The Impact of Trading Information Sets on Exchange Rate Change and Volatility: Evidence From Taiwan

Ying-Sing Liu

Abstract
This study explores the Taiwan Dollar (TWD) as the currency of a small island economy, using the trading information sets from overseas and the market itself to examine the impacts on the adjustment of daily spot exchange rates. The daily USD/TWD is explained by the trading information sets, contain which the daily trading activities and the ratio of the real body on the daily candlestick chart of technical analysis on the Taipei Foreign Exchange Market, as well as the US-dollar index return to explain the USD/TWD spot rate change. The results showed that some of the USD/TWD changes were related to the US-dollar index return on overseas, and that the effect of the US-dollar index return was not limited to the adjustment rate from the previous closing rate to the opening rate on the day, which would affect the adjustment spot exchange rate in the intraday opening-to-closing period. There is a significant positive relationship between the real body ratio of the daily candlestick chart and the return of the exchange rate, supporting the real body ratio related to the change of the exchange rate. The study model can greatly improve the model interpretation ability of the change of exchange rate by about 50% after considering the trading activity factors. Finally, this study found that the volatility has a positive effect on Mondays and the 2008-financial crisis, and based on the shock that the news of depreciation was higher than the news of appreciation, so there exist asymmetry volatility.

Keywords
information set, US-dollar index, monday effect, financial crisis, asymmetry volatility

Introduction
The foreign exchange market is the world’s foremost financial market for liquid currency. In particular, the exchange of currencies determines the exchange value of goods imported and exported among countries. Accordingly, the study of exchange rate changes has always been a hot topic in the discussion of international financial markets. Many prior theories have sought to explain long-term changes in exchange rates, including the international payments balance theory based on payment imbalances (IPBT) (Iyoboyi et al., 2014; Shahbaz et al., 2012), and the resultant difference in the value of the two currencies from the perspective of the purchasing power parity theory (PPPT) (Abua & Jorion, 1990; Clements & Lan, 2010; Jiang et al., 2016). Moreover, arbitrage activities arising from differences in interest rates among different financial markets are explained by the interest rate parity theory (IRPT) (Baba & Packer, 2009), suggesting that financial assets are subject to the risk effect of equal and perfect substitution based on the monetary method (MAT) (Melvin & Norrin, 2013). Relevant references have been widely discussed.

Most theories focus on explaining monthly rather than daily exchange rate changes. Especially with the development of modern networks, exchange rates change with the rapid transmission of information so that market participants have increasingly focused on daily exchange rate change patterns. This study explores explanatory key factors for short-term changes in the exchange rate and volatility of the daily spot rate of the United States dollar against the Taiwan dollar (USD/TWD). Based on multi-regression and GJR-GARCH models, this research uses the return rate of the USD index (USDX) as a proxy variable for USD changes in international foreign exchange markets and tests the relationship between the USDX return rate and USD/TWD spot rate changes. USDX is calculated using the weighted geometric mean of six major currency pairs: EUR/USD, USD/JPY, GBP/USD, USD/CAD, USD/SEK, and USD/CHF. The value 100 was adopted as a benchmark to measure the overall performance of the USD in the international foreign exchange market. That is, the

1Chaoyang University of Technology, Taichung

Corresponding Author:
Ying-Sing Liu, College of Humanities & Social Sciences, Chaoyang University of Technology,(R.O.C)168, Jifeng E. Road, Wufeng District, Taichung 413330.
Email: liuyingsing@yahoo.com.tw
USD/week exchange rate adjustments comprising the "overnight effect" (from the previous closing-to-opening rates), *intraday adjustments* (from the opening-to-closing rate), and the characteristics of *exchange rate volatility*.

The research contributions of this study are as follows: First, it is confirmed that USDX return rates can explain the extent of USD/TWD rate changes and the associated impact on the TFEM. The explanatory power of *spot rate changes* is used to clarify the reference position and value of USDX on the TFEM. Second, our study supplements current information on the impact of the 2008 financial crisis, particularly on USD movement, changes in the USD/TWD spot rate, and their volatility. Third, we examine the movement in the international USD passed over a longer period (Saturday and Sunday) with enhanced explanatory ability on Mondays—compared to other trading days of the week—for changes in TFEM exchange rates. Finally, from the exchange rate model established in this study, we can understand the efficiency of price adjustments of the USD/TWD spot rate on the TFEM. Reference information on exchange rate changes is also presented, including candlestick charts, USDX, and daily trading values.

This study is structured as follows: section 1 discusses the Literature Review; section 2 presents Data and Methodologies; section 3 shows the Empirical Results; and section 4 is our Discussion and Conclusions.

**Literature Review**

Some studies have found that, in many developing countries, exchange rate adjustments are relatively inefficient for the flow of information sets in foreign exchange markets. For example, Al-khazali et al. (2011) examined the random walk hypothesis (RWH) for five Asian emerging currencies against three benchmarks; the results supported their assertion of currency inefficiencies. Chen (2018) evaluated China’s foreign exchange market efficiency for changes in the Renminbi (RMB) against major currencies and found that market inefficiencies prevailed. Baharumshah et al. (2011) examined the responsiveness of exchange rate changes by comparing the official market to the black market—black market exchange rate adjustments were far quicker than official markets and official exchange rates were slower to adjust to information flows and inefficiencies.

Katusiime et al. (2015) examined Ugandan foreign exchange market efficiencies and found that *buy and sell signals* could be used to accurately predict exchange rate movements and yield higher returns, supporting the hypothesis that weak-form inefficiency exists in this market. When previous and current information sets flow to the foreign exchange market, inefficiencies influence exchange rate changes. In this trading market environment past information sets cannot fully reflect exchange rates, thus only contributing reference values.

Previous studies have found that exchange rate returns or changes may be influenced by technical analysis or trading factors. Nevertheless, questions remain concerning the application of technical analysis in understanding exchange rate changes. Chang and Osler (1999) use technical trading signals in the *head-and-shoulders pattern* as a potential source of exchange rate prediction that defies reason; this rule is profitable, but not effective. Osler (2003) used the document clustering of currency *stop-loss* and *take-profit* orders to explain and support two common technical analysis predictions. Bauer and Herz (2004) examined technical trading and exchange rate changes, particularly the excessive volatility of those foreign exchange markets with flexible exchange rate regimes. They found that chartists changed the composition of the foreign exchange market and caused excessive volatility. Hsu et al. (2016) used a large-scale investigation to confirm the substantial profitability of technical trading rules for specific periods, examining the temporary role of *not-fully rational behavior* and *market immaturity* in generating technical predictability and potential excess profitability.

Moreover, some studies have found that some foreign exchange trading activities and rate changes have a significant relationship. Mansfield (1997) explored the relationships between Australian-dollar rate changes and the daily trading activities of the Reserve Bank which improved predictions of the daily returns gained by holding Australian dollars. Tsuyuguchi and Wooldridge (2008) investigated the evolution of trading activity in Asian foreign exchange markets and found that volumes grew rapidly from 2004 to 2007 with an increase in the diversity of market participants. Except for the Japanese Yen (JPY), Hong Kong Dollar (HKD), and Singapore Dollar (SGD), the proportion of non-resident activity is relatively small, and markets are still in their infancy. Offshore non-performing markets developed insufficient control measures, causing fragmentation in trading activity, with Herstatt risks in Asian foreign exchange markets remaining high.

Payne (2003) confirmed information asymmetries in interdealer forex markets using the USD/DEM dataset, which includes the activities of multiple dealers over one trading week. Lei and Wu’s (2005) discussion of trading activity is divided into *informed* and *uninformed*. Moore and Payne (2011) use trading data and counter-party identities to explore sources of information advantage in inter-dealer forex trading among traders and found that in liquid dollar exchange rates, information was concentrated on the rate of the most frequently traded and special dealer activities, indicating that specialist traders can forecast exchange rate changes.
Bajo (2010) supported trading volume as an efficient proxy for information flow, thereby enhancing the information set of investors. Danielsson et al. (2012) found that changing the frequency of data verification of four exchange rates—EUR/USD, EUR/GBP, GBP/USD, and USD/JPY—from 5 minutes to 1 week, and the order flow for exchange rate changes had strong explanatory power. Chaboud and LeBaron (2001) analyzed the relationship between daily trading volumes on the currency futures market and foreign exchange intervention by the Federal Reserve; their results showed a significant positive correlation. However, neither contemporaneous nor predicted volatility can fully explain the increase in trading activity; publicly reported interventionist activities appear to be an important determinant of trading volumes.

