東海大學管理學院財務金融研究所

碩士論文

選擇權淨買壓對價格偏差的影響

The Impact of Net Buying Pressure on Option Price dispersions

指導教授：陳昭君　博士

研究生：王怡乃

中華民國一〇二年六月

東海大學碩士學位論文

學位考試委員審定書

本校 **財務金融研究所** 碩士班 王怡乃 君

所提之論文(中文)：淨買壓對選擇權價格偏差的影響

(英文)：The Impact of Net Buying Pressure on Option Price Dispersions

經本委員會審查，符合碩士學位論文標準

學位考試委員會

召 集 人 李宗穎 教授

考試委員 莊凱旭 教授 ________ 教授

李宗穎 教授 陳昭君 教授

指導教授 陳昭君 教授 ________ 教授

系所主任 張永松 教授

中華民國 102 年 6 月 20 日

東海大學財務金融學系

碩士論文學術倫理聲明書

本人 王怡[illegible] (學號: G10044018)已完全了解學術倫理之定義。僅此聲明，本人呈交之碩士論文絕無抄襲或由他人代筆之情事。若被揭露具有違背學術倫理之事實或可能，本人願自行擔負所有之法律責任。對於碩士學位因違背學術倫理而被取消之後果，本人也願一併概括承受。

立證人： 王怡[illegible] (簽名)

中華民國 103 年 11 月 27 日

致謝

時光飛逝，兩年的研究所生涯即將畫上句點，感謝東海大學財金系提供我優良的學習環境並且給予我們豐富的學習資源。在這兩年的研究生活中，感謝系上的老師除了授予我們財金的專業知識，當我們在生活上與到困難時也適時的給予我們建議與幫助，無論是在教學上或是在生活上都讓我獲益良多。此外，感謝班上的同學在學習的過程中幫助我解決課程上的困難，在不斷切磋的過程中讓我學習到很多。

在此特別感謝指導老師 陳昭君老師。在寫論文的路程上，老師循序漸進的方式指引我研究論文的方向並適時的給予我們建議。此外，老師除了在學術論文上的建議也教導我未來在職場上的工作方式及做人處事的態度。同時也感謝口試委員 葉宗穎老師及莊凱旭老師，在百忙之中審閱我們的論文並提供我寶貴的建議，讓我的論文能更加完備。

最後，感謝我父母親的用心栽培，讓我能選擇我想要的方向並且給予我無限的支持與包容，因為他們的鼓勵與陪伴，讓我專注在學業上並順利的完成碩士學位，僅將此論文獻給我的家人、師長、同學及同窗好友。

王怡乃 謹誌于

東海大學財務金融所

民國一百零二年六月

選擇權淨買壓對定價誤差的衝擊

中文摘要

本文透過台指選擇權之日內資料探討選擇權淨買壓與選擇權價格偏離之間的關係。本文發現擇權價格偏離的變化與選擇權淨買壓存在直接的關係，特別是可以透過方向學習假說來解釋選擇權淨買壓對於擇權價格偏離的影響。這表示握有資訊的投資人會先在高槓桿的選擇權市場中交易而非在現貨市場中交易，因此而導致擇權價格偏離的產生。本文提出套利學習假說來探討套利交易者對於選擇權市場價格的影響，惟實證結果發現套利學習假說並不會影響選擇權的價格以及導致擇權價格偏離的變化。最後，本文探討在不同市場氣氛下選擇權價格與淨買壓之間的相互影響關係，本文以前一期指數報酬率做為虛擬變數來判別市場多頭與空頭的指標。本文發現在台灣加權股價指數跌幅達 0.2%時，台指選擇權受到方向學習交易者的影響更為顯著。因此，在方向學習假說下，當現貨市場會隨著選擇權市場的變化而改變現貨市場的方向，握有資訊的交易者可以從選擇權市場中獲取利潤。

關鍵字:淨買壓;學習假說;隱含波動度;歷史波動度;定價誤差

The Impact of Net Buying Pressure on Option Price Dispersions

Chao-Chun Chen[1], *I-Nai Wang*[2]

Abstract

This paper investigates the relation between net buying pressure and price dispersion by using the intraday data of the TAIEX option market. We find that changes in price dispersion are directly related to net buying pressure. Particularly, the impact of net buying pressure on price dispersion is able to account for the direction-learning hypothesis. It indicates that the tendency among informed traders to take a position in the high-leverage option market before in the stock market is one of causes inducing option price dispersion. We also propose a new hypothesis, arbitrage-learning hypothesis, to explore the impact of arbitrager's trading on option prices. As the volatility-learning hypothesis does, the empirical results show that the arbitrage-learning hypothesis plays no role on changes in option prices and price dispersion. Last but not least, to investigate whether the market status influences the relationship between option prices and net buying pressure, a dummy variable of lagged underlying asset return is adopted in the regression model as a proxy for the degree of market being weak. We find that the TAIEX option market is influenced by direction traders. Especially, the direction trader impact the TAIEX option more significant as the lagged underlying asset return is lower than 0.2%. As the index is supposed to trail the movements of option markets, informed traders are likely to trade the opposite direction with the market phenomenon in option market to make profits.

Key words: Net buying pressure; Learning hypothesis; Implied volatility; Realized volatility; Price dispersion.

[1] Department of Finance, Tunghai University, Email: jawjiun@thu.edu.tw.
[2] Department of Finance, Tunghai University, Email: G10044018@thu.edu.tw.

Contents

Table contents

Figure contents

1 Introduction

Price dispersion in the option market is widely found in both of the literature and practices. A myriad of reasons may bring about price dispersion in the option market. To illustrate, hedging pressure, trading volume, and even price dispersion in the underlying stock are able to be associated with price dispersion.

In the literature, Hayunga, Holowczak, Lung, and Nishikawa (2012) investigate the option investors' reaction when the underlying stock is mispriced by examining the price divergence between the observed equity asset and the options-implied synthetic share. They find the positive relation between the level of stock mispricing and price deviation in derivatives. Contrary to link the price dispersion in the underlying stock and options up, Guozhou, Gan, and Treepongkaruna (2009) claim that hedging pressure is capable of clarifying the difference between implied volatility and realized volatility. Finally, relationships between Black-Scholes price dispersion and trading volume in the option market are also studied in the literature. Long and Officer (1997) find that the heavily-traded call options are priced more efficient and have lower mispricing errors than thinly-traded option.

The linkage of option price dispersion and order imbalance still lacks in the literature. Larkin, Brooksby, Lin, Zurbruegg (2012) find evidence that the excess returns from unhedged and delta-neutral trading strategies is likely to demonstrate the difference between implied volatility and realized volatility. Thus, they conjecture net buying pressure from market participants appears to be a source of mispricing. Nevertheless, no literature directly reveals the connection between option mispricing and net buying pressure.

According to Bollen and Whaley (2004), the net buying pressure is defined as the difference between the number of buyer-motivated contracts and seller-motivated contracts multiplied by the absolute value of the options' delta. Majority of research examines the impact of net buying pressure on implied volatility and finds that the net buying pressure can describe the shape of implied volatility functions. In addition to examine the shape of implied volatility functions, Bollen and Whaley (2004) and Kang and Park (2008) propose two hypotheses to investigate the impact of informed trading on option prices based on net buying pressure, which are volatility-learning hypothesis and direction-learning hypothesis. In accordance with learning hypotheses, an increase in the number of buyer-motivated contracts may raise the implied volatility, whereas an increase in the number of seller-motivated contracts decreases the implied volatility. Consequently, these learning hypotheses associate option prices with order imbalance and connect with the underlying asset prices and variance rate as what the Black-Scholes model asserts. It follows that order imbalance probably is a source of option price dispersion. Accordingly, the first contribution of this research is to investigate the impact of net buying pressure on option price dispersion.

