Net Buying Pressure and Implied Volatility in SP500 Index Futures Options: The Effect of Market Cycles and Intraday Trading

Kam C. Chan [a], and Carl R. Chen* [b], Peter P. Lung [b]

[a] Gordon Ford College of Business, Western Kentucky University, Bowling Green, KY 42101
[b] School of Business Administration, University of Dayton, Dayton, OH 45469-2251

Abstract

We analyze the cyclical behavior and intraday pattern of net buying pressure in S&P 500 futures options market. The test results suggest that net buying pressure of puts is counter-cyclical and the pressure is more intense during market downturn. The trading profits for put options during the bear markets thus far exceed those in the bull markets. Net buying pressure also exhibits intraday pattern and trading profits in the early trading sessions are higher than those for the rest of a day. In addition, we show that an hourly-basis hedging yields smaller profits than a daily-basis hedging. This suggests that the trading profits based on daily-basis hedging may contain risk premium associated with discretely rebalanced "risk-free" option portfolios.

Keywords: Net buying pressure; Volatility smile; Microstructure; Market cycle

JEL classification: G13

*Corresponding author: Carl Chen, Department of Economics and Finance, 300 College Park, Dayton, OH 45469-2251; Tel.: +1-937-229-2418; fax: +1-937-229-2477; e-mail: chen@udayton.edu

Net Buying Pressure and Implied Volatility in SP500 Index Futures Options: The Effect of Market Cycles and Intraday Trading

Abstract

We analyze the cyclical behavior and intraday pattern of net buying pressure in S&P 500 futures options market. The test results suggest that net buying pressure of puts is counter-cyclical and the pressure is more intense during market downturn. The trading profits for put options during the bear markets thus far exceed those in the bull markets. Net buying pressure also exhibits intraday pattern and trading profits in the early trading sessions are higher than those for the rest of a day. In addition, we show that an hourly-basis hedging yields smaller profits than a daily-basis hedging. This suggests that the trading profits based on daily-basis hedging may contain risk premium associated with discretely rebalanced "risk-free" option portfolios.

Net Buying Pressure and Implied Volatility in SP500 Index Futures Options: The Effect of Market Cycles and Intraday Trading

1. Introduction

The literature has documented that implied volatility function (IVF) in index option displays a "smirk" across options exercise prices. Although there are several possible reasons for the "smirk", Bollen and Whaley (2004) find that net buying pressure caused by excess demand for the index put options from institutional hedgers prompts the market makers to raise the premium, resulting in a monotonically declining implied volatility across option moneyness. They report that net buying pressure from out-of-the-money index put options drives up the options premiums and hence, pushes implied volatility higher than the "constant" volatility embedded in the options pricing model. In a trading simulation based on daily hedging strategies, Bollen and Whaley report positive and significant abnormal returns by selling the delta-hedged S&P 500 index out-of-the-money put options. Following the Bollen and Whaley's methodology, Chan, Cheng, and Lung (2004, 2006) document similar net buying pressure findings based on the Hong Kong Hang Seng Index options. Brown and Pinder (2005) also find net buying pressure in SPI futures options in Australia.

In light of the current findings about net buying pressure in index options market, we extend Bollen and Whaley (2004) and other studies in several aspects. First, we use the S&P 500 futures options data compiled by the Chicago Mercantile Exchange. With the exception of Brown and Pinder (2005), most implied volatility studies are confined to spot options. Given that futures options are an alternative and popular tool for investors to hedge their underlying positions, our study of implied volatilities based upon futures options sheds light if the net buying pressure hypothesis provides robust explanation for the implied volatility shapes in different options markets.

Second, we examine the cyclical behavior of net buying pressure. During the sample period, the US stock market experienced a long bull market (1996 – 2000) and followed by the burst of internet bubbles, hence a bear market beginning early 2000s. Having the transaction data on futures options available from 1996 to 2002, we are in a unique position to investigate how options net buying pressure differs during the bull and bear market cycles. Since it is intuitively clear that the incentive and the need to hedge is different between a bull and a bear market, we seek to understand the validity of net buying pressure hypothesis under various market conditions.

Third, we study the intraday implied volatility function and the impact of intraday option trading activity on trading profits. It is well documented that spot market intraday volatility displays a "U" shape across trading time in the day. Volatility is found higher around the market opening in the equity markets (e.g., Chan, Chan, and Karolyi (1991)). If implied volatility in the option markets also resembles the volatility behavior in the equity markets, trading profits caused by the net buying pressure could be higher during the market opening hours because a higher implied volatility drives up option premiums and leads to higher profits from selling options.

Fourth, we analyze whether the abnormal trading profits generated by the daily hedging strategies are compensation for risk associated with discretely rebalanced options portfolios. Conceptually, an option portfolio consisting of options and the underlying assets is risk free only if traders could continuously rebalance the portfolio. The abnormal trading profits found in Bollen and Whaley (2004), Chan, Cheng, and Lung (2004, 2006), and Brown and Pinder (2005), are based on a daily-basis hedging trading strategy. Since trading simulation results can suffer from the risk of intraday price movements, particularly major price changes, significant trading profits can be the result of the risk not fully eliminated by daily-basis hedging. Because a continuous hedging strategy is not practically feasible, we reexamine the trading profits based on hourly-basis hedging. The results should shed light on the risk associated with the daily-basis hedging.

Finally, we conduct our analysis for both put and call options. By conducting trading simulations for put and call options separately, we are able to analyze if net buying pressure on put options is transmitted into call options through the put-call-parity. Similar to Chan, Cheng, and Lung (2004, 2006), we also conduct trading simulations using options with different time to maturities. The use of different maturities enables a wider scope beyond a single (one-month) maturity in Bollen and Whaley. Hence, we can control for the possible maturity effect in testing the validity of the net buying pressure hypothesis.

By relating changes in implied volatility to net buying pressure and market expectations across market cycles, we confirm that net buying pressure, instead of market expectations, plays a major role in determining the shape of IVF in the index futures options. The net buying pressure hypothesis of Bollen and Whaley is robust. We also find that net buying pressure of put options is counter-cyclical and is more profound during a bear market. Net buying pressure of calls, however, is pro-cyclical and is more prevalent in the bull market. Overall, net buying pressure of put options is more pervasive than call options.

Based on the delta-hedge and the vega-hedge trading simulation strategies, we find that selling out-of-the-money put index futures options generates positive and significant trading profits. Trading profits during the bear market are higher than those during the bull market for puts, but the opposite is true for calls. Net buying pressure on out-of-the-money put options, however, seems not fully transmitted into the corresponding in-the-money call options.

Comparing daily-basis hedging with hourly-basis hedging, we find that both strategies yield significant and positive profits. Hourly-basis hedging, however, has slightly lower returns than daily-basis hedging. This suggests that abnormal trading profits are affected by the risk associated with discretely rebalanced options portfolios.

Examining intraday volatility pattern, we also show that options' implied volatility around market opening is higher than that for the rest of the day. Consistent with this trading pattern, net buying pressure is higher in the early trading sessions and options trading profits at the market opening are greater than those for the rest of the day.

The rest of the paper is organized as follows: Section 2 provides a literature review; Section 3 discusses data source and volatility dynamics. Empirical tests of net buying pressure hypothesis are carried out in Section 4 according to market cycles, and Section 5 conducts trading profit simulations. Empirical tests and trading profit simulations based upon intraday trading patterns are presented in Section 6, while Section 7 concludes.

2. Literature Review

The implied volatility "smirk" refers to the non-constant implied volatility across exercise prices. Two major schools of thought provide some explanations to the "smirk". The first school examines the validity of constant volatility assumption in the Black-Scholes options pricing model. These studies use different volatility processes to replace the constant volatility in the options pricing model. In essence, this strand of literature derives modified versions of the options pricing model using different volatility processes. Dupire (1994), Derman and Kani

(1994), and Rubinstein (1994) use deterministic local volatility assumptions. Chernov, Galland, Ghysels, and Tauchen (2001) and Anderson, Benzoni, and Lund (2002) employ stochastic volatility assumptions. Bakshi, Cao, and Chen (1997) and Bates (2000) explicitly model volatility jumps in the options pricing model. However, empirical studies in this strand of literature only partially capture the implied volatility "smirk".

The second school of literature focuses on the options market microstructure. The literature suggests that non-constant IVF in index options can be attributed to the options market microstructure. Shleifer and Vishny (1997) argue that the ability of professional arbitrageurs to exploit mispriced options is limited by their power in absorbing short-term or intermediate term trading losses. Liu and Longstaff (2000) suggest that investors' margin requirements limit the size of potential profitable positions taken. These studies imply the existence of different segments in the options market depending on options exercise prices. Along the same line of logic, Bollen and Whaley (2004) stipulate that a market maker cannot sell unlimited amount of options contracts at the same premium given exercise price. As the market makers build up their position in a particular option segment, their hedging costs and volatility risk exposure increase. Hence, prices for these options must be raised accordingly.

According to Bollen and Whaley (2004), therefore, the net buying pressure of the options market in a particular options segment drives up the options prices. Hence, options implied volatilities become non-constant across different exercise prices (market segments). Specifically, Bollen and Whaley (2004) argue that institutional investors usually purchase large quantities of out-of-the-money index puts to hedge underlying cash positions. However, there are not enough natural counterparties to absorb these large quantities of buying orders. In order to provide market liquidity, market makers step in and serve as the counterparties for out-of-the-money put options buying orders. Thus, the imbalanced demand and supply drives up out-of-the-money put options premiums and implied volatilities. Consequently, implied volatilities in the index options market become negatively correlated with exercise prices. The options market microstructure literature attributes the non-constant implied volatility to the limitations or constraints of the market participants in trading index options. The net buying pressure hypothesis highlights this strand of literature.