Evans (2002) examined the sources of exchange rate dynamics by focusing on the information structure of forex trading and found that public news is rarely the main source of exchange rate volatility. Frömmel et al. (2008) posit exchange rate volatility as private information and news as public information and found that larger-sized order flows could explain volatility expressed as informed trading, but that order flows from commercial customers did not, thereby supporting exchange rate volatility as reflecting information processing. Menkhoff et al. (2016) showed that order flows are valuable predictors of future exchange rates, supporting the argument that different client groups exhibit different predictive abilities, trading styles, and risk exposures, and that risk can be effectively mitigated through foreign exchange brokers.

Hagiwara and Hercz (1999) supported endogenous sources of exchange rate volatility. McKenzie and Mitchell (2002) believed that in capturing exchange rates’ stylized features of volatility, the GARCH (1, 1) model captured the presence of symmetric responses (Aziz et al., 2020), and will be preferred. Kwek and Koay (2006) explored the conditional volatility of the daily spot nominal exchange rate and found it reasonable to use the GARCH class as an explanatory model. As for asymmetric effects in unexpected appreciations and depreciation of currencies, the GJR model was deemed suitable as an analytical method (Bedoui et al., 2019). The results showed that although most currencies’ volatility indicated little evidence of the existence of asymmetric effects (such as the Japanese Yen and UK Pound), indicating that currency volatility was not asymmetric.

Finally, there were differences in the movements of South Korean and Japanese currencies during the 2008 financial crisis (Choi et al., 2010). Khademalomoom and Narayan (2019) found that the bilateral exchange rates of these currencies exhibited strong time-of-the-day effects and supported the existence of three new intraday effects on local markets post-opening activities and market overlapping times; the monetary behavior caused by these intraday effects had an impact on investors.

Data and Methodologies

Daily USD/TWD spot rate data were collected from the Taipei Foreign Exchange Market Development Foundation website (http://www.tpefx.com.tw/web/index/index.jsp)—this data comprised the opening rate, high rate, low rate, closing rate, and trading value (USD 1 million) on the TFEM. Daily USDX data were derived from the Trade Weighted U.S. Dollar Index, code-named DTWEXM. DTWEXM was collected from the Economic Research Division of the Federal Reserve Economic Data website (https://fred.stlouisfed.org/series/DTWEXM/) between January 2, 2001, and October 31, 2018. Overall, 4,449 sets of daily trading data were collected.

The Percentage of the Daily Exchange Rate is Calculated as:

\[
R_t = \ln \left( \frac{P_t}{P_{t-1}} \right) \times 100\% \tag{1}
\]

where:

- \( R_t \) is the percentage of the exchange rate for the \( t \)th period (trading day), \( P_t \) is the closing rate for the \( t \)th period (trading day), and \( \ln (\cdot) \) is a natural logarithmic function. The adjustment in the percentage of daily exchange rate change (\( R_{close/\text{close},t} \)) also divides the price adjustments from the closing rate on the previous trading day to the opening rate on the day (\( R_{open/\text{close},t} \)), and the intraday price adjustment from the opening-to-closing period (\( R_{close/\text{open},t} \)).

We observe the information of the previous day generated by the international USDX change and the real body ratio of the daily candlestick chart, together with the impact of the opening price of the USD/TWD spot exchange rate on the TFEM. It is further established whether past daily information sets and trading activities still have a significant impact on the opening-to-closing period.

We can observe the information of the previous day generated by the international USDollar index change and the real body ratio on the daily candlestick chart, as well as the impact of the opening price of USD/TWD spot exchange rate in the TFEM. In addition, it is further understood whether the past information sets and trading activities on the day still have a significant impact on the opening-to-closing period.

The Real Body Ratio of the Daily Candlestick Chart

Candlestick charts are often used by technical analysts as a method to analyze the price movements of financial assets, using the frequency of the data observed, such as daily, weekly, and monthly trading information; this study was based on daily candlestick charts. For the observed data, the information on the four daily exchange rates—such as the opening rate, high rate, low rate, and closing rate—on the trading day is plotted in Figure 1.
In Figure 1, when the closing rate is higher than the opening rate, a hollow candlestick is drawn (left chart)—the top of the body represents the closing rate, and the bottom represents the opening rate. When the closing rate is lower than the opening rate, a full candlestick is drawn, the bottom of which represents the closing rate (right chart), and the top represents the opening rate. For a larger ratio of the real body of the daily candlestick chart, the degree of difference between the opening and closing rates is greater, indicating that changes in the exchange rate appreciation or devaluation during the observed period are more divergent. This study uses the candlestick chart in the foreign exchange market of the previous day as information sets—transformed into a proxy index using the ratio of the real body of the daily candlestick chart—to determine whether the exchange rate signal for the previous trading day’s USDX information can be used to explain (i) the daily change ratio of the USD/TWD spot exchange rate on the TFEM; (ii) whether the daily exchange rate changes can be divided into changes from the closing price of the previous trading day to the opening price of the day (overnight changes); and (iii) changes from the opening to closing prices of the day (intraday changes).

The equation can be expressed as follows:

\[
RRB_t = \frac{P_{close,t} - P_{open,t}}{P_{high,t} - P_{low,t}} - 1 \leq RRB_t \leq 1
\]  

where:

\(P_{high,t}\) and \(P_{low,t}\) are the high and low rates for the USD/TWD currency pair on the \(t\)th trading day, respectively. The term \(P_{high,t} - P_{low,t}\) is often used to represent the rate adjustment degree to which the exchange rate of depreciation/appreciation is incorporated into the difference between the highest and lowest rates on the \(t\)th trading day. Because exchange rate adjustments can be categorized into appreciation and depreciation, the opening rate of the foreign exchange market may reflect a portion of the information accumulated before the opening of the trading day. The closing rate reflects the information after the opening of the spot foreign exchange market or what was not reflected in the exchange rate before the opening. If \(RRB_t\) is positive (negative), it means that the exchange rate of the USD/TWD at the closing rate will be higher (lower) than the opening rate, indicating a tendency to depreciate (appreciate)—a value closer to 1 (−1) denotes the strongest degree of depreciation (appreciation) on the daily trading day.

**Models of Previous Day Trading Information Sets**

Our models were developed to assess the relationship between the return rate of the USDX in recent trading information passed from overseas financial markets on the \(t\)-th trading day and the ratio of the real body of the daily candlestick chart from the USD/TWD spot rate on the \(t-1\)th trading day. The USDX’s return is used to proxy an index of the performance of the USD in the international foreign exchange market, and to evaluate the sensitivity of the USD/TWD spot rate for international USD changes. The information set at this time, as a measure of the rate change trended by the USD in international financial markets, is relevant to the change in the TWD exchange rate on the TFEM. The model is expressed as:

\[
R_t = \alpha_1 + \beta_1 \cdot R_{USDX,t-1} + \beta_{Mon} \cdot D_{Mon} \cdot R_{USDX,t-1} + \delta \cdot RRB_{t-1} + \epsilon_t
\]  

In equation (3), \(R_t\) is the percentage of the USD/TWD spot rate change on the \(t\)th trading day, from the closing rate on the \(t-1\)th trading day to the closing rate on the \(t\)th trading day.
day (R_{close/close,t}) and the closing rate on the t−jth trading day to the opening rate on the rth trading day (R_{open/close,r}) or opening-to-closing rate on the rth trading day (R_{close/open,r}), respectively. R_{USDX,t−1} is the return rate of the USDX on the t−jth trading day given the news of the USDX return rate. D_{Mon} is the dummy variable representing a Monday on the TFEM, where D_{Mon} = 1 if the rth trading day is Monday, and 0 otherwise. D_{2008} is the dummy variable for the 2008 financial crisis, where D_{2008} = 1 if the rth trading day is during the 2008 financial crisis on Wall Street in the USA, and 0 otherwise. \( e_t \) is the error term; it should go through the diagnostic checking and goodness-of-fit process using the \( p \)-value of the ARCH effect test to infer whether the null hypothesis is accepted or rejected; \( e_t \) is not heterogeneous.