By combing the net buying pressure with the price dispersion, a second contribution of this article is to proffer another learning hypothesis, arbitrage-learning hypothesis and examine the impact of trading from arbitragers on option prices. In the previous literature, the volatility-learning hypothesis examines the impact of volatility traders on option prices, whereas the direction-learning hypothesis illustrates the impact of direction traders on option prices. There is still another type of traders, arbitragers, who take arbitrage strategy to make profits as the option prices deviate from the fair prices. Based on the movements of option price dispersion and the underlying asset prices, we are able to develop the arbitrage-learning hypothesis and investigate whether arbitrage-learning hypothesis is likely to elucidate the option price dispersion.

The last contribution of this research is to investigate whether the market phenomenon or the latest underlying asset return magnifies the impact of net buying pressure on option price dispersion, because most investors have a tendency to sell their position when the latest underlying asset descends evidently. We find that direction-learning hypothesis portrays the TAIEX option prices and the impact of direction traders on TAIEX option prices is significantly greater when the latest underlying index return is in the 10% worst.

This research examines three issues. First, we investigate whether net buying pressure results in option price dispersion. Second, given that net buying pressure is one source of option price dispersion, we further investigate which type of traders induces more option price dispersion. Finally, whether the market phenomenon or the latest underlying asset return magnifies the impact of net buying pressure on option price dispersion is also examined in this research.

2 Net buying pressure hypotheses and Price dispersion

This section describes the relationship between net buying pressure and the movement of price dispersion. Based on the assumption of frictionless markets proposed by Black and Scholes (1973), a supplier of option liquidity is able to perfectly and costless hedge his positions, so the supply curve is supposed to be horizontal. However, the market is imperfect in practice, the option price is probably influenced by the demands to buy and sell their positions.

Bollen and Whaley (2004) examine the relationship between net buying pressure and the shape of implied volatility function. They argue that the implied volatility function is due to order imbalance in the option market and also document that the difference of demands and supplies on net buying pressure is liable to account for the implied volatility function in smile. In their empirical research, they find the net buying pressure and implied volatility is related to positive. They proposed two alternative hypotheses to explain the relationship between net buying pressure and implied volatility function which are limit of arbitrage hypothesis and learning hypothesis. Kang and Park (2008) extend the learning hypothesis which is proposed by Bollen and Whaley (2004). Kang and Park (2008) distinguish learning hypotheses into direction learning hypothesis and volatility learning hypothesis. They document that direction learning hypothesis can explain the relation between net buying pressure and implied volatility. In this paper, we extend learning hypotheses into three parts to examine informed trading effect in option market.

Under limit of arbitrage, the option of supply curve is positive. As the supply curve is positive, the option price is determined by demand. Bollen and Whaley (2004) argue that the limit of arbitrage exists in the option market. Shleifer and Vishny (1997) document that the professional arbitrageurs take advantage of mispriced securities are limited by the investors to absorb intermediate loses. Liu and Longstuff (2004) argue that the arbitrageurs are limit to the margin requirement. Green and Figlewski (1999) mention that the arbitrageurs are supposed to face different kind of risk as hedging their position, for instance, model misspecification biased parameter estimation and discretely rebalanced portfolio. As the market maker is supposed to provide the market liquidity are required to absorb numerous options and their hedging cost and required return are increase accordingly.

Based on the discussion above, we are able to observe that the excess demand tends to increase the option price. In contrast, the excess supply is supposed to decrease the option price. Once the option price is influenced by the excess demand and excess supply, the B-S model option price is not change stronger than the market price and there is an opportunity for option traders to make a profit in the option market. Furthermore, there are three sorts of approaches to change the option price. Concerning the change of volatility in the future underlying asset price. Another consideration is the direction of the future underlying asset price movement which is predicted by the informed trader. The last concern is that the option trader observes whether the option price is deviate from the fair price. Bollen and Whaley (2004) document that option traders who pay attention to the change of implied volatility when volatility shock occurred. In this case, the option trader delivers the information of trading activity to market maker who is able to observe the expectation from the option traders and updates the option price as well. Kang and Park (2008) call the learning hypothesis the *volatility-learning hypothesis*. According to the volatility-learning hypothesis, the market price changes as the volatility shock occurred, yet the B-S model option price will larger or smaller than the market price. As it concerned, the volatility traders are likely to obtain the profit by the price gap between the market price and theoretical price in the option market.

Kang and Park (2008) argue that the order imbalance reflects the expectation of investor in the future price movement from the underlying asset and the option price will change accordingly. Kang and Park (2008) call this condition of learning hypothesis the *direction-learning hypothesis*. Based on the figures which are proposed by Kang and Park (2008), we embed the B-S model price and the movement of price dispersion in Figure 1 and Figure 2. Figure 1 shows reaction of the underlying asset prices and option price dispersion to positive direction shock under the direction-learning hypothesis. In contract, Figure 2 reveals the negative direction shock. The informed traders realize that the positive (negative) shock during the time interval t and take advantage of the information to trade in the option market. It is able to observe that the positive (negative) net buying pressure on call options and negative (positive) net buying pressure on put options. The net buying pressure due to higher (lower) call option prices and price dispersion of call options and lower (higher) put option prices and price dispersion of put options at time t. Furthermore, the movement of theoretical price is the same to the index price. When the information is spread to the stock market during the time t+1, the index price and theoretical price will increase (decrease) at time t+1. Therefore, the price dispersion of call option will fall (rise) and the price dispersion of put options will rise (fall) at time t+1.

There is another possibility that option traders are arbitrage traders. As the option price is deviate from the fair price, the option traders are able to arbitrage from the call (put) option by purchasing the options. We call this version of learning hypothesis as *arbitrage-learning hypothesis*. As the information shock impulse to the option market, it probably force the option price deviate from the fair price. The arbitrageurs is able to make profit under this condition. The Figure 3 displays the reaction of the underlying asset prices and option price dispersion to positive shock under the arbitrage-learning hypothesis. Figure 4 display the negative shock under the arbitrage-learning hypothesis. The positive (negative) shock occurred and the arbitrageurs are likely to take advantage of the observation to trade in the option market. The arbitrageurs are disposed to scrutinize the negative (positive) net buying pressure on call options and positive (negative) net buying pressure on put options. The net buying pressure owing to lower (higher) call option prices and higher (lower) put option prices. Besides, the theoretical call option price is lead to higher (lower) and the theoretical put option price is lower (higher). As the arbitrageurs trade in the bullish (bear) market, the price dispersion of call option owing to decrease (increase). In contrast, the price dispersion of put option lead to increase (decrease) in the bullish (bear) market.

3 Sample description

This paper examines the impact of net buying pressure on price dispersion of TAIEX options and investigates whether the trading behavior of option investors varies with the recent performance of TAIEX. In this section, we describe data used in this research and introduce the way to compute the implied volatility and option price dispersion.

3.1 Data

The data analyzed in this research are the TAIEX options, whose underlying index is the Taiwan Capitalization Weighted Stock Index (TAIEX). The TAIEX options are European-style and expire on the third Wednesday of the expiration month. Furthermore, the contract months of TAIEX options are the two consecutive following months plus three nearest the quarterly cycle. In the recent year, the TAIEX options have been one of the most actively traded and important index options in the world.

Our intraday data set contains the trading time, trading price, bid price, ask price, strike price, maturity month, and volume of TAIEX options traded on Taiwan Future Exchange from January 2, 2007 to December 28, 2012. Transaction of TAIEX options and quotes of TAIEX are obtained from the database of CMoney – Institutional Investors Investment Decision Support System. Since options with long time to expiration are usually less liquid, we follow Macbeth and Merville (1979) to focus our research on options with maturity less than ninety days. Similarly, transactions of options with maturity less than three days are excluded from our data, because options near the expiration date are less liquid as well.

The trading hour of Taiwan Stock Exchange Corporation is different from that of Taiwan Futures Exchange. Specifically, the TAIEX is quoted from 9:00 to 13:30 on the opening day, for TAIEX options are traded from 8:45 to 13:45 on the opening day. The trading hour of TAIEX option begins 15 minutes earlier than TAIEX and ends 15 minutes later than TAIEX. To synchronize the trading data, we exclude the transaction before 9:00 and after 13:30 from our data set. After removing these trading, the transactions for call options used in our empirical research are 28,798,156, whereas trading for put options are 25,667,302. In sum, the final data set contains 54,465,458 transactions.

