東海大學管理學院財務金融研究所

碩士論文

選擇權淨買壓假說之探討-新理論模型與方法

Investigate Net-buying-pressure Hypotheses in Option Markets - New Theory and Methodology

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選擇權淨買壓假說之探討–新理論模型與方法

中文摘要

方向學習假說與波動學習假說是探討淨買壓與隱含波動度曲線關係的兩大假說。前者主張在標的資產預期上漲時，投資人會購買買權，反之，則購買賣權。後者認為在市場預期波動衝擊出現時，投資人會購買買權與賣權。過去文獻檢驗此兩假說之條件為互斥，使得此兩個假說無法同時成立。有鑑於投資人可能同時依據方向衝擊與波動衝擊進行其交易決策，本文發展出分解淨買壓的新方法，將淨買壓分解成來自方向衝擊與波動衝擊兩個面向，以獨立檢驗方向假說與波動假說，並以 2011 年臺指選擇權之交易資料進行研究，探討臺指選擇權投資人同時為方向交易者與波動交易者的可能性。有別於文獻的發現，本文結果顯示歷經主權債風暴後臺指選擇權買權之隱含波動度曲線由微笑波動轉變成反微笑波動。實證結果亦指出臺指選擇權賣權市場同時存在方向學習與波動學習效果。

關鍵字：淨買壓、隱含波動度、波動學習假說、方向學習假說、獨立性檢定

Investigate Net-buying-pressure Hypotheses in Option Markets - New Theory and Methodology

Abstract

Two important hypotheses about the relation between net buying pressure and the shape of the implied volatility function are the direction-learning hypothesis and volatility-learning hypothesis. The former asserts that investors buy call/put options if the underlying asset price is anticipated to rise/fall, whereas the latter declares that investors buy call and put options once volatility shocks are expected. Since the conditions adopted in the literature to inspect the two hypotheses are mutually exclusive, the two hypotheses cannot be found out concurrently. It motivates us to investigate the possibility that investors make trading decisions based on both directional shocks and volatility shocks by using the one-minute-basis intraday data of the TAIEX option in 2011. Specifically, we develop a new method to decompose the net buying pressure of option trading into two components: the net buying pressure due to directional shocks and that due to volatility shocks, and test direction-learning and volatility-learning hypotheses independently based on the two types of net buying pressures. In contrast with the findings in the literature, we find that the shape of the implied volatility curve for TAIEX call options changes from a smirk to un-smile during the sovereign debt crisis. Empirical evidences also show that net-buying-pressure hypotheses can be valid simultaneously, which is very different from the findings in the literature.

Key words: Net buying pressure; Implied volatility; Volatility-learning hypothesis; Direction-learning hypothesis; Independent test

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1 Introduction

A common observation concerning the Black-Scholes implied volatilities of index options is the implied volatility smirk. Indeed, as pointed out in Bollen and Whaley (2004), the implied volatility curve of S&P 500 index options looks like smile before the October 1987 market crash, but it turns to be a smirk after October 1987. Nevertheless, these findings are not consistent with the assumption of the Black-Scholes (1973) model, in which the volatility of the asset underlying options is assumed to be flat and constant through time.

Many documents investigate the reason why the implied volatility curve of index options smirks. Bakshi, Cao, and Chen (1997), Fleming (1999), Bates (2000), and Ederington and Guan (2002) demonstrate that the phenomenon of implied volatility smirk is due to model misspecification. Another branch of literature points out that the order imbalance between the supply and demand of options results in the implied volatility changing across exercise prices, including Bollen and Whalley (2004), Kang and Park (2008), and Shiu et al. (2010), to name a few. Among them, Bollen and Whaley (2004) define the net buying pressure as the difference between the number of buyer-motivated contracts and seller-motivated contracts multiplied by the absolute value of the options' delta. They provide an empirical test to investigate the limit of arbitrage hypothesis and volatility-learning hypothesis and propose empirical evidence that the net buying pressure derives the shape of the implied volatility curve. Kang and Park (2008) extend the idea behind Bollen and Whaley (2004) and demonstrate that both the two types of news, i.e., news concerning volatility changes and news about the direction of the future underlying asset prices, are able to move option prices. They test the volatility-learning hypothesis and direction-learning hypothesis based on the following regressions:

$$\Delta\sigma_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{C,t}^{ATM} + \alpha_4 NBP_{P,t}^{ATM} + \alpha_5 \Delta\sigma_{i,t-1}^{ATM} + \epsilon_t, \quad (1)$$

$$\Delta\sigma_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{i,t}^{OTM} + \alpha_4 NBP_{j,t}^{ATM} + \alpha_5 \Delta\sigma_{i,t-1}^{OTM} + \epsilon_t, \qquad (2)$$

where $i, j \in \{C, P\}$ and $j \neq i$. Moreover, $\Delta\sigma_{i,t}^{ATM}$ and $\Delta\sigma_{i,t}^{OTM}$ denote the change in the average implied volatility for at-the-money (ATM) calls/puts and out-of-the-money (OTM) calls/puts at time interval t, RS_t indicates the index returns over the time interval t, and VS_t is the summed trading volume of the index for the time interval t. Kang and Park (2008) calculate all variables based on a five-minute basis. Importantly, $NBP_{i,t}^{ATM}$, where $i \in \{C, P\}$, displays the net buying pressures of ATM calls/puts summed across the time interval t, whereas $NBP_{i,t}^{OTM}$ denotes the net buying pressures of OTM calls/puts over the time interval t. Based on the Kang and Park's (2008) empirical test, the direction-learning hypothesis for each category option market can be concluded in case of the coefficients of α_3 and α_4 being with different signs, whereas the volatility-learning hypothesis can account for the same size and sign of coefficients α_3 and α_4.

The assertion proposed in Kang and Park (2008) that volatility traders and directional traders have different impacts on implied volatilities is very coincident with the practice of option markets. However, a possible paradox behind in Kang and Park's (2008) methodology is the volatility-learning hypothesis and direction-learning hypothesis cannot hold at the same time, since the condition of the direction-learning hypothesis being valid: $\alpha_3\alpha_4 < 0$ and the condition that the volatility-learning hypothesis holds: $\alpha_3\alpha_4 > 0$ cannot be true at the same time. In this paper, we propose a new methodology to decompose net buying pressure into two excess demands: one induced by directional shocks and the other induced by volatility shocks, and test the two hypotheses independently. In other words, the volatility-learning effect and direction-learning effect are allowed to hold in the meanwhile under the proposed methodology.

Summarily, there are two distinctive contributions provided in this paper. First, we investigate the empirical properties of implied volatilities calculated from the TAIEX options. In contrast with the findings in Bollen and Whaley (2004), in which they observe the shape of the implied volatility curve changing from a smile to smirk after October 1987 market crash, our empirical evidence shows that the implied volatility curve of call options shapes from a smirk to un-smirk during the sovereign debt crisis. Secondly, to solve the contradiction existing in the literature that the direction-learning hypothesis and volatility-learning hypothesis cannot be true at the same time, we propose a method to test the two learning hypothesis independently. We find that the direction-learning hypothesis is supported by all of the ATM and OTM options in the TAIEX option market, but the volatility-learning effect is not always observed. Moreover, both the direction-learning effect and volatility-learning effect are hold in the ATM puts and OTM puts before the occurrence of the sovereign debt crisis, whereas the two effects are found in the ATM puts, OTM calls, and OTM puts after the onset of the sovereign debt crisis. These empirical evidence is very different with that of Kang and Park (2008), in which the two learning effects cannot be found at the same time.

The remaining parts of this paper are arranged as follows. Section 2 introduces the theoretical background. Section 3 provides the data description and method to calculate implied volatilities. We also analyze the empirical properties of implied volatilities in this section. Section 4 develops a new methodology to decompose net buying pressure into two types of order imbalances and test the volatility-learning hypothesis and direction-learning hypothesis separately. Section 5 empirically investigates the linkage between the order imbalance of options and movements in implied volatilities and provides empirical results by the proposed method. Concluding remarks are given in the last section.

2 Literature review

Based on the assumption of the Black-Scholes (1973) model, options with the same underlying asset and the same time to maturity but different strike price should have a flat implied volatility curve. However, Bollen and Whaley (2004) point out that the implied volatility curve of S&P 500 index options looks like smile before the October 1987 market crash, but it turns to be a smirk after the market crash. The implied volatility is relatively lower for ATM options, but becomes progressively higher as an option moves either in-the-money (ITM) or OTM options. The phenomenon is regarded as the implied volatility smile. However, the implied volatility smirk means that the implied volatility curve of index options across different strike prices tends to be downward sloping.

Many documents investigate the reason why the implied volatility curve of index options smirk. Some studies explain the volatility curve by using different volatility assumptions. Emanuel and MacBeth (1982) propose the Cox and Ross (1976) constant elasticity of variance (CEV) to modify the Black-Scholes (1973) model assumptions. Dupire (1994), Rubinstein (1994), and Derman and Kani (1998) offer deterministic local volatility structure. Anderson et al. (2002) and Chernov et al. (2003) employ stochastic volatility assumptions. However, those studies are short of providing a completely satisfactory explanation of implied volatility smile.

Recently, some studies use the incomplete market characteristics such as the discrete trades, non-synchronized trading, transaction costs, and market order imbalance to explain the implied volatility smirk phenomenon. Bollen and Whaley (2004) define the investor demands for S&P 500 index option as net buying pressure and conclude that the implied volatility smile is attributed to the net buying pressure from order imbalance. They provide an empirical test to investigate two alternative hypothesis: one is limit of arbitrage hypothesis and the other is volatility-learning hypothesis, and supply empirical evidence supporting the limit of arbitrage hypothesis.

