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MODELING THE IMPACTS OF MARKET ACTIVITY ON BID-ASK SPREADS
IN THE OPTION MARKET

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*Modeling the Impacts of Market Activity
on Bid-Ask Spreads in the Option Market*

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In this paper, we examine the impact of market activity on the percentage bid-ask spreads of S&P 100 index options using transaction data. We propose a new market microstructure theory called a derivative hedge theory, in which option market percentage spreads will be inversely related to the option market maker's ability to hedge his positions in the underlying market, as measured by the liquidity of this underlying market. In a perfect hedge world, spreads arise from the illiquidity of the underlying market, rather than from inventory risk or informed trading in the option market itself.

We estimate three models to investigate various market microstructure theories. In the static model, option spreads are a function of moneyness, time to maturity, option prices, hedge ratios and volatility. The dynamic model includes time between trades or duration and average volume per transaction while the cross-market model adds cross option market activity and spreads in the underlying market.

We find option market volume is not a significant determinant of option market spreads, which challenges the validity of volume as a proxy for liquidity and supports my theory. Option market spreads are positively related to spreads in the underlying market, again supporting our theory. However, option market duration does affect option market spreads, with very slow and very fast option markets both leading to bigger spreads. Only the fast market result would be predicted by asymmetric information theory. Inventory models predict big spreads in slow markets. Neither would be observed if the underlying securities market provided a perfect hedge. We interpret these mixed results to mean that the option market maker is able to only imperfectly hedge his positions in the underlying securities market.

Our result of insignificant option volume casts doubt on the price discovery argument between stock and option markets (Easley, O'Hara, and Srinivas (1997)). Asymmetric information costs in either market are naturally passed to the other market by market maker's hedging and therefore it is unimportant where the informed traders trade.

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I. Introduction

Considerable and widespread attention has been focused on the question of how bid-ask spreads are affected by the level of market activity. Inventory and asymmetric information models purport to explain the relationship between market activity and spreads. Although these models have been developed to explain the relation between spreads and stock market activity, they should be applicable to option market spreads and their market activity as well. However, bid-ask spreads in derivative markets, especially, in option markets may be determined not only by derivative market but also by underlying market activity. In this case, options spreads should be examined in terms of activity in both markets.

This paper examines the impact of market activity on the percentage bid-ask spreads of S&P 100 index options using transaction data. For this purpose, we propose a new market microstructure theory called "derivative hedge theory" in order to address the relation between option and underlying asset markets. If market makers in derivative markets can perfectly hedge their position with an underlying security, then liquidity and spreads in derivative markets will be determined by liquidity measured as spreads in the underlying market. Therefore, in a perfect derivative-hedge world, spreads arise because of the illiquidity of an underlying market, rather than because of inventory risk or informed trading in the option market itself. Spreads in options markets increase when there is informed trading in the underlying market.

We model bid-ask percentage spreads in relation to market activities in order to investigate market microstructure theories in explaining options market makers' quoting. For this purpose, we propose three models: a static model, a dynamic model, and a cross-market model. The last includes cross-option market as well as underlying market effects. In the static model bid-ask percentage spreads in options markets are explained by the main characteristics of option contracts: moneyness, time to maturity and option prices and by underlying stock market activities such as hedge ratios and volatility. Trading intensity variables of duration and average volume per transaction are added in the dynamic model. The cross-market model includes, in addition, cross-market effects;

including, cross option market trading activity. This is measured as the inverse of cross option transaction duration, and underlying stock market activity measured by the average percentage spreads of the underlying stocks. In particular, variables that provide the evaluation of the three market microstructure theories are specified. Variables such as the average volume of options transactions, duration between transactions and the average percentage spreads of underlying securities are those which enable us to distinguish the role of those models in options spreads.

We find option market volume is not a significant determinant of option market spreads. This finding challenges the validity of volume as a proxy for liquidity and supports our theory. Option market spreads are positively related to spreads in the underlying market, again supporting our theory. However, option market duration does affect option market spreads, with very slow and very fast option markets both leading to bigger spreads. Only the fast market result would be predicted by asymmetric information theory. Inventory models predict big spreads in slow markets. Neither would be observed if the underlying securities market provided a perfect hedge. We interpret these mixed results to mean that the option market maker is able to only imperfectly hedge his positions in the underlying securities market.

Examining the implications of market activities of options as well as its relation with the underlying market may give one possible explanation of the price discovery argument. Option markets have been regarded, according to Black (1974), as an ideal venue for informed trading because of low transaction costs, less stringent margin conditions, and the absence of the uptick rule for shorting. This leads to the role of information in price discovery between stock markets and options markets. According to the asymmetric information model if there are venues where informed traders gather, then the location of informed trading may have implications of price discovery between markets. Easley, O'Hara and Srinivas (1997) show that option markets are a venue for informed trading and that option trade volumes are informative for the future movement of stock prices. However, according to the derivative-hedge model, the argument of price discovery between stocks and options markets may not be relevant since the information content in option market transactions does not affect the option market maker's behavior if a market maker can hedge his position perfectly with underlying assets. In this case,

the option volume as a proxy for options market activity may not play a significant role in determining the spreads in options markets, since liquidity in the underlying market can be tapped through the hedging behavior of market makers.

Our finding of insignificant option volume effects casts doubt on the price discovery argument between stock and option markets (Easley, O'Hara, and Srinivas (1997)). Asymmetric information costs in either market are immediately passed to the other market by the market maker's hedging and therefore it is unimportant where the informed traders trade.

This paper is organized as follows. In section II, we discuss the inventory and asymmetric information market microstructure theories. We also propose our derivative hedge theory. In section III, we describe the data and describe the statistics on transactions in options markets. In section IV, we present the static model to explain the spreads in options markets. Section V extends the static model to a dynamic one, incorporating the relation to options market activities. In section VI, the cross market model for the relation between options spreads and cross option market activities as well as underlying stock market activities are presented. In section VII, we discuss the empirical results in the framework of market microstructure theories. The price discovery arguments are also examined. Section VIII concludes.

II. Market Micro-Structure Theories in Derivative Markets

When market microstructure theories seek to explain order arrival and quote revision, the central concept is liquidity. Liquidity is the price of immediacy. An asset is liquid if it is readily exchangeable, which is to say that liquidity is here the willingness of traders (often but not necessarily market makers) to take the opposite side of the trade. A market is liquid if traders can sell or buy many shares quickly at low transaction cost

There are at least four dimensions to liquidity, known as width, depth, immediacy, and resiliency. Width simply refers to the bid-ask spread (and to brokerage commissions and other fees per share) for a given number of shares. Depth refers to the maximum number of shares which can be traded at the given bid and ask quotes. Immediacy refers

to the speed at which trades of a given size can be done at a given cost. Resiliency refers to how quickly prices recover to former levels after a change resulting from large order flow imbalances. However, liquidity is hard to measure because it is not easy to distinguish between normal price movements and price movements resulting from large orders. One of the most frequent proxies is the bid-ask spread because it represents the average cost of a round-trip transaction of a normally traded quantity.

Bid-ask spreads can be explained by the inventory and asymmetric information theories. According to the inventory model, the bid-ask spread exists to compensate market makers for bearing the risk of holding undesired inventory. That is, when there is an order imbalance that moves the market maker away from his desired inventory position, he adjusts the bid-ask spread to attract orders and re-optimizes his inventory position. Therefore, the market maker increases the spread as the inventory imbalance accumulates (Stoll (1978), Amihud and Mendelson (1980), and Ho and Stoll (1981)).¹

While the inventory model depends on the assumption of risk aversion of the market maker, in asymmetric information models the market maker can be risk neutral. This model assumes the existence of traders with superior information. Given his informational disadvantage, the market maker must keep spreads wide enough to compensate for losses from trading with informed traders. Trading costs arise solely as a result of the presence of informed traders, whose profits are at the expense of the uninformed liquidity traders. That is, adverse selection imposes a cost which must be made up by a spread, even for a risk neutral, competitive market maker. In a one-period model, Copeland and Galai (1983) formalize the idea by considering the market maker's profit maximization problem with asymmetric information and find that nothing further is

¹ According to the model presented by Stoll (1978), the bid-ask spread increases with the size of trades, with both risk aversion and volatility while it does not depend on the size of inventory. Several empirical studies attempt to explain bid-ask spreads in inventory models. Lee, Mucklow, and Ready (1993) show that the bid-ask spreads for NYSE stocks become wider in response to higher trading volume. Hasbrouck and Sofianos (1993) show that the trades in which NYSE specialists participate tend to have a bigger and more rapid effect on spreads than trades with no specialist participation. Madhavan and Smidt (1993) report that bid-ask quote revisions are positively related to order imbalances. George and Longstaff (1993) develop taxonomy of spreads for the S&P100 index options in terms of inventory cost. They argue that the cross sectional differences in the S&P100 index option bid-ask spread should be related to cost-related variables.

required to induce spreads.² They predict that the spread increases with price level and volatility but decreases with market activity, depth, continuity, and the degree of competition. As a result, higher volume measured by number of transactions is associated with lower spreads. Glosten and Milgrom (1985) and Easley and O'Hara (1987) develop models where transactions signal information in dynamic settings. Spreads increase in the Glosten and Milgrom model because when an agent wishes to buy the market maker revises upward his expectation of the asset's value and moves his quotes accordingly; when an agent wishes to sell the opposite revision occurs. Easley and O'Hara allow for trades of different sizes and assume that traders who possess superior information prefer larger size transactions. Adverse selection arises because a rational market maker interprets large orders as a signal of information trading and adjusts the price and spread accordingly.