In terms of empirical results, Bollen and Whaley (2004), Chan, Cheng, and Lung (2004, 2006), and Brown and Pinder (2005) all offer support to net buying pressure hypothesis. Nonetheless, it is still unclear how the interaction of net buying pressure relates to intraday trading patterns, transmission between put and call options, and in particular different market cycles although evidence that economic agent behaves differently during various market states are abundant. Our study aims to fill this void. In addition, we offer robust results by examining hourly-basis hedging strategies instead of the commonly used daily-basis strategies.

3. Market Cycles and Volatility Dynamics

3.1. Data Source

We use intraday S&P 500 futures options and S&P 500 futures data from 1996 to 2002 obtained from the Chicago Mercantile Exchange for the study. The options transaction data include trading time (year, month, hour, minute, and second), bid and ask options premiums, options types, exercise prices, and expiration dates. We match the index futures level to the corresponding futures options. The matching eliminates non-synchronous trading problem in estimating implied volatilities. In total, 239,875 put options and 215,857 call options have usable transaction data from 1996 to 2002.

3.2. The Impact of Market Cycle on Volatility

We examine volatility dynamics based on the entire sample period (January 1996 to December 2002), a bull market period (January 1996 to March 2000), and a bear market period (April 2000 to December 2002). The sample partitioning is based upon the fact that S&P 500 index experienced a long expansion beginning 1996 and ending early 2000, followed by the burst of the internet bubbles. The boom and bust of the S&P500 index can be seen in Figure 1 where we plot the time-series data of the index value.

Since it is known that market volatility is higher during periods of economic contraction (Hamilton and Lin, 1996), we present the realized volatility (annualized) of the S&P 500 index for one-month and two-month holding periods in Table 1. The realized volatility is measured by the standard deviation of the S&P 500 index returns, which is calculated as the $\sqrt{252}$ multiple of daily standard deviation. During the bull market, the average realized volatility ranges from 16.83% for one-month to 16.92% for two-month holding horizon. In the bear market, it varies from 22.28% for one-month to 22.65% for two-month holding horizon. The results in Table 1 suggest that the volatility behavior of the S&P 500 index is significantly different in the bull and bear markets.[1] It is thus reasonable to expect different hedging needs during various market cycles.

3.3. The Impact of Market Cycle on Implied Volatility

To estimate implied volatility, delta, and vega for the S&P 500 futures options, we use Black's (1976a) futures option pricing model specified as:

$$C = e^{-rd \times \tau} [\, F \cdot N(d_1) - X \cdot N(d_2) \,]$$

[1] Similar to Chan, Cheng, and Lung (2006), we also use Nelson's (1991) exponential generalized autoregressive conditional heteroskedasticity (EGARCH) model to examine the S&P 500 process. We find the model parameters differ between the bull and the bear market. The results are available upon request.

$$P = X^{-rd \times \tau}[1-N(d_2)] - F \cdot [1-N(d_1)]$$

$$d_1 = [\ln(F/X) + (\sigma^2/2) \times \tau] / \sigma\sqrt{\tau}$$

$$d_2 = d_1 - \sigma\sqrt{\tau} \qquad (3.1)$$

where C (P) refers to the price of the S&P 500 futures call (put) options; F is the S&P 500 futures price; r_d is the continuously compounded risk free rate proxied by the 3-month T-bill rate; X is the exercise price; $N(\cdot)$ stands for the standard cumulative normal distribution function; σ is the annualized volatility of the index returns; and τ is the time to expiration. To characterize net buying pressure on the S&P 500 futures options, we group options according to options delta.[2] Option delta is calculated as:

$$Call\ Delta = N(d_1)$$

$$Put\ Delta = N(-d_1) \qquad (3.2)$$

The absolute value of delta, |delta|, ranges from 0 to 1. We categorize options into five moneyness groups: deep out-of-the-money ($0.02 \leq |Delta| < 0.2$, hereafter DOTM), out-of-the-money ($0.2 < |Delta| < 0.4$, hereafter OTM), at-the-money ($0.4 \leq Delta < 0.6$, hereafter ATM), in-the-money ($0.6 \leq |Delta| < 0.8$, hereafter ITM), and deep in-the-money ($0.8 \leq |Delta| < 0.98$, hereafter DITM). Following Bollen and Whaley, options with absolute delta below 0.02 or above 0.98 are discarded because of the potential distortions caused by price discreteness. To examine the effect of maturity on net buying pressure, we also classify options into two maturity classes: one-month and two-month.

Table 2 presents the summary statistics of implied volatility estimates. We partition the options into five moneyness (DOTM, OTM, ATM, ITM, and DITM), two maturities (one month

[2] Conventional measurement of the moneyness for a call (put), which is based on the underlying asset price (exercise price) to exercise price (underlying asset price) ratio, fails to account for the fact that the likelihood the options is in the money at expiration also depends on the volatility and the time to maturity. Following Bollen and Whaley (2004), we use the delta of options to account for these effects, because delta is sensitive to volatility and maturity.

and two months), and three sample periods (the entire, bull, and bear markets). Panel 2A reports implied volatility statistics for call and put futures options for the entire sample period (1996-2002). It shows that implied volatilities of the S&P 500 futures put options exhibit a nearly monotonic and inverse relationship with exercise prices for both maturities. These results are consistent with the previous findings. The inverse relation in the implied volatilities for call options, however, is not as clear as for put options. This suggests that net buying pressure on the S&P 500 futures put options is not fully transmitted into corresponding call options. The results for the bull market in Panel 2B are similar to those reported in Panel 2A. The implied volatilities for the bear market in Panel 2C, as expected, are much larger than those in the bull market.

4. Testing the Impact of Net Buying Pressure

4.1. Methodology

To explore the impact of net buying pressure on options volatility in the S&P 500 futures options market, similar to Bollen and Whaley, we specify the test model as:

$$\Delta IV_t = \alpha + \beta_R R_t + \beta_{VOL}\, VOL_t + \beta_1 NBP_{1,t} + \beta_2 NBP_{2,t} + \beta_{\Delta IV(-1)}\, \Delta IV_{t-1} + \varepsilon_t \qquad (4)$$

In Equation (4), ΔIV_t measures the changes in implied volatility at time t. R_t is the index return at time t. VOL_t is the trading volume of underlying asset at time t, and ΔIV_{t-1} is the lagged ΔIV. NBP_1 and NBP_2 are two proxies for daily net buying pressure on options estimated based on the difference between the trading frequency of buyer-motivated options contracts and seller-motivated options contracts within a trading day. Specifically, using the intraday tick-by-tick S&P 500 futures options data, we classify an option trade as buyer-motivated (seller-motivated) if the option has higher (lower) implied volatility than the prevailing implied volatility with the same exercise price and time to expiration. We then scale the net buying pressure by the overall options trading frequency in that day.

Following Bollen and Whaley (2004), Equation (4) is designed to distinguish two different explanations for the changes in implied volatilities. If the changes in implied volatilities are attributed to investor expectations, then the market makers will adjust the options premiums continuously. As a result, the changes in implied volatility will be permanent and uncorrelated. Under this explanation, coefficient for the lagged implied volatility, $\beta_{\Delta IV(-1)}$, will not be significant. Alternatively, under the net buying pressure hypothesis, if the changes in implied volatilities are the results of excess demand for options, then the changes in options demand will generate price pressure, causing options prices and implied volatilities to change. As the market makers rebalance their portfolios, the changes in implied volatilities will be, at least, partially reversed. Consequently, a significant and negative $\beta_{\Delta IV(-1)}$ will be observed.

To measure the net buying pressure based upon different options categories, we expand Equation (4) to the following three testable regressions:

$$\Delta IV_{All,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_ALL_t + \beta_2 C\_ALL_t + \beta_{\Delta IV(-1)} \Delta IV_{All,t-1} + \varepsilon_{t1} \qquad (4.1)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_OTM_t + \beta_2 C\_ATM_{,t} + \beta_{\Delta IV(-1)} \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \qquad (4.2)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_OTM_t + \beta_2 P\_ATM_{,t} + \beta_{\Delta IV(-1)} \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \qquad (4.3)$$

In Equation (4.1), $\Delta IV_{All,t}$ is calculated as $ln(IV_{all,t}/IV_{all,t-1})$. $IV_{all,t}$ is a vega-weighted average IV based on all options traded at time t.[3] C_All (P_All) stands for the net buying pressure calculated based on all of the call (put) options. This equation examines investors' trading motivation. If option trading is caused by market expectations about volatility change, β_1 and β_2 should not be significantly different. This is because in general call options and put

[3] For Equations (4.1) through (4.3), the choice of the calculation for aggregated IV is subjective. We also use the equally weighted method and find the test results similar.

options respond to the changes in volatility similarly. However, when options are traded for different motivations and excess demand drives certain options premiums but not others, β_1 and β_2 will be different.

Equations (4.2) and (4.3) examine the impact of net buying pressure on the volatility changes of OTM put options using different net buying pressure variables.[4] These variables are structured to further investigate whether volatility changes are affected by market expectations or net buying pressure. $IV_{P\_OTM,t}$ refers to the vega-weighted average IV based on OTM put options at time t. $\Delta IV_{P\_OTM,t}$ is calculated as $ln(IV_{P\_OTM,t}/IV_{P\_OTM,t-1})$. In Equation (4.2), P_OTM_t is the net buying pressure derived from OTM put options and C_ATM_t is the net buying pressure estimated based on ATM call options. In Equation (4.3), P_ATM_t is the net buying pressure calculated from ATM put options. If the changes in implied volatility are mainly caused by market expectations, the coefficients of C_ATM_t and P_ATM_t should be significant and larger than that of P_OTM_t. This is because ATM options are more sensitive to volatility changes and are more likely to be used if market expectations of future volatility changes drive trading. Alternatively, if volatility changes are primarily driven by the demand for OTM puts to hedge the underlying assets risk, then β_1 should be significant and larger than β_2.

