Pricing Clustering in U.S. Listed Equity Options

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Abstract

Price clustering has been found for financial markets. Nevertheless, research on price clustering in the equity option market is not concluded. By examining U.S. listed index and individual equity option quotes, this study offers evidence that price clustering in low-price options is attributed to *zero-value* options. After downsizing tick sizes alters clustering frequencies, high-price options are persistently and highly clustered on round and half-round dollar. We find that price clustering is a positive function of the price level, the bid-ask spread and trading volume and a negative function of open interest and implied volatility.

JEL classification: G12, G13, G18

Keywords: Option price clustering, the price resolution hypothesis, the negotiation hypothesis, the attraction hypothesis, the collusion hypothesis

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1. Introduction

The asset price clustering phenomenon has been found in many financial markets. For stock markets, price clustering on trade and quote prices is discussed by Harris (1991), Hamed and Terry (1998), Huang and Stoll (2001), Kandel et al. (2001), Brown et al. (2002), Cooney et al. (2003), and Ohta (2006). For derivative markets, Gwilym et al. (1998) first present the evidence of the clustering phenomenon for futures and options on the FTSE 100 stock index over the sample period of January 24, 1992 to June 30, 1995. Gwilym et al. (1998) and Gwilym and Alibo (2003) find the evidence of price clustering in government bond futures and FTSE 100 futures traded on the London International Financial Futures and Options Exchange and a higher degree of clustering for the futures with larger bid-ask spreads, respectively. Schwartz et al. (2004) find clustering at pricing grids of x.00 and x.50 for the intraday S&P 500 futures traded in 1999 and 2000. They show that transaction price clustering is a positive function of volatility and a negative function of volume and open interest. In addition, they find a lower degree of clustering in the settlement price but a higher degree of clustering in the opening and closing prices. A slightly dissenting focus is Ni et al. (2005), who find the closing prices of stocks with listed options cluster at option strike prices at option maturities. Most prior research concentrates on the price clustering in the spot, index futures and index option markets. Nevertheless, the index option contracts only account for 5 percent of U.S. listed options. In other words, the clustering phenomenon in almost 95 percent of U.S. listed option contracts still remains unknown. This study fills this gap by examining price clustering of U.S. listed index and individual equity options.

Prior studies propose four hypotheses to rationalize the pricing clustering phenomenon, including the price resolution hypothesis (Ball et al., 1985), the negotiation hypothesis (Harris, 1991), the attraction hypothesis (Goodhart and Curcio, 1991), and the collusion hypothesis (Christie and Schultz, 1994). First, Ball et al. (1985) argue that the degree of price resolution is positively related to the amount of information available in the market, and negatively to the level and variability of the asset price. As a result, an increase either in the level or in volatility corresponds to an increased probability of observing a higher degree of rounding. Second, Harris (1991) argues that clustering should be considered when analyzing the effect of price discreteness on estimators. Harris (1991) further proposes that stock price clustering occurs if traders use *discrete price sets* to lower the cost of negotiation. Therefore, stock price clustering increases with the price level and volatility, and decreases with capitalization and transaction frequency. The assumption behind Harris' (1991) negotiation hypothesis is that clustering for high-price stocks represents the use of discrete price sets that are coarser than the set determined by the *minimum price variation* (*tick size*) *regulation*. This implication results in a higher clustering for the markets with a lower minimum price variation regulation.

Third, the collusion hypothesis proposed by Christie and Schultz (1994) suggests that the structure of multiple dealers in the NASDAQ market is designed to produce narrow bid-ask spreads through the order-flow competition among individual dealers. Therefore, the price clustering in stock markets reflects dealer collusion intended to maintain wider bid-ask spreads than would prevail under full competition. In other words, as bid-spread spreads increase, the degree of price clustering in the security also increases. Finally, the attraction hypothesis proposed by Goodhart and Curcio (1991) suggests that discrete trading prices are obtained from rounding continuously distributed underlying values to the nearest available final digit. However, the rounding does not solely depend on linear distance, but also on the basic attraction of the round number. The attraction hypothesis implies that the prices of x.0 for a security are more frequently quoted than other final digits.

This study characterizes price clustering based on daily bid and offer quotes of U.S. listed equity options. Several observations from our results are in order. First, on the one hand, low-price options cluster at bids on x.0 and offers on x.25 over the period of January 1996 to June 2007. On the other hand, both bid and offer quotes for high-price options have been clustered around x.0 and x.5 since 2001. Those clustering phenomena support the price resolution hypothesis (Ball et al., 1985), since the price resolution on round dollar and half-round dollar quotes of high-price options are more conspicuous. However, in order to maintain a minimum bid-ask spread, $0.25, for market makers, options with bids at $0.0 and offers at $0.25 are denoted "*zero-value option quotes*", which account for 72.68% and 85.01% of the U.S. listed equity options for the x.0 in bids and x.25 in offers, respectively. Once we remove the quotes with $0.0 in bids and $0.25 in offers from the low-price options, the clustering phenomenon in low-price options no longer exists. Hence, the clustering phenomenon in low-price options is completely attributed to zero-value options.

Second, index options are more frequently quoted on round dollar and half-round dollar than individual equity options. The result is supportive of the price resolution hypothesis (Ball et al., 1985), since high-value options such as index options have higher price resolution than low-value options such as individual equity options. Third, downsizing the minimum price variation by the exchanges in 2001 enhances the clustering phenomenon of option price quotes. The pricing clustering appears to be significantly stronger after 2000 than the period of 1996 to 2000. The result is consistent with the negotiation hypothesis (Harris, 1991). Finally, this study finds a positive relationship between clustering percentage and the bid-ask spread, as supportive of the collusion hypothesis of Christie and Schultz (1994) that bid-spread spreads are widen as price clustering in security prices is observed.

