Two Essays on Option Market Microstructure

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Dedication

The author wishes to dedicate this dissertation to her husband, Jonathan, who has been a continual presence of inspiration and encouragement; her children, Jack and Lucy, who have brought new meaning to her life; to her mother, Mary Beth, and father-in-law, Bobby, who have both taught her the value of hard work and discipline; and to all of her family and friends for all of their love and support.

Abstract of Two Essays on Option Market Microstructure

In this dissertation I first evaluate the institution details of competitive market maker behavior in the natural gas futures options and futures markets in order to determine the characteristics of traders subsuming the market making role in these markets. I also decompose option portfolio risk for options market makers by evaluating their intraday and end of day risk holdings. The premise that market makers in futures options markets strategically manage their exposure to volatility (vega) while using futures to offset exposure to changes in the underlying price (delta) is examined. In my second essay, I evaluate price discovery in the futures and futures options natural gas markets using a transaction based approach that uses both the buy and sell prices under the Hasbrouck information share methodology. The model incorporates the implied volatility of option prices using a binomial pricing model to compute an implied futures price from a set of option prices using a two-stage estimation procedure. I also investigate the impact of moneyness and option type on informed trading.

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Introduction

In the following dissertation, I investigate both the functions of the market maker in futures-options markets, as well as the amount of price discovery occurring in the futures-options market for natural gas on the New York Mercantile Exchange (NYMEX) using 20 months of transactions level data.[1] The natural-gas market is an important market for studying trader and price behavior because it constitutes nearly one quarter of United States energy consumption. This market also plays a predominant role in energy trading, which has recently been highlighted by the $4.5 billion dollar loss by Amaranth Advisors, a Connecticut based hedge fund, in September 2006.

The first essay in this dissertation evaluates the functions and risk exposure of market makers in the NYMEX natural-gas futures-option market. Market makers in futures-options markets follow an open and competitive system, by which a designated market maker does not exist. Floor traders acting as market makers in the futures-option markets are unique in that they are able to observe physically the price formation process with levels of transparency not seen elsewhere due to the trading of these contracts in the open outcry trading pits. Identification and characterization of the behavior of the group of traders who play the role of the market makers by providing liquidity to the market is examined. An investigation of the characteristics of member proprietary trades, as well as those for the brokerage house, another member on the floor, and a customer are performed in order to evaluate the behavior of market makers in the futures-option market.[2] The characteristics evaluated include the average daily number of trades, the average daily trade size, the average daily time between trades, and the average daily

[1] Natural gas derivatives also trade on the ICE or Intercontinental Commodity Exchange.
[2] The data identify the type of principal behind a trade, such as clearing member, member, the trader's personal account, or an outside customer.

volume for four trade categories. Also included in the analysis are the daily average income levels and the daily ending inventory for member proprietary traders. An evaluation of the extent of competitive forces in each trade category and the use of interdealer trades to expel unwanted inventory is also conducted in order to provide more information on the institutional details of option market making.

In addition to exploring the characteristics and trading behavior of futures-option market makers, the exposure of these market makers to various types of inventory holding risk is evaluated. The risk characteristics of an option portfolio can be described, in part, by its sensitivity to the futures price and to changes in volatility. To calculate this sensitivity, intraday, lagged estimates of volatility are used with the contemporaneous futures price in an option-pricing model to calculate the relevant delta, gamma, and vega. These intraday measures are then evaluated and compared against the end of day calculations to determine the extent to which futures-option market makers mitigate their overnight risk and identify the emergence of any intraday patterns in risk management.

The second essay evaluates the contribution of natural-gas option markets to price discovery through the use of Hasbrouck's (1995) information share approach. The implied futures price and implied standard deviation are estimated to obtain a price series that is compared to the observed futures price to allow cointegration analysis to be performed. The option markets' contribution to price discovery is evaluated across various levels of option moneyness and option type to determine whether informed traders have preferences in the types of options that they trade.

This dissertation is organized as follows: Section II contains the first essay, which covers market making and risk exposure in futures-options markets; Section III develops the second essay, which studies where price discovery occurs and the preferences of certain types of options by informed traders.

Essay I
Market Makers in Options Markets:
An Investigation of the NYMEX Natural-Gas Market

Introduction

In most markets, there are traders who can be identified as market makers who, at a minimum, provide liquidity and influence prevailing market prices. The services that market makers provide serve a vital role in the proper and orderly functioning of the aggregate market system. Although market makers charge a fee for the services that they provide in the form of a bid-ask spread, without their presence, the market system would be less efficient and more costly to maintain. Market makers can be categorized within two central structures: (a) a designated structure under which the market maker has an assigned role and is obligated to perform certain duties including but not limited to providing liquidity, filling orders, setting prices, and maintaining price continuity or (b) an open structure in which a market maker is governed only by the rules set forth by the exchange for all traders. Futures and futures options (options on futures) operate under the latter market making structure. Thus, in futures and futures-options markets, floor traders who seemingly perform the duties of a market maker are not required to maintain inventory or price continuity and can enter and exit the market freely and without constraint.

O'Hara (1995) explained that the rules of a market determine its trading mechanism, including what can be traded, who can trade, when and how orders are submitted, how the orders are processed, and how prices are set. These rules play a particularly dominant role for trading in the futures and futures-options markets due to the lack of a designated market maker. The NYMEX trading rules specify the obligations of the floor traders and how trades are to be executed and recorded. The open outcry trading platform requires floor traders to be responsible for both trade-type identification and reporting to the exchange.

Certain institutional features create a direct relationship between the futures and futures-options markets. Trading in both markets takes place through both open outcry and electronic trading[3] within the framework of an organized auction market, thus allowing for levels of transparency in the price setting process not observable in any other type of market. Floor traders in both markets can be categorized as trading for their own account, their clearing firm's account, another floor trader, or a non-member customer (CTI 1, 2, 3, and 4 respectively). An individual floor trader may also trade for more than one customer type in a given day; thus, the floor trader's income may come from both speculative trading and brokerage functions.

Although futures and options markets both function under a competitive market-making structure with similar rules for trading and institutional features, traders in these markets differ primarily with respect to their risk levels as futures contracts represent an obligation to perform while options contracts offer the ability to perform. Participation in futures options allows traders to benefit from favorable market moves while mitigating their downside risk due to adverse market conditions. The holder of a long option contract is limited to downside losses only by the amount paid for the premium while holding the ability to realize unlimited upside gains. These gains are the same as would have been achieved if the trader had held the long futures position established at that strike price less the original premium paid for the option. Thus, the ability to participate

[3] NYMEX options are not traded electronically over the sample period. NYMEX futures began simultaneous pit electronic trading in September 2006.

in favorable market moves through futures markets is available with a known cost of price protection.

The divergence in risk exposure in futures and futures-options markets may lead to differences in the market-making function of traders in option markets versus those in futures markets. Identification of market makers in futures markets, as well as their function, has received limited attention in the literature. The research aimed at examining market making in futures markets has established that member proprietary trading serves the market-maker function in futures markets with trading behavior that is characterized by low end-of-day inventory holdings, small trades, and large volumes (Kuserk & Locke, 1993, 1994).

Much less research has focused on the market-maker role in options markets, and, to my knowledge, the role of the market maker in futures options has not yet been addressed in the literature. The market maker's role in futures options is unique due to trading occurring in an open outcry trading pit. This venue allows trader behavior, as well as the price-setting process, to be physically observed by other floor traders. The ability to interact with a counterparty to a trade should affect how futures-options market makers function by decreasing informational asymmetries inherent in providing market-making services such as liquidity and price discovery. This research adds to the literature base on markets dominated by open market-making structures through a comprehensive examination of member proprietary trading behavior in futures-options markets by investigating whether the characteristics of futures market makers universally hold in the NYMEX natural-gas option market in order to confirm the existence and examine the dynamics of market making in the futures-option market.

It is shown that member proprietary trading in futures-options markets serves the market-making function. This finding corresponds to research focused on market making in futures markets, which also found that member proprietary trades provide liquidity to the market. These trades are distinctly different from other types of trades in the futures-option market because the initiator of the trade is also the trader. These traders trade for their own accounts, maintain their own inventories, and, due to their participation in the market as a dealer, are exposed to higher levels of risk (via inventory holding) than other traders. Member proprietary traders are characterized by their low trade size, high volumes, small amount of time between trades, and low end-of-day inventory levels. These characteristics are indicative of a market maker performing the tasks of providing liquidity and price setting.