Lagged ΔIV is also included in Equations (4.2) and (4.3) to distinguish whether the volatility changes are transitory or permanent. In addition to the net buying pressure variables, R_t and VOL_t in Equations (4.1) through (4.3) are used to control for the leverage effect and information flow. It is well documented that volatility changes are inversely related to price changes due to the firm's leverage effect and positively related to information flow. VOL is estimated based on the daily trading volume of the S&P500 index.

[4] Following Bollen and Whaley (2004) and Chan, Chen, and Lung (2004), we use out-of-the-money put options in the test. The test results based on deep-out-of-the-money put options are qualitatively similar.

4.2. Empirical Results – the Effect of Market Cycle

In this section, we report the empirical results of net buying pressure hypothesis based upon Equations (4.1) to (4.3). The results are shown in Table 3. In Panel 3A where results for the entire sample period are reported, we observe that all β_1's are larger than β_2's. More specifically, β_1 and β_2 for Equation (4.1) are $2.01*10^{-2}$ and $1.26*10^{-2}$, respectively. Although both parameters are statistically significant, the larger β_1 estimate indicates that, during the entire sample period, net buying pressure influences implied volatility changes, and put options carry more weights than call options in determining the shape of implied volatility.

Results in Equation (4.2) also show that β_1 ($3.58*10^{-2}$) is significant and larger than β_2 ($2.26*10^{-2}$) -- which is not significant, suggesting that net buying pressure from OTM put options better explains the implied volatility changes than ATM call options. Therefore, options buying pressure instead of market expectations is more consistent with our findings because ATM options is the favored instrument to capitalize the changes in market expectations due to its sensitivity to volatility changes. Results based on Equation (4.3) reaffirm the conclusion obtained from Equation (4.2).

The parameter estimates of the lagged changes in implied volatility further enhance this argument. All of the $\beta_{\Delta IV-1}$ estimates are negative and significant at the one percent level. This suggests that the changes in implied volatility are not permanent, and the market makers rebalance their positions gradually such that implied volatilities are adjusted partly to their previous levels. For example, the magnitude of $\beta_{\Delta IV-1}$ in Equation (4.1) is -0.13 showing that 13% of the volatility changes are reversed on the following trading day.

Among the control variables, all β_R estimates are negative and significant suggesting an inverse relation between returns and volatility changes. On the other hand, all β_{VOL} estimates are positive and significant, indicating a positive relation between volatility and information flow. In sum, the test results presented are more consistent with the net buying pressure hypothesis of implied volatility changes. Out-of-the-money put options are under stronger buying pressure caused by hedging activities, and the impact of net buying pressure on put options volatility is transitory.

In Panel 3B and 3C, we report the test results for the bull and bear markets, respectively. Panel 3B reports the empirical results based upon data in the bull markets. Similar to the findings in Panel 3A where the entire sample is used, all β_1's are larger than β_2's, suggesting that net buying pressure of put options has a stronger effect on the implied volatility than the call options during the bull market period. Coefficient β_2 in Equations (4.1) and (4.2), however, are statistically significant, suggesting that net buying pressure of call options also have an impact on the changes in implied volatility during the bull market period although the effect is not as strong as the pressure of put options. The elevated demand for call options during the bull markets, however, does not diminish the support for the put options net buying pressure hypothesis because the parameters of $\beta_{\Delta IV-1}$ are all negative and significant, consistent with the market makers' rebalancing act which causes a reversal of changes in put options implied volatility.

In Panel 3C where the results are reported for the bear markets, we observe different net buying pressure parameter estimates. Specifically, not only all β_1's are larger than β_2's, two of the β_2's carry a negative sign, and none of the β_2's are statistically significant. This result stands a sharp contrast to the result reported in Panel 3B. Obviously, net buying pressure occurs in both put and call options during the periods of bull markets, while it happens only in put options during the bear markets. Comparing the magnitude of the parameters β_1's between Panel 3B and 3C, we also find that β_1's in Panel 3C are much larger than the same statistics in Panel 3B. These statistics suggest that net buying pressure of put options is stronger and institutional hedgers are more active during the bear market.

5. Options Trading Profit

5.1. Methodology

To examine the futures options trading profit caused by net buying pressure, we perform two simulated trading strategies— the delta-hedge and the vega-hedge trading strategy. In the trading simulations, futures options are sold at the bid prices according to the transaction records, and short positions are held until expiration dates. To avoid the subjective selection bias, we use all observations in the sample to analyze how the impact of futures options buying pressures on trading profits varies across times to maturity.

The delta-hedge trading strategy makes the short options position delta-neutral. The strategy longs (shorts) |delta| units of the S&P 500 index futures for a call (put) short position and the index position is revised by changing the number of units in the underlying asset at daily closing. Any gains or losses are carried forward until the futures options' expiration date. The trading profit of the delta-hedge strategy is stated as:[5]

$$DH\_R_{Call} = \left[(C_0 e^{rT} - C_T) + \delta_0 (F_T - F_0 e^{rT}) + \sum_{t=0}^{T-1} \delta_t (F_{t+1} - F_t) e^{r(T-t)} \right] / |\delta_0 S_0 - C_0| \quad (5.1)$$

$$DH\_R_{Put} = \left[(P_0 e^{rT} - P_T) + \delta_0 (F_T - F_0 e^{rT}) + \sum_{t=0}^{T-1} \delta_t (F_{t+1} - F_t) e^{r(T-t)} \right] / |\delta_0 S_0 - P_0| \quad (5.2)$$

C_0 (P_0) is the call (put) futures options premium when the short position is initiated. C_T is the Max (0, F_T-X). P_T is the Max (0, X-F_T). $C_0 e^{rT} - C_T$ ($P_0 e^{rT} - P_T$) thus measures the profit in

[5] Unlike S&P500 index, S&P500 index futures do not carry any dividends. Therefore, we do not consider dividends in the profit calculation.

index points of the naked trading strategy for call (put) options. For options with quarterly expirations (March, June, September, and December), F_T is the cash settlement S&P 500 futures index level on expiration day based on the special opening quotation of the S&P 500 Index on the third Friday of the contract month. For serial month contracts, F_T is the S&P 500 index futures price on the third Friday at 3:15 p.m., Chicago time. δ_t is the delta value of the short options at time t; F_t is the closing index futures price at time t; "r" refers to the risk-free rate, estimated based on the Eurodollar spot rates;[6] and T is the time to maturity. Intuitively, the second term in the right hand side of Equations (5.1) and (5.2) is the profit from the original long (short) position of the S&P 500 index futures due to delta hedging. The third term is the overall mark-to-market profit from daily delta revision.

Because of the changes in volatility, a portfolio of derivatives that is delta hedged still can incur changes in value. Vega-hedge strategy, however, can be used to eliminate this volatility risk. The strategy hedges a short options position by purchasing other S&P 500 futures options to cover the short volatility position.[7] After the short options position is initiated, the strategy requires the traders to take a long position in a number of other S&P 500 futures options, and to conduct delta-hedge based on the net delta of total futures options positions. To perform the vega-hedge trading strategy, the number of options purchased can be calculated as:

Number of options in vega-hedge

= (Vega of the short options position) / (Vega of the options used in vega-hedge) (6)

[6] Assuming borrowing rate is higher than lending rate, we use Eurodollar rate instead of T-bill rate in Equations (5.1) and (5.2).

[7] It is imperative to discuss vega-hedge in the trading strategy simulation. Without a vega-hedge, the profits of the trading strategy can be seen as compensation for providing an investment vehicle that is positively related to volatility. It is argued that investors value these securities because equity returns in general are negatively related to volatility. Therefore, our conclusions with respect to the profitability of selling options would be in doubt without including a vega-hedge.

The number of the S&P 500 futures contracts purchased is equal to the net delta of the options portfolio. Vega-hedge and delta-hedge are revised daily to free the portfolio from delta and vega risk. The daily gains/losses from the vega-hedge are carried forward at the risk-free rate to the option's expiration.

The trading profit of the vega-hedge strategy is calculated as:

$$VH\_R_{Call} = [(C_0\, e^{rT} - C_T) + \delta'_0(F_T - F_0\, e^{rT}) + \sum_{t=0}^{T-1} \delta'_t\, (F_{t+1} - F_t)e^{r(T-t)} + \nu'_0\, (O_T - O_0\, e^{rT})$$

$$+ \sum_{t=0}^{T-1} \nu'_t\, (O_{t+1} - O_t\,)e^{r(T-t)}] \;/\; |\, \delta'_0 S_0 + \nu'_0\, O_0 - C_0| \qquad (7.1)$$

$$VH\_R_{Put} = [\, (P_0\, e^{rT} - P_T) + \delta'_0(F_T - F_0\, e^{rT}) + \sum_{t=0}^{T-1} \delta'_t\, (F_{t+1} - F_t)e^{r(T-t)} + \nu'_0\, (O_T - O_0\, e^{rT})$$

$$+ \sum_{t=0}^{T-1} \nu'_t\, (O_{t+1} - O_t\,)e^{r(T-t)}] \;/\; |\, \delta'_0 S_0 + \nu'_0 O_0 - P_0|, \qquad (7.2)$$

where δ' is the net delta for the options portfolio, ν' is the number of options in vega-hedge stated in Equations (7.1) and (7.2). O_t refers to the premium of the options used in vega-hedge at time t. The first three terms of Equations (7.1) and (7.2) are similar to those defined in Equation (5). The fourth term accounts for the profit in index points from the original vega-hedge long options position. The last term captures the overall profits/losses from daily vega revision.

As the choice of which options to use in vega-hedge is subjective, we follow the literature and use the options with the highest vega around the hedging time. The option with the highest vega is chosen in this conventional strategy because the higher the vega, the fewer contracts are needed for hedging.