If the \( p \)-value of the ARCH effect test is less than .05, this signifies the heteroscedasticity of the residual terms in equation (3). We consider the heteroscedasticity of the conditional variance in equation (3). Assuming that the residual term is \( e_t \), heteroscedasticity exists and leads to \( e_t \sim \mathcal{N}(0, h_t) \). To capture the heteroscedastic asymmetry of the residual terms (Kang, 1999), this study uses the threshold GARCH model proposed by Glosten et al. (1993) as the conditional variance equations. The threshold GARCH \((p, q)\) model of conditional variance is given by:

\[
h_t = \omega + \sum_{i=1}^{p} a_i \cdot e_{t-i}^2 + \sum_{k=1}^{r} b_k \cdot D_{t-k} \cdot e_{t-k}^2 + \sum_{j=1}^{q} c_j \cdot h_{t-j}
\]

In equation (4), \( p, r, \) and \( q \) are the length of lags for the ARCH terms, asymmetric terms, and GARCH terms, respectively. \( \omega \) is an intercept, \( a_i \) is a parameter of the ARCH term on the \( i \)th order, \( b_k \) is an asymmetric coefficient on the \( k \)th order, and \( c_j \) is a parameter of the GARCH term on the \( j \)th order. \( D_{t-k} \) is an indicator variable for the 2008 financial crisis; if \( D_{t-k} = 1 \) or \( D_{t-k} = 0 \) otherwise. According to Chen et al. (2008) and Ahmad et al. (2015), bad news is defined where \( e_{t-k} < 0 \); otherwise, \( e_{t-k} \geq 0 \) is considered good news, where USD news affects the USD/TWD spot rate change on the \( t \)-th trading day \((R_{t-k})\). It has a differential effect on the model of conditional variance; good news on the USD has an impact of \( a_k + b_k \). If \( b_k \) is not equal to zero, then the news impact is asymmetric. In equation (4), it is obtained using goodness-of-fit measures and diagnostic checking. Given that \( p = 1, r = 1, \) and \( q = 1 \) is determined by Akaike’s Information Criterion and Schwarz’s Information Criterion, Heteroskedastic Test is verified using ARCH Test. We use \( k = 1 \) and the GJR-GARCH \((1,1)\) model to capture the heteroscedasticity of the residual variance equation (Ahmad et al., 2015), and the formula becomes:

\[
h_t = \omega + a_1 \cdot e_{t-1}^2 + b_1 \cdot D_{t-1} \cdot e_{t-1}^2 + c_1 \cdot h_{t-1}
\]

Equations (3) and (5) use the maximum likelihood (MLE) method to estimate the parameters: \( \alpha \) is a constant and \( \beta_1 \) is the beta coefficient. \( R_{USDX,t} \) is significantly positively correlated with \( R_t \) and can be supported if the parameter \( \beta_1 \) is significant and greater than 0 using a \( t \)-test. When the return rate of USDX change is positive (negative), the USD/TWD spot rate changes are also positive (negative). Hence, news of the USDX’s return rate is an appropriate index for examining changes in the USD/TWD spot rate on the TFEM. \( \beta_{Mon} \) is the extra beta coefficient of the Monday trading day. If \( \beta_{Mon} \) is not equal to zero, then the news of the USDX’s return rate has Monday effects or DOW effects on the TFEM; there is a Monday effect on equation (3), given news of the USDX’s return on Monday, with an effect of \( \beta_{Mon} \) for \( R_t \), while post-holiday news of the USDX’s return rate impacts \( \beta_t + \beta_{Mon} \cdot D_{2008} \) represents the premium on additional risk of the financial 2008 crisis; if \( \beta_{2008} > 0 \), then it has an additional risk premium \( \beta_{2008} \) for \( R_t \) during the 2008 financial crisis. \( \delta \) is a parameter of the ratio of the real body on the previous day of the candlestick chart’s impact on \( R_t \). If \( \delta \) is greater than zero, a larger ratio of the daily trading rate range is reflected in the real body of the candlestick chart of the previous trading day, results in a larger exchange rate change on the day, which is positively correlated. This result confirms a significant relationship between the past information set of the technical analysis—the ratio of the real body in the daily candlestick chart of the previous trading day—and the spot rate adjustment for the current trading day.

In equation (5), \( \omega \) is an intercept, \( a_1 \) is a parameter of the ARCH term, and \( c_1 \) is a parameter of the GARCH term, where \( a_1 > 0 \) and \( c_1 > 0 \). If it has a differential effect on the model of conditional variance, the impact of good news \((e_{t-1} \geq 0)\) on the conditional variance is \( a_1 \), while the impact of bad news \((e_{t-1} < 0)\) on the conditional variance is \( a_1 + b_1 \). If \( b_1 > 0 \), then the shock of bad news for the USA index is greater than the impact of good news on the volatility of the USD/TWD spot rate, indicating asymmetric volatility for the news of the international USD index return.

**Extended Model Under Information Set of Daily Trading Activity**

This study explores the relationship between the USDX’s return rate, daily trading activity, and exchange rate changes, and the Monday effect and the financial crisis on the conditional variance. Equation (3) joins the trading activity variables, and equation (5) adds dummy variables for the Monday effect and 2008 financial crisis. The equations are expressed as:

\[
R_t = \alpha + \beta \cdot R_{USDX,t-1} + \beta_{Mon} \cdot D_{Mon} \cdot R_{USDX,t-1} + \beta_{2008} \cdot D_{2008} \cdot R_{USDX,t-1} + \delta \cdot RR_{B,4} + \gamma \cdot I(\cdot) \cdot \ln(value) + \lambda \cdot CTA_t + e_t
\]

\[
h_t = \omega + a_1 \cdot e_{t-1}^2 + b_1 \cdot D_{t-1} \cdot e_{t-1}^2 + c_1 \cdot h_{t-1} + d \cdot D_{Mon} + e \cdot D_{2008}
\]
In equation (6)—because foreign exchange trading can be based on an appreciation or depreciation trend—I(·) was defined as an index function representing an appreciation (depreciation) day for the TFWD to analyze the trading activity of the USD/TWD spot exchange rate during depreciation (appreciation). In this instance, $R_t > 0$ denotes an appreciation of the USD and a depreciation of the TWD, represented by $I(·) = 1$. $R_t \leq 0$ denotes a non-appreciation (depreciation) in USD and a non-depreciation (appreciation) in the TWD, represented by $I(·) = -1$. $\ln(value_t)$ is the natural logarithm of the USD/TWD trading value on the TFEM for the $t$th trading day. $\delta\gamma$ is the change rate in the daily trading value of the USD/TWD spot exchange market on the $t$th trading day. In Equations (6) and (7), the MLE is used to estimate parameters to explore the relationship between the USDX’s return rate, daily trading activity, and USD/TWD exchange spot rate changes, and the parameters for capturing conditional volatility in the exchange rate.

In equation (6), $\gamma$ is the coefficient of trading activity. When $\gamma$ is positive, the depreciation (appreciation) of the USD/TWD spot rate increases as the exchange rate market activity increases. This definition supports the argument that the absolute change rate of the USD/TWD currency pair ($|R_{USD/TWD,t}|$) increases concurrently with the trading activity (value) on the TFEM. The parameter of the percentage change in trading activity is represented by $\lambda$. When $\lambda$ is positive, the USD/TWD spot rate rises concurrently with a significant increase in trading value on the $t$th trading day relative to the $t-1$th trading day.

