2.9914	π_3	0.2813***	3.0426
	0.3039***	3.1621		0.3610**	2.0982	ϑ_3	0.2918 ***	3.2157

Note: *** and ** denote statistically significant at 1% and 5% level, respectively.

Regarding the effects of dummy variables (D_{1t} and D_{2t}) estimated in the conditional co-variance equation. The impact effects ($\pi_1 = 0.2862,\ \pi_2 = 0.3279$ and $\pi_3 = 0.2813;\ \vartheta_1 = 0.3039,\ \vartheta_2 = 0.3610\ and\ \vartheta_3 = 0.2918$) of the US-China trade war (D_{1t}) and COVID-19 pandemic (D_{2t}) outbreaks on the conditional co-variance for each pair-wise exchange rate markets between Taiwan-Hong Kong, Taiwan-Japan, and Hong Kong-Japan are positive and statistically significant at the 1% level (Table 7). We can justify that the average values of the conditional co-variance for each pair-wise exchange rate markets in Taiwan, Hong Kong and Japan increased during the US-China trade war and COVID-19 pandemic outbreak events occurred. We can prove that the foreign exchange markets of Taiwan and Hong Kong, Taiwan and Japan, and Hong Kong and Japan are more closely linked to each other in the face of the two major events. The US-China trade war and COVID-19 pandemic outbreak have triggered risk contagion, crisis in one country would soon spread to another, strengthening the link between each pair of the foreign exchange markets of Taiwan, Hong Kong and Japan.

3.4. Diagnostic Checking for the Estimated Model

In order to test the adequacy of the estimated model, we apply Ljung-Box tests for up to 5th and 10th order serial correlation ($Q(5)$and$Q(10)$) in the standardised residuals, the squared standardised residuals and the cross-product of the standardised residuals which calculated from the whole estimated model. As is shown in Table 8, all results of

Table 8. Goodness-of-Fit Test and Diagnostic Checking

	Taiwan	Hong Kong	Japan
	$Z_{TER_{s,t}} = \varepsilon_{TER_{s,t}} / \sqrt{var(\varepsilon_{TER_{s,t}})}$	$Z_{HER_{s,t}} = \varepsilon_{HER_{s,t}} / \sqrt{var(\varepsilon_{HER_{s,t}})}$	$Z_{JER_{s,t}} = \varepsilon_{JER_{s,t}} / \sqrt{var(\varepsilon_{JER_{s,t}})}$
$Q(5)$	2.2115	6.3991	4.0010
$Q(10)$	4.3115	9.5051	6.5100
	$Z^2_{TER_{s,t}}$	$Z^2_{HER_{s,t}}$	$Z^2_{JER_{s,t}}$
$Q(5)$	3.2151	2.4450	5.0175
$Q(10)$	19.3314	2.9915	7.6215
	$Z_{TER_{s,t}}\ Z_{HER_{s,t}}$	$Z_{TER_{s,t}} Z_{JER_{s,t}}$	$Z_{HER_{s,t}}\ Z_{JER_{s,t}}$
$Q(5)$	2.6615	1.2021	2.7115
$Q(10)$	7.8812	4.5510	5.6602
Asymmetric Effects Test of $Z_{TER_{s,t}}, Z_{HER_{s,t}}\ and\ Z_{JER_{s,t}}$			
	Taiwan($Z_{TER_{s,t}}$)	Hong Kong($Z_{JER_{s,t}}$)	Japan ($Z_{JER_{s,t}}$)
SBT	1.5011	0.3115	0.3731
NSBT	0.5721	1.0201	1.5051
PSBT	-1.901	-1.8321	1.1625
JT	6.2145	5.5541	4.4426

Note: 1. $Z_{i,t} = \varepsilon_{i,t}/\sqrt{var\ (\varepsilon_{i,t})}$, $Z_{i_t}^{2}$ and $Z_{i,t}\ Z_{j,t}$ indicate standardised residuals, squared standardised residuals and cross-product of standardised residuals, respectively.
2. SBT, NSBT, PSBT are tested by t-values, while JT is tested by F-value.
3. *** and ** denote statistically significant at 1% and 5% level, respectively.

Ljung-Box Q tests (Q (5) and Q (10)) fail to reject the null hypothesis that the estimated standardised residuals ($Z_{TER_{s,t}}$, $Z_{HER_{s,t}}$ and $Z_{JER_{s,t}}$), squared standardised residuals($Z^2_{TER_{s,t}}$, $Z^2_{HER_{s,t}}$ and $Z^2_{JER_{s,t}}$) and cross-product of the two standardised residuals ($Z_{TER_{s,t}}\ Z_{HER_{s,t}}$, $Z_{TER_{s,t}} Z_{JER_{s,t}}$ and $Z_{HER_{s,t}}\ Z_{JER_{s,t}}$) have no autocorrelation and ARCH effects. We also test whether the standardised residual of the estimate has asymmetric behaviour of volatility (SBT, NSBT, PSBT and JT), and show that the estimated model does not have asymmetric effect of volatility. Therefore, these above tests validate that our estimated VEC GJR-Asymmetric GARCH model is an appropriate specification for these three markets, and the empirical results are useful and applicable.