We also conduct a mean test to analyze the statistical significance of the profit from a short options position. Since previous studies find that the distribution of profits from short options is asymmetrical, we employ the modified t-test of Johnson (1978, p. 537), which explicitly accounts for the asymmetric distribution for the test.[8]

To test the impact of discrete rebalancing procedure on trading profits, we conduct and compare two rebalancing procedures—daily-basis hedging and hourly-basis hedging. The daily-basis hedging rebalances the risk-free portfolio at the end of each day. The hourly-basis hedging rebalances the portfolio at the end of each hour. Thus, the hourly-basis hedging is closer to a continuous rebalancing procedure. We perform the difference-in-mean tests between these two procedures. Because the distribution of profits is asymmetrical, we employ the Wilcoxon-Mann-Whitney rank sum test for the difference-in-means. The test statistic is specified as:

$$t_{\text{rank}} = (R_D - R_H) / [\sigma_p \times \sqrt{1/N_D + 1/N_H}\ ] \quad (8)$$

R_D and R_H are the sample means of ranks for the daily-basis and hour-basis hedging procedures, respectively. σ_p is the pooled standard deviation of the ranks. N_D and N_H are the number of observations for the daily-basis and hour-basis hedging procedures, respectively.

5.2. Empirical Results – the Impact of Market Cycle

Tables 4 to 6 report the results of trading simulations. In these tables, "profit" is calculated based on Equations (5.1), (5.2), (6), (7.1), and (7.2). "DH" and "VH" represent the mean of trading profits for the delta-hedge and vega-hedge strategies, respectively. The symbol "†" indicates that the statistic is *not* significant at the 5% level. The test rules are based on Johnson's modified t-test. Daily-basis hedging refers to rebalancing the risk-free portfolio daily, while hourly-basis hedging refers to hourly rebalancing. The symbol ">" indicates that the profit

[8] The test statistic, t_{Johnson} is specified as: $t_{Johnson} = [(\tilde{x} - u) + \frac{u_3}{6\sigma^2 N} + \frac{u_3}{3\sigma^4}(\tilde{x} - u)^2\ ]\ [s_2/N]^{-1/2}$, $\tilde{x}$ is the sample mean, μ, σ^2, and μ_3 are the first, second and third central moments, respectively, s_2 is the sample variance, and N is the sample size. In the mean tests, μ is set at zero, σ^2 is estimated by the sample variance, and μ_3 are estimated by the sample skewness.

of the daily-basis hedging is greater than the profit of the hourly-basis hedging at the 5% significance level or better. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test.

Table 4 presents the simulation results for the entire sampling period (1996~2002). Panel 4A shows the results for put options. The results are classified into delta-hedge, vega-hedge, daily rebalancing, hourly rebalancing, two maturities, and five options moneyness. For the delta-hedge trading strategy, most of the profits are positive and significant across two maturities. Irrespective of maturities and rebalancing frequencies, DOTM put options show the greatest profit ratios followed by OTM puts. This inverse relation between exercise price and profit is consistent with the net buying pressure hypothesis and the regression results presented in Table 3.

Comparing daily-basis hedging with hourly-basis hedging in Panel 4A, we find that, although both show significant and positive trading profits, returns from hourly-basis hedging are uniformly lower than that of daily-basis hedging across all option moneyness. Under the delta-hedge strategy, for example, the DOTM put option with 2-month maturity generates 1.74% return from the daily-basis hedging, whereas it yields 1.60% return based on hourly-basis hedging. The larger trading profits based on daily-basis hedging relative to hourly-basis hedging implies that daily-basis hedging contains risk premium that results from discrete portfolio rebalancing. Nonetheless, the overall findings in hourly-basis trading also offer support to net buying pressure hypothesis.

For the vega-hedge trading strategy, our results show significant losses across all maturities and options moneyness. The longer the maturity and the lower the exercise price, the more severe the losses are. Consistent with Bollen and Whaley (2004), this finding suggests that market makers should charge a higher volatility risk premium in order to cover the pitfalls in conducting vega-hedge. Because of the imperfection for vega-hedge in practice, rebalancing option portfolios becomes more costly as time to maturity increases.

The simulation results for call options are presented in Panel 4B. Similar to the findings reported in Panel 4A, delta-hedge trading strategies generate profits, and the vega-hedge trading strategies result in severe losses. Also, daily-basis hedging yields higher profits than hourly-basis hedging. However, unlike the trading profits for put options, the profits for calls tend to be positively related to exercise prices. This finding suggests that excess buying orders also exist in the call options. Given the differences in the magnitude of the profit ratios, it indicates that the impact of net buying pressure on DOTM and OTM put options are not fully transmitted into the corresponding DITM and ITM call options. The magnitudes of the delta-hedge profits for put options are uniformly larger than that of the call options, indicating greater net buying pressure for the put options. This conclusion is again consistent with the test results reported in Table 3.

The simulation results of trading profit for the bull and the bear markets are reported in Tables 5 and 6. Although they are qualitatively similar to the findings reported in Table 4, a number of findings are worth of highlighting. First, we find the profit of DOTM and OTM put options during the bear markets to be significantly greater than that in the bull markets, which suggests a stronger net buying pressure on DOTM and OTM put options during the bear markets. For example, according to Panels 5A and 6A for the 1-month daily-basis hedging strategy, the profit ratio for DOTM puts is 1.54% in the bull markets, but it is 2.57% (67% larger) in the bear markets. The same conclusion is also found in the hourly-basis hedging strategy. These results are consistent with those in Table 3 that net buying pressure of puts is more intense in the bear markets.

Second, profits from call options strategies during the bull markets are higher than those in the bear markets, which is in opposite to the findings for put options. In fact, DOTM and OTM calls in the bear markets result in negative profits for the 1-month maturity. For example, based on the 1-month delta-hedge trading strategy rebalanced on daily basis, the profit for DOTM call options drops from 0.83% (in Panel 5B) to -0.95% (in Panel 6B) as market shifts from the bulls to the bears. The results in Panels 5B and 6B are also consistent with the regression results reported in Table 3 that out-of-the money call options could also experience excessive buying orders, but this excess demand occurs predominately in the bull markets.

Third, hourly-basis hedging produces similar results except that the profits are slightly below that of the daily-basis hedging. Similar to the results reported in Table 4, vega-hedge produces negative profits, and the negative profits do not exhibit any cyclical behavior.

In sum, based upon Tables 5 and 6, two major findings are worth noting. First, because institutional hedging activities create net buying pressure, selling DOTM and/or OTM put options is profitable. The effect of put net buying pressure, however, is counter-cyclical and is stronger during the bear markets. Second, selling call options can also generate positive returns and it is more profitable during the bull markets. Presumably investors are more active buyers of call options in the bull markets, which bring a stronger buying pressure on calls in the uptrend periods. Therefore, our results are consistent with the conjecture that net buying pressure is market cycle dependent.

6. The Intraday Pattern of Net Buying Pressure

In this section, we study the effect of intraday trading pattern on net buying pressure hypothesis and the resulting trading profit.

6.1. Intraday Volatility

We begin this section by examining the intraday volatility pattern in 5-minute intervals. The intraday 5-minute volatility is computed based on an extreme volatility method (see Chang, Jain, and Locke (1995) and Andersen and Bollerslev (1998)). We first calculate the difference between the high and low prices for each 5-minute interval, and divide the difference by the beginning price of the interval. Then we average these differences over the sample period. Figure 2 depicts the 5-minute volatility against trading time in a day. Similar to the findings reported elsewhere, intraday volatility displays a "U" shaped pattern. However, volatility at the market opening is much greater than at the market closing. Hence, if this intraday volatility pattern is also reflected in the options market, we will observe a higher implied volatility at the market opening. Consequently, option premiums will be higher in the early morning trading sessions and selling options around the market opening may be more profitable than selling options for the rest of the day.

We find that implied volatilities exhibit intraday pattern. In a similar fashion, we calculate the average implied volatility for each 5-minute interval. Figure 3 depicts the intraday pattern of implied volatility for the entire sample period. To save space, we only present the 5-minute implied volatility for one-month DOTM put options. In Figure 3, the implied volatility spikes during the first 30 minutes, decreases throughout the following trading hours. Although the implied volatility pattern does not perfectly mimic the realized volatility, given its intraday pattern it is warranted to examine if net buying pressure also exhibits similar pattern and whether trading profits are different between the first 30 minutes of trading and the rest of a day.

6.2. Intraday Pattern of Net Buying Pressure

We examine if net buying pressure also exhibits an intraday pattern using Equations (4.1) through (4.3). We partition the sample into two trading periods, trades before 9:00 a.m., and trades after 9:00 a.m. The results are presented in Table 7. We observe a few patterns. First, parameters associated with net buying pressure of put options are all positive and statistically significant, irrespective of before or after 9:00 a.m. trades. Second, parameters associated with net buying pressure of call options are sporadically significant. Third, parameters β_1's are larger in magnitude for the sample before 9:00 a.m. Together, the results reaffirm the existence of put options net buying pressure after the leverage effect and intraday information flow are controlled for, and the pressure is more intense in the early morning trades than in the trades that occurred after 9:00 a.m.

6.3. The Effect on Trading Profits

To examine the impact of intraday net buying pressure pattern on the simulated option trading profits, we compare the trading profits before and after 9:00 a.m., central time. 9:00 a.m. is chosen as the separating point because implied volatilities are higher at the market opening as shown in Figure 3. If indeed net buying pressure exhibits intraday pattern and is higher during early trading hours after controlling for information flows, we expect the trading profits before 9:00 a.m. to be greater than those after 9:00 a.m. Table 8 reports the simulated results. To save space, we only report the out-of-the-money put options. Panel 8A reports the results for the bull market, and Panel 8B for the bear markets. The symbol "*" indicates that profit before 9:00 a.m. is greater than profit for the rest of the day at the 5% significance level or better. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test. Comparing the test results before and after 9:00 a.m., we find that all trading profits before 9:00 a.m. are greater than those after 9:00 a.m., and are statistically significant at less than the 5% significance level. These results are robust across maturities and market cycles. Intraday profit simulation results, therefore, are consistent with the intraday pattern of implied volatility and suggest that net buying pressure exists throughout all trading hours, but the pressure is more intense during the early trading sessions of the day.