**Adjustment Intraday Spot Exchange Rate Model: Opening-To-Closing Period**

We further explore the relationship between the closing rate on the $t$–$t$th trading day and the opening rate on the $t$th trading day ($R_{open/close,t}$), and the opening-to-closing rate on the $t$th trading day ($R_{close/open,t}$) in the TFEM. The adjusted opening rate, added to equation (6) is $\text{adj}_t R_{open/close,t}$ through the deduction of $R_{open/close,t}$ estimated in Equations (3) and (5), that is, $\text{adj}_t R_{open/close,t} = R_{open/close,t} - \delta R_{open/close,t}$. The adjusted intraday spot exchange rate model for the opening-to-closing period is:

$$R_{close/open,t} = \alpha + \rho \cdot \text{adj}_t R_{open/close,t} + \beta \cdot R_{USDX,t-1} + \beta \cdot D_{Mon} \cdot R_{USDX,t-1} + \beta \cdot D_{2008} \cdot R_{USDX,t-1} + \delta \cdot R_{RB,t-1} + \gamma \cdot I(·) + \delta \lambda \cdot CTA_t + \varepsilon_t$$

where:

Equation (8) is the conditional volatility equation (7), which together with the use of MLE, was used to estimate the parameters. In Equations (8) and (7), the results of the estimated parameters are used to explore the relationship between the adjustment rates in the daily intraday trading period from opening to closing. If $\rho > 0$ ($\rho < 0$), then the adjusted past closing-to-opening rate ($\hat{R}_{open/close,t}$) will continue to affect the intraday adjustment rate ($R_{close/open,t}$) in the opening-to-closing period and the positive (reverse) relationship, shows that the adjustment rate on the intraday trading period is a persistence effect (reversal effect), which also implies that the opening rate is an underreaction (overreaction) to the information set. The interpretation of the other variables is similar to the conditional mean in equation (6) and the conditional variance in equation (7), but the focus is on the relationship between the effects of the exchange rate adjustment on the daily opening-to-closing period. It should be noted that $R_{USDX,t-1}$ and $RR_{RB,t}$ are the post information sets that flowed into the market before the opening; if the adjustment of information in the foreign exchange market is efficient, then theoretically $\beta$ and $\delta$ tend to zero. This argument is based on the efficient market hypothesis (Fama, 1970) that—when the exchange rate market is supported—the exchange rate will fully reflect past information, while the technical analysis (candlestick chart) will be unable to anticipate exchange rate changes.

**Empirical Results**

Figure 2 shows the statistical graphs for the sample of 4,449 data sets from the 2nd of January 2001 and the 31st to October 2018. The line graph in Figure 2(a) shows the bimodal distribution range of the USD/TWD (28.8–35.2). In Figure 2(b), the spike graph in Figure 2(b) shows that most of the daily change rates of USD/TWD are between −1% and +1%, and not exceeding ±3%, although the daily change rate of the USDX fell over 2% to −4.107% on March 19, 2009, as indicated in Figure 2(f). The daily change rates of the USDX are slightly higher than those of the daily USD/TWD spot rates. Figure 2(c) shows that most of the daily trading values of USD/TWD on the TFEM lies between 500 and 1,000 (USD 1 million), while the daily trading value in TWD during the 2008 financial crisis was larger. Finally, it can be seen from the dot plot graph in Figure 2(d) that, during the period from 2007 to the end of 2015, the ratios of the real body were not uniformly distributed in 2007, but rather concentrated between 0 and 0.75; most of the values fell in the range from 0.0 to 0.5, during 2011 to 2015.

Table 1 lists the results of the summary statistics and Augmented Dickey-Fuller (ADF) tests. The mean USD/TWD ($R_{close/open,t}$) rate is −0.0014%, suggesting that in the long term—relative to USD—TWD exhibited slight appreciation. The mean of $R_{USDX,t}$ is −0.0026%, suggesting that in the long term—relative to other international currencies—the USD exhibited slight appreciation. The standard deviation of USD/TWD ($R_{close/open,t}$) is 0.2407%, which is smaller than the standard deviation of $R_{USDX,t}$ (0.4595%), suggesting that changes in the USD/TWD spot rate are smaller than...
those in the rates of the USD paired with other currencies. For all sequences in Table 1, the estimated Jarque-Bera values were significant at the 5% level, suggesting that they were non-normally distributed. At the 1% significance level, based on the ADF tests of the t-statistic, only the closing rate for USD/TWD and the USDX failed to achieve significance and could be validated as stationary sequences. The remaining sequences were stationary in the ADF test.

The mean of the daily USD/TWD rate change during the study period indicated appreciation ($R_{\text{close}/\text{close},t} = -0.0014\%$), but compared to the mean of the adjusted previous closing-to-opening rate, this represented depreciation.
Table 1. Descriptive Statistics (Observations = 4,449).

| Market | Part A. The USD/TWD spot rate in taipei foreign exchange market | Part B. International US-dollar index |
|--------|---------------------------------------------------------------|-------------------------------------|
| Set    | The USD/TWD spot rate                                          | The candlestick charts and trading activity | The US-dollar index |
| Variable | Estimator | $P_{\text{close,t}}$ | $R_{\text{close/lose},t}$ (%) | $R_{\text{open/close},t}$ (%) | $R_{\text{close/open},t}$ (%) | $\text{RRB}_{t-1}$ | $\text{value}_t$ (USD 1 million) | $\ln(\text{value}_t)$ | $\text{CTA}_t$ (%) | $P_{\text{close,t-1}}$ | $R_{\text{USDX,t-1}}$ (%) |
| Mean   | 31.9051 | -0.0014 | 0.0251 | -0.0265 | -0.0492 | 755.49 | 6.5507 | 0.0142 | 84.6757 | -0.0026 |                      |
| Median | 32.0450 | 0.0000 | 0.0000 | -0.0202 | -0.0690 | 712 | 6.5681 | -0.5658 | 82.9417 | 0.0000 |                      |
| Maximum | 35.1740 | 2.9563 | 1.1286 | 2.9832 | 1.0000 | 5012 | 8.5196 | 188.68 | 113.10 | 2.4859 |                      |
| Minimum | 28.6320 | -1.5009 | -1.1898 | -1.2707 | -1.0000 | 111 | 4.7095 | 188.68 | 113.10 | 2.4859 |                      |
| Std. Dev. | 1.7177 | 0.2407 | 0.1631 | 0.2354 | 0.4777 | 311.73 | 0.3962 | 34.2973 | 10.7505 | 0.4595 |                      |
| Skewness | 0.0515 | 0.5289 | -0.7595 | 0.8607 | 0.2072 | 2.1902 | -0.2860 | 0.1539 | 0.7554 | -0.1985 |                      |
| Kurtosis | 1.8988 | 11.6076 | 11.9486 | 12.6219 | 2.2851 | 18.1231 | 4.1275 | 5.4020 | 2.8819 | 6.9402 |                      |
| Jarque-Bera | 226.77 | 13942.10 | 15268.71 | 17711.52 | 126.52 | 45953.63 | 296.31 | 1086.82 | 425.71 | 2906.55 |                      |
| ADF (t-statistic) | -1.6130 | -62.6830** | -7.5529** | -9.9408** | -10.5247** | -8.9210** | -6.6823** | -29.5944** | -1.7174 | -67.3690** |                      |
| Monday (n = 870) | 31.9245 | 0.0096 | -0.0218 | 0.0314 | -0.0619 | 717.8787$ | 6.4905$ | -3.4084$ | 84.6807 | 0.0131 |                      |
| Non-Monday (n = 3579) | 31.9004 | -0.0041 | -0.0276 | 0.0236 | -0.0462 | 764.6363 | 6.5653 | 0.8456 | 84.6769 | 0.0064 |                      |
| 2008 year (n = 251) | 31.5433$ | 0.0051 | -0.0301 | 0.0351 | -0.0567 | 1200.71$ | 7.0207$ | -0.0041 | 74.5043$ | 0.0320 |                      |
| Non-2008 year (n = 4198) | 31.9267 | -0.0018 | -0.0262 | 0.0245 | -0.0488 | 728.87 | 6.5226 | 0.0153 | 85.2859 | -0.0047 |                      |

