Lead-lag relationship, volatility asymmetry, and overreaction phenomenon

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Abstract

Purpose – The purpose of the paper is to investigate the price interrelationship between the Taiwanese and US financial markets.

Design/methodology/approach – The trivariate GJR-GARCH (1,1) model and event study were employed to investigate volatility asymmetry and overreaction phenomenon, respectively.

Findings – The empirical results show that return volatility reveals the asymmetric phenomenon, and the holding period returns on US index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market are an important reference for investors in the Taiwanese stock market. Additionally, the paper presents an overreaction of the Taiwan Stock Exchange Capitalization Weighted Stock Index to a drastic price rise of E-min NASDAQ 100 Index futures at the opening of the Taiwanese stock market.

Research limitations/implications – This paper deletes the observations arising from the different national holidays of the USA and Taiwan, to have the same number of observations in both markets, which might contaminate the empirical results.

Practical implications – Investors in the Taiwanese stock market tend to pay more attention to the fluctuations in the share prices of high-technological companies in the USA.

Originality/value – Most of the previous studies regarding price transmission between the Taiwanese and US stock markets focused mainly on the Taiwanese market reactions to the overnight returns of the US market. This paper enlarges the current field by examining the lead-lag relationship, the volatility asymmetry, and the overreaction phenomenon between the Taiwanese and US financial markets according to the most updated US stock index information.

Keywords United States of America, Taiwan, Stock markets, Stock prices

Paper type Research paper

1. Introduction

To generate profitable returns in the internationalized investment environment, a good knowledge of the price interrelationship between international financial markets is necessary. Because the US financial market is the largest in the world, previous studies on price interrelationship in the international financial market have mostly focused on price transmission between the US financial market and the markets of other countries.

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Masih and Masih (2002) and Yang and Bessler (2004) found that the both US and British financial markets are world market leaders. Yang *et al.* (2006) and Aloui (2007) pointed out that the US market has long-term price relationships with some European stock markets and causality transmissions exist between them. As mentioned above, the US stock market inevitably has an impact on other stock markets, including that of Taiwan. As a result, early studies such as that by Becker *et al.* (1992), Liu *et al.* (1996) and Hsu and Tsai (2008) revealed the evidence of price information transmission between the US and Taiwanese stock markets.

Although previous studies have proven the existence of price transmission between the US and Taiwanese stock markets, they made use of the daily returns of the US and Taiwanese stock markets for empirical analysis (i.e. they adopted the closing prices of the two stock markets at normal trading hours to calculate daily returns). However, the two stock markets trade at different times – the Taiwan Stock Exchange Corporation (TWSE) trades from 9.00 p.m. to 1.30 a.m. Eastern Daylight Time (EDT), and the New York Stock Exchange trades from 9.30 a.m. to 4.00 p.m. EDT. Therefore, the past research may have ignored important information that emerged between the closing of normal trading hours of the US stock market and the opening of trading on the Taiwanese stock market (4.00-9.00 p.m. EDT). Neglecting this information may lead to a reduction in the accuracy of empirical results. Taiwanese stock market investors can refer to up-to-date information by making investment decisions at 9.00 p.m. EDT as the Taiwan stock market opens, and not basing decisions only on the 4.00 p.m. EDT closing price data of the US stock market. Consequently, the use of "the most updated information of the US stock index" to examine the price transmission between the US and Taiwanese financial markets can help to improve accuracy.

Earlier studies on price interrelationships were ignorant of the effect of the most updated information on price transmission between the US and Taiwanese financial markets, and mostly highlighted price transmission, volatility transmission, and lead-lag relationship between the two markets. However, according to the empirical findings of behavioral finance (Poteshman, 2001; Hirschey, 2003; Madura and Richie, 2004), it is more likely for investors of one financial market to overemphasize the importance of rare events in another market and overreact. A rare event often results in drastic price changes that seldom previously occurred in the financial markets, and Michelfelder and Pandya (2005) had revealed that US shocks are rapidly transmitted to the remainder of the world. As a result, there is a need to examine the overreaction of a certain market to drastic price changes in the US stock index. In particular, retail investors are the main participants in the Taiwanese stock market and they are more inclined to overemphasize the importance of events regarding drastic price changes in the US stock index. Hence, overreaction is more likely to be observed in the Taiwanese stock market.

The statistical properties of the stock return data play an important role in the price transmission between two markets. Previous literature (Mandelbrot, 1963) presented the time series data for stock returns as having the characteristic of autoregressive conditional heteroskedasticity (ARCH), but not satisfying the assumption of constant conditional variance. Accordingly, the ARCH model and generalized ARCH (GARCH) model were proposed. Earlier studies (Theodossiou and Lee, 1993) adopted the multivariate GARCH model and obtained an effective estimation result of volatility transmission, yet Bollerslev (1986) believed that the GARCH model is likely to underestimate actual volatility following large negative return surprises and may also overestimate actual volatility following large positive return surprises. In terms of the above-mentioned asymmetric volatility phenomenon, many continuous studies developed asymmetric GARCH models to improve the prediction of volatility. Among those studies, Nelson (1991) suggested the exponential GARCH model to capture volatility asymmetry and volatility transmission effects. Glosten *et al.* (1993) used the GJR-GARCH model to explore the existence of significant asymmetry results between the positive return impact (good news) and the negative return impact of the previous period (bad news). For the performance of a family of GARCH models, Engle and Ng (1993) pointed out that among various asymmetric GARCH models, the GJR-GARCH model has the optimal and efficient command of asymmetry results. Hentschel (1995) analyzed the prediction of popular symmetric and asymmetric GARCH models and found that daily US stock returns reject symmetric GARCH models because of the volatility asymmetry: the symmetric GARCH models frequently estimate conditional variances that are more than twice as high as those from the asymmetric GARCH models.

This study aims to investigate the price transmission, the volatility asymmetry, and the overreaction effect between the Taiwanese and US financial markets. Further, this study differs from the previous literature in three distinct ways: first, previous studies primarily investigated the price interrelationship between these two markets using daily returns data. This study, on the other hand, investigates the holding period returns on the US index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market, to examine the price transmission between the Taiwanese and US financial markets. Second, previous studies commonly adopted the GARCH model to examine the volatility transmission, and thereby failed to capture the different influences of positive and negative unanticipated shocks on conditional volatility, while this study employs a trivariate GJR-GARCH (1,1) model to investigate return volatility asymmetry. Finally, in contrast with previous studies that seldom explored the overreaction between these two markets, this study examines the overreaction phenomenon associated with the Taiwanese stock market in terms of the most updated US index futures information. On the other hand, in order to decrease the possibility of contaminated empirical results, this study ensures the robustness of its analysis by ruling out observations during the period of the 9/11 terrorist attacks in 2001.

The remainder of this paper is organized as follows. Section 2 describes the methodology and data pertaining to our analyses. Section 3 presents our empirical findings. Section 4 investigates the impact of the 9/11 terrorist attacks on our empirical findings, and the final section offers conclusions.

2. Data and methodology

2.1 Data

This study began by adopting daily return data to examine the price interrelationships between the Taiwan Stock Exchange Capitalization Weighted Stock Index (TAIEX), the S&P 500 Index, and the NASDAQ Composite Index. In order to adopt the most updated information to examine the dynamic price relationship between the US and Taiwanese stock indexes, this study used the holding period returns on the stock index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market; these were used to investigate the price transmission across the TAIEX, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures.

Owing to the first nearby futures contract having higher trading volume and smaller basis risk compared with the other calendar month contracts, this study adopted the return data of the first nearby futures contract for its empirical investigation. This study selected the E-mini S&P 500 Index futures and E-mini NASDAQ 100 Index futures as the research subjects because some index futures electronic trading continues beyond the normal trading hours of the US stock market; the E-mini S&P 500 Index futures and E-mini NASDAQ 100 Index futures trade at high volumes during this period. Accordingly, this holding period return data represented the most updated information.

Regarding the adjustment in the holding period returns for the weekends (and the longer time-lag), this study made the adjustment as follows:

- Because this study adopted the holding period returns on the US index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market for each day, if trading days between the two markets differed due to national holidays (non-weekends) or other factors, this study would delete the observation. For example, on July 4, 2002 (Tuesday), the US futures market was closed due to the US national holiday, but in Taiwan it was a trading day (due to the time difference, 4.30-9.00 p.m. EDT on July 4 was 4.30-9.00 a.m. China Standard Time (CST) on July 5). This study, therefore, deleted the observation for that trading day.
- Different trading days on weekends due to time differences between Taiwan and the USA will be reserved for observation. For instance, on October 18, 2002 (Friday), from 4.30 p.m. to 9.00 p.m. EDT it is October 19, 2002 (Saturday), from 4.30 a.m. to 9.00 a.m. CST; on that day, the stock market in Taiwan was closed because it was a weekend. Yet, October 21, 2002 (Monday), was a trading day in Taiwan and we reserved the observation on that day. Notably, the holding period returns on Friday under the above situation were different from those for Monday-Thursday. This study adopted the holding period returns from the opening of the US index futures electronic trading on Friday to its closing on Saturday (i.e. 4.15 p.m. EDT) in order to represent the most updated information of the US stock index before the opening of the Taiwanese stock market on Monday; while we adopted the holding period returns on the US index futures from 4.30 p.m. to 9.00 p.m. EDT for Tuesday-Thursday (from 6.00 to 9.00 p.m. EDT for Monday).

The daily and holding period returns data were both derived from the *Taiwan Economic Journal* database, the TradeStation, and Reuters for the period from January 1, 2000 to January 31, 2004, providing 981 observations for each index series in total.

2.2 The test of lead-lag relationship

In order to, respectively, examine the lead-lag relationships between "the TAIEX and S&P 500 Index," "the TAIEX and NASDAQ Composite Index," "the TAIEX and E-mini S&P 500 index futures," and "the TAIEX and E-mini NASDAQ 100 index futures," this study, according to the method of Chiang and Fong (2001), established its research model with a generalized method of moment (GMM) to estimate the regression coefficients. We began by estimating equations (1) to (5) and then error items acquired from the equations replaced the actual returns on the TAIEX, the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures. The equations (1) to (5) are described as follows:

$$R_{tw,t} = a_{tw} + b_{tw}R_{tw,t-1} + r_{tw,t}, \quad (1)$$

$$R_{sp,t} = a_{sp} + b_{sp}R_{sp,t-1} + r_{sp,t}, \quad (2)$$

$$R_{nd,t} = a_{nd} + b_{nd}R_{nd,t-1} + r_{nd,t}, \quad (3)$$

$$R_{sf,t} = a_{sf} + b_{sf}R_{sf,t-1} + r_{sf,t}, \quad (4)$$

$$R_{nf,t} = a_{nf} + b_{nf}R_{nf,t-1} + r_{nf,t}, \quad (5)$$

where $R_{tw,\ t}$ is the daily returns on the TAIEX for day t; $R_{sp,\ t}$ is the daily returns on the S&P 500 Index for day t; $R_{nd,\ t}$ is the daily returns on the NASDAQ Composite Index for day t; $R_{sf,\ t}$ is the holding period returns on the E-mini S&P 500 Index futures from the opening of the E-mini S&P 500 Index futures to the opening of the Taiwanese stock market for day t; $R_{nf,\ t}$ is the holding period returns on the E-mini NASDAQ 100 Index futures from the opening of the E-mini NASDAQ 100 Index futures to the opening of the Taiwanese stock market for day t; $r_{tw,t}, r_{sp,t}, r_{nd,t}, r_{sf,t}$, and $r_{nf,\ t}$ refer to the proxy variables of $R_{tw,t}, R_{sp,t}, R_{nd,t}, R_{sf,t}$, and $R_{nf,t}$, respectively; $a_{tw}, a_{sp}, a_{nd}, a_{sf}, a_{nf}, b_{tw}, b_{sp}, b_{nd}, b_{sf}$, and b_{nf} are regression coefficients.