3.2 Implied volatility

Once the market price of TAIEX options is at hand, we are able to estimate the implied volatility for each transaction by using the Black and Scholes (1973) model. The Black-Scholes (1973) formulae to value call and put option prices are:

$$C_t = S_t e^{-q(T-t)} N(d_1) - K e^{-r(T-t)} N(d_2), \tag{1}$$

and

$$P_t = K e^{-r(T-t)} N(-d_2) - S_t e^{-q(T-t)} N(-d_1), \tag{2}$$

where

$$d_1 = \frac{\ln(S_t / K) + (r - q + 0.5\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}}, \tag{3}$$

and

$$d_2 = d_1 - \sigma\sqrt{(T-t)}. \tag{4}$$

The notations of Equation (1)-(4) are as follows: C_t and P_t are the market price of call and put option during the time interval *t*, S_t is the spot index level, K stands for the exercise price of an option, T is the time to maturity, r is the risk-free rate of interest, q is the dividend yield of TAIEX, and $N(\cdot)$ is the normal cumulative density function. Among them, the risk-free rate is the average of one-month time deposit interest rates from five major banks in Taiwan list in the database of Taiwan Economic Journal (TEJ). The dividend yields announced by Taiwan Stock Exchange Corporation (TWSE) in each month are collected from the website of Taiwan Stock Exchange Corporation (TWSE). Given the spot index level S_t, exercise price K, dividend yield q, risk-free rate r, and the trading price of options, C_t and P_t, the implied volatility can be estimated by Equation (1)-(4).

This paper follows the method in Bollen and Whaley (2004) and Kang and Park (2008) to classify the moneyness of options by option's delta. For each transaction of TAIEX options, the deltas for call and put options can be computed by:

$$\Delta c = N\left[\frac{\ln(S_t / K) + (r - q + 0.5\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}}\right], \tag{5}$$

$$\Delta p = N\left[\frac{\ln(S_t / K) + (r - q + 0.5\sigma^2)(T - t)}{\sigma\sqrt{(T - t)}}\right] - 1. \tag{6}$$

As the method used in Bollen and Whaley (2004) and Kang and Park (2008), the proxy for the standard deviation is estimated by the historical volatility of the TAIEX index return during the past sixty trading days. Option transactions with absolute delta below 0.02 or above 0.98 are excluded due to the distortions caused by price discreteness. According to the deltas, options are classified to five moneyness categories as listed in Table 2.

3.3 Price dispersion

Macbeth and Merville (1979) define the ratio of the actual option price minus the theoretical Black-Scholes price with respect to the theoretical option price as a proxy of option price dispersion. The following formulae compute the proxy of price error on call and put options:

$$V_t = \frac{C_t - C_{BS}(\hat{\theta}_{0t})}{C_{BS}(\hat{\theta}_{0t})}, \tag{7}$$

and

$$V_t = \frac{P_t - P_{BS}(\hat{\theta}_{0t})}{P_{BS}(\hat{\theta}_{0t})}, \tag{8}$$

where C_t and P_t are the market price of call and put option during the time interval *t*, $C_{BS}(\hat{\theta}_{0t})$ and $P_{BS}(\hat{\theta}_{0t})$ are the Black-Scholes theoretical price given the volatility is $\hat{\theta}_{0t}$, and $\hat{\theta}_{0t}$ is the estimation for implied volatility of the ATM option.

As pointed out in Macbeth and Merville (1979), the price error from ATM options is usually least. Accordingly, we follow the method which is adopted in Macbeth and Merville (1979) to estimate the implied value of volatility for ATM options by the following regression model:

$$\sigma_t = \theta_{0t} + \theta_{1t} m_t + \varepsilon_t, \tag{9}$$

where

$$m_t = \frac{S_t - Ke^{-rt}}{Ke^{-rt}}, \tag{10}$$

σ_t is the implied volatility for all options at time *t*, S_t is the price of TAIEX index at time *t* and Ke^{-rt} is the present value of the exercise price at time *t*.

Please note that the implication in Equation (7) and Equation (8) is consistent with the shape observed in the implied volatility function for both call and put options. In the literature, the implied volatility of ITM call options is usually observed to be higher than that of OTM call options. In contrast, the implied volatility of OTM put options is usually found to be higher than the implied volatility of ITM put options. On the other hand, the value of m_t defined in Equation (10) is positive/negative for ITM/OTM call options, whereas the value of m_t is negative/positive for ITM/OTM put options. Based on the empirical findings in the implied volatility functions and the definition of m_t, the shapes of the regression model displayed in Equation (7) and Equation (8) for call and put options are similar. We thus estimate the implied value of volatility for ATM options by all option transaction data. Particularly, we calculate the implied volatility of TAIEX options for each strike price *K* and each time interval *t*, and estimate parameters, θ_{0t} and θ_{1t}, based on the regression model (9). The estimation $\hat{\theta}_{0t}$ is adopted to calculate both the theoretical Black-Scholes ATM call and put prices, i.e., $C_{BS}(\hat{\theta}_{0t})$ and $P_{BS}(\hat{\theta}_{0t})$.

Based on discussion above, we do not distinguish the data in call and put option as we measure the values of θ_{0t} in the Equation (9). The estimated value of θ_{0t}, $\hat{\theta}_{0t}$, is the estimation of volatility implied by the Black-Scholes model at the time interval *t* for ATM options. Indeed, the $\hat{\theta}_{0t}$ is a weighted sum of the implied values of volatility for options at time *t* and thus is consistent to the weighted average implied standard deviation of Latane and Rendelman (1976) and Schmalensee and Trippr (1978).

3.4 Net buying pressure

Bollen and Whaley (2004) define net buying pressure as the difference between the number of buyer-motivated trades and the number of seller-motivated trades, multiplied by the absolute value of the option's delta. Herein, the buyer-motivated trades indicates transactions with a market price higher than the midpoint of prevailing ask/bid quotes, whereas the seller-motivated trades are transactions with a market price lower than the midpoint of prevailing ask/bid quotes. When the net buying pressure is positive, the options are in an excess demand. Contrarily, a negative net buying pressure means an excess supply in the option market.

Table 1 reveals the summary of number of contracts traded, net purchases of contracts, and the net buying pressure of call options and put options. Panel A reveals that 55% contracts traded are call options, which is higher than the proportion of put options, i.e., 45%. Panel B shows that the number of seller-motivated trades is more than that of buyer-motivated trades, no matter the option is a call option or put option. It indicates that the option investors buy options at a price lower than prevailing ask/bid quotes more often.

Panel C reveals the net buying pressure of call options and put options. The difference between Panel B and Panel C is that the Panel C is multiplied by the absolute value of the option's data. Panel C reports that the aggregated net buying pressure are negative for both call and put TAIEX options during the sample period.

4 Regression specifications

In this section, we examine four learning hypotheses in terms of relationship between price dispersion and net buying pressure. Estimating the impact of net buying pressure on price dispersion is measured by the change of price dispersion in a particular moneyness category on contemporaneous measures of the index return, index trading volume, net buying pressure, and lagged change of price dispersion. Index return and index trading volume are control variables which is included in the regression model and represent as leverage and information flow effect. According to Black (1976) and Anderson (1996), index return volatility is analogous with index returns which is negatively result in leverage effect; however, index return volatility is associated with index returns that is due to information flow effect.

To examine the impact of net buying pressure on price dispersion, we specify the test model as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_i^{ATM} + \alpha_4 NBP_j^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM}, \tag{11}$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_i^{OTM} + \alpha_4 NBP_j^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM}, \tag{12}$$

where $i \in \{C, P\}$, $j \in \{C, P\}$, and $i \neq j$. $\Delta V_{i,t}^{ATM}$ and $\Delta V_{i,t}^{OTM}$ are the proxy as price dispersion on ATM and OTM moneyness category during the time interval *t*, RS_t is the underlying security return at time *t*, VS_t is the trading volume of the Taiwan Weighted Stock Index during the time interval *t* expressed in millions of New Taiwan dollars, and NBP^{ATM} and NBP^{OTM} denote the net buying pressure of ATM and OTM options during the time interval *t*.