However, the bid-ask spread in derivative markets, and especially, in option markets may be determined not only by derivative market activity but also by activity in the underlying market. Therefore we propose our derivative hedge theory which focuses on the relationship between liquidity in the underlying market and hedge risk in the derivative markets. What market participants want is liquidity; the assurance that their orders will be executed without any adverse price movement resulting from the orders themselves. The traditional focus of most liquidity-building activity at derivatives exchanges has been directed at locals, the traditional market makers and the source of capital in derivatives markets. However, there is another source of liquidity for derivatives markets, the already existing liquidity of other deeper markets that can be tapped through hedging. If the market maker in the derivative markets hedges all his position, then he will no longer be subject to either inventory or asymmetric information risks in that market. In other words, if he trades with informed traders and hedges his position perfectly, he will not be hurt by such trades since the liquidity in the market will be a function of the liquidity in the underlying market, rather than of the activity of the derivative market. Thus, if there are informed traders in the underlying markets, then the spreads in those markets will be wide and the spreads in the derivative market will also

² Copeland and Galai characterize the cost of the market maker's spread as a combination of a put and a call option (straddle).

be wide. Here, spreads in the derivative markets exist because market makers in those markets find it difficult to hedge their position because of an illiquid underlying market.

Therefore, asymmetric information and derivative hedge theory give different interpretations for the derivative market activity measured by volume and for the price discovery argument between underlying security market and derivative market. Easley, O'Hara, and Srinivas (1997) investigate informational linkage between option markets and equity markets, examining the role of transaction volume in option markets.³ Given that trading causes information to affect and thus be captured by prices, if the options market is more attractive to informed traders, then options transactions would convey information on future stock prices which was not yet embodied in those prices.⁴ However, according to derivative hedge theory, the informational linkage between option and stock markets for price discovery become meaningless, since the informed option trading activity may not be revealed in the options spreads if the options market maker can perfectly hedge his position with underlying stocks.⁵ Since it is the liquidity of the

³ Easley, O'Hara, and Srinivas argue that options trades (rather than option prices) may first reflect information due to the fact that option pricing models need the stock price and volatility to determine the option price, but the new information would not yet have been incorporated into stock prices. The role of options in impounding information into security prices is not a new idea. Black (1975) suggested that the higher leverage available in option markets might induce informed traders to transact options rather than stocks. Manaster and Rendleman (1982), Bhattacharya (1987), Vijh (1988), Anthony (1988), Conrad (1989), Stoll and Whaley (1990), Stephen and Whaley (1990), Detemple and Jorion (1990), Damdoran and Lim (1991), Chan, Chung and Johnson (1993), Srinivas (1993), Sheikh and Ronn (1994), Mayhew, Sarin and Shastri (1995), Fleming, Ostdiek, and Whaley (1996) empirically investigate the links between options and equity markets. The evidence on market interrelationships, however, is inconclusive as to which of the two markets reflects new information earlier.

⁴ In their model, "positive news" option volumes (buying a call or selling a put) provides a positive signal for stock price movement to all market makers, who then increase their bid and ask prices while "negative news" options volumes (selling a call or buying a put) depresses quotes

⁵ According to the asymmetric information, hedging by risk averse market makers could potentially result in option transactions affecting stock prices. A market maker who writes a call, for example, could hedge this position by buying the stock, and this would result in the stock price moving to the ask price. If option market makers hedge every transaction in the stock market, then one might have expected to see evidence of this in the effects of option volume and on stock price changes, an action consistent with the information-based price discovery argument. Easley, O'Hara and Srinivas (1997) argue that stock prices lead option volumes, an expected result given that changes in stock prices should induce hedge-related trading in options. However, they also argue that total option volume and call option volume does not lead stock prices interpreting that the market maker hedge his position with options contract at least partially.

underlying market that determines whether the options market maker can hedge his position perfectly, there may be no causality from option volume to stock price movement. Furthermore, asymmetric information costs in either market are naturally passed to the other market by market maker's hedging and therefore it is not important where informed traders trade.

Clyman, Allen, and Jaycobs (1997) find evidence of the relation between the liquidity of underlying market and the hedge behavior of the Dublin-based trading of FINEX's U.S. Dollar Index (USDIX) contracts. They question the validity of using volume as a proxy for liquidity. The analysis shows that the USDIX market in Dublin, a very low volume market, is far more liquid than its volume would indicate, suggesting a market whose liquidity comes from hedging rather than trading in locals. That implies that as long as it is possible to hedge a derivative position by taking offsetting positions in underlying markets, and as long as there is sufficient competition among the hedgers, then even when the only link is the risk-hedge activity of market makers, the liquidity of the underlying markets can be transferred to the derivative market, thereby causing it to be liquid even when it is not active.

III. Option Market Data

The S&P100 index option is traded at the CBOE in a continuous, open-cry auction among competitive market makers. There are two types of traders for the index options, floor brokers and market makers. Floor brokers bring public orders to the floor of the exchange and execute them at the best possible prices. All market makers of S&P 100 index options trade only for their own accounts and they are free to seek out the best profit opportunities. The market maker is restricted to acting as either a broker or dealer for any particular security on the same day and he can not do both on the same day.⁶

⁶ The AMEX options market has the combination of the market maker and the specialist system. It has floor broker/dealer but also has a specialist for each option. Relative to the competitive market maker, the specialist may have information and execution advantages. He may have exclusive knowledge of the limit order book and can participate as both broker and a dealer on the same day.

Market makers have a responsibility to quote bid and ask prices in a way that contributes to the maintenance of a fair and orderly market and of price continuity, and as a result, provide both liquidity and immediacy to the market. In addition, each option has an order book official. These officials are employed by the exchange to display the highest bid and lowest ask prices and to record limit orders for later execution.

We use intraday transaction and quote data for S&P 100 American call options from May 1993, as reported in the CBOE. They consist of 180239 observations. Each day a market maker trades options of three different times-to-maturity consisting of May, June, July or August.⁷ In call options markets, trading tends to concentrate in near-to-maturity and close-to-the-money contracts, and thus more than 90% of active trading (more than 100 trades per day) are in series expiring in the current or immediately subsequent month.

We consider at-the-money options and out-of-the-money options. The shortest 10-day maturity options are excluded. Also, the quotes of zero bid prices are excluded because lower bounds may truncate the spread and bias it toward zero.

Here, we consider percentage spreads rather than absolute spreads. Percentage spreads are measured as spreads by dividing by the midpoint of the bid and ask prices. Percentage spreads are used instead of absolute spreads because this is the theoretically relevant price since discreteness in quotes means that the absolute spread may not deal smoothly with option prices.

Percentage spreads may be seen as a measure of trading cost. First, percentage spreads reveal the transaction cost a trader faces for immediacy.⁸ A trader has to pay different prices for buying and for selling. Simply, the round trip transaction cost of a \$100 transaction is the percentage spread. Percentage spreads also reveal the costs that a market maker faces. There are three types of costs that a market maker faces. Holding costs are imposed by suboptimal portfolio positions to which the market makers commit. There may be order processing costs that reflect the nature of the trading mechanism such as exchange fees, transfer taxes, etc. Finally, there is a cost from trading with informed

⁷ Since the expiration date is May 19th, 1993, the time-to-maturity consists of June, July and August after the expiration date.

⁸ Demsetz (1968) was the first to formalize bid-ask spreads as a transaction cost to the trader and analyze it in a static supply and demand framework.

traders. If the market is competitive, then a market maker's bid-ask prices must just compensate him for the costs of accepting the trade, and hence equal the trading cost.

Examining the location of transactions within the percentage spread provides one perspective on transaction costs. Transactions are categorized in three ways. Trades are 'at-the-spread' if the transaction price equals the bid or ask price. Transactions 'in-the-spread' are those where the transaction price is in between the bid and ask prices. Trades 'out-of-the-spread' are those where the price is either lower than the bid price or higher than the ask price.

<Table 1> and <table 2> show the relation between transaction prices and bid-ask prices of the S&P100 index call options: one for at-the-money options and one for out-of-the-money options. Here, the bid and ask prices quoted right before the transactions are considered. That is, bid and ask prices are the most recent quotes before transactions occur. Lee and Ready (1991) argue that NYSE protocols cause quote revisions to be reported before the trades during these revisions; they therefore suggest that current trades be classified with the quote recorded 5 seconds prior. Such adjustment is not appropriate for trades on the CBOE, in that the frequency of quote revision is greater, and thus using the most recent quote does not induce a bias.⁹

According to <table 1> and <table 2> the distribution of call options transactions is skewed toward ask prices. That is, a large fraction of trade occur at the ask price and these trades are of a smaller size. S&P100 index options seem to be increasingly 'buy', which means options are actively bought, rather than sold.