After acquiring the proxy variables for the various indices, this study estimated the lead-lag relationship in equations (6) to (9):

$$r_{tw,t} = c_{sp} + \sum_{k=-m}^{-1} d_{k,sp}r_{sp,t+k} + d_{0,sp}r_{sp,t} + \sum_{l=1}^{m} d_{l,sp}r_{sp,t+l} + \eta_{tw,t}, \quad (6)$$

$$r_{tw,t} = c_{nd} + \sum_{k=-m}^{-1} d_{k,nd}r_{nd,t+k} + d_{0,nd}r_{nd,t} + \sum_{l=1}^{m} d_{l,nd}r_{nd,t+l} + \psi\varepsilon_{tw,t}, \quad (7)$$

$$r_{tw,t} = c_{sf} + \sum_{k=-m}^{-1} d_{k,sf}r_{sf,t+k} + d_{0,sf}r_{sf,t} + \sum_{l=1}^{m} d_{l,sf}r_{sf,t+l} + \lambda_{tw,t}, \quad (8)$$

$$r_{tw,t} = c_{nf} + \sum_{k=-m}^{-1} d_{k,nf}r_{nf,t+k} + d_{0,nf}r_{nf,t} + \sum_{l=1}^{m} d_{l,nf}r_{nf,t+l} + \xi_{tw,t}, \quad (9)$$

where m refers to the period number of lead-lag relationships (assumed as three); $c_{sp}, c_{nd}, c_{sf}, c_{nf}, d_{k,sp}, d_{k,nd}, d_{k,sf}, d_{k,nf}, d_{0,sp}, d_{0,nd}, d_{0,sf}, d_{o,nf}, d_{l,sp}, d_{l,nd}, d_{l,sf}$, and $d_{l,\ nf}$ are regression coefficients; $\eta_{tw,t}, \psi_{tw,t}, \lambda_{tw,t}$, and $\xi_{tw,\ t}$ are error items for day t. If $d_{k,sp}, d_{k,nd}, d_{k,sf}$, and $d_{k,nf}$ ($d_{l,sp}, d_{l,nd}, d_{l,sf}$, and $d_{l,\ nf}$) are significantly different from zero, then the TAIEX leads (lags) the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures by k (l) periods, respectively. Moreover, this study adopted the proposal of Chiang and Fong (2001) and assumed the period number of lead-lag relationships as three lags/leads. If the first three lead/lag coefficients were all significantly different from 0, we added the period number of lead-lag relationships until there was at least one lead/lag coefficient that was insignificant. Because the coefficient of the fourth lags/leads was insignificantly different from 0, we used three lags/leads for our study (we did not report the result of the four lags/leads for the sake of brevity).

2.3 Trivariate GJR-GARCH (1,1) model

Although many studies have used a symmetric GARCH model of Bollerslev (1986) to capture the conditional heteroskedasticity in financial asset returns, Hentschel (1995) applied the family of GARCH models to daily abnormal returns on US stocks and found that negative return surprises generate higher volatility than equally positive return surprises. Therefore, the direct application of the symmetric GARCH model does not capture an asymmetric effect correctly when the volatility asymmetry exists for both the US and Taiwanese financial markets. Our model was based on the GJR-GARCH model of Glosten *et al.* (1993) to examine volatility transmission and volatility asymmetry between the daily returns (or holding period returns) in different markets, since Engle and Ng (1993) pointed out that the GJR-GARCH model has superior performance at capturing the asymmetry. The generic definition of the GJR-GARCH model is described as follows:

$$R_{tw(sp,nd,sf,nf),t} = \theta_0 + \theta_1 R_{tw(sp,nd,sf,nf),t-1} + \varepsilon_{tw(sp,nd,sf,nf),t}, \quad \varepsilon_{tw(sp,nd,sf,nf),t}|\Omega_{t-1} \sim N(0, h_{tw(sp,nd,sf,nf),t}), \tag{10}$$

$$h_{tw(sp,nd,sf,nf),t} = \alpha_0 + \sum_{z=1}^{q} \alpha_z \varepsilon^2_{tw(sp,nd,sf,nf),t-z} + \sum_{j=1}^{p} \beta_j h_{tw(sp,nd,sf,nf),t-j} + \gamma \varepsilon^2_{tw(sp,nd,sf,nf),t-1} I_{tw(sp,nd,sf,nf),t-1}, \tag{11}$$

where p and q are the number of lag periods on the conditional variance (h_t) and unconditional variance (ε_t), respectively; Ω_{t-1} is the information set for day $t-1$. In terms of the selection of the lag structure on the GJR-GARCH model, this study referred to Francis *et al.* (2006) and assumed that both the number of the lag periods on the conditional variance and unconditional variance are 1. In order to justify the assumption of the lag structure, we also compared the models of GJR-GARCH (1,1), GJR-GARCH (1,2), GJR-GARCH (2,1), and GJR-GARCH (2,2). When both the number of the lag periods on the conditional variance and unconditional variance were 1, the minimum values of Akaike's information criterion (AIC) and Schwartz's Bayesian criterion (SBC) were found (we did not report the values of AIC and SBC for the sake of brevity); as a result this study used a trivariate GJR-GARCH (1,1) model to examine volatility asymmetry.

With the adoption of the trivariate GJR-GARCH (1,1) model, this study investigated whether an asymmetric effect existed between the positive and negative returns of the lagged periods and the current one. We described the trivariate GJR-GARCH(1,1) model used by this study as follows:

(1) A trivariate GJR-GARCH(1,1) model for the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index:

$$R_{tw,t} = \theta_{10} + \theta_{11} R_{tw,t-1} + \varepsilon_{tw,t}, \tag{12}$$

$$R_{sp,t} = \theta_{20} + \theta_{21} R_{tw,t-1} + \theta_{22} R_{sp,t-1} + \varepsilon_{sp,t}, \tag{13}$$

$$R_{nd,t} = \theta_{30} + \theta_{31} R_{tw,t-1} + \theta_{32} R_{sp,t-1} + \theta_{33} R_{nd,t-1} + \varepsilon_{nd,t}, \tag{14}$$

$$\{\varepsilon_{tw,t}, \varepsilon_{sp,t}, \varepsilon_{nd,t}\}' = \varepsilon_t|\Omega_{t-1} \sim N(0, H_t); \quad H_t = \{h_{tw,t}, h_{sp,t}, h_{nd,t}\}, \tag{15}$$

$$h_{tw,t} = \alpha_{10} + \alpha_{11}\varepsilon^2_{tw,t-1} + \beta_{11} h_{tw,t-1} + \gamma_{11}\varepsilon^2_{tw,t-1} I_{tw,t-1}, \tag{16}$$

$$h_{sp,t} = \alpha_{20} + \alpha_{21}\varepsilon^2_{tw,t-1} + \alpha_{22}\varepsilon^2_{sp,t-1} + \beta_{21} h_{tw,t-1} + \beta_{22} h_{sp,t-1} + \gamma_{22}\varepsilon^2_{sp,t-1} I_{sp,t-1}, \tag{17}$$

$$h_{nd,t} = \alpha_{30} + \alpha_{31}\varepsilon^2_{tw,t-1} + \alpha_{32}\varepsilon^2_{sp,t-1} + \alpha_{33}\varepsilon^2_{nd,t-1} + \beta_{31}h_{tw,t-1} + \beta_{32}h_{sp,t-1} + \beta_{33}h_{nd,t-1} + \gamma_{33}\varepsilon^2_{nd,t-1}I_{nd,t-1}, \quad (18)$$

$$h_{uv,t} = \rho_{uv}(h_{u,t} \times h_{v,t})^{0.5}; \quad u \neq v; \quad u: tw, sp, nd; \quad v: tw, sp, nd. \quad (19)$$

(2) A trivariate GJR-GARCH(1,1) model for the TAIEX, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures:

$$R_{tw,t} = \theta'_{10} + \theta_{11}R_{tw,t-1} + \varepsilon_{tw,t}, \quad (20)$$

$$R_{sf,t} = \theta'_{20} + \theta'_{21}R_{tw,t-1} + \theta'_{22}R_{sf,t-1} + \varepsilon_{sf,t}, \quad (21)$$

$$R_{nf,t} = \theta'_{30} + \theta'_{31}R_{tw,t-1} + c'_{32}R_{sf,t-1} + \theta'_{33}R_{nf,t-1} + \varepsilon_{nf,t}, \quad (22)$$

$$\{\varepsilon_{tw,t}, \varepsilon_{sf,t}, \varepsilon_{nf,t}\}' = \varepsilon'_t|\Omega'_{t-1} \sim N(0, H'_t); \quad H'_t = \{h_{tw,t}, h_{sf,t}, h_{nf,t}\}, \quad (23)$$

$$h_{tw,t} = \alpha'_{10} + \alpha'_{11}\varepsilon^2_{tw,t-1} + \beta'_{11}h_{tw,t-1} + \gamma'_{11}\varepsilon^2_{tw,t-1}I_{tw,t-1}, \quad (24)$$

$$h_{sf,t} = \alpha'_{20} + \alpha'_{21}\varepsilon^2_{tw,t-1} + \alpha'_{22}\varepsilon^2_{sf,t-1} + \beta'_{21}h_{tw,t-1} + \beta'_{22}h_{sf,t-1} + \gamma'_{22}\varepsilon^2_{sf,t-1}I_{sf,t-1}, \quad (25)$$

$$h_{nf,t} = \alpha'_{30} + \alpha'_{31}\varepsilon^2_{tw,t-1} + \alpha'_{32}\varepsilon^2_{sf,t-1} + \alpha'_{33}\varepsilon^2_{nf,t-1} + \beta'_{31}h_{tw,t-1} + \beta'_{32}h_{sf,t-1} + \beta'_{33}h_{nf,t-1} + \gamma'_{33}\varepsilon_{nf,t-1}I_{nf,t-1}, \quad (26)$$

$$h_{uv,t} = \rho_{uv}(h_{u,t} \times h_{v,t})^{0.5}; \quad u \neq v; \quad u: tw, sf, nf; \quad v: tw, sf, nf. \quad (27)$$

where, when $\varepsilon_{tw(sp,nd,sf,nf),t-1} < 0$ (the abnormal return on day $t-1$ is less than zero), $I_{tw(sp,nd,sf,nf),t-1} = 1$; when $\varepsilon_{tw(sp,nd,sf,nf),t-1} \geq 0$ (the abnormal return on day $t-1$ is zero or a positive value), $I_{tw(sp,nd,sf,nf),t-1} = 0$; ρ_{uv} is the correlation coefficient between ε_u and ε_v.