To further understand the structure of option price clustering, we appeal to a regression analysis to study the association between the clustering percentage and factors that are contract-specific or market condition-dependent. In some sense, the contract-specific variables help detect the existence of cross-sectional determinants in option price clustering, whereas implied volatility and open interest serve to indicate whether the price clustering over time is related to the uncertainty in market conditions and opinion divergence. The results from a cross-sectional regression show a positive relationship between the pricing clustering on U.S. listed equity options and the price level, which is consistent with the findings of Harris (1991), Gwilym et al. (1998), Hamed and Terry (1998), Brown et al. (2002), Cooney et al. (2003) and Ahn et al. (2005). Price clustering on U.S. listed equity option quotes is also positively related to the bid-ask spread (in line with Huang and Stoll, 2001) and trading volume (in line with Ohta, 2006).

Furthermore, open interest of option contracts and implied volatility are negatively related to option price clustering. Under the general assumption of higher uncertainty about the future value of the stock, both hedgers and speculators may seek to increase their exposure to the options market. Hedgers may have an increased interest in limiting the downside risk of their stock portfolios while speculators will enlarge option positions to place a bet on either a relatively large upward or downward movement in the stock price or changes in the volatilities implied in option prices. Donders et al. (2000) show that investors buy, rather than sell, options to anticipate on subsequent information releases. This excess demand will cause option prices, and thus implied volatilities, to be higher than the normal period. Open interest and implied volatility are expected to be positively related to the degree of disagreement among traders, and are thus negatively related to the degree of price clustering.

The remainder of the study is organized as follows. Section 2 describes the data. Section 3 presents our empirical findings on clustering phenomena. Section 4 analyzes clustering determinants. Section 5 concludes.

2. Data Description

Option data are obtained from Ivy DB OptionMetrics available from the Warton Research Data Service (WRDS) website. Ivy DB OptionMetrics provides historical prices for the U.S. equity options. The dataset contains data on all U.S. exchange-listed and NASDAQ equities and market indices, as well as all US listed index and individual equity options, starting from January 1996. The option data contain the end-of-day bids and offers on every U.S. listed equity option. As stated by Brown et al. (2002), the intraday bids and offers should be used to characterize more refined properties of option price clustering. Since intraday quotes for U.S. listed equity options are not available from OptionMetrics, this study simply follows Ni et al. (2005) to characterize option price clustering solely based on daily bid and offer quotes.

The sample period spans from January 1996 through June 2007. A total of 92.08% (96.81%) of U.S. listed equity options are individual option bids (offers). Of these, 94.38% (94.84%) are American option bids (offers). In other words, the majority of our sample is individual equity options and American-style. The minimum price variation (tick size) for option quotes is different for the entire data period. Prior to 2001, options with a quote less than and larger than 3 dollar are limited to a tick size of 0.0625 (1/16) and 0.125 (1/8), respectively. On January 3, 2001, the minimum price variation for options with a quote below and above 3 dollar are narrowed down to 0.05 (1/20) and 0.10 (1/10), respectively. According to Harris' (1991) negotiation cost hypothesis, downsizing tick size might induce higher price clustering. Therefore, this study divides the whole sample period into two subsample periods. The first subperiod includes the data from January 1996 to December 2000, whereas the second subperiod contains the data from January 2001 through June 2007.

A high-price option represents the option with a quote larger than 3 dollar, whereas a low-price option is denoted the option that is quoted less than 3 dollar. Furthermore, the term x.0 is used to summarize the option quotes of 0.0, 1.0, 2.0, 3.0, 4.0, etc., while the term x.0625 is used to summarize the quote prices of 0.0625, 1.0625, 2.0625, 3.0625, etc. In summary, the quote price on low-price options ranges from x.0, x.0625, x.125, etc. to x.9375 prior to 2000, and from x.0, x.05, x.1, etc. to x.95 after 2000. For high-price options, the quote ranges from x.0, x.125, etc. to x.875 prior to 2000 and from x.0, x.1, x.2, etc. to x.9 after 2000.

3. Pricing Clustering Results

This section provides possible explanations for price clustering in the U.S. listed equity option market. As mentioned earlier, Ball et al. (1985) suggest the prices may cluster to reduce search costs. Harris (1991) suggests that clustering may reduce the cost of negotiation. Christie and Schultz (1994) suggest that multiple market dealers' collusion may lead to a greater amount of price clustering. Clustering of prices may also be of interest to securities traders for attraction reasons (Goodhart and Curcio, 1991).

3.1 Clustering of Low-Price Options ─ Price Resolution Hypothesis (Ball et al., 1985)

Following Ball et al. (1985), the percentage of quotes in the U.S. listed equity option markets is used as the proxy of the amount of information arrival. Percentages of option quotes at each tick are reported in Table 1 and Figure 1. The results show that *low-price* option bids (offers) cluster on the price of x.0 (x.25) over the sample period, whereas *high-price* option bids and offers cluster on the price of x.0, followed by x.5, starting in 2001. However, there is no clear evidence showing that *high-price* option bids and offers cluster on any digits prior to 2001. The details are given as follows. 25.68% and 34.66% of the low-price option bids cluster on the price of x.0 from 1996 to 2000 and from 2001 to June 2007, respectively. Approximately 17.77% and 13.56% of the low-price option offers cluster on the price of x.25 prior to and subsequent 2001, respectively. From 2001 to June 2007, 17.55% and 15.95% of high-price option bids are clustered on the prices of x.0 and x.5, respectively. Further, 17.72% and 15.67% of high-price option offers cluster on the prices of x.0 and x.5 after 2000, respectively.

[Table 1 about here]

[Figure 1 about here]

Hypothesis tests for high-price option price clustering on round and half-round digits over the period from January 2001 to June 2007 are also performed and the results are presented in Table 2. Since the tick size for high-price options is 1/10 after 2000, the frequency of each of final digits for U.S. listed high-price option quotes should follow a uniform distribution with mean 10% if there is no clustering on any final digits. The percentages of high-price option bids and offers on x.0 and x.5 for the period after 2000 are significantly different from 10% within their minimum price variable of 1/10 with the t statistics of 131.36 (x.0 for bid), 53.39 (x.0 for offer), 107.82 (x.5 for bid) and 124.19 (x.5 for offer), respectively. The results in Tables 1 and 2 are supportive of Ball et al.'s (1985) price resolution hypothesis since the final digits of U.S. listed high-price option quotes deviating from uniformity is statistically significant at the 1% level.