In order to understand more fully the trading behavior and, ultimately, the price-setting practices of futures-option market makers, the risks that member proprietary traders are exposed to from carrying inventory are also evaluated. Option-market-maker risk will be related to the factors that directly influence option prices. Several variables are known to affect options prices: the price of the underlying asset, the options strike price, the time until expiration, the volatility of the price of the underlying asset, the risk free rate, and the value of the dividends expected during the life of the option. In this study, the vector of risk parameters that include the influence of the underlying asset's price and the volatility of the underlying asset are examined through an evaluation of option delta, gamma, and vega.

Several researchers have postulated that option market makers hedge inventory risk exposures by maintaining delta-neutral positions (Figlewski, 1989; Cox &

Rubinstein, 1985). Thus, it is thought that option market makers engage in hedging by (for example) purchasing a quantity of futures options while simultaneously executing a certain number of contracts in the underlying futures contract, seeking instantaneous delta neutrality. The degree to which these traders hedge by participating in both markets will determine their vulnerability to the risk of holding positions in the option market. The short-run exposure of the futures-option market maker to price risk, delta, is expected to be small if they are instantaneously delta-hedged while the exposure to volatility, vega, may more accurately represent the "inventory" that the market maker is carrying.

Contrary to the belief that options market makers will maintain delta-neutral positions by using the underlying futures market, this study shows that futures-option market makers are better at hedging price risk using other options than they are at using contracts in the underlying futures market. Futures-option market makers maintain very low levels of price risk over the course of a trading day while their levels of rebalancing risk and volatility risk are much higher. Thus, futures-option market makers' primary exposure is to gamma and vega, or the speed at which delta changes in response to a change in the underlying futures price and the response of the option price to a change in the volatility of the futures price, respectively.

The remainder of this essay is organized as follows: Section II provides information regarding the data; Section III investigates the behavior of market makers in options markets, with direct comparison to the corresponding futures market; Section IV analyzes market-maker risk in the option market; Section V concludes.

Data

The data for this research consist of 20 months of transactions-level data in the natural-gas futures and option markets traded on NYMEX, spanning September 2005 through April 2007. This data set is maintained by the U.S. Commodity Futures Trading Commission and comes from the computerized trade reconstruction (CTR) records compiled and maintained by the agency from data feeds from the exchanges.

The NYMEX trading rules specify the obligations of the floor traders and how trades are to be executed and recorded. The floor trader conducting a sale of a contract, either futures or futures option, is responsible for reporting the transaction to a designated NYMEX exchange employee within one minute of completion. For a futures contract, the report must indicate the price at which the transaction was executed, the name of the trader executing the sale, quantity traded, commodity, delivery month, and the name of the trader conducting the purchase, against whom the transaction was executed. If the contract is for an option, the trading member conducting the sale must indicate the premium at which the transaction was executed, the trading member's name, quantity, commodity, strike price, expiration month, whether it was a put or call, and the name of the trader purchasing the contract.

An important responsibility of floor traders on NYMEX is to report on the Trade Allocation System the appropriate CTI and indicator codes for transactions executed on the exchange. There are four categories of trades: (a) CTI 1: This type of indicator code is used for trades executed from a floor trader's personal account, an account he or she controls, or for an account that he or she has an ownership of or financial interest in; (b) CTI 2: This type of indicator code is used when a floor trader executes trades for the trading account of a member firm or clearing member; (c) CTI 3: This type of indicator code is used for trades that a floor trader executes for the personal account of another floor-trading member or for an account that the floor-trading member knows is controlled by another floor trading member; (d) CTI 4: This type of indicator code is used when a floor-trading member executes trades for any account other than those in CTI 1-3.

The data for this analysis include the records of all open-outcry trades and provide information including the price, quantity of the trade, trade date, trade time to the second, trade direction (buy or sell), delivery month and year of the contract, customer type (trade for the member's account, his or her house's account, another member on the floor, or a customer), counterparty's customer type, and the floor trader's identification. The data taken after September 2006 also contain electronic trade data for the futures market. Daily settlement prices are obtained from the U.S. CFTC Large Trader Reporting System. The interest rate used in the estimation of the risk parameters is the daily, secondary-market, 3-month treasury bill rate obtained from the St. Louis Federal Reserve.

The trading time for the open-outcry natural-gas pits is from 9:00 am to 2:30 pm (ET). The futures contracts trade in units of 10,000 British thermal units (mmBtu) and require physical settlement. The minimum price fluctuation is $0.001 per mmBtu, or $10 per contract. The price limit is $3.00 per mmBtu, or $30,000 per contract.

Delivery is conducted through the Sabine Pipe Line Company, Henry Hub in Louisiana, and can take place no earlier than the first calendar day of the delivery month and no later than the last calendar day of the delivery month. The Henry Hub is the nexus of 16 intrastate and interstate natural-gas pipeline systems that serve markets throughout the U.S. east coast, the Gulf coast, and the Midwest up to the Canadian border. The seller is responsible for the movement of the gas through the Hub and pays all Hub fees while the buyer is responsible for movement from the Hub.

The volatility in natural-gas futures prices makes futures and futures options an attractive trading venue for speculators. These markets are also used by a wide variety of companies, from those involved in exploration and the production of natural gas to substantial end users of natural gas to hedge their price risk. In the U.S. natural-gas market, price peaks and troughs over a market cycle are cyclical and highly dependent upon weather conditions, with warmer weather driving prices down and colder weather leading to increases.[4]

Market-Making Behavior in Options Markets

Historically, exchanges do not designate market makers for futures or option markets. Indeed, a member trading for his or her own proprietary account is under no obligation to provide liquidity or maintain an orderly market or price continuity. It is important to uncover those who subsume the market-making role in futures and futures-options markets in order to understand market-making behavior, which will ultimately allow for an evaluation of the dynamics of the price setting function in futures, options, and other similarly structured open market-making systems. Limited research in futures markets suggests that traders known as scalpers can be identified, those who behave like market makers in that they buy and sell often and in small quantities and, therefore, provide liquidity to the market. Working (1967, 1977) found that traders identifying themselves as scalpers make their income from frequent buys at the bid followed by a sell

[4] Although seasonal patterns do exist in natural gas prices, I will not control for them here because I am using the underlying futures contracts as a means of comparison. That is, the relationship between the futures and futures-options market should not be seasonal.

at the ask after a favorable price change, which is consistent with market-maker behavior.[5] Silber (1984) examined the trading activities of one scalper working on the New York Futures Exchange and found that success in scalping activities involves frequent trading, in small quantities, with little inventory accumulation. Kuserk and Locke (1993, 1994) also examined scalper behavior and found that traders conducting member proprietary trades earn income that differs across commodities and is correlated with the range of income from other traders.

Based on the previous research by Working (1967, 1977), Silber (1984), and Kuserk and Locke (1993, 1994) the hypothesis is tested that traders carrying out member proprietary trades, also known as CTI 1 trades, take on the role of market makers within the competitive framework of an option market. Due to the link, both institutionally and through arbitrage conditions, of the futures and futures-options markets, it is an empirical question as to whether the descriptive characteristics of market makers in futures markets universally hold in the option market. In order to test this hypothesis, the positions and levels of market-making activity are determined through an examination of several variables that have been shown to distinguish market makers from other types of floor traders in the futures market. The average daily number of trades, volume, trade size, and time between trades are examined in order to gauge contract activity rates and levels, as well as to provide information about market maker’s daily-trading patterns. Each of these analyses are performed across all four trade-type classifications (CTI 1, 2, 3, and 4) and the nearby, first deferred, and second deferred contract expirations. Average daily inventory is evaluated to determine the risk and exposure of option market makers to

[5] Note that *bid* and *offer*, when used in this double oral auction framework, are not clearly identified by the exchange for pit trading. Instead, the process of a trade involves active negotiations on both sides rather than the passive bid or offer and an active order to hit the bid or offer.

overnight volatility.[6] Evaluation of the extent of competitive forces in each trade category and the use of interdealer trades to expel unwanted inventory is conducted in order to provide additional information on the institutional details of option-market making and to begin to develop a more comprehensive understanding of how option market makers manage their exposure to risk. Together, these descriptive statistics will allow for the discovery of how market makers in options markets make the market.