According to equations (12)-(27), the error term of the lagged period, $\varepsilon_{tw(sp,nd,sf.nf),t-1}$, refers to the deviation from the expected returns in the previous day; therefore, $\alpha_{11}, \alpha_{21}, \alpha_{22}, \alpha_{31}$, and α_{32} ($\alpha'_{11}, \alpha'_{21}, \alpha'_{22}, \alpha'_{31}$, and α'_{32}) are the influence level of the previous day's unanticipated new information on today's return volatility. γ_{11}, γ_{22}, and γ_{33} ($\gamma'_{11}, \gamma'_{22}$, and γ'_{33}) refer to the measure of volatility asymmetry. The conditional variance of error term in the lagged period, $h_{tw(sp,nd,sf,nf),t-1}$, presents the return volatility of the previous day. Because the return volatility of the previous day is influenced by information from a day in advance, $\beta_{11}, \beta_{21}, \beta_{22}, \beta_{31}, \beta_{32}$, and β_{33} ($\beta'_{11}, \beta'_{21}, \beta'_{22}, \beta'_{31}, \beta'_{32}$, and β'_{33}) refer to the influence level of information from the previous day on today's return volatility, that is, the impact of old information.

When estimating the trivariate GJR-GARCH (1,1) model, this study referred to Bollerslev (1986) and assumed that the error terms follow a conditional normal distribution, and the maximum likelihood estimation (MLE) is introduced for estimating parameters. For the measure of volatility asymmetry, the null and alternative hypotheses are $\gamma_{11(22,33)} \leq 0$ and $\gamma_{11(22,33)} > 0$ or $\gamma'_{11(22,33)} \leq 0$ and $\gamma'_{11(22,33)} > 0$. If the null hypothesis is rejected, there is an asymmetric phenomenon and according to the definition of $I_{tw(sp,nd,sf,nf),t-1}$, negative information exerts a stronger influence on the stock price of the current day than positive information.

2.4 Event study

In addition to the investigations on lead-lag relationship and volatility asymmetry, we investigated the overreaction of investors in the Taiwanese stock market toward the drastic changes in the price of US stock index futures. This study divided drastic changes in the price of US stock index futures into drastic rise in the price of US stock index futures and drastic fall in the price of US stock index futures. Drastic changes refer to rare and extreme fluctuations in the price of US stock index futures. If the return distribution of US stock index futures is close to normal distribution, 15.87 per cent of the observed US index futures returns are larger than "the sum of the mean and standard deviation of US index futures returns;" meanwhile, 15.87 per cent of the observed US index futures returns are smaller than "the difference between the mean and standard deviation of US index futures returns." Because the above situation is a "rare" and "extreme" price change, this study calculated the mean and standard deviation of US stock index futures returns during the research period and defined a drastic rise in the price of US stock index futures as the returns on US index futures for a certain day that were larger than the sum of the mean and standard deviation of US index futures returns; a drastic fall in the price of US stock index futures was defined as the returns on US stock index futures for a certain day that were smaller than the difference between the mean and standard deviation of US index futures returns.

This study adopted the event study to examine whether the Taiwanese stock market overreacts to extreme returns on the US index futures. Specifically, the event refers to what happens on day 0, from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market. We thus define a good (bad) surprise as the event wherein the holding period returns on the US index futures for the above-mentioned period were above (below) the sum (difference) of the mean and standard deviation of holding period returns across all observations during the research period. We estimated the regression model using daily returns during the 60-day pre-announcement period from day −80 to day −21 as follows:

$$\mathrm{R_{i,T,t}} = \alpha_\mathrm{i} + \beta_\mathrm{i}\mathrm{R_{i,A,t}} + \mathrm{e_{i,t}} \quad \text{for } t = -80, \ldots, -21, \tag{28}$$

where $R_{i,\,T,\,t}$ refers to the daily returns on the TAIEX for day t due to surprise i, $\mathrm{R}_{i,A,t}$ is the holding period returns on the E-mini S&P 500 Index futures (E-mini NASDAQ 100 Index futures) between the opening of the US index futures electronic trading and the opening of the Taiwanese stock market for day t as a result of surprise i, and e_{it} is the error term for day t due to surprise i.

Next, this study calculated the daily abnormal returns (ARs) during the event period from day −10 to day 10, the average abnormal returns (AARs) across all good (bad) surprises for day t, and the cumulative AARs (CAARs) for days t to $t+h$ as follows:

$$\mathrm{AR_{i,T,t}} = \mathrm{R_{i,T,t}} - \widehat{\mathrm{R}}_{\mathrm{i,T,t}}, \quad \text{for } t = -10, \ldots, 10, \tag{29}$$

$$\mathrm{AAR}_{t,T} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{AR_{i,T,t}}, \quad \text{for } t = -10, \ldots, 10, \tag{30}$$

$$\mathrm{CAAR}_{t,t+h,T} = \sum_{\mathrm{w=t}}^{\mathrm{t+h}} \mathrm{AAR_{w,T}}, \tag{31}$$

where $\mathrm{AR}_{i,\,T,\,t}$ is the abnormal returns on the TAIEX for day t due to surprise i; $\hat{R}_{i,T,t}$ is the expected returns on the TAIEX for day t due to surprise i; $AAR_{t,\,T}$ is the average abnormal returns on the TAIEX for day t; N is the number of good (bad) surprises; $CAAR_{t,t+h,T}$ is the cumulative average abnormal returns on the TAIEX for days t to $t+h$.

We adopted the method of Brown and Warner (1985) to test whether $CAAR_{t,t+h,T}$ was significantly different from zero. The testing method is described as follows:

H0. $\mathrm{CAAR_{t,t+h,T}} = 0$

H1. $\mathrm{CAAR_{t,t+h,T}} \neq 0$

$$t_{59} = \frac{\mathrm{CAAR_{t,t+h,T}}}{\sqrt{h+1}\sigma_{\mathrm{AAR,T}}}, \tag{32}$$

where:

$$\sigma^2_{\mathrm{AAR,T}} = \frac{1}{59}\sum_{t=-80}^{-21}\left(\mathrm{AAR_{t,T}} - \overline{\mathrm{AAR_T}}\right)^2 \text{ and } \overline{\mathrm{AAR_T}} = \frac{1}{100}\sum_{t=-80}^{-21}\mathrm{AAR_{t,T}}.$$

3. Empirical results

3.1 The result of the lead-lag relationship between the Taiwanese and US financial markets

Before testing the lead-lag relationship between the financial markets of the US and Taiwan, this study adopted the augmented Dickey-Fuller unit root test of Dickey and Fuller (1981) to avoid spurious regression resulting from a non-stationary data structure when testing the stationary characteristics of the return data of the TAIEX, the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures. Table I shows the results of "the pure random walk model,"

Indices		Pure random walk model	A drift term	A drift and linear trend
TAIEX	DF	−27.81*	−27.79*	−27.79*
	ADF	−14.24*	−14.24*	−14.24*
S&P 500 Index	DF	−29.54*	−29.52*	−29.55*
	ADF	−15.00*	−14.99*	−15.047*
NASDAQ Composite Index	DF	−31.05*	−31.03*	−31.10*
	ADF	−15.14*	−15.13*	−15.24*
E-mini S&P 500 Index futures	DF	−29.51*	−29.50*	−30.50*
	ADF	−15.04*	−15.04*	−15.11*
E-mini NASDAQ 100 Index futures	DF	−30.52*	−29.54*	−30.57*
	ADF	−15.14*	−15.14*	−15.24*

Notes: Significant at: *1 per cent level; the critical values at 1 per cent significance level for the pure random walk model, the model with a drift item, and the model with a drift and linear time trend are −2.57, −3.44, −3.97, respectively; this study adopted the augmented Dickey-Fuller unit root test of Dickey and Fuller (1981) to test the stationary characteristics of the return data of the TAIEX, the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures; three models of the augmented Dickey-Fuller unit root test (i.e. the pure random walk model, the model with a drift item, and the model with a drift and linear time trend) are used in this study and the estimation horizon is from January 1, 2000 to January 31, 2004, providing 981 observations for each index series in total

Table I.
The result of unit root test

"the model with a drift item," and "the model with a drift and linear time trend," respectively. According to the results of the three models in Table I, the return data of the various indices all display stationary characteristics.

After confirming these stationary characteristics, this study adopted the GMM to estimate the regression coefficients of equations (6) to (9). Table II shows the result of the lead-lag relationship for the financial markets of the USA and Taiwan. Panel A of Table II demonstrates that the coefficients of the current period ($d_{0,sp}$ and $d_{0,\ nd}$) are statistically significantly positive, indicating contemporaneous correlation of the TAIEX and S&P 500 Index as well as the TAIEX and NASDAQ Composite Index. In addition, Panel A of Table II also shows that coefficients $d_{-2,nd}, d_{-1,nd},$ and $d_{1,nd}$ are significantly more than zero, indicating the NASDAQ Composite Index led the TAIEX by two periods while the TAIEX only led the NASDAQ Composite Index by one period. On the other hand, coefficients $d_{-3,sp}, d_{-2,sp}, d_{-1,sp},$ and $d_{1,sp}$ on Panel A of Table II are