7. Conclusions

This study extends Bollen and Whaley's (2004) net buying pressure hypothesis and differs from them in several aspects. We use a different instrument, and we analyze the cyclical behavior and intraday pattern of the net buying pressure hypothesis. Our results provide four insights regarding the net buying pressure in the S&P 500 index futures options market. First, net buying pressure exhibits cyclical behavior. Specifically, net buying pressure on put options is counter-cyclical in that the pressure is more intense during the bear markets although the pressure also exists in the bull markets. On the other hand, we also find some evidence of call options net buying pressure, but this net buying pressure of call options is pro-cyclical in the sense that the pressure is higher during the periods of market boom.

Second, trading profits from put options are greater during the bear markets while the opposite is true for the call options. These trading profit results are consistent with our test results of the net buying pressure hypothesis and further support the cyclical behavior of net buying pressure. Third, trading profits from daily-basis hedging are higher than those from hourly-basis hedging. It indicates that the abnormal returns based on daily-basis hedging may contain risk premium caused by non-continuously rebalanced option portfolios. Finally, we find an intraday pattern of net buying pressure. Trading profits exhibit intraday pattern that is consistent with the net buying pressure pattern, i.e., trading profits are greater before 9:00 a.m.

Reference

Andresen, T., T. Bollerslev, 1998. Deutsche Mark-Dollar Volatility: Intraday Activity Patterns, Macroeconomic Announcements, and Longer Run Dependencies, *Journal of Finance*, 53, 219-265.

Anderson, T., L. Benzoni, and J. Lund, 2002. An empirical investigation of continuous-time equity return models, *Journal of Finance*, 57, 1239-1284.

Bekaert, G., and G. Wu, 2000. Asymmetric volatility and risk in equity markets, *The Review of Financial Studies*, 13, 1-42.

Bakshi, G., C. Cao, and Z. Chen, 1997. Empirical performance of alternative option pricing models, *Journal of Finance*, 52, 2003-2049.

Bates, D.S., 2000. Post-'87 crash fears in the S&P500 futures options market, *Journal of Econometrics*, 94, 181-238.

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

Black, Fisher, 1976a. The pricing of commodity contracts, *Journal of Financial Economics*, 3, 167-179.

Black, Fisher, 1976b. Studies of stock price volatility changes, Proceedings of the meetings of the American Statistical Association, Business and Economics Section, Chicago, 177-181.

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

Brown, C. and S. Pinder, 2005. The Impact of Net Buying Pressure on Implied Volatilities Observed from SPI Futures Options, *Review of Futures Markets*, 14, 199-216.

Campbell, J.Y., and L. Hentschel, 1992. No news is good news: an asymmetric model of changing volatility in stock returns, *Journal of Financial Economics*, 31, 281-318.

Chan, K, K.C. Chan, and G.A. Karolyi, 1991. Intraday Volatility in the Stock Index and Stock Index Futures Markets, *The Review of Financial Studies*, 4, 657-684.

Chan, K.C., L. Cheng, and P. Lung, 2004. Net buying pressure, volatility smile, and abnormal profit of Hang Seng Index options, *Journal of Futures Markets*, 24, 1165-1194.

Chan, K.C., L. Cheng, and P. Lung, 2006. Testing the net buying pressure hypothesis during the Asian financial crisis: evidence from HSI options, *Journal of Financial Research*, 29, 43-62.

Chang, Eric, P.C. Jain, and P.R. Locke, 1995. Standard & Poor's Index Futures Volatility and Price Changes Around the New York Exchange Close, *Journal of Business*, 68, 61-84.

Chernov, M., R. Gallant, E. Ghysels, and G. Tauchen, 2001. Alternative models of stock price dynamics, working paper, Columbia University.

Christie, A.A., 1982. The Stochastic behavior of common stock variances: value, leverage and interest rate effects, *Journal of Financial Economics*, 10, 407-432.

Cox, J. C., and S. A. Ross, 1976. The valuation of options for alternative stochastic processes, *Journal of Financial Economics*, 3, 145–166.

Dupire, B., 1994. Pricing with a smile, *Risk*, 7, 18-20.

Derman, E. and I. Kani, 1994. Riding on the smile, *Risk*, 7, 32-39.

French, K.R., G.W. Schwert, and R.F. Stambaugh, 1987. Expected stock returns and volatility, *Journal of Financial Economics*, 19, 3-29.

Johnson, N.E., 1978. Modified t-tests and confidence intervals for asymmetrical populations, *Journal of American Statistical Association*, 73, 536-544.

Hamilton, J.D., and G. Lin, 1996. Stock market volatility and the business cycle, *Journal of Applied Econometrics*, 11, 573-93.

Liu, J. and F.A. Longstaff, 2000. Losing money on arbitrage: optimal dynamic portfolio choice in markets with arbitrage opportunities, working paper, UCLA.

Nelson, D., 1991. Conditional heteroskedasticity in asset returns: a new approach, *Econometrica* 59, 347-370.

Pindyck, R.S., 1984. Risk, Inflation, and the Stock Market, *American Economic Review*, 74, 334-351.

Rubinstein, M., 1994. Implied binomial trees, *Journal of Finance*, 49, 771-818.

Shleifer, A. and R. Vishny, 1997. The limits of arbitrage, *Journal of Finance*, 52, 35-55.

Table 1
Summary statistics of the S&P 500 realized volatility

This table reports the descriptive statistics for the annualized S&P 500 realized volatility across three holding intervals (1 month and 2 months) during the entire sample period (January 1996~ December 2002), bull market (January 1996~March 2000), and bear market (April 2000~December 2002).

Entire period (January 1996~ December 2002)				
	Obs.	Mean	MIN	MAX
1-month	1743	18.92%	7.18%	47.06%
2-month	1743	19.12%	8.72%	39.37%
Bull market (January 1996~March 2000)				
	Obs.	Mean	MIN	MAX
1-month	1074	16.83%	7.18%	44.10%
2-month	1074	16.92%	8.72%	36.21%
Bear market (April 2000~December 2002)				
	Obs.	Mean	MIN	MAX
1-month	669	22.28%	7.92%	47.06%
2-month	669	22.65%	10.61%	39.37%

Table 2
Summary statistics of the implied volatility for the S&P 500 futures options

This table provides descriptive statistics for implied volatility across five moneynesses classified by delta levels (DOTM, OTM, ATM, ITM, DITM) and two maturities (1 month and 2 months) during the entire sample period (January 1996~December 2002), bull market (January 1996~March 2000), and bear market (April 2000~December 2002). DOTM group contains options with 0.02 ≤ |Delta| < 0.2, OTM group contains options with 0.2 ≤ |Delta| < 0.4, ATM group contains options with 0.4 ≤ |Delta| < 0.6, ITM group contains options with 0.6 ≤ |Delta| < 0.8, and DITM group contains options with 0.8 ≤ |Delta| < 0.98. Options with absolute delta below 0.02 or above 0.98 are discarded because of the potential distortions caused by price discreteness.

Panel 2A. Entire sample period (January 1996~ December 2002)

		Put options				Call options			
	Moneyness	Obs.	Mean	MIN	MAX	Obs.	Mean	MIN	MAX
1-month	DOTM	34,373	29.71%	11.65%	65.60%	26,395	20.93%	11.54%	43.55%
	OTM	23,273	24.80%	13.20%	65.10%	22,808	21.09%	11.88%	46.14%
	ATM	14,533	21.39%	11.28%	63.74%	17,470	23.37%	11.56%	50.49%
	ITM	2,406	19.93%	9.45%	84.49%	2,394	23.68%	11.00%	56.47%
	DITM	497	18.94%	5.06%	54.17%	396	23.87%	13.64%	49.02%
2-month	DOTM	51,382	30.25%	16.38%	68.33%	30,903	22.18%	12.19%	36.57%
	OTM	28,851	26.01%	14.14%	80.64%	25,738	20.38%	8.86%	41.49%
	ATM	15,209	22.41%	11.93%	66.46%	20,132	21.47%	13.38%	47.17%
	ITM	1,982	21.24%	10.28%	52.41%	2,921	22.94%	14.26%	56.23%
	DITM	465	23.45%	6.44%	44.54%	509	22.09%	13.05%	54.89%

Panel 2B. Bull markets (January 1996~March 2000)

		Put options				Call options			
	Moneyness	Obs.	Mean	MIN	MAX	Obs.	Mean	MIN	MAX
1-month	DOTM	24,297	28.94%	11.65%	61.10%	17,243	20.19%	12.39%	32.28%
	OTM	16,238	23.18%	13.20%	52.75%	16,029	19.60%	13.28%	38.10%
	ATM	9,264	20.17%	11.59%	44.65%	11,903	23.32%	12.53%	43.41%
	ITM	1,439	17.82%	9.45%	43.81%	1,810	23.56%	11.00%	48.47%
	DITM	242	16.09%	6.62%	39.76%	263	23.52%	13.64%	49.02%
2-month	DOTM	34,189	29.75%	17.54%	68.33%	19,082	20.95%	12.19%	36.57%
	OTM	19,579	24.70%	14.45%	63.89%	17,446	19.51%	12.25%	40.38%
	ATM	9,397	21.77%	12.66%	56.63%	12,318	20.95%	13.38%	47.17%
	ITM	1,152	20.88%	10.96%	52.41%	2,116	22.55%	14.32%	56.23%
	DITM	176	19.74%	6.88%	44.54%	318	20.73%	13.05%	50.93%

Panel 2C. Bear markets (April 2000~December 2002)

