Bid-ask spread component analysis on the KOSPI200 index options market.

Jangkoo Kang, Hyoung-Jin Park and Doojin Ryu[1]

This version: June 12, 2006

Abstract

This paper analyzes the variation of the bid-ask spread and its components in the KOSPI200 index option market by option deltas. While most of the previous works examine the bid-ask spread components in quote-driven markets where designated market makers exist, this study focuses on a purely order-driven market. To our knowledge, this paper is the first study using a spread component analysis on an index options market.

Using Madhavan et al (MRR)'s model, we investigate how the adverse selection cost and the order processing cost vary by option deltas. Although the classical theories suggest that informed traders would prefer low-delta options to exploit the leverage effect more efficiently, our results show that the trading cost due to informed trading can be larger at the high-delta options in the KOSPI200 index option market.

Option traders with optimistic information might prefer buying call options to selling put options. Thus, we estimate the spread components separately depending on who initiates trades, i.e., buyer-initiated trades and seller-initiated trades. The permanent spread component is higher when the initiated trader is a buyer at the high delta options where the ratio of informed traders is high. There is not so much difference in case of the temporary spread component irrespective of who initiate trade at all options.

We extend the MRR model so that the spread components depend on the trade volume and check how the trade volume affects transaction costs and its components. It seems that the volume effect does not exist in the KOSPI200 index options market.

Keywords: KOSPI200 index option market; Order-driven market; Bid-ask spread; Adverse selection cost; Informed trading; Option delta;

---

[1] Corresponding author(Doojin Ryu): Graduate School of Management, Korea Advanced Institute of Science and Technology, 207-43 Cheongryangri-dong, Dongdaemun-gu, Seoul 130-722, Korea; Phone:+82-2-958-3693, Mobile: +82-2-11-9084-4483, E-mail address: sharpjin@kgsm.kaist.ac.kr

1. Introduction

One of the hot issues in the microstructure area is why the bid price and the ask price is different and what the bid-ask spread is composed of. Since the pioneering work conducted by Demsetz (1968), many theoretical and empirical papers have focused on the spread and its components in many financial markets.

There are many models to analyze the bid-ask spreads. They can be roughly classified into two categories. One is the covariance spread model and the other is the trade indicator spread model. In their seminal paper, Huang and Stoll (1997) present and compare existing models and develop their own structural model (HS three way decomposition model), which can imply existing models to decompose the components of bid-ask spread. Their model is the trade indicator model that decomposes the bid-ask spread into the adverse selection cost component, the inventory holding cost component and the order processing cost component. The adverse selection cost component is the portion of the spread that compensates liquidity providers for the losses that they suffer when trading with traders who have superior information. The inventory holding cost component is the portion that covers the risk from holding specific assets. The order processing cost component is the portion to compensate for providing liquidity.

Madhavan et al (1997) develop their own structural model (MRR model) to analyze the reason for changes in security prices. They note the fact that all price changes are only attributable to new public information in case of an efficient market, but the market friction such as information asymmetry among traders or transaction costs can cause order flow to affect the price movement. Namely, the trading itself affects the price movement in an inefficient market.

The above two models are independently developed but they have similar structures. However, unlike Huang and Stoll (1997), Madhavan et al (1997) explain that the bid-ask spread implied by their model has only two components, the adverse selection cost portion (the permanent spread component) that is attributable to the information asymmetry cost and the transaction cost portion (the temporary spread component) that is attributable non-information parts such as the inventory holding cost or the order processing cost.

Although most emerging markets are pure order driven markets where designated market makers do not exist, most theoretical and empirical studies on the bid-ask spread components deal with quote driven markets. The existence of dealers or specialists are assumed in many structural models including Huang and Stoll (1997)'s model and Madhavan et al (1997)'s

There still exists the explicit bid-ask spread in pure order driven markets. Cohen et al (1981) insist that the positive bid-ask spread exists in an order driven market due to the transaction costs of assessing information, monitoring markets, and conveying orders to the market, and these costs impact on trader's decision. According to Glosten (1994)'s paper, because there is still the possibility that liquidity traders transact with traders who have private information, a positive bid-ask spread exists in an order driven market that has an electronic limit order book.

It can be thought that multiple liquidity providers transact with each other and transact with informed traders in an order driven market. Consequently, those structural models developed to investigate spread components in the NASDAQ or NYSE, for example the HS three way decomposition model or the MRR model, can be used to analyze the spread and its components in an order driven market.

There are some papers which focus on the bid-ask spread in order driven markets using structural models. Kim et al (2002) examine the bid-ask spared components of the Nikkei 225 index futures market using the HS three way decomposition model. Ahn et al (2002) investigate the bid-ask spread components in the Tyoko Stock Exchange using the MRR model. Ahn et al (2002) conclude that the permanent spread component increases with trade size and the temporary spread component decreases with trade size. They report that both the two components exhibit an intraday U-shape pattern, whereas Madhavan et al (1997)'s result shows that the permanent spread component declines and the temporary spread component increases during the day. Angelidis and Benos (2005) analyze the components of the bid-ask spread in the Athens Stock Exchange. They extend the MRR model considering trading volume, and find that the permanent spread component exhibits an intraday U-shape pattern, and the pattern of the temporary spread component depends on the stock price.

While many spread component analysis are conducted on stock markets, there is little research on derivative markets. Our study deals with the index options market where designated market makers do not exist. Using the MRR model and the volume dependent model which extends the MRR model, we investigate how the permanent spread component and the temporary spread component vary by the option delta. To decompose the temporary component into two parts as Huang and Stoll (1997) did, the trade reversal probability should be larger than 0.5. However, our sample data suggests the presence of trade continuation rather than trade reversal as most other pure order driven markets do.[2] Furthermore, it may be inappropriate to explicitly decompose the

[2]As a matter of fact, the original sample data of Huang and Stoll (1997) also suggests the presence of price continuation. They deliberately bunched their sample data and make a new data set in which the trade price reversal probability is greater than 0.5.

temporary spread component into two parts, the inventory holding cost component and the order processing cost component in a pure order driven market.

To our knowledge, this paper is the first research using a spread component analysis on an index options market considering option deltas. Although the classical theories suggest that informed traders would prefer low-delta options to exploit the leverage effect more efficiently, our results show that the transaction cost due to informed trading can be larger in high-delta options in the KOSPI200 index option market.

According to Pan and Poteshman (2006), option traders with positive information might prefer buying call options to selling put options, so we decompose the adverse selection cost component into two parts depending on who initiates trades, i.e., buyer-initiated trades and seller-initiated trades. As expected, the buyer-initiated trade generally seems to be higher information-based than the seller-initiated trade at high-delta options.

We analyze spread components of the KOSPI200 index options market. The KOSPI200 index options market is the most actively traded options market in the world. It has abundant liquidity and a narrowly quoted bid-ask spread. In the Korean options market, there is little liquidity in the individual options market. Furthermore before 2005, the warrant on individual stocks was not traded at all in Korea. So if informed traders want to trade in the derivative markets, they are likely to choose KOSPI200 index options as their trading venue. The anonymity and abundant liquidity also may be appealing factors to attract informed traders to the KOSPI 200 index options market. Moreover the leverage effect of options can induce informed traders to buy index options rather than to invest in a portfolio of stocks.

We expect the ratio of informed traders is not the same by the option moneyness or the option delta. Chakravarty, Gulen, and Mayhew (2004) show that informed traders prefer OTM(out-of-the-money) options because OTM options provide the highest leverage for investors. Black (1975) reports that the leverage is the key reason that informed traders invest in option markets. Kaul, Nimalendran, and Zhang (2002) claim informed trading is frequent in ATM (at-the-money) options when ATM options have higher sensitivity to volatility, higher liquidity and lower bid-ask spreads than other options. De Jong, Koedijk, and Schnitlein (2001) insist that informed traders choose ITM options as their trading venue because ITM options have higher sensitivity to underlying equity price changes than other options. Therefore, these results raise an empirical question: where do informed traders go and how does their informed trading affect trading costs. Although there are studies about what kinds of options informed traders more prefer by the option moneyness, but there is only limited research that investigates how the bid-ask spread and its adverse selection cost component vary by the option moneyness.

We try to examine how much informed trading affects the formation of the bid-ask spread by the option delta rather than the option moneyness. We expect that informed traders consider options having different deltas as different options. Namely, we use the option delta as the dividing criterion instead of the option moneyness.

Option moneyness is defined by the ratio of the underlying asset's price to the exercise price. The option delta is the sensitivity of the option to the underlying asset's price. It gives a similar implication to option moneyness, but it considers the time to maturity and the underlying asset's volatility. Although the value of today's moneyness is the same as that of next day's, the option delta may be different because the time to maturity and the volatility of underlying asset change.

Lee and Yi (2001) investigate the relation between the extent of information-motivated trading and the trade size in the Chicago Board Options Exchange (CBOE) option market and the NYSE stock market. They measure the price impact and the realized spread for size-categorized trades in each market and conclude large informed traders prefer the option market, and small informed traders prefer the stock market. They attribute this result to the fact that large informed traders are reluctant to trade in the CBOE option market, because large traders are not anonymous there. Also, they report the price impact is the biggest in the lowest delta call option that offers the highest leverage effect to traders.

They use only call options data and did not concentrate on put options. Moreover, because traders can split their orders, informed traders can disguise themselves as uninformed traders in the CBOE options market if they want. Consequently, their analysis on the relationship between the price impact and trade size may be spurious.

2. Data

The KOSPI 200 index options market is an order driven market where transactions occur without the intermediation of designated market makers. Instead there is an electronic limit order book in the KOSPI200 index options market. All orders from uninformed and informed traders are transacted through this limit order book. The market opens at 9:00 and closes at 15:15[3]. Traders can order 1 hour before opening, and their orders accumulate in the limit order book. At opening time, all orders that were previously accepted in the limit order book are transacted at the unit price under

[3] The KOSPI200 index options market opens 1 hour later on the first trading day of the year and the National Examination Day.

the batch clearing process (the call auction market). From 9:00 to 15:05, transactions happen under the continuous double auction market. From 15:05 to 15:15 all orders are cleared under the call auction market process as in the previous opening time period.

One option contract is a hundred thousand Korean Won. If the transaction price is larger than 3 points, the minimum price change tick size is 0.05 point, and if the transaction price is smaller than 3 points, the minimum price change tick size is 0.01 point. The minimum trading unit (MTU) is a one option contract. There are always four kinds of options by maturity. Each option that has the same maturity day can be classified into nine different options by exercise price.

The sample period is from January 1, 2002 to December 31, 2002. We organize the electronic limit order book using the historical quote and trade tick data of KOSPI200 index options, and extract the quoted spread and the midpoint price just before every transaction during continuous double auction market time. Even if an incoming order transacts with multiple standing orders and it is recorded as multiple trades in the original trade data, we count that trade as one transaction.

The trade data includes the information on the order type, the transaction time and the trade volume, etc. The order type information classifies orders into a normal order, a correct order that corrects the order that he or she have previously made, and a cancel order that cancels the order that he or she have previously made. The time information is ten times the millisecond unit. We can easily check who has initiated the trade because all trades are time-stamped. For example, if a buyer's order time is later than a seller's order time, it is a buyer-initiated trade. Unlike in a quote driven market, all trade should hit either ask or bid price in a pure order driven market.

We are only interested in normal trading samples under a continuous double auction.

Since no trading halts (circuit breaker) occur during our entire sample period, all transaction data from 9:00 to 15:05 can be used. We extract the first month options and the second month options. The liquidity of the first month options dominate other month options. Other month options except the first and second month options are barely traded.

The KOSPI200 index value is announced every minute. Using these values, we calculate option moneyness and option deltas. Before calculating option deltas, we should estimate the implied volatility by the Black-Sholes option pricing formula. Quoted midpoint prices that we have already made are used for the option's market prices to eliminate the bid-ask bounce effect. If these midpoint prices do not violate the lower arbitrage bound, we can estimate the option's implied volatility. The equation (1) and (2) presents the lower arbitrage bounds of European call and European put.

$$S_0 - D - Ke^{-r\tau_2} \leq c \qquad (1)$$

$$D + Ke^{-r\tau_2} - S_0 \leq p \qquad (2)$$

c and p are each the quoted midpoint call and put option prices. S_0 is the current value of the KOSPI200 index. K is the exercise price. D is the present value of the lump-sum dividend. r is the continuously compounding risk free interest rate. The CD91 rate is used for the proxy for the risk-free interest rate[4].

Whereas quoted midpoint prices of deep ITM and ITM options sometimes violate the

---

[4] The CD91 rate (r_{CD}) can be transformed into continuously compounding rate (r_c).

$$(1+\frac{r_{CD}/100}{4})^4 = e^{r_c}, \quad r_c = 4\ln(1+\frac{r_{CD}/100}{4})$$

lower arbitrage bound, quoted midpoint prices of all ATM and OTM options in the whole sample do not violate that bound. So we assume the implied volatility estimated from the ATM option's price for the representative stock index's volatility at that time interval. Equation (3) shows how to calculate option delta using the estimated implied volatility.

$$Delta = wN(wd_1)$$

w =1 if call option

=−1 if put option

$$d_1 = \frac{\ln(S_0 - D/K) + r\tau_2 + \sigma^2\tau_1/2}{\sigma\sqrt{\tau_1}} \qquad (3)$$

σ is the implied volatility estimated from the ATM option's quoted midpoint price.