The level of analysis used to conduct the testing of whether member proprietary trader behavior is indicative of that of market makers in futures options is meant to provide an indication of how an average trader conducting a certain type of trade behaves and the characteristics of each type of trade. The three nearest to expiration contracts are examined separately to determine whether differences exist in the characteristics of trades in longer maturities with historically lower volumes. The total number of trades each day is determined through a frequency analysis, which provides a count of the number of trades every day in a given month by each trade group across the three nearest contract expirations. The daily average number of trades is found by taking the monthly average of the total number of daily trades obtained from the frequency analysis (the total number of trades in a given month divided by the number of trader days in that month). The daily average volume is found by first summing the total quantity of purchases traded in a day (buy observations only) by an individual trader, for a trade type and contract expiration,[7] providing the total sum of quantity traded for each trader on every day in a particular month for a trade type and contract expiration. This total is averaged

[6] CTI 1 trades are the only trade category in which the trade is actually initiated by the trader; therefore, inventory levels are evaluated only for this set of trades over the 3 nearest to expiration contracts.
[7] The data allow for the identification of individual traders; however, because an individual trader can trade in any one of the four trade-type categories, an individual trader may be appearing more than once in this compilation.

over the total trader days in a month by trade category and contract expiration to obtain a monthly daily average level of trading volume for all traders appearing in the month.[8] The same analysis is also conducted using the trades for the traders who fall into the top 10 traders in terms of the overall volume each day.[9] The average trade size is found by evaluating the average quantity traded for each trade category and expiration. The average time between trades is found by evaluating the average time between each trade for each trade category and expiration over each month. Daily average income for futures option and futures (in dollars) for each trade type across the nearest three expirations is found by marking to market each trade over the course of a trader day and averaging the values over all of the days in the sample. If the trade is a sell, the income is found by taking the difference between the trade price and the settlement price and multiplying by the quantity. If the trade is a buy, the income is found by taking the difference between the settlement price and the trade price and multiplying by the quantity.

Information on the total and average number of trades per day, total and average volume, average trade size, and average time between trades for the option markets is displayed in Table 1, and the same information for the futures markets is displayed in Table 2 (see Appendix). The statistics described above are performed in monthly batches, which are then aggregated for display purposes over the 20 months in the sample period for all four trader categories and the three nearest contract expirations.

Table 1 (see Appendix) indicates that CTI 1 trades present the highest levels in both the nearby and first deferred contracts with values that are almost twice the number

[8]While individual trader identifications are used to find the total volume of trade, the daily average volume ignores the actions of any one trader and simply serves to indicate the aggregate characteristics by trade type and contract expiration.
[9] The top 10 are determined on a daily basis, so a particular trader may appear in the top 10 only once over the sample period.

of trades of the next highest trade category (CTI 4). In the second deferred contract, CTI 3 (trades for a customer) trades have the highest daily average number of trades at 161 and total number of trades at 92,585 versus 157 daily average number of trades and 90,543 total number of trades for CTI 1 trades. The nearby and first deferred contracts are typically the most actively traded contracts and, as such, should have the greatest impact on prevailing market prices and trading behavior.

Table 1 also presents information on the daily average and total volume for each of the trade categories across the three nearest expirations (see Appendix). The volume levels indicate that while CTI 1 trades occur more frequently than their other trade counterparts, the average volumes for this group do not exceed the next highest trade category by a significant order of magnitude. This is in line with the previous research on market making in futures markets, which found that market makers tend to trade in small amounts.

Tables 3 and 4 provide information on the percentage of total volume handled by the top 10% of traders (see Appendix). These data imply that trading in the options market is much more concentrated than that in the futures market with over 50% of the overall volume handled by only 10 traders in the options market versus approximately one-fifth in the futures market. Trading in the further-to-expiration contracts indicates a similar pattern.

The average trade-size numbers further support the notion that market makers tend to trade in small amounts with the average trade size for CTI 1 trades being almost three times lower than any other trade category at 38.22 versus 90.50, 95.08, and 118.34 for CTI 2, 3, and 4 trades respectively. As expected, the participation in the first and second deferred contract is much less than the nearby contract in terms of the number of trades and the volume of trade. It is of interest to note that the average trade size for the second deferred contract is much larger across all trade categories, indicating that trading in further-out contracts may be due to temporary disequilibrium in prices and that traders are attempting to maximize their profits by capitalizing on market frictions.

The daily average time between trades is not significantly different for each trade group. The time between trades shows a monotonic decline in the further-to-expiration contracts. Thus, although the levels of activity in terms of volume are higher in the nearby contract, the time between trades is actually longer.

Evaluation of the trading activity of natural-gas futures traders in Table 2 paints a similar picture (see Appendix). The CTI 1 trades dominate the market in terms of their participation levels. Trading in the futures markets takes place on a much lower per-trade level than the options market with the highest number of trades averaging at about 89 for CTI 1 trades and the daily average volume at 13,352 trades per day on average. The average trade size for CTI 1 trades is still the smallest; however, the relative difference between CTI 1 trades and other trade groups narrows in the futures market. Similar findings were also shown for the daily average time between trades for the options and futures markets, with a monotonic decline in the first and second deferred contracts. As expected, trading in the futures market occurs on a much more frequent basis than trading in the options market as shown from the much shorter time in between trades across all trade groups and contract expirations.

Tables 5 and 6 provide the average daily ending inventory levels for CTI 1 trades and the three nearest-to-expiration contracts (see Appendix). CTI 1 option trades have very small levels of average ending inventory in the nearby and first deferred contracts and the second to smallest level in the second deferred contracts. Similar results are found in the futures market. This observation provides evidence that futures-option and futures market makers try to mitigate their exposure to unexpected information that may accumulate overnight by ending the trading day with very low levels of inventory accretion.

The income levels of the four trade types across all three contract expirations from Tables 7 and 8 show that on average, market making in the nearby contract in options markets is unprofitable as measured by both the mean and median levels of income for personal traders; however, market making in the further-to-expiration contracts becomes profitable for this trade group (see Appendix). These results indicate that market makers may be providing a liquidity service in the nearby contract while using the less liquid contracts to make the majority of their profits. Why these traders are providing this service without due compensation does not fall under the risk-return tradeoff of rational investor behavior. A reasonable explanation for the lack of average profitability in the options market may be due to asymmetry in income levels among traders; there may be a few traders losing large sums of money while the vast majority earn positive income. On the other hand, market making in futures markets appears to be profitable on average. Customer-initiated trades are not profitable across all contract expirations in both options and futures markets while those that are initiated by the brokerage house earn the highest levels of income in all but the first-deferred contracts.

Overall, the above analysis supports previous literature that has shown that traders conducting member proprietary, or CTI 1, trades are those who subsume the market-making role in futures markets and extend this to the option market. On average, market makers in the option market trade often, in small amounts, with very little time in between trades, are responsible for the highest levels of activity in terms of volume. They also end the trading day with very low levels of inventory in order to mitigate their exposure to overnight inventory-holding risk. An evaluation of the extent of competitive forces in each trade category and the use of interdealer trades to expel unwanted inventory follows and is conducted in order to provide additional information on the institutional details of option market making.

Options and Futures Market Making: A Competition-Based System

Futures and options markets have systems that can be identified as having market-making competition, which is in stark contrast to the designated system of the NYSE specialist. Competition among dealers has been found to lower spreads (Stoll, 1978; Benston & Hagerman, 1974; Tinic & West, 1972, Wahal, 1997; Klock & McCormick, 1999). Understanding the dynamics of the price formation process requires an evaluation of the competitive forces among market makers, including why and how bid-ask spreads exist and are formed, as well as the impact of competition within market makers.

Demsetz (1968) evaluated the costs and services of dealers and proposed the notion that the overall service provided by dealers is immediacy, the cost of which is the bid-ask spread. The bid-ask spread is a function of the price and a transaction rate variable while the number of markets on which the asset is traded is found to be an insignificant determinant.