		Put options				Call options			
	Moneyness	OBS	Mean	MIN	MAX	OBS	Mean	MIN	MAX
1-month	DOTM	10,076	31.56%	14.35%	65.60%	9,152	22.33%	11.54%	43.55%
	OTM	7,035	28.54%	13.29%	65.10%	6,779	24.61%	11.88%	46.14%
	ATM	5,269	23.52%	11.28%	63.74%	5,567	23.47%	11.56%	50.49%
	ITM	967	23.08%	9.71%	84.49%	584	24.04%	13.10%	56.47%
	DITM	255	21.64%	5.06%	54.17%	133	24.55%	14.90%	46.92%
2-month	DOTM	17,193	31.26%	16.38%	59.75%	11,821	24.17%	12.30%	35.61%
	OTM	9,272	28.76%	14.14%	80.64%	8,292	22.21%	8.86%	41.49%
	ATM	5,812	23.44%	11.93%	66.46%	7,814	22.29%	13.97%	40.41%
	ITM	830	21.74%	10.28%	40.87%	805	23.95%	14.26%	43.75%
	DITM	289	25.72%	6.44%	44.50%	191	24.35%	13.58%	54.89%

Table 3

Regression results for the impact of net buying pressure on the changes in implied volatility

$$\Delta IV_{All,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_ALL_t + \beta_2 C\_ALL_t + \beta_{\Delta IV(-1)} \Delta IV_{All,t-1} + \varepsilon_{t1} \quad (4.1)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_OTM_t + \beta_2 C\_ATM_{,t} + \beta_{\Delta IV(-1)} \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \quad (4.2)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL} VOL_t + \beta_1 P\_OTM_t + \beta_2 P\_ATM_{,t} + \beta_{\Delta IV(-1)} \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \quad (4.3)$$

This table reports the empirical results about the impact of net buying pressure on implied volatility changes in different moneyness categories. ΔIV_t is the change of aggregated implied volatility at time t, R_t, is index return at time t, VOL_t is the underlying asset's trading volume at time t, and ΔIV_{t-1} is the change of implied volatility at time t-1. P_ALL_t , C_ALL_t ,P_OTM_t, $C\_ATM_{,t}$, and $P\_ATM_{,t}$ are net buying pressure variables as specified from Equations (4.1) to (4.3). *t*(.) represents the t-statistics. 'a', 'b', and 'c' indicate the significance at 1%, 5% and 10% respectively.

Panel 3A. Entire period (January 1996~ December 2002)

ΔIV	NBP_1	NBP_2	Obs.	α	$t(\alpha)$	β_R	$t(\beta_R)$	$\beta_{VOL(*10^{-8})}$	$t(\beta_{VOL})$	$\beta_{1(*10^{-2})}$	$t(\beta_1)$	$\beta_{2(*10^{-2})}$	$t(\beta_2)$	$\beta_{\Delta IV(-1)}$	$t(\beta_{\Delta IV(-1)})$	R^2
(4.1) ΔIV_{All}	P_all	C_all	1,743	-0.02	-2.63[a]	-1.63	-9.26[a]	4.66	3.62[a]	2.01	2.18[b]	1.26	3.71[a]	-0.13	-6.05[a]	10.28%
(4.2) ΔIV_{P_OTM}	P_OTM	C_ATM	1,743	-0.03	-2.27[b]	-0.61	-1.79[c]	7.84	2.41[b]	3.58	2.27[b]	2.26	1.59	-0.21	-11.29[a]	8.16%
(4.3) ΔIV_{P_OTM}	P_OTM	P_ATM	1,743	-0.02	-2.92[a]	-2.87	-18.36[a]	4.55	3.21[a]	1.74	2.01[b]	1.61	1.53	-0.09	-7.33[a]	20.25%

Panel 3B. Bull markets (January 1996~March 2000)

ΔIV	NBP_1	NBP_2	Obs.	α	$t(\alpha)$	β_R	$t(\beta_R)$	$\beta_{VOL(*10^{-8})}$	$t(\beta_{VOL})$	$\beta_{1(*10^{-2})}$	$t(\beta_1)$	$\beta_{2(*10^{-2})}$	$t(\beta_2)$	$\beta_{\Delta IV(-1)}$	$t(\beta_{\Delta IV(-1)})$	R^2
(4.1) ΔIV_{All}	P_all	C_all	1,074	-0.02	-2.28[b]	-1.85	-10.25[a]	3.39	2.87[a]	2.18	3.03[a]	1.32	4.76[a]	-0.13	-6.59[a]	9.81%
(4.2) ΔIV_{P_OTM}	P_OTM	C_ATM	1,074	-0.05	-1.69[c]	-0.39	-1.89[c]	5.59	1.79[c]	4.05	1.79[c]	2.01	1.72[c]	-0.20	-10.35[a]	7.10%
(4.3) ΔIV_{P_OTM}	P_OTM	P_ATM	1,074	-0.04	-2.31[b]	-3.26	-20.56[a]	3.92	2.15[b]	2.11	1.89[c]	1.81	1.56	-0.08	-7.42[a]	17.92%

Panel 3C. Bear markets (April 2000~December 2002)

ΔIV	NBP_1	NBP_2	Obs.	α	$t(\alpha)$	β_R	$t(\beta_R)$	$\beta_{VOL(*10^{-8})}$	$t(\beta_{VOL})$	$\beta_{1(*10^{-2})}$	$t(\beta_1)$	$\beta_{2(*10^{-2})}$	$t(\beta_2)$	$\beta_{\Delta IV(-1)}$	$t(\beta_{\Delta IV(-1)})$	R^2
(4.1) ΔIV_{All}	P_all	C_all	669	-0.06	-3.22[a]	-1.15	-5.28[a]	18.71	3.95[a]	2.98	1.78[c]	-1.82	-0.81	-0.14	-4.05[a]	11.21%
(4.2) ΔIV_{P_OTM}	P_OTM	C_ATM	669	-0.10	-2.18[b]	-0.84	-1.70[c]	33.28	2.68[a]	12.79	3.15[a]	-1.24	-1.26	-0.23	-3.98[a]	8.92%
(4.3) ΔIV_{P_OTM}	P_OTM	P_ATM	669	-0.08	-3.37[a]	-1.79	-9.05[a]	19.26	3.79[a]	4.95	1.98[b]	2.86	1.51	-0.16	-4.41[a]	21.33%

Table 4
Trading simulation results for the entire sample period
(January 1996 ~ December 2002)

This table presents the test results of the options trading simulations across five moneynesses classified by delta levels (DOTM, OTM, ATM, ITM, DITM) and two maturities (1 month and 2 months) during the entire sample period (January 1996 ~ December 2002). DOTM group contains options with $0.02 \leq |Delta| < 0.2$, OTM group contains options with $0.2 \leq |Delta| < 0.4$, ATM group contains options with $0.4 \leq |Delta| < 0.6$, ITM group contains options with $0.6 \leq |Delta| < 0.8$, and DITM group contains options with $0.8 \leq |Delta| < 0.98$. Options with absolute delta below 0.02 or above 0.98 are discarded because of the distortions result from price discreteness. "Profit" is calculated based on Equations (6), (7), and (9). "DH" and "VH" are the mean of trading profits for the delta-hedge and vega-hedge strategies, respectively. "†" indicates that the statistic is *not* significant at less than 5% level. The test rules are based on Johnson's modified t-test. Daily-basis hedging refers to rebalancing the risk-free portfolio daily. Hourly-basis hedging rebalances the portfolio hourly. ">" indicates that the profit of the daily-basis hedging is greater than the profit of the hourly-basis hedging at less than 5% significance level. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test.

Panel 4A Put options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		1.18%>	-5.10%>	1.15%	-5.29%
	DOTM	34,373	1.84%>	-5.48%>	1.81%	-5.71%
	OTM	23,273	1.06%>	-5.39%>	1.03%	-5.57%
	ATM	14,533	0.09%>	-4.21%>	0.05%†	-4.31%
	ITM	2,406	-0.13%>	-3.12%>	-0.23%	-3.20%
	DITM	497	-0.31%>	-1.43%>	-0.35%	-1.60%
2-month	Average		1.31%>	-14.60%>	1.21%	-14.82%
	DOTM	51,382	1.74%>	-17.22%>	1.60%	-17.43%
	OTM	28,851	1.18%>	-13.26%>	1.12%	-13.50%
	ATM	15,209	0.34%>	-9.63%>	0.23%	-9.84%
	ITM	1,982	0.17%>	-7.10%>	0.12%†	-7.30%
	DITM	465	0.00%†>	-3.65%>	-0.08%	-3.92%

Panel 4B Call options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		0.44%>	-4.97%>	0.39%	-5.16%
	DOTM	26,395	0.21%	-6.42%>	0.20%	-6.55%
	OTM	22,808	0.55%>	-4.94%>	0.49%	-5.22%
	ATM	17,470	0.61%>	-3.31%>	0.54%	-3.50%
	ITM	2,394	0.69%	-2.04%>	0.65%	-2.24%
	DITM	396	0.52%>	-0.12%>	0.45%	-0.29%
2-month	Average		0.91%>	-13.51%>	0.85%	-13.63%
	DOTM	30,903	1.00%	-18.70%	0.95%	-18.72%
	OTM	25,738	0.87%>	-12.60%>	0.80%	-12.73%
	ATM	20,132	0.83%>	-8.15%>	0.79%	-8.40%
	ITM	2,921	0.78%>	-5.60%	0.76%	-5.71%
	DITM	509	0.64%	-1.83%>	0.57%	-2.02%

Table 5
The trading simulation results during the bull markets
(January 1996 ~ March 2000)

This table presents the test results of the options trading simulations across five moneynesses classified by delta levels (DOTM, OTM, ATM, ITM, DITM) and two maturities (1 month and 2 months) during the bull market (January 1996 ~ March 2000). DOTM group contains options with 0.02 ≤ |Delta| < 0.2, OTM group contains options with 0.2 ≤ |Delta| < 0.4, ATM group contains options with 0.4 ≤ |Delta| < 0.6, ITM group contains options with 0.6 ≤ |Delta| < 0.8, and DITM group contains options with 0.8 ≤ |Delta| < 0.98. Options with absolute delta below 0.02 or above 0.98 are discarded because of the distortions result from price discreteness. "Profit" is calculated based on Equations (6), (7), and (9). "DH", and "VH" are the mean of trading profits for the delta-hedge and vega-hedge strategies, respectively. "†" indicates that the number is *not* significant at less than 5% level. The test rules are based on Johnson's modified t-test. Daily-basis hedging refers to rebalance the risk-free portfolio daily. Hourly-basis hedging is to rebalance the portfolio hourly. ">" indicates that the profit of the daily-basis hedging is greater than the profit of the hourly-basis hedging at less than 5% significance level. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test.