τ_1 is the ratio of trading times until maturity to trading times per year[5].

τ_2 is the ratio of calendar days until maturity to calendar days per year.

We reassemble all the option data that has a similar option delta value. The delta interval is 0.05. The option delta is checked per every 15 minutes[6].

Since the quoted midpoint price of the highest delta option may be incorrect due to infrequent trading, and the transaction price of the lowest delta option often equals the minimum tick size, we only include the option data of which the option deltas lie between 0.05 and 0.95 in our final sample data.[7]

---

[5] The option is traded until 14:50 on a maturity day.

[6] We also use the data in which the option delta is updated every 5 minutes. But there is no significant difference when using the option delta updated every 15 minutes.

[7] Vijh (1990) and Yi and Lee (2001) select data whose option deltas lie between 0.15 and 0.95. They insist that the option pricing function cannot be estimated reliably for

[Table 1 about here]

Table 1 shows some transaction information by option deltas. The number of transactions equals the number of observations. The total trade volume is the sum of all transaction volumes throughout the whole sample period. The average trade volume is the ratio of the total trade volume to the number of transactions. The transaction price is the volume weighted average value.

Liquidity can be measured by the number of transaction or the total trade volume. Using either measure, the ordering is the same. Liquidity generally decreases with the absolute value of the option delta.

3. Models and empirical results

3.1. MRR model

Although Madhavan et al (1997)'s structural model was originally designed to estimate the permanent spread component, the temporary spread component, and the implied spread for the quote driven market, it can be applied to the order driven market such as the KOSPI200 index options market. As Greene (1996) directs, a limit order trader can be thought of as a market maker. Moreover, Ahn et al (2002) applies the MRR model to the Tyoko Stock Exchange, which is a pure order driven market like the KOSPI200 index options market.

Madhavan et al (1997) use equation (4) and equation (6) for the estimation.

---

deep in-the money options and deep out-of-money options.

$$E[x_t \mid x_{t-1}] = \rho x_{t-1} \qquad (4)$$

x_t is the trade indicator variable at time t. x_t is 1 for the buyer-initiated trade (trade happens at ask price) at time t, and -1 for the seller-initiated trade (trade happens at bid price) at time t. Since all transactions happen at the quoted ask or bid price in a pure order driven market, the realized value of the trade indicator variable can be only 1 or -1[8]. ρ is the first-order autocorrelation of the trade indicator variable.

$$\rho = E[x_t x_{t-1}] / Var[x_{t-1}] = 2\gamma - (1-\lambda) = (1-2\pi) \qquad (5)$$

γ is the probability of trade continuation, and π is the probability of trade reversal. λ is the probability of a trade between the ask price and the bid price. In our case, λ always equals zero.

$$\Delta P_t = P_t - P_{t-1} = (\alpha + \beta)x_t - (\beta + \rho\alpha)x_t + u_t, \quad u_t = \varepsilon_t + \xi_t - \xi_{t-1} \qquad (6)$$

α represents the permanent effect of order flow on price. This measures the degree of the information asymmetry among traders. β represents the temporary effect of the order flow on price. This measures the compensation to liquidity providers for the order processing cost and risk bearing due to holding an asset.

Using equation (4) and (6), we set up moment conditions shown below.

---

[8] In the Madhavan et al (1997)'s paper, x_t =0 if trade happens between the ask price and the bid price.

The Generalized Method of Moments is robust for heteroscedasticity and serial correlation. Moreover it does not need distributional assumptions for the estimation.

$$E\begin{bmatrix} x_t x_{t-1} - x_{t-1}^2\rho \\ u_t - u_0 \\ (u_t - u_0)x_t \\ (u_t - u_0)x_{t-1} \end{bmatrix} = 0 \quad (7)$$ [9]

u_0 means constant drift (average pricing error).

[Table 2 about here]

Table 2, which is based on the absolute delta value, shows GMM estimates of the permanent spread component (Alpha), the temporary spread components (Beta), the autocorrelation of trade flow (Rho), the fraction of the implied spread that is attributable to the asymmetric information (Gamma), and the implied spread by the model. All the estimated values for alpha, beta and implied spread are multiplied by a hundred. We employ Hansen's J-test to test model fitness for all options. All optimized function values are very small and all p-values are nearly one. So we conclude that over-identifying moment conditions are proper.

[Table 3 about here]

Table 3 shows that adjusted estimate of the permanent spread component (Alpha), the

[9] $|x_t| - (1-\lambda)$ is always zero, so we omit this moment condition.

temporary spread component (Beta), and the implied spread. The adjusted estimates are calculated by dividing estimates by the median value of the each delta interval or the weighted average transaction price. It the Table 3, (%) term means estimates are divided by the volume weighted average transaction prices. We divide the estimates by the deltas as Lee and Yi (2001) or Vijh (1990) did, and this means that all the estimates adjust to the stock equivalent position. Also, to investigate the effect by one currency unit, we divide the estimates by the prices as Ahn et al (2002) did. As you can see in the Table 3, two kinds of adjusted measures show nearly identical patterns so we just draw price-adjusted measures in the Figure 1.

[Figure1 about here]

The permanent spread component (α) explains the part of the implied spread due to information asymmetry among traders. The concept behind informed trading and informed traders in an index option market may be a little bit different from the concept behind them in individual stock or option markets because traders may have difficulty in getting private information on index options. Schlag and Stoll (2005) insist that informed trading in an index option market can be defined by how fast a trader is able to trade using public information before other traders trade so that the price totally reflects all public information. Namely, the speed is the informational advantage of an informed trader in the index option market. Also, traders who can better analyze the public news than others and use it appropriately for their investments can be considered as informed traders. Vega (2005) define an informed trader as a sophisticated agent who can predict the future macroeconomic activity well using public news on markets such as bond and foreign exchange markets where the concept of insider trading is hard to define. In fact, unlike the US financial market, in Korea, since some high priced stocks such as Samsung Electronics that dominate other stocks comprising the KOSPI200 index, traders who have private information on those big companies can be regarded as informed traders.

Our results show that the relative magnitude of estimates of α is strongly negatively correlated with the number of transactions that is the adequate proxy of market liquidity. Liquidity providers are more prone to deal with informed traders in the lower liquidity market. This is one of the reasons that the adjusted α estimate decreases with the number of transaction.

The adjusted α estimate generally increases with an option delta, but it still has quite high value in the very low-delta option.

An increase in the adjusted α estimates implies more dependence on the signal contents of order flows. The high value of the adjusted α estimate implies liquidity providers can learn about the fundamental value of options more quickly through the trading process, or this can be interpreted that the relative portion of informed traders increases in the market. It is more natural to focus the latter interpretation in a pure order driven market. Of course, in case most traders in the market are informed traders, α estimates can be relatively small, but it is not reasonable to think that this situation would occur in the index options market. So, we can conclude the relative portion of informed traders generally increases with the option delta[10] and the relative portion of uninformed traders generally decreases with the option delta. This result can be

[10] However, because the liquidity generally decreases with the option delta, the number of informed traders may not increase with the option delta even though their relative portion increases.

explained if informed traders prefer choose delta index options as their trading venue because of its high sensitivity to underlying index price as De Jong, Koedijk, and Schnitlein (2001) pointed out. Or since hedgers want to prepare for the future against the current situation, they may try to invest in low delta options. Also, noise traders may prefer low delta options just because they are cheaper than high delta options.

However, the relative portion of informed traders is not the smallest for the lowest delta option. It seems that the high leverage effect of the lowest delta option attracts a substantial number of informed traders.

The temporary spread component (β) explains the part of the implied spread due to the order processing cost or the risk of carrying inventory. Of course it may reflect both of them. The price adjusted β estimate generally decreases with the option delta. This reflects the fact that even though the order processing cost is about the same regardless of the option delta, the inventory holding cost for low-delta options may be larger than other options. Low delta options have high price elasticity with respect to the underlying price. Low delta options correspond to OTM options. They are very likely to expire without profit. Furthermore, since our sample data mainly contains short maturity options, these options will be useless without rapid price changes.

The positive value of ρ estimates means the positive continuation of trade rather than the reversal of trade. The estimated ρ value is about the same by most options except low delta options. It is about two times higher for low delta options than high-delta options. This may reflect the fact that informed traders may split their orders for the low delta options.

The estimate of γ is the mean fraction of the implied spread that is attributable to the adverse selection spread component. The bigger γ is, the larger the portion of the implied spread that is attributable to asymmetric information is. γ shows a gradual increase with the option delta. The estimates of γ is negatively correlated with the number of transactions that is the adequate proxy of market liquidity. If market liquidity is not sufficient, the portion of the implied spread caused by informed trading increase.

3.2. Volume Dependent Model

Madhavan et al (1997) assume a fixed order size. They did not consider incorporating the volume effect when estimating parameters. However, they admit that their model may be extended if considering the trade volume effect because there is much evidence that trade volume is strongly correlated with informed trading. Easley and O'Hara (1987) insist that informed investors prefer trading in large volumes. Lee and Yi (2001) show that informed traders who try to order in large volumes are reluctant to use the CBOE options market because they are revealed to be informed traders if they transact in the CBOE.

We incorporate the trade volume as an independent variable in the structural model. Angelidids and Benos (2005) extend the MRR model by incorporating the trade volume as an independent variable to examine about Athens stock market. However, we extend the MRR model a little bit differently in our approach. They assume the permanent spread component is only proportional to the square root of the trade volume while the temporary spread component is divided into one component which depends on the trade volume and the other component which is independent of the trade volume.[11] We allow both components to be divided into two parts.

[11] Their moment condition for GMM estimation is a little bit absurd.

$$\mu_t = \mu_{t-1} + (\alpha_0 + \alpha_1\sqrt{V_t})(x_t - E[x_t \mid x_{t-1}]) + \varepsilon_t\,,\ \ \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \qquad (8)$$

$(x_t - E[x_t \mid x_{t-1}])$ means a surprise in order flow. $(\alpha_0 + \alpha_1\sqrt{V_t})(x_t - E[x_t \mid x_{t-1}])$ is the change in belief due to order flow considering trading volume. ε_t is the innovation in beliefs between time t-1 and t because of public news. μ_t is the post trade expected value of the stock, which is conditional on the new public information and the trade indicator variable[12] .

$$P_t = \mu_t + (\beta_0 + \beta_1\sqrt{V_t})x_t + \xi_t\,,\ \ \xi_t \sim iid(0, \sigma_\xi^2) \qquad (9)$$

P_t is the transaction price at time t. ξ_t can be the rounding errors due to the price discreteness or the errors because of the time varying return. Combining the equation (8) and (9),

$$\Delta P_t = (\alpha_0 + \beta_0)x_t - (\rho\alpha_0 + \beta_0)x_{t-1} + (\alpha_1 + \beta_1)x_t\sqrt{V_t} - \beta_1 x_{t-1}\sqrt{V_{t-1}} - \rho\alpha_1 x_{t-1}\sqrt{V_t} + u_t \quad (10)$$

where $u_t = \varepsilon_t + \xi_t - \xi_{t-1}$

α_0 coefficient and β_0 coefficient capture the components that do not depend on the trade volume, while α_1 and β_1 capture the components that depend on the trade volume. Using the equation (5) and (9), we set up moment conditions to estimate five parameters as in equation (11).

---

[12] $\mu_t = E[V_t \mid x_t, (\varepsilon_{t-1}, \varepsilon_{t-2}, \ldots \varepsilon_1)]$ V_t is the fundamental value of an asset.

$$E\begin{bmatrix} x_t x_{t-1} - x_{t-1}^2\rho \\ u_t - u_0 \\ (u_t - u_0)x_t \\ (u_t - u_0)x_{t-1} \\ (u_t - u_0)x_t\sqrt{V_t} \\ (u_t - u_0)x_{t-1}\sqrt{V_t} \\ (u_t - u_0)x_{t-1}\sqrt{V_{t-1}} \end{bmatrix} = 0 \qquad (11)$$

[Table 4 about here]

Table 4 shows that all estimates of α_0 are significant. The sizes of α_0 estimates dominate those of α_1 estimates at high delta options where the relative portion of informed traders is high. Most estimates of α_1 are relatively very small and are not significant at very high delta options. This implies that the trade volume is not the key factor to determine the permanent spread component, and our extended model is more appropriate than Angelidids and Benos(2005)'s. The permanent spread component is $\alpha_0 + \alpha_1\sqrt{\bar{V}}$. $\bar{V}$ is the average trade volume at each sample interval.

Although most estimates of β_1 are significant, β_0 is more important than β_1 . Absolute values of β_0 estimates are much larger than those of β_1 estimates at all options. Consequently, we can see that the volume effect is still not so high in case of the temporary spread component. The temporary spread component is $\beta_0 + \beta_1\sqrt{\bar{V}}$. The estimates of β_1 are negative at all option deltas. The results on the temporary spread component are consistent with Angelidids and Benos (2005)'s. As they suggest, the order processing cost decreases with the trade volume while the inventory holding cost remains unchanged. This implies that there is the economy of scale in trading. However, even though the estimates of β_1 coefficients are significant, they are very small. So we conclude that the order processing cost decreases with trade volume. But the effect is not large enough.