For detecting four net buying pressure hypotheses, we summarize the rules in Table 4. Comparing the size and the sign of coefficient on net buying pressure by α_3, α_4, and α_5 in Equation (11) and Equation (12) which are in order to distinguish four alternative hypotheses. Table 4 shows the rules to inspect net buying pressure by hypotheses on mispricing. For ATM option, the limit of arbitrage hypothesis required $\alpha_3 \neq \alpha_4$ and the volatility-learning hypothesis required $\alpha_3 = \alpha_4$. We are able to observe that these two conditions are unable to exist at the same time. Similarly, the conditions of $\alpha_3 > \alpha_4$ and $\alpha_3 < \alpha_4$ for limit of arbitrage hypothesis and volatility-learning hypothesis which cannot be true at the same time. Comparing the direction-learning hypothesis and arbitrage learning hypothesis, we are unable to distinguish by the coefficient of α_3 and α_4. Under the direction-learning hypothesis, the ΔV_{t-1} is supposed to negative and insignificant under the arbitrage-learning hypothesis, these are provide us to distinguish two alternative hypotheses.

Equation (11) and Equation (12) investigate the relationship between net buying pressure and price dispersion. Based on Black (1976) and Anderson (1996), the underlying asset return volatility is negatively related to stock return due to leverage effect. Besides, the underlying asset return volatility is positively associated with trading volume which is result from the information flow effect. As mentioned above, the coefficient of β_1 is expected to negative, whereas the coefficient of β_2 is expected to be positive.

In this paper, we also investigate the impact of net buying pressure on price dispersion in different market phenomenon. In order to examine the impact of net buying pressure on price dispersion in different market condition, the regression model is specified as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D) NBP_{i,t}^{ATM} + (\alpha_4 + \alpha_4' D) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM}, \qquad (13)$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D) NBP_{i,t}^{OTM} + (\alpha_4 + \alpha_4' D) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM}, \qquad (14)$$

where D serves as a dummy variable that takes a value of 1 as $RS_{t-1} < 0$, and 0 otherwise.

In practices, the trading behavior of investors may be very different when the market falls abnormally. To further investigate the relationship between the net buying pressure and option price dispersion in case that the market is abnormally downward, another dummy variable D^* that takes a value of 1 as $RS_{t-1} < -0.002$ and 0 otherwise is adopted. As shown in the following table, the threshold -0.2% is in 10% percentile. One may expect that the trading behavior of investors may be abnormal when the market is in the worst 10%. The regression model is specified as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D^*) NBP_{i,t}^{ATM} + (\alpha_4 + \alpha_4' D^*) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM}, \qquad (13')$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D^*) NBP_{i,t}^{OTM} + (\alpha_4 + \alpha_4' D^*) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM}, \qquad (14')$$

where D^* serves as a dummy variable that takes a value of 1 as $RS_{t-1} < -0.002$, and 0 otherwise.

5 Empirical analysis

In this section, we adopt the proposed method to investigate and reinvestigate four net buying pressure hypotheses by using the intraday data of TAIEX option from January 2, 2007 to September 28, 2012. We also embed the dummy variables of lagged underlying asset return in the regression model as a proxy for bullish-bear market.

We display the regression results for changes on price dispersion of ATM and OTM options which is embedded the dummy variable of lagged underlying asset return in the regression model. Table 5 shows that the regression results for price dispersion of ATM and OTM options based on the model without the dummy variables. Tables 6 and 7 are embedded the dummy variable of lagged underlying asset in the regression model and results are consist with direction-learning hypothesis. The difference between Tables 6 and 7 is the level of lagged underlying asset return. We are supposed to observe that the TAIEX option market is influenced by the direction traders in Table 5, Table 6, and Table 7. With incorporating the dummy variable, Table 5 find that the TAIEX option market is strongly influenced by direction traders. Table 6 mainly investigates the TAIEX option market is influenced by the direction trader as the lagged underlying asset return is negative. By setting up a stricter condition on the lagged underlying asset return, Table 7 shows that the direction trader impacts the TAIEX option market more significant than the result list in Table 6 at 1% significant level.

We discuss the coefficients of regression model as follows. Among all regression models, the coefficients of index return, $\alpha_1 s$ are negatively and statistically significant at the 1% significance level, revealing that the index return volatility is analogous with index returns. Based on the direction-learning hypothesis, the coefficient of RS_t is negative related to call options and positive related to the put options. We are able to observe that all of the coefficient of lagged changes on price dispersion, $\alpha_5 s$, are negatively and statistically significant at the 1% significant level which are consist with the direction-learning hypothesis. The direction-learning hypothesis also reported that the information initially reflected in the option market and then spread the information to the stock market. According to the coefficients of the trading volume, we find that the ATM put option is positively relative the change of price dispersion. However, the OTM call option and OTM put option is negatively relative to the change of price dispersion Table 5, Table 6, and Table 7.

This paper mainly examines the impact of net buying pressure on price dispersion which reveals in the coefficients of the net buying pressure, $\alpha_3 s$ and $\alpha_4 s$. The coefficients of the options is correspond to their own net buying pressure, for instance, ATM calls for ATM calls, OTM calls for OTM calls, ATM puts for ATM puts, and OTM puts for OTM puts, As we can find that the coefficients of α_3 and α_4 are statistically significant at the 1% significant level on price dispersion in Table 5. As the option of net buying pressure is corresponding to the option of price dispersion, we could find that the net buying pressure positively impact the change of price dispersion. On the other hand, the option is opposite to the change of price dispersion option then the net buying pressure negatively impact the change of price dispersion. We also could find the same circumstance in Tables 6 and 7 without dummy variables. However, we discover that the net buying pressure with dummy variable positively/negatively impact the change of price dispersion. Under the change of price dispersion of ATM and OTM call option, we find that the net buying pressure with dummy variable of call option negatively impact the change of price dispersion. Furthermore, under the change of price dispersion of ATM and OTM put option, we discover the net buying pressure with dummy variable of call option positively impact the change of price dispersion. As the net buying pressure is combined with the dummy variable, the results are not consistent with any hypothesis.

In the second part, when the dummy variable is equal to one, the coefficient of net buying pressure are $(\alpha_3 + \alpha_3')s$ and $(\alpha_4 + \alpha_4')s$. We are likely to observe that the coefficients of $(\alpha_3 + \alpha_3')s$ are positive and statistically significant at 1% significant level in Table 6 and Table 7. Moreover, the coefficients of $(\alpha_4 + \alpha_4')s$ are negative and statistically significant at significant level in Table 6 and Table 7 exclude the OTM call option is insignificant in Table 6. In sum, the regression results in Table 6 and Table 7 are consist with the direction-learning hypothesis, yet the limit of arbitrage hypothesis and volatility-learning hypothesis are unable to account for these results. As the index is supposed to move trail behind the movements of option market under the direction-learning hypothesis, the informed traders are likely to trade in the option market before it arrives at the stock market.

6 Conclusion

Majority of researches concerning net buying pressure focus on examining the shape of implied volatility by net buying pressure and how the implied volatility changes with net buying pressure, although meager researches connect price dispersion to the impact of net buying pressure. This research first investigates whether option price dispersion can be attributed to the excess demand by examining the impact of net buying pressure on price dispersion of TAIEX options. Based on empirical results, we find that changes in price dispersion are directly related to net buying pressure. Moreover, the impact of net buying pressure on price dispersion is able to explain the direction-learning hypothesis. It indicates that the behavior of informed traders that exploits their private information in the option market before in the stock market is one of reasons inducing option price dispersion.