Panel 5A Put options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		0.98%>	-5.06%>	0.96%	-5.25%
	DOTM	24,297	1.54%>	-5.68%>	1.52%	-5.89%
	OTM	16,238	0.67%	-5.07%>	0.65%	-5.32%
	ATM	9,264	0.26%>	-3.92%>	0.22%	-3.96%
	ITM	1,439	-0.01%>	-2.54%>	-0.17%	-2.56%
	DITM	242	-0.27%>	-1.18%	-0.32%	-1.31%
2-month	Average		1.28%>	-14.60%>	1.15%	-14.84%
	DOTM	34,189	1.62%>	-17.24%>	1.45%	-17.50%
	OTM	19,579	1.13%>	-12.95%>	1.08%	-13.19%
	ATM	9,397	0.53%>	-9.60%>	0.36%	-9.76%
	ITM	1,152	0.24%>	-6.63%>	0.15%	-6.83%
	DITM	176	-0.08%>	-3.84%>	-0.25%	-4.12%

Panel 5B Call options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		0.80%>	-4.84%>	0.78%	-5.01%
	DOTM	17,243	0.83%	-6.34%>	0.82%	-6.43%
	OTM	16,029	0.81%>	-4.80%>	0.79%	-5.08%
	ATM	11,903	0.76%>	-3.25%>	0.74%	-3.38%
	ITM	1,810	0.72%	-1.86%>	0.72%	-2.07%
	DITM	263	0.41%>	-0.54%>	0.37%	-0.76%
2-month	Average		1.00%>	-14.37%>	0.96%	-14.47%
	DOTM	19,082	1.09%>	-20.45%	1.06%	-20.46%
	OTM	17,446	0.98%>	-13.00%>	0.94%	-13.08%
	ATM	12,318	0.93%>	-8.74%>	0.86%	-9.02%
	ITM	2,116	0.85%>	-5.41%>	0.83%	-5.47%
	DITM	318	0.80%	-1.78%>	0.79%	-1.99%

Table 6
The trading simulation results during the bear markets
(April 2000 ~ December 2002)

This table presents the test results of the options trading simulations across five moneynesses classified by delta levels (DOTM, OTM, ATM, ITM, DITM) and two maturities (1 month and 2 months) during the bear market (April 2000 ~ December 2002). DOTM group contains options with $0.02 \leq |Delta| < 0.2$, OTM group contains options with $0.2 \leq |Delta| < 0.4$, ATM group contains options with $0.4 \leq |Delta| < 0.6$, ITM group contains options with $0.6 \leq |Delta| < 0.8$, and DITM group contains options with $0.8 \leq |Delta| < 0.98$. Options with absolute delta below 0.02 or above 0.98 are discarded because of the distortions result from price discreteness. "Profit" is calculated based on Equations (6), (7), and (9). "DH", and "VH" are the mean of trading profits for the delta-hedge and vega-hedge strategies, respectively. "†" indicates that the number is *not* significant at less than 5% level. The test rules are based on Johnson's modified t-test. Daily-basis hedging refers to rebalance the risk-free portfolio daily. Hourly-basis hedging is to rebalance the portfolio hourly. ">" indicates that the profit of the daily-basis hedging is greater than the profit of the hourly-basis hedging at less than 5% significance level. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test.

Panel 6A Put options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		1.61%>	-5.20%>	1.57%	-5.37%
	DOTM	10,076	2.57%>	-5.01%>	2.52%	-5.27%
	OTM	7,035	1.94%>	-6.11%>	1.91%	-6.13%
	ATM	5,269	-0.22%>	-4.72%>	-0.26%	-4.93%
	ITM	967	-0.31%	-3.99%>	-0.32%	-4.16%
	DITM	255	-0.35%†>	-1.66%>	-0.39%	-1.88%
2-month	Average		1.37%>	-14.61%>	1.32%	-14.79%
	DOTM	17,193	1.96%>	-17.17%>	1.90%	-17.28%
	OTM	9,272	1.28%>	-13.90%>	1.20%	-14.14%
	ATM	5,812	0.03%†	-9.68%>	0.02%†	-9.96%
	ITM	830	0.08%†	-7.76%>	0.08%†	-7.96%
	DITM	289	0.04%†	-3.53%>	0.02%†	-3.80%

Panel 6B Call options

			Profit based on daily-basis hedging		Profit based on hourly-basis hedging	
		Obs.	DH	VH	DH	VH
1-month	Average		-0.32%>	-5.25%>	-0.44%	-5.49%
	DOTM	9,152	-0.95%>	-6.57%>	-0.98%	-6.78%
	OTM	6,779	-0.07%>	-5.28%>	-0.24%	-5.55%
	ATM	5,567	0.29%>	-3.45%>	0.10%	-3.74%
	ITM	584	0.59%>	-2.58%>	0.42%	-2.77%
	DITM	133	0.74%>	0.70%†>	0.59%	0.63%†
2-month	Average		0.74%>	-11.98%>	0.66%	-12.13%
	DOTM	11,821	0.85%>	-15.86%>	0.77%	-15.92%
	OTM	8,292	0.65%>	-11.74%>	0.49%	-11.98%
	ATM	7,814	0.68%	-7.22%>	0.68%	-7.41%
	ITM	805	0.58%	-6.09%>	0.57%	-6.32%
	DITM	191	0.36%>	-1.91%>	0.19%†	-2.07%

Table 7
Regression results for the impact of net buying pressure on the changes in implied volatility before and after 9:00 a.m.

$$\Delta IV_{All,t} = \alpha + \beta_R R_t + \beta_{VOL}\, VOL_t + \beta_1\, P\_ALL_t + \beta_2\, C\_ALL_t + \beta_{\Delta IV(-1)}\, \Delta IV_{All,t-1} + \varepsilon_{t1} \qquad (4.1)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL}\, VOL_t + \beta_1\, P\_OTM_t + \beta_2\, C\_ATM_{,t} + \beta_{\Delta IV(-1)}\, \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \qquad (4.2)$$

$$\Delta IV_{P\_OTM,t} = \alpha + \beta_R R_t + \beta_{VOL}\, VOL_t + \beta_1\, P\_OTM_t + \beta_2\, P\_ATM_{,t} + \beta_{\Delta IV(-1)}\, \Delta IV_{P\_OTM,t-1} + \varepsilon_{t3} \qquad (4.3)$$

This table reports the empirical results about the impact of net buying pressure on implied volatility changes before and after 9:00 a.m. ΔIV_t is the change of aggregated implied volatility at time t, R_t, is index return at time t, VOL_t is the underlying asset's trading volume at time t, and ΔIV_{t-1} is the change of implied volatility at time t-1. P_ALL_t , C_ALL_t ,P_OTM_t, $C\_ATM_{,t}$, and $P\_ATM_{,t}$ are net buying pressure variables as specified from Equations (4.1) to (4.3). *t*(.) represents the t-statistics. 'a', 'b', and 'c' indicate the significance at 1%, 5% and 10% respectively.

Panel 7A. Entire period (January 1996~ December 2002) before 9:00 a.m.

ΔIV	NBP_1	NBP_2	Obs.	α	t(α)	β_R	t(β_R)	$\beta_{VOL(*10^{-8})}$	t(β_{VOL})	$\beta_{1(*10^{-2})}$	t(β_1)	$\beta_{2(*10^{-2})}$	t(β_2)	$\beta_{\Delta IV(-1)}$	t($\beta_{\Delta IV(-1)}$)	R^2
(4.1) ΔIV_{All}	P_all	C_all	1,743	-0.01	-2.85[a]	-1.49	-3.52[a]	1.29	2.31[b]	2.12	2.87[a]	3.17	3.82[a]	-0.12	-6.69[a]	9.16%
(4.2) ΔIV_{P_OTM}	P_OTM	C_ATM	1,743	-0.02	-3.06[a]	-2.17	-3.58[a]	2.60	2.01[b]	3.22	3.18[a]	1.79	0.76	-0.14	-7.91[a]	12.06%
(4.3) ΔIV_{P_OTM}	P_OTM	P_ATM	1,743	-0.03	-4.20[a]	-1.97	-4.91[a]	1.52	1.82[c]	3.39	2.06[b]	2.98	1.32	-0.17	-9.71[a]	10.46%

Panel 7B. Entire period (January 1996~ December 2002) after 9:00 a.m.