γ is the mean fraction of the implied spread that is attributable to the adverse selection cost. The γ coefficient is defined here,

$$\gamma = \frac{\alpha_0 + \alpha_1\sqrt{\overline{V}}}{\alpha_0 + \alpha_1\sqrt{\overline{V}} + \beta_0 + \beta_1\sqrt{\overline{V}}} \qquad (12)$$

γ shows a gradual increase with the option delta like in previous sections.

[Table 5 about here]

Table 5 shows the delta and price adjusted measures. They show patterns that are similar to those in the previous section.

[Figure 2 about here]

The consequence of the volume dependent model implies that large trading volume is not always more information-based than small trading volume in the KOSPI200 index options market. One possible explanation is that informed traders split their orders to reduce the market impact.

3.3. Bid/Ask Side

Pan and Poteshman (2006) insist that option volumes are informative to predict the future stock price change. They show informed trading prevails in option markets and suggest Easely, O'hara, and Srinivas (1998)'s pooling equilibrium. Especially, they report that the open-buy option volume is more informative than the open-sell option volume. They claim informed traders who have a positive signal prefer buying call options to selling put options, and informed traders who have a negative signal prefer buying put options to selling call options. This phenomenon can be explained by the fact that if informed traders buy options, their upside potential gain is considerable if their signal turns out to be true, and their loss is just the option premium if their signal turns out to be wrong. On the other hand, whereas the short position in options at best provides the option premium if they are correct, a substantial loss may occur if they are incorrect.

Unlike the individual stock or option market, informed traders may not be certain one hundred percent about their positive or negative information in an index options market. Since the degree of informed trading may be different for the buy side and the sell side, we investigate how spread components are different for the buyer-initiated trader and for the seller-initiate trader separately.

$$\Delta P_t^i = (\alpha^i + \beta^i) x_t^i - (\beta^i + \rho\alpha^i) x_{t-1}^i + u_t^i \qquad (13)$$

i represents the buyer initiated trade(B) or the seller initiated trade(S) category.

x_t^B and x_{t-1}^B each represent x_t and x_{t-1} if a buyer-initiated trade at time t, and are censored otherwise. x_t^S and x_{t-1}^S each represent x_t and x_{t-1} if a seller-initiated trade at time t, and are censored otherwise.

The equation (14) is the moment conditions for the estimation.

$$E\begin{bmatrix} x_t x_{t-1} - x_{t-1}^2\rho \\ (u_t^i - u_0^i)x_t^i \\ (u_t^i - u_0^i)x_{t-1}^i \end{bmatrix} = 0 \quad (14)$$ [13]

[Table 6 about here]

Since all estimated parameters are significant, we only report adjusted measures of estimates in Table 6. The buy column means buyer-initiated trades and the sell column means seller-initiated trades. The number of transactions and the total volume of seller-initiated trades are larger than those of buyer-initiated trade at all options.

Table 6 shows that the estimated values of the permanent spread component of buy trades are generally larger than those of sell trades. And this gap is more prominent for high-delta options where the portion of informed traders is relatively high.

On the other hand, the estimated values of the temporary spread component of buy trades are not much different from those of sell trades at all options. Their difference does not show consistent patterns. This result makes sense in that there is no reason for the order processing cost to vary depending on who initiates trade.

[Figure 3 about here]

4. Conclusion

---

[13] We still use x_t and x_{t-1} to estimate ρ.

This study examines the bid-ask spread component in the KOSPI200 index options market. Our findings are different from those on other markets such as the CBOE or NYSE. Our results show that the spread components vary with the option delta and the liquidity, and the volume effect is not large in the KOSPI200 index options market.

Whereas Yi and Lee (2001) report that the adverse selection component of the bid-ask spread measured by the price impact decreases with the option delta, our results show both the MRR model and the volume dependent model imply that the opposite is true in the KOSPI200 index option market. Yi and Lee (2001) also report that the realized spread, which corresponds to the temporary spread component in our paper, decreases with the option delta. This is roughly consistent with our findings, but our results show that the temporary spread component is very high at very low-delta option. Since the option's elasticity is inversely related to the option delta, very low-delta options have a high inventory holding risk. This effect is highlighted by the variation temporary spread cost component by the option delta.

While Yi and Lee(2001)'s sample data shows the liquidity is nearly same at all option delta, our sample data shows the liquidity decreases with option delta. Thus, we imply that the relative portion of informed traders has a strong relationship with the liquidity of the market.

Our results suggest buyer initiated trade is generally more information based than seller-initiated trade. This is more conspicuous at high delta options where the ratio of informed traders is relatively high.

References

Black, F., 1975, Fact and fantasy in the use of options, *Financial Analyst Journal* 31, 36-41

Christian Schlag. Hans Stoll., 2005. Price impact of options volume. *Journal of Financial Markets* 8, 69-97.

Cohen, K., Maier, S., Schwartz, R., Whitcomb, D., 1981. Transaction costs, order placement strategy, and existence of the bid– ask spread, *Journal of Political Economy* 89, 287– 305.

Cyriel de Jong, Kees G.Koedijik, Charles R. Schnitzlein, 2006. Stock market quality in the presence of a traded option. forthcoming, *Journal of business*.

Demsetz, H., 1968. The costs of transacting, *Quarterly Journal of Economics* 82, 33– 53.

Easley, D., M. O'Hara, P. Shinivas, 1998. Option volume and stock prices: Evidence on where informed trades trade, *Journal of Finance* 53, 431-465

Glosten, L., 1994. Is the electronic open limit-order book inevitable? *Journal of Finance* 49, 1127–1161.

Greene, J., 1996. The impact of limit-order executions on trading costs in New York Stock Exchange stocks, *Working paper*, Georgia State University.

Huang, R., Stoll, H., 1997. The components of the bid– ask spread: a general approach, *Review of Financial Studies* 10, 995–1034.

Jason Lee, Cheong H. Yi, 2001. Trade size an information-motivated trading in the options and stock markets, *The Journal of Financial and Quantitative Analysis*, 36, 485-501

Jun Pan, Allen M. Poteshman, 2006. The Information in option volume for future stock prices. forthcoming, *Review of Financial Studies.*

Kaul, G., Nimalendran, M., Zhang, D., 2004, Informed Trading and Option Spreads, *Working paper*, University of Michigan at Ann Arbor

Kim, Ko, Noh, 2002. Time-varying bid-ask components of Nikkei 225 index futures on SIMEX, *Pacific-Basin Finance Journal* 10, 183-200

Madhavan, A., Richardson, M., Roomans, M., 1997. Why do security prices change? A transaction-level analysis of NYSE stocks. *Review of Financial Studies* 10, 1035– 1064.

Timotheos Angelidis, Alexandros Benos, 2005. The components of the bid-ask spread: The case of the Athens stock exchange, *working paper*

Vega, C, 2006. Stock price reaction to public and private information, forthcoming, *Journal of Financial Economics*.

Vijh, A., 1990.Liquidity of the CBOE Equity Options, *The Journal of Finance* 45, 1157-1179

Table 1
Descriptive Statistics of the Sample Data

|Delta|	Call Option				Put Option			
	No. of Transaction	Total Trade Volume	Average Volume	Transaction Price	No. of Transaction	Total Trade Volume	Average Volume	Transaction Price
0.05~0.1	1607237	159046963	98.96	0.248	1565717	152510198	97.41	0.266
0.1~0.15	2014030	179495826	89.12	0.438	1760958	142057686	80.67	0.465
0.15~0.2	2010976	157148857	78.15	0.631	1715192	118814366	69.27	0.653
0.2~0.25	1842130	119007823	64.60	0.799	1428007	78861193	55.22	0.824
0.25~0.3	1525967	76471944	50.11	0.953	1223986	54377317	44.43	0.977
0.3~0.35	1318777	53967859	40.92	1.171	951664	36550062	38.41	1.164
0.35~0.4	989615	36112423	36.49	1.261	791109	25648880	32.42	1.385
0.4~0.45	909812	29190672	32.08	1.442	605130	17629809	29.13	1.614
0.45~0.5	606459	17192056	28.35	1.691	473213	13692921	28.94	1.725
0.5~0.55	495439	14595487	29.46	1.728	337567	9593840	28.42	1.827
0.55~0.6	360030	9187259	25.52	2.149	274678	8481485	30.88	1.862
0.6~0.65	267335	7223373	27.02	2.162	189575	4965050	26.19	2.256
0.65~0.7	179197	4324961	24.14	2.621	140577	3680797	26.18	2.626
0.7~0.75	122995	2746486	22.33	3.184	114345	2953630	25.83	2.806
0.75~0.8	104778	2359981	22.52	3.264	74302	1541719	20.75	3.861
0.8~0.85	77744	1717329	22.09	3.600	54426	1143365	21.01	4.614
0.85~0.9	68472	1529534	22.34	3.748	40795	812474	19.92	4.953
0.9~0.95	54126	1117943	20.65	4.676	41966	857637	20.44	5.477
Entire Sample	14555119	872436776	59.9402	35.766	11783207	674172429	57.2147	39.355

Table 1 presents the descriptive statistics for the KOSPI200 index options that have different delta values. The first column shows the absolute values of each delta interval. The summary includes the number of transactions, the total trade volume, the average trade volume and the transaction price. The number of transactions equals the number of observations. The total trade volume is the sum of all transaction volumes throughout the whole sample period. The average trade volume is the ratio of the total trade volume to the number of transactions. The transaction price is the volume weighted average value.

Table 2
GMM model estimates of spread components, aoutocorrelation of trade flow, Gamma, and implied spread

Panel A. Call Option

	Alpha		Beta		Rho		Gamma	Implied Spread(X100)
|Delta|	Coeff.(X100)	T-statistic	Coeff.(X100)	T-statistic	Coeff.	T-statistic		
0.05~0.1	0.033	58.80	0.370	369.40	0.49	356.29	0.08	0.806
0.1~0.15	0.043	95.15	0.367	570.19	0.43	353.86	0.11	0.821
0.15~0.2	0.062	105.55	0.363	567.46	0.36	293.03	0.14	0.850
0.2~0.25	0.083	104.99	0.355	466.89	0.31	249.87	0.19	0.876
0.25~0.3	0.116	110.88	0.348	340.08	0.26	204.55	0.25	0.927
0.3~0.35	0.150	110.43	0.338	241.64	0.24	178.03	0.31	0.976
0.35~0.4	0.196	100.80	0.322	202.86	0.22	146.02	0.38	1.037
0.4~0.45	0.237	97.06	0.348	126.50	0.21	138.14	0.40	1.169
0.45~0.5	0.305	74.18	0.442	54.49	0.21	113.86	0.41	1.494
0.5~0.55	0.405	68.40	0.487	86.65	0.21	109.22	0.45	1.783
0.55~0.6	0.503	59.23	0.485	65.34	0.20	88.28	0.51	1.976
0.6~0.65	0.625	45.72	0.445	47.75	0.20	76.70	0.58	2.140
0.65~0.7	0.840	40.52	0.395	34.24	0.18	62.87	0.68	2.470
0.7~0.75	1.099	35.37	0.390	19.27	0.19	53.11	0.74	2.979
0.75~0.8	1.225	31.58	0.383	18.50	0.18	45.21	0.76	3.217
0.8~0.85	1.428	27.67	0.309	12.05	0.19	39.60	0.82	3.474
0.85~0.9	1.552	24.75	0.300	8.57	0.19	38.50	0.84	3.705
0.9~0.95	1.884	22.70	0.262	6.05	0.20	38.65	0.88	4.292

Panel B. Put Option

	Alpha		Beta		Rho		Gamma	Implied Spread(X100)
|Delta|	Coeff.(X100)	T-statistic	Coeff.(X100)	T-statistic	Coeff.	T-statistic		
0.05~0.1	0.034	82.84	0.363	472.11	0.49	367.11	0.08	0.794
0.1~0.15	0.049	92.85	0.361	534.47	0.42	325.15	0.12	0.819
0.15~0.2	0.071	97.27	0.356	459.63	0.34	262.61	0.17	0.853
0.2~0.25	0.108	104.88	0.341	375.94	0.28	207.75	0.24	0.898
0.25~0.3	0.146	104.68	0.329	263.67	0.25	176.29	0.31	0.951
0.3~0.35	0.193	104.40	0.314	193.56	0.22	149.08	0.38	1.015
0.35~0.4	0.252	95.67	0.318	138.41	0.20	132.38	0.44	1.141
0.4~0.45	0.315	79.87	0.366	102.50	0.20	117.44	0.46	1.362
0.45~0.5	0.419	66.26	0.421	83.27	0.20	104.59	0.50	1.680
0.5~0.55	0.499	53.71	0.446	62.92	0.20	85.33	0.53	1.889
0.55~0.6	0.588	44.63	0.421	50.08	0.20	77.10	0.58	2.018
0.6~0.65	0.727	37.93	0.411	33.36	0.19	63.38	0.64	2.275
0.65~0.7	0.900	35.45	0.434	30.24	0.19	54.17	0.67	2.668
0.7~0.75	0.999	28.73	0.426	23.27	0.18	46.18	0.70	2.851
0.75~0.8	1.393	29.18	0.483	14.54	0.19	41.36	0.74	3.751
0.8~0.85	1.761	28.49	0.424	9.26	0.20	36.05	0.81	4.370
0.85~0.9	1.949	20.91	0.372	7.01	0.20	33.02	0.84	4.641
0.9~0.95	1.898	21.58	0.355	6.24	0.21	34.24	0.84	4.506

Table 2 presents the GMM estimates of the parameters and their T-statistics for all options when we use the MRR model. Alpha is the permanent spread component. Beta is the temporary spread component. Rho is the first-order autocorrelation of the trade indicator variable. Gamma is the mean fraction of the implied spread that is attributable to the adverse selection cost. The implied spread is two times the summation of Alpha estimates and Beta estimates. We multiply all coefficient estimates by a hundred.