[Table 2 about here]

Interestingly, this study finds that the clustering phenomenon on low-price options is associated with the zero-value options, where a bid of $0.0 and an offer of $0.25 are denoted zero-value options. Zero-value options may be seen inducing no trading in the market, and convey no information contents. As shown in Table 3, 65.39% of bids of x.0 are for a bid of $0.0 and 68.22% of offers of x.25 are for an offer of $0.25, respectively. This indicates that zero-value options are largely constituted by x.0 on bids and x.25 on offers. By reviewing zero-value option quotes as a percentage of total quotes, evidence shows that zero-value bids of $0.0 are 14.54% of total bids and zero-value offers of $0.25 are 6.47% of total offers, respectively.

[Table 3 about here]

After excluding the quotes of $0.0 on bids and $0.25 on offers from the data bank, the clustering phenomena at x.0 for low-price bids and at x.25 for low-price offers no longer exist over the period from January 1996 to June 2007. Therefore, the study concludes that price clustering on low-price options is simply attributed to zero-value options.

3.2 Clustering of High-Price European/American Options on

Index/Individual Equities ─ Price Resolution Hypothesis (Ball et al., 1985)

Ball et al. (1985) point out a fact that an increase in the level of security prices corresponds to an increased probability of observing a higher degree of rounding. Since the U.S. stock market shows an upward trend during the sampling period from January 2001 to June 2007, index options are valued more than individual equity options. Therefore, the clustering phenomenon on index options is expected to be more apparent than individual equity options if Ball et al.'s (1985) price resolution hypothesis holds.

On the other hand, Grossman et al. (1997) and Kleidon and Willig (1995) suggest that uncertainty in the price of a security may lead to a greater amount of price clustering. When compared to European options, this study argues that American options with early exercise features can help reduce uncertainty in the underlying asset. Therefore, under the price resolution hypothesis we expect that European and index options are clustered more on halves and integers than American and individual equity options, respectively.

From the data bank of Ivy DB OptionMetrics for the period from January 2001 to June 2007, 63.78% of index options are European style. Of these, 100 percent of European options are index options and all individual equity options are American style. As shown in Table 4, the percentage on high-price bids and offers on x.0 and x.5 for index options and European options are significantly larger than those for individual equity options and American options, respectively.

[Table 4 about here]

Figure 2 shows the clustering frequencies for individual equity and index options, as well as American and European options, on each of high-price bids and offers from January 2001 to June 2007. Approximately 28.25% and 55.84% of high-price bids for individual equity options and index options, respectively, cluster on x.0 for the period of post 2000. About 16.26% (14.83%) and 30.49% (26.46%) of the offer prices on high-price individual equity options and index options cluster on x.0 (x.5), respectively. The price clustering on bids of x.0 for index options is twice as large as that for individual equity options. Further, approximately 29.18% and 57.16% of high-price bids for American options and European options cluster on the price of x.0, respectively. About 16.66% and 30.95% of high-price offers for American options and European options cluster on the price of x.0, respectively. In addition, 15.13% and 27.36% of high-price offers on American options and European options cluster on the price of x.5.

On the one hand, Panels A and C of Figure 2 show that high-price bids for individual equity options and American options cluster on x.0, however, high-price bids for index options and European options cluster on both x.0 and x.5. On the other hand, Panels B and D of Figure 2 demonstrate that high-price offers for all options cluster on both x.0 and x.5.

[Figure 2 about here]

Given the evidence that the clustering phenomenon for high-price quotes for index options and European options are much more severe than individual equity options and American options, the study concludes that Ball et al.'s (1985) price resolution hypothesis holds for U.S. listed option quotes.

3.3 Downsizing the Minimum Price Variation ─ Negotiation Hypothesis (Harris, 1991)

Harris (1991) argues that traders use discrete price sets to lower their cost of negotiation. The behavior that investors submit fewer discrete prices in order to gain negotiation power and to lower their negotiation cost in trading will induce a higher level of price clustering. Since a small set of prices attributed to the negotiation hypothesis bounds the number of different bids and offers that can be made, negotiations may therefore converge more rapidly. A small set of prices also limits the amount of information that must be exchanged between negotiators. Therefore, price clustering will occur if traders use discrete price sets to simplify their negotiation.

Harris (1991) evidences that stock prices cluster on round fractions. The proxy for the unobserved degree of reservation price dispersion used by Harris (1991) is time-series volatility, firm size, transaction frequencies, and the price level. Volatility should be positively correlated with stock price clustering because information processing around event announcements is not uniformly distributed. Firm size (capitalization) should be negatively correlated with clustering because more information is produced and distributed for large firms than for small firms. Transaction frequency should also be inversely correlated with clustering because trading tends to reveal stock value by aggregating the information possessed by different traders.

As pointed out by Harris (1991), many exchanges require that quotes and transaction prices should be stated as some multiples of a minimum price variation (tick size). These regulations may simply ensure that all traders use the same discrete price set so that the benefits of discrete prices can be realized. As mentioned earlier, exchanges downsize the minimum price variation from 1/16 to 1/20 for low-price options and from 1/8 to 1/10 for high-price options in January 2001. Therefore, we expect that Harris' (1991) negotiation cost hypothesis holds for our option data after 2000, since downsizing the minimum price variation enlarges the discrete price set.

As revealed in Figure 1, the clustering frequency of high-price bids and offers reveal obvious price clustering after 2000, however, no price clustering on high-price bids and offers are found before 2001. The result for testing whether downsizing tick size induces higher price clustering on U.S. listed options is reported in Table 5.