ΔIV	NBP_1	NBP_2	Obs.	α	t(α)	β_R	t(β_R)	$\beta_{VOL(*10^{-8})}$	t(β_{VOL})	$\beta_{1(*10^{-2})}$	t(β_1)	$\beta_{2(*10^{-2})}$	t(β_2)	$\beta_{\Delta IV(-1)}$	t($\beta_{\Delta IV(-1)}$)	R^2
(4.1) ΔIV_{All}	P_all	C_all	1,743	-0.02	-3.02[a]	-0.80	-4.44[a]	6.83	3.46[a]	1.11	2.48[b]	1.63	3.95[a]	-0.15	-8.52[a]	4.72%
(4.2) ΔIV_{P_OTM}	P_OTM	C_ATM	1,743	-0.03	-2.29[b]	-0.55	-1.70[c]	7.46	2.24[b]	2.84	1.86[c]	3.98	1.67[c]	-0.24	-13.23[a]	6.37%
(4.3) ΔIV_{P_OTM}	P_OTM	P_ATM	1,743	-0.03	-3.76[a]	-1.33	-7.50[a]	7.22	3.81[b]	2.82	2.10[b]	2.12	1.02	-0.19	-10.75[a]	6.44%

Table 8
The comparison of trading simulation results before and after 9 O'clock for out-of-the-money put options

This table presents the trading simulation results before and after 9:00 a.m. for out-of-the-money put options. DOTM group contains options with $0.02 \leq |\text{Delta}| < 0.2$, and OTM group contains options with $0.2 \leq |\text{Delta}| < 0.4$. "Profit" is calculated based on Equations (5.1), (5.2), (6), (7.1), and (7.2). "DH", and "VH" are the mean of trading profits for the delta-hedge and vega-hedge strategies, respectively. "†" indicates that the number is *not* significant at less than 5% level. The test rules are based on Johnson's modified t-test. Daily-basis hedging refers to rebalance the risk-free portfolio daily. Hourly-basis hedging is to rebalance the portfolio hourly. ">" indicates that the profit of the daily-basis hedging is greater than the profit of the hourly-basis hedging at less than 5% significance level. "*" indicates that the profit before 9:00 a.m. is greater than the profit after 9:00 a.m. at less than 5% significance level. The difference in mean test is based on the Wilcoxon-Mann-Whitney rank sum test.

Panel 8A Bull markets (January 1996 ~ March 2000)							
			Obs.	DH	VH	DH	VH
1-month	DOTM	Before 9:00	3,434	1.82%>	-4.53%	1.76%	-4.13%
		After 9:00	20,863	1.50%	-5.87%>	1.48%	-6.18%
		Difference:		0.32%*	1.34%*	0.28%*	2.05%*
	OTM	Before 9:00	2,309	1.01%>	-3.71%>	0.93%	-3.84%
		After 9:00	13,929	0.61%	-5.30%>	0.61%	-5.57%
		Difference:		0.40%*	1.59%*	0.32%*	1.73%*
2-month	DOTM	Before 9:00	5,285	1.89%>	-16.18%	1.66%	-15.43%
		After 9:00	28,904	1.57%>	-17.44%>	1.41%	-17.88%
		Difference:		0.32%*	1.26%*	0.25%*	2.45%*
	OTM	Before 9:00	2,851	1.51%>	-11.95%	1.28%	-10.64%
		After 9:00	16,728	1.07%	-13.12%>	1.05%	-13.63%
		Difference:		0.44%*	1.17%*	0.23%*	2.99%*
Panel 8B Bear markets (April 2000 ~ December 2002)							
			Obs.	DH	VH	DH	VH
1-month	DOTM	Before 9:00	1,873	2.85%>	-3.86%	2.76%	-3.51%
		After 9:00	8,203	2.51%	-5.27%>	2.47%	-5.67%
		Difference:		0.34%*	1.41%*	0.29%*	2.16%*
	OTM	Before 9:00	1,334	2.16%>	-4.99%	2.26%	-3.27%
		After 9:00	5,701	1.89%>	-6.37%>	1.83%	-6.80%
		Difference:		0.27%*	1.38%*	0.43%*	3.53%*
2-month	DOTM	Before 9:00	2,889	2.30%>	-15.95%	2.13%	-14.95%
		After 9:00	14,304	1.89%>	-17.42%	1.85%	-17.75%
		Difference:		0.41%*	1.47%*	0.28%*	2.80%*
	OTM	Before 9:00	1,665	1.66%>	-12.90%	1.40%	-11.59%
		After 9:00	7,607	1.20%>	-14.12%>	1.16%	-14.70%
		Difference:		0.46%*	1.22%*	0.24%*	3.11%*

Figure 1
The S&P 500 Index from 1996 through 2002

This figure depicts the S&P 500 index level from January 1996 through December 2002.

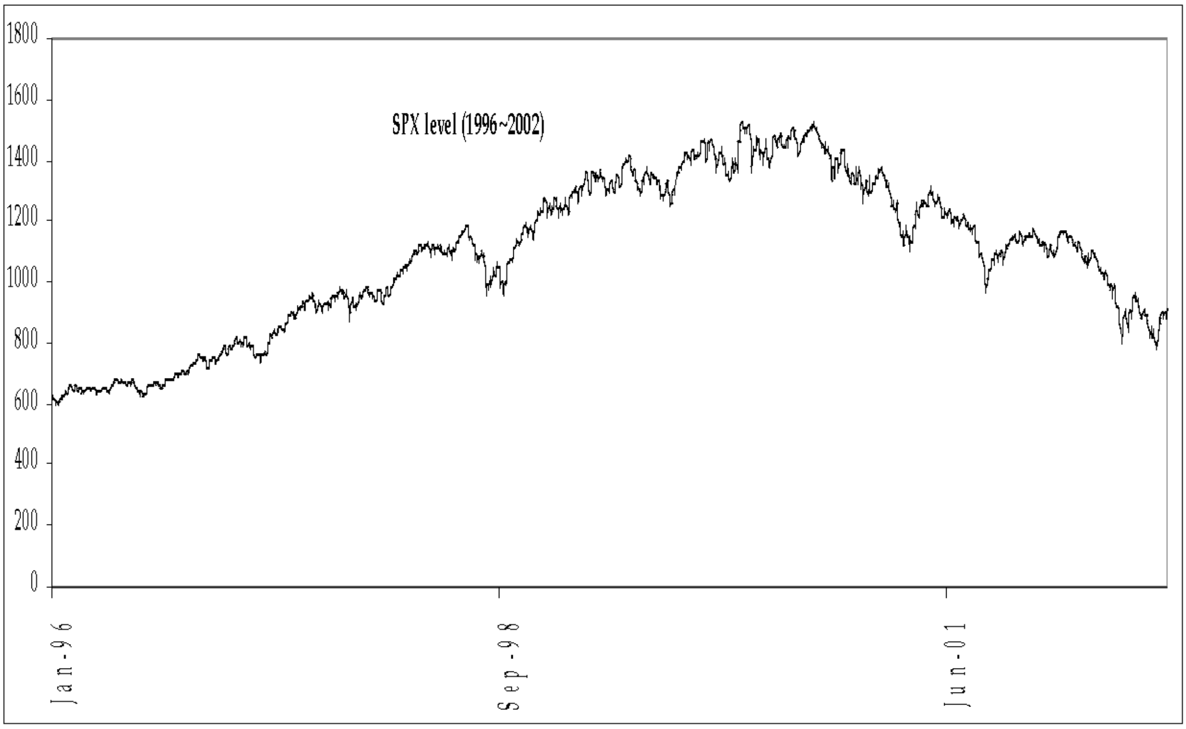

Figure 2
Realized intraday 5-minute volatility of the S&P 500 index

The intraday 5-minute volatility is computed based on extreme volatility method. We select the high and low prices for each 5-minute interval, form the difference, and divide the difference by the beginning price of the interval. Then we average these differences for the entire sampling period (January 1996 ~ December 2002).

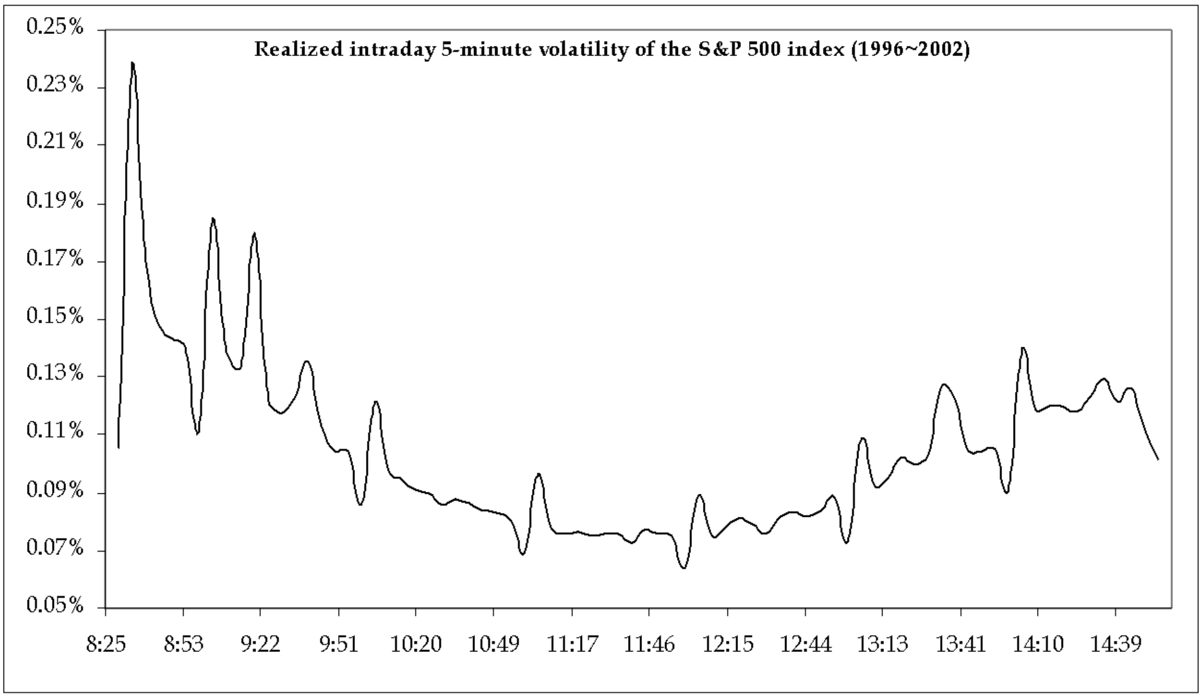

Figure 3
Intraday implied volatility

This figure depicts the intraday implied volatility patterns in 5-minute interval based on DOTM put options during the entire sample period (January 1996 ~ December 2002). The implied volatility is the average of implied volatilities in a 5-minute interval during the sample period.