75% of at-the-money options and 81% of out-of-the-money options are traded at the spread. This is a greater percentage than in NYSE trades.¹⁰ Two explanations can here be offered. If market makers behave competitively, then they offer the lowest acceptable quote in the outset, and simply can not afford bargain. Alternatively, if informed trading is significant on the CBOE, the market markers protect themselves by

⁹ Easley, O'Hara, and Srinivas (1997) also use the most recent quote for the trading classification for the same reason.

¹⁰ Vijh (1990) shows the specialist structure for NYSE stocks has lower average spreads and a larger fraction of trades executed between the prevailing bid and ask prices than the CBOE competitive market maker structure for options on these stocks. Neal (1992) shows the spreads in market structures are related to trading volume. According to Neal when trading volume is low, the specialist structure has lower bid-ask spreads than competitive market maker structure. As

trading at the quoted price more often since it may be harder to detect informed trading given the multiplicity of dealers.

The interesting case is that of out-of-the-spread transactions. Here, the spread underestimates the transaction costs because traders face worse prices than posted prices for their transaction. That is, if the average of the bid and ask prices is a measure of true option value, then the cost of liquidity for a given trade can be estimated by the difference between the trade price and one-half of the quoted bid and ask spread. The table also shows that out-of-the-spread trades have higher average volumes per transaction. The big trading volume may be the reason for these transaction costs if a big volume of transactions has bigger effect on the prices than a small volume. When traders create large order flow imbalances and if market makers are unwilling to provide low cost liquidity to such an imbalance, the order flow imbalances may be satisfied at a price which does not reflect the fundamental value.¹¹

Another interesting fact is that in-the-spread transactions happen rarely. When the market maker quotes a wide spread there is less motive for a trader to trade with the market maker since he sees the spread as a cost which he has to pay. Therefore, in this case, transactions occur in the spreads because in multiple market makers system where market makers compete with each other, some of them are willing to offer liquidity to lower the cost for trades that they already intend to trade.

The principal difference between options and stocks is that an option contract can be distinguished by its moneyness and maturity terms. Moneyness is defined as the difference between the stock price and the strike price. It is positive for in-the-money options, zero for at-the-money options, and negative for out-of-the-money options. Comparing at-the-money, out-of-the money, and in-the-money options gives insight into the cross-sectional perspective of percentage spreads and liquidity. Analyzing option percentage spreads in terms of moneyness, one would expect the more liquid market to have a lower percentage spread. In order to investigate how moneyness is related to percentage spreads, the piecewise spline method is applied to get a nonlinear relation. The percentage spreads are a nonlinear function of logged moneyness. Here, moneyness

volume rises, this difference appears to diminish.

¹¹ These traders may be informed and prefer to undertake a larger transaction outside the bid-ask

is measured as stock price divided strike price, S / Ke^{-rt} , where S is stock price, K is strike price, r is interest rate, and t is time to maturity. The determination of moneyness is based on the daily closing stock price. The piecewise spline model is set up as follows.

$$\text{Percentage Spreads} = w + \mathbf{b}_0 \log (\text{moneyness}) + \mathbf{b}_1 Z_1 + \mathbf{b}_2 Z_2 + \mathbf{b}_3 Z_3 + \dots + \mathbf{b}_n Z_n + e$$

where $\log (\text{moneyness}) \in [a, b]$,¹²

a : minimum of $\log (\text{moneyness})$

b : maximum of $\log (\text{moneyness})$

$a < [C_1, C_2, C_3, \dots, C_n] < b$

$Z_i = \log (\text{moneyness}) - C_i$ if $\log (\text{moneyness}) > C_i$,

$Z_i = 0$ otherwise

$1 \leq i \leq n$

The result of an application of this method is presented in <Figure 1>. It shows that out-of-the-money options have bigger percentage spreads than in-the-money options and that at-the-money option percentage spreads are the lowest. This interesting feature allows one to investigate the prediction of the asymmetric information model that the more liquid market has smaller percentage spreads or the prediction of derivative-hedge model that the liquidity of the derivative market depends on whether a market maker in the options market can perfectly hedge his position with underlying stocks.

Comparing <table 1> and <table 2> shows that out-of-the-money options have bigger average volume per transactions than at-the-money-options while the market is less active in terms of the number of transaction. According to the asymmetric information theory, if informed traders use options markets as their trading venue, then out-of-the-money options may be preferred for informed trading since an informed trader would profit more by using more leveraged contracts. The bigger percentage spread of

spread. Or they may be block-trading institutions.

¹² Including out-of-the money and at-the-money options the minimum moneyness is 0.941437 while 1.01210 is its maximum. Therefore, the logged moneyness spans from -0.06035 to 0.012114 and these two numbers correspond to a and b in the spline regression. In order to get spline regression, we subsample data using 10%-iles cumulative density of logged moneyness. C_1

out-of-the-money options may imply the existence of informed traders in that market. The widely recognized fact that at-the-money options are traded heavily may also explain why the at-the-money option has the lowest percentage spread. One possible explanation is that liquidity traders prefer at-the-money options for optimal portfolio management, hedges. If volume, measured by number of transactions, is used as a proxy for liquidity, heavy trading and smaller percentage spreads in this market suggest that the at-the-money option market is more liquid than the out-of-the-money option market.

The relationship between the bid-ask spread and trading volume may take two forms in an asymmetric information framework. First, the proportion of informed traders may be higher for thinly traded assets. This implies a negative correlation between the bid-ask spread (or the percentage spread) and trading volume holding the size of the transaction constant. Second, the proportion of informed trading may increase if informed trading is positively correlated with the size of the transaction. In this case, there will be a positive correlation between volume and the bid-ask spread (or the percentage bid-ask spread) holding the number of transactions (per unit time) constant. Thus, in intertemporal asymmetric information models a large average trade size suggests the presence of informed traders leading to a wider spread. On the other hand, from a cross sectional perspective a large volume of trades (large number of transactions) also correspond to greater liquidity, and this increased liquidity should work to narrow spreads. According to Easley, Kiefer, O'Hara, and Paperman (1996) the probability of informed trading is low for frequently traded stocks (high volume stocks). They show that frequently traded stock tends to have a higher probability of information events and higher arrival rates of informed traders, but that these are more than offset by the higher arrival rates of uninformed traders. As a result, market makers in less active stocks face a greater risk of informed trading, and so larger spreads in these stocks are consistent with this information-based explanation. In this case, out-of-the-money options may have a higher probability of informed trading since those options are traded infrequently and are more leveraged compared to at-the-money options. This analysis may be supported by the argument in Neal (1989) that a sufficiently high trading volume, measured as the number of transactions could reduce the bid-ask spread to the minimum percentage

is the number for 10% logged moneyness, while C_9 is the number for 90% logged moneyness.

spread.

An alternative explanation is that these percentage spreads are determined by the hedging costs of the market makers. Rather than holding exposed positions the market makers could continually delta hedge their position. If the underlying market is highly liquid then the spread in the options market would be determined by the liquidity in the underlying security market and the hedge ratio of the asset. Here, the liquidity of the at-the-money and out-of-the-money options market are decided by the same underlying assets, the S&P100 index. Therefore the different percentage spreads of at-the-money options and out-of-the-money options may imply that delta hedging in each market is not perfect since it is more difficult for the market maker to hedge his position in of out-of-the-money options which have a bigger hedge ratio. In this case, the at-the-money market may have smaller percentage spreads compared to the out-of-the-money market. Also out-of-the-money options have bigger average volume per transaction than at-the-money options, again leading to different percentage spreads. If the underlying security market is liquid then the difference in volume in each option should not matter. However, if the perfect hedge is not possible because of an illiquid underlying market, then the options market activity measured as the average volume per transaction may be significant in explaining the difference in percentage spreads. Therefore, this cross-sectional analysis may give an evidence of imperfect hedge.

IV. Static Model

In order to model spreads in S&P100 index options, we first consider the static model. The options percentage spreads in the static model are explained by moneyness, time to maturity, option prices, volatility and delta hedge ratio. Moneyness, time to maturity and option prices are included to capture the main characteristics of option markets while volatility and the delta hedge ratios are used to measure the relation between options and their underlying markets and to evaluate these market microstructure theories. With that in mind, we adopt the following model, in which the squared terms and cross terms are included to capture the nonlinearity of percentage

spreads.

$$\begin{aligned} \frac{SP}{C} = & \mathbf{b}_0 + \mathbf{b}_1 \frac{\log(C)}{\sqrt{t}} + \mathbf{b}_2 \frac{\log(moneyness)}{\sqrt{t}} + \mathbf{b}_3 \log(t) + \mathbf{b}_4 \log(\%delta) + \mathbf{b}_5 \log(volatility) \\ & + \mathbf{b}_6 \left[\frac{\log(moneyness)}{\sqrt{t}} \right]^2 + \mathbf{b}_7 [\log(t)]^2 + \mathbf{b}_8 \left[\frac{\log(moneyness)}{\sqrt{t}} \right] \cdot \log(\%delta) + \mathbf{e}_s \end{aligned}$$

where SP = bid-ask spread
 C = mid-quote as an option price
 moneyness = S/Ke^{-rt}
 S = stock price
 K = strike price
 r = interest rate
 t = time to maturity
 %delta = $(\Delta C / \Delta S) \cdot (S / C)$

Using moneyness measured as the stock price divided by the strike price, we expect that the more out-of-the-money is the option, the bigger will be the percentage spread since those options provide the most leverage. It is consistent with the cross-sectional examination of <Figure 1> in section III.