The first hypothesis is related to limit to arbitrage and suggests that the supply curve of an option has a positive slope. Figlewski (1989) and Green and Figlewski (1999) discuss that as market makers are required to absorb larger positions in particular option series, their hedging costs and/or desired compensation for risk will increase. Liu and Longstaff (2004) report that underinvestment in the arbitrage by taking a smaller position is more appropriate than collateral constraint in optimal investment policy, since intermediate market-to-market losses may force liquidation of investor position prior to convergence. Thus, with an upward sloping supply curve, differently implied volatility curve in different markets can be expected.

The second hypothesis is the volatility-learning hypothesis. Bollen and Whaley (2004) implied that if a volatility shock occurs and an order imbalance signals the shock to investors, then the order imbalance merely reflected a change in investors expectations about future volatility. In other words, the trading activity of investors provides the information to the market maker, who continually learns about the underlying asset dynamics and updates prices as a result.

Kang and Park (2008) extend Bollen and Whaley (2004) volatility-learning hypothesis to examine informed trading effects in an option market. They propose the direction-learning hypothesis which argue that implied volatility of options may driven by the directional traders. The direction-learning hypothesis assumes that the news about the direction of the underlying asset future prices will change the expectations of investors regarding the future price movements of the underlying asset, and the option prices will move accordingly.

Moreover, Kang and Park (2008) apply Bollen and Whaley (2004) two empirical tests to differentiate the three hypotheses. The first test is the regression includes the lagged changes in implied volatility that examines the relation between changes in implied volatility and option demand. Under the limit of arbitrage hypothesis, since investors take a risk by supply liquidity and hold risk, they would want to rebalance their portfolio. Thus, changes in the implied volatility will reverse. According to the volatility-learning hypothesis, there is no serial correlation in changes in implied volatility due to new information is already reflected in the price and the implied volatility by investors' trading activities.

Unlike volatility-learning hypothesis, the direction-learning hypothesis implied a negative coefficient on the lagged changes in implied volatility. Figure 4 shows the dynamics of the option price, index price, and implied volatility under the Kang and Park's (2008) direction-learning hypothesis. As the information is disseminated to the stock market at time $t+1$, and the index price will rise at time $t+1$; thus, the implied volatilities of calls will go down (up), and the implied volatilities of puts will go up (down). Therefore, the direction-learning hypothesis implied a negative serial correlation of changes in implied volatility.

The second test examines the relationship between the implied volatility and net buying pressure. Under the limit of arbitrage hypothesis, the net buying pressure of calls/puts and implied volatility has a positive relationship. Under the volatility-learning hypothesis, as the ATM options have the highest value of vega and are more informative about the future volatility, the changes in the implied volatility of all options are driven by the net buying pressure of ATM options. Therefore, changes in the implied volatility of all options should move in the same direction. As shown in Figure 4, under the direction-learning hypothesis, the directional traders trade regarding the expected price of underlying asset. When the price of underlying asset is expected to rise, the implied volatility and premium of calls (puts) are expected to rise (fall); thus, the demand for calls (puts) will increase (decrease). As a result, the implied volatility of calls and net buying pressure of calls (puts) are positive (negative) relationship and the implied volatility of puts and net buying pressure of calls (puts) are negative (positive) relationship.

Recently, many studies investigate the net buying pressure of the option to explain option implied volatility changes in major events. Chan, Cheng, and Lung (2006) test the relationship between the net buying pressure and implied volatility of the Hong Kong's Hang Seng index options during the Asian financial crisis. Their empirical results are consistent with the limit of arbitrage hypothesis. Shiu et al. (2010) investigate the implied volatility curve before and after the subprime crisis and to examine the relationship between the net buying pressure and changes in implied volatility in Taiwan Futures Exchange options. They find that the implied volatility for TAIEX options change from a smile before the subprime mortgage crisis to a smirk after the beginning of the crisis.

3 Sample description

3.1 Data

This paper proposes a new method to decompose the net buying pressure into two components: the net buying pressure due to directional shocks and that due to volatility shocks, and explores the possibility that traders make decisions based on both directional shocks and volatility shocks by using the two types of net buying pressures. We analyze the intraday data of TAIEX options traded on Taiwan Futures Exchange from January 3, 2011 to December 30, 2011. To investigate the impact of sovereign debt crisis on the prices of TAIEX options, we divide the whole sample period into two subperiods by the onset of the sovereign debt crisis. Subperiod I ranging from January 2011 to May 2011 represents the period before sovereign debt crisis. Subperiod II starts from June 2011 and ends in December 2011. During this period the European and U.S. sovereign debt crises are coming one after another. Thus, we are able to highlight the impact of sovereign debt crises by comparing the empirical findings from Subperiod I and II.

The intraday data of Taiwan Capitalization Weighted Stock Index (TAIEX) and TAIEX option are obtained from the database of CMoney - Institutional Investors Investment Decision Support System. The TAIEX options are European-style options. The expiration date is the third Wednesday of the maturity month. Moreover, there are always five expirations of TAIEX options outstanding in the markets, including two consecutive following months and three nearest the quarterly cycle. This research focus on analyzing the nearest-month option contracts. Since options are traded infrequently near the expiration date and thus induce problems in estimating implied volatilities, we switch the option contracts to the next expiration month when the remaining days to expiration are less than two days.

The trading time of TAIEX is different from that of TAIEX options. The TAIEX is traded from 9:00 to 13:30 each day, while TAIEX options are traded from 8:45 to 13:45. To synchronize the trading data, we omit trading before 9:00 and after 13:25 from our data set. Please note that the transactions traded five minutes before closing are excluded due to the Call Auction Mechanism. After removing these trading, the transactions for call options used in our empirical research are 4,887,946, whereas trading for put options are 4,892,930. In total, the final data set have 9,780,876 transactions.

The implied volatility for call and put options, C_t and P_t, are calculated by the following Black and Scholes model:

$$C_t = S_t e^{-q(T-t)} N(d_1) - K e^{-r(T-t)} N(d_2), \tag{3}$$

and

$$P_t = K e^{-r(T-t)} N(-d_2) - S_t e^{-q(T-t)} N(-d_1), \tag{4}$$

where

$$d_1 = \frac{\ln(S_t/K) + (r - q + 0.5\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}}, \tag{5}$$

and

$$d_2 = d_1 - \sigma\sqrt{(T-t)}. \tag{6}$$

Moreover, the implied volatility can be calculated by:

$$\Delta_C = N\left[\frac{\ln(S_t/K) + (r - q + 0.5\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}}\right]. \tag{7}$$

Herein, the risk-free interest rate is the average of one-month time deposit interest rates of five major banks in Taiwan, which are collected from the website of the Central Bank of the Republic of China. Based on Central Bank of the Republic of China, the dividend yield of TAIEX is equal to 5.83% in 2011.

By Equations (3)-(7), the implied volatility and delta can be calculated for each transaction and each option series. Once the value of delta is at hand, we are able to classify the moneyness for each option transaction. This research follows Bollen and Whaley (2004) and Kang and Park (2008) to classify the moneyness of options. Table 1 displays the way to classify options into five moneyness categories. According to Christensen and Prabhala (1998), Fleming (1998), and George and Tian (2005), the implied volatility is generally better than historical volatility in terms of the effectiveness of prediction in forecasting period, we thus adopt the implied volatility as the proxy for the standard deviation of the underlying asset in calculating the value of delta. This calculation method is different from those in Bollen and Whaley (2004), in which they use the realized return volatility of the index over the most recent sixty trading days as the proxy variable.

Finally, options with absolute deltas below 0.02 or above 0.98 are excluded because the value of deeply in the money and deeply out of the money options are extraordinarily insensitive to volatility changes and the trading volume of these options are vary small. The option transactions with the trading price above its theoretically upper bound or below its theoretically lower bound are also deleted, since the implied volatility cannot be estimated reasonably in case of the market price violating the Black-Scholes price bounds. Herein, the boundary of call options is:

$$S_t e^{-q(T-t)} - K e^{-r(T-t)} \leq C_t \leq S_t,$$

and that of put options is:

$$K e^{-r(T-t)} - S_t e^{-q(T-t)} \leq P_t \leq K e^{-r(T-t)}.$$

3.2 Empirical properties of implied volatilities

This subsection analyse the relation between net buying pressure and the shape of the implied volatility function, in which implied volatilities are calculated by Black and Scholes (1973) model for each contract and group options into five different moneyness categories as described above. For analyzing the shape of the implied volatility function, we further calculate the average implied volatility for each moneyness category.

Figure 1 plots the time series properties of the realized volatility, the implied volatility of ATM options, and the level of the TAIEX over the whole period. A salient feature of this plot is observed that while the implied volatility of ATM call (put) options and realized volatility spreads increase, the level of the TAIEX drops rapidly, especially in the August. In addition, the different between the implied volatility of ATM call (put) options and the realized volatility after the occurrence of sovereign debt crisis becomes more than that before the occurrence of sovereign debt crisis. Obviously, the sovereign debt crisis affect the trade in TAIEX option market and the option price (implied volatility).

The average implied volatility of call options and put options are plotted respectively in Figure 2 and Figure 3, including the whole period, Subperiod I, Subperiod II, and each month during the Subperiod II. During the whole period, the shape of put implied volatility in Figure 3 is smirk, but the call implied volatility curve in Figure 2 is un-smirk. This shape of call options is different from literature and it may be resulted from the sovereign debt crisis.