Table 3
Summary statistics of adjusted GMM model parameters

	Call Option						Put Option					
	Alpha		Beta		Implied Spread		Alpha		Beta		Implied Spread	
|Delta|	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)
0.05~0.1	0.004	0.134	0.049	1.492	0.108	3.251	0.004	0.127	0.048	1.367	0.106	2.987
0.1~0.15	0.003	0.099	0.029	0.838	0.066	1.875	0.004	0.105	0.029	0.776	0.066	1.763
0.15~0.2	0.004	0.098	0.021	0.576	0.049	1.347	0.004	0.108	0.020	0.545	0.049	1.307
0.2~0.25	0.004	0.103	0.016	0.445	0.039	1.096	0.005	0.131	0.015	0.414	0.040	1.090
0.25~0.3	0.004	0.122	0.013	0.365	0.034	0.973	0.005	0.150	0.012	0.337	0.035	0.973
0.3~0.35	0.005	0.128	0.010	0.289	0.030	0.834	0.006	0.166	0.010	0.270	0.031	0.872
0.35~0.4	0.005	0.156	0.009	0.256	0.028	0.823	0.007	0.182	0.008	0.230	0.030	0.824
0.4~0.45	0.006	0.164	0.008	0.241	0.028	0.810	0.007	0.195	0.009	0.227	0.032	0.844
0.45~0.5	0.006	0.180	0.009	0.262	0.031	0.884	0.009	0.243	0.009	0.244	0.035	0.974
0.5~0.55	0.008	0.234	0.009	0.282	0.034	1.032	0.010	0.273	0.008	0.244	0.036	1.034
0.55~0.6	0.009	0.234	0.008	0.226	0.034	0.920	0.010	0.316	0.007	0.226	0.035	1.083
0.6~0.65	0.010	0.289	0.007	0.206	0.034	0.990	0.012	0.322	0.007	0.182	0.036	1.008
0.65~0.7	0.012	0.320	0.006	0.151	0.037	0.942	0.013	0.343	0.006	0.165	0.040	1.016
0.7~0.75	0.015	0.345	0.005	0.122	0.041	0.935	0.014	0.356	0.006	0.152	0.039	1.016
0.75~0.8	0.016	0.375	0.005	0.117	0.042	0.986	0.018	0.361	0.006	0.125	0.048	0.972
0.8~0.85	0.017	0.397	0.004	0.086	0.042	0.965	0.021	0.382	0.005	0.092	0.053	0.947
0.85~0.9	0.018	0.414	0.003	0.080	0.042	0.988	0.022	0.393	0.004	0.075	0.053	0.937
0.9~0.95	0.020	0.403	0.003	0.056	0.046	0.918	0.021	0.347	0.004	0.065	0.049	0.823

Table 3 presents the adjusted estimates of the GMM model parameters, when we use the MRR model. All estimates are adjusted by dividing by deltas or weighted average transaction prices. 1/delta column shows the estimates adjusted for stock equivalent position and (%) column shows the estimates adjusted for price.

Table 4
Volume Dependent Model
GMM model estimates of spread components, aoutocorrelation of trade flow, Gamma, and implied spread

Panel A. Call Option

	Alpha0		Alpha1		Permanent Cost	Beta0		Beta1		Temporary Cost	Rho		Gamma	Implied Spread
|Delta|	Coeff. X100	T-statistic	Coeff. X100	T-statistic	X100	Coeff. X100	T-statistic	Coeff. X100	T-statistic	X100	Coeff.	T-statistic		X100
0.05~0.1	−0.013	−21.74	0.007	103.29	0.055	0.407	446.45	−0.005	−106.78	0.356	0.48	354.31	0.13	0.822
0.1~0.15	−0.010	−17.57	0.010	172.48	0.083	0.411	654.11	−0.008	−191.92	0.338	0.42	357.24	0.20	0.842
0.15~0.2	−0.006	−8.19	0.013	173.45	0.105	0.420	651.33	−0.010	−187.98	0.330	0.35	297.90	0.24	0.871
0.2~0.25	0.008	8.65	0.015	148.48	0.126	0.419	541.06	−0.012	−162.28	0.323	0.31	256.02	0.28	0.897
0.25~0.3	0.032	25.01	0.018	108.45	0.156	0.416	386.26	−0.014	−113.98	0.320	0.26	208.21	0.33	0.952
0.3~0.35	0.053	30.75	0.022	96.82	0.193	0.413	272.05	−0.016	−99.69	0.309	0.24	179.88	0.38	1.005
0.35~0.4	0.102	42.23	0.022	64.02	0.235	0.401	226.15	−0.017	−75.67	0.296	0.22	147.64	0.44	1.063
0.4~0.45	0.132	44.08	0.026	55.50	0.281	0.437	139.26	−0.022	−60.25	0.315	0.21	139.01	0.47	1.192
0.45~0.5	0.153	28.57	0.040	36.06	0.368	0.552	75.92	−0.034	−35.89	0.372	0.20	114.18	0.50	1.478
0.5~0.55	0.270	40.33	0.036	32.63	0.463	0.618	85.04	−0.038	−40.41	0.413	0.21	109.06	0.53	1.752
0.55~0.6	0.341	33.90	0.045	23.20	0.569	0.659	66.01	−0.048	−29.24	0.419	0.20	88.11	0.58	1.977
0.6~0.65	0.502	31.78	0.036	17.88	0.688	0.607	52.08	−0.046	−26.85	0.367	0.19	76.65	0.65	2.109
0.65~0.7	0.733	30.30	0.032	11.18	0.891	0.585	38.68	−0.056	−23.40	0.313	0.18	62.97	0.74	2.408
0.7~0.75	0.996	26.42	0.032	6.67	1.144	0.568	24.70	−0.053	−14.48	0.320	0.19	53.11	0.78	2.928
0.75~0.8	1.146	24.18	0.025	4.01	1.263	0.554	19.77	−0.052	−11.14	0.308	0.18	45.20	0.80	3.142
0.8~0.85	1.420	22.03	0.002	0.27	1.430	0.476	14.08	−0.050	−9.52	0.244	0.19	39.69	0.85	3.349
0.85~0.9	1.599	20.65	−0.012	−1.28	1.543	0.455	10.03	−0.051	−7.34	0.217	0.19	38.57	0.88	3.520
0.9~0.95	1.996	14.58	−0.032	−1.01	1.855	0.362	3.60	−0.035	−1.18	0.207	0.20	38.65	0.90	4.123

Panel B. Put Option

	Alpha0		Alpha1		Permanent Cost	Beta0		Beta1		Temporary Cost	Rho		Gamma	Implied Spread
|Delta|	Coeff. X100	T-statistic	Coeff. X100	T-statistic	X100	Coeff. X100	T-statistic	Coeff. X100	T-statistic	X100	Coeff.	T-statistic		X100
0.05~0.1	−0.014	−25.10	0.008	130.70	0.068	0.404	540.66	−0.006	−151.73	0.342	0.47	362.56	0.16	0.819
0.1~0.15	−0.013	−18.42	0.011	159.01	0.090	0.412	613.20	−0.009	−181.06	0.331	0.40	325.29	0.21	0.842
0.15~0.2	−0.004	−3.76	0.014	153.31	0.115	0.420	495.03	−0.012	−143.66	0.320	0.33	264.42	0.26	0.870
0.2~0.25	0.024	18.15	0.017	117.38	0.150	0.411	428.97	−0.014	−136.11	0.309	0.28	211.34	0.33	0.919
0.25~0.3	0.054	30.13	0.020	89.71	0.186	0.404	293.97	−0.015	−104.78	0.302	0.25	179.04	0.38	0.977
0.3~0.35	0.098	41.64	0.022	67.61	0.234	0.393	216.58	−0.017	−77.66	0.287	0.22	150.09	0.45	1.042
0.35~0.4	0.143	44.42	0.027	58.52	0.297	0.410	147.98	−0.022	−60.45	0.286	0.21	133.47	0.51	1.166
0.4~0.45	0.179	37.71	0.035	45.08	0.367	0.488	99.48	−0.031	−48.93	0.321	0.20	117.33	0.53	1.376
0.45~0.5	0.286	38.00	0.035	33.13	0.473	0.550	81.47	−0.037	−39.65	0.352	0.20	104.26	0.57	1.652
0.5~0.55	0.364	33.97	0.035	23.78	0.549	0.582	64.42	−0.041	−31.91	0.362	0.19	84.91	0.60	1.822
0.55~0.6	0.505	33.08	0.023	13.88	0.633	0.555	53.44	−0.038	−28.06	0.346	0.20	76.97	0.65	1.957
0.6~0.65	0.649	27.78	0.024	9.67	0.771	0.582	37.07	−0.051	−24.21	0.322	0.19	63.34	0.71	2.187
0.65~0.7	0.846	27.37	0.018	5.24	0.938	0.603	32.87	−0.051	−18.27	0.343	0.19	54.10	0.73	2.562
0.7~0.75	0.935	22.24	0.019	4.10	1.029	0.615	21.08	−0.055	−10.56	0.338	0.18	46.14	0.75	2.733
0.75~0.8	1.256	22.09	0.045	5.00	1.457	0.737	17.48	−0.083	−12.05	0.364	0.19	41.33	0.80	3.641
0.8~0.85	1.769	23.11	−0.001	−0.11	1.764	0.674	12.33	−0.077	−9.08	0.328	0.20	36.17	0.84	4.183
0.85~0.9	1.985	17.03	−0.007	−0.46	1.953	0.616	9.25	−0.081	−7.44	0.261	0.20	33.00	0.88	4.430
0.9~0.95	1.892	17.31	0.004	0.25	1.909	0.574	7.54	−0.074	−5.37	0.247	0.21	34.26	0.89	4.313

Table 4 presents the GMM estimates of the parameters and their T-statistics for all options when we use the volume dependent model. Alpha0 is the part of the permanent spread component that does not depend on trade volume. Alpha1 is the part of the permanent spread component that depends on trade volume. Beta0 is the part of the temporary spread component that does not depend on trade volume. Beta1 is the part of the temporary spread component that does not depend on trade volume. The permanent spread component is $\alpha_0 + \alpha_1\sqrt{\overline{V}}$ and the temporary spread component is $\beta_0 + \beta_1\sqrt{\overline{V}}$.

The implied spread is two times the summation of the permanent spread component and the temporary spread component. We multiply all above coefficient estimates by a hundred. Rho is the first-order autocorrelation of the trade indicator variable. Gamma is the mean fraction of the implied spread that is attributable to the adverse selection cost.

Table 5
Volume Dependent Model
Summary statistics of adjusted GMM model parameters

	Call Option						Put Option					
	Permanent cost		Temporary cost		Implied Spread		Permanent cost		Temporary cost		Implied Spread	
|Delta|	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)	1/delta	(%)
0.05~0.1	0.007	0.221	0.048	1.438	0.110	3.316	0.009	0.254	0.046	1.286	0.109	3.080
0.1~0.15	0.007	0.190	0.027	0.770	0.067	1.921	0.007	0.195	0.026	0.712	0.067	1.813
0.15~0.2	0.006	0.166	0.019	0.524	0.050	1.380	0.007	0.176	0.018	0.490	0.050	1.332
0.2~0.25	0.006	0.158	0.014	0.404	0.040	1.123	0.007	0.182	0.014	0.376	0.041	1.116
0.25~0.3	0.006	0.164	0.012	0.335	0.035	0.999	0.007	0.191	0.011	0.309	0.036	1.000
0.3~0.35	0.006	0.165	0.010	0.264	0.031	0.858	0.007	0.201	0.009	0.247	0.032	0.895
0.35~0.4	0.006	0.187	0.008	0.235	0.028	0.843	0.008	0.214	0.008	0.207	0.031	0.842
0.4~0.45	0.007	0.195	0.007	0.219	0.028	0.826	0.009	0.227	0.008	0.199	0.032	0.853
0.45~0.5	0.008	0.217	0.008	0.220	0.031	0.874	0.010	0.275	0.007	0.204	0.035	0.958
0.5~0.55	0.009	0.268	0.008	0.239	0.033	1.014	0.010	0.300	0.007	0.198	0.035	0.997
0.55~0.6	0.010	0.265	0.007	0.195	0.034	0.920	0.011	0.340	0.006	0.186	0.034	1.051
0.6~0.65	0.011	0.318	0.006	0.170	0.034	0.976	0.012	0.342	0.005	0.143	0.035	0.969
0.65~0.7	0.013	0.340	0.005	0.119	0.036	0.919	0.014	0.357	0.005	0.131	0.038	0.976
0.7~0.75	0.016	0.359	0.004	0.100	0.040	0.919	0.014	0.367	0.005	0.120	0.038	0.974
0.75~0.8	0.016	0.387	0.004	0.094	0.041	0.962	0.019	0.377	0.005	0.094	0.047	0.943
0.8~0.85	0.017	0.397	0.003	0.068	0.041	0.930	0.021	0.382	0.004	0.071	0.051	0.907
0.85~0.9	0.018	0.412	0.002	0.058	0.040	0.939	0.022	0.394	0.003	0.053	0.051	0.894
0.9~0.95	0.020	0.397	0.002	0.044	0.045	0.882	0.021	0.349	0.003	0.045	0.047	0.787

Table 5 presents the adjusted estimates of the permanent spread component, temporary spread component and implied spread, when we use the volume dependent model. All estimates are adjusted by dividing by deltas or weighted average transaction prices. 1/delta column shows the estimates adjusted for stock equivalent position and (%) column shows the estimates adjusted for price.