If bid and ask prices are based on full public information and if they are symmetrically distributed about the true option value, then the average of the bid and ask prices is a measure of the true option value. The option price measured as a mid-quote of the spread may have a positive relation to absolute spreads. One explanation for this possible positive relation is found in CBOE tick-size rules. Options with prices of \$3 or more have tick sizes of \$1/8, whereas options with lower prices have tick sizes of \$1/16. This means that narrow spreads that are feasible for lower price options are not feasible for higher option prices. This positive relation can be explained with inventory models because costs incurred by market makers may be positively related to the price of options

traded, in that higher priced options imply greater changes in inventory value.

Time to maturity may affect the percentage spread because of the exercise notification procedure for the S&P100 index options which result in horizon specific hedge demand.¹³ Near-maturity options may have wider bid-ask spreads than other options because they are more likely to be exercised and, as a writer, a market maker will require a wide spread to compensate for the loss from a trader's exercise since he may find it difficult to keep a neutral position.¹⁴ According to the Black-Scholes formula, a near maturity option has less value and if the near maturity option is purchased then there is a high possibility that the trader is informed since with information it may be a good strategy to buy a cheap near maturity option and to exercise it. Therefore, the trader of near maturity options may suspect that his counter-positions have information.

The volatility of stock returns is considered following the argument of Copeland and Galai that the spread increases with the volatility of the underlying stock. In an asymmetric information world, volatility in the stock market may result from informed trading, and, in that case, informed traders may also be present in the option market since options gives more leverage. It implies that if there is informed trading in the option markets it leads to wider spreads. However, according to the derivative hedge theory, large price changes in the stock market imply that the underlying market becomes illiquid, which may result from large volume transactions or from informed trading. As a result, spreads in underlying markets tend to be wider and options markets also become illiquid since it is difficult to tap the liquidity of the underlying markets to options markets and, in turn, spreads in options markets will also be wider. In order to explain the relation, implied volatility is used.¹⁵ At-the-money options of greater than ten-day time-to-maturity are considered for the implied volatility.

¹³ When a holder exercises his option, the index level used in determining the payoffs is the level prevailing at the end of the day of exercise. The writer of the option does not know that an exercise has been assigned until the next day. By this time, the index value could have changed substantially. Therefore, index options impose price risks on market makers who write the options, because covered positions are costly to maintain.

¹⁴ Harvey and Whaley (1991) show that S&P 100 index options are frequently exercised early. The majority of the early exercise occurs during the 10 days prior to expiration. Put options are exercised early more frequently than call options.

¹⁵ It is the volatility implied by the option price observed in the market and the value when the stock price, strike price, interest rate and time-to maturity are substituted into the Black-Scholes formula.

The hedge ratio, delta, is incorporated into the static model in order to evaluate the asymmetric information and derivative hedge theories. If the hedge ratio is significant in explaining the percentage spreads in options market, then we can see the importance of the role of hedging. The hedge ratio, measured by percentage delta, may influence the percentage spread in options since it considers the elasticity of option prices with respect to the underlying stock prices. It is expected to have a positive correlation with percentage spreads because options with the biggest percentage deltas are the options whose returns are the most sensitive to changes in the S&P100 index.¹⁶ An interpretation of the delta can be found in the relation to the moneyness.¹⁷ The absolute value of delta (positive for calls, negative for puts) is approximately equal to the probability that the option will finish in-the-money.¹⁸ As the delta moves closer to zero, the option becomes less and less likely to finish in-the-money.¹⁹ However, when one considers the percentage delta, an out-of-the-money option has a bigger percentage delta. This means that the relation between percentage delta and percentage spread is expected to be positive; that is, the less the option is in the money and the higher the percentage delta, and the greater the percentage spreads.

The market maker as a writer of a call option needs to hedge his position with a long share position. If the percentage delta is higher then the market maker would increase the percentage spread since the market maker may find it costly to fully hedge

¹⁶ Cox and Rubinstein (1985) show that out-of-the-money have the highest elasticity with respect to the index.

¹⁷ Delta also can be interpreted in other three ways: as the hedge ratio,¹⁷ as the rate of change in the theoretical value, and as the equivalent underlying position. Suppose a trader had a delta long position of 0.5 (\$0.50). If the trader intends to maintain a delta neutral position, he must sell 1/2 underlying contracts (hedge ratio interpretation). However, if he believes the market will rise and wants to maintain his delta position, he knows that in theory he is long 1/2 underlying contracts (the equivalent underlying position interpretation). And finally, if he maintains his delta position of 0.5, the value of his position will change at 1/2 times the rate of the underlying market (the rate of change interpretation). Even though a trader may interpret the delta differently at different times, each interpretation is mathematically the same and a trader interprets a delta position depending primarily on his trading strategy.

¹⁸ As an option's delta moves closer to 1 for call or -1 for puts, the option become more and more likely to finish in-the-money. A call with a delta of 0.25, or a put with a delta of -0.25, has approximately a 25% chance of finishing in-the-money.

¹⁹ Then it is reasonable that at-the-money options have deltas close to 0.5. If price is assumed to change randomly, there is approximately a 50% probability that the market will rise (the option goes into-the-money), and a 50% probability that the market will fall (the option goes out-of-the-money).

his position. Biais and Hillion (1990) show that inventory risk from hedging is related to spreads. It may be explained in asymmetric information theory even though the theory itself does not explicitly address the relation between stock volatility and percentage spreads of options. If the out-of-the-money market is a venue for informed trading and out-of-the money options have bigger percentage spreads, then the percentage spread and percentage delta would have a positive relation. Here, percentage delta is computed using implied volatility of at-the-money options of greater than ten-day time-to maturity.

V. Dynamic Model

To explain the dynamics of the bid-ask percentage spread, we consider the effect of trading intensity in the options markets on their spreads. For this purpose, the average volume of a pre-determined number of transactions and the duration between transactions are considered. Considering these relations, we propose a dynamic model for bid-ask percentage spread of the following form.

$$\frac{SP}{C} = \text{StaticModel} + \mathbf{b}_{10} \log(\text{duration}) + \mathbf{b}_{11} [\log(\text{duration})]^2 + \mathbf{b}_{12} \log(\text{volume}) + \mathbf{e}_D$$

where, SP = bid-ask spread

C = mid-quote as an option price,

duration = average duration for 10 transactions

volume = average volume for 10 transactions

In order to understand the relation between trading intensity and percentage spreads, average duration and average volume are calculated using the past 10 transactions of the appropriate type.

In Easley and O'Hara's model, the market maker increases the bid-ask percentage spread following a large transaction since informed traders prefer a larger size of

transaction. Hence, for a given number of transactions in each options market, regardless of its moneyness, the bid-ask percentage spread will be wider following a large transaction if each option behaves as an Easley and O'Hara asset. That is, the market maker will increase the bid-ask percentage spread when there is a high average transaction volume given the number of transactions, concluding that these transactions are initiated by informed traders. If this hypothesis were correct then the average transaction volume would be positively related to percentage spreads. However, in a perfect hedge world, if the market maker can hedge his position through the liquidity of the underlying market, then percentage spreads in the options market depend on activities in underlying markets rather than those in options markets. Then the volume in the options market itself may not be a good proxy for liquidity in options markets. It implies that average transaction volume may enable us to evaluate those two theories.

Short transaction duration implies that the market is moving fast, possibly showing the presence of informed traders. If informed traders come into possession of news, then they will enter the market. Therefore, the market maker will increase the percentage spread leading to a negative relation between duration and spread. On the other hand, in an inventory model, market activities are negatively related to spreads because of the market maker's risk inventory risk.²⁰ However, in a derivative hedge theory, duration between transaction should not affect the percentage spreads in option market because the market maker's perfect hedging make option market activity independent of percentage spreads. Therefore the fast moving market and its relation with its percentage spreads would be predicted by asymmetric information theory while inventory models predict big spreads in slow markets. Neither will be observed if the underlying market provide a perfect hedge. In order to examine those arguments, we add the squared term of duration. If traditional theories, asymmetric information and an inventory model, are right, then percentage spreads may be u-shaped with respect to durations, with extremes having bigger spreads.