The second contribution of this research is to propose a new learning hypothesis, arbitrage-learning hypothesis, to examine the impact of arbitrager's trading on option prices. As the volatility-learning hypothesis does, the empirical results reveal that the trading of arbitrager plays no role on changes in option prices and price dispersion.

Finally, the relation between option prices and net buying pressure is related to the degree of market being bullish. We employ the dummy variable of lagged underlying asset return in the regression model as a proxy for bullish-bear market status. Empirical results show that the impact of net buying pressure on option prices and price dispersion varies with the degree of market being bullish. We find that direction traders impact the TAIEX option market and the volatility trader and arbitrage trader is unlikely to explain the impact of net buying pressure on price dispersion. Especially, the underlying asset return is lower than -0.2% is more significant. The informed trader intends to trade in the option market rather than stock market as the index should move behind the movement of option market since the direction traders are able to make profits in the option market.

Reference

Black, Fisher, and Myron Scholes, 1973, The pricing of options and corporate liabilities, *Journal of Political Economy*, 81, 637-659.

Black, Fischer, 1976, Studies of stock price volatility changes, in *Proceedings of the 1976 meetings of the Business and Economics Section*, 177-181.

Bollen, N.P.B., and R.E. Whaley, 2004, Does net buying pressure affect the shape of implied volatility function, *Journal of Finance*, 59, 711-753.

Green, T. Clifton, and Stephen Figlewski, 1999, Market risk and model risk for a financial institution writing option, *Journal of Futures Markets*, 15, 1465-1499

Guozhou Li, Christopher Gan, and Sirimon Treepongkaruna, 2009, Impact of Hedging Pressure on Implied Volatility in Financial Times and London Stock Exchange (FTSE) Market, *The International Journal of Business and Finance Research*, 3, 103-118.

Hayunga D. K., R. D. Holowczak, P.P. Lung, and Takeshi Nishikawa, 2012, Derivatives traders' reaction to mispricing in the underlying equity, *Journal of Banking & Finance*, 36, 2438-2454.

Kang, J., and H.J. Park, 2008, The information content of net buying pressure: Evidence from KOSPI 200 index option market, *Journal of Financial Market*, 11, 36-56.

Latane H. A. and Rendleman R. J., 1976, Standard deviations of stock price ratios implied in option prices, *Journal of Finance*, 31, 369-381.

Long D. M. and Officer D. T., 1997, The relation between option mispricing and volume in the black-scholes option model, *Journal of Financial Research*, 20, 1-12.

Liu, Jun, and Francis A. Long staff, 2004, Losing money on arbitrages: Optimal dynamic portfolio choice in markets with arbitrage opportunities, *The Review of Financial Studies*, 17, 611-641.

Larkin J., A. Brooksby, C.T. Lin, and R. Zurbruegg, 2012, Implied volatility smiles, option mispricing and net buying pressure: evidence around the global financial crisis, *Accounting and Finance*, 52, 47-69.

Macbeth J. D. and Merville L. J., 1979, An empirical examination of the black-scholes call option pricing model, *Journal of Finance*, 34, 1173-1186.

Schmalensee R. and Trippi R., 1978, Common stock volatility expectations implied by option premia, *Journal of Finance*, 33, 129-147.

Shleifer, Andrei, and Robert Vishny, 1997, The limit of arbitrage, *Journal of Finance*, 41, 579-590

Table 1. Summary for the number of TAIEX options traded and the net buying pressure

Delta value category	Call options		Put options	
	No. of contracts	Prop. of total	No. of contracts	Prop. of total
Panel A. Number of contracts traded				
1	825,978	0.0022	45,434,507	0.1195
2	11,103,210	0.0292	81,060,355	0.2132
3	60,737,042	0.1597	37,262,974	0.0980
4	104,641,925	0.2752	6,665,287	0.0175
5	31,781,563	0.0836	752,429	0.0020
Totals	209,089,718	0.5499	171,175,552	0.4501
Panel B. Net purchases of contracts				
1	-40,014		166,059	
2	-210,522		-2,884,659	
3	-1,450,676		-516,390	
4	-2,769,441		-41,839	
5	-862,785		-52,075	
Totals	-5,333,438		-3,328,904	
Panel C. Net buying pressure				
1	-36,425		-6,418	
2	-157,130		-737,075	
3	-656,219		-195,558	
4	-733,178		-42,121	
5	-51,655		-48,273	
Totals	-1,634,606		-1,029,445	

Note: (1) The sample period is from January 2, 2007 to December 28, 2012. (2) The net purchases of contracts reveals in Panel B are computed as the number of buyer-motivated contracts minus the number of seller-motivated contracts. (3) The net buying pressure displays in Panel C. is defined as the number of contracts traded above the prevailing bid/ask midpoint less the number of contracts traded lower than the prevailing bid/ask midpoint times the absolute value of the option's delta.

Table 2. Moneyness category definitions

Call options			Put options		
Category	Category description	Delta range	Category	Category description	Delta range
1	DITM	$0.875 < \Delta_C \leqq 0.980$	1	DOTM	$-0.125 < \Delta_P \leqq -0.020$
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	$0.020 < \Delta_C \leqq 0.125$	5	DITM	$-0.980 < \Delta_P \leqq -0.875$

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 3. Percentile of underlying asset return

	Percentile										
	100%	**99%**	**95%**	**90%**	**75%**	**50%**	**25%**	**10%**	**5%**	**1%**	**0%**
Return	2.0%	0.5%	0.3%	0.2%	0.1%	0.0%	-0.1%	-0.2%	-0.3%	-0.5%	-2.5%

Notes: The return is measure by the Taiwan Capitalization Weighted Stock Index return from January 2, 2007 to December 28, 2012.

Table 4. Rules to inspect net-buying-pressure by hypotheses on price dispersion

Hypothesis		Estimates parameter			
		α_1	α_3	α_4	α_5
Panel A. Conditions adopted to inspect the corresponding hypothesis 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 call	Negative	Positive	Negative	Negative
	For put	Positive	Positive	Negative	Negative
Arbitrage-learning	For call	Positive	Positive	Negative	Insignificant
	For put	Negative	Positive	Negative	Insignificant
Panel B. Conditions adopted to inspect the corresponding hypothesis 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 call	Negative	Positive	Negative	Negative
	For put	Positive	Positive	Negative	Negative
Arbitrage-learning	For call	Positive	Positive	Negative	Insignificant
	For put	Negative	Positive	Negative	Insignificant

Note: All parameters used to determine the effect of price dispersion and estimated from the following equations:

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

and

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

where $i \in \{C, P\}$, $j \in \{C, P\}$, and $i \neq j$. $\Delta V_{i,t}^{ATM}$ and $\Delta V_{i,t}^{OTM}$ are the proxy for price dispersion during the time interval *t*, RS_t is the underlying security return at time *t*, VS_t is the trading volume of the TAIEX expressed in millions of New Taiwan dollars, and NBP^{ATM} and NBP^{OTM} are the net buying pressure for ATM and OTM option , respectively during the time interval *t*. Where price dispersion is greater than zero, option is underpriced. In contrast, option is overpriced.

Table 5. Regression results for the impact of net buying pressure on changes on price dispersion

	Parameter estimates					
	α_0	α_1	α_2	α_3	α_4	α_5
Panel A. For ATM options						
Call	0.0456	-0.0254 ***	-0.0017	0.3971 ***	-0.3979 ***	-0.0693 ***
Put	-0.2503 ***	-0.0201 ***	0.0119 ***	0.3570 ***	-0.4350 ***	-0.0867 ***
Panel B. For OTM options						
Call	0.1500 ***	-0.0488 ***	-0.0066 ***	0.5369 ***	-0.3263 ***	-0.0624 ***
Put	0.2957 ***	-0.0352 ***	-0.0137 ***	0.8319 ***	-0.4079 ***	-0.0796 ***

Note: The regression model are constructed as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{i,t}^{ATM} + \alpha_4 NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM},$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + \alpha_3 NBP_{i,t}^{OTM} + \alpha_4 NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM},$$

where $i \in \{C, P\}, j \in \{C, P\}$, and $i \neq j$. $\Delta V_{i,t}^{ATM}$ and $\Delta V_{i,t}^{OTM}$ is the proxy for price dispersion of ATM and OTM options during the time interval *t*, RS_t is the underlying security return at time *t*, VS_t is the trading volume of TAIEX expressed in millions of New Taiwan dollars, and NBP^{ATM} and NBP^{OTM} denote the net buying pressure of ATM and OTM options during the time interval *t*. The sample includes TAIEX options with a maturity date less than 90 days. All variables are calculated at a five-minute time interval. Moreover, we adopt the realized return volatility of the underlying asset over the most recent sixty days to calculate the option's moneyness category.