Locke and Venkatesh (1997) evaluated a measure of the transaction cost to trading costs estimators based on bid-ask quotes. Through the analysis of futures transaction data on the Chicago Mercantile Exchange, the authors found that quote-based costs estimators have little relationship to the effective trading costs in futures markets.

Yiuman and Zabotina (2004) evaluated the transition of open-outcry trading to electronic trading from the London International Financial Futures and Options Exchange (LIFFE) to LIFFE CONNECT, its electronic trading system for the Financial Times Stock Exchange (FTSE) 100 Index futures contracts. Lower spreads were found in the electronic market after the transition, but the quality of the market, as measured by the variance of pricing error, was higher in the open-outcry market. They also found that trades in the open-outcry market had higher informational content.

Tinic (1972) found that spreads were actually lower when there was greater competition from other markets, while Tinic and West (1972) found that spreads were lower when there were multiple dealers present. Benston and Hagerman (1974) were among the first to evaluate the relationship between the number of market makers and bid-ask spreads. They postulated that spreads should be a function of volume or market activity, share price, risk of carrying costs, risk related to adverse selection, and the number of market makers. They found a significantly negative relationship between the number of market makers and spreads.

Stoll (1978) analyzed the factors that determine the price of dealer services, as well as the number of dealers willing to make a market in a stock using end-of-day data from the NASDAQ, OTC market. He described the three costs that a dealer incurs as: holding costs, order costs, and information costs. Holding costs arise from requests to trade that move dealers away from their optimal level of portfolio holdings and diversification. Order costs are fixed costs that stem from communications and handling fees. Information costs are those due to trading with agents who have superior information and reflect the expected value of the adverse information possessed by those with whom he trades. Stoll developed a model, which he later tested, that postulates a positive relationship between bid-ask spreads and the riskiness of the stock, the reluctance of the dealer to bear risk, the amount of informational trading, the level of order costs, and the lack of competition among dealers in a stock. He found that increased competition among dealers reduces spreads and that there exist an optimal number of dealers in each stock.

Wahal (1997) examined the determinants, frequency, and impact of entry and exit of market makers for stocks on the NNM. He showed that the number of dealers in a security is a function of trading intensity, volatility, and the bid-ask spread. These variables were also found to be important determinants of entry and exit, a pervasive occurrence. Consistent with the competitive model of dealer pricing, market entry is associated with declines in bid-ask spreads. Wahal also found that a nonlinear relationship exists between the change in the number of market makers and the change in spread and concluded that spread changes are larger for issues with few market makers.

Klock and McCormick (1999) provided a more recent view of market maker competition in the NASDAQ OTC market. Similar to that of Wahal (1997) and others, they find a negative relationship exists between the number of market makers and spread. Further, this relationship is nonlinear with a decreasing impact by the marginal market maker. Klock and McCormick also found that NASDAQ spreads have declined over time and that structural changes in the NASDAQ have had significant changes in the relation between spread and the number of market makers.

While the emphasis here is not on the proportion of bid-ask spread attributable to competition, the number of traders is examined across markets and trade and contract type to determine the extent of competitive forces in each of the various trade categories. Traders in these markets can conduct more than one type of trade. The analysis that follows counts the number of traders in each trade category, regardless of whether that particular trader also appeared in another trade group. Thus, the number of traders may include a trader more than once if he or she trades in more than one trade category.

The results in Tables 9 and 10 (see Appendix) indicate that CTI 4 and CTI 1 trades have the greatest amount of individual participation holding 53% (55%) and 39% (34.5%) respectively of the overall participation in option (futures) market. There are very few CTI 2 and CTI 3 trades in either the options or the futures market. Further, as anticipated, the nearby contract has the highest percentage of traders at 46.5% (51%) of the overall. These results indicate that, based on the competitive model of dealer pricing, spreads for the CTI 1 and CTI 4 trades should be lower, on average, than those for CTI 2 and CTI 3 trades.

Inventory Control

The inventory-control models of market microstructure assume that market makers face exogenous demands to buy and sell and that these market makers earn profits from buying and selling at the bid and ask prices respectively. The models predict that market makers will manage their risks and control inventory levels by adjusting the bid and ask prices to induce buying or selling in order to bring inventory levels into a preferred range. A line of literature has evaluated the dynamics of multiple dealer markets and inventory control mechanisms.

Ho and Stoll (1983) considered markets with several dealers and stocks over several periods to develop a theoretical model of equilibrium in a market with competing dealers, which provides an empirical basis for the comparison of competing and monopolistic dealer markets. Dealers face risk that stems both from uncertainty about the returns on their inventories as well as the arrival of transactions. Each dealer also recognizes that his welfare depends on the actions of other dealers and works to maximize his expected utility of wealth when setting prices.

Hansch, Naik, and Viswanathan (1998) tested the implications of Ho and Stoll (1983) that inventory differences determine dealer behavior. They found that relative inventories explain which dealers obtain large trades and that movements between best bid, best ask, and straddle are highly correlated with inventory changes. They further found that interdealer trading plays a large role in managing large inventory positions, with a key determinant of variations in interdealer trades being inventory levels.

Reiss and Werner (1998) used data from the London Stock Exchange to test whether interdealer trade facilitates inventory risk sharing among dealers. Their main focus was on whether dealers primarily use interdealer trades to reduce their inventory exposure, which they found to be the case. In fact, interdealer counterparties most often have the most extreme inventory imbalances. Furthermore, Manaster and Mann (1996) evaluated the cross-section relationship between market-maker inventory positions and trade activity using futures transactions data. They found that not only do traders control inventory throughout the day but also there is a strong positive correlation between inventory and reservation price with increases in inventory leading to higher prices. Lyons (1995) also provided evidence suggesting that market makers set their prices as a function of inventory levels. Finally, Locke and Sarajoti (2004) found that dealers use interdealer trading as a management tool to control their inventory positions. In fact, they found that dealers were more likely to use interdealer trades rather than customer trades to reduce their inventory positions.

In this study, the percentage of trades occurring within each trade type is analyzed in order to evaluate whether dealers may be using interdealer trades to reduce their inventory positions. The percentage is determined through a frequency analysis that counts the fraction of the total number of trades occurring in each subset, with the findings presented in Tables 11 and 12 (see Appendix) for options and futures trades respectively. As discussed in Locke and Sarajoti (2004), interdealer trades are typically more costly to initiate than trades conducted with other trade groups; thus, the only rational explanation for the existence of a significant percentage of interdealer trades is inventory control: These traders would rather immediately transfer their unwanted inventory than face the uncertainty of waiting for customer orders. Traders conducting member proprietary trades are counterparties in 94.88% of the trades in the options market versus 40.07% in the futures market. The levels of interdealer trades across contract expirations for the options market decrease in expiration but are not significantly different. They subsume a substantial amount of the overall trading activity (22.82%, 17.82%, and 16.33% in the nearby, first deferred, and second deferred contracts respectively), lending support to the notion that interdealer trades are used by market makers for inventory-control purposes. In the futures market, the highest percentage of interdealer trades occurs in the first deferred contract at 15.39% while the next highest is in the second deferred contract. These results provide evidence that market makers in the futures markets are using interdealer trades to control their inventory levels in the less liquid contract markets.

The institution characteristics of futures-options markets indicate that competition among traders conducting member proprietary trades and trades for customers are very high. This observation provides an avenue for future research to evaluate whether the spreads for these types of trades are higher than those for the other trade types or whether, due to higher volume of trade in these two groups, the spreads are actually lower. The high levels of competition within the futures-option market may be the driving force behind the loss of profit for traders conducting member proprietary trades. Further, the use of interdealer trading by member proprietary traders to shed unwanted inventory in the futures-option market may also be driving the costs of trading up and the levels of profit down. Overall, while member proprietary traders seem to maintain the characteristics traditionally held by market makers, the lack of profit by this group again does not fall under the rational framework of greater reward for greater degrees of risk. Thus, the risk structure of member proprietary traders must be evaluated in order to understand more fully the constraints that these traders face and how these frictions can help explain the behavior and price setting practices of market makers in futures-option markets.

Option Market Makers Risk Exposure

Analysis of market-making dynamics in options markets has received very little attention in the literature and has primarily focused on the overall risk that option market maker bears. Understanding the risk exposure of the option market maker is important because how and whether the market maker is able to dispel certain portions of risk will ultimately determine his or her trading and price setting behavior. Research has shown that the risk that option market makers are exposed to greatly depends on the stochastic nature of stock returns.