For two subperiod analysis, implied volatility curve for calls are volatility smirk and for puts are volatility smile in Subperiod I. However, in Subperiod II, the shape of implied volatility for calls changes from a smile to a un-smirk but the shape of implied volatility for puts is still smirk. One possible explanation for this phenomenon is that the sovereign debt crisis changes very differently the investors' trading behavior for different moneyness categories, especially in ITM, ATM, and OTM call options. To analyse this phenomenon further, we draw the implied volatility by month from Subperiod II to investigate whether the monthly implied volatility curve have a phenomenon of volatility smirk. We find that the shape of implied volatility for calls is un-smirk in June, July, and August, but those is unchanged in September to December. For puts, the shape of implied volatility for puts is reverse-skew in July. It implies that in TAIEX option market the trade for call options is very different from that for put options after the sovereign debt crisis.

3.3 Net buying pressure

Based on Bollen and Whaley (2004), the buyer-motivated trades is defined by the transaction price higher than the midpoint of prevailing ask/bid quotes, and the seller-motivated trades is defined by the transaction price below than the midpoint of prevailing ask/bid quotes. Therefore, net buying pressure is calculated as the difference between the number of buyer-motivated trades and the number of seller-motivated trades and then times the absolute value of the option's delta. When net buying pressure is greater than zero, it means that the market is buyer-dominated; if the net buying pressure is less than zero, the market is seller-dominated.

Table 2 reports the summary of number of contracts traded and net purchases of contracts in TAIEX options, respectively. Panel A of Table 2 displays that during the whole period the calls initiated 51% of the total option trades, while the puts initiated 49% of the total option trades. There are a similar result during Subperiod I and Subperiod II It implies that investors prefer trading the put options to trading the call options in TAIEX option market. This is different from the U.S. option market reported in literature. To take account of trading motivation, Panel B of Table 2 shows that the main trading motivation is seller-motivated in TAIEX option market.

Comparing across moneyness categories, TAIEX option investors are net sellers for most options during the whole period. However, after the sovereign debt crisis, investors buy the DOTM and OTM puts on TAIEX, indicating an increase in the demand for hedging in the stock market. The sudden increase in the demand for OTM puts is consistent with the transformation of the implied volatility curve from a smile to a smirk. One possible reason is that during the sovereign debt crisis, the hedge trading strategy by selling TAIEX spots are more difficulty owing to the falling stock index have increasingly obligated put option writers. Hence, writers would require for a higher price to compensate for their high risk bearing.

Table 3 reports net buying pressure of call options and put options. The result is similar to that in Panel B of Table 2 because it is adjusted by multiplying the absolute value of the option's delta. Table 3 shows that investors generally have net selling positions except DOTM put options in TAIEX option market. To comparing Subperiod I and Subperiod II, the net buying pressure of call options was 1.4 times that of puts during Subperiod I, while the net buying pressure of call options was only 0.91 times that of puts during Subperiod II. This result suggests that the sovereign debt crisis changed investors' motivation of trading on TAIEX options again.

4 A new method to test the learning hypotheses

Recently, most of researches study the relation between movements in implied volatility and investors' demand for options. Bollen and Whaley (2004) suggest two alternative hypotheses, limit to arbitrage hypothesis and learning hypothesis, and design empirical test to examines the relation. Further, Kang and Park (2008) specify the learning hypothesis in Bollen and Whaley (2004) and define two different type of the learning hypothesis, the volatility-learning hypothesis and the direction-learning hypothesis. Based on Bollen and Whaley's empirical test, Kang and Park (2008) suggest that option traders are directional traders in the KOSPI 200 index option market.

Kang and Park's regressions, which follow Bollen and Whaley's empirical test, are specified as Equations (1) and (2). The size and sign of the net buying pressure coefficients, α_3 and α_4, can be used to distinguish the three hypotheses. However, the design/assumption of the regressions implies that the volatility-learning hypothesis and the directional-learning hypothesis are mutually exclusive.

To illustrate, Table 4 summarizes rules for detecting net-buying-pressure hypotheses proposed by Kang and Park (2008). This table clearly indicates that the limit of arbitrage hypothesis and volatility-learning hypothesis can not hold simultaneously under Kang and Park's (2008) framework. For ATM options, the conditions required by the limit of arbitrage hypothesis and volatility-learning hypothesis are $\alpha_3 \neq \alpha_4$ and $\alpha_3 = \alpha_4$, respectively, but the two conditions can not be true at the same time. Similarly, the necessary conditions for the limit of arbitrage hypothesis and volatility-learning hypothesis in the OTM option market are $\alpha_3 > \alpha_4$ and $\alpha_3 < \alpha_4$, respectively, and the two conditions can not occur at the same time as well. The direction-learning and volatility-learning effects can not be observed in the option market concurrently, too. As shown in Table

4, the conditions that the volatility-learning hypothesis holds are $\alpha_3 > 0$ and $\alpha_4 > 0$. However, under the direction-learning hypothesis, $\alpha_3 < 0$ and $\alpha_4 < 0$ should be true for put and call options, respectively. It indicates that option's traders are not able to trade based on both directional expectations and volatility expectations. Hence, it motivates us to design new empirical methodology.

As mentioned above, the net buying pressure is calculated by the difference between the number of buyer-motivated contracts and seller-motivated contracts multiplied by the absolute value of options' delta. Thus, an excess supply force in the option market induces the net buying pressure increases, whereas an excess demand force results in a decrease in the net buying pressure.

Denote $C_{k,t}$ and $P_{k,t}$ as the time t prices of call and put options that belong to moneyness category k, respectively. Suppose that the excess demand (supply) force of options is a function of expected changes in option prices, that is:

$$NBP_{C,t}^{k} = f\left(\Delta C_{k,t}^{E}\right), \tag{8}$$

and

$$NBP_{P,t}^{k} = f\left(\Delta P_{k,t}^{E}\right), \tag{9}$$

where $\Delta C_{k,t}^{E}$ and $\Delta P_{k,t}^{E}$ are the expected price changes at time t for call and put options in moneyness category k, where $k \in \{\mathrm{OTM}, \mathrm{ATM}, \mathrm{ITM}\}$. Moreover, we assume that the impact of expected call price changes on net buying pressures is equivalent to that of put options when they are in the same moneyness category, i.e., $f'(\Delta C_{k,t}^{E}) \equiv f'(\Delta P_{k,t}^{E})$.

Given that investors make trading decisions based on expectations about the price changes of the underlying asset ΔS^{E} and volatility changes $\Delta\sigma^{E}$, the order imbalance will result from the two kinds of expectations. Accordingly, we decompose the net buying pressure into two parts:

$$NBP^k_{C,t} = NBPD^k_{C,t} + NBPV^k_{C,t},$$

and

$$NBP^k_{P,t} = NBPD^k_{P,t} + NBPV^k_{P,t},$$

where $k \in \{ATM, OTM, ITM\}$. Herein, $NBPD^k_{C,t}$ and $NBPD^k_{P,t}$ denote the net buying pressure due to directional shocks for call/put options with moneyness category k. The amount of order imbalances is summed across the time interval t. $NBPV^k_{C,t}$ and $NBPV^k_{P,t}$ represent the net buying pressure due to volatility shocks for k-category call/put options during the time interval t. By applying Chain rule to Equations (8) and (9), the excess demand (supply) can be decomposed as:

$$\begin{aligned} NBP^k_{C,t} &= NBPD^k_{C,t} + NBPV^k_{C,t} \\ &= f^{'}(\Delta C^E_{k,t})\Delta^k_C \Delta S^E + f^{'}(\Delta C^E_{k,t})\mathcal{V}^k_C \Delta\sigma^E, \end{aligned} \tag{10}$$

and

$$\begin{aligned} NBP^k_{P,t} &= NBPD^k_{P,t} + NBPV^k_{P,t} \\ &= f^{'}(\Delta P^E_{k,t})\Delta^k_P \Delta S^E + f^{'}(\Delta P^E_{k,t})\mathcal{V}^k_P \Delta\sigma^E, \end{aligned} \tag{11}$$

where $\Delta_C = \Delta C/\Delta S$, $\Delta_P = \Delta P/\Delta S$, $\mathcal{V}_C = \Delta C/\Delta\sigma$, and $\mathcal{V}_P = \Delta P/\Delta\sigma$.

We note that the property of vega and delta plays an important role in refining out the value of $NBPD^k_{i,t}$ and $NBPV^k_{i,t}$ from $NBP^k_{i,t}$. First, the vega of a call option is the same as that of its corresponding put option, that is:

$$\mathcal{V}^k_C = \mathcal{V}^k_P. \tag{12}$$

It is trivial from the Black-Scholes model. Secondly, the property of delta that can be observed obviously from Table 1 is:

$$\Delta^k_C = -\Delta^k_P. \tag{13}$$

It means that the values of delta for call and put options for the same moneyness category k have equivalent values but different signs.