[Table 5 about here]

From Table 5, option clustering for high-price bids on x.0 and x.5 is significantly stronger for the period of post 2001. The *t* statistics for high-price bids on x.0 and x.5 are 9.23 and 11.45, both of which are statistically significant at the 1% level. On the other hand, option clustering for high-price bids on x.0 and x.5 is significantly larger for the period of post 2001. Their *t* statistics are 8.91 and 11.62, respectively, for high-price bid on x.0 and x.5, both of which are significant at the 1% level. Therefore, the negotiation hypothesis proposed by Harris (1991) holds since downsizing the minimum price variation by the exchanges in 2001 has induced significantly larger clustering frequencies of high-price bids and offers on x.0 and x.5.

3.4 Rounding Shares ─ Attraction Hypothesis (Goodhart and Curcio, 1991)

Goodhart and Curcio (1991) assert that asset price clustering on round dollar is simply because round dollar is more attractive to others. Therefore, we conduct the hypothesis test to show whether clustering frequencies of high-price options on x.0 are higher than those on other digits for the period of post 2001.

As shown in Table 6, clustering frequencies of high-price bids and offers on x.0 are significantly larger than those on other digits for the period from January 2001 to June 2007, as supportive of Goodhart and Curcio's (1991) attraction hypothesis. Therefore, the study concludes that round dollar (x.0) of U.S. listed high-price equity option quotes are more attractive to investors.

[Table 6 about here]

4. Determinants of Option Quote Clustering

What determines quote price clustering in the U.S. listed high-price equity options? As suggested by the price resolution hypothesis and the negotiation hypothesis, price clustering is a positive function of the price level. Further, the transaction frequency and volatility are also possible explanations according to Harris (1991). Ohta (2006) provides evidence that trading volume, as a proxy for the transaction frequency, is significantly and positively related to price clustering. Harris (1991), Gwilym et al. (1998), Hamed and Terry (1998), Brown et al. (2002) and Cooney et al. (2003) find that price clustering increases with the price level and volatility. Chen et al. (1995) demonstrate that when volatility goes up, investors would like to allure more people into the market to share the risk. Since investors are unwilling to reduce their market risk exposure solely through selling stocks, they share risk by selling the derivatives, and the open interest of derivatives therefore increases. Chen et al. (1995) and Ferris et al. (2002) also find that open interest is significantly and positively related to implied volatility. A significantly negative relationship between open interest and time to option maturity is found by Chen et al. (1995). Further, Schwartz et al. (2004) propose that clustering is a negative function of time to maturity on S&P 500 futures contracts; that is, when S&P 500 futures contracts approach expiry, price clustering is higher. Finally, Christie and Schultz's (1994) Collusion hypothesis suggests that bid-ask spreads widen when price clustering is found. Huang and Stoll (2001) also provide the evidence that the degree of price clustering increases with the bid-ask spread.

In this section, we examine the relationship between option quote clustering and the bid-ask spread, trading volume, open interest, the price level, implied volatility, and time to expiration. A cross-sectional regression analysis on the price clustering of high-price option quotes is conducted for the period of post 2000. Following Gwilym et al. (1998), Ahn et al. (2005), Schwartz et al. (2004), Cooney et al. (2003) and Ohta (2006), this study uses an Ordinary Least Square (OLS) regression to investigate possible determinants of price clustering. Our regression model is given as follows,

$$\begin{aligned} Clustering = Constant &+ \alpha_1\, BidAskSperead + \alpha_2\, TradingVolume + \alpha_3\, OpenInterest \\ &+ \alpha_4\, PriceLevel + \alpha_5\, ImpliedVolatility + \alpha_6\, DateUntilExpiry + \varepsilon \end{aligned}$$

Quote price clustering is measured as the percentage of high-price option quotes that occur at pricing increments of x.0 and x.5 for the period of post 2000. We use the inverse of the standard normal cumulative distribution to transform the option quote price clustering, which is denoted *Clustering*. We regress *Clustering* against the bid-ask spread (denoted *BidAskSpread*) of option quotes, the trading volume of options (denoted *TradingVolume*), the open interest of outstanding options (denoted *OpenInterest*), the price level of options (denoted *PriceLevel*), the implied volatility (denoted *ImpliedVolatility*), and the remaining time to maturity of outstanding options (denoted *DateUntilExpiry*). All of the data are obtained from WRDS OptionMetrics. Monthly averages of daily time series for each regression variable are used in each regression. A total of 78 months are available for the period from January 2001 to June 2007.

Table 7 presents the regression results of high-price option clustering. The results indicate that the collusion hypothesis holds for high-price option quotes since the bid-ask spread is significantly and positively related to option quote clustering either on bids or offers at a 5% level for the period of post 2000. The price resolution hypothesis is also supported by high-price option quotes since the price level is significantly and positively related to clustering at a 1% significant level. Further, the negotiation cost hypothesis proposed by Harris (1991) also holds for high-price option quotes since both the price level and trading volume are significantly positively related to clustering at a 1% level.

Finally, our empirical results show that price clustering is significantly negatively related to both implied volatility and open interest at a 5% level. Chen et al. (1995) and Ferris et al. (2002) have shown that open interest is positively related to implied volatility. However, an inverse relationship between price clustering and historical volatility has been addressed by Harris (1991), Gwilym et al. (1998), Hamed and Terry (1998), Brown et al. (2002) and Cooney et al. (2003). Since implied volatility is endogeneous, as opposed to historical volatility, changes in implied volatility may provide new insights about information processing.

[Table 7 about here]

In summary, our regression analyses show a positive relationship between price clustering of high-price option quotes and the price level, which is consistent with Harris (1991), Gwilym et al. (1998), Hamed and Terry (1998), Brown et al. (2002), Cooney et al. (2003) and Ahn et al. (2005). Price clustering of high-price option quotes is positively related to the bid-ask spread (in line with Huang and Stoll, 2001), and trading volume (in line with Ohta, 2006).

5. Conclusion

Price clustering has been found for the stock, bond, exchange rate, bank lending, and financial derivatives. Nevertheless, research on price clustering in the equity option market is not concluded. Although Gwilym et al. (1998) first evidence the existence of price clustering on FTSE100 index options, their work deals with the index options that only count for 5% of option trades in the equity option market. This study fills the gap by investigating price clustering of all U.S. listed index and individual equity options over the period of January 1996 to June 2007.