Table II.
The result of lead-lag relationship

Coefficient	TAIEX and S&P 500 Estimated value	TAIEX and S&P 500 t-value	TAIEX and NASDAQ Estimated value	TAIEX and NASDAQ t-value
Panel A. TAIEX, S&P 500, and NASDAQ Composite Index				
$c_{0,sp}/c_{0,nd}$	0.0003	0.49	0.0004	0.62
$d_{-3,sp}/d_{-3,nd}$	0.08	1.98^{*}	0.02	0.98
$d_{-2,sp}/d_{-2,nd}$	0.13	3.02^{**}	0.04	2.04^{*}
$d_{-1,sp}/d_{-1,nd}$	0.10	2.24^{*}	0.08	4.16^{**}
$d_{0,sp}/d_{0,nd}$	0.36	8.49^{**}	0.18	8.87^{**}
$d_{1,sp}/d_{1,nd}$	0.09	2.08^{*}	0.06	2.89^{**}
$d_{2,sp}/d_{2,nd}$	−0.03	−0.61	−0.02	−0.87
$d_{3,sp}/d_{3,nd}$	0.002	0.05	−0.02	−0.94
Panel B. TAIEX, E-mini S&P 500 Index futures, and E-mini NASDAQ 100 Index futures				
$c_{0,sf}/c_{0,nf}$	0.0003	0.57	0.0003	0.54
$d_{-3,sf}/d_{-3,nf}$	0.07	1.56	0.02	0.95
$d_{-2,sf}/d_{-2,nf}$	0.13	2.99^{**}	0.03	1.63
$d_{-1,sf}/d_{-1,nf}$	0.10	2.24^{*}	0.08	4.02^{**}
$d_{0,sf}/d_{0,nf}$	0.36	8.44^{**}	0.17	8.63^{**}
$d_{1,sf}/d_{1,nf}$	0.10	2.33^{*}	0.06	3.21^{**}
$d_{2,sf}/d_{2,nf}$	−0.04	−0.82	−0.02	−1.03
$d_{3,sf}/d_{3,nf}$	0.01	0.18	−0.005	−0.23

Notes: Significance at: *5 and **1 per cent levels; the estimation horizon is from January 1, 2000 to January 31, 2004 (981 observations for each index series) and the parameters are estimated from the following equations:

$$\mathrm{r_{tw,t}} = \mathrm{c_{sp}} + \sum_{\mathrm{k}=-\mathrm{m}}^{-1} \mathrm{d_{k,sp} r_{sp,t+k}} + \mathrm{d_{0,sp} r_{sp,t}} + \sum_{\mathrm{l}=1}^{\mathrm{m}} \mathrm{d_{l,sp} r_{sp,t+l}} + \eta_{\mathrm{tw,t}},$$

$$\mathrm{r_{tw,t}} = \mathrm{c_{nd}} + \sum_{\mathrm{k}=-\mathrm{m}}^{-1} \mathrm{d_{k,nd} r_{nd,t+k}} + \mathrm{d_{0,nd} r_{nd,t}} + \sum_{\mathrm{l}=1}^{\mathrm{m}} \mathrm{d_{l,nd} r_{nd,t+l}} + \varepsilon_{\mathrm{tw,t}},$$

$$\mathrm{r_{tw,t}} = \mathrm{c_{sf}} + \sum_{\mathrm{k}=-\mathrm{m}}^{-1} \mathrm{d_{k,sf} r_{sf,t+k}} + \mathrm{d_{0,sf} r_{sf,t}} + \sum_{\mathrm{l}=1}^{\mathrm{m}} \mathrm{d_{l,sf} r_{sf,t+l}} + \lambda_{\mathrm{tw,t}},$$

$$\mathrm{r_{tw,t}} = \mathrm{c_{nf}} + \sum_{\mathrm{k}=-\mathrm{m}}^{-1} \mathrm{d_{k,nf} r_{nf,t+k}} + \mathrm{d_{0,nf} r_{nf,t}} + \sum_{\mathrm{l}=1}^{\mathrm{m}} \mathrm{d_{l,nf} r_{nf,t+l}} + \xi_{\mathrm{tw,t}},$$

where m refers to the period number of lead-lag relationship. If $\mathrm{d_{k,sp}, d_{k,nd}, d_{k,sf},}$ and $\mathrm{d_{k,nf}}$ ($\mathrm{d_{l,sp}, d_{l,nd}, d_{l,sf},}$ and $\mathrm{d_{l,nf}}$) are significantly different from zero, then the TAIEX leads (lags) the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures by k (l) periods, respectively all a significantly positive value. As a result, the S&P 500 Index led the TAIEX by three periods while the TAIEX only led the S&P 500 Index by one period. The above results correspond to Fernandez's (2005) price spillovers from North America to Asia. Overall, empirical evidence indicates that there is a lead-lag relationship in the stock markets of the US and Taiwan, but the influence of the US stock market on the Taiwanese stock market is stronger than that of the Taiwanese stock market on the US stock market.

To examine the influence of the most updated information and the price discovery ability of the futures contract, this study explored the lead-lag relationship between the TAIEX and the most updated US stock index information (the holding period returns on the US index futures from the opening of the US index futures electronic trading to the opening of the Taiwan stock market). Panel B of Table II shows statistically significantly positive values of the coefficients of the current period ($d_{0,sf}$ and $d_{0,nf}$), and the significance is higher than for other regression coefficients, indicating contemporaneous correlation between the TAIEX and the US index futures. Furthermore, although Panel B of Table II shows that the TAIEX led the US index futures by one period ($d_{1,\,sf}$ and $d_{1,\,nf}$ are significantly different from zero), it remains obvious that the US index futures led the TAIEX, as the E-mini S&P 500 Index futures led the TAIEX by two periods ($d_{-2,\,sf}$ and $d_{-1,\,sf}$ are significantly different from zero) and the E-mini NASDAQ 100 Index futures led the TAIEX by one period ($\mathrm{d}_{-1,\ \mathrm{nf}}$ are significantly different from zero and the significance of $d_{-1,\,nf}$ is more than that of $d_{1,\,nf}$). Thus, the above results prove that the holding period returns on US index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market represent an important reference for investors in the Taiwanese stock market.

In brief, the results on Panels A and B of Table II indicate that there are close economic and trading relationships as well as frequent international investment results in a closed price interrelationship between the Taiwanese and the US stock markets. Furthermore, the US stock market and economy are both number one globally so that the US stock index is of greater significance than the TAIEX. The implication of this result to international portfolio management is that investors should make good use of the lead-lag relationship between the US and Taiwanese stock markets to make investment decisions, as well as to improve international portfolio performance on the one hand and avoid inefficient diversification of international investment on the other.

3.2 Volatility asymmetry

Antoniou and Holmes (1995) believed that under the assumption of an efficient market, stock prices are influenced by new information (the unexpected shocks of the previous day); therefore, α_z and β_j of equation (11) indicate, respectively, the shocks of new and old information on stock returns, and γ of equation (11) is used to measure volatility asymmetry. Table III shows the empirical results of the price transmission, return volatility transmission, and volatility asymmetry.

According to Panel A of Table III, α_{21} and α_{22} are significant positive values, indicating that the returns on the S&P 500 Index in the current period were positively influenced by the unanticipated shocks to the TAIEX and S&P 500 Index in the previous period. In addition, Panel A of Table III also shows significant positive values for α_{31}, α_{32}, and α_{33}, indicating that the unanticipated shocks to the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index in the previous period were the determinants of the

Table III.
The result of the trivariate GJR-GARCH(1,1) model

Coefficient	Panel A. TAIEX, S&P 500 Index, and NASDAQ Composite Index Estimated value	t-value	p-value	Panel B. TAIEX, E-mini S&P 500 futures and E-mini NASDAQ 100 futures Estimated value	t-value	p-value
α_{10}/α'_{10}	0.00004	6.26	0.00**	0.00005	5.60	0.00**
α_{20}/α'_{20}	0.000001	1.80	0.07	0.000006	3.59	0.00**
α_{30}/α'_{30}	0.000005	2.91	0.00**	0.00002	3.39	0.00**
α_{11}/α'_{11}	0.05	2.58	0.01**	0.10	3.53	0.00**
α_{21}/α'_{21}	0.09	4.21	0.00**	0.04	1.84	0.07
α_{22}/α'_{22}	0.03	6.00	0.00**	0.07	5.24	0.00**
α_{31}/α'_{31}	0.10	5.32	0.00**	0.06	3.59	0.00**
α_{32}/α'_{32}	0.03	7.35	0.00**	0.07	6.47	0.00**
α_{33}/α'_{33}	0.02	3.91	0.00**	0.07	7.51	0.00**
β_{11}/β'_{11}	0.65	15.45	0.00**	0.56	10.85	0.00**
β_{21}/β'_{21}	−0.38	−2.26	0.02*	−0.66	−8.46	0.00**
β_{22}/β'_{22}	0.93	128.78	0.00**	0.87	41.94	0.00**
β_{31}/β'_{31}	−0.60	−6.22	0.00**	−0.85	−22.23	0.00**
β_{32}/β'_{32}	0.93	135.35	0.00**	0.88	49.09	0.00**
β_{33}/β'_{33}	0.95	148.61	0.00**	0.89	63.83	0.00**
γ_{11}/γ'_{11}	0.22	4.64	0.00**	0.25	5.25	0.00**
γ_{22}/γ'_{22}	0.04	7.38	0.00**	0.02	5.09	0.00**
γ_{33}/γ'_{33}	0.03	8.82	0.00**	0.03	4.47	0.00**

Notes: Significance at: *5 and **1 per cent levels; this study applied the trivariate GJR-GARCH(1,1) model to examine the price transmission, volatility transmission, and volatility asymmetry of the returns on the various indices. Our research period is from January 1, 2000 to January 31, 2004, providing 981 observations for each index series in total. The MLE is introduced for estimating parameters and the parameters are estimated from the following equations:

(*continued*)

(1) A trivariate GJR-GARCH(1,1) model for the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index:

$$
\begin{aligned}
R_{tw,t} &= \theta_{10} + \theta_{11}R_{tw,t-1} + \varepsilon_{tw,t},\\
R_{sp,t} &= \theta_{20} + \theta_{21}R_{tw,t-1} + \theta_{22}R_{sp,t-1} + \varepsilon_{sp,t},\\
R_{nd,t} &= \theta_{30} + \theta_{31}R_{tw,t-1} + \theta_{32}R_{sp,t-1} + \theta_{33}R_{nd,t-1} + \varepsilon_{nd,t},\\
\varepsilon_{tw,t}, \varepsilon_{sp,t}, \varepsilon_{nd,t}{}' &= \varepsilon_t|\Omega_{t-1} \sim N(0, H_t); H_t = h_{tw,t}, h_{sp,t}, h_{nd,t},\\
h_{tw,t} &= \alpha_{10} + \alpha_{11}\varepsilon^2_{tw,t-1} + \beta_{11}h_{tw,t-1} + \gamma_{11}\varepsilon^2_{tw,t-1}I_{tw,t-1},\\
h_{sp,t} &= \alpha_{20} + \alpha_{21}\varepsilon^2_{tw,t-1} + \alpha_{22}\varepsilon^2_{sp,t-1} + \beta_{21}h_{tw,t-1} + \beta_{22}h_{sp,t-1} + \gamma_{22}\varepsilon^2_{sp,t-1}I_{sp,t-1},\\
h_{nd,t} &= \alpha_{30} + \alpha_{31}\varepsilon^2_{tw,t-1} + \alpha_{32}\varepsilon^2_{sp,t-1} + \alpha_{33}\varepsilon^2_{nd,t-1} + \beta_{31}h_{tw,t-1} + \beta_{32}h_{sp,t-1} + \beta_{33}h_{nd,t-1} + \gamma_{33}\varepsilon^2_{nd,t-1}I_{nd,t-1},\\
h_{uv,t} &= \rho_{uv}(h_{u,t} \times h_{v,t})^{0.5}; u \neq v; \quad u: tw, sp, nd; v: tw, sp, nd.
\end{aligned}
$$