Note. This table reports the descriptive statistics for a sample of 4,449 from 2 January 2001 and 31 October 2018. In part A, $P_{\text{close,t}}$ represents the daily closing rate of the USD/TWD on the $t$th trading day; $R_{\text{close/lose},t}$ is the change rate of USD/TWD on the $t$th trading day; $R_{\text{open/close},t}$ is the adjustment change rate of the USD/TWD from closing rate on the $t−1$th trading day to opening rate on the $t$th trading day; $R_{\text{close/open},t}$ is the intraday adjustment change rate of the USD/TWD from opening rate to closing rate on the $t$th trading day; $\text{RRB}_{t-1}$ is the ratio of real body of Candlestick Chart for the USD/TWD spot rate on the $t−1$th trading day. The $\text{value}_t$ is the daily trading value (US dollar 1 million) on the USD/TWD spot rate; $\ln(\text{value}_t)$ is the natural logarithm of the USD/TWD trading value in the TFEM; $\text{CTA}_t$ is the change rate in the daily trading value of the USD/TWD spot exchange market on the $t$th trading day. In part B, $P_{\text{close,t-1}}$ represents the closing price of the US-dollar index on the $t−1$th trading day; $R_{\text{USDX,t-1}}$ is the percentage of USDX return on the $t−1$th trading day. The Jarque-Bera statistic is Chi-square distribution under the null hypothesis that series are normality; ADF is the unit root test of Augmented Dickey-Fuller test.

** and *** represent significance at the 5% and 1% levels, respectively.

$represent significance at the 5% using the result of ANOVA tests.
Table 2: Correlations Matrix.

| Variable | $P_{\text{close},t}$ | $R_{\text{open}/\text{close},t}$ | $R_{\text{close}/\text{open},t}$ | $R_{\text{USDX},t-1}$ | $I(\cdot)\cdot\ln(\text{value},t)$ | $\text{CTA}_t$ |
|----------|---------------------|-------------------------------|-------------------|-------------------|-----------------|----------------|
| $R_{\text{close}/\text{close},t}$ | 1                   |               |               |               |               |               |
| $R_{\text{open}/\text{close},t}$ | 0.3711              | $0.7655$        |               |               |               |               |
| $R_{\text{close}/\text{open},t}$ | $0.7655$            | 1               |               |               |               |               |
| $R_{\text{USDX},t-1}$ | $0.3045$            | $0.2872$        | $0.1123$       | 1               |               |               |
| $I(\cdot)\cdot\ln(\text{value},t)$ | $0.6930$            | $0.2910$        | $0.5070$       | $0.2747$        | 1               |               |
| $\text{CTA}_t$ | $0.0767$            | $0.0093$        | $0.0720$       | $-0.0073$       | $0.0548$        | 1 |
| $\text{RBR}_{t-1}$ | $0.0869$            | $-0.2147$       | $0.2376$       | $0.1800$        | $0.0560$        | $-0.0728$ |

Note. The table reports the Correlations Matrix. $R_{\text{open}/\text{close},t}$ is the change rate of the USD/ TWD on the t-th trading day; $R_{\text{close}/\text{open},t}$ is the adjustment change rate of the USD/ TWD from closing rate on the $t-1$ th trading day to opening rate on the $t$ th trading day; $R_{\text{USDX},t-1}$ is the intraday adjustment change rate of the USD/ TWD from opening rate to closing rate on the $t$ th trading day; $R_{\text{USDX},t-1}$ is the return ratio of USDX on the $t-1$ th trading day; $I(\cdot)$ is an index function representing on appreciation (depreciation) day. If $R_{\cdot} > 0$ then $I(\cdot) = 1$ otherwise $I(\cdot) = -1$; $\ln(\text{value},t)$ is the natural logarithm of the USD/TWD trading value in the TFEM on the $t$ th trading day; $\text{CTA}_t$ is the change rate in the daily trading value of the USD/TWD spot exchange market on the $t$ th trading day; $\text{RBR}_{t-1}$ is the ratio of real body of Candlestick Chart for the USD/TWD spot rate on the $t-1$ th trading day.

$(R_{\text{open}/\text{close},t} = 0.0251\%)$. The intraday price adjustment during the opening-to-closing period was appreciation $(R_{\text{close}/\text{open},t} = -0.0265\%)$. This showed that the TWD’s spot rate was normally higher than the previous opening depreciation of the previous day’s closing rate, but the closing rate on the same day was generally lower than the opening rate, due to appreciation.

In Table 1, one-way ANOVA was used to determine whether there was a significant difference in the average level of these study variables between groups, such as Monday versus non-Monday trading days, and the 2008 financial crisis versus non-2008. There was a significant difference, at the 5% level, in the mean of the close rate between Monday versus non-Monday. There was a significant difference, at the 5% level, in the mean of the close rate between groups, such as non-2008 financial crisis and non-2008 financial crisis. In 2008, the weak international USDX was 31.5433 and 31.9267, respectively. The daily trading value was 0.5070, implying that $\text{USDX,} \text{USDX,} \text{USDX,} \text{USDX,}$ were significantly lower than the mean on Mondays versus non-Mondays. In addition, during the 2008 financial crisis, the daily trading value was lower than 0.1413% when the USDX increased (decreased) by 1%, showing that the impact of the financial crisis on the trading value of the TFEM was more pronounced than the rate. In model B, the average index of the closing rate $P_{\text{close},t}$ of the International USDX in the 2008 financial crisis was 74.5043, well below the non-2008 financial crisis, and the average index of closing rate $P_{\text{close},t-1}$ was 85.2859, indicating the weak international USDX in 2008.

Table 2 shows the correlation matrix for correlations among $R_{\text{close}/\text{close},t}$, $R_{\text{open}/\text{close},t}$, $R_{\text{close}/\text{open},t}$, $R_{\text{USDX},t-1}$, $I(\cdot)\cdot\ln(\text{value},t)$, $\text{CTA}_t$, and $\text{RBR}_{t-1}$. Table 2 presents the correlation coefficient of $R_{\text{close}/\text{close},t}$ and $I(\cdot)\cdot\ln(\text{value},t)$; and $R_{\text{close}/\text{close},t}$ and $R_{\text{USDX},t-1}$ (as 0.3045 and 0.6930, respectively). These correlation coefficients were all higher than 0.3, implying that $I(\cdot)\cdot\ln(\text{value},t)$ and $R_{\text{USDX},t-1}$ were positively correlated with $R_{\text{close}/\text{close},t}$. Moreover, the correlation coefficient of $R_{\text{close}/\text{open},t}$ and $I(\cdot)\cdot\ln(\text{value},t)$ was 0.5070, with similar results. When variables are highly correlated, special attention should be paid to the occurrence of multicollinearity in multi-regression analysis. Finally, it was found that the four independent variables of $R_{\text{USDX},t-1}$, $I(\cdot)\cdot\ln(\text{value},t)$, $\text{CTA}_t$, and $\text{RBR}_{t-1}$ were not highly correlated with each other, so it was less likely that the multi-regression models discussed in the follow-up would be more likely to produce multicollinearity.

Table 3 shows results using the ratio of the international USDX return and the ratio of the real body of the daily candlestick chart for the previous day as the explanatory variables of the daily USD/TWD spot rates; the parameter estimation results of the model were carried out in OLS without consideration for the heterogeneity of model residuals. Then, considering the heterogeneity of model residuals and using the GJR-GARCH (1, 1) model, conditional volatility was captured. Table 3 shows the regression models A1, B1, and C1. The variance inflation factor (VIF) was employed to test the multicollinearity of the explanatory variables in the multiple regression equations. Generally, a VIF of greater than 4 represents multicollinearity. In model A1, $\beta_1$ is 0.1413, and its p-value is 0.0000. At the 1% level of significance, $\beta_1$ is significantly greater than 0, thus showing that $R_{\text{close}/\text{close},t}$ and $R_{\text{USDX},t}$ are positively correlated. In other words, TWD exhibits a depreciation (appreciation) of 0.1413% when the USDX increased (decreased) by 1%, revealing that the TWD changes are slightly sensitive to the USD trends in the international financial market.