Quotes on low-price options cluster at x.0 on bids and at x.0 and x.5 on offers. However, after excluding the zero-value options of bids at 0.0 and offers at 0.25 from the data bank, the clustering phenomenon on low-price options no longer exists. This indicates that the price clustering on low-price options is largely produced by the zero-value options. In addition, no obvious tendency for high-price bids and offers is observed over the period from 1996 to 2000, while quoting high-price options is highly concentrated at prices x.0 and x.5 from January 2001 to June 2007. By classifying options into equity options, index options, American options, and European options, the price clustering is higher on index options and European options. This evidence is supportive of the price resolution hypothesis, since index options are valued higher than individual equity options and options with early exercise provisions help reduce uncertainty.

In 2001, the exchanges narrowed down the tick size of traded options from 1/16 to 1/20 for the options priced below three dollar and from 1/8 to 1/10 for the options priced above three dollar, respectively. This regulation change helps us perform a formal test on the applicability of Harris' (1991) negotiation hypothesis to option price clustering. Our results accept the negotiation hypothesis to illustrate high-price option clustering. Further, by analyzing the relationship between the bid-ask spread and option quote price clustering, our result also supports Christie and Schultz's (1994) collusion hypothesis. Finally, based on cross-sectional regression analyses, we show that option quotes price clustering significantly increases with the price level, trading volume, and the bid-ask spread. In contrast, the option quote price clustering is negatively related to the open interest and implied volatility.

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Table 1 Percentage of U.S. Listed Option Quotes at Each Tick from 1996 to June, 2007

The sample period is from January 1996 to June, 2007. The minimum tick size for the option price less than 3 dollar was 0.0625 and 0.05 for the periods of 1996 to 2000 and 2001 to June 2007, respectively. The notation, x.0, represents the last digit of quotes is .0, which includes the quotes of 0.0, 1.0, 2.0, 3.0, 4.0, etc., while x.0626 represents the last digit of quotes is .0625, which contains the quotes of 0.0625, 1.0625, 2.0625, 3.0625, etc. The unit of the figures in the table is the percentage.

1996-2000	x.0	x.0625	x.125	x.1875	x.25	x.3125	x.375	x.4375	x.5	x.5625	x.625	x.6875	x.75	x.8125	x.875	x.9375
Low-Price Bid	25.68	7.39	7.03	5.64	5.79	5.00	5.17	4.57	5.06	4.35	4.70	3.43	5.06	3.16	4.90	3.07
High-Price Bid	13.94		13.34		12.75		12.34		12.34		11.88		11.85		11.56	
Low-Price Offer	3.53	4.78	7.31	8.54	17.77	5.98	6.72	5.60	6.38	5.01	5.16	4.61	5.19	4.45	4.69	4.29
High-Price Offer	13.04		13.14		13.08		12.84		12.17		12.11		11.89		11.74	

2001-2007	x.0	x.05	x.1	x.15	x.2	x.25	x.3	x.35	x.4	x.45	x.5	x.55	x.6	x.65	x.7	x.75	x.8	x.85	x.9	x.95
Low-Price Bids	34.48	6.61	5.23	4.39	4.11	3.92	3.65	3.38	3.36	3.10	3.31	2.90	3.05	2.61	2.95	2.63	2.84	2.40	2.78	2.30
High-Price Bid	17.55		2.26		7.75		7.58		11.70		15.95		11.27		6.99		6.95		10.80	
Low-Price Offer	2.73	10.92	7.49	7.75	7.08	13.56	4.64	4.19	4.30	3.78	5.05	3.44	3.43	3.24	3.21	3.49	3.11	2.92	2.91	2.78
High-Price Offer	17.72		2.20		7.83		7.54		11.67		15.67		11.28		7.07		7.09		10.73	

Table 2 Clustering Hypothesis Tests for High-Price Options on Round and Half-Round Digits from January 2001 to June 2007

The figures on the row of "Bid Quote" are the *t*-statistics under the null hypothesis that the percentage of high-price bids on x.0 and x.5 are on average less than 10% from January 2001 to June 2007. Similarly, the figures on the row of "Offer Quote" are the *t*-statistics and *P*-value under the null hypothesis that the percentage of high-price offers on x.0 and x.5 are on average less than 10% over the period January 2001 to June 2007. The symbols of ***, ** and * indicate significance of *t*-statistics and *P*-value at the 1%, 5% and 10% levels, respectively.

		All Options		American Options		European Options		Individual Equity Options		Index Options	
Option Quotes		x.0	x.5	x.0	x.5	x.0	x.5	x.0	x.5	x.0	x.5
Bid Quote	*t* statistics	131.36***	107.82***	44.18***	36.47***	50.40***	44.94***	41.27***	33.52***	108.32***	103.84***
	P value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Offer Quote	*t* statistics	53.39***	124.19***	32.38***	34.26***	32.38***	32.38***	35.74***	32.38***	63.51***	90.67***
	P value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 Percentage of Zero-value Options from January 1996 to June 2007

Panel A : Percentage of zero-value option quotes on x.0 at bids and on x.25 at offers from January 1996 to June 2007

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average
Bid Price = $0	50.75%	58.02%	57.82%	54.26%	52.42%	66.93%	70.42%	73.70%	74.07%	76.05%	74.93%	75.33%	65.39%
Offer Price = $0.25	37.65%	47.25%	50.29%	46.56%	44.13%	79.17%	90.05%	87.41%	87.12%	84.78%	81.53%	82.69%	68.22%

Panel B : Percentage of zero-value option quotes out of total option quotes from January 1996 to June 2007

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average
Bid Price = $0	9%	11.80%	11.80%	10.60%	10.20%	14.10%	17.10%	17%	17.20%	19%	18.20%	18.50%	14.54%
Offer Price = $0.25	4.80%	7.00%	8.00%	7.30%	7.00%	8.30%	8.00%	6.60%	6.30%	5.30%	4.20%	4.80%	6.47%

Table 4 Hypothesis Tests for High-Price Options Clustering on Round Digits and Half-Round Digits: Evidence from Index Options against Individual Equity Options and European Options against American Options

This table performs eight null hypotheses shown as follows.