Combining the conditions that $\mathcal{V}_C^k = \mathcal{V}_P^k$ and $\Delta_P^k = -\Delta_C^k$, the order imbalance caused of directional shocks for call options with moneyness category k can be measured by:

$$\begin{aligned} NBPD_{C,t}^k &\equiv f^{'}(\Delta C_{k,t}^E)\Delta_C^k \Delta S^E \\ &= \frac{NBP_{C,t}^k - NBP_{P,t}^k}{2}, \end{aligned} \tag{14}$$

and the excess demand (supply) due to volatility shocks for call options with moneyness category k can be sized by:

$$\begin{aligned} NBPV_{C,t}^k &\equiv f^{'}(\Delta C_{k,t}^E)\mathcal{V}_C^k \Delta \sigma^E \\ &= \frac{NBP_{C,t}^k + NBP_{P,t}^k}{2}. \end{aligned} \tag{15}$$

Similarly, the net buying pressures for put options induced by directional shocks and volatility shocks are measured by:

$$\begin{aligned} NBPD_{P,t}^k &\equiv f^{'}(\Delta P_{k,t}^E)\Delta_P^k \Delta S^E \\ &= \frac{NBP_{P,t}^k - NBP_{C,t}^k}{2}, \end{aligned} \tag{16}$$

and

$$\begin{aligned} NBPV_{P,t}^k &\equiv f^{'}(\Delta P_{k,t}^E)\mathcal{V}_P^k \Delta \sigma^E \\ &= \frac{NBP_{P,t}^k + NBP_{C,t}^k}{2}. \end{aligned} \tag{17}$$

Once the order imbalance can be divided by the direction source and volatility source, the regressions for investigating the relationship between the net buying pressure and implied volatility can be constructed as follow:

$$\Delta\sigma_{i,t}^{ATM} = \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{ATM} + \beta_4 NBPV_{i,t}^{ATM} + \beta_5 \Delta\sigma_{i,t-1}^{ATM} + \epsilon_t \ , \tag{18}$$

$$\begin{aligned}\Delta\sigma_{i,t}^{OTM} =& \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{OTM} + \beta_4 NBPV_{i,t}^{OTM} + \beta_5 \Delta\sigma_{i,t-1}^{OTM} \\ &+ \beta_6 NBPD_{i,t-1}^{ATM} + \epsilon_t \ , \qquad\qquad i \in \{C, P\},\end{aligned} \tag{19}$$

where $\Delta\sigma_{i,t}^{ATM}$ is the change in the average implied volatility of ATM call/put options, and $\Delta\sigma_{i,t}^{OTM}$ is the change in the average implied volatility of OTM call/put. RS_t is the Taiwan Weighted Stock Index return during the time interval t, and VS_t is the trading volume of the Taiwan Weighted Stock Index on the interval t expressed in millions of New Taiwan (NT) dollars. $NBPD_{i,t}^{ATM}$ and $NBPD_{i,t}^{OTM}$ are the net buying pressure of ATM and OTM options due to directional shocks during the time interval t. Moreover, $NBPV_{i,t}^{ATM}$ and $NBPV_{i,t}^{OTM}$ are the net buying pressure of ATM and OTM options due to volatility shocks during the time interval t. $\Delta\sigma_{i,t-1}^{ATM}$ and $\Delta\sigma_{i,t-1}^{OTM}$ are the lagged implied volatility of ATM and OTM options. All variables are calculated across one-minute time interval in our research.

Equations (18) and (19) are designed to explore the relationship between the net buying pressure and implied volatility. We follow Bollen and Whalley (2004) and Kang and Park (2008) to include the index return RS_t and trading volume VS_t as control variable for leverage and information flow effects. Based on Black (1976) and Anderson (1996), stock return volatility is negatively associated with stock returns due to a leverage effect, while the stock return volatility is positively related to trading volume due to an information flow effects. Accordingly, the estimate of the parameter β_1 is expected to be negative, whereas the estimate of β_2 is expected to be positive.

Estimations of parameters β_1, β_3, β_4, β_5, and β_6 are used to determine three net-buying-pressure hypotheses for options within a particular moneyness category. Please note that the coefficient of RS_t, i.e., β_1, is not only related with the leverage hypothesis, but also dominated by the direction-learning hypothesis. In what follows, we display the main assertion for each net-buying-pressure hypothesis and display the rules for determining the three net-buy-pressure hypotheses. These rules are summarized in Table 5, which contains possible five scenarios for validness of these hypotheses.

The limit of arbitrage hypothesis assumes the slope of the supply curve to be positive for each option. Shleifer and Vishny (1997) and Liu and Longstaff (2004) point out that the market makers will not stand ready to sell an unlimited number of contracts in an option series, even if there are profitable arbitrage opportunities in the market, as market makers are risk-averse and it is a possibility that market-to-market losses may force liquidation of their positions before convergence. With a upward-sloping supply curves, an excess of buyer-motivated trades will cause price and implied volatility to rise, and an excess of seller-motivated trades will cause implied volatility to fall. It follows that the coefficient estimates of the net buying pressure should be positive under the limit of arbitrage hypothesis. However, we note that a change in the net buying pressure induced from volatility changes, i.e., $NBPV_{i,t}^k$, alters the implied volatility even when the supply curve is flat. This is because the supply curve shifts parallel as volatility changes. Accordingly, a better way to judge the limit of arbitrage hypothesis is a positive parameter estimates for $NBPD_{i,t}^k$, i.e., $\beta_3 > 0$, solely. We note that this inspecting rule is very different with that in Bollen and Whalley (2004) and Kang and Park (2008), in which the judgement for the limit of arbitrage hypothesis depends on the parameter estimates of the *total* net buying pressure, including the direction source and volatility source.

The second characteristic for the limit of arbitrate hypothesis is a negative parameter estimates for the lagged changes in implied volatility, i.e., $\beta_5 < 0$. This is because traders who take a risk by supplying liquidity want to rebalance their portfolio, which results in the reverse of the lagged changes in implied volatility, $\Delta\sigma_{i,t-1}$. Moreover, the parameter of $NBPD^{ATM}_{i,t}$ in Equation (19) is also used to detect the limit of arbitrage hypothesis. Under this hypothesis, the option series' own demand will affect its implied volatility, implying that the implied volatilities of different option series do not have to move together. Thus, the parameter of $NBPD^{ATM}_{i,t}$ in Equation (19) would be positive but smaller than the parameter of $NBPD^{OTM}_{i,t}$, i.e., $\beta_6 > 0$ and $\beta_3 > \beta_6$. The determinant rules for the limit of arbitrage hypothesis are consistent in the Scenario 1 in Table 5.

The direction-learning hypothesis first proposed by Kang and Park (2008) asserts that the order imbalance and option-implied volatility will move when new information about the future price movement of the underlying asset is expected. In the opinion of Kang and Park (2008), the option's supply curve is flat under this hypothesis. Unlike Kang and Park (2008), we note that the assertion of the direction-learning hypothesis implies a positive-slope supply curve, because only volatility shocks move option prices in case of a flat supply curve. Accordingly, the direction-learning hypothesis holds only when the limit of arbitrage hypothesis is valid.

Based on the assertion of the direction-learning hypothesis, the new information about the future price change of the underlying asset induces the occurrence of order imbalance and change in option price, the parameter of $NBPD^{k}_{i,t}$ would be positive, i.e., $\beta_3 > 0$. Since buying a call (put) option can be regarded as taking a long (short) position in the underlying asset, traders with information about the future underlying asset price movements can enjoy higher returns by taking a position in options than by taking a position in the underlying asset. Accordingly, traders who expect the price changes in the underlying asset will take a position in options before the directional shock arrives, and close out their position after the directional shock hits the market. The trading behavior induces two effects. First, the changes in implied volatility, $\Delta\sigma^k_{i,t}$, will be negatively related with the return of the underlying asset, RS_t, for call options but positively correlated with RS_t for put options. Secondly, the changes in implied volatility, $\Delta\sigma^k_{i,t}$, are negatively correlated with the lagged changes in implied volatility, $\Delta\sigma^k_{i,t-1}$. Or equivalently, the parameter of $\Delta\sigma^k_{i,t-1}$ would be negative, i.e., $\beta_5 < 0$. The rules for inspecting the direction-learning hypothesis are summarized in Scenario 2 of Table 5.

The volatility-learning hypothesis asserts that the order imbalance and option-implied volatility will move when volatility shocks occur. We note that the volatility-learning effect may happen no matter the supply curve is flat or positive-slope, since a volatility shock shifts the supply curve and induces option prices changing. Since this hypothesis asserts that the net buying pressures induced by volatility shocks will result in the implied volatility changing, the parameter of $NBPV^k_{i,t}$ would be positive, i.e, $\beta_4 > 0$. On the other hand, under the volatility-learning hypothesis, due to the information is already reflected in the price and the implied volatility by investors' trading activities, there should be no serial correlation in changes in implied volatility. It implies that the coefficients of the lagged change in implied volatility in Equations (18) and (19), β_5, would be indifferent from zero. The above-mentioned determinant rules are outlined in Scenario 5 of Table 5.

Please note that one distinguish feature of this research from that of Kang and Park (2008) is these net-buying-pressure hypotheses can be hold at the same time, because the proposed methodology divides the net buying pressure into two sources: the directional source and volatility source. As shown in Scenario 3 of Table 5, when all of the three net-buying-pressure hypothesis hold, both the impacts of the two kinds of net buying pressures on changes in implied volatilities are positive, i.e., $\beta_3 > 0$ and $\beta_4 > 0$. It is worth noting that there are two effects working on the parameter of the lagged changes in implied volatility, β_5, when all of the three hypotheses hold. Particularly, the estimate of β_5 should be negative under the limit of arbitrage hypothesis and direction-learning hypothesis, while the volatility-learning hypothesis asserts that the lagged changes in implied volatility, $\Delta\sigma^k_{i,t-1}$, have no impact on the changes in implied volatility, $\Delta\sigma^k_{i,t}$. Accordingly, the net effects display on the parameter estimates of β_5 will be negative, i.e., $\beta_5 < 0$, given that the three hypotheses hold in the meanwhile. The similar phenomenon can be found out in Scenario 4 of Table 5.

5 Empirical analysis

This section adopts the proposed method to empirically re-investigate three net-buying-pressure hypotheses by using the intraday data of TAIEX options in 2011. As mentioned above, in order to analyze the impact of sovereign debt crises on the behavior of option investors, we divide the whole sample period into two subperiods. Subperiod I ranges from January 2011 to May 2011, while Subperiod II starts from June 2011 to December 2011. Obviously, only the Subperiod II suffers from sovereign debt crises.