Table 6. Regression result of changes in ATM and OTM price dispersion with $\Delta RS_{t-1} < 0$

	Parameter estimates							
	α_0	α_1	α_2	α_3	α_3'	α_4	α_4'	α_5
Panel A. For ATM options								
Call	0.0454	-0.0253 ***	-0.0179	0.4357 ***	-0.0818 ***	-0.3461 ***	-0.0975 ***	-0.0695 ***
Put	-0.2513 ***	-0.0203 ***	0.1205 ***	0.2978 ***	0.1111 **	-0.4750 ***	0.0841 ***	-0.0866 ***
Panel A. For OTM options								
Call	0.1500 ***	-0.0486 ***	-0.0069 ***	0.6039 ***	-0.1365 ***	-0.2868 ***	-0.0791	-0.0625 ***
Put	0.2942 ***	-0.0355 ***	-0.0138 ***	0.6786 ***	0.2945 **	-0.4810 ***	0.1471 *	-0.0795 ***

Note: The regression model are constructed as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D) NBP_{i,t}^{ATM} + (\alpha_4 + \alpha_4' D) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM}, \quad (8)$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D) NBP_{i,t}^{OTM} + (\alpha_4 + \alpha_4' D) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM}, \quad (9)$$

where $i \in \{C, P\}$, $j \in \{C, P\}$, and $i \neq j$. $\Delta V_{i,t}^{ATM}$ and $\Delta V_{i,t}^{OTM}$ is the proxy for price dispersion of ATM and OTM options during the time interval *t*, RS_t is the underlying security return at time *t*, VS_t is the trading volume of TAIEX expressed in millions of New Taiwan dollars, NBP^{ATM} and NBP^{OTM} denote the net buying pressure of ATM and OTM options during the time interval *t*, and D serves as a dummy variable that takes a value of 1 as $\Delta RS_{t-1} < 0$, and 0 otherwise. The sample includes TAIEX options with a maturity date less than 90 days. All variables are calculated at a five-minute time interval. Moreover, we adopt the realized return volatility of the underlying asset over the most recent sixty days to calculate the option's moneyness category.

Table 7. Regression result of changes in ATM and OTM price dispersion with $\Delta RS_{t-1} < -0.2\%$

	Parameter estimates							
	α_0	α_1	α_2	α_3	α_3'	α_4	α_4'	α_5
Panel A. For ATM options								
Call	0.0483	-0.0253 ***	-0.0187	0.4070 ***	-0.1761 ***	-0.3810 ***	-0.1677 ***	-0.0692 ***
Put	-0.2544 ***	-0.0203 ***	0.1220 ***	0.3378 ***	0.1914 ***	-0.4502 ***	0.3056 ***	-0.0867 ***
Panel A. For OTM options								
Call	0.1570 ***	-0.0485 ***	-0.0070 ***	0.5578 ***	-0.3117 ***	-0.2990 ***	-0.2871 ***	-0.0624 ***
Put	0.2874 ***	-0.0352 ***	-0.0132 ***	0.7881 ***	0.5696 **	-0.4319 ***	0.3857 **	-0.0795 ***

Note: The regression model are constructed as follows:

$$\Delta V_{i,t}^{ATM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D^*) NBP_{i,t}^{ATM} + (\alpha_4 + \alpha_4' D^*) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{ATM}, \quad (8)$$

and

$$\Delta V_{i,t}^{OTM} = \alpha_0 + \alpha_1 RS_t + \alpha_2 VS_t + (\alpha_3 + \alpha_3' D^*) NBP_{i,t}^{OTM} + (\alpha_4 + \alpha_4' D^*) NBP_{j,t}^{ATM} + \alpha_5 \Delta V_{i,t-1}^{OTM}, \quad (9)$$

where $i \in \{C, P\}, j \in \{C, P\}$, and $i \neq j$. $\Delta V_{i,t}^{ATM}$ and $\Delta V_{i,t}^{OTM}$ is the proxy for price dispersion of ATM and OTM options during the time interval *t*, RS_t is the underlying security return at time *t*, VS_t is the trading volume of TAIEX expressed in millions of New Taiwan dollars, NBP^{ATM} and NBP^{OTM} denote the net buying pressure of ATM and OTM options during the time interval *t*, and D^* serves as a dummy variable that takes a value of 1 as $\Delta RS_{t-1} < -0.2\%$, and 0 otherwise. The sample includes TAIEX options with a maturity date less than 90 days. All variables are calculated at a five-minute time interval. Moreover, we adopt the realized return volatility of the underlying asset over the most recent sixty days to calculate the option's moneyness category.