H_1: *The mean value of high-price bids on x.0 for index options is greater than that for individual equity options*
H_2: *The mean value of high-price bids on x.5 for index options is greater than that for individual equity options*
H_3: *The mean value of high-price offers on x.0 for index options is greater than that for individual equity options*
H_4: *The mean value of high-price offers on x.5 for index options is greater than that for individual equity options*
H_5: *The mean value of high-price bids on x.0 for European options is greater than that for American options*
H_6: *The mean value of high-price bids on x.5 for European options is greater than that for American options*
H_7: *The mean value of high-price offers on x.0 for European options is greater than that for American options*
H_8: *The mean value of high-price offers on x.5 for European options is greater than that for American options*

The sample period is from January 1996 to June 2007. The symbol of *** indicates significance of *t*-statistics and *P*-value at the 1% level.

		Mean	Variance	*t* statistics	*P* value			Mean	Variance	*t* statistics	*P* value
H_1: Bid on x.0	Index Option	0.2867	0.0002	55.0342***	0.0000	H_2: Bid on x.5	Index Option	0.2651	0.0002	57.4947***	0.0000
	Individual Equity Option	0.1658	0.0002				Individual Equity Option	0.1503	0.0002		
		Mean	Variance	*t* statistics	*P* value			Mean	Variance	*t* statistics	*P* value
H_3: Offer on x.0	Index Option	0.3017	0.0008	44.6386***	0.0000	H_4:Offer on x.5	Index Option	0.2597	0.0002	51.1577***	0.0000
	Individual Equity Option	0.1641	0.0003				Individual Equity Option	0.1479	0.0002		
		Mean	Variance	*t* statistics	*P* value			Mean	Variance	*t* statistics	*P* value
H_5: Bid on x.0	European Option	0.3177	0.0035	23.6898***	0	H_6: Bid on x.5	European Option	0.2683	0.0007	37.3709***	0.0000
	American Option	0.1688	0.0003				American Option	0.1517	0.0002		
		Mean	Variance	*t* statistics	*P* value			Mean	Variance	*t* statistics	*P* value
H_7:Offer on x.0	European Option	0.2991	0.0012	31.1268***	0.0000	H_8:Offer on x.5	European Option	0.2761	0.0012	30.0513***	0.0000
	American Option	0.1693	0.0002				American Option	0.1538	0.0002		

Table 5 Hypothesis Tests for Downsizing the Minimum Price Variation Associated with Pricing Clustering

This table performs four hypothesis tests to see whether downsizing the minimum price variation induces a higher level of clustering for U.S. listed option quotes. The symbol of *** indicates significance of *t*-statistics and *P*-value at the 1% level. These four null hypothesis are given by

H_1: *The mean percentage of high-price option bids on x.0 is greater for the period of 2001-2007 than that for the period of 1996-2000*

H_2: *The mean percentage of high-price option bids on x.5 is greater for the period of 2001-2007 than that for the period of 1996-2000*

H_3: *The mean percentage of high-price option offers on x.0 is greater for the period of 2001-2007 than that for the period of 1996-2000*

H_4: *The mean percentage of high-price option offers on x.5 is greater for the period of 2001-2007 than that for the period of 1996-2000*

	Average Percentage for Jan 1996 − Dec 2000	Average Percentage for Jan 2001 − Jun 2007	*t* statistics	*P* value
H_1: Bid on x.0	13.71%	17.55%	9.2283***	0.0000
H_2: Bid on x.5	12.40%	15.95%	11.4499***	0.0000
H_3: Offer on x.0	13.11%	17.72%	8.9146***	0.0000
H_4: Offer on x.5	12.27%	15.67%	11.6191***	0.0000

Table 6 Statistical Tests for Goodhart and Curcio's (1991) Attraction Hypothesis

This table performs two statistical tests under the null hypothesis of Goodhart and Curcio's (1991) attraction hypothesis for bids on x.0 and offers on x.0.

H_1: *Clustering frequency of high-price bids on x.0 is larger than other digits*

H_2: *Clustering frequency of high-price offers on x.0 is larger than other digits*

where the null hypothesis of H_1 (H_2) tests for whether the clustering frequency of bids (offers) on x.0 is larger than bids (offers) on x.1, x.2, x.3, x.4, x.6, x.7, x.8, x.9. The data range for high-price bids and offers are from January 2001 to June 2007. The clustering frequencies on each digit are calculated as the monthly average of daily clustering frequencies. The symbols of ***, ** and * indicate significance of *t*-statistics and *P*-value at the 1%, 5% and 10% levels, respectively.

	Mean Clustering Frequency on Each Digit for High-Price Offers from January 2001 to June 2007									
Bid on x.0	x.0	x.1	x.2	x.3	x.4	x.5	x.6	x.7	x.8	x.9
Mean	17.29%	2.33%	7.96%	7.79%	11.98%	15.72%	11.52%	7.18%	11.07%	7.13%
t statistics		264.4985***	153.9993***	154.0507***	92.9989***	20.53684***	101.1597***	169.9983***	108.8292***	173.421***
P value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Mean Clustering Frequency on Each Digit for High-Price Offers from January 2001 to June 2007									
Offer on x.0	x.0	x.1	x.2	x.3	x.4	x.5	x.6	x.7	x.8	x.9
Mean	17.33%	2.26%	8.05%	7.76%	11.94%	15.47%	11.57%	7.28%	7.28%	11.01%
t statistics		108.945***	65.5639***	67.1489***	38.1705***	12.9443***	41.4823***	71.1862***	72.3036***	45.6372***
P value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