We display the regression results for changes in implied volatility of ATM options in Table 6 and Table 7 show the results for OTM options. We first note that parameter estimates for the control variable, VS_t, are positive and statistically significant for both ATM and OTM options during the whole sample period, which confirm the information flow effect proposed by Anderson (1996). However, the information flow effect is not always found out for each moneyness-category options and each subperiods. Specifically, the parameter estimates of the trading volume VS_t, i.e., the estimates of β_2, are not significantly positive for ATM and OTM call options during Subperiod I, while during Subperiod II the estimate of β_2 is not found to be positive and statistical significant for ATM puts. Those results contradict the information flow hypothesis.

The parameter estimates of β_1, β_3, β_4, and β_5 play important roles in exploring the relation between changes in implied volatilities and net buying pressure. As shown in Table 6, we find that all parameter estimates for $NBPD^{ATM}_{C,t}$, i.e., β_3, are positive and statistically significant at the 1% significance level for each period. Moreover, the parameter estimates of RS_t and $\Delta\sigma^{ATM}_{i,t-1}$, i.e., β_1 and β_5 are negative and statistically significant at the 1% significance level for ATM calls and for each period. These empirical results of ATM call options are consistent with both the direction-learning hypothesis and limit of arbitrage hypothesis, no matter in the whole sample period, Subperiod I, or Subperiod II. In the contrary, the volatility-learning hypothesis is not supported by the findings of ATM call options, since the parameter estimates for the volatility-source net buying pressure, β_4, are insignificantly for all periods. These behaviors of ATM call options correspond to the Scenario 2 displayed in Table 5, which imply that the investors of ATM calls are directional traders in the TAIEX option market and make decision mainly based on directional shocks. We also find that the trading behavior of investors in the ATM call option market do not change due to the onset of the sovereign debt crisis, which mean that the occurrence of the crisis does not influence the investors' purpose for trading call options.

Unlike the findings in the ATM call option market, the empirical evidences from the ATM puts support all of the three net-buying-pressure hypotheses, since all parameter estimates for RS_t, $NBPD_{P,t}^{ATM}$, and $NBPV_{P,t}^{ATM}$ i.e., β_1, β_3, and β_4, are positively significant at the 1% or 10% significance level and parameter estimates for $\Delta\sigma_{i,t-1}^{ATM}$, i.e., β_5, are negatively significant at the 1% significance level. The results from ATM puts correspond to Scenario 3 in Table 5, and imply that the investors of ATM puts are both directional traders and volatility traders in the TAIEX option market. Moreover, these findings are consistent in all periods, indicating the intelligence of investors in ATM puts does not alter by the onset of the sovereign debt crisis.

Summarily, Table 6 shows that the behavior of ATM calls is consistent with the direction-learning and limit of arbitrage hypotheses no matter whether the sovereign debt crisis happens, while the behavior of ATM put options is in agreement with all of the three net-buying-pressure hypotheses, including the volatility-learning effect. These findings are very different from those in the literature, where the volatility-learning effect and direction-learning effect cannot be found out simultaneously.

Similar results can be observed from the OTM options. As shown in Table 7, we find that all parameter estimates for $NBPD_{C,t}^{OTM}$, i.e., β_3, are positive and statistically significant at the 1% significance level for each period. The parameter estimates of RS_t and $\Delta\sigma_{i,t-1}^{ATM}$, i.e., β_1 and β_5 are negative and statistically significant at the 1% significance level for each period. Additional, the coefficient of $NBPD_{C,t}^{ATM}$, β_6, are significantly positive for all periods and less than the coefficient of $NBPD_{C,t}^{OTM}$, i.e., $\beta_3 > \beta_6$. Apparently, the net buying pressure of OTM calls has a greater influence on the its implied volatility $\Delta\sigma_{C,t}^{OTM}$ than does the net buying pressure of ATM calls. All of these empirical results support the validness of both the direction-learning hypothesis and limit of arbitrage hypothesis, no matter in the whole sample period, Subperiod I, or Subperiod II. Similar to the ATM calls, the empirical evidences from the OTM calls contradict the volatility-learning hypothesis in most of periods. Based on the findings of ATM and OTM call options, we conclude that investors of different moneyness-category call options have the same behavior.

In two subperiod analysis considering the sovereign debt crisis in 2011, our results offer an interesting insight. Before the sovereign debt crisis, in Panel B of Table 7, the results of β_3, β_4, β_5, and β_6 are equivalent to those in whole period. However, after the crisis, the coefficient of $NBPV_{C,t}^{OTM}$, β_4, become to be significantly positive in Panel C of Table 7, while that is insignificantly in Panel B of Table 7. It implies that investors react differently to the the sovereign debt crisis. Hence, for the OTM call option, investors prefer trading in regard to the direction-learning hypothesis before the sovereign debt crisis, while they prefer trading in regard to the direction-learning hypothesis and the volatility-learning hypothesis after the sovereign debt crisis.

For OTM put options, no matter what period is taken into account, the results in Panel A, Panel B, and Panel C of Table 7 show that both of coefficients β_3 and β_6 are significant positive and the relation $\beta_3 > \beta_6$ holds. Additionally, the coefficients β_4 and

β_5 are significantly positive and negative, respectively. Hence, those evidences mean that both direction-learning hypothesis and volatility-learning hypothesis can explain simultaneously about the investors' behavior for OTM put options in TAIEX option market.

In summary, this section documents a strong statistical relationship between changes in implied volatility and the new method for decomposing the net buying pressure of option trading into two components: the net buying pressure due to directional shocks and that due to volatility shocks. Additionally, the result shows that the new method is well to test direction-learning and volatility-learning hypotheses independently based on the two types of net buying pressures. In contrast with the findings in the literature, both the direction-learning hypothesis and volatility-learning hypothesis can account for the behavior of option-implied volatility in TAIEX option market.

6 Conclusions

In this study, we investigate the impact of net buying pressure in the TAIEX option market and provide two distinctive contributions. First, we examine the empirical properties of implied volatilities calculated from the TAIEX options in 2011. We find that the implied volatility curve for TAIEX call options look like a smirk before the sovereign debt crisis. After the onset of the crisis, the implied volatility curve changes to be a un-smile. These findings are very different from that in Bollen and Whaley (2004), in which they demonstrate the implied volatility curve of S&P 500 changing from a smile to smirk after the October 1987 market crash.

Secondly, we develop a method to solve the contradiction existing in the literature that the direction-learning hypothesis and volatility-learning hypothesis cannot be found out simultaneously. The empirical evidences in this study show that both the net buying pressures driven by the directional shocks and volatility shocks affect the implied volatility of put options. We conclude that the investors of put options are both directional traders and volatility traders in the TAIEX option market, and the intelligence of investors in the put option market does not alter by the onset of the sovereign debt crisis.

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Table 1. Moneyness category definitions

Call category		Delta range	Put category		Delta range
1	DITM	$0.875 < \Delta_C \leqq 0.98$	1	DOTM	$-0.125 < \Delta_P \leqq -0.02$
2	ITM	$0.625 < \Delta_C \leqq 0.875$	2	OTM	$-0.375 < \Delta_P \leqq -0.125$
3	ATM	$0.375 < \Delta_C \leqq 0.625$	3	ATM	$-0.625 < \Delta_P \leqq -0.375$
4	OTM	$0.125 < \Delta_C \leqq 0.375$	4	ITM	$-0.875 < \Delta_P \leqq -0.625$
5	DOTM	$0.02 < \Delta_C \leqq 0.125$	5	DITM	$-0.98 < \Delta_P \leqq -0.875$

Notes: (1). This paper measures moneyness of an option by using the option's delta, since it can be regarded as the possibility of options being in the money at maturity. (2). Trading records of call options with delta below 0.02 and above 0.98 are excluded. Similarly, trading records of put options with delta below -0.98 and above -0.02 are excluded as well. (3). This definition of moneyness category is the same as the method used in Bollen and Whaley (2004) and Kang and Park (2008).

Table 2. Summary statistics of TAIEX options traded in 2011

Delta value category	Whole period				Subperiod I				Subperiod II			
	Call		Put		Call		Put		Call		Put	
	No. of contracts	Prop. of total	No. of contracts	Prop. of total	No. of contracts	Prop. of total	No. of contracts	Prop. of total	No. of contracts	Prop. of total	No. of contracts	Prop. of total
Panel A. Number of contracts traded												
1	168,148	0.0023	9,595,149	0.1287	97,027	0.0030	3,971,021	0.1239	71,121	0.0017	5,624,128	0.1324
2	1,971,842	0.0265	17,065,122	0.2290	1,046,521	0.0327	6,822,600	0.2129	925,321	0.0218	10,242,522	0.2410
3	8,888,910	0.1193	7,410,714	0.0994	4,089,855	0.1276	3,244,193	0.1012	4,799,055	0.1129	4,166,521	0.0981
4	18,205,813	0.2443	1,930,274	0.0259	7,687,219	0.2399	1,007,473	0.0314	10,518,594	0.2475	922,801	0.0217
5	9,103,802	0.1221	195,871	0.0026	3,992,938	0.1246	83,678	0.0026	5,110,864	0.1203	112,193	0.0026
Totals	38,338,515	0.5144	36,197,130	0.4856	16,913,560	0.5278	15,128,965	0.4722	21,424,955	0.5042	21,068,165	0.4958
Panel B. net purchases of contracts												
1	-6,556		95,535		-6,197		24,802		-359		70,733	
2	-42,640		-490,060		-28,265		-345,198		-14,375		-144,862	
3	-223,710		-90,174		-86,843		-62,649		-136,867		-27,525	
4	-177,267		-53,898		16,189		-46,193		-193,456		-7,705	
5	-196,814		-17,995		-18,958		-10,965		-177,856		-7,030	
Totals	-646,987		-556,592		-124,074		-440,203		-522,913		-116,389	

Note: (1). The whole sample period that ranges from January 3, 2011 to December 31, 2011 is divided into two subperiods. Subperiod I is from January 3, 2011 to May 31, 2011, whereas Subperiod II indicates the sample period after May 31, 2011. (2). The net purchases of contracts displayed in Panel B are calculated as the number of buyer-motivated contracts minus the number of seller-motivated contracts.