(2) A trivariate GJR-GARCH(1,1) model for the TAIEX, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures:

$$
\begin{aligned}
R_{tw,t} &= \theta'_{10} + \theta'_{11}R_{tw,t-1} + \varepsilon_{tw,t},\\
R_{sf,t} &= \theta'_{20} + \theta'_{21}R_{tw,t-1} + \theta'_{22}R_{sf,t-1} + \varepsilon_{sf,t},\\
R_{nf,t} &= \theta'_{30} + \theta'_{31}R_{tw,t-1} + c'_{32}R_{sf,t-1} + \theta'_{33}R_{nf,t-1} + \varepsilon_{nf,t},\\
\varepsilon_{tw,t}, \varepsilon_{sf,t}, \varepsilon_{nf,t}{}' &= \varepsilon'_t|\Omega'_{t-1} \sim N(0, H'_t); \quad H'_t = h_{tw,t}, h_{sf,t}, h_{nf,t},\\
h_{tw,t} &= \alpha'_{10} + \alpha'_{11}\varepsilon^2_{tw,t-1} + \beta'_{11}h_{tw,t-1} + \gamma'_{11}\varepsilon^2_{tw,t-1}I_{tw,t-1},\\
h_{sf,t} &= \alpha'_{20} + \alpha'_{21}\varepsilon^2_{tw,t-1} + \alpha'_{22}\varepsilon^2_{sf,t-1} + \beta'_{21}h_{tw,t-1} + \beta'_{22}h_{sf,t-1} + \gamma'_{22}\varepsilon^2_{sf,t-1}I_{sf,t-1},\\
h_{nf,t} &= \alpha'_{30} + \alpha'_{31}\varepsilon^2_{tw,t-1} + \alpha'_{32}\varepsilon^2_{sf,t-1} + \alpha'_{33}\varepsilon^2_{nf,t-1} + \beta'_{31}h_{tw,t-1} + \beta'_{32}h_{sf,t-1}\\
&\quad + \beta'_{33}h_{nf,t-1} + \gamma'_{33}\varepsilon_{nf,t-1}I_{nf,t-1},\\
h_{uv,t} &= \rho_{uv}(h_{u,t} \times h_{v,t})^{0.5}; u \neq v; u: tw, sf, nf; \quad v: tw, sf, nf,
\end{aligned}
$$

where, when $\varepsilon_{tw(sp,nd,sf,nf),t-1} < 0$ (the abnormal return on day $t-1$ is less than zero), $I_{tw(sp,nd,sf,nf),t-1} = 1$; when $\varepsilon_{tw(sp,nd,sf,nf),t-1} \geq 0$ (the abnormal return on day $t-1$ is zero or a positive value), $I_{tw(sp,nd,sf,nf),t-1} = 0$; ρ_{uv} is the correlation coefficient between ε_u and ε_v; according to the above equations, the error term of the lagged period, $\varepsilon_{tw(sp,nd,sf.nf),t-1}$, refers to the deviation from the expected returns in the previous day; therefore, $\alpha_{11}, \alpha_{21}, \alpha_{22}, \alpha_{31}$, and α_{32} ($\alpha'_{11}, \alpha'_{21}, \alpha'_{22}, \alpha'_{31}$, and α'_{32}) are the influence level of the previous day's unanticipated new information on today's return volatility. γ_{11}, γ_{22}, and γ_{33} (γ'_{11}, γ'_{22}, and γ'_{33}) refer to the measure of volatility asymmetry; the conditional variance of error term in the lagged period, $h_{tw(sp,nd,sf,nf),t-1}$, presents the return volatility of the previous day; because the return volatility of the previous day is influenced by information from a day in advance, $\beta_{11}, \beta_{21}, \beta_{22}, \beta_{31}, \beta_{32}$, and β_{33}, ($\beta'_{11}, \beta'_{21}, \beta'_{22}, \beta'_{31}, \beta'_{32}$, and β'_{33}) refer to the influence level of information from the previous day on today's return volatility, that is, the impact of old information

Table III.

returns on the NASDAQ Composite Index in the current period. Overall, the coefficients α_{21}, α_{22}, α_{31}, α_{32}, and α_{33} revealed the price transmission effect among the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index.

In Panel A of Table III, β_{11}, β_{21}, β_{22}, β_{31}, β_{32}, and β_{33} are all significantly different from 0, indicating that the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index all had price fluctuations due to the impact of old information. Each index had the transmission effect of return volatility. Furthermore, γ_{11}, γ_{22}, and γ_{33} are statistically positive values indicating there was an asymmetry phenomenon with respect to the volatility transmission between the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index. Negative unanticipated shocks (bad news) had a stronger influence on the return volatility of the current period than did positive unanticipated shocks (good news).

In short, Panel A of Table III shows significant evidence of volatility asymmetry in the equity market, which is consistent with Chiang *et al.* (2007) and Jayasuriya and Rossiter (2008). Comparing Panel A of Table III with Panel B of Table III led to the discovery of a very similar result: there was a significant price transmission effect, return volatility transmission effect, and volatility asymmetry between the TAIEX, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures ($\alpha'_{11}, \alpha'_{22}, \alpha'_{31}, \alpha'_{32}, \beta'_{11}, \beta'_{21}, \beta'_{22}, \beta'_{31}, \beta'_{32}, \beta'_{33}, \gamma'_{11}, \gamma'_{22}$, and γ'_{33} are all significantly different from zero). As per the empirical findings for the stock market, unanticipated bad news exerted a stronger influence on the futures market than unanticipated good news. The above results show that there is significant price transmission and volatility transmission between either the US spot index or the US index futures and the TAIEX; therefore, the US financial market's return volatility critically influences the Taiwanese financial market. The reasons for this are "the US is a major trading partner of Taiwan," "the US financial market is the global financial center," and "the popularity of international investment." Another reason is the structure of participants in the Taiwanese stock market. According to TWSE statistics, the holding percentage of foreign institutional investors and foreign individual investors in publicly listed companies in the TWSE increased from 6.93 per cent in 1982 to 25.86 per cent in 2008, among which, US institutional and individual investors are the leading majority shareholders. Thus, due to the international capital movement, stock prices in Taiwan are easily influenced by the USA.

3.3 The short-term overreaction of the Taiwanese stock market to US index futures

3.3.1 The short-term overreaction of the TAIEX to good surprises. In order to examine further the price interrelationship between the Taiwanese and the US financial markets, this study investigated whether the TAIEX overreacts to a good surprise (i.e. the price of US index futures shows significant advances at the opening of the Taiwanese stock market). According to the overreaction hypothesis, the overreaction phenomenon to a surprise indicates that the significant positive (negative) abnormal returns on the TAIEX exist on the day of a good (bad) surprise, but that the TAIEX shows significant negative (positive) abnormal returns after a good (bad) surprise.

Panel A of Table IV reports the estimates of AARs for the good surprises group. It shows that for day 0, a significant positive value for the AARs resulted from the TAIEX's reaction to the drastic rise in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market; but for days 1 and 10, the AARs were

Day	Panel A. The good surprises group: TAIEX and E-mini S&P 500 ($n = 185$) AARs (%)	t-value	Panel A: TAIEX and E-mini NASDAQ 100 ($n = 189$) AARs (%)	t-value	Panel B. The bad surprises group: TAIEX and E-mini S&P 500 ($n = 178$) AARs (%)	t-value	Panel B: TAIEX and E-mini NASDAQ 100 ($n = 183$) AARs (%)	t-value
−10	−0.16	−0.45	−0.17	−0.61	0.25	0.89	−0.18	−0.67
−9	−0.18	−0.56	−0.23	−0.82	−0.08	−0.29	−0.23	−0.88
−8	−0.06	−0.20	−0.08	−0.28	−0.43	−1.55	0.41	1.52
−7	0.45	1.36	0.08	0.27	0.30	1.11	0.05	0.19
−6	−0.19	−0.59	−0.19	−0.67	0.09	0.32	0.37	1.40
−5	−0.21	−0.63	0.15	0.53	−0.25	−0.89	−0.04	−0.16
−4	−0.08	−0.24	−0.02	−0.05	0.41	1.50	0.11	0.40
−3	−0.15	−0.46	−0.24	−0.83	−0.17	−0.61	0.09	0.32
−2	0.25	0.76	0.21	0.73	0.27	1.00	−0.36	−1.35
−1	0.07	0.22	0.30	1.05	−0.11	−0.39	−0.02	−0.07
0	0.25	0.76	0.63	2.19*	0.27	0.98	−0.07	−0.27
1	0.14	0.43	−0.73	−2.56**	0.15	0.53	−0.20	−0.76
2	0.48	1.48	−0.04	−0.16	0.26	0.94	0.01	0.02
3	0.22	0.68	0.20	0.70	0.48	1.74	0.06	0.23
4	0.01	0.02	0.09	0.32	0.08	0.31	0.24	0.91
5	−0.21	−0.63	−0.19	−1.01	−0.27	−0.99	−0.44	−1.64
6	0.06	0.18	0.01	0.04	−0.40	−1.45	−0.18	−0.67
7	−0.27	−0.84	−0.21	−0.72	0.17	0.62	−0.60	−2.26*
8	0.53	1.61	0.11	0.39	0.23	0.85	−0.03	−0.10
9	0.21	0.64	−0.10	−0.35	0.11	0.41	0.31	1.15
10	−0.29	−0.89	−0.58	−2.05*	0.02	0.07	−0.23	−0.85

Notes: Significance at: *5 and **1 per cent levels; this study adopted the event study to examine whether the Taiwanese stock market overreacts to extreme returns on the US index futures; we define a good (bad) surprise as the event wherein the holding period returns on the US index futures for day 0 were above (below) the sum (difference) of the mean and standard deviation of holding period returns across all observations during the period from January 1, 2000 to January 31, 2004; the t-statistic for AAR is calculated as follows:

$$t_{59} = \frac{AAR_{t,T}}{\sigma_{AAR,T}},$$

where $\sigma^2_{AAR,T} = (1/59)\sum_{t=-80}^{-21}(AAR_{t,T} - \overline{AAR_T})^2$ and $\overline{AAR_T} = (1/100)\sum_{t=-80}^{-21} AAR_{t,T}$

Table IV. AARs for the good and bad surprises groups

significantly less than zero. This result means that the TAIEX may have overreacted to the drastic rise in the price of E-mini NASDAQ 100 Index futures. On the other hand, in terms of the TAIEX reaction to the drastic rise in the price of E-mini S&P 500 Index futures at the opening of the Taiwanese stock market, Panel A of Table IV indicates that all AARs (even the AARs for day 0) were statistically insignificantly different from zero. The above result means that the influence of the drastic rise in the price of E-mini S&P 500 Index futures on the TAIEX was negligible and there was no evidence of overreaction of the TAIEX to the drastic rise in the price of E-mini S&P 500 Index futures.