4. CONCLUDING REMARKS

This study focuses on the foreign exchange markets of Taiwan, Hong Kong, and Japan, and uses the VEC GJR-GARCH model to explore the relationships of the three foreign exchange markets' spot exchange rates and the interactions after the inclusion of Japanese forward premium/discount $(JER_{f,t}\text{-}JER_{s,t})$ as an information variable. The impacts of the US-China trade war and the spread of COVID-19 shocks on these three foreign exchange markets are also examined. The important findings and implications from empirical results are discussed below:

We apply the Johansen's MLE method to verify and find that the exchange rates of Taiwan, Hong Kong and Japan do have a long-term equilibrium co-integration relationship and there is an obvious set of co-integration vectors. The market satisfies long-term general equilibrium conditions and possess certain degree of co-integration meaning that due to external impact, three foreign exchange markets can then restore to long-term equilibrium relationship after dynamic adjustment of error correction term. Thus, error correction term needs to be incorporated into the model so that the short-run dynamics do not diverge from the long-run equilibrium.

Taiwan’s spot exchange rate return is significantly affected by the impact of lagging Hong Kong and Japan's spot exchange rate returns; The spot exchange rate return of Hong Kong is significantly affected by the lagging Taiwan's spot exchange rate return; the spot exchange rate return of Japan is also significantly affected by the lagging spot exchange rate return of Taiwan. This means that investors can use past spot exchange rates to predict future spot exchange rates. After including the Japanese forward premium/discount, it can be found that the Taiwan spot exchange rate return of is affected by Hong Kong and Japan's spot exchange rate returns both at lagging one period. Hong Kong's foreign exchange rate return is affected by Taiwan's foreign exchange rate return in the fifth lagging period. Japan’s spot foreign exchange rate return is affected by Taiwan's spot exchange rate return at the fifth lagging period. In terms of the dynamic adjustment effect of short-term disequilibrium, the impact effects of error correction terms for Taiwan, Hong Kong and Japan are all significantly negative. It means that when external shocks deviate from the long-term equilibrium relationship, the error correction term can be used to adjust the fluctuation of the exchange rate return to achieve long-run equilibrium. Among the three countries, the absolute value of

0.0035 for Japan's error correction term is the smallest, which shows that the error correction term of Japan's foreign exchange is the fastest to adjust to long-run equilibrium. In addition, the Japanese forward premium/discount has a significant impact on the Taiwan and Japan’s foreign exchange markets, while the impact on the Hong Kong foreign exchange market is not significant. Therefore, it can be concluded that the information effect of the Japanese forward premium/discount has a more significant explanatory power for the Taiwan and Japanese exchange markets. Additionally, the US-China trade war and the spread of COVID-19 creates a significant negative shock on spot exchange rate returns of these three foreign exchange markets.

In terms of conditional variance, the volatilities of Taiwan, Hong Kong and Japan’s spot exchange rate returns will all be affected by their own prior-period volatilities (GARCH effects), which means that the current volatilities of Taiwan, Hong Kong Japan’s spot exchange rate returns can be predicted by their past own volatilities. In addition, the volatilities of the Taiwan, Hong Kong and Japanese spot exchange rate returns have significant volatility shock (ARCH effects), that is, the Taiwan, Hong Kong, and Japanese exchange markets will be affected by unexpected shocks. We also find that when the US-China trade war and the spread of COVID-19 occur, the return volatility of the three foreign exchange markets increases, indicating that the three currencies experienced large fluctuations during the outbreak of these two events.

If the Japanese forward premium/discount does not incorporate into the model, The Taiwanese foreign exchange market is affected by the volatility spillover effect from the Japanese foreign exchange market, and the Hong Kong foreign exchange market is affected by the volatility spillover effects from the Japanese and Taiwanese foreign exchange markets. However, the estimated model includes the Japanese forward premium/discount as an information variable, and the original cross-market spillover effects have disappeared. It shows that the Japanese forward premium/discount indeed plays an intermediary role that causes the cross-market volatility spillovers of the Taiwan, Hong Kong and Japanese foreign exchange markets and has co-movement effect or contagion effect. International investors may suggest to use the Japanese forward premium/discount to achieve the purpose of forecasting or hedging the spot exchange rates of Taiwan, Hong Kong and Japan.

The conditional co-variance between Taiwan-Hong Kong, Taiwan-Japan and Hong Kong-Japan has a previous own-covariance effect. The conditional co-variance of the current period can be predicted by the previous conditional co-variance, that is, the co-variance of each two exchange markets. The co-variance will be affected by the impacts of mutual changes for past return between two markets, there is an interaction between each two markets; changes over time. In addition, the conditional co-variance between Hong Kong and Japan spot exchange rate returns can be predicted by the their residual cross-term, and this unexpected shock reflect that the addition of new information that will create a closer dynamic interaction between markets. Especially, we justify that the foreign exchange markets of Taiwan and Hong Kong, Taiwan and Japan, and Hong Kong and Japan are more closely linked to each other in the face of the two major events. The US-China trade war and the COVID-19 pandemic outbreak have triggered risk contagion, The US-China trade war and the COVID-19 outbreak have triggered risk contagion, with a crisis in one country quickly spreading to another, intensifying the link between the foreign exchange markets of Taiwan, Hong Kong and Japan.

All in all, the foreign exchange rates of Taiwan, Hong Kong and Japan are indeed interactively related. When investors want to avoid risks through exchange rates information, they should consider the relationship with other countries' exchange rates and the effects of volatility spillovers and risk contagion from these two major events to construct effective investment or hedging portfolios. The Japanese forward premium/discount is indeed a variable of information centre and play a mediating effect for the linkage of the three markets. Therefore, investors may consider the information implicit in Japanese forward premium/discount when investing in Taiwan, Hong Kong and Japanese spot foreign exchange markets. Our findings may help also policymakers find responses to such foreign exchange market turbulence.

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