In model A1 equation (2), $\beta_1$ and $\beta_{\text{USDX}}$ were significantly positive at a significance level of 1% (0.1413 and 0.0794 respectively)—the return ratio of the international USDX and the change of USD/TWD spot rate showed a significant positive relationship. In particular, the Taipei foreign exchange market on Monday trading days presented a significantly higher BETA value, showing the return ratio of the international USDX after a long time (holiday) of delivering news for the USD/TWD spot rate adjustment affects the transmission time difference. At a significant level of 5%, $\delta$ equal to 0.0175 is significantly positive, which indicates that the previous day’s technical analysis of the real...
Table 3. The Results of Estimated Parameters in Six Study Models Under Three Change Rates of USD/TWD Spot Exchange Rate.

| Dependent variable | $R_{\text{close}/\text{close},t}$ | $R_{\text{open}/\text{close},t}$ | $R_{\text{close}/\text{open},t}$ |
|--------------------|----------------------------------|----------------------------------|----------------------------------|
| **Mean equation:** from equation **(3)** | | | |
| $\alpha_t$ | $-0.0003$ ($0.9209$) | $-0.0028$ ($0.3582$) | $0.0209$$^**$ ($0.0000$) | $0.0265$$^**$ ($0.0000$) | $-0.0213$$^**$ ($0.0000$) | $-0.0231$$^**$ ($0.0000$) |
| $\beta_k$ | $0.1413$$^**$ ($0.0000$) | $0.1268$$^**$ ($0.0300$) | $0.1252$$^**$ ($0.0000$) | $0.0943$$^**$ ($0.0000$) | $0.0161$ ($0.1588$) | $0.0209$$^**$ ($0.0000$) |
| $\gamma_{\text{mon}}$ | $0.0794$$^**$ ($0.0000$) | $0.0581$$^**$ ($0.0000$) | $0.0261$$^*$ ($0.0000$) | $0.0075$ ($0.1834$) | $0.0533$$^**$ ($0.0000$) | $0.0392$$^**$ ($0.0000$) |
| $\beta_{1008}$ | $-0.0110$ ($0.6093$) | $-0.0053$ ($0.7264$) | $-0.0804$$^**$ ($0.0000$) | $-0.0484$$^**$ ($0.0000$) | $-0.0694$$^**$ ($0.0000$) | $0.0624$$^**$ ($0.0000$) |
| $\delta$ | $0.0175$$^*$ ($0.0167$) | $0.0099$ ($0.0924$) | $-0.0935$$^**$ ($0.0000$) | $-0.0430$$^**$ ($0.0000$) | $0.1110$$^**$ ($0.0011$) | $0.0661$$^**$ ($0.0000$) |
| **Variance equation:** from equation **(5)** | | | |
| $\omega$ | $-$ | $-$ | $-$ | $-$ | $-$ | $-$ |
| $\alpha$ | $-$ | $-$ | $-$ | $-$ | $-$ | $-$ |
| $\beta$ | $-$ | $-$ | $-$ | $-$ | $-$ | $-$ |
| $\gamma$ | $-$ | $-$ | $-$ | $-$ | $-$ | $-$ |
| $\zeta$ | $-$ | $-$ | $-$ | $-$ | $-$ | $-$ |
| $R$-squared | $0.0976$ | $0.0957$ | $0.1630$ | $0.1363$ | $0.0654$ | $0.0570$ |
| Adj. $R$-squared | $0.0968$ | $0.0948$ | $0.1622$ | $0.1355$ | $0.0645$ | $0.0562$ |
| Log likelihood | $252.9178$ | $693.7943$ | $2150.9770$ | $3252.7780$ | $274.1360$ | $809.5469$ |
| F-statistic | $120.1666$$^**$ | $216.3046$$^**$ | $77.6789$$^**$ | $77.6789$$^**$ | $77.6789$$^**$ | $77.6789$$^**$ |
| Heteroskedasticity | $0.0000$ | $0.5244$ | $0.0000$ | $0.0087$ | $0.0000$ | $0.3782$ |

Note: This table reports the results of estimated parameters in six study models. The models examine on the relationships between the US-dollar index return, the trading activity, uncertainty and the change ratio of the USD/TWD on the $t$th trading day. $\hat{\alpha}$ is a constant; $\hat{\beta}$ is the BETA coefficient; $\hat{\gamma}_{\text{mon}}$ is a change in the BETA coefficient of USD/TWD spot rate during a bullish day in the USDX; $\hat{\omega}$, $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$, and $\hat{\zeta}$ represent estimated parameters. D.W. stat. is the Durbin-Watson statistic to the test the autocorrelation in the residuals; VIF is the variance inflation factor test for multicollinearity.

*and ** represent significance at the 5% and 1% levels, respectively.

body ratio of the daily candlestick chart to the USD/TWD spot rate change has a significant positive correlation; this representation of technical analysis for the USD/TWD indicates significance (greater than 0). In the coefficient of volatility asymmetry, $\beta_3 = -0.0228$ was significantly less than 0. This result indicated that the daily rates of USD/TWD ($R_{\text{close}/\text{close},t}$) that tend to appreciate exhibited smaller volatility parameters ($4 + \beta_3 = 0.1244 - 0.0228 = 0.1016$), supported the daily change rates of USD/TWD ($R_{\text{close}/\text{close},t}$) and had less volatility sensitivity to devaluation news compared to appreciation news, with volatility asymmetry.

In Table 3, the opening price was adjusted from the closing price on the $t$-th trading day to the opening price on the $t$-th trading day ($R_{\text{open}/\text{close},t}$). The estimated parameter results in Model B1 from equation (2), and B2 equations (2) and (5) indicated consistency between Model A2 and Model B2’s conditional volatility equation of the GJR-GARCH (1, 1) model. The conditional mean equations were significantly positive at a significance level of 1%, with $\beta_1$ calculated as...
0.1252; the international USDX trend and the USD/TWD spot rate of opening price adjustment showed a significant positive relationship, but Monday’s BETA values (β_{Mon}) estimated for Models B1 and B2 were inconsistent. Moreover, during the 2008 financial crisis (β_{2008}) estimated parameters and the real body ratio of the daily candlestick chart (δ), at a significance level of 1%, the results estimated by Models B1 and B2 were significantly less than 0, indicating that in the 2008 financial crisis, if the previous day had a higher USDX return rate, the opening price adjustment of the USD/TWD indicated a significant reverse relationship. The real body ratio of the daily candlestick chart (δ) on the previous day also showed a significant reverse relationship with the opening price adjustment of the USD/TWD spot rate. This exchange rate opening price adjustment phenomenon may be related to the opening of market makers; a deliberate reverse price operation phenomenon.

In Table 3, the price adjusted for the opening-to-closing price on the nth trading day (R_{close/open,n}) estimated the results of the parameter in Models C1 from equation (2), and C2 equations (2) and (5), indicating that the conditional volatility equation of the GJR-GARCH (1, 1) model in Models C2, A2, and B2 were consistent. At a significance level of 1%, we found that β_1, β_{Mon}, β_{2008}, and δ were significantly positive; the international USDX trend and the USD/TWD spot rate adjusted for the opening-to-closing price showed a significant positive relationship, and on Monday trading days, there was a higher BETA value due to the Monday effect. The estimated parameters during the 2008 financial crisis (β_{2008}) and the real body ratio of the daily candlestick chart (δ) also showed significance (greater than 0), indicating that during the 2008 financial crisis, if there was a higher USD return rate on the previous day, then the price adjusted for the opening-to-closing trading period exhibited a significant positive relationship. The real body ratio of the daily candlestick chart (δ) presented a significant positive correlation with the USD/TWD spot rate adjusted for the opening-to-closing trading period with a reference value.