Panel A of Table V presents the estimates of CAARs for the good surprises group. It shows that for the (−2,0), (−1,0), and (0) event windows regarding the TAIEX's reaction to the drastic rise in the price of E-mini NASDAQ 100 Index futures at

Windows	Panel A. The good surprises group: TAIEX and E-mini S&P 500 ($n = 185$) CAARs (%)	t-value	Panel A: TAIEX and E-mini NASDAQ 100 ($n = 189$) CAARs (%)	t-value	Panel B. The bad surprises group: TAIEX and E-mini S&P 500 ($n = 178$) CAARs (%)	t-value	Panel B: TAIEX and E-mini NASDAQ 100 ($n = 183$) CAARs (%)	t-value
(−10,0)	−0.02	−0.02	0.43	0.45	0.57	0.62	0.11	0.13
(−5,0)	0.13	0.17	1.03	1.47	0.44	0.65	−0.30	−0.46
(−3,0)	0.42	0.64	0.89	1.57	0.27	0.49	−0.36	−0.68
(−2,0)	0.57	1.00	1.13	2.29*	0.44	0.92	−0.45	−0.98
(−1,0)	0.32	0.69	0.93	2.29*	0.16	0.42	−0.09	−0.24
(0)	0.25	0.76	0.63	2.19*	0.27	0.98	−0.07	−0.27
(0,1)	0.39	0.84	−0.11	−0.26	0.41	1.07	−0.27	−0.73
(0,2)	0.87	1.54	−0.15	−0.30	0.67	1.42	−0.27	−0.58
(0,3)	1.10	1.68	0.05	0.09	1.15	2.10*	−0.21	−0.39
(0,5)	0.90	1.12	−0.15	−0.21	0.97	1.43	−0.40	−0.61
(0,10)	1.13	1.04	−0.92	−0.97	1.10	1.21	−1.13	−1.28

Notes: Significance at: *5 per cent level; this study adopted the event study to examine whether the Taiwanese stock market overreacts to extreme returns on the US index futures; we define a good (bad) surprise as the event wherein the holding period returns on the US index futures for day 0 were above (below) the sum (difference) of the mean and standard deviation of holding period returns across all observations during the period from January 1, 2000 to January 31, 2004; the *t*-statistic for CAAR is calculated as follows:

$$t_{59} = \frac{CAAR_{t,t+h}}{T\sqrt{h+1}\sigma_{AAR,T}},$$

where $\sigma^2_{AAR,T} = (1/59)\sum_{t=-80}^{-21}(AAR_{t,T} - \overline{AAR_T})^2$ and $\overline{AAR_T} = (1/100)\sum_{t=-80}^{-21}AAR_{t,T}$

Table V.
CAARs for the good and bad surprises groups

the opening of the Taiwanese stock market, the CAARs were all significantly positive values, and those for the (0,1), (0,2), (0,5) and (0,10) event windows were all of negative value (although statistically insignificant). There are two important implications associated with the above finding. First, the Taiwanese stock market responded earlier to the drastic rise in the price of E-mini NASDAQ 100 Index futures. Second, Taiwanese investors tend to overreact to the drastic rise in the price of E-mini NASDAQ 100 Index futures. In addition, in terms of the reaction of the TAIEX to the drastic rise in the price of E-mini S&P 500 Index futures at the opening of the Taiwanese stock market, Panel A of Table V shows that although the CAARs for the (0) event window were an insignificant positive value, the CAARs for all event windows were statistically insignificantly different from zero. The finding means that the evidence of overreaction of the TAIEX to the drastic rise in the price of E-mini S&P 500 Index futures was insignificant. In other words, the drastic rise in the price of E-mini S&P 500 Index futures at the opening of the Taiwanese stock market did not cause the TAIEX overreaction.

Overall, Panel A of Table IV and Panel A of Table V revealed the possibility of the overreaction of investors in the Taiwanese stock market to an event regarding the drastic rise in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market. However, there should be no possibility of overreaction phenomenon arising from the effect of the drastic rise in the price of E-mini S&P 500 Index futures on the TAIEX. This study concludes that due to the dominance of electronics industry firms listed on the TWSE, investors in the Taiwanese stock market pay more attention to the price of E-mini NASDAQ 100 Index futures than to that of E-mini S&P 500 Index futures, and they also tend to react more to the fluctuations in the share prices of high-technological companies in the USA.

3.3.2 The short-term overreaction of the TAIEX to bad surprises. Panel B of Table IV shows the estimates of AARs for the bad surprises group. According to these results, regarding the TAIEX's reaction to the drastic fall in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market, for each day except day 7 the AARs were all statistically insignificantly different from zero. This finding means that the drastic fall in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market did not provide useful information content to the Taiwanese stock market. Further, in terms of the reaction of the TAIEX to the drastic fall in the price of E-mini S&P 500 Index futures, no AARs were significantly different from zero, and the AARs for day 0 were insignificant positive values. Therefore, we did not find evidence of overreaction of the TAIEX to the drastic fall in the price of E-mini S&P 500 Index futures.

Panel B of Table V reports the estimates of CAARs for the bad surprises group: for each event window regarding the TAIEX's reaction to the drastic fall in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market, the CAARs were all statistically insignificantly different from zero. Moreover, except for the (0,3) event window, there was also no significant statistical evidence for results regarding the TAIEX's reaction to the drastic fall in the price of E-mini S&P 500 Index futures. These results indicate that although the US financial market is the largest in the world and the leader of the global economy, negative surprises from the US futures market at the opening of the Taiwanese stock market did not cause investor overreaction in the Taiwanese stock market. Further, as a result of the significant industrial differences between the TAIEX and the S&P 500 Index constituents and the weak linkage between them, the TAIEX reacted inconsistently on day 0 in response to the drastic fall in the price of E-mini S&P 500 Index futures (i.e. the positive AARs for day 0 regarding the TAIEX's reaction to the drastic fall in the price of E-mini S&P 500 Index futures at the opening of the Taiwanese stock market are inconsistent with the signal of a bad surprise).

It is worthy of note that according to Panel B of Table IV and Panel B of Table V, both reactions of the TAIEX to the drastic falls in the prices of E-mini NASDAQ 100 and E-mini S&P 500 Index futures at the opening of the Taiwanese stock market did not provide any supporting evidence of the overreaction. This finding is inconsistent with Bauman *et al.* (1995), Womack (1996), McKnight and Todd (2006) and Chiang *et al.* (2007) who found that the stock price reaction of negative shocks was more than that of positive shocks. The empirical results in the present study may have stemmed from overconfidence and excessive optimism of investors in the Taiwanese stock market. The behavioral pitfalls of overconfidence and excessive optimism seen in investors during bull markets are more significant than those displayed during bear markets. The effect of a bad surprise on the Taiwanese stock market during a bull market is weak because investors have displayed greater degrees of overconfidence and excessive optimism regarding the future trends of the TAIEX. Therefore, it is likely that we did not find an overreaction of the TAIEX to the bad surprises due to our research period falling within a recent bull market in Taiwan.

In conclusion, Table IV and Table V indicate that although the most updated information of the US stock index influences the decision-making process of investors in the Taiwanese stock market, investors are more likely to overreact to a drastic rise in the price of NASDAQ 100 Index futures. This also shows the close relationship between these two countries' high-tech companies. High-tech companies in these two countries have long cooperated in technology, capital, and procurement (in recent years, electronics products from these two countries have begun to compete with each other) and as a result, under the highly relevant operational environment, the NASDAQ 100 Index, where high-tech stocks are traded, has a more significant influence on Taiwanese stocks than the S&P 500 Index has. Meanwhile, investors who invest in both Taiwanese and US stock markets should watch for the close interrelationship between the stock prices of Taiwanese and US high-tech companies. If the investment goal is diversification, "non high-tech stocks" in both Taiwan and the US should be included in an international portfolio.

4. Robust analysis

This study investigates the period between January 1, 2000 and March 31, 2004. During the research period, the US was struck by the most serious man-made disaster in history: the terrorist attacks on September 11, 2001. This incident not only shattered the confidence of US investors but also precipitated great economic loss that resulted in drastic fluctuations in the global stock markets (including the Taiwanese stock market). The huge impact of the 9/11 terrorist attacks on the global stock markets is an issue that deserves an in-depth discussion on the structural change of the price interrelationship between Taiwanese and US financial markets. In order to improve the accuracy of price interrelationship results between Taiwanese and US financial markets, this study further examines the impact of the 9/11 terrorist attacks by conducting an empirical analysis of data collected after the 9/11 terrorist attacks (499 observations for each index series from January 1, 2002 to March 31, 2004) and discusses the lead-lag relationship, volatility asymmetry, and overreaction effect between the financial markets in the USA and Taiwan.

Panel A of Table VI shows the significant contemporaneous correlation between the "TAIEX and S&P 500 Indices," as well as the "TAIEX and NASDAQ Composite Indices," (both $d_{0,\,sp}$ and $d_{0,\,nd}$ are significantly different from zero). In addition, the S&P 500 Index and NASDAQ Composite Index led the TAIEX by one period (both $d_{-1,\,sp}$ and $d_{-1,\,nd}$ are significantly different from zero), while the TAIEX led the S&P 500 Index and NASDAQ Composite Index by one period (both $d_{1,\,sp}$ and $d_{1,\,nd}$ are significantly different from zero). Furthermore, Panel B of Table VI indicates the significant contemporaneous correlation between "TAIEX and E-mini S&P 500 index futures," as well as "TAIEX and E-mini NASDAQ 100 index futures (both $d_{0,\,sf}$ and $d_{0,\,nf}$ are significantly different from zero)"; E-mini S&P 500 Index futures and E-mini NASDAQ 100 Index futures both led the TAIEX by two periods ($\mathrm{d}_{-2,\,\mathrm{sf}}$, $\mathrm{d}_{-2,\,\mathrm{nf}}$, $\mathrm{d}_{-1,\,\mathrm{sf}}$, and $\mathrm{d}_{-1,\,\mathrm{nf}}$ are all significantly different from zero), while the TAIEX led the E-mini S&P 500 Index futures and E-mini NASDAQ 100 Index futures by one period (both $\mathrm{d}_{1,\,\mathrm{sf}}$ and $\mathrm{d}_{1,\,\mathrm{nf}}$ are different from zero). The comparison between Table II and Table VI indicates there are more significant leading price phenomena in the US financial markets than in Taiwanese financial markets, but after the 9/11 terrorist attacks, the price interrelationship between the Taiwanese and US financial markets has been weakened.