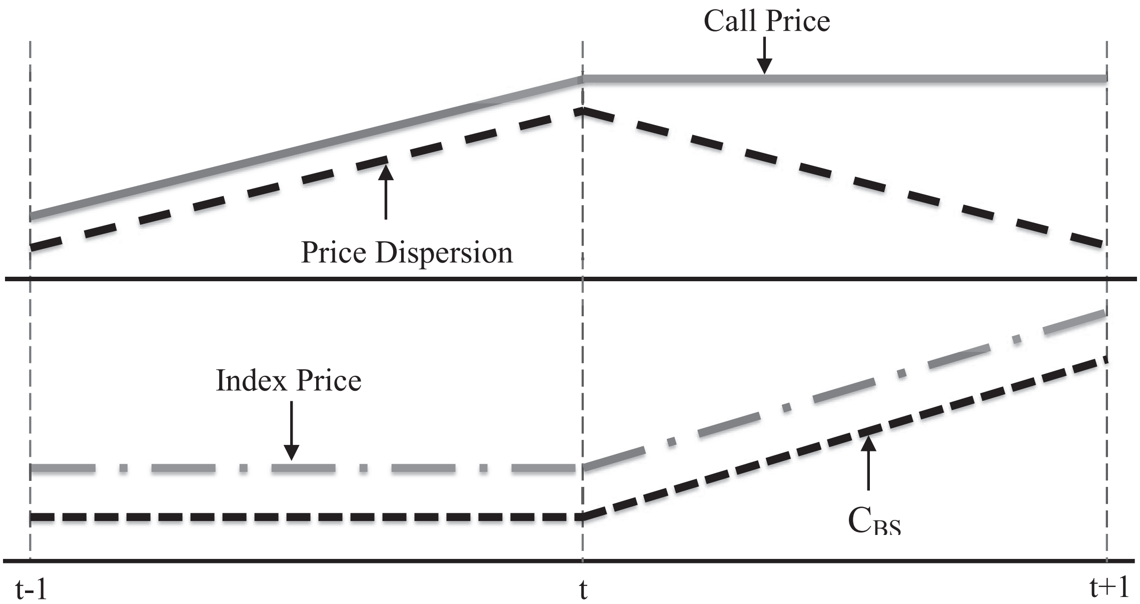

Figure 1a. Positive net buying pressure of call option

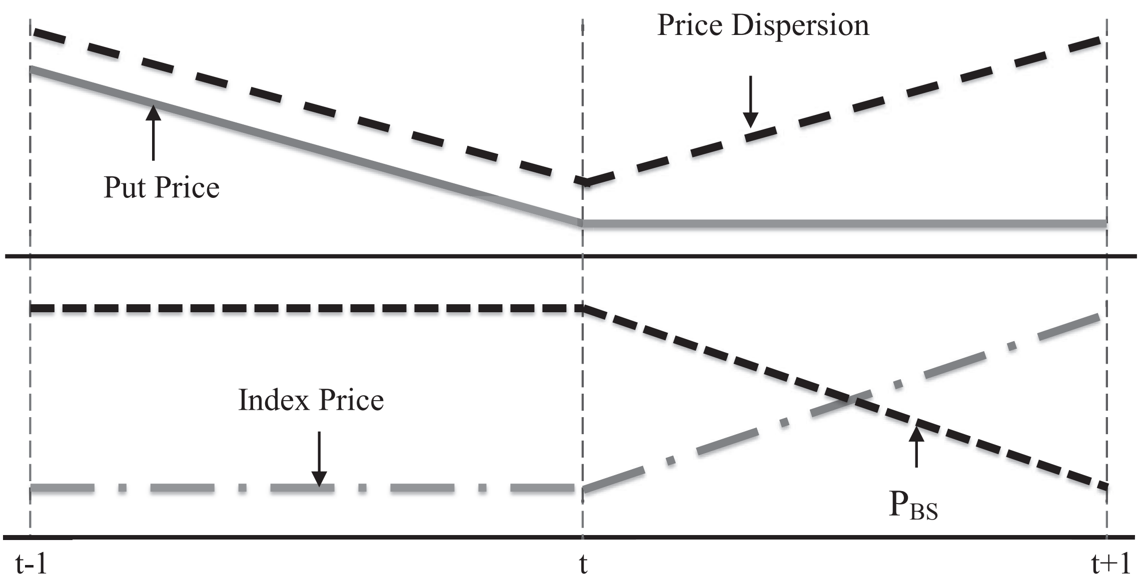

Figure 1b. Negative net buying pressure of put option

Figure 1. Reaction of the underlying asset prices and option price dispersion to positive direction shock under the direction-learning hypothesis.

Note: The figures depict the movements of the call price, put price, index price, price dispersion, and theoritical option price when index price is expected to rise.

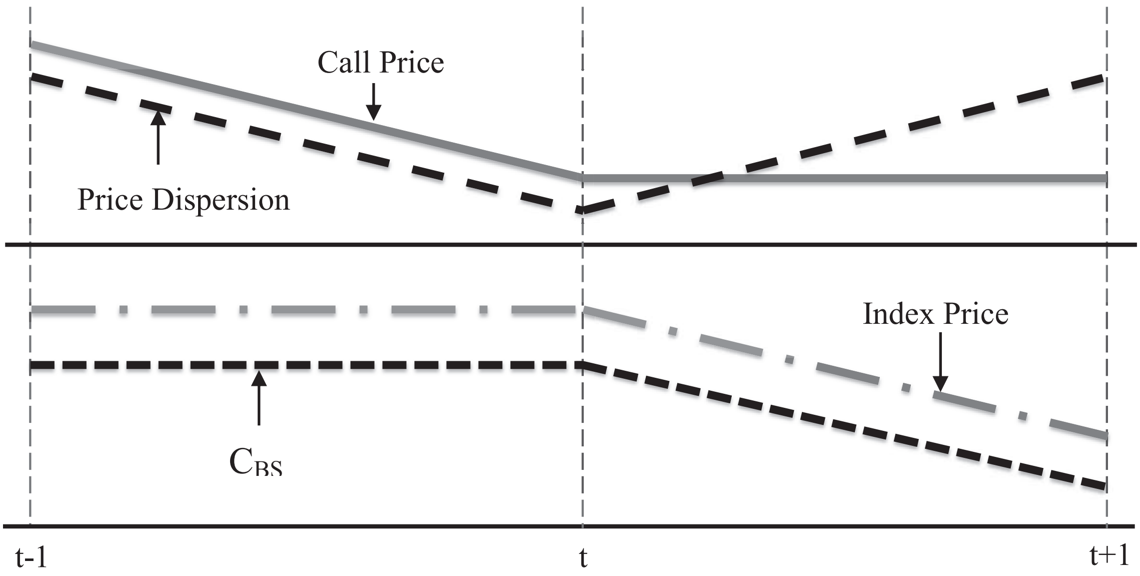

Figure 2a. Negative net buying pressure of call option

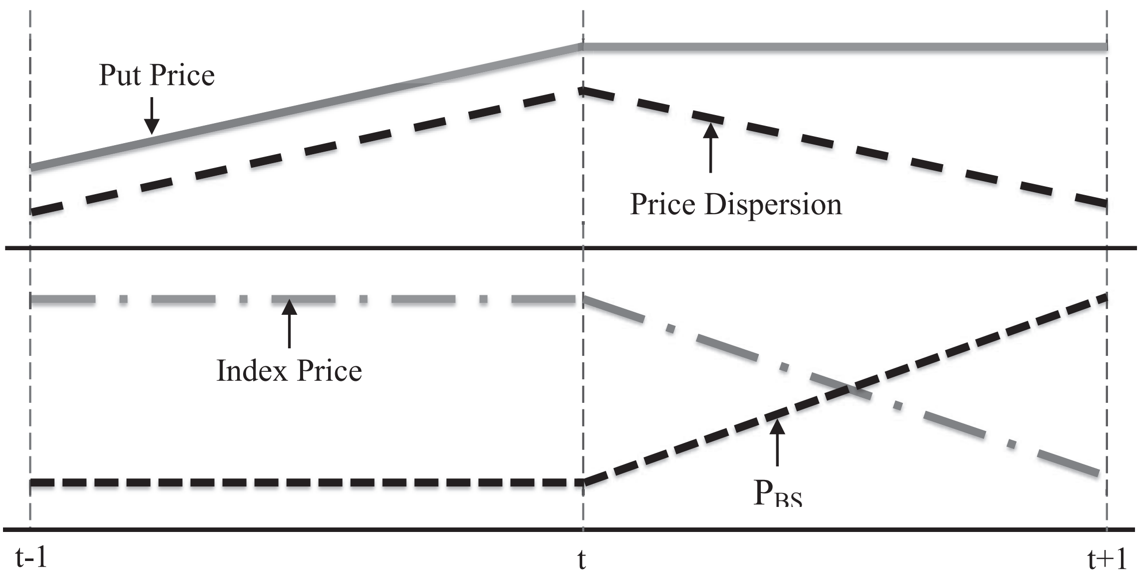

Figure 2b. Positive net buying pressure of put option

Figure 2. Reaction of the underlying asset prices and option price dispersion to negative direction shock under the direction-learning hypothesis.

Note: The figures depict the movements of the call price, put price, index price, price dispersion, and theoritical option price when index price is expected to fall.