Table 3. Net buying pressure

Delta value category	Whole period		Subperiod I		Subperiod II	
	Call	Put	Call	Put	Call	Put
1	-6,210	8,069	-5,832	6,563	-378	1,506
2	-34,635	-118,060	-23,010	-40,032	-11,625	-78,028
3	-100,302	-38,432	-39,816	-10,282	-60,486	-28,150
4	-66,398	-44,597	-13,186	-7,212	-53,212	-37,384
5	-12,309	-16,658	1,215	-6,441	-13,524	-10,216
Totals	-219,854	-209,677	-80,628	-57,404	-139,226	-152,272

Note: (1). The whole sample period that ranges from January 3, 2011 to December 31, 2011 is divided into two subperiods. Subperiod I is from January 3, 2011 to May 31, 2011, whereas Subperiod II indicates the sample period after May 31, 2011. (2). The net buying pressure is defined as the number of contracts traded above the prevailing bid/ask midpoint less the number of contracts traded below the prevailing bid/ask midpoint times the absolute value of the option's delta.

Table 4. Rules to determine net-buying-pressure hypotheses in Kang and Park's (2008) framework

Hypothesis		Estimates parameter			
		α_1	α_3	α_4	α_5
Panel A. Conditions that the corresponding hypotheses holds for ATM options					
Limit of arbitrage	for all options	- -	Positive and $\alpha_3 \neq \alpha_4$	Positive	Negative
Volatility-learning	for all options	- -	Positive and $\alpha_3 = \alpha_4$	Positive	Insignificant
Direction-learning	for calls	Negative	Positive	Negative	Negative
	for puts	Positive	Negative	Positive	Negative
Panel B. Conditions that the corresponding hypotheses holds for OTM options					
Limit of arbitrage	for all options	- -	Positive and $\alpha_3 > \alpha_4$	Positive	Negative
Volatility-learning	for all options	- -	Positive and $\alpha_3 < \alpha_4$	Positive	Insignificant
Direction-learning	for calls	Negative	Positive	Negative	Negative
	for puts	Postive	Negative	Positive	Negative

Note: In Kang and Park (2008), all parameters used to determine net-buying-pressure hypotheses are estimated from the following two equations:

$$\Delta\sigma_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{C,t}^{ATM} + \alpha_4 NBP_{P,t}^{ATM} + \alpha_5 \Delta\sigma_{t-1}^{ATM} + \varepsilon_t, \quad (1)$$

and

$$\Delta\sigma_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{i,t}^{OTM} + \alpha_4 NBP_{j,t}^{ATM} + \alpha_5 \Delta\sigma_{t-1}^{OTM} + \varepsilon_t, \quad (2)$$

where $i \in \{C, P\}$, $j \in \{C, P\}$, and $j \neq i$. Furthermore, $\Delta\sigma_{i,t}^{ATM}$ and $\Delta\sigma_{i,t}^{OTM}$ are the change in average implied volatility of ATM and OTM options, RS_t denotes the index return, and VS_t displays the index volume. Moreover, $NBP_{C,t}^{ATM}$ and $NBP_{P,t}^{ATM}$ are the net buying pressure of ATM calls and ATM puts, respectively.

Table 5. Rules to determine net-buying-pressure hypotheses under the proposed methodology

Scenario		Estimated parameter					Result of hypothesis testing		
		β_1	β_3	β_4	β_5	β_6	Limit of arbitrage	Direction learning	Volatility learning
Panel A. For ATM options									
Scenario 1		- -	Positive	$\beta_4 \leq 0$	Negative	- -	✓	×	×
Scenario 2	Call	Negative	Positive	$\beta_4 \leq 0$	Negative	- -	✓	✓	×
	Put	Positive	Positive	$\beta_4 \leq 0$	Negative	- -			
Scenario 3	Call	Negative	Positive	Positive	Negative	- -	✓	✓	✓
	Put	Positive	Positive	Positive	Negative	- -			
Scenario 4		- -	Positive	Positive	Negative	- -	✓	×	✓
Scenario 5		- -	Insignificant	Positive	Insignificant	- -	×	×	✓
Panel B. For OTM options									
Scenario 1		- -	Positive	$\beta_4 \leq 0$	Negative	Positive and $\beta_3 > \beta_6$	✓	×	×
Scenario 2	Call	Negative	Positive	$\beta_4 \leq 0$	Negative	Positive and $\beta_3 > \beta_6$	✓	✓	×
	Put	Positive	Positive	$\beta_4 \leq 0$	Negative	Positive and $\beta_3 > \beta_6$			
Scenario 3	Call	Negative	Positive	Positive	Negative	Positive and $\beta_3 > \beta_6$	✓	✓	✓
	Put	Positive	Positive	Positive	Negative	Positive and $\beta_3 > \beta_6$			
Scenario 4		- -	Positive	Positive	Negative	Positive and $\beta_3 > \beta_6$	✓	×	✓
Scenario 5		- -	Insignificant	Positive	Insignificant	Insignificant	×	×	✓

Note: Under the proposed methodology, all parameters used to determine net-buying-pressure hypotheses are estimated from the following two equations:

$$\Delta\sigma_{i,t}^{ATM} = \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{ATM} + \beta_4 NBPV_{i,t}^{ATM} + \beta_5 \Delta\sigma_{i,t-1}^{ATM} + \varepsilon_t, \quad (18)$$

and

$$\Delta\sigma_{i,t}^{OTM} = \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{OTM} + \beta_4 NBPV_{i,t}^{OTM} + \beta_5 \Delta\sigma_{i,t-1}^{OTM} + \beta_6 NBPD_{i,t}^{ATM} + \varepsilon_t, \qquad i \in \{C, P\}, \quad (19)$$

where $\Delta\sigma_{i,t}^{ATM}$ and $\Delta\sigma_{i,t}^{OTM}$ are the change in the average implied volatility of ATM and OTM options, RS_t is the index return, and VS_t is the index volume. Moreover, $NBPD_{i,t}^{ATM}$ is the net buying pressure due to directional shocks and $NBPV_{i,t}^{ATM}$ is the net buying pressure due to volatility shocks.

Table 6. Regression results of changes in ATM implied volatility

$\Delta\sigma_{i,t}^{ATM}$	Parameter estimates					
	β_0	β_1	β_2 ($\times 10^4$)	β_3 ($\times 10^3$)	β_4 ($\times 10^3$)	β_5
Panel A. Whole Period						
Call	-0.0079 **	-4.3426 ***	0.1786 **	3.3851 ***	-0.0463	-0.1916 ***
Put	-0.0110 ***	1.5329 ***	0.2039 **	3.2999 ***	0.2646 ***	-0.2123 ***
Panel B. Subperiod I						
Call	0.0010	-4.8763 ***	-0.0274	2.8439 ***	-0.1766 ***	-0.1651 ***
Put	-0.0159 ***	3.2987 ***	0.3161 ***	2.9093 ***	0.2949 ***	-0.1218 ***
Panel C. Subperiod II						
Call	-0.0112 **	-4.1678 ***	0.2748 **	4.0734 ***	0.1062	-0.1989 ***
Put	-0.0102 *	0.8466 ***	0.1768	3.9381 ***	0.2216 *	-0.2356 ***

Notes: The regression model is constructed as follows:

$$\Delta\sigma_{i,t}^{ATM} = \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{ATM} + \beta_4 NBPV_{i,t}^{ATM} + \beta_5 \Delta\sigma_{i,t-1}^{ATM} + \varepsilon_t,\ i \in \{C, P\}, \tag{18}$$

where $\Delta\sigma_{i,t}^{ATM}$ denotes the change in the average implied volatility for ATM calls or puts, RS_t indicates the index returns over the time interval t, and VS_t is the trading volume of the TAIEX index expressed in billions of New Taiwan Dollars for the time interval t. All variables are calculated at a one-minute time interval. Moreover, the net buying pressure due to directional shocks, $NBPD_{i,t}^{ATM}$, and the net buying pressure due to volatility shocks, $NBPV_{i,t}^{ATM}$, are measured by:

$$NBPD_{i,t}^{ATM} = \begin{cases} \left(NBP_{C,t}^{ATM} - NBP_{P,t}^{ATM}\right)/2, & \text{for } i = C \\ \left(NBP_{P,t}^{ATM} - NBP_{C,t}^{ATM}\right)/2, & \text{for } i = P \end{cases} \text{ and } NBPV_{i,t}^{ATM} = \left(NBP_{C,t}^{ATM} + NBP_{P,t}^{ATM}\right)/2.$$

The symbol "*", "**", and "***" denote the parameter is significantly greater than zero at the 10%, 5%, and 1% level, respectively.