Coefficient	TAIEX and S&P 500 Estimated value	TAIEX and S&P 500 *t*-value	TAIEX and NASDAQ Estimated value	TAIEX and NASDAQ *t*-value
Panel A. TAIEX, S&P 500, and NASDAQ Composite Index				
$c_{0,sp}/c_{0,nd}$	0.0004	0.56	0.0004	0.60
$d_{-3,sp}/d_{-3,nd}$	0.08	1.81	0.04	0.91
$d_{-2,sp}/d_{-2,nd}$	0.10	1.94	0.08	1.88
$d_{-1,sp}/d_{-1,nd}$	0.09	2.17*	0.13	3.85**
$d_{0,sp}/d_{0,nd}$	0.30	7.50**	0.22	7.93**
$d_{1,sp}/d_{1,nd}$	0.12	2.01*	0.05	3.03**
$d_{2,sp}/d_{2,nd}$	−0.03	−0.64	−0.02	−0.74
$d_{3,sp}/d_{3,nd}$	0.003	0.07	−0.01	−0.56
Panel B. TAIEX, E-mini S&P 500 Index futures, and E-mini NASDAQ 100 Index futures				
$c_{0,sf}/c_{0,nf}$	0.0003	0.62	0.0003	0.44
$d_{-3,sf}/d_{-3,nf}$	0.07	1.63	0.03	0.89
$d_{-2,sf}/d_{-2,nf}$	0.16	3.17**	0.09	2.02*
$d_{-1,sf}/d_{-1,nf}$	0.13	3.06**	0.10	3.81**
$d_{0,sf}/d_{0,nf}$	0.28	6.70**	0.11	7.64**
$d_{1,sf}/d_{1,nf}$	0.15	2.10*	0.07	3.76**
$d_{2,sf}/d_{2,nf}$	−0.06	−0.79	−0.01	−0.73
$d_{3,sf}/d_{3,nf}$	0.01	0.20	−0.01	−0.42

Notes: Significance at: *5 and **1 per cent levels; the estimation horizon is from January 1, 2002 to January 31, 2004 (499 observations for each index series) and the parameters are estimated from the following equations:

$$r_{tw,t} = c_{sp} + \sum_{k=-m}^{-1} d_{k,sp} r_{sp,t+k} + d_{0,sp} r_{sp,t} + \sum_{l=1}^{m} d_{l,sp} r_{sp,t+l} + \eta_{tw,t},$$

$$r_{tw,t} = c_{nd} + \sum_{k=-m}^{-1} d_{k,nd} r_{nd,t+k} + d_{0,nd} r_{nd,t} + \sum_{l=1}^{m} d_{l,nd} r_{nd,t+l} + \varepsilon_{tw,t},$$

$$r_{tw,t} = c_{sf} + \sum_{k=-m}^{-1} d_{k,sf} r_{sf,t+k} + d_{0,sf} r_{sf,t} + \sum_{l=1}^{m} d_{l,sf} r_{sf,t+l} + \lambda_{tw,t},$$

$$r_{tw,t} = c_{nf} + \sum_{k=-m}^{-1} d_{k,nf} r_{nf,t+k} + d_{0,nf} r_{nf,t} + \sum_{l=1}^{m} d_{l,nf} r_{nf,t+l} + \xi_{tw,t},$$

where m refers to the period number of lead-lag relationship. If $d_{k,sp}, d_{k,nd}, d_{k,sf}$, and $d_{k,nf}$ ($d_{l,sp}, d_{l,nd}, d_{l,sf}$, and $d_{l,nf}$) are significantly different from zero, then the TAIEX leads (lags) the S&P 500 Index, the NASDAQ Composite Index, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures by k (l) periods, respectively

Table VI. The result of lead-lag relationship after the 9/11 terrorist attacks

Panel A of Table VII shows the existence of a price transmission effect ($\alpha_{11}, \alpha_{21}, \alpha_{22}, \alpha_{31}$, and α_{32} are all significantly different from zero) and return volatility transmission effect ($\beta_{11}, \beta_{21}, \beta_{22}, \beta_{31}, \beta_{32}$, and β_{33} are all significantly different from zero) among the TAIEX, S&P 500 Index, and NASDAQ Composite Index; the influence of negative shocks on the return volatility of the current period is more than that of positive shocks (γ_{11}, γ_{22}, and γ_{33} are all significantly more than zero). Similarly, Panel B of Table VII also indicates the return volatility asymmetry and significant price transmission effect among the TAIEX, E-mini S&P 500 Index futures, and E-mini NASDAQ 100 Index futures ($\alpha'_{11}, \alpha'_{21}, \alpha'_{22}, \alpha'_{31}, \alpha'_{32}, \beta'_{11}, \beta'_{21}, \beta'_{22}, \beta'_{31}, \beta'_{32}, \beta'_{33}, \gamma'_{11}, \gamma'_{22}$, and γ'_{33} are all significantly different from zero). The comparison of Table III and Table VII also finds a corresponding result. Thus, the 9/11 terrorist attacks did not cause structural changes in the price transmission, volatility transmission, or volatility asymmetry in both the Taiwanese and the US stock markets.

Table VII.
The result of the trivariate GJR-GARCH (1,1) model after the 9/11 terrorist attacks

Coefficient	Panel A. TAIEX, S&P 500 Index, and NASDAQ Composite Index			Panel B. TAIEX, E-mini S&P 500 futures and E-mini NASDAQ 100 futures		
	Estimated value	t-value	p-value	Estimated value	t-value	p-value
α_{10}/α'_{10}	0.00003	5.59	0.00**	0.00005	5.82	0.00**
α_{20}/α'_{20}	0.000001	1.75	0.08	0.000004	3.27	0.00**
α_{30}/α'_{30}	0.000005	3.02	0.00**	0.00003	3.33	0.00**
α_{11}/α'_{11}	0.06	2.53	0.01**	0.14	4.72	0.00**
α_{21}/α'_{21}	0.12	4.76	0.00**	0.03	2.00	0.04*
α_{22}/α'_{22}	0.03	5.63	0.00**	0.08	4.96	0.00**
α_{31}/α'_{31}	0.11	6.17	0.00**	0.07	3.44	0.00**
α_{32}/α'_{32}	0.04	7.80	0.00**	0.08	6.70	0.00**
α_{33}/α'_{33}	0.02	3.84	0.00**	0.07	6.82	0.00**
β_{11}/β'_{11}	0.59	13.17	0.00**	0.63	12.71	0.00**
β_{21}/β'_{21}	−0.34	−2.31	0.01*	−0.48	−5.29	0.00**
β_{22}/β'_{22}	0.85	92.15	0.00**	0.79	52.60	0.00**
β_{31}/β'_{31}	−0.57	−7.10	0.00**	−0.83	−18.69	0.00**
β_{32}/β'_{32}	0.90	115.72	0.00**	0.80	60.75	0.00**
β_{33}/β'_{33}	0.96	136.14	0.00**	0.92	81.38	0.00**
γ_{11}/γ'_{11}	0.27	5.10	0.00**	0.36	5.78	0.00**
γ_{22}/γ'_{22}	0.03	6.08	0.00**	0.02	4.91	0.00**
γ_{33}/γ'_{33}	0.03	8.51	0.00**	0.04	6.11	0.00**

Notes: Significance at: *5 and **1 per cent levels; this study applied the trivariate GJR-GARCH(1,1) model to examine the price transmission, volatility transmission, and volatility asymmetry of the returns on the various indices. Our research period is from January 1, 2002 to January 31, 2004, providing 499 observations for each index series in total. The MLE is introduced for estimating parameters and the parameters are estimated from the following equations:

(continued)

Table VII.

(1) A trivariate GJR-GARCH(1,1) model for the TAIEX, the S&P 500 Index, and the NASDAQ Composite Index:

$$R_{tw,t} = \theta_{10} + \theta_{11} R_{tw,t-1} + \varepsilon_{tw,t},$$
$$R_{sp,t} = \theta_{20} + \theta_{21} R_{tw,t-1} + \theta_{22} R_{sp,t-1} + \varepsilon_{sp,t},$$
$$R_{nd,t} = \theta_{30} + \theta_{31} R_{tw,t-1} + \theta_{32} R_{sp,t-1} + \theta_{33} R_{nd,t-1} + \varepsilon_{nd,t},$$
$$\varepsilon_{tw,t}, \varepsilon_{sp,t}, \varepsilon_{nd,t}{}' = \varepsilon_t | \Omega_{t-1} \sim N(0, H_t); H_t = h_{tw,t}, h_{sp,t}, h_{nd,t},$$
$$h_{tw,t} = \alpha_{10} + \alpha_{11} \varepsilon^2_{tw,t-1} + \beta_{11} h_{tw,t-1} + \gamma_{11} \varepsilon^2_{tw,t-1} I_{tw,t-1},$$
$$h_{sp,t} = \alpha_{20} + \alpha_{21} \varepsilon^2_{tw,t-1} + \alpha_{22} \varepsilon^2_{sp,t-1} + \beta_{21} h_{tw,t-1} + \beta_{22} h_{sp,t-1} + \gamma_{22} \varepsilon^2_{sp,t-1} I_{sp,t-1},$$
$$h_{nd,t} = \alpha_{30} + \alpha_{31} \varepsilon^2_{tw,t-1} + \alpha_{32} \varepsilon^2_{sp,t-1} + \alpha_{33} \varepsilon^2_{nd,t-1} + \beta_{31} h_{tw,t-1} + \beta_{32} h_{sp,t-1} + \beta_{33} h_{nd,t-1} + \gamma_{33} \varepsilon^2_{nd,t-1} I_{nd,t-1},$$
$$h_{uv,t} = \rho_{uv} (h_{u,t} \times h_{v,t})^{0.5}; \quad u \neq v; u : tw, sp, nd; \quad v : tw, sp, nd.$$