Model D1 (daily change rate of USD/TWD as the dependent variable) is from the original equation (3), adding the change rate of trading value (CTA_t) and value in the direction of the devaluation and appreciation of the day (1(·)·ln(value_t)) to form equation (6). This model does not consider the heterogeneity of residual items and uses OLS to estimate the parameters. In Model D1, the result of the ARCH test (p-value < .01) supports the existence of heteroskedasticity for residuals, thus employed the GJR-GARCH (1, 1) model and adding dummy variables for Mondays and 2008 financial crisis to equation (7) to capture the heterogeneity and asymmetry of exchange rate volatility. This verified the existence of the Monday and 2008 financial crisis effects on the volatility of the exchange rate with significantly different results.

In Model D1, at a significance level of 1%, the BETA values of the International USDX (β), the Monday (β_{Mon}) and 2008 (β_{2008}) trading days, the parameters of the real body ratio of the candlestick chart (δ = 0.0165), the trading value parameters in the direction of the appreciation or devaluation day (γ), and the value change rate parameter (λ) were greater than zero. The estimated VIF was, likewise, less than 2 without multicollinearity, and the R-squared of the model was 0.5001 (adjusted r-squared of 0.4994) showing a certain explanatory ability, but the results of the ARCH test (p-value < .01) confirmed that the residual item exhibited heteroskedasticity.

Considering the heterogeneity of the residual item in the conditional volatility, the estimated parameters of Model D2 were obtained using equation (7), and the parameters of the mean equation were the same as the Model D1 estimations. This supported the BETA value of the International USDX (β), and the parameters of the real body ratio of the candlestick chart (δ = 0.0165). The market trading activity variables (γ), such as trading activity (λ), exhibited a significant positive relationship with the daily USD/TWD rates. The BETA values of the International USDX traded on Mondays (β + β_{Mon}) and during the 2008 financial crisis (β + β_{2008}) were significantly higher than on other trading days, indicating that the delivery time of the information set of the international USDX change and the period of the 2008 financial crisis for the daily USD/TWD spot rates had a significantly higher impact. The parameter results of the conditional volatility equation supported the volatility heterogeneity and asymmetry. At the 1% level of significance, the preceding d and e estimated parameters were all significantly greater than 0. The results showed that Monday trading days and the 2008 financial crisis had a positive effect on exchange rate volatility.

On the right half of Table 4, the previous closing to opening price adjustments (adj R_{close/open}) were incorporated into equation (6), to form equation (8) and we used OLS to estimate the parameters in equation (8). Simultaneously, equations (8) and (7) were used to estimate the parameters of the conditional mean equation and conditional variation equation using the MLE. Models E1 and E2 analyzed the relationships among variables such as the change in the international USDX, the real body ratio of the candlestick chart, the day trading activity, and the opening-to-closing price adjustment (R_{close/open,t}), and we also explored the volatility of the opening-to-closing price. This study aimed to understand the information set of the international USDX return and the real body ratio of the candlestick chart impact on the opening-to-close price adjustment of the currency market.

In Models E1 and E2, the ρ values of −0.7133 and −0.7063 were significantly negative, representing the opening-to-closing price adjustment (R_{close/open,t}) and the post-close to open price adjustment (adj R_{open/close,t}) in a reverse relationship. In equation (3), the adjusted close to opening price could not explain why the error was larger; rather, it made the adjusted opening-to-closing price of (R_{close/open,t}) smaller. The BETA value (β) of the
International USDX was significantly less than 0, indicating that the new international USD trend was in the price of the exchange rate at the opening of the Taipei currency market—with a possible overreaction—which leads to a significant reverse anomaly in the relationship with a price adjustment after the opening-to-closing period. The BETA values of the trading days on a Monday ($\beta_{\text{Mon}}$) and during 2008 ($\beta_{2008}$), the real body ratio parameter of the candlestick chart ($\delta = 0.0165$), the parameter of daily trading value of the depreciation and appreciation direction ($\gamma$), and the parameter of the trading value change rate ($\lambda$) was greater than 0, indicating that these explanatory variables contained a certain degree of relationship with the trading price adjustment of the exchange rate after the opening, and not at the opening of the transaction price; the variable information was fully reflected in the price. In Model E2, the estimation of the conditional volatility equation of the GJR-GARCH $(1,1)$ model was equivalent to the results of Model D2, which supported the price volatility equation of the exchange rate in the opening-to-closing period of a trading day, as well as heterogeneity and asymmetry. During the Monday trading days, when financial markets in Europe and the USA were closed, and during the 2008 financial crisis, there was significant anomalous volatility compared to other trading days.

### Discussion

To establish an explanatory model for exchange rate changes and volatility, this study used the return on overseas USDX of the previous trading day, as well as the real body ratio of the daily candlestick chart of the exchange rate of the previous day, and the daily trading activity to explain the causal factors of exchange rate changes. The results of these models show that part of the USD/TWD spot rate change had a significant relationship to information about changes in the USDX overseas from the previous trading day, thus proving the important reference position of USDX in the TFEM. It was found that the impact of trading information from overseas USDX on the rate adjustment of the USD/TWD spot rate was not limited to the exchange rate adjustment at the opening time, but had a sustained positive effect on the adjustment of the intraday spot exchange rate during the opening-to-closing period.
Moreover, a significant positive relationship between the ratio of the real body of the daily candlestick exchange rate chart from the previous day was proven, rendering it of some reference value to support the analysis of the exchange rate change by the ratio of the real body of the daily candlestick chart in technical analysis. This result confirms that the technical analysis, based on the candlestick chart, can be applied to TFEM. The daily trading value, with consideration for the direction of depreciation and appreciation, showed positive correlations among daily trading value, rate of daily trading value change, and exchange rate change; with these models including the variables of trading activity, we greatly improved the interpretation ability of models of exchange rate changes and indicated the importance of their related trading activities.

The USD/TWD spot rate indicated a lower average daily trading value, and the change ratio of trading value was negative on Mondays, which may be related to the closure of foreign exchange markets in Europe and America at that time. The BETA value of the USDX had a positive effect and a higher level on Mondays, so the sensitivity of the information of international transactions in the transmission time persists for longer, and there will be a past holiday effect on the exchange rate change. In the financial turmoil of 2008, there were significantly higher average daily trading values, with the USD/TWD spot rate undergoing an appreciation effect. In 2008, especially, there was a significant decline in the risk of international USDX changes, with a more stable TWD exchange rate to the USD compared to other important international currencies.

Whether the daily exchange rate or the daily intraday exchange rate changes, the volatility of the USD/TWD spot rate exhibits heterogeneous, clustered, and asymmetric qualities; the news of the depreciation of the TWD in the exchange rate adjustment was significantly more sensitive than corresponding new on currency appreciation. The trading days during the 2008 financial crisis and on Mondays for exchange rate volatility indicated positive effects and significantly larger volatility.

Finally, from our research findings on the TFEM, there has long been a special phenomenon; the closing rate was lower than the opening rate—the closing rate exhibited appreciation compared to the opening rate. Whether this phenomenon was related to the price-making behavior of market markers on the exchange rate, or the market size of currency transactions was too small, requires further study.

**Conclusions**

This study does not consider the trading costs of exchange rates, central bank adjustments to monetary policy, interest rate changes, and other economic factors that may affect exchange rate movements. We focused on the explanatory power and direction of exchange rate changes in the USDX, the indicators of the candlestick chart, and currency trading activity. Based on empirical results, we found that daily trading activity was the primary explanatory factor for the change in the USD/TWD spot rate on the TFEM and that daily exchange rate changes were mainly caused by the trading behavior of participants. This study proved the important reference position of the USDX on the TFEM and found that the impact of information by USDX return rate on exchange rate adjustment was not immediate, indicating the weak efficiency of the TFEM. Moreover, our model results were verified by the defined candlestick line indicator, which confirmed that technical analyses based on the candlestick chart can be used for the TFEM.