Table 6
GMM estimates of buy/sell category model (adjusted measures)

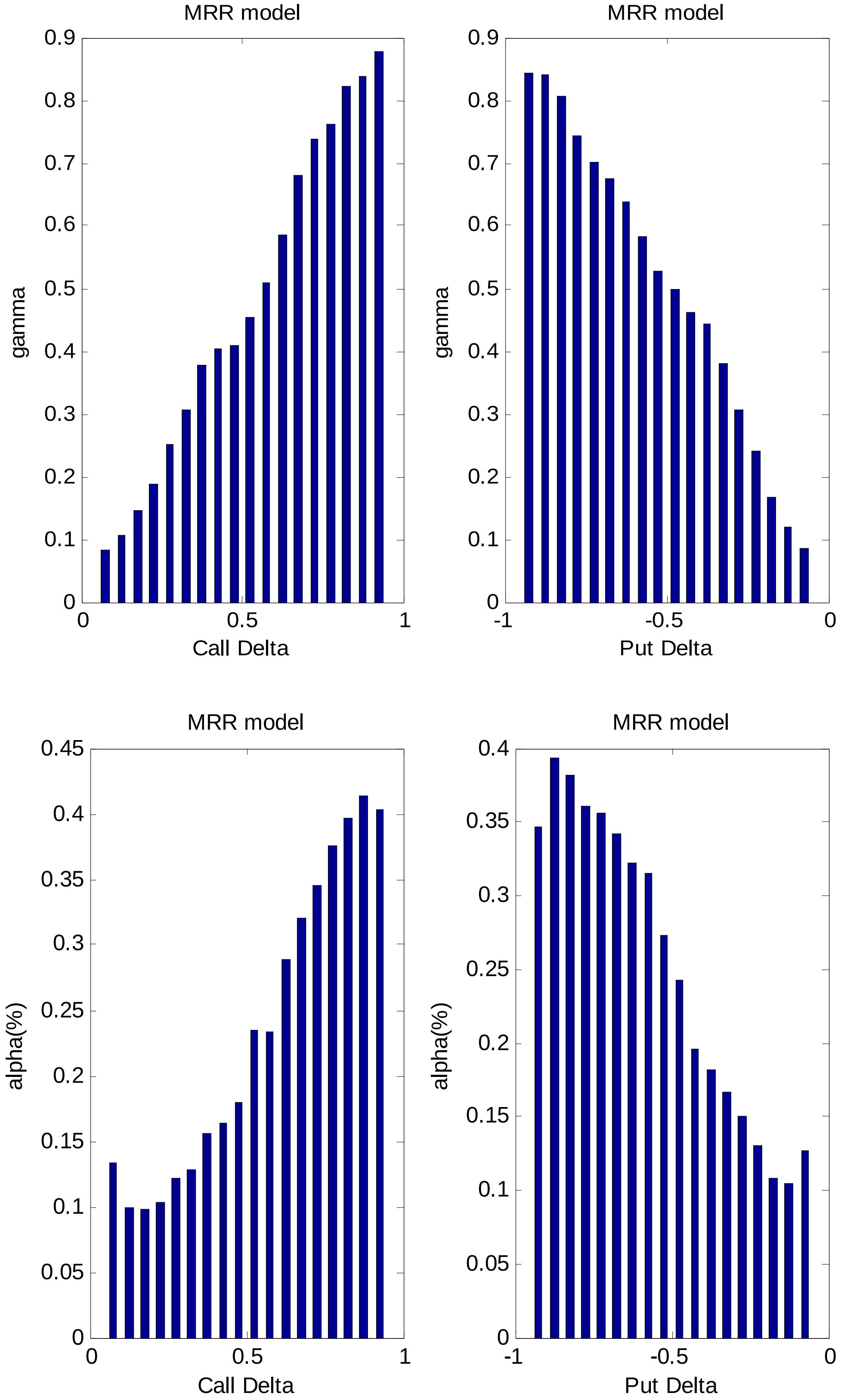
Panel A. Call Option

									Alpha				Beta				Implied Spread			
	No. of transaction		Total volume		Transaction price		Gamma		1/delta		(%)		1/delta		(%)		1/delta		(%)	
|Delta|	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell
0.05~0.1	713446	893791	77698206	80750316	0.253	0.243	0.08	0.08	0.004	0.004	0.134	0.131	0.050	0.049	1.501	1.484	0.108	0.107	3.271	3.230
0.1~0.15	904192	1109838	87444868	91676191	0.443	0.433	0.10	0.11	0.003	0.004	0.093	0.101	0.030	0.029	0.853	0.826	0.066	0.065	1.893	1.855
0.15~0.2	926573	1084403	76534985	80311339	0.637	0.625	0.13	0.15	0.003	0.004	0.091	0.101	0.021	0.020	0.590	0.564	0.049	0.048	1.363	1.330
0.2~0.25	847057	995073	57699703	61101643	0.805	0.793	0.18	0.20	0.004	0.004	0.099	0.105	0.016	0.015	0.457	0.434	0.039	0.038	1.112	1.079
0.25~0.3	712440	813527	37355440	38984021	0.960	0.945	0.24	0.26	0.004	0.004	0.119	0.123	0.013	0.012	0.375	0.356	0.034	0.033	0.988	0.956
0.3~0.35	620761	698016	26308375	27545088	1.182	1.158	0.29	0.32	0.004	0.005	0.124	0.130	0.011	0.010	0.299	0.280	0.030	0.030	0.845	0.821
0.35~0.4	467383	522232	17580597	18453251	1.266	1.253	0.36	0.39	0.005	0.005	0.153	0.157	0.009	0.008	0.266	0.246	0.028	0.027	0.838	0.806
0.4~0.45	428362	481450	14204148	14914538	1.456	1.426	0.39	0.42	0.005	0.006	0.161	0.165	0.009	0.008	0.251	0.233	0.028	0.027	0.823	0.796
0.45~0.5	282003	324456	8392205	8744428	1.704	1.671	0.40	0.41	0.006	0.006	0.179	0.179	0.010	0.009	0.272	0.252	0.032	0.031	0.903	0.862
0.5~0.55	230180	265259	7160855	7377490	1.750	1.693	0.45	0.45	0.008	0.007	0.241	0.225	0.010	0.009	0.289	0.276	0.035	0.033	1.061	1.002
0.55~0.6	167470	192560	4461164	4672085	2.193	2.086	0.51	0.50	0.009	0.008	0.243	0.224	0.009	0.008	0.229	0.223	0.035	0.033	0.944	0.894
0.6~0.65	126003	141332	3541828	3634195	2.182	2.111	0.60	0.57	0.011	0.009	0.304	0.274	0.007	0.007	0.204	0.208	0.035	0.033	1.017	0.962
0.65~0.7	85452	93745	2182013	2106716	2.638	2.562	0.71	0.65	0.013	0.012	0.343	0.298	0.005	0.006	0.140	0.161	0.038	0.036	0.966	0.919
0.7~0.75	58230	64765	1352841	1353966	3.210	3.088	0.76	0.72	0.016	0.014	0.367	0.324	0.005	0.006	0.117	0.128	0.042	0.040	0.967	0.903
0.75~0.8	50170	54608	1148400	1171952	3.247	3.181	0.77	0.75	0.017	0.015	0.392	0.359	0.005	0.005	0.114	0.120	0.043	0.040	1.013	0.958
0.8~0.85	37226	40518	841736	842340	3.554	3.504	0.83	0.82	0.018	0.017	0.405	0.389	0.004	0.004	0.084	0.088	0.043	0.042	0.977	0.953
0.85~0.9	32699	35773	766563	724833	3.717	3.558	0.82	0.86	0.017	0.018	0.406	0.420	0.004	0.003	0.092	0.069	0.043	0.042	0.996	0.979
0.9~0.95	25691	28435	511024	563368	4.527	4.455	0.90	0.85	0.022	0.019	0.427	0.380	0.002	0.003	0.046	0.065	0.048	0.045	0.945	0.891