(2) A trivariate GJR-GARCH(1,1) model for the TAIEX, the E-mini S&P 500 Index futures, and the E-mini NASDAQ 100 Index futures:

$$R_{tw,t} = \theta'_{10} + \theta'_{11} R_{tw,t-1} + \varepsilon_{tw,t},$$
$$R_{sf,t} = \theta'_{20} + \theta'_{21} R_{tw,t-1} + \theta'_{22} R_{sf,t-1} + \varepsilon_{sf,t},$$
$$R_{nf,t} = \theta'_{30} + \theta'_{31} R_{tw,t-1} + c'_{32} R_{sf,t-1} + \theta'_{33} R_{nf,t-1} + \varepsilon_{nf,t},$$
$$\varepsilon_{tw,t}, \varepsilon_{sf,t}, \varepsilon_{nf,t}{}' = \varepsilon'_t | \Omega'_{t-1} \sim N(0, H'_t); \quad H'_t = h_{tw,t}, h_{sf,t}, h_{nf,t},$$
$$h_{tw,t} = \alpha'_{10} + \alpha'_{11} \varepsilon^2_{tw,t-1} + \beta'_{11} h_{tw,t-1} + \gamma'_{11} \varepsilon^2_{tw,t-1} I_{tw,t-1},$$
$$h_{sf,t} = \alpha'_{20} + \alpha'_{21} \varepsilon^2_{tw,t-1} + \alpha'_{22} \varepsilon^2_{sf,t-1} + \beta'_{21} h_{tw,t-1} + \beta'_{22} h_{sf,t-1} + \gamma'_{22} \varepsilon^2_{sf,t-1} I_{sf,t-1},$$
$$h_{nf,t} = \alpha'_{30} + \alpha'_{31} \varepsilon^2_{tw,t-1} + \alpha'_{32} \varepsilon^2_{sf,t-1} + \alpha'_{33} \varepsilon^2_{nf,t-1} + \beta'_{31} h_{tw,t-1} + \beta'_{32} h_{sf,t-1} + \beta'_{33} h_{nf,t-1} + \gamma'_{33} \varepsilon_{nf,t-1} I_{nf,t-1},$$
$$h_{uv,t} = \rho_{uv} (h_{u,t} \times h_{v,t})^{0.5}; \quad u \neq v; u : tw, sf, nf; \quad v : tw, sf, nf$$

where, when $\varepsilon_{tw(sp,nd,sf,nf),t-1} < 0$ (the abnormal return on day $t - 1$ is less than zero), $I_{tw(sp,nd,sf,nf),t-1} = 1$; when $\varepsilon_{tw(sp,nd,sf,nf),t-1} \geq 0$ (the abnormal return on day $t - 1$ is zero or a positive value), $I_{tw(sp,nd,sf,nf),t-1} = 0$; ρ_{uv} is the correlation coefficient between ε_u and ε_v. According to the above equations, the error term of the lagged period, $\varepsilon_{tw(sp,nd,sf.nf),t-1}$, refers to the deviation from the expected returns in the previous day; therefore, $\alpha_{11}, \alpha_{21}, \alpha_{22}, \alpha_{31}$, and α_{32} ($\alpha'_{11}, \alpha'_{21}, \alpha'_{22}, \alpha'_{31}$, and α'_{32}) are the influence level of the previous day's unanticipated new information on today's return volatility. γ_{11}, γ_{22}, and γ_{33} ($\gamma'_{11}, \gamma'_{22}$, and γ'_{33}) refer to the measure of volatility asymmetry. The conditional variance of error term in the lagged period, $h_{tw(sp,nd,sf,nf),t-1}$, presents the return volatility of the previous day. Because the return volatility of the previous day is influenced by information from a day in advance, $\beta_{11}, \beta_{21}, \beta_{22}, \beta_{31}, \beta_{32}$, and β_{33} ($\beta'_{11}, \beta'_{21}, \beta'_{22}, \beta'_{31}, \beta'_{32}$, and β'_{33}) refer to the influence level of information from the previous day on today's return volatility, that is, the impact of old information

Panel A of Table VIII shows that the drastic rise in the price of the E-mini S&P 500 Index futures did not generate a significant abnormal return on the TAIEX. In regard to the TAIEX's reaction to the drastic rise in the price of E-mini NASDAQ 100 Index futures, the CAARs for the event window (0) are significantly more than zero while the CAARs for the event window (1) are a marginally significant negative value (i.e. CAARs are significantly less than zero at the 10 per cent level of significance). In addition, Panel B of Table VIII presents that the CAARs of all event windows are insignificantly different from zero. A comparison of Table V and Table VIII indicates that the two results find a short-term overreaction of TAIEX toward a drastic rise in the price of E-mini NASDAQ 100 Index futures, yet after the 9/11 terrorist attacks, there is only weaker evidence to support the above-mentioned short-term overreaction.

In sum, although the result of this robust analysis indicates that the 9/11 terrorist attacks have had a limited impact on the accuracy of our empirical findings, only with the adoption of the most updated US stock index information for empirical analysis are we able to find evidence of "more significant US financial market prices leading Taiwanese financial market prices than Taiwanese financial market prices leading US financial market prices." Therefore, information on the holding period returns on the US index futures from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market will help to predict the TAIEX. In addition, the result after the 9/11 terrorist attacks also proves the existence of return volatility asymmetry

Table VIII.
CAARs for the good and bad surprises groups after the 9/11 terrorist attacks

	Panel A. The good surprises group				Panel B. The bad surprises group			
	TAIEX and E-mini S&P 500 ($n = 97$)		TAIEX and E-mini NASDAQ 100 ($n = 98$)		TAIEX and E-mini S&P 500 ($n = 87$)		TAIEX and E-mini NASDAQ 100 ($n = 90$)	
Windows	CAARs (%)	*t*-value	CAARs (%)	*t*-value	CAARs (%)	*t*-value	CAARs (%)	*t*-value
(−10,0)	−0.06	−0.05	0.24	0.24	0.49	0.52	−0.02	−0.02
(−5,0)	0.21	0.25	0.79	1.09	0.35	0.69	−0.27	−0.42
(−3,0)	0.45	0.65	0.68	1.14	0.14	0.25	−0.35	−0.66
(−2,0)	0.58	0.97	0.90	1.75	0.35	0.71	−0.47	−1.03
(−1,0)	0.39	0.80	0.76	1.81	0.17	0.42	−0.15	−0.40
(0)	0.23	0.66	0.59	1.99*	0.28	0.99	−0.09	−0.34
(1)	0.16	0.46	−0.51	−1.72	0.12	0.42	−0.24	−0.91
(0,1)	0.39	0.80	0.08	0.19	0.40	1.00	−0.33	−0.88
(0,2)	0.91	1.52	0.02	0.04	0.61	1.24	−0.26	−0.57
(0,3)	1.10	1.59	0.18	0.30	0.92	1.62	−0.16	−0.30
(0,5)	1.03	1.21	0.12	0.16	0.74	1.07	−0.33	−0.51
(0,10)	1.24	1.08	−0.45	−0.46	0.98	1.04	−0.94	−1.07

Notes: Significant at: *5 and **1 per cent levels; this study adopted the event study to examine whether the Taiwanese stock market overreacts to extreme returns on the US index futures; we define a good (bad) surprise as the event wherein the holding period returns on the US index futures for day 0 were above (below) the sum (difference) of the mean and standard deviation of holding period returns across all observations during the period from January 1, 2002 to January 31, 2004. The *t*-statistic for CAAR is calculated as follows:

$$t_{59} = (\mathrm{CAAR}_{t,t+h,T} / \sqrt{h+1}\,\sigma_{\mathrm{AAR},T}),$$

where $\sigma^2_{\mathrm{AAR},T} = (1/59)\sum_{t=-80}^{-21}(\mathrm{AAR}_{t,T} - \overline{\mathrm{AAR}_T})^2$ and $\overline{\mathrm{AAR}_T} = (1/100)\sum_{t=-80}^{-21}\mathrm{AAR}_{t,T}$

between the US and Taiwanese financial markets; further, only the reaction of the TAIEX to the drastic rise in the price of E-mini NASDAQ 100 Index futures is found to be one of overreaction. It is worth noting that the result of robust analysis shows that after the 9/11 terrorist attacks, price interrelationship between both Taiwanese and US markets was decreased and the TAIEX was found to have weak evidence of overreaction toward the drastic rise in the price of E-mini NASDAQ 100 Index futures. Possible reasons may be the gradually decreasing closeness of the trade relationship between the two countries. Even after the 9/11 terrorist attacks and the dot com bust, the USA is still the number one economy, yet its importance in the global economy is decreasing and, relatively, the US financial market has only limited impact on the global financial market. Taiwan's number one export destination has shifted from the USA to China. After the 9/11 terrorist attacks, only the most updated information of the US stock index (i.e. the holding period returns on the US index futures) can provide important reference information for investors in the Taiwanese stock market. In addition, another possible reason is that investors in the Taiwanese stock markets are more concerned about the price information of derivatives. After 1997, 1998, and 2001, when warrants, stock index futures, and stock index options were, respectively, launched in the Taiwanese market, investors in that market became more familiar with derivatives. Along with displaying increased sophistication, Taiwanese stock market investors pay more attention to the price information of US index futures during the period from the opening of the US index futures electronic trading to the opening of the Taiwanese stock market.

5. Conclusions

The purpose of this study was to examine the lead-lag relationship, the volatility asymmetry, and the overreaction phenomenon between the financial markets of the USA and Taiwan. In contrast with previous studies, we focused on three differentiating features. That is, in order to get a more complete picture of the price interrelationship between the US and the Taiwanese financial markets, this study investigated, respectively, "the price transmission between the most updated information of the US stock index and the TAIEX," "the volatility asymmetry applying a trivariate GJR-GARCH (1,1) model," and "the overreaction phenomenon of emerging market investors to the drastic price changes in a sophisticated market." In addition, we explored the possibility that the 9/11 terrorist attacks in 2001 contaminated our empirical results.

The empirical results of the whole research period revealed that although there is a lead-lag relationship between the financial markets in the USA and Taiwan, there is only weak evidence indicating that the TAIEX led the spot and futures prices in the USA, in contrast with strong evidence indicating that the spot and futures prices in the USA led the spot index in Taiwan. Moreover, we showed that there is a significant price transmission effect and volatility asymmetry among the TAIEX, the US spot index, and the US index futures. The volatility of stock returns is more likely to be influenced by bad news than good news. As a result, we propose that the US spot index and index futures are important reference sources for investors in the Taiwanese stock market. Finally, the greater overconfidence and more excessive optimism of investors during the prevailing bull market caused a significant overreaction of the TAIEX to a drastic rise in the price of E-mini NASDAQ 100 Index futures at the opening of the Taiwanese stock market, but we did not find any supporting evidence for an overreaction of the Taiwanese stock market to a drastic fall in the price of US index futures. The implication of this finding is that investors who invest in both the US and Taiwanese stock markets should make good use of the close interrelationship between the two markets' high-tech stock prices, and the "non high-tech stocks" in the two markets should be appropriately included in their portfolio to achieve diversification.

Notably, the robust analysis considering the contaminating possibility of the 9/11 terrorist attacks in 2001 revealed that although the impact of the 9/11 terrorist attacks was limited, the price interdependence between the US and Taiwanese financial markets has decreased after the 9/11 terrorist attacks. Besides, after the 9/11 terrorist attacks, we found only evidence regarding price spillovers from the price of the US index futures to the TAIEX. This indicated that after the 9/11 terrorist attacks, Taiwanese investors paid more attention to the holding period returns on the US index futures between the opening of the US index futures electronic trading and the opening of the Taiwanese stock market and less to daily returns on the US spot index. The decreasing influence of the US market on global markets and Taiwanese investors' increasing attention to derivatives may be the reason that only the most updated information of the US stock index dominated the price transmission between the US and the Taiwanese financial markets after the 9/11 terrorist attacks.

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