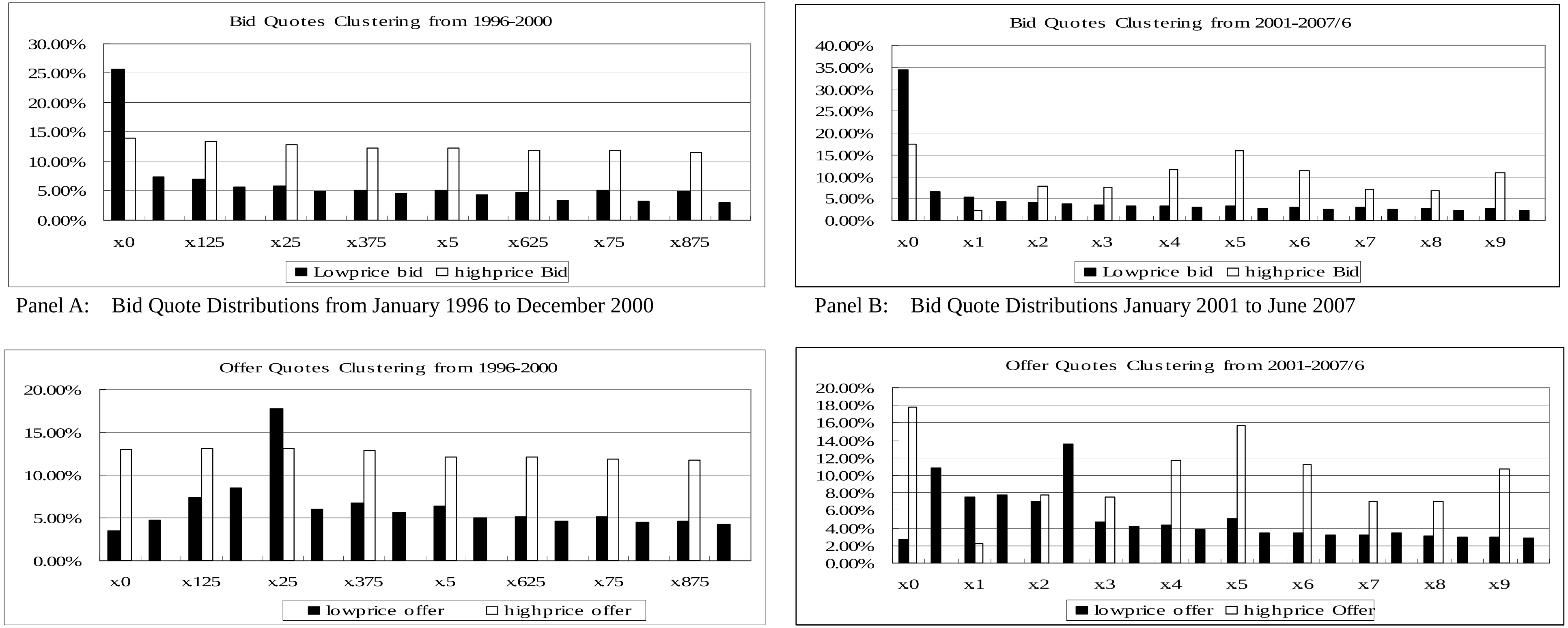
Table 7 Regression of Price clustering on Bid-ask Spread, Trading Volume, Open Interest, Price Level, Implied Volatility, and Date until Expiration

Price clustering is measured as the percentage of option quotes that occur at pricing increments of x.0 and x.5. We use the inverse of the standard normal cumulative distribution to transform the quote price clustering variable, which we will call *Clustering*. We regress *Clustering* against the bid-ask spread (*BidAskSpread*), trading volume (*TradingVolume*), open interest (*OpenInterest*), the price levels of options (*PriceLevel*), implied volatility (*ImpliedVolatility*), and the time to maturity of options (*DateUntilExpiry*).

$$Clustering = Constant + \alpha_1\, BidAskSperead + \alpha_2\, TradingVolume + \alpha_3\, OpenInterest + \alpha_4\, PriceLevel + \alpha_5\, ImpliedVolatility + \alpha_6\, DateUntilExpiry + \varepsilon$$

BidAskSpread is calculated as end-of-day offer minus bid for each option contract. *TradingVolume* is the trading volume of each option contract. *OpenInterest* denotes the open interest for each option. *PriceLevel* denotes the price levels of option contracts. *ImpliedVolatility* denotes the implied volatility of the option contracts. *DateUntilExpiry* denotes the time to maturity of option contracts. Monthly averages of daily time series for each regression variable are used in each regression. The sample period is from January 2001 to June 2007. x.0 represents the last digit of quotes is .0, which includes the quote of 0.0, 1.0, 2.0, 3.0, 4.0, etc., while x.5 represents the last digit of quotes is .5, which includes the quote of 0.5, 1.5, 2.5, 3.5, 4.5, etc. The symbols of ***, ** and * indicate significance of *t*-statistics and *P*-value at the 1%, 5% and 10% levels, respectively.

	Constant	*BidAskSpread*	*TradingVolume*	*OpenInterest*	*PriceLevel*	*ImpliedVolatility*	*DateUntilExpiry*	R-Square
Bid on x.0	-1.1266***	0.0702***	0.0008***	-0.0001*	0.0061***	-0.0052***	0.0002**	0.6921
	(-38.4861)	(3.5308)	(2.6662)	(-1.8667)	(6.5334)	(-3.2487)	(2.0003)	
Bid on x.5	0.2434***	0.0246**	0.0001***	-0.0000**	0.0046***	-0.0043***	-0.0000	0.7464
	(18.4491)	(2.3931)	(0.4449)	(-2.0123)	(7.7003)	(-5.9113)	(-0.2379)	
Offer on x.0	-1.1639***	0.1096***	0.0006*	-0.0008**	0.0055***	-0.0011	0.0003**	0.9123
	(-28.8532)	(17.8952)	(1.8549)	(-2.0371)	(4.6925)	(-1.1331)	(2.0126)	
Offer on x.5	0.2249***	0.0230**	0.0014***	-0.0000	0.0029***	-0.0037***	0.0001*	0.7573
	(9.9138)	(2.0005)	(5.3728)	(-1.0289)	(3.0560)	(-3.5086)	(1.6847)	