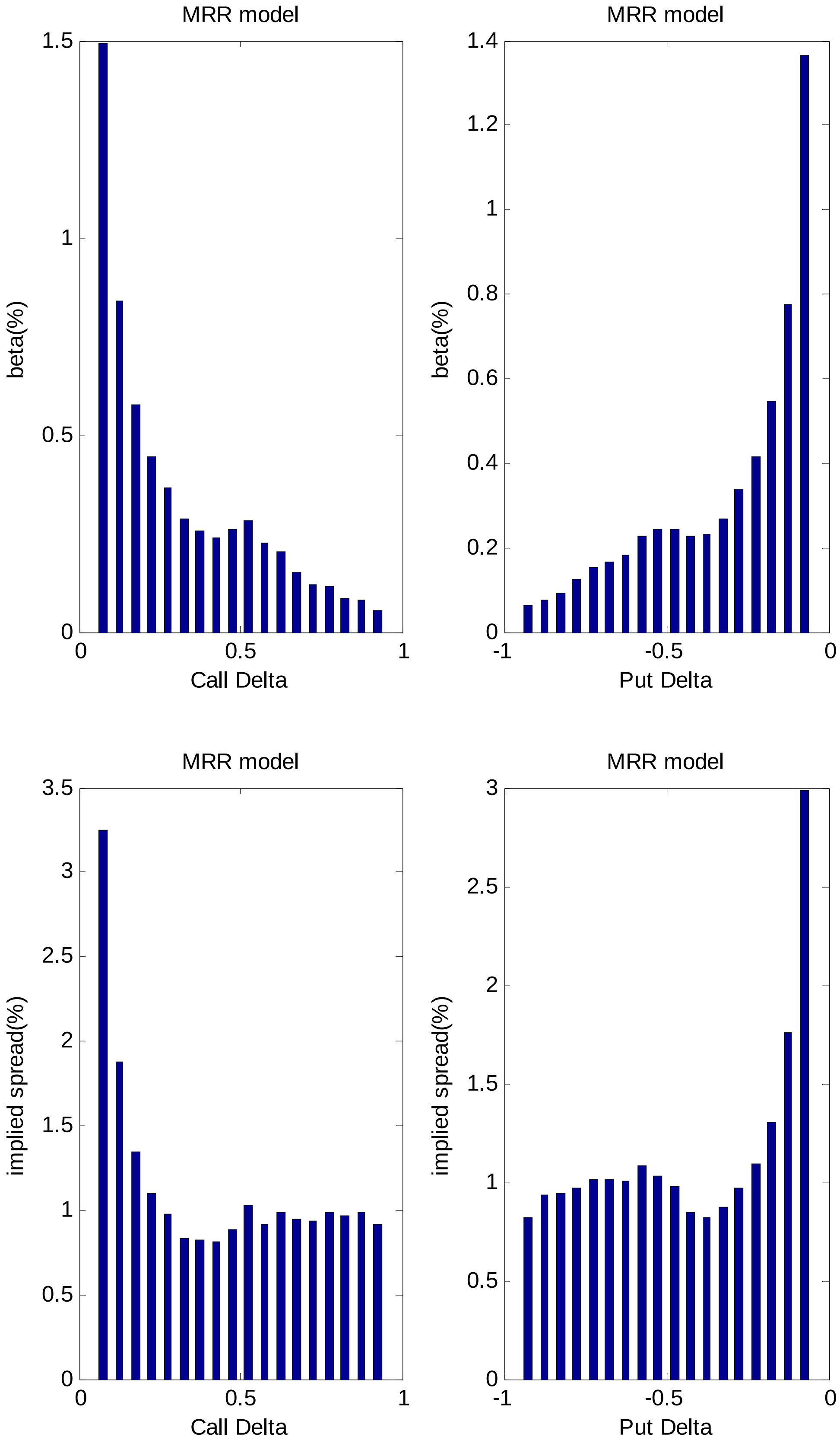
Panel B. Put Option

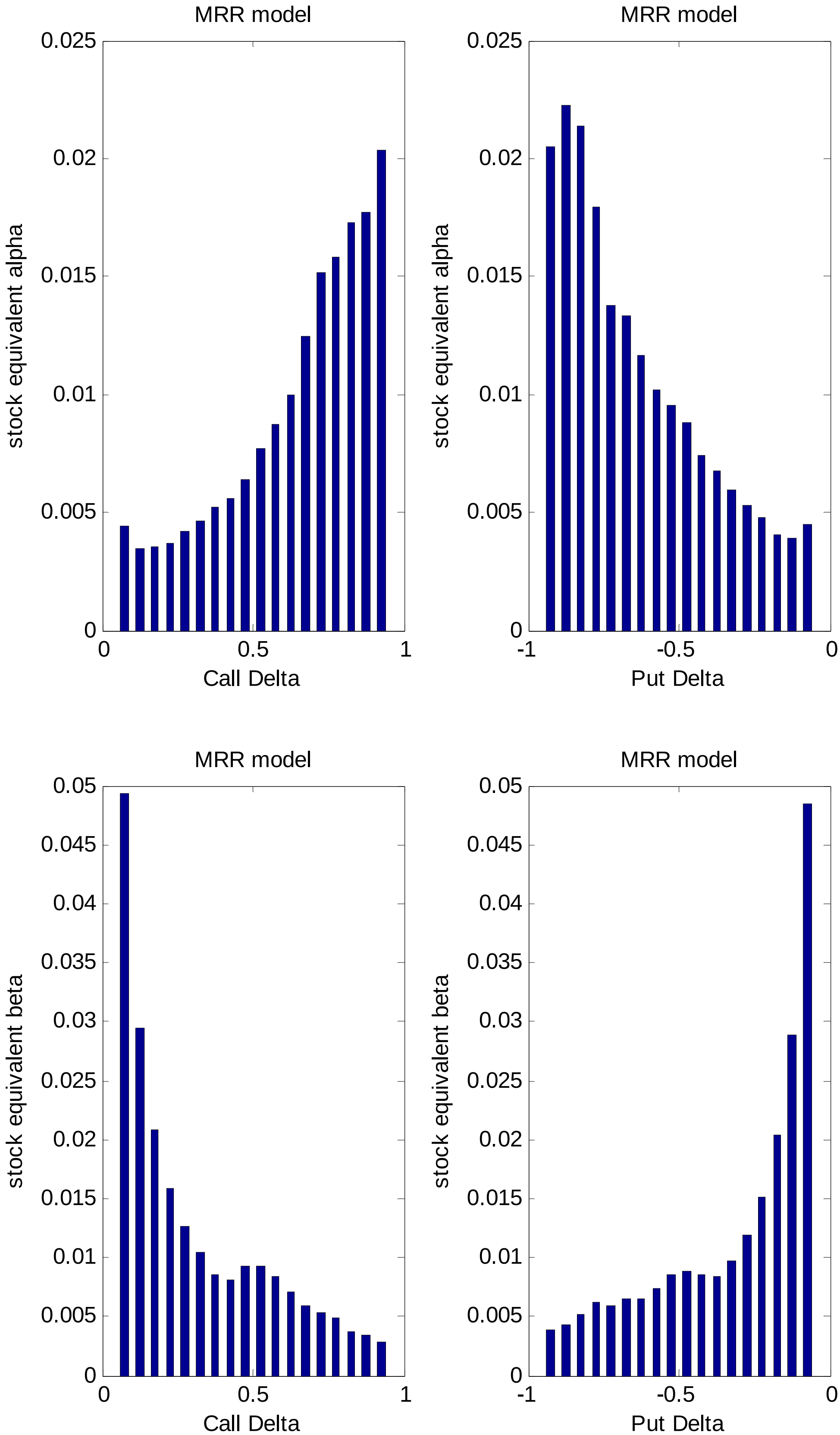
									Alpha				Beta				Implied Spread			
	No. of transaction		Total volume		Transaction price		Gamma		1/delta		(%)		1/delta		(%)		1/delta		(%)	
|Delta|	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell	buy	sell
0.05~0.1	712388	853329	74319973	77612501	0.270	0.261	0.09	0.08	0.005	0.004	0.128	0.123	0.049	0.048	1.373	1.362	0.106	0.105	3.002	2.970
0.1~0.15	801615	959343	69123477	72586352	0.471	0.459	0.12	0.12	0.004	0.004	0.104	0.104	0.029	0.029	0.786	0.768	0.066	0.065	1.780	1.744
0.15~0.2	797694	917498	57919258	60647330	0.658	0.647	0.16	0.17	0.004	0.004	0.107	0.108	0.021	0.020	0.554	0.537	0.049	0.048	1.322	1.290
0.2~0.25	662996	765011	38217031	40490344	0.829	0.818	0.23	0.24	0.005	0.005	0.129	0.130	0.016	0.015	0.425	0.405	0.041	0.039	1.108	1.070
0.25~0.3	568182	655804	26298352	27952801	0.981	0.971	0.30	0.31	0.005	0.005	0.149	0.149	0.012	0.012	0.347	0.328	0.035	0.034	0.991	0.954
0.3~0.35	441174	510490	17516213	18942936	1.167	1.158	0.37	0.38	0.006	0.006	0.167	0.163	0.010	0.009	0.280	0.261	0.032	0.030	0.893	0.850
0.35~0.4	364958	426151	12385962	13187182	1.380	1.385	0.44	0.44	0.007	0.007	0.186	0.177	0.009	0.008	0.237	0.223	0.031	0.030	0.846	0.800
0.4~0.45	277726	327404	8576503	8994958	1.612	1.608	0.47	0.45	0.008	0.007	0.204	0.185	0.009	0.008	0.233	0.222	0.033	0.031	0.873	0.813
0.45~0.5	218058	255155	6664552	6967823	1.735	1.700	0.51	0.49	0.009	0.008	0.255	0.230	0.009	0.009	0.247	0.241	0.036	0.034	1.005	0.942
0.5~0.55	154308	183259	4640488	4903792	1.869	1.765	0.55	0.50	0.010	0.009	0.297	0.249	0.008	0.009	0.239	0.249	0.037	0.035	1.072	0.996
0.55~0.6	128389	146289	4203427	4229142	1.899	1.795	0.62	0.54	0.011	0.009	0.348	0.285	0.007	0.008	0.213	0.238	0.036	0.034	1.121	1.046
0.6~0.65	89252	100323	2461918	2459346	2.295	2.163	0.68	0.60	0.013	0.011	0.354	0.292	0.006	0.007	0.167	0.196	0.038	0.035	1.042	0.976
0.65~0.7	66872	73705	1778437	1859160	2.607	2.561	0.72	0.63	0.015	0.012	0.377	0.310	0.006	0.007	0.147	0.183	0.041	0.038	1.048	0.986
0.7~0.75	53774	60571	1430201	1483022	2.876	2.628	0.76	0.65	0.015	0.013	0.393	0.323	0.005	0.007	0.127	0.175	0.040	0.039	1.040	0.995
0.75~0.8	35038	39264	746127	761083	3.897	3.662	0.78	0.70	0.020	0.016	0.393	0.330	0.005	0.007	0.109	0.140	0.050	0.047	1.005	0.939
0.8~0.85	25838	28588	528752	580156	4.468	4.507	0.82	0.80	0.022	0.020	0.399	0.364	0.005	0.005	0.090	0.094	0.055	0.051	0.979	0.915
0.85~0.9	19246	21549	378985	401899	4.736	4.788	0.85	0.83	0.023	0.022	0.404	0.383	0.004	0.004	0.072	0.078	0.054	0.052	0.952	0.922
0.9~0.95	19572	22394	349971	470800	5.360	5.177	0.87	0.82	0.021	0.020	0.360	0.335	0.003	0.004	0.055	0.074	0.049	0.048	0.829	0.817

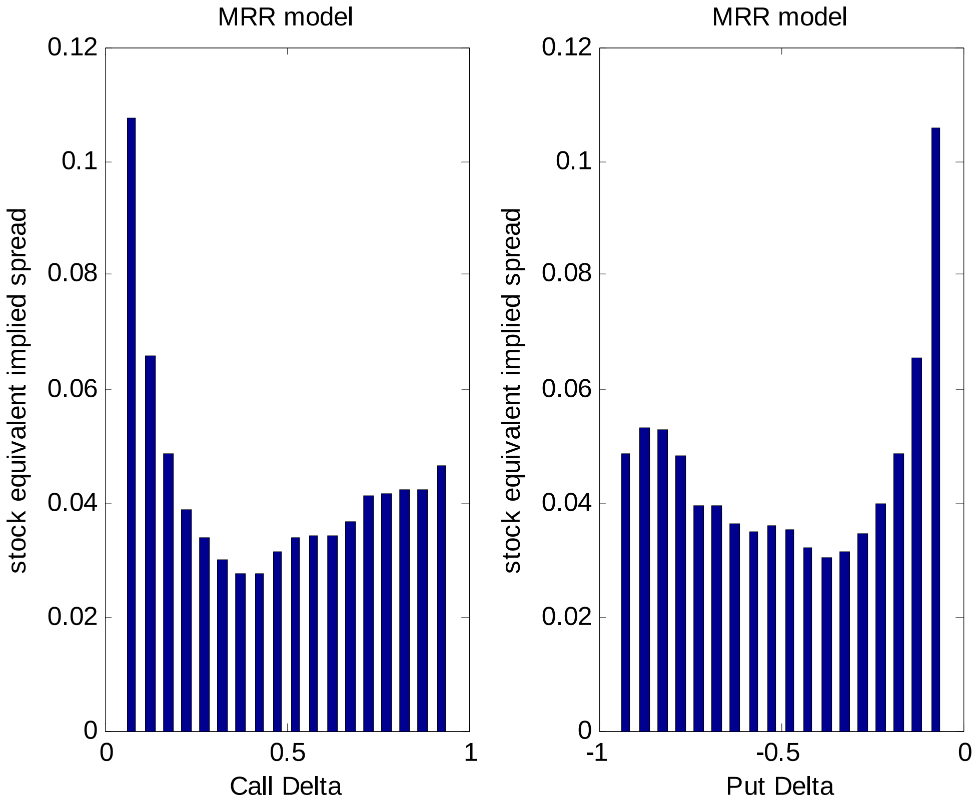
[Figure 1]



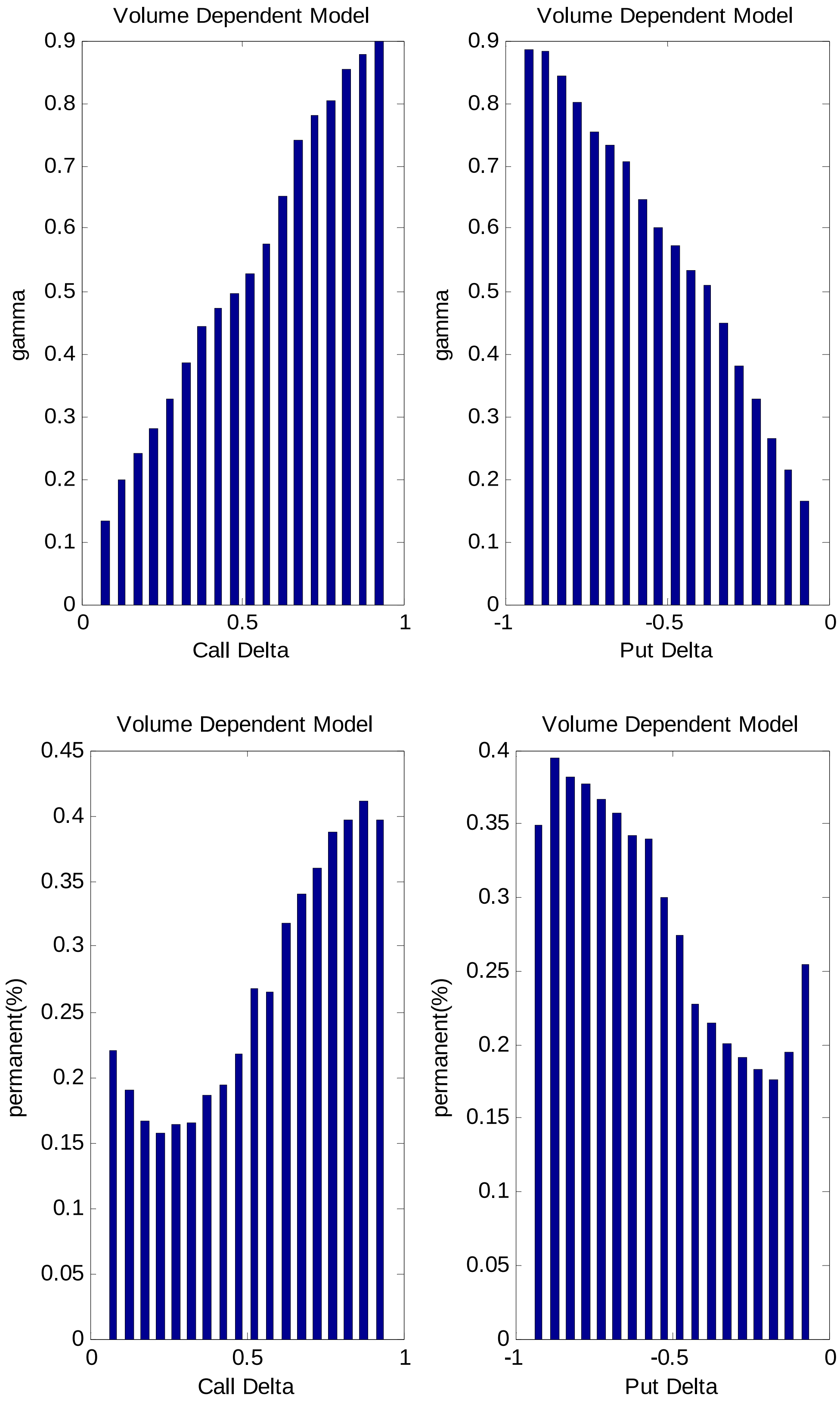
MRR model
gamma
Call Delta
MRR model
gamma
Put Delta
MRR model
alpha(%)
Call Delta
MRR model
alpha(%)
Put Delta