Ho and Stoll (1983) showed that, if the stock return volatility is constant, the market maker's risk exposure per dollar of investment is nonstochastic over the interval during which the inventory is held. However, unless the option market maker can trade continuously, an option transaction's contribution to the dealer's risk exposure will be stochastic because the volatility of an option is a function of both its (stochastic) hedge ratio and the underlying asset's return volatility.

Jameson and Wilhelm (1992) evaluated the risks that options market makers face and provided empirical evidence that their risk factors are unique to option markets due to the stochastic volatility of the stock return and the inability to rebalance the option position continuously. Specifically, by measuring the impact of delta, gamma, and vega on bid-ask spread, they found that gamma and vega are significant determinants of spreads. These risks can be reduced through diversification; however, the authors' finding of significant influence of the risks on spreads indicates that diversification does not completely eliminate the risk due to discrete rebalancing and stochastic volatility on the option market makers' portfolio.

Giannetti, Zhong, and Wu (2004) developed an inventory-based approach to study market-making behavior in option markets. They posit that the hedging practices of option market makers have a substantial impact on the setting of bid-ask spreads and optimal inventory control. By adding hedging mechanisms to the standard inventory-control model, the authors derived the market makers optimum option quote setting and inventory-control policies.

Of vital importance to studying market maker behavior in option markets is evaluation of these traders' exposure to risk. Options market makers' primary exposure to risk comes from price movement in the option and underlying asset markets, rebalancing needs, and volatility of the underlying assets. As noted above, much of the previous research has focused on the price movement and stochastic nature of the underlying assets. However, to determine the overall extent of option market makers exposure to risk, inventory positions must be examined in terms of a vector of risk measures, which include delta, gamma, and vega. Exposure to these risks is due to the influence of certain variables on the option price. Several variables are known to affect option prices: the price of the underlying asset, the options strike price, the time until expiration, the volatility of the price of the underlying asset, the risk free rate, and the value of the dividends expected during the life of the option. The sensitivity of the option price to both the price of the underlying asset and the volatility of the price of the underlying asset are evaluated through an examination of delta, gamma, and vega.

Delta measures the degree to which an option price will move given a change in the underlying asset or, in this case, the sensitivity of the option to the futures price. The delta is often called the neutral hedge ratio; with a portfolio of *n* shares of a stock, *n* divided by delta gives the number of calls needed to be written to create a neutral hedge. A positive delta indicates that the option position will rise in value as the stock price rises and drop in value as the stock price falls. A negative delta, on the other hand, means that the options position should rise in value if the stock price falls and drop in value if the stock price rises. The delta of a call option can range from 0 to 1, whereas the delta of a put option can range from -1 to 0. Thus, a short call has a negative delta, and the long call has a positive delta with these values reversed for puts and the same for stocks. The closer an option's delta is to either -1 or +1, the more the price of the option will respond like an actual long or short stock when the stock price fluctuates.

Gamma indicates how much the delta changes for a $1.00 change in the stock price. It is the second partial derivative of the option price with respect to the underlier. If gamma is small, delta changes slowly, and to keep a portfolio of options, delta neutral one can rebalance the portfolio less frequently. If gamma is large, delta is extremely sensitive to changes in the underlying price, and, therefore, the portfolio will have to be adjusted more frequently. Both long calls and puts have positive gamma. That is, long call positions will have deltas that become more positive and move towards 1 when the underlying price changes but move toward zero when the underlying price falls. Long puts will have deltas that move toward -1 when the stock price falls and move toward 0 when the stock price rises. Short calls and puts have negative gamma; thus, the opposite effects take place. Futures will always have a gamma of zero because the delta value is always 1.0; thus, it never changes.

The vega of an option indicates how much the price of the option will change as the volatility of the underlying asset changes. Vega is calculated to show the theoretical price change for every 1% point change in implied volatility. Long calls and puts both have positive vega, which indicates that the value of the option will increase as the volatility increases and decrease when volatility decreases. Short calls and puts both have negative vega, which means that the value of the option will increase when volatility decreases and decrease when volatility increases. Vega is the greek which has the most impact on option prices second to delta. Jameson and Wilhelm (1992) showed that an options gamma and vega were important in the determination of option market makers' bid-ask spreads and provided an indication of the inventory-risk exposure these traders faced.

The risk characteristics of a portfolio of options can be described by the sum of the risk characteristics of the portfolio components. If the assumption of instantaneous delta hedging in the futures market holds true, market makers in futures-options markets may work to manage the portfolio vega strategically while allowing the option portfolio delta to fluctuate over the course of the trading day. Of critical importance to the evaluation of the risk characteristic that provides the most information about exposure to inventory-holding risk is whether market makers in option markets maintain delta neutrality by hedging their trades in the option market with offsetting positions in the underlying futures market. While many have speculated this to be the case, due to data limitations, it has not been formally tested. This unique data set facilitates the evaluation of traders' positions in both the futures and option markets, which allows for incorporation of information about whether these traders are maintaining delta neutral positions by conducting simultaneous, off-setting trades. Two issues are addressed in the analysis that follows: (a) Which of the risk parameters better captures the overall inventory risk that the option market maker bears? (b) Do option market makers use the underlying futures market to maintain delta neutrality? These questions are addressed by evaluating the market maker's risk holdings end-of-day, midday, and intraday.

End-of-Day Analysis

To evaluate the risk characteristics of market makers in option markets, the market maker's end-of-day position risk parameters are examined. If a trader is simultaneously trading in both the option and futures markets, position delta will reflect the extent to which the trader is maintaining a delta-neutral portfolio at the end of each day by creating offsetting trades from participation in both markets. If the trader is only participating in the option market, the position delta will be calculated using only the trades from the option market and will also provide information about end-of-day delta neutrality. The gamma and vega of futures are zero; thus, those values incorporate only information about trades in the option market. Evaluation of the end-of-day positions allows for an assessment of the extent to which market makers in the options market work to mitigate exposure to overnight price and volatility risk.

In order to facilitate the analysis of the position parameter levels, several simplifying assumptions must be made. First, it is assumed that traders conducting member proprietary trades begin each trading day with an inventory level of zero. Manaster and Mann (1996) provided evidence that daily changes in inventory are concentrated around zero, so it is reasonable to assume that all traders begin the day with a zero-inventory position. This notion is further supported by our observations from Tables 5 and 6 (see Appendix) that market makers end their trading day with very low levels of inventory in order to mitigate their exposure to overnight information. Thus, as in Manaster and Mann (1996), it is assumed here that traders begin each day with zero inventory. Second, while the analysis for the option market is performed by broker identification numbers, which are unique for a particular trader, in order to track trades from the option to the futures market, account numbers must be used when matching trades in both markets. The trades are matched by account number and time; thus, it is assumed that if a trade occurs within the same minute for the same account, it is instigated by the same broker. There may be more than one broker per account number; therefore, noise will be introduced into the matching process. Finally, trades in the options market will contain only those performed by traders conducting CTI 1 trades, whereas they are matched with both CTI 1 and CTI 3 trades from the futures market because it is reasonable to assume that a trader in either category of trade in the futures market could be executing offsetting trades for the option market makers.

In order to calculate the parameter estimates, a price series must be formed for the option and futures markets. There are two issues to address in forming a matched price series for the option and futures markets: (a) which contract expiration to use and (b) how to address nonsynchronous trading issues. The first issue arises because the contract with the highest volume may not be the nearby contract. Volume is well known to be a proxy for information and highly related to open interest; thus, the contract that has the highest amount of volume on a given day in the sample is chosen for use in this analysis. The second issue arises because futures markets are much more active than the relatively illiquid option market; thus, issues involving nonsynchronous trading must be addressed. NYMEX requires that trades be reported within one minute of execution, so it is reasonable to aggregate prices over a one-minute time span in order to form a price series that alleviates some of the nonsynchronous trading.

Thus, volume-weighted average prices for observations from proprietary trades (CTI 1 trades) for the contract with the highest amount of volume are computed over one minute intervals for both the option and the futures markets in order to address issues with nonsynchroneity of trade occurring due to the much higher levels of trading in futures versus the option market. The volume weighted average prices are found by multiplying the trade price for a given observation by the quantity traded at that price with the average taken over all observations in a minute.