The daily USD/TWD exchange rate changes and volatility existed in the Monday and 2008 financial crisis effects. These two effects caused the daily USD/TWD exchange rate in TFEM to show a significant depreciation trend, and the daily volatility was significantly larger. Finally, this study supported the daily volatility of the USD/TWD spot rate with heterogeneity, clustering, and asymmetry. The asymmetry of the volatility of the USD/TWD spot rate was different from that of the UK Pound and Japanese Yen, but the same as that of the Swiss Franc, Canadian Dollar, Australian Dollar, and Singapore Dollar (Kwek & Koay, 2006).

**Declaration of Conflicting Interests**

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author received no financial support for the research, authorship, and/or publication of this article.

**Research Involving Human Participants and/or Animals: Ethical Approval**

This article does not contain any studies with human participants performed by any of the authors.

**ORCID iD**

Ying-Sing Liu https://orcid.org/0000-0002-3161-2136

**References**

Abuaf, N., & Jorion, P. (1990). Purchasing power parity in the long run. *Journal of Finance, 45*(1), 157–174.

Ahmad, M. H., Ping, P. Y., Yaziz, S. R., & Miswan, N. H. (2015). Forecasting Malaysian gold using a hybrid of ARIMA and GJR-GARCH models. *Applied Mathematical Sciences, 9*(30), 1491–1501.

Al-Khazali, O. M., Leduc, G., & Pyun, C. S. (2011). Market efficiency of floating exchange rate systems: Some evidence from Pacific-Asian countries. *Global Finance Journal, 22*(2), 154–168.

Aziz, T., Sadhwan, R., Habibah, U., & Janabi, M. A. M. A. (2020). Volatility spillover among equity and commodity markets. *SAGE Open, 10*(2), 215824402092441. https://doi.org/10.1177/2158244020924418
Baba, N., & Packer, F. (2009). Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08. *Journal of Banking and Finance, 33*(11), 1953–1962.

Bahraini, A. Z., Mohd, S. H., & Soon, S. V. (2011). Purchasing power parity and efficiency of black market exchange rate in African countries. *Emerging Markets Finance and Trade, 47*(5), 52–70.

Bajo, E. (2010). The information content of abnormal trading volume. *Journal of Business Finance and Accounting, 37*(7–8), 950–978.

Bauer, C., & Herz, B. (2004). Technical trading and the volatility of exchange rates. *Quantitative Finance, 4*(4), 399–415.

Bedoui, R., Braiek, S., Guesmi, K., & Chevallier, J. (2019). RETRACTED: On the conditional dependence structure between oil, gold and USD exchange rates: Nested copula based GJR-GARCH model. *Energy Economics, 80*, 876–889. https://doi.org/10.1016/j.eneco.2019.02.002

Chaboud, A., & LeBaron, B. (2001). Foreign-exchange trading volume and Federal Reserve intervention. *Journal of Futures Markets, 21*(9), 851–860.

Chang, P. H. K., & Osler, C. L. (1999). Methodical madness: Technical analysis and the irrationality of exchange-rate forecasts. *Economic Journal, 109*(458), 636–661.

Chen, C. R., Su, Y., & Huang, Y. (2008). Hourly index return autocorrelation and conditional volatility in an EAR–GJR-GARCH model with generalized error distribution. *Journal of Empirical Finance, 15*(4), 789–798.

Chen, W. D. (2018). Effective or manipulated crawling pegged? Examining the efficiency of China’s foreign exchange markets. *Emerging Markets Finance and Trade, 54*(12), 2834–2850.

Choi, Y. J., Kim, D., & Sung, T. (2010). Global crisis, exchange rate response, and economic performance: A story of two countries in East Asia. *Global Economic Review, 39*(1), 25–42.

Clements, K. W., & Lan, Y. (2010). A new approach to forecasting exchange rates. *Journal of International Money and Finance, 29*(7), 1424–1437.

Danielsson, J., Luo, J., & Payne, R. (2012). Exchange rate determination and inter-market order flow effects. *European Journal of Finance, 18*(9), 823–840.

Evans, M. D. D. (2002). FX trading and exchange rate dynamics. *Journal of Finance, 57*(6), 2405–2447.

Fama, E. F. (1970). Efficient capital market: A review of theory and empirical work. *Journal of Finance, 25*, 383–417.

Frömmel, M., Mende, A., & Menkhoff, L. (2008). Order flows, news, and exchange rate volatility. *Journal of International Money and Finance, 27*(6), 994–1012.

Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. *Journal of Finance, 48*(5), 1779–1801.

Hagiwara, M., & Herce, M. A. (1999). Endogenous exchange rate volatility, trading volume and interest rate differentials in a model of portfolio selection. *Review of International Economics, 7*(2), 202–218.

Hsu, P. H., Taylor, M. P., & Wang, Z. (2016). Technical trading: Is it still beating the foreign exchange market?. *Journal of International Economics, 102*, 188–208.

Iyoboyi, M., Muftau, O., & McMillan, D. (2014). Impact of exchange rate depreciation on the balance of payments: Empirical evidence from Nigeria. *Cogent Economics and Finance, 2*, 1–23.

Jiang, C., Jian, N., Liu, T. Y., & Su, C. W. (2016). Purchasing power parity and real exchange rate in Central Eastern European countries. *International Review of Economics and Finance, 44*, 349–358.

Kang, I. B. (1999). International foreign exchange agreements and nominal exchange rate volatility: A GARCH application. *North American Journal of Economics and Finance, 10*(2), 453–472.

Katusiime, L., Shamsuddin, A., & Agbola, F. W. (2015). Foreign exchange market efficiency and profitability of trading rules: Evidence from a developing country. *International Review of Economics and Finance, 35*, 315–332.

Khademalomoom, S., & Narayan, P. K. (2019). Intraday effects of the currency market. *Journal of International Financial Markets, Institutions and Money, 58*, 65–77.

Kwek, K. T., & Koay, K. N. (2006). Exchange rate volatility and volatility asymmetries: An application to finding a natural dollar currency. *Applied Economics, 38*(3), 307–323.

Lei, Q., & Wu, G. (2005). Time-varying informed and uninformed trading activities. *Journal of Financial Markets, 8*(2), 153–181.

Mansfield, P. (1997). The relationship between the trading activities of the Reserve Bank of Australia and movements in the value of the Australian dollar. *International Review of Financial Analysis, 6*(1), 49–61.

McKenzie, M., & Mitchell, H. (2002). Generalized asymmetric power ARCH modelling of exchange rate volatility. *Applied Financial Economics, 12*(8), 555–564.

Melvin, M., & Norrbom, S. C. (2013). *International money and finance: Chapter 14- the monetary approach* (8th ed., pp. 271–284). Copyright Elsevier Inc.

Menkhoff, L., Sarno, L., Schmelzing, M., & Schrimpf, A. (2016). Information flows in foreign exchange markets: Dissecting customer currency trades. *Journal of Finance, 71*(2), 601–634.

Moore, M. J., & Payne, R. (2011). On the sources of private information in FX markets. *Journal of Banking and Finance, 35*(5), 1250–1262.

Osler, C. L. (2003). Currency orders and exchange rate dynamics: An explanation for the predictive success of technical analysis. *Journal of Finance, 58*(5), 1791–1819.

Payne, R. (2003). Informed trade in spot foreign exchange markets: An empirical investigation. *Journal of International Economics, 61*(2), 307–329.

Shahbaz, M., Jalil, A., & Islam, F. (2012). Real exchange rate changes and the trade balance: The evidence from Pakistan. *International Trade Journal, 26*(2), 139–153.

Tsuyuguchi, Y., & Wooldridge, P. D. (2008). The evolution of trading activity in Asian foreign exchange markets. *Emerging Markets Review, 9*(4), 231–246.