MRR model
beta(%)
Call Delta
0
0.5
1
1.5
0
0.5
1
MRR model
beta(%)
Put Delta
0
0.2
0.4
0.6
0.8
1
1.2
1.4
-1
-0.5
0
MRR model
implied spread(%)
Call Delta
0
0.5
1
1.5
2
2.5
3
3.5
0
0.5
1
MRR model
implied spread(%)
Put Delta
0
0.5
1
1.5
2
2.5
3
-1
-0.5
0

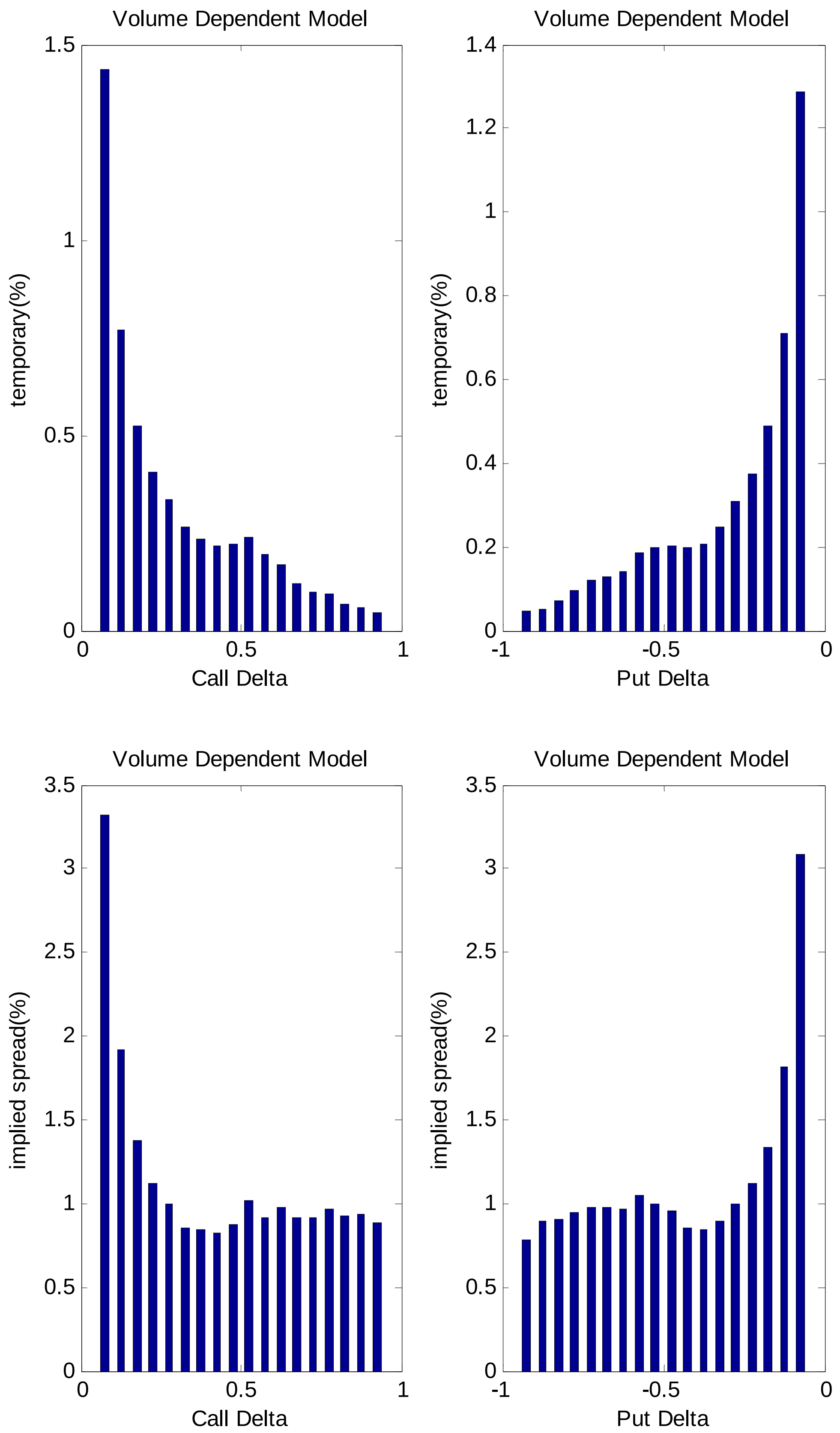

MRR model
stock equivalent alpha
Call Delta
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
MRR model
stock equivalent alpha
Put Delta
-1
-0.5
0
MRR model
stock equivalent beta
Call Delta
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
MRR model
stock equivalent beta
Put Delta

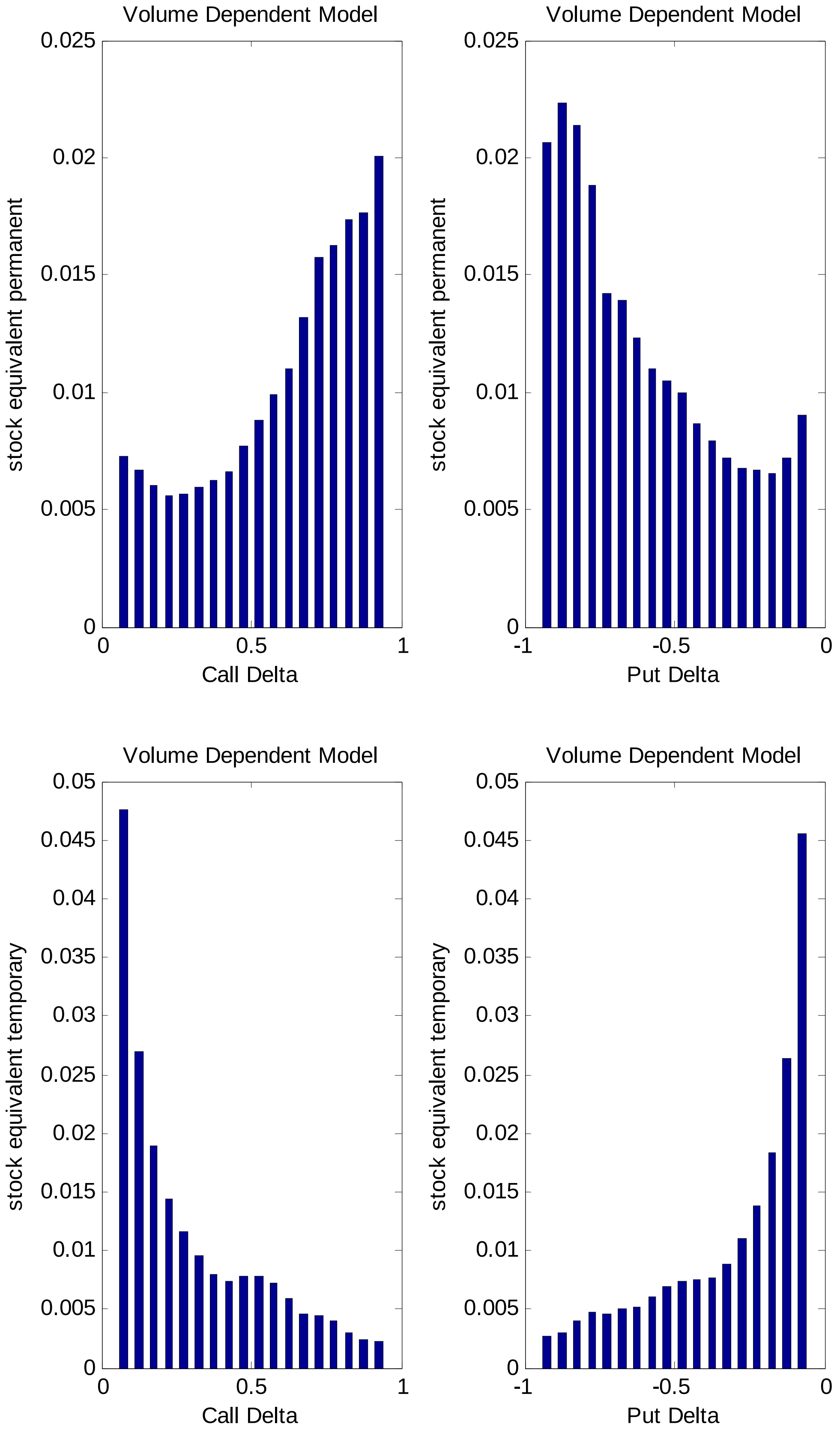

MRR model
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
0
0.5
1
Call Delta
MRR model
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
-1
-0.5
0
Put Delta

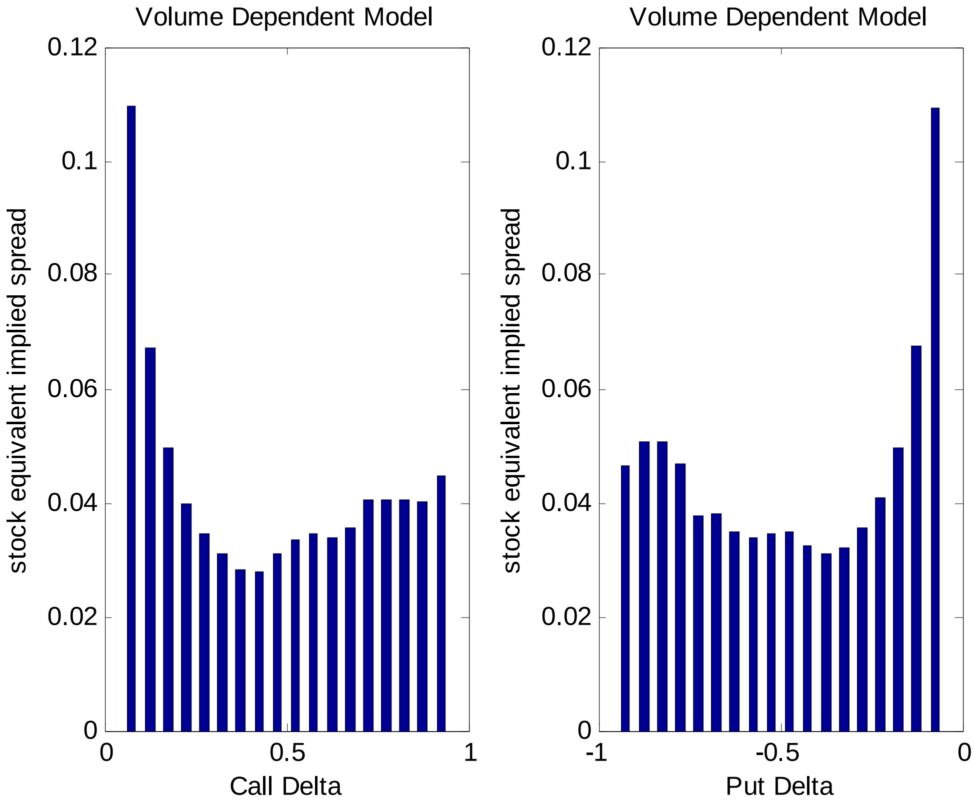
[Figure 2]



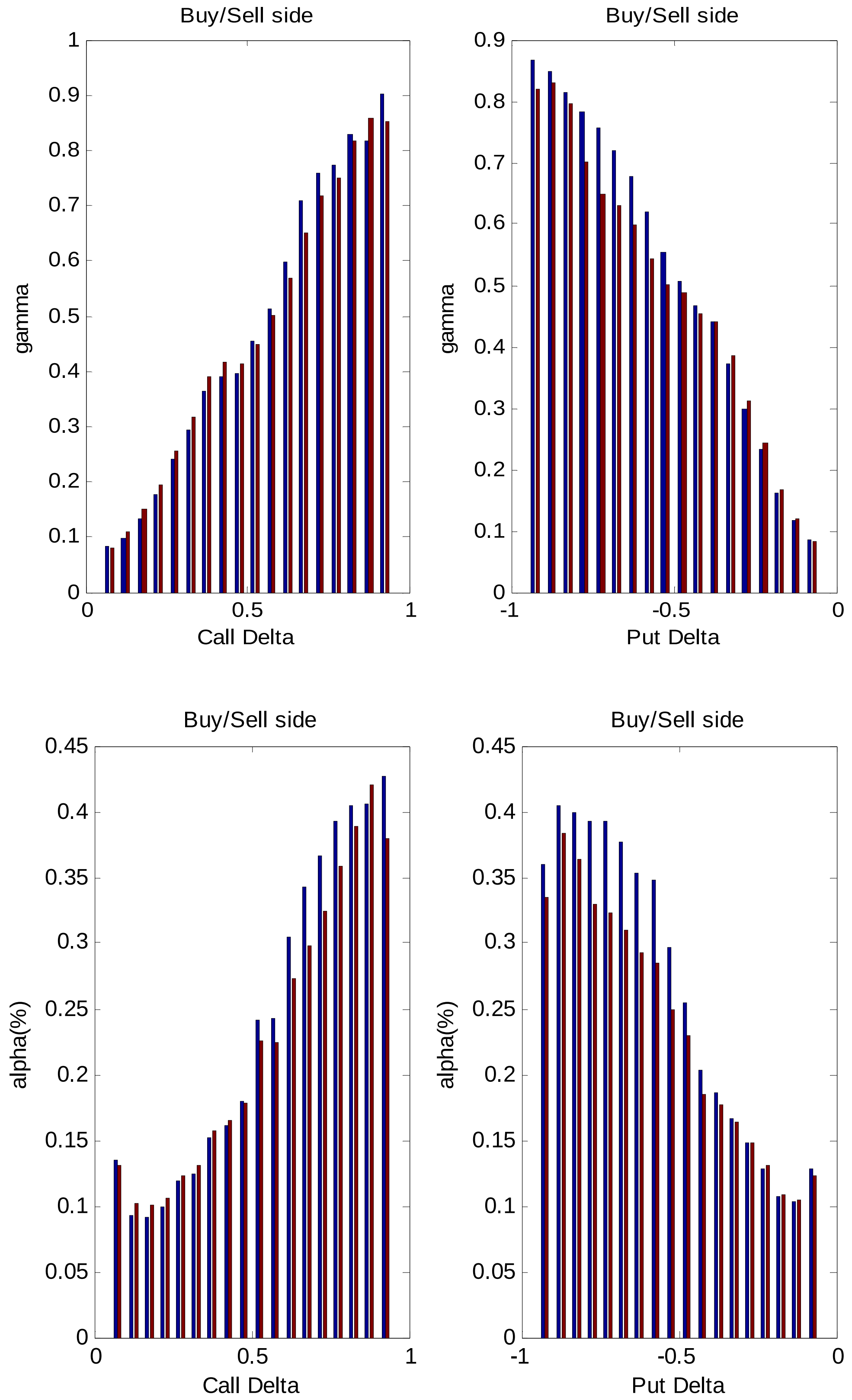
Volume Dependent Model
gamma
Call Delta
Volume Dependent Model
gamma
Put Delta
Volume Dependent Model
permanent(%)
Call Delta
Volume Dependent Model
permanent(%)
Put Delta