Once a volume-weighted average price is found, the observations (minutes) that do not have simultaneous trading in both markets are removed from the sample. For the end-of-day analysis, the last observation at each strike, for each option type (put and call) is taken along with the futures-settlement price and used in a binomial pricing model to estimate the option premiums and futures prices.

The binomial option-pricing model facilitates modeling of the underlying instrument over time, as opposed to a particular point in time; thus, it is used to allow for the early exercise component of futures contracts. Also known as American-style options, which can be exercised at any point in time, early exercise is a unique feature of options on futures contracts that stems from the minimal time value associated with in-the-money futures options. It is advantageous to exercise in-the-money futures options early and reinvest the proceeds at the risk free rate in order to earn a higher overall rate of return.

An implied standard deviation is used as a proxy for σ_F which, along with the time duration of a step, t, measured in years, is used to calculate the probability that the price of the underlying asset will move up or down at each step in the binomial tree. This implied standard deviation is calculated from the most actively traded, near-the-money option for the settlement futures price. A grid search is used to find the implied standard deviation, which minimizes the mean-squared error over the trading day by comparing the average option premium to the observed premium for each hypothetical sigma.

This method ensures that the tree is recombinant, which reduces the number of tree nodes and speeds up the computation of the option price. This property also allows for the underlying price to be calculated directly from a formula at each node rather than from having to build the entire tree. It is well known that option valuations cycle from high to low as the number of steps increases, holding time to maturity constant; therefore, two separate steps are used, 30 and 31, to calculate the average option value for each hypothetical sigma.

Once the premiums, futures prices, and implied standard deviation have been found, the delta, gamma, and vega are calculated as in Hull (2000). Again, delta is the first partial derivative of the option price with respect to the underlier, gamma is the second partial derivative of the option price with respect to the underlier, and vega measures the change in the option price with respect to a change in the volatility of the underlier. An estimate of delta, gamma, and vega are computed for each strike price and option type (put and call).

Positions delta, gamma, and vega are obtained for each trader in each trading day in the sample. The position levels are found by first multiplying the parameter estimate by the quantity traded. These values are then summed for each trader every day, providing a data set that contains the overall, ending position parameter values for each trader in every day of the sample. These values are then averaged each month across all of the traders to obtain a daily average parameter position. It should be noted that no individual trader identifications are used in this final step. The average position parameter level is calculated to provide an indication of the average level of risk for any given trader conducting member proprietary trading. These values are calculated for each month and then aggregated over all months in the sample.

The results of this analysis are presented in Table 13 (see Appendix). The median value of all of the risk parameters is zero, and the mean values are very small in relative terms. Position gamma is positive on average, indicating that traders do not need to rebalance their portfolio very often in order to mitigate their risk to changes in the price of the underlier. This also addresses concerns that the discrete rebalancing option market makers are exposed to increases their overall price risk; while this may be more of an issue intraday, over the course of any one day this concern is alleviated. Position vega is negative on average, which means that the average position will gain as volatility falls. Overall, it appears that market makers in option markets reduce their exposure to overnight price and volatility risk by ensuring that their end-of-day values are very small. To test for the use of simultaneous trading in the option and underlying futures markets, position delta was also calculated using only trades in the options market. The mean value was significantly higher at 5.77, thus providing support to the notion that some market makers use the futures markets to maintain delta neutral positions.

Intraday Analysis

Of further importance is whether and how the market maker's inventory holding risks are changing over the course of the trading day. Examining the intraday as well as the end-of day values of delta, gamma, and vega allows for a decomposition of the characteristics that option market makers manage in order to mitigate their exposure to inventory risk. By evaluating the distribution of the risk characteristics over the trading day, it can be determined whether any intraday patterns in risk management exist for market makers in the options market. Intraday analysis also allows for a determination of whether incremental rather than end-of-day delta neutrality exists.

The initial approach to studying the intraday risk holdings of market makers in the option market is to evaluate position parameter levels at midday. Parameter estimates for delta, vega, and gamma are calculated using the daily implied standard deviations that were found in the end-of-day analysis. The market makers' position delta, gamma, and vega are then calculated by aggregating their trades over the time period spanning 9:00 am until 12:00 pm, with the results found in Table 14 (see Appendix).

Position delta is slightly higher midday than end-of-day at 2.17 versus 0.23, lending minor support to the hypothesis that market makers allow fluctuation in their portfolio delta due to maintaining delta-neutral positions. Gamma is also larger in absolute terms, indicating that intraday delta changes more quickly and market makers must rebalance their portfolios more often in order to maintain delta-neutral positions. Position vega, on the other hand, is smaller in absolute terms, possibly due to the intraday maintenance of market makers' exposure to volatility risk.

To further explore the risk of the market maker in futures options, intraday market-maker risk is evaluated over five time increments. A time increment consists of one hour of trading, except the initial increment that consists of the first 2 hours of trading.[10] An implied standard deviation is calculated during each increment, similar to the daily analysis. However, rather than the futures settlement price, the last volume-weighted average futures price in the increment is used as a proxy for the settlement

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[10] Due to the lack of trading in the first hour, the first 2 hours of trade are combined for the incremental analysis.

price. The last observation at each strike for both option types in each increment, combined with the futures settlement proxy, is then used to calculate the option prices and find the implied standard deviation. Thus, risk parameters are obtained for each increment. The position levels are marked to market at the end of each increment to account for open positions (either long or short) in the computation of the position parameter levels.[11]

Several different sample subsets are evaluated. First, a sample using the average of the volume-weighted average bid and ask prices is evaluated with the results shown in Table 15 (see Appendix). A Wilcoxon signed-rank test is performed on the aggregated data to test whether the position levels in each increment are significantly different from zero.

Theory posits that options traders[12] will use the futures market to hedge their trades; however, here it is found that options traders do not effectively use the futures market for hedging purposes. In fact, option traders are more adept at hedging their price risk using other options than they are at using the futures markets, a tendency that can be seen from the higher levels of price risk when the futures trades are combined with the trades from the option market. It is also shown that option traders maintain very low and virtually constant levels of price risk, with all but one increment revealing levels that are insignificantly different from zero. Thus, the hypothesis that traders allow their price risk to fluctuate during the course of the trading day can be rejected. Position gamma increases monotonically over the course of the trading day, indicating that issues with

[11] Marking the position parameter levels to market each increment entails summing the positions of each increment to carry forward the balance (if the trader is net long in the increment) or debit (if the trader is net short in the increment) of trades. The balance is then added to the first trade in the increment and multiplied by the increment's parameter estimate to calculate the increment's parameter position level.
[12] *Option traders* refers only to member proprietary traders or CTI 1 traders.

discrete rebalancing become more important towards the end of the trading day when trading volume is also the highest. The mean values of position vega indicate a sinusoidal behavior, starting off low, rising to a peak at midday, falling off during the fifth hour of trade before rising to the highest level at the end of the trading day. However, when one evaluates the median levels of both gamma and vega, it appears that market makers are mitigating most of the exposure to these risks by maintaining very low and virtually constant levels of risk.

The second subsampling involves partitioning the buy trades from the sell trades and performing the above analysis on the two separate groupings, with the results presented in Tables 10 and 11 for buys and sells respectively (see Appendix). In general, it appears that being long exposes a market maker to much higher levels of price and volatility risk than being short. Position delta for buys and sells becomes non-zero at midday (increments 2 and 3) but begins and ends the day with levels that are close to zero. For long trades, position delta without futures fluctuates around zero, whereas for sell trades, position delta without futures is insignificantly different from zero across all time increments.

Traders will have the same impact in the averaging technique regardless of their relative size. Therefore, a separate analysis is performed for traders who fall in the top 10 in terms of volume traded on a daily basis versus those who do not in order to determine whether a difference exists between large and small traders. Larger traders have a more difficult time managing their inventory as shown in Table 18 (see Appendix) with position delta values that are larger than those for traders not in the top 10 as shown in Table 19 (see Appendix). The lack of liquidity in the option market may make it difficult for traders to unwind large positions, thus increasing their inventory-holding risk. For both groups, position delta tends to fluctuate around zero in a similar pattern. Volatility risk is much higher for the group of traders in the top 10.