Table 7. Regression results of changes in OTM implied volatility

$\Delta\sigma_{i,t}^{OTM}$	Parameter Estimates						
	β_0	β_1	β_2 ($\times 10^4$)	β_3 ($\times 10^3$)	β_4 ($\times 10^3$)	β_5	β_6 ($\times 10^3$)
Panel A. Whole Period							
Call	-0.0077 ***	-3.1528 ***	0.1437 ***	1.6516 ***	0.0469	-0.1676 ***	0.9431 ***
Put	-0.0122 ***	0.6883 ***	0.3036 ***	1.9949 ***	0.6718 ***	-0.2708 ***	0.9719 ***
Panel B. Subperiod I							
Call	-0.0021	-3.4611 ***	0.0038	1.3410 ***	-0.0739	-0.1493 ***	0.8961 ***
Put	-0.0182 ***	2.0789 ***	0.4308 ***	1.5489 ***	0.3816 ***	-0.2779 **	1.0051 ***
Panel C. Subperiod II							
Call	-0.0103 ***	-3.0621 ***	0.2279 ***	1.9302 ***	0.1607 **	-0.1718 ***	1.0732 ***
Put	-0.0101 **	0.1285 *	0.2563 **	2.3869 ***	0.9160 ***	-0.2707 ***	1.1624 ***

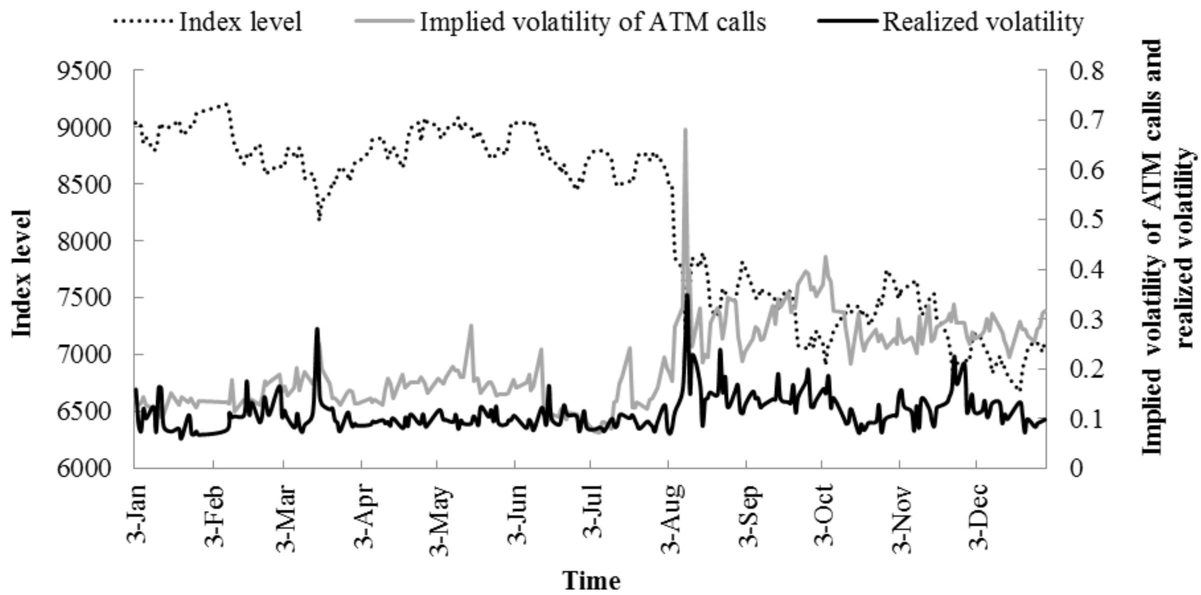
Notes: The regression model is constructed as follows:

$$\Delta\sigma_{i,t}^{OTM} = \beta_0 + \beta_1 RS_t + \beta_2 VS_t + \beta_3 NBPD_{i,t}^{OTM} + \beta_4 NBPV_{i,t}^{OTM} + \beta_5 \Delta\sigma_{i,t-1}^{OTM} + \beta_6 NBPD_{i,t}^{ATM} + \varepsilon_t, i \in \{C, P\}, \tag{19}$$

where $\Delta\sigma_{i,t}^{OTM}$ denotes the change in the average implied volatility for OTM calls or puts, RS_t indicates the index returns over the time interval t, and VS_t is the trading volume of the TAIEX index expressed in billions of New Taiwan Dollars for the time interval t. All variables are calculated at a one-minute time interval. Moreover, the net buying pressure due to directional shocks, $NBPD_{i,t}^{OTM}$, and the net buying pressure due to volatility shocks, $NBPV_{i,t}^{OTM}$, are measured by:

$$NBPD_{i,t}^{OTM} = \begin{cases} \left(NBP_{C,t}^{OTM} - NBP_{P,t}^{OTM}\right)/2, & \text{for } i = C \\ \left(NBP_{P,t}^{OTM} - NBP_{C,t}^{OTM}\right)/2, & \text{for } i = P \end{cases} \text{ and } NBPV_{i,t}^{OTM} = \left(NBP_{C,t}^{OTM} + NBP_{P,t}^{OTM}\right)/2.$$

The symbol "*", "**", and "***" denote the parameter is significantly greater than zero at the 10%, 5%, and 1% level, respectively.



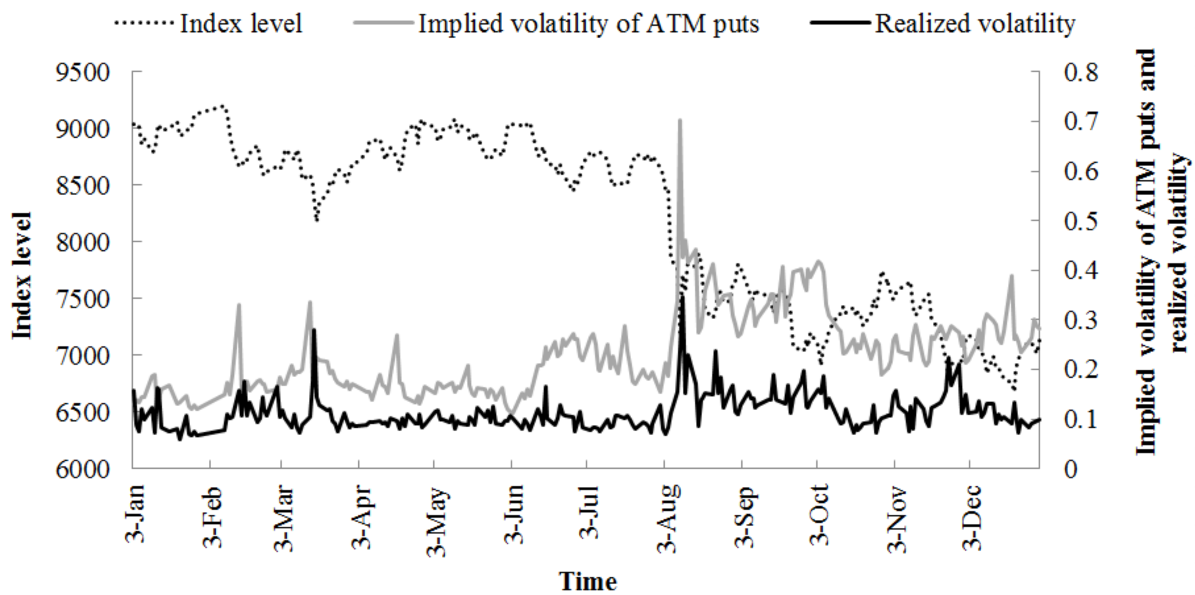


Figure 1. Index, realized volatility, and implied volatility of TAIEX options

Notes: The data ranges from January 3, 2011 to December 31, 2011. The index level in this figure displays the closed price of Taiwan Weighted Stock Index. Realized volatility is calculated based on one-minute index returns. The Implied volatility of ATM calls and implied volatility of ATM puts are computed by Black-Scholes (1973) model.