Volume Dependent Model
temporary(%)
Call Delta
Volume Dependent Model
temporary(%)
Put Delta
Volume Dependent Model
implied spread(%)
Call Delta
Volume Dependent Model
implied spread(%)
Put Delta

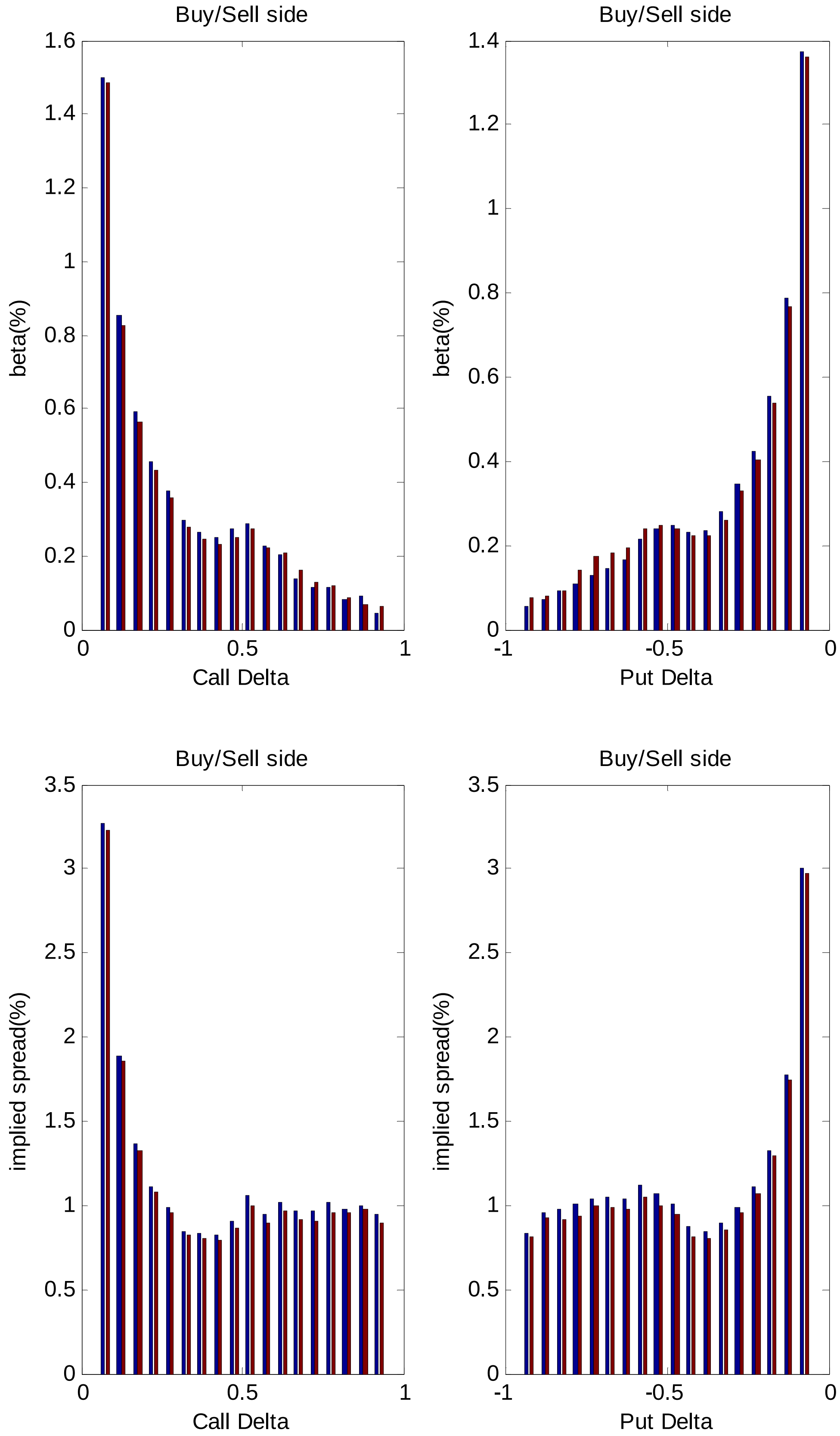

Volume Dependent Model
stock equivalent permanent
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
Call Delta
Volume Dependent Model
stock equivalent permanent
0.025
0.02
0.015
0.01
0.005
0
-1
-0.5
0
Put Delta
Volume Dependent Model
stock equivalent temporary
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
Call Delta
Volume Dependent Model
stock equivalent temporary
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-1
-0.5
0
Put Delta

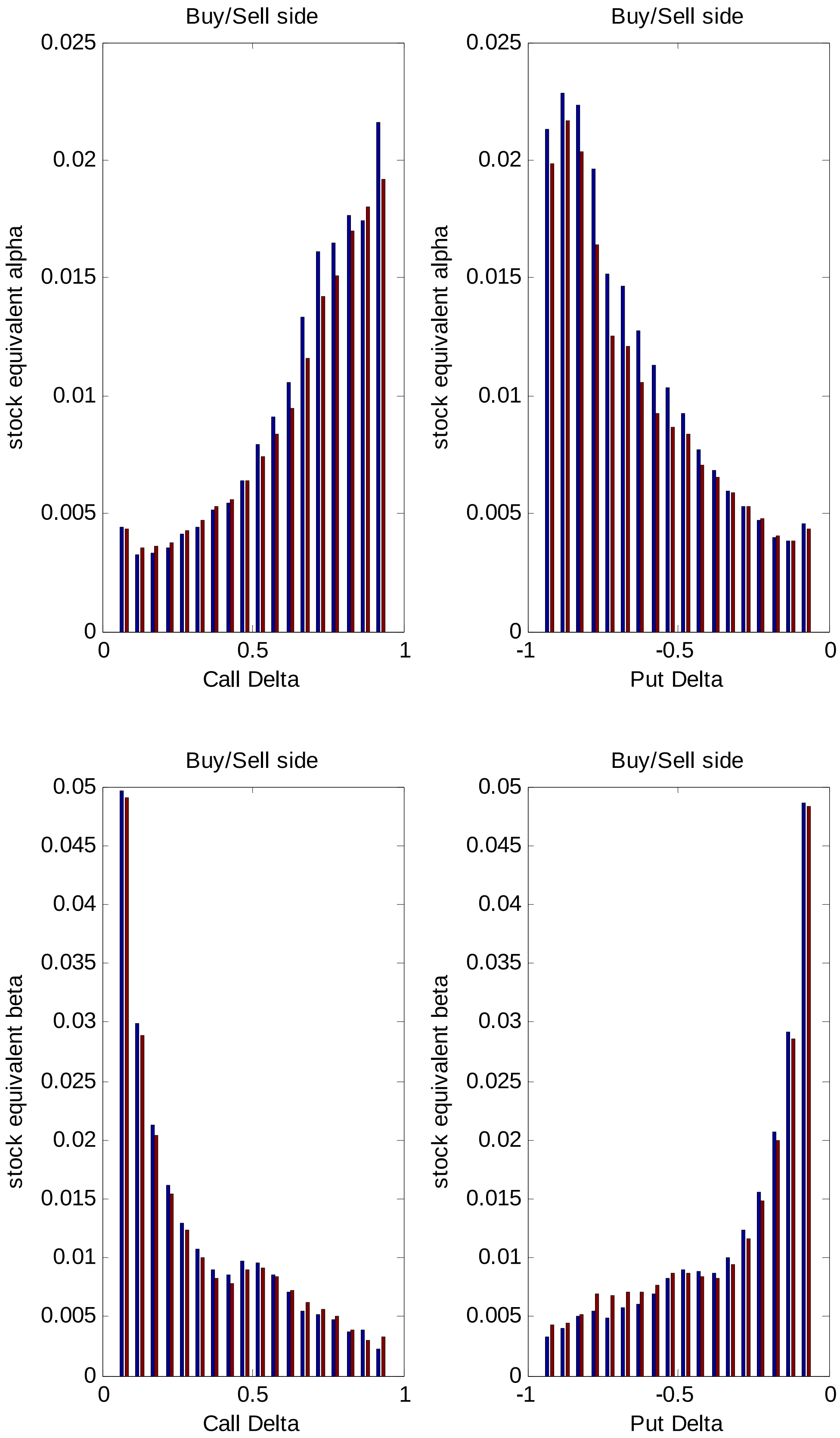

Volume Dependent Model
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
0
0.5
1
Call Delta
Volume Dependent Model
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
-1
-0.5
0
Put Delta

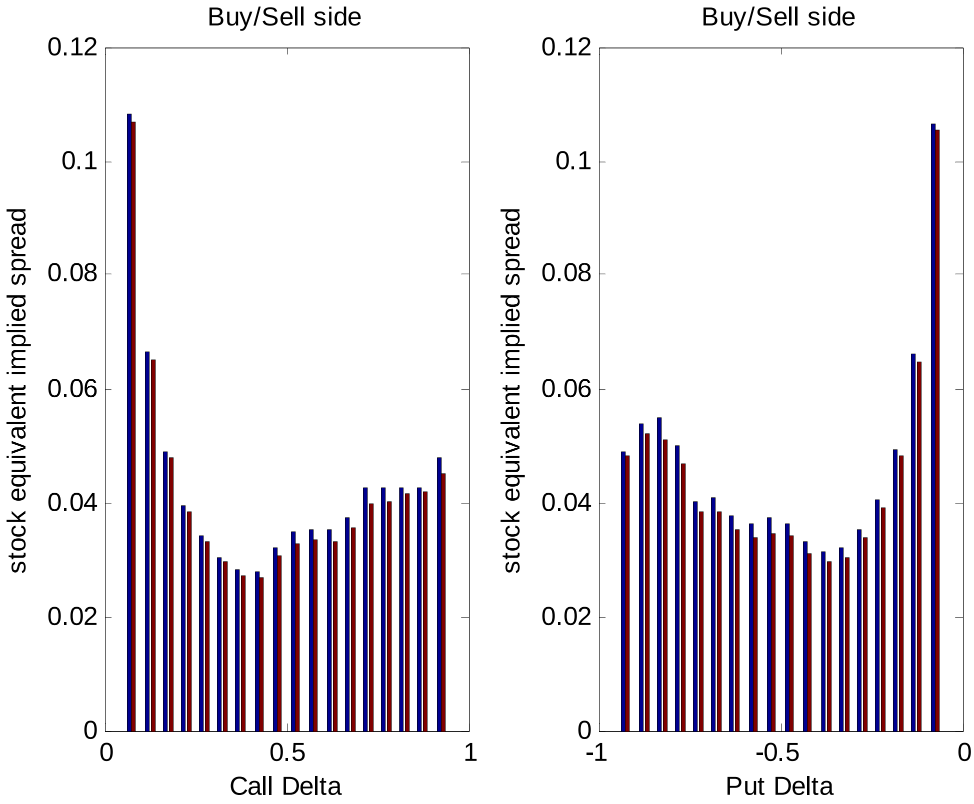
[Figure3]



Buy/Sell side
gamma
Call Delta
Buy/Sell side
gamma
Put Delta
Buy/Sell side
alpha(%)
Call Delta
Buy/Sell side
alpha(%)
Put Delta


Buy/Sell side
beta(%)
Call Delta
Buy/Sell side
beta(%)
Put Delta
Buy/Sell side
implied spread(%)
Call Delta
Buy/Sell side
implied spread(%)
Put Delta


Buy/Sell side
stock equivalent alpha
Call Delta
Buy/Sell side
stock equivalent alpha
Put Delta
Buy/Sell side
stock equivalent beta
Call Delta
Buy/Sell side
stock equivalent beta
Put Delta


Buy/Sell side
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
0
0.5
1
Call Delta
Buy/Sell side
0.12
0.1
0.08
0.06
0.04
0.02
0
stock equivalent implied spread
-1
-0.5
0
Put Delta