Due to the finding that options market makers are not, on average, adept at managing price risk using the futures market, an additional analysis was performed to determine whether options market makers tend to specialize in hedging in a particular market. To evaluate whether option market makers specialize in hedging only in options or in futures the first month of the sample, September 2005, is evaluated. A frequency analysis of the number of traders engaging in trades in both the futures and option markets versus the option market only is performed, with the results shown in Table 20 (see Appendix). The frequency provides a count of the number of trades for a particular trader. Of the 65 option market makers who were trading in September 2005, 25, or 38.64%, traded only in the option market and did not use the futures market to hedge. Of these traders, their overall trading activity is very low, capturing only 3.8% of the overall number of trades conducted that month.

Forty, or 61.54%, of the options market makers engage in trading in both markets. The number of trades in the futures market far surpasses the number of trades in the options market with 3020 and 4452 trades in options and futures respectively. Thus, hedging options trades in the futures market is not a one-for-one strategy. Trading in options captures 38.88% of the overall number of trades for the month, whereas trades in the futures market are at about 57.32%. Higher amounts of trading in the futures market may be one explanation for why the levels of position delta are higher when both option and futures trades are evaluated than when only the options trades are evaluated. Market makers who are using both markets to hedge are overestimating their exposure to price risk, resulting in holding (or selling) too many of the underlying futures contracts to offset their positions in the options market.

A similar analysis is performed to determine whether certain option market makers tend to trade in particular categories of moneyness. It is reasonable to assume that certain traders may choose to specialize in a group of options determined by moneyness due to the relative differences in cost and structure of the various option types. For instance, deep in-the-money options are almost perfect substitutes for the underlying security, while in-the-money options are the cheapest. If option market makers have certain trading strategies based on the differences between moneyness categories, patterns in trading certain options should emerge.

Typically ranges rather than a point estimate are used to calculate moneyness levels. There is a lack of a universal definition of an appropriate range for each type of moneyness; therefore, many different ranges of moneyness are explored in order to determine the appropriate moneyness level for this sample: moneyness was defined by a range of 1%, 2%, 3%, 4%, and 5%. In other words, for a range of 1%, an at-the-money (ATM) option is one whose strike price is within 1% of the price of the futures settlement price, an out-of-the-money (OTM) option is one whose strike price is above 1% of the futures settlement price, and an in-the-money (ITM) option is one whose strike price is below 1% of the futures settlement price. Skewed ranges are also examined which use a range of within 1% of the futures settlement price for ITM options and within 4% of the futures settlement price for OTM options. The same analysis is conducted using 2% and 5% for ITM and OTM options respectively.

As is shown in Table 21 (see Appendix), the majority of the trades were in out-of-the-money options, for both puts and calls. A moneyness level of 3% is chosen because it has similar trade levels to the skewed ranges and offers the greatest range of observations in each moneyness group.

A frequency analysis is performed to determine whether market makers specialize in moneyness groups. This analysis reveals that the vast majority of options market makers trade in all types of moneyness with only 11 of the 65 trading in only one or two categories of option moneyness. For those 11 traders, all but two conduct only one trade during the month of September. Of the remaining 54 traders who participate in trading across all levels of moneyness, 66.17% of their trades are in out-of-the-money options, 18.87% are in at-the-money options, and 14.12% of their trades are in in-the-money options as shown in Table 22 (see Appendix). Thus, it does not appear that market makers focus on only one category of moneyness, but instead trade across moneyness groups, with the majority of their trading focused on out-of-the-money options, probably due to their cost-relative at-the-money or in-the-money options.

Conclusion

The institutional characteristics of traders behind four different trade classifications are evaluated for the option and futures NYMEX natural-gas markets in order to decompose trade-type characterization. It is found that traders conducting member proprietary trading in the natural-gas option market behave as though they are market makers, on average, trading often in small amounts with very little time in between trades, and are responsible for the highest levels of activity in terms of volume. They also end the trading day with very low levels of inventory in order to mitigate their exposure to overnight inventory-holding risk. The finding of a lack of profitability for these trades is not in line with previous findings on market-making activities and falls outside of the rational relationship between risk and return. It is reasonable to assume that the incomes of traders are asymmetric, with several traders losing large sums of money while the vast majority earn positive profits. Evaluation of the extent of competitive forces in each trade category and the use of interdealer trades to expel unwanted inventory are also conducted in order to provide more information on the institutional details of option market making. It is shown that traders who conduct member proprietary trading are one of the largest trader groups and engage in significant amounts of interdealer trading in order to maintain their preferred inventory levels.

The portfolios of option market makers are examined in terms of their exposure to daily levels of risk as measured by delta, gamma, and vega. It is found that end-of day positions are very small, a result that supports the hypothesis that market makers try to mitigate their exposure to overnight risk. The midday analysis provides higher values of delta and gamma and smaller values of vega, providing limited evidence that option market makers work to maintain their exposure to volatility risk. Intraday, delta is shown to be relatively constant and very small while vega oscillates around zero and gamma increases monotonically throughout the trading day; this result lends support to the hypothesis that market makers in options markets work to maintain their exposure to both price and volatility risk. Interestingly, futures-option market makers appear to use the options market more often than the futures market to hedge, and they are also more adept at offsetting trades in the option market. This tendency leads to lower levels of position delta when considering only trades in the option market than when the futures trades are included as well.

This essay provides an in-depth analysis of how market makers in option markets make their market and lays the foundation for a wealth of future research paths. Future research directly stemming from this analysis should evaluate how changes in risk holdings affect the prices that market makers maintain. Patterns in bid-ask spreads are well documented; thus, the intraday changes in risk holdings and the movement of traders into and out of the market may serve as additional measures to help explain their U-shaped patterns. It is also of interest as to whether the introduction of electronic trading of NYMEX natural-gas futures in September 2006 and NYMEX natural-gas options in June 2007 affected the trading behavior of market makers in these markets. Other issues that deserve further examination include why market makers in the option market provide liquidity services if they are earning negative income, how option market makers are using the option market to mitigate their exposure to price risk, the impact of a market event on the number and ability of traders providing market-making services, as well as the extent to which interdealer trading impacts risk levels and, ultimately, market prices. These are largely unaddressed areas in the literature and warrant further investigation.

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Appendix: Tables

Table 1 displays summary statistics for all trade categories over the first three nearest contract months for options. The level of analysis used to conduct the testing of whether member proprietary trader behavior is indicative of that of market makers in futures options is meant to provide an indication of how an average trader conducting a certain type of trade behaves and the characteristics of each type of trade. The total number of trades each day is determined through a frequency analysis that provides a count of the number of trades every day in a given month by each trade group across the three nearest contract expirations. The daily average number of trades is found by taking the monthly average of the total number of daily trades obtained from the frequency analysis (the total number of trades in a given month divided by the number of trader days in that month). The daily average volume is found by first summing the total quantity of purchases traded in a day (buy observations only) by an individual trader for a trade type and contract expiration. This provides the total sum of quantity traded for each trader on every day in a particular month for a trade type and contract expiration. This total is averaged over the total trader days in a month by trade category and contract expiration to obtain a monthly daily average level of trading volume for all traders appearing in the month. The average trade size is found by evaluating the average quantity traded for each trade category and expiration. The average time between trades is found by evaluating the average time between each trade for each trade category and expiration over each month.