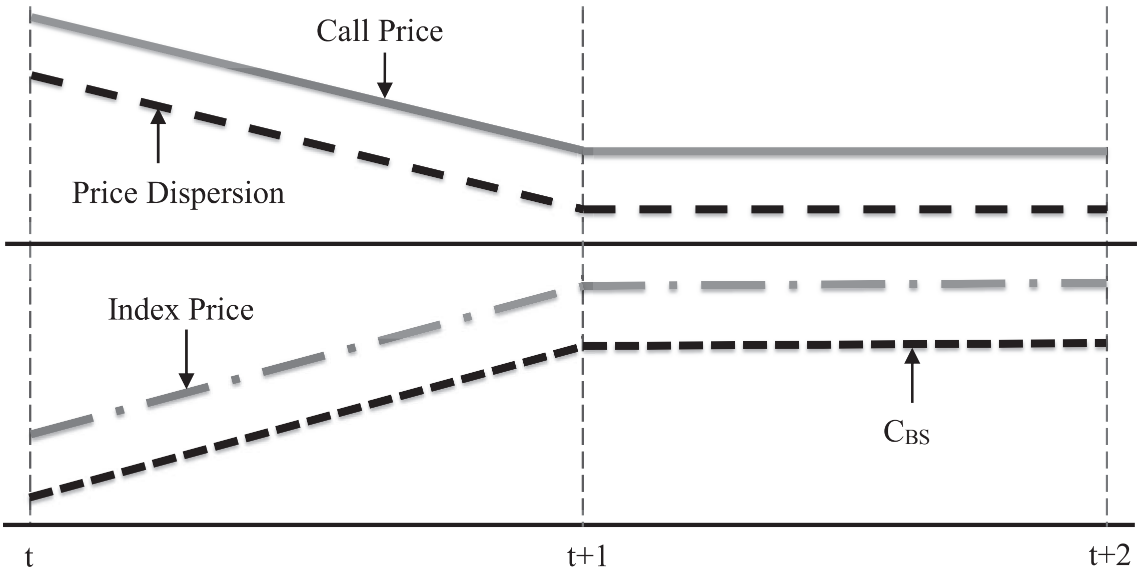

Figure 3a. Negative net buying pressure of call option

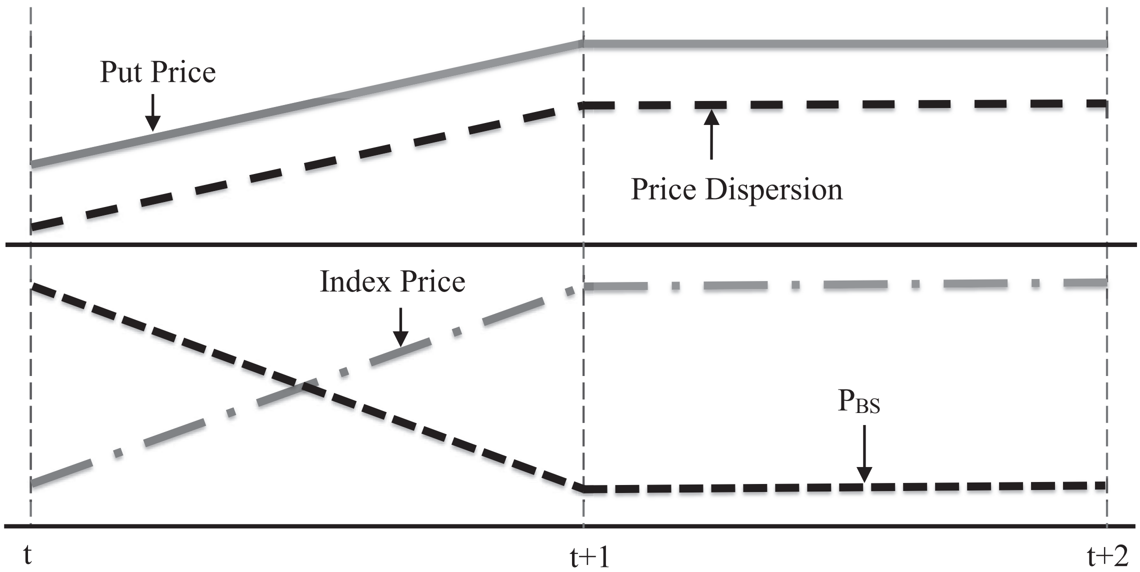

Figure 3b. Positive net buying pressure of put option

Figure 3. Reaction of the underlying asset prices and option price dispersion to positive shock under the arbitrage-learning hypothesis.

Note: The figures depict the movements of the call price, put price, index price, price dispersion, and theoritical option price when index price is expected to rise.

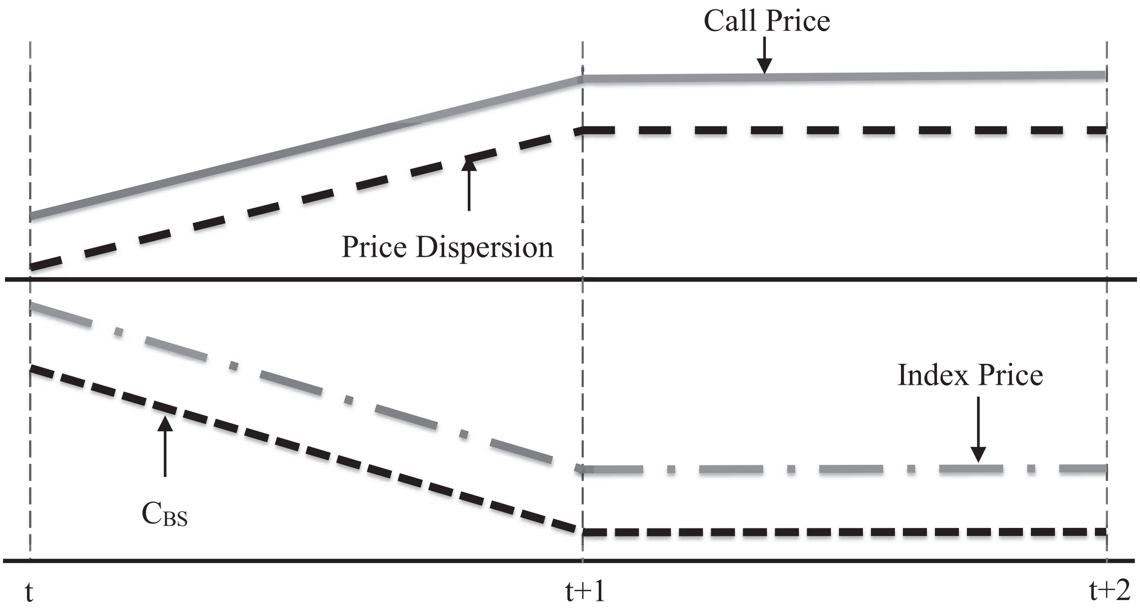

Figure 4a. Positive net buying pressure of call option

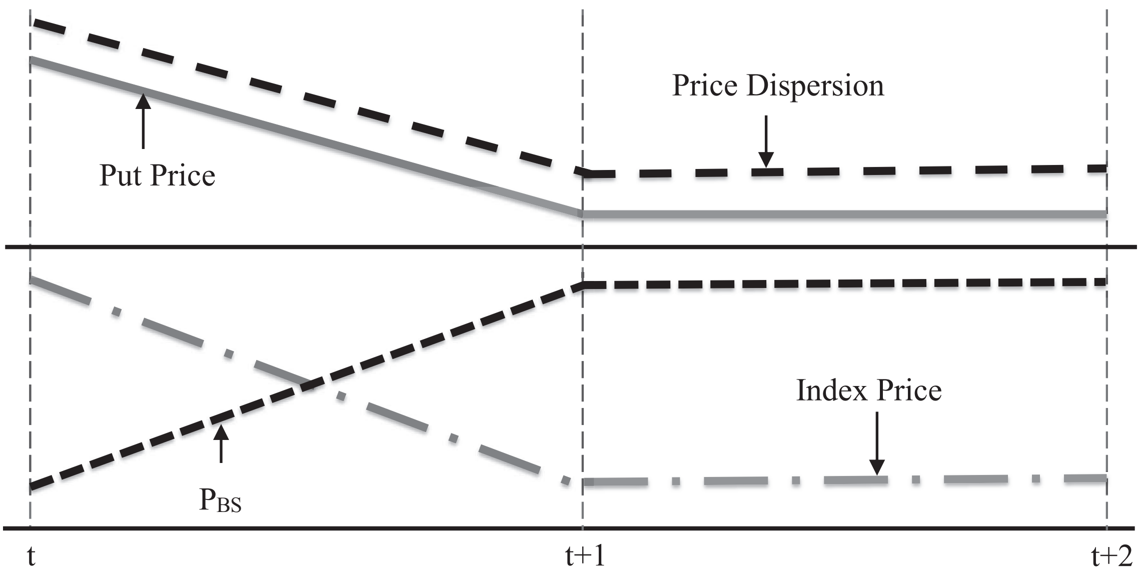

Figure 4b. Negative net buying pressure of put option

Figure 4. Reaction of the underlying asset prices and option price dispersion to negative shock under the arbitrage-learning hypothesis.

Note: The figures depict the movements of the call price, put price, index price, price dispersion, and theoritical option price when index price is expected to fall.