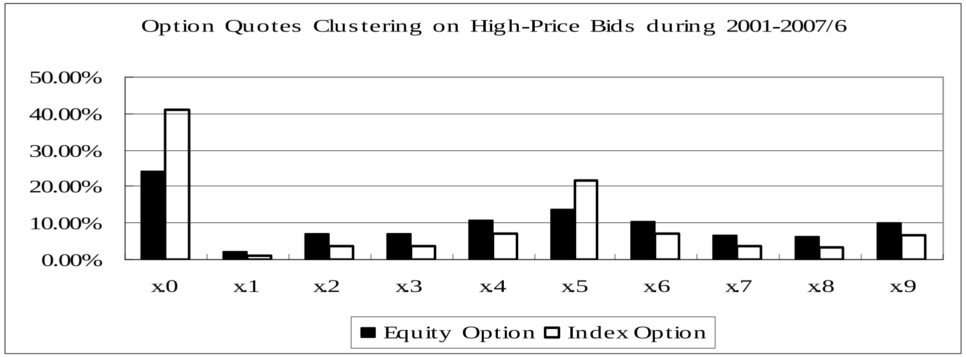
Panel A: Bid Quote Distributions from January 1996 to December 2000

Panel B: Bid Quote Distributions January 2001 to June 2007

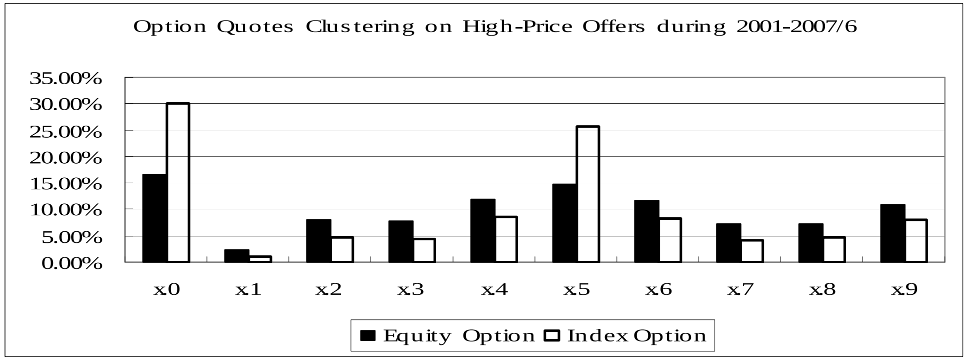
Panel C: Offer Quote Distributions from January 1996 to December 2000

Panel D: Offer Quote Distributions from 2001 to June 2007

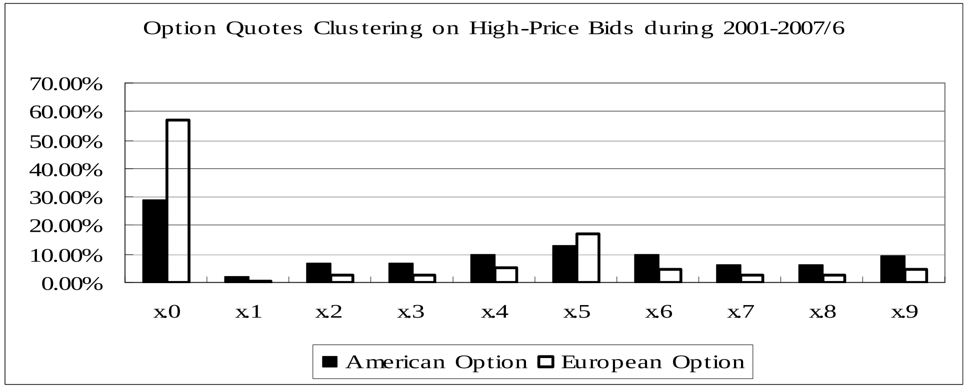
Figure 1 Quote Distributions of Option Bids and Offers. During 1996 to 2000, the minimum tick size for the option price was 0.0625 for options priced below 3 dollar and 0.125 for options priced above 3 dollar. From 2001, the minimum tick size for the option price is 0.05 for options priced below 3 dollar and 0.1 for options priced above 3 dollar. The notation, x.0, means the quote price which is 0.0, 1.0, 2.0, 3.0, etc. The dark bar indicates the quotes greater than 3 dollar, while the white bar indicates the quote prices less than 3 dollar.



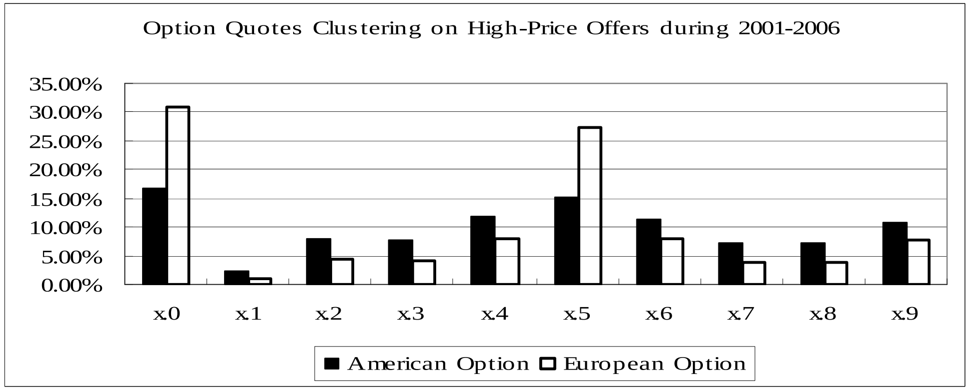
Panel A: Option Quotes of High-Price Bids for Individual Equity and Index Options



Panel B: Option Quotes of High-Price Offers for Individual Equity and Index Options



Panel C: Option Quotes of High-Price Bids for American and European Options



Panel D: Option Quotes of High-Price Offers for American and European Options

Figure 2 Quote Distributions of High-Price Bids and Offers for Individual Equity Options, Index Options, American Options and European Options from January 2001 to June 2007.