In addition to estimating a dynamic model, we perform the cubic spline regression

²⁰ By examining options in a cross section perspective George and Longstaff (1993) show that spreads are larger for options that trade less actively. Without considering the effects of adverse selection, they report that a \$1/16 increase in the spread increases the average time between trades by 2.91 minutes for calls and 2.90 minutes for puts.

of percentage spreads on duration. <Table 3> shows that duration has an asymmetric distribution. The median duration is 139 seconds for the at-the-money options and 473 seconds for the out-of-the-money options. That shows that the short duration consists of almost 50% of data for the at-the-money options and that the at-the-money options market moves faster than the out-of-the-money options market. This asymmetry of distribution for duration leads to difficulties in decomposing the data for the spline regression because the method of subsetting the data may affect the results. For those reasons we use two criteria such as percentiles of duration and unit time intervals.²¹ <Figure 2> to <figure 4> fits percentage spreads on duration which is log normalized to capture U-shaped asymmetric distribution of data for at-the-money, out-of-the-money and all-the-money combining both.²²

VI. Cross Market Model

Because all of the these options are written on the same underlying stocks, percentage spreads in one option may depend on market activities in cross option markets as well as the underlying stock market. When a market maker quotes a spread for one option, his behavior might be conditioned on information derived from the trading activity of other options as well as of the underlying market.

In order to incorporate cross-market activities, we add the cross option market activity measured as an inverse of cross options duration. That is, for at-the-money options percentage spreads we include the effect of out-of-the-money option market activities. If the inverse of the out-of-the-money options duration is big, which means that the out-of-the-money options markets is active, then the market maker may receive a

²¹ For the cubic spline regressions, the percentiles and the unit-time interval are used for the criteria for the data. 25%, 20%, 10% and 5% tiles of duration are used for the regressions. The unit interval criterion includes every 30, 60, 120, 180, 240 and 360 seconds of data. We can still find almost same minimum percentage spread in the cubic spline regression for each options regardless of methods of subsampling data. Here we report the result using percentiles subsampling.

²² The minimum of the fitted percentage spreads from the cubic spline regressions corresponds to 1111 seconds for the at-the-money options and 54 seconds for the out-of-the-money options, and 64 seconds for the all-the-money options.

signal of informed trading in these markets. As a result, he may change quotes to increase the percentage spreads for an at-the-money as well as those for an out-of-the-money option. The at-the-money option market activity may have similar effects on the behavior of the market maker in deciding the out-of-the-money options' spreads.

According to derivative hedge theory, the spreads in derivative markets are determined by the liquidity of the underlying markets. If the market maker cannot perfectly hedge his position with underlying assets, then the spreads in options markets reveal the presence of informed trading in underlying markets that are illiquid. In order to consider this argument, we include the spreads in underlying markets in the cross-market model. If options can be traded at the right price, the index futures will be the best substitutes that an index option trader can find. Traders in S&P100 index options markets are always searching for an acceptable substitute for the underlying basket of 100 stocks. A future contract on this index would be an ideal substitute but, unfortunately, one does not exist. Therefore, we use an average of previous one minute percentage spreads of 21 actively traded stocks on NYSE for the underlying market liquidity in order to examine the relation between the options markets and their underlying markets. This result tests the derivative-hedge theory. The underlying stocks are IBM, General Motors, Disney, Johnson and Johnson, Philip Morris, Boeing, Eastman Kodak, Exxon, Proctor and Gamble, Walmart, Dupont, McDonald, Morgan JP, Minnesota MNG & MFG, Merck, AT&T, Westinghouse Electric, Hewlett Packard, Chevron, Utd Technologies, and Good Year. They are chosen since they are component of the DJIA.

The cross market model is suggested as follows.

$$\frac{SP}{C} = \text{DynamicModel} + \mathbf{b}_{13} \log(\text{cross options markets}) + \mathbf{b}_{14} \log(\% \text{ spread of stocks}) + \epsilon_{ED}$$

Where, SP = bid-ask spread

C = mid-quote as an option price,

cross option markets = cross options market activity

%spread of stocks = percentage spreads of underlying stock markets

Here, cross options market activity is measured as the inverse of duration for 10 transactions of cross options. For example, in order to explain the percentage spreads of at-the-money options the inverse of the duration of 10 out-of-the money transactions is used. *%spreads* as an independent variable is measured as the average of the previous one minute average percentage spreads in 21 underlying stock markets.

VII. Empirical Results and the Interpretations.

The analysis of S&P 100 index options reveals the intuition of how market activities affect the market maker's quoting behavior. Percentage spreads are explained in three different models, the static, dynamic, and cross-market. The empirical results are presented within the framework of market microstructure theories focusing on the derivative hedge theory that we propose.

In order to explain percentage spreads with respect to market activity, at-the-money options and out-of-the-money options are respectively investigated. We also consider the whole market that combines at-the-money and out-of-the-money options. The empirical results are reported in <table 4> to <table 6>.

In a static model, we consider the variables such as moneyness, option price, time to maturity, volatility and percentage delta. The tables show that percentage spreads are a decreasing function of moneyness. Out-of-the-money options have bigger spreads than at-the-money options. From the perspective of a market maker, the less active options (more out-of-the-money options) are riskier, since there is a higher probability that any trade comes from an informed trader. Or it might be related to hedge behavior of market makers. Market makers may find it difficult to neutralize their option positions that are more out-of-the-money since more out-of-the-money option has a higher hedge ratio. On the other hand, the at-the-money option with smaller spreads may be the place where liquidity traders trade.

The coefficient on the call option price has a negative sign. However, it is not surprising, because the model uses the percentage spread rather than absolute spread. If the call price measured as a mid-quote increases but the spread increases at a smaller rate then the percentage spread will be negatively correlated with the call price while the absolute spread is positively related to the call price.²³

The coefficient of time to maturity is negative because the near-maturity option is more likely to be exercised and as a result it may be difficult for the market maker to maintain hedged positions. Or there may be a greater probability that a trader who prefers a cheap option is informed.

Volatility and the percentage delta have positive signs as expected. If the stock price is more volatile and the elasticity of the option price with respect to the stock price is bigger, then a market maker will widen the percentage spread. This result supports the derivative hedge theory since volatility and percentage deltas are related to the underlying market's liquidity and this relationship is what matters in that theory. If a market maker cannot tap the liquidity from the underlying market then the market maker may increase spreads to compensate for the risk of exposing his positions. The significance of percentage delta supports the derivative hedge theory.

In a dynamic model variables to measure the option trading intensity are considered. An interesting result is that option transaction volume is not a significant determinant of option market percentage spreads, challenging the validity of volume as a proxy for liquidity.²⁴ This is quite different from the analysis of the stock market that reports bigger spreads with bigger size per trade. Our result supports the derivative hedge theory that the volume in an option market itself does not affect the spreads in the option market if a market maker can find a liquid underlying market for his hedge.

²³ As Copeland and Galai point out, if the probability of liquidity trading for buying options is a declining function of the difference between ask price and option price; then the proportional change in option value and ask price will cause the benefit of a market maker from potential liquidity trading to increase at a slower rate. Then it is expected that an option with a higher price will have a relatively narrower percentage spread than an option with a lower price.

²⁴ Neal (1992) also obtains similar results for the relation between spreads and average size of transaction of CBOE and AMEX options. He uses 3 different measures of spreads: the quoted spread, the current spread, and the effective spread. The positive trade size coefficients for the quoted spread and the current spread specifications are consistent with the model by Easley and O'Hara. However, in the effective spread specification, the coefficient is negative but more than one standard error below zero.

However, we find that the duration of the past 10 transactions does affect option market percentage spreads. It has a negative relationship in levels but there is a positive relationship with squared duration. This implies that spreads are a U-shaped function of duration, which incorporates the existence of informed trading at short duration and inventory risk at long duration.²⁵ These results would not be observed if the underlying market provided a perfect hedge.

The interesting aspect of this result is that we can calculate the duration for the minimum percentage spreads. According to the table the duration is 148 seconds,²⁶ which is close to the median of duration for the at-the-money options. (See table 3.) Therefore, the O'Hara and Easley asymmetric information world explains half of the data for duration, which implies that informed trading in option markets might happen frequently.

In the cross-market model, the cross-option market activity has an interesting interpretation. The market activity of out-of-the-money options is significant in explaining the spread of at-the-money options in positive way while the market activity of at-the-money options is not significant for the spreads of out-of-the-money options. These results can be motivated using cross sectional analysis. As we see in <Figure 1>, out-of-the-money options have bigger spread than at-the-money options. The active out-of-the-money option market may send a signal of the presence of informed trading to market makers who, as a result, increase the spread for at-the-money options as well as for out-of-the-money options.

An interesting result is the role of average percentage spreads of 21 underlying stocks on the percentage spreads of options. In <Table 4> it has a positive effect that is expected in the derivative-hedge model. The percentage spreads in underlying stocks reveals their liquidity and this liquidity is transferred to the options markets directly by

²⁵ Also if a market maker hedges his position using options contracts at least partially, the difficulty of a market maker's hedge using options contracts, when the market is inactive may explain this result.

²⁶ The duration for the minimum percentage spreads from the dynamic model is calculated as exponential value for the coefficient of duration divided by twice the coefficient of squared duration. Here exponential function is taken since in dynamic model, we consider logged duration and logged squared duration. However, it is not same as the duration for minimum value of fitted percentage spreads in cubic spline regression since they are obtained from the different estimation.

the market makers' hedge behavior. This result is consistent with the insignificance of average volume in the dynamic model. According to the derivative-hedge model, it may not matter whether the derivative market has a bigger volume since its liquidity is determined by the underlying market condition. Therefore, this result seems to support the derivative-hedge model.

The variables such as the volatility, percentage delta, average volume for past 10 option transaction, and the percentage spreads for the underlying market are suggested in order to evaluate the importance of derivative hedge theory. The empirical results show that the derivative-hedge model is supported by those variables even though the overall empirical results may also be interpreted from the perspective of traditional market microstructure theories.

We interpret these mixed results to mean that the option market maker is only able to imperfectly hedge his position in the underlying market. If a market maker can not hedge his position perfectly, then the option market activity itself may affect the market maker's quoting behavior. That is, a perfect hedge would make option market spreads depend only on the liquidity of the underlying stock markets while the illiquidity in the underlying asset leads to an imperfect hedge in the option markets and as a result, the option market activity itself still may have an effect on the spreads of options.

The result of insignificant option volume casts doubt on the price discovery argument between stock and option markets (Easley, O'Hara, and Srinivas (1997)). Asymmetric information costs in either market are naturally passed to the other market by market maker's hedging and therefore it is unimportant where the informed traders trade.

VIII. Conclusion

In this paper, we examine the impact of market activity on the percentage bid-ask spreads of S&P 100 index options using transaction data. We propose a new market microstructure theory called derivative hedge theory, in which option market percentage spreads will be inversely related to the option market maker's ability to hedge his

positions in the underlying market, as measured by the liquidity of this underlying market. In a perfect hedge world, spreads arise from the illiquidity of the underlying market, rather than from inventory risk or informed trading in the option market itself.

We estimate three models to investigate various market microstructure theories. In the static model, option spreads are a function of moneyness, time to maturity, option prices, hedge ratios and volatility. The dynamic model includes time between trades or duration and average volume per transaction while the cross-market model adds cross option market activity and spreads in the underlying market.

We find option market volume is not a significant determinant of option market spreads, which challenges the validity of volume as a proxy for liquidity and supports my theory. Option market spreads are positively related to spreads in the underlying market, again supporting our theory. However, option market duration does affect option market spreads, with very slow and very fast option markets both leading to bigger spreads. Only the fast market result would be predicted by asymmetric information theory. Inventory models predict big spreads in slow markets. Neither would be observed if the underlying securities market provided a perfect hedge. We interpret these mixed results to mean that the option market maker is able to only imperfectly hedge his positions in the underlying securities market.

Our result of insignificant option volume casts doubt on the price discovery argument between stock and option markets (Easley, O'Hara, and Srinivas (1997)). Asymmetric information costs in either market are naturally passed to the other market by market maker's hedging and therefore it is unimportant where the informed traders trade.

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<TABLE 1> TRADING OF AT-THE-MONEY CALL OPTIONS

Trading of At-the-Money Options

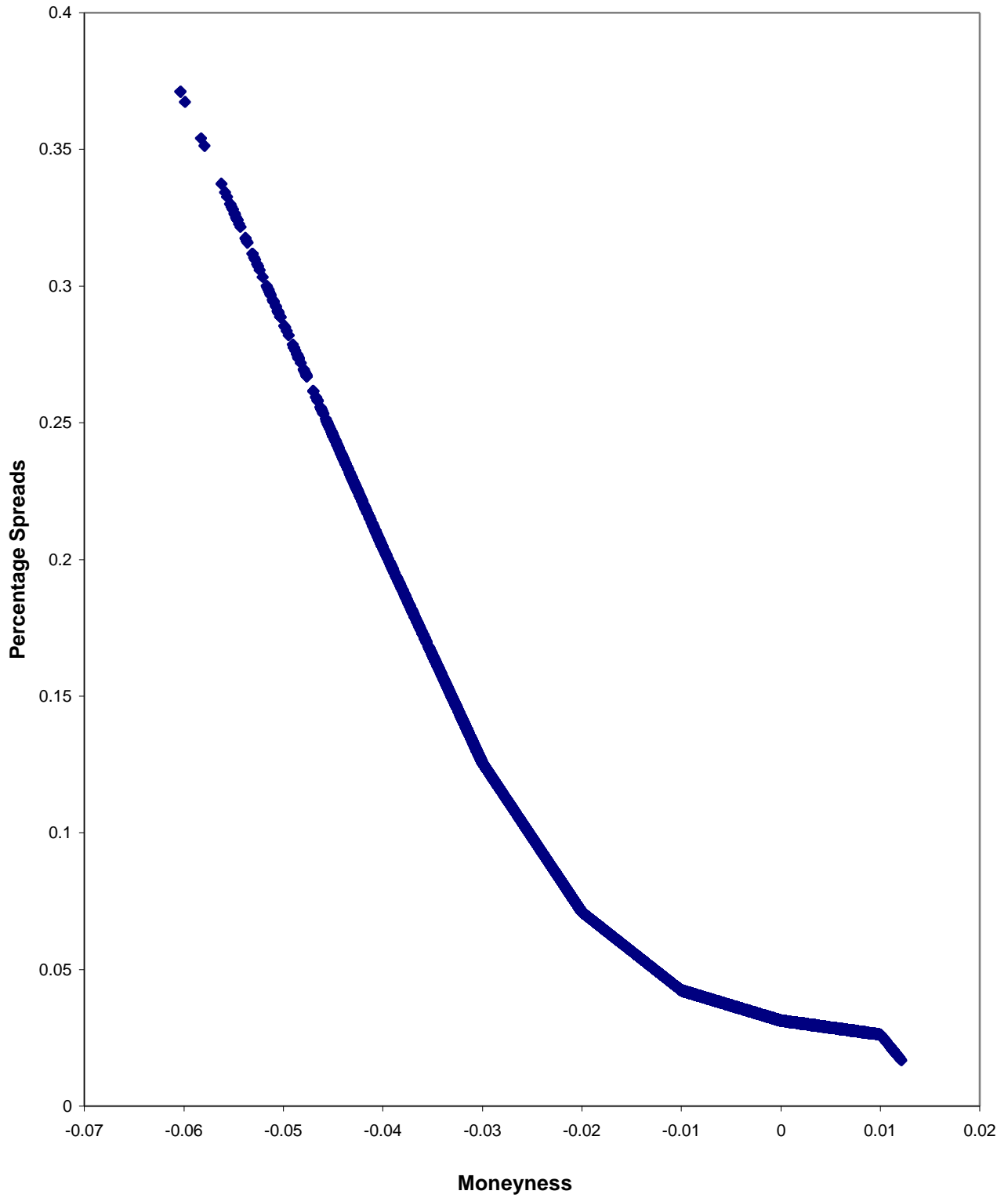
Trading	Classifications	Frequencies		Percentages		Spreads	%spreads	Volume
At-the-Spread	Transaction Price = Bid Price	13932	6463	73	34	0.11	0.03	19.80
	Transaction Price = Ask Price		7469		39	0.11	0.03	17.99
In-the-Spread	Bid Price < Transaction Price < Ask Price	335	335	2	2	0.24	0.05	18.16
Out-of-the-Spread	Transaction Price < Bid Price	4773	2348	25	12	0.11	0.03	25.98
	Transaction Price > Ask Price		2425		13	0.10	0.03	22.65
Total		19040	19040	100	100			

<TABLE 2> TRADING OF OUT-OF-THE-MONEY CALL OPTIONS

Trading of Out-of-the-Money Options

Trading	Classifications	Frequencies		Percentages		Spreads	%spreads	Volume
At-the-Spread	Transaction Price = Bid Price	17059	7785	82.5	37.7	0.08	0.09	29.41
	Transaction Price = Ask Price		9274		44.9	0.08	0.09	23.60
In-the-Spread	Bid Price < Transaction Price < Ask Price	486	486	2.4	2.4	0.17	0.13	28.96
Out-of-the-Spread	Transaction Price < Bid Price	3127	1358	15.1	6.6	0.08	0.04	29.35
	Transaction Price > Ask Price		1769		8.6	0.07	0.05	29.36
Total		20672	20672	100	100			

< Figure 1 > Percentage Spreads and Moneyiness



**<Table 3> The Statistics of Duration for Call Options
- Cumulative Distribution**

At-the-Money Options

100% Max	5166	99%	4338
75% Q3	325	95%	2169
50% Median	139	90%	1207
25% Q1	82	10%	55
0% Min	15	5%	44
		1%	29

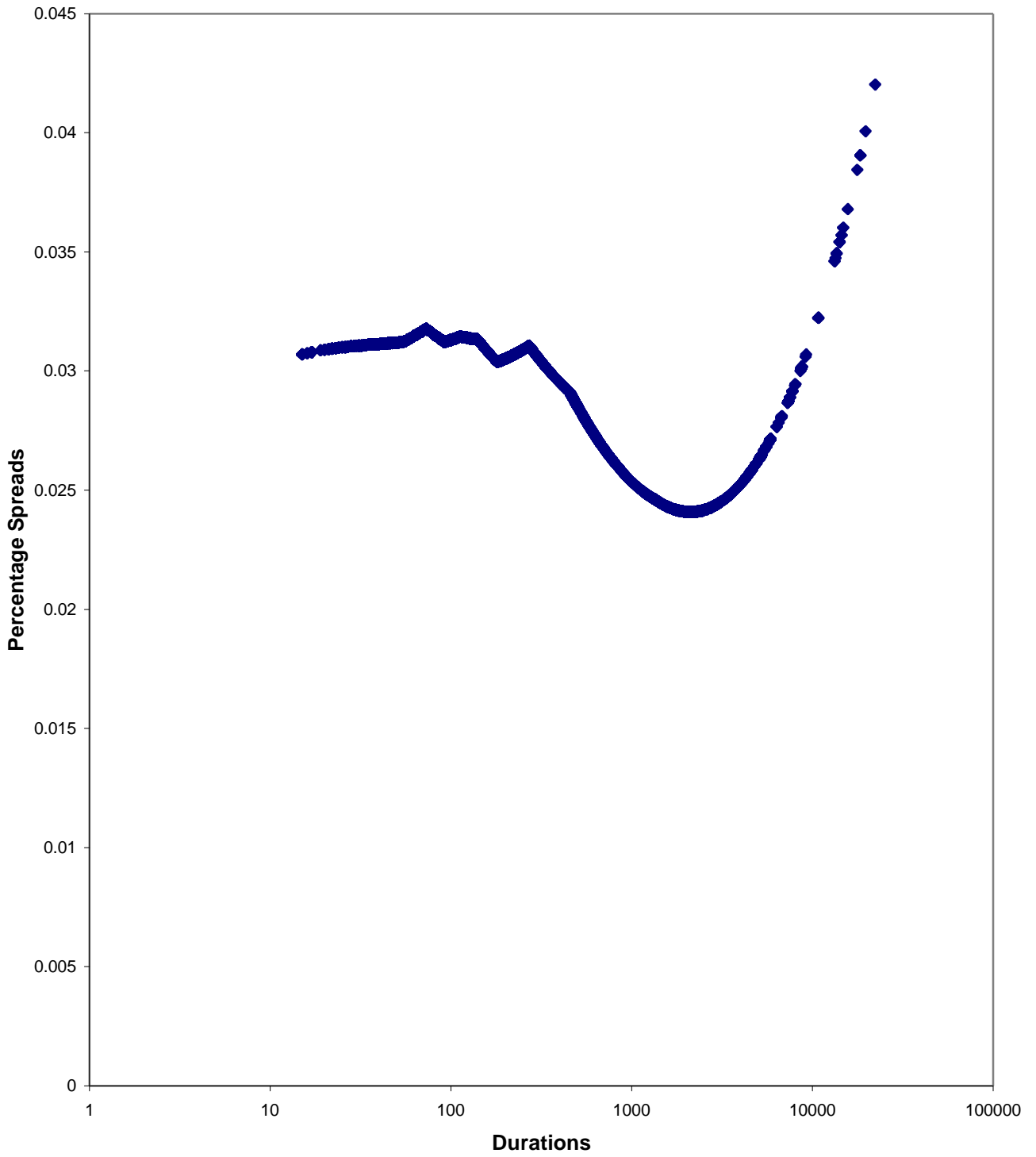
Out-of-the-Money Options

100% Max	14278	99%	12196
75% Q3	1445	95%	6645
50% Median	473	90%	3767
25% Q1	196	10%	94
0% Min	14	5%	60
		1%	29

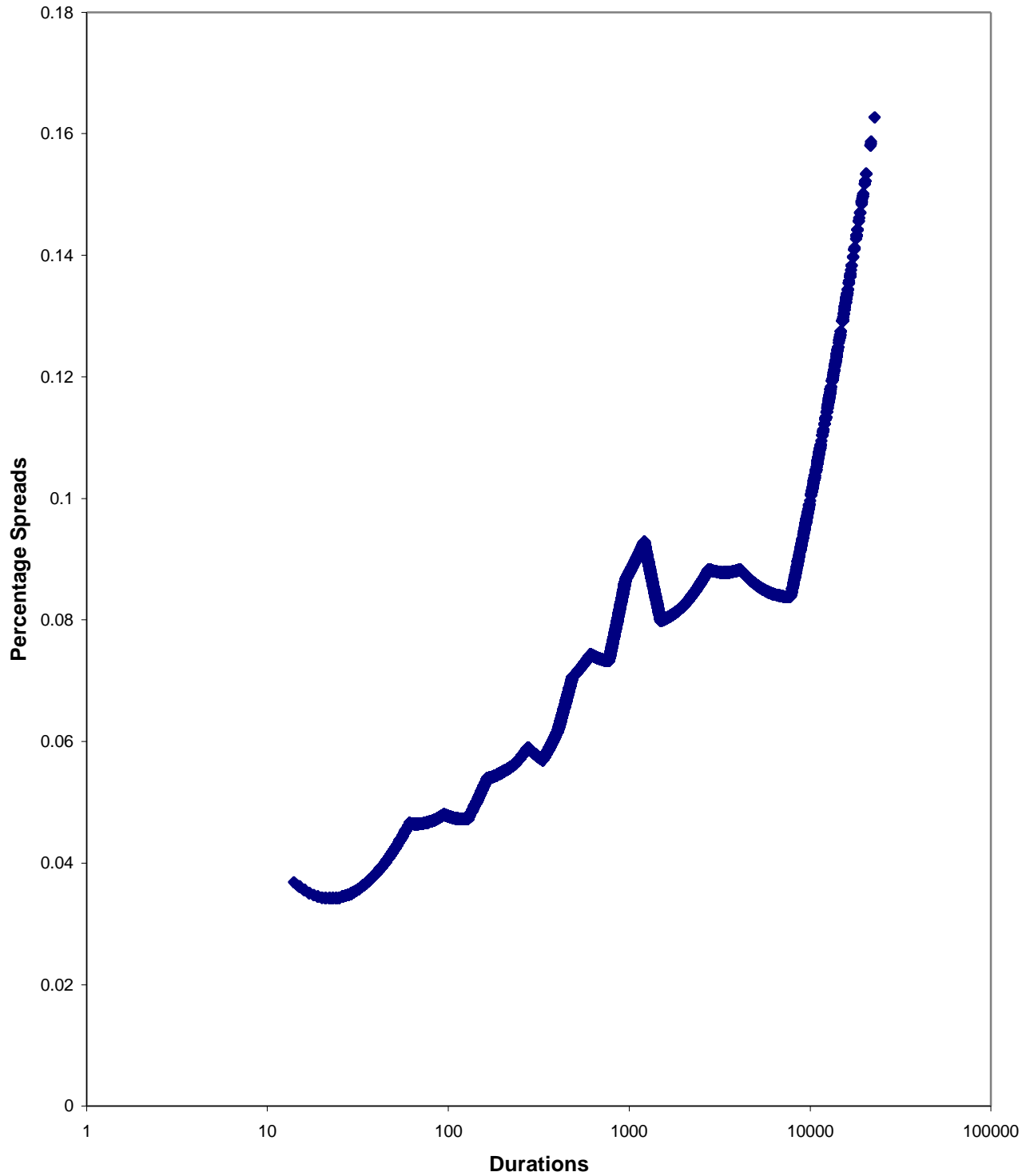
All-the-Money Options combining out-of-the-money and at-the-money options

100% Max	13004	99%	10250
75% Q3	1009	95%	4683
50% Median	287	90%	2768
25% Q1	119	10%	66
0% Min	14	5%	49
		1%	29

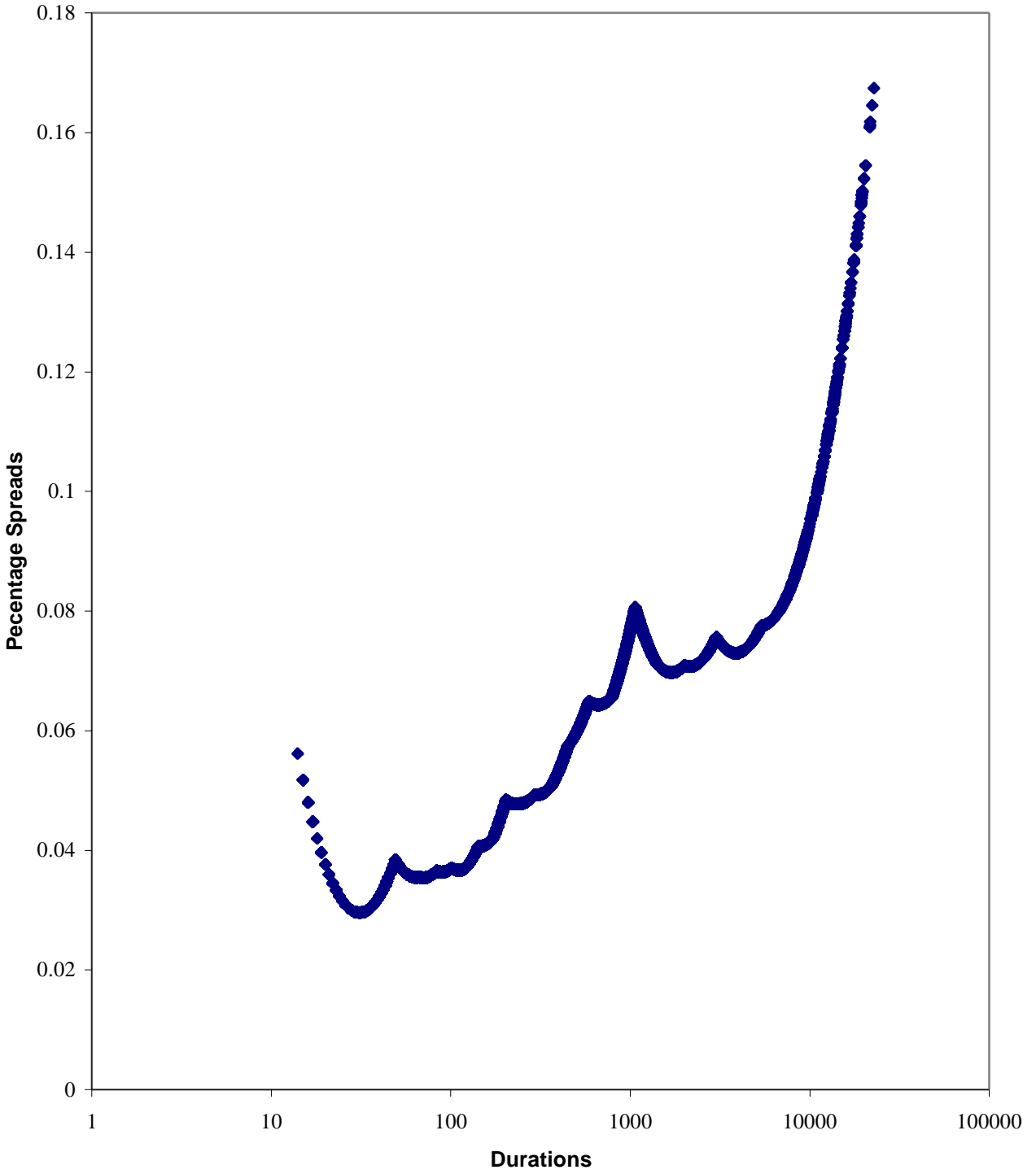
**< Figure 2 > Percentage Spreads and Durations
(At-the-Money Options)**



**< Figure 3 > Percentage Spreads and Durations
(Out-of-the-Money Options)**



**< Figure 4 > Percentage Spreads and Durations
(All-the-Money Options)**



<TABLE 4> MODEL SPECIFICATIONS FOR PERCENTAGE BID-ASK SPREADS

	con	call	mon	time	%delta	vol	mon_s	t*mon	time_s	money*d	dur	dur_s	volume	cross	under_s	
At-the-Money Options																
STATIC MODEL																
	0.1827	-0.061	-0.048	-3.3298	-0.068	0.0021	0.007	-4.0048	-0.43635	-0.009	0.051356					
t-value	-10.094	-8.606	-17.844	-26.75	1.4984	4.583	-3.9947	-9.3798	-22.25	6.48435						
DYNAMIC MODEL																
	0.1927	-0.093	-0.027	-3.4604	-0.092	0.0059	0.01	-3.7359	-0.43136	-0.013	0.054088	-0.0071	0.0007	2.11E-05		
t-value	-12.419	-4.61	-18.534	-27.15	4.1382	6.208	-3.7175	-9.27353	-23.56	6.82696	-11.176	11.8957	0.13707			
CROSS-MARKET MODEL																
	0.19339	-0.0938	-0.027	-3.5118	-0.091	0.0069	0.01	-3.5131	-0.42064	-0.013	0.56359	-0.0071	0.00072	4.32E-05	0.00046	
t-value	-12.525	-4.625	-18.742	-26.97	4.6813	6.07	-3.4882	-9.02136	-23.51	7.08602	-11.142	12.1956	0.28103	3.10375		
	0.208	-0.0751	-0.006	-2.9303	-0.08	0.0085	0.012	-4.2566	-0.44306	-0.012	0.39676	-0.0072	0.00071	6.18E-05	0.0020	
t-value	-8.4322	-0.864	-13.512	-20.79	5.1264	6.285	-3.9188	-8.61131	-18.3	4.44732	-9.7422	10.6742	0.35818	3.3608		
	0.2081	-0.0957	-0.027	-3.5371	-0.092	0.0066	0.01	-3.415	-0.41164	-0.013	0.57681	-0.0068	0.0007	3.58E-05	0.00032	0.0000
t-value	-12.711	-4.594	-18.853	-27.09	4.5173	6.11	-3.3888	-8.80311	-23.61	7.23733	-10.68	11.8414	0.23174	2.06445	2.4630	
Where	con= constant, call = call price, mon = moneyness, time = time to maturity, vol = volatility, mon_s = squared moneyness, t*mon = time to maturity*moneyness, time_s = squared time to maturity, dur = duration, dur_s = squared duration, cross = duration for cross options, and under_s = percentage spreads of underlying stocks.															

<TABLE 5> MODEL SPECIFICATIONS FOR PERCENTAGE BID-ASK SPREADS

con	call	mon	time	%delta	vol	mon_s	t*mon	time_s	money*d	dur	dur_s	volume	cross	under_s
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Out-of-the-Money Options

STATIC MODEL

0.813889	0.2868	-0.41	-5.7065	-0.059	0.0192	0.012	17.723	-15.6679	0.0083	1.060085				
t-value	29.168	-59.75	-2.0148	-12.62	9.2915	4.799	103.58	-22.5373	10.186	14.33738				

DYNAMIC MODEL

0.814678	0.2813	-0.402	-5.2979	-0.035	0.0197	0.016	17.306	-14.9277	0.0041	1.073307	-0.0096	0.000865	-0.00016	
t-value	26.388	-57.14	-1.8686	-6.522	9.5379	6.118	97.701	-21.3468	4.3806	14.49288	-7.3982	8.490507	-0.45583	

CROSS-MARKET MODEL

0.814685	0.2823	-0.403	-5.0564	-0.034	0.0192	0.016	17.288	-14.8745	0.004	1.065466	-0.0097	0.00087	-0.00014	4.99E-05
t-value	26.344	-57.09	-1.7758	-6.378	8.9994	5.919	97.033	-21.1984	4.2607	14.29275	-7.4462	8.528524	-0.40256	0.9207

Where con= constant, call = call price, mon = moneyness, time = time to maturity, vol = volatility, mon_s = squared moneyness, t*mon = time to maturity*moneyness, time_s = squared time to maturity, dur = duration, dur_s = squared duration, cross = duration for cross options, and under_s = percentage spreads of underlying stocks.

<TABLE 6> MODEL SPECIFICATIONS FOR PERCENTAGE BID-ASK SPREADS

con	call	mon	time	%delta	vol	mon_s	t*mon	time_s	money*d	dur	dur_s	volume	cross	under_s
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All Options combining at-the-money and out-of-the-money options

STATIC MODEL

	0.8317	0.1614	-0.281	-1.6809	-0.021	0.0167	0.021	11.841	-13.2426	0.002	1.045464			
t-value	36.015	-98.04	-27.83	-9.654	27.022	11.98	196.36	-54.606	4.747	41.709				

DYNAMIC MODEL

	0.8342	0.1045	-0.28	-1.3636	-0.038	0.0123	0.022	11.184	-11.7162	-0.004	0.941252	-0.0168	0.001594	0.000589
t-value	16.557	-98.32	-22.213	-12.09	19.144	12.2	169.04	-47.099	-8.135	37.232	-18.635	21.642	2.214	

CROSS-MARKET MODEL

	0.8358	0.297	-0.329	-1.701	-0.032	0.0048	0.022	12.303	-13.7964	0.0038	1.187166	-0.0124	0.001133	-0.00061	0.00243
t-value	33.486	-53.27	-23.308	-7.457	4.01	8.351	138.12	-40.012	4.657	39.201	-12.759	14.054	-2.182	10.096	

Where con= constant, call = call price, mon = moneyness, time = time to maturity, vol = volatility, mon_s = squared moneyness, t*mon = time to maturity*moneyness, time_s = squared time to maturity, dur = duration, dur_s = squared duration, cross = duration for cross options, and under_s = percentage spreads of underlying stocks.