Table 1

Summary Statistics for NYMEX Natural-Gas Options

CTI	Daily average number of trades	Total number of trades	Daily average volume	Total volume	Average trade size	Average time between trades
			Nearby contract			
1	1969	1,136,352	5,232	2,160,672	38.22	20.05
2	179	103,062	613	227,330	09.50	20.21
3	89	51,005	458	177,324	95.08	18.98
4	1082	622,898	4,675	1,930,659	118.34	19.73
			First deferred contract			
1	802	461,583	2,993	1,236,031	42.51	13.18
2	88	50,770	585	189,577	109.67	13.94
3	38	21,693	233	63,144	88.48	12.21
4	496	286,259	3,108	1,283,489	113.19	12.85

CTI	Daily average number of trades	Total number of trades	Daily average volume	Total volume	Average trade size	Average time between trades
Second deferred contract						
1	157	90,543	1,679	693,520	44.89	8.88
2	91	52,370	399	99,440	113.81	11.31
3	161	92,585	232	43,763	122.79	10.56
4	87	50,333	2,029	838,143	128.95	10.13

Table 2 displays summary statistics for all trade categories over the first three nearest contract months for futures. The level of analysis used to conduct the testing of whether member proprietary trader behavior is indicative of that of market makers in the futures market is meant to provide an indication of how an average trader conducting a certain type of trade behaves and the characteristics of each type of trade. The total number of trades each day is determined through a frequency analysis that provides a count of the number of trades every day in a given month by each trade group across the three nearest contract expirations. The daily average number of trades is found by taking the monthly average of the total number of daily trades obtained from the frequency analysis (the total number of trades in a given month divided by the number of trader days in that month). The daily average volume is found by first summing the total quantity of purchases traded in a day (buy observations only) by an individual trader for a trade type and contract expiration. This provides the total sum of quantity traded for each trader on every day in a particular month for a trade type and contract expiration. This total is averaged over the total trader days in a month by trade category and contract expiration to obtain a monthly daily average level of trading volume for all traders appearing in the month. The average trade size is found by evaluating the average quantity traded for each trade category and expiration. The average time between trades is found by evaluating the average time between each trade for each trade category and expiration over each month.

Table 2

Summary Statistics for NYMEX Natural-Gas Futures

CTI	Daily average number of trades	Total number of trades	Daily average volume	Total volume	Average trade size	Average time between trades
			Nearby contract			
1	89	146,903	13,352	3,591,645	7.94	2.98
2	5	6,056	1,797	483,409	18.45	3.85
3	4	6,017	628	1669,027	10.84	2.35
4	55	90,644	9,363	2,518,702	15.17	4.12
			First deferred contract			
1	47	76,841	7,521	2,023,137	10.07	0.27
2	4	3,458	1,777	478,070	26.73	0.78
3	2	2,005	318	85,605	10.51	0.40
4	33	54,117	6,112	1,644,106	20.73	0.74

CTI	Daily average number of trades	Total number of trades	Daily average volume	Total volume	Average trade size	Average time between trades
			Second deferred contract			
1	26	43,242	3,182	856,016	11.74	0.28
2	3	1,881	1,076	287,270	35.86	0.33
3	2	1,068	150	40,137	14.69	0.08
4	20	32,103	2,727	733,686	25.27	0.41

The daily volume of each options trader identified as conducting a member proprietary trade was found by summing the quantity traded over each day in the sample. The top 10 CTI 1 traders were then identified by their daily total volume of trade. Their overall percentage of volume was determined by computing the amount of volume captured by the top 10 traders each day as a portion of the total volume of trade for a day by all traders conducting CTI 1 trades. The average daily volume handled by the top 10 traders conducting CTI 1 trades was found by averaging the percentage of volume over all of the trade days in a month. The statistics listed below are aggregated over all of the months in the sample.

Table 3

Average Daily Volume Handled by Top 10 CTI 1 Options Traders

Contract type	Average percent volume
Nearby	47.05%
First deferred	27.14%
Second deferred	15.63%

The daily volume of each futures trader identified as conducting a member proprietary trade was found by summing the quantity traded over each day in the sample. The top 10 CTI 1 traders were then identified by their daily total volume of trade. Their overall percentage of volume was determined by computing the amount of volume captured by the top 10 traders each day as a portion of the total volume of trade for a day by all traders conducting CTI 1 trades. The average daily volume handled by the top 10 traders conducting CTI 1 trades was found by averaging the percentage of volume over all of the trade days in a month. The statistics listed below are aggregated over all of the months in the sample.

Table 4

Average Daily Volume Handled by Top 10 CTI 1 Futures Traders

Contract type	Average percent volume
Nearby	18.91%
First deferred	13.89%
Second deferred	8.11%

The average daily ending inventory levels for the first three nearest expirations in the CTI 1 trade category in options are found by summing the quantity traded over both buys and sells for each individual trader every day, thus providing an ending inventory level for each trader on each trade day in the sample. The average daily ending inventory level was determined by taking a simple average of the individual ending inventory levels over all traders and all days in a particular month. The levels shown here are aggregated over all months in the sample.

Table 5

Average Daily Ending Inventory for CTI 1 Traders in the Options Market

Contract	Daily average ending inventory
Nearby	-0.85
First Deferred	-0.33
Second Deferred	5.05

The average daily ending inventory levels for the first three nearest expirations in the CTI 1 trade category in futures are found by summing the quantity traded over both buys and sells for each individual trader every day, thus providing an ending inventory level for each trader on each trade day in the sample. The average daily ending inventory level was determined by taking a simple average of the individual ending inventory levels over all traders and all days in a particular month. The levels shown here are aggregated over all months in the sample.

Table 6

Average Daily Ending Inventory for CTI 1 Traders in the Futures Market

Contract	Daily average ending inventory
Nearby	0.92
First deferred	0.22
Second deferred	-0.53

Daily average income for options (in dollars) for each trade type across the nearest three expirations is found by marking to market each trade over the course of a trader day and averaging the values over all of the days in the sample. If the trade is a sell, the income is found by taking the difference between the trade price and the settlement price and multiplying by the quantity. If the trade is a buy, the income is found by taking the difference between the settlement price and the trade price and multiplying by the quantity.

Table 7

Daily Income Levels for Natural-Gas Options Trade Types

CTI type	Total average income	Minimum	25%	Median	75%	Maximum
			Nearby contract			
1	-42,408	-6,494,048	-993,451	-23,529	863,279	16,700,880
2	3,045,416	-110,379,000	-1,485,390	698,316	5,335,166	230,910,000
3	617,374	-15,757,970	-770,640	140,585	1,743,332	27,729,125
4	-180,553	-15,617,995	-749,090	-53,608	564,773	4,885,047
			First deferred contract			
1	-7,237	-13,429,218	-1,030,840	107,488	1,089,424	9,725,842
2	3,432,201	-147,140,000	-2,276,844	972,105	7,782,250	171,105,958
3	-217,173	-93,160,510	-1,764,750	-1,088	2,363,283	29,993,960
4	-152,672	-8,394,095	-989,541	-233,478	588,856	15,087,628
			Second deferred contract			
1	124,997	-14,813,153	-976,624	238,196	1,360,609	20,105,475
2	2,986,422	-254,290,000	-3,079,333	771,900	7,017,500	157,716,000
3	199,238	-51,402,000	-2,378,880	-34,500	3,238,500	57,064,000
4	-290,023	-25,641,226	-1,328,300	-281,002	753,261	13,914,056

Daily average income for futures (in dollars) for each trade type across the nearest three expirations is found by marking to market each trade over the course of a trader day and averaging the values over all of the days in the sample. If the trade is a sell, the income is found by taking the difference between the trade price and the settlement price and multiplying by the quantity. If the trade is a buy, the income is found by taking the difference between the settlement price and the trade price and multiplying by the quantity.

Table 8

Daily Income Levels for Natural-Gas Futures Trade Types

CTI type	Total average income	Minimum	25%	Median	75%	Maximum
			Nearby contract			
1	1,045	-64,492	-1,424	629	3,481	63,629
2	2,084	-500,889	-11,796	399	13,184	277,329
3	167	-105,120	-4,823	-76	5,240	68,584
4	-759	-30,721	-2,118	-387	921	21,642
			First deferred contract			
1	2,054	-27,909	-1,523	1,094	3,764	85,499
2	-5,300	-418,458	-21,385	-1,284	11,188	238,041
3	490	-154,821	-5,334	195	6,132	195,384
4	-485	-48,328	-3,031	-434	2,267	50,882
			Second deferred contract			
1	1,163	-63,395	-1,924	761	3,835	44,878
2	6,730	-572,000	-16,728	1,320	20,628	1,415,205
3	2,606	-357,997	-8,031	-52	8,954	2,380,200
4	-1,998	-178,295	-5,991	-631	3,150	66,210

This analysis is performed to determine the extent of concentration and competition in the options market. The daily average number of options traders per day for the three nearest expirations in the options market is found by first summing the number of traders, where a trader is identified by unique identification number each day. These values are then averaged over the number of trader days in a month to obtain an average daily number of option traders in each month