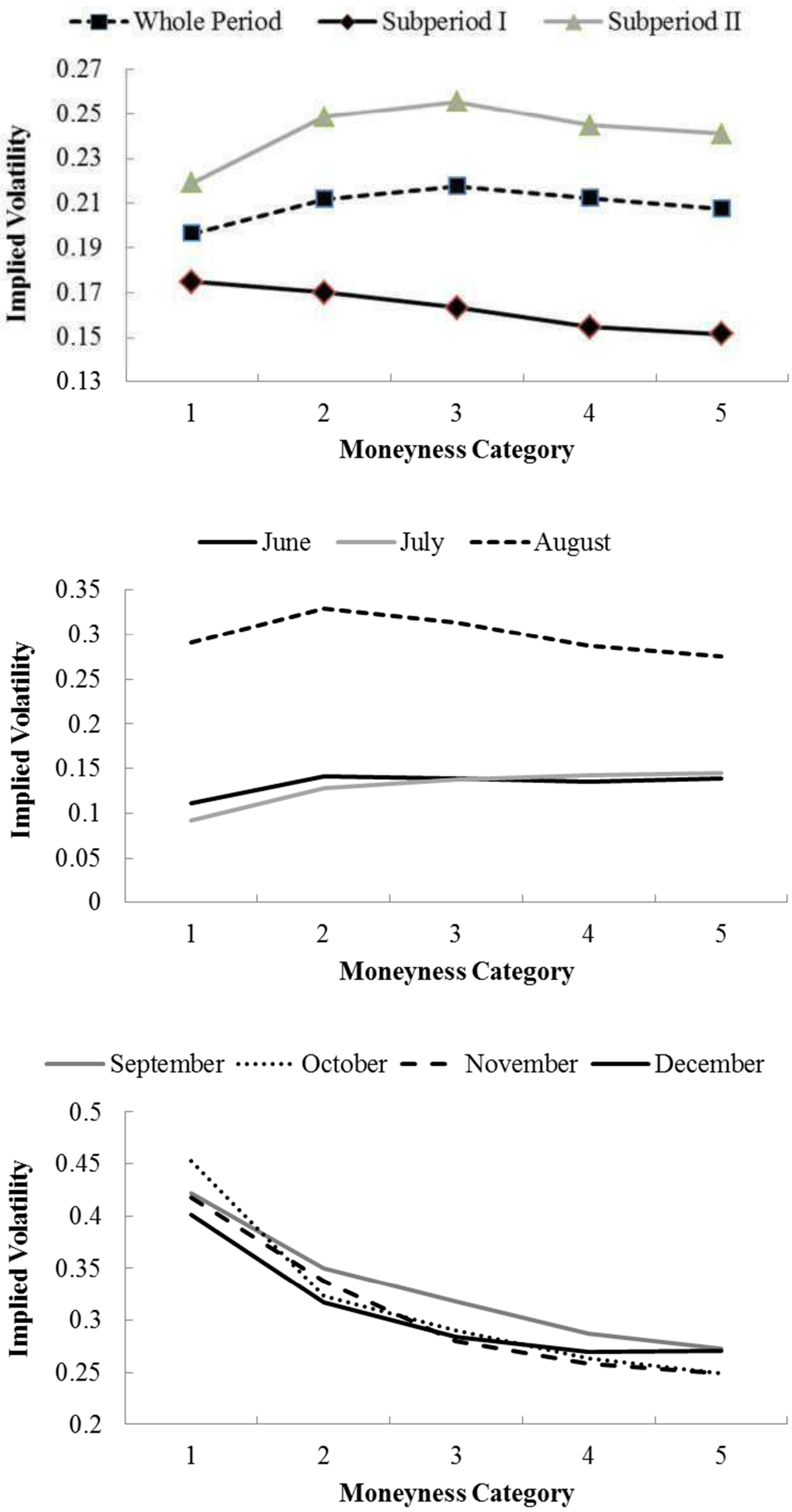


Figure 2. Implied volatility functions of TAIEX call options

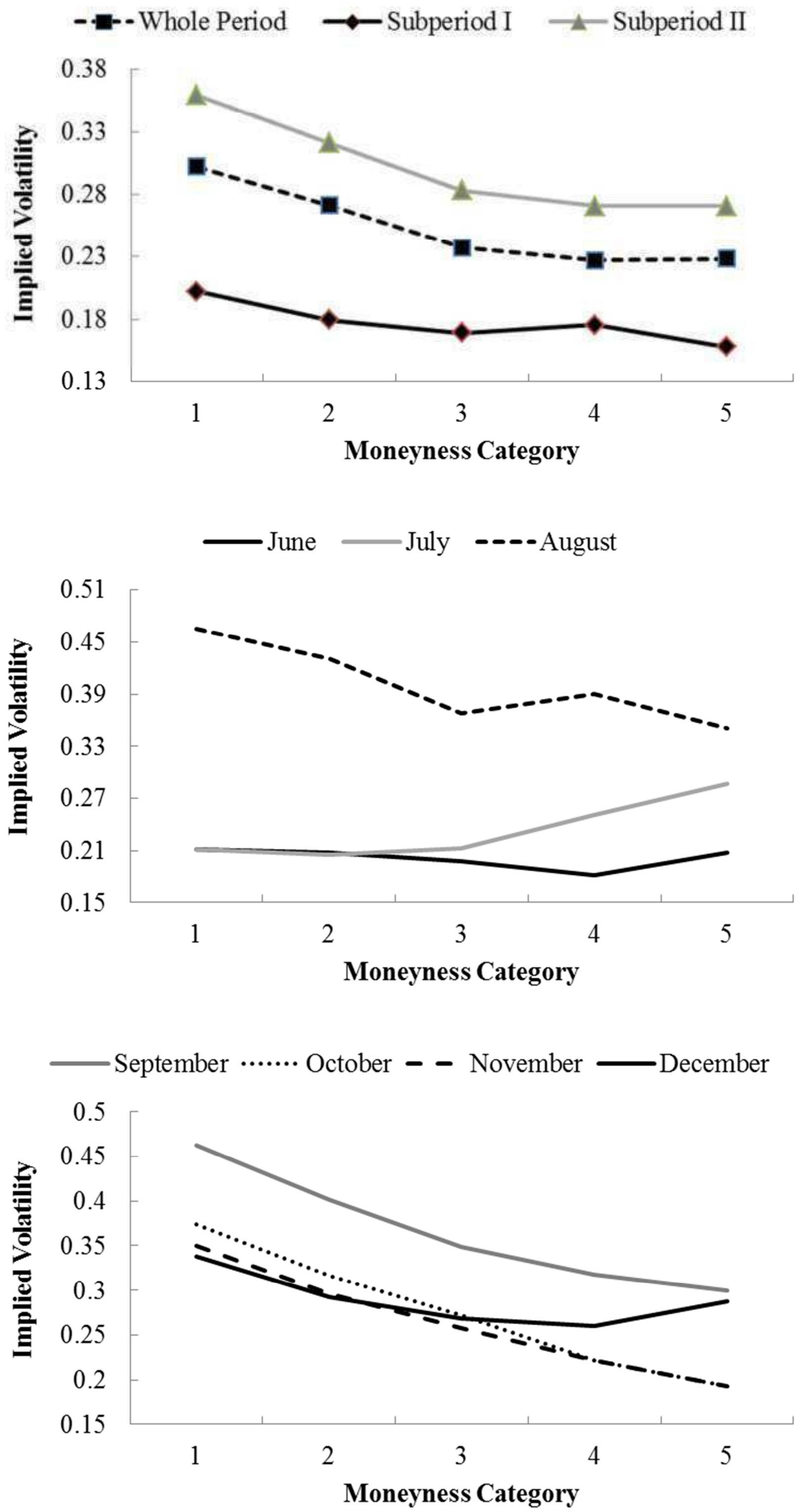


Figure 3. Implied volatility functions of TAIEX put options

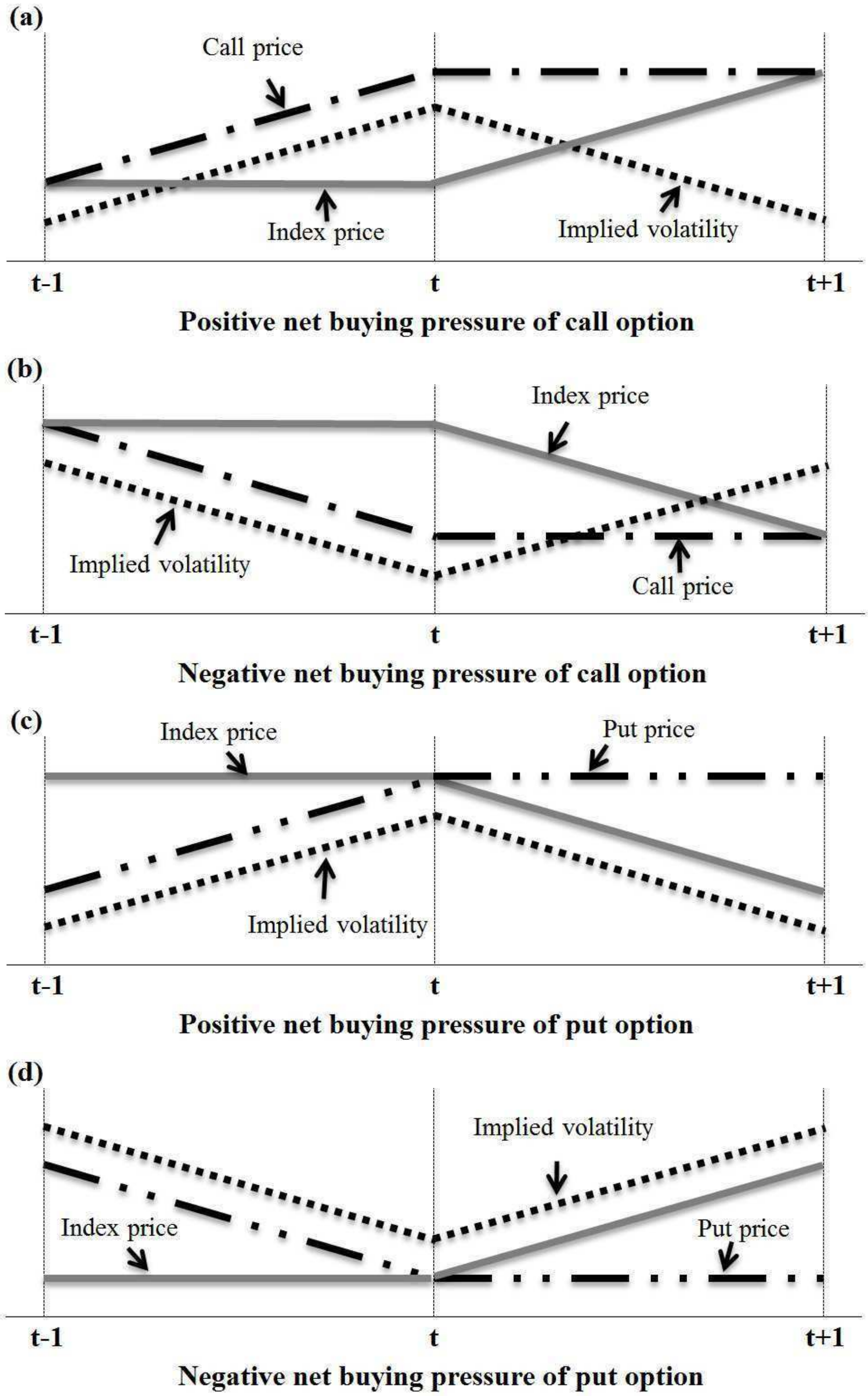


Figure 4. Dynamics of the underlying asset prices and implied volatility under the Kang and Park's (2008) directional-learning hypothesis

Note: The figures depict the movements of the call/put price, index price, and implied volatility. (a) and (d) display the dynamics of prices and implied volatility when index price is expected to rise, and (b) and (c) show those when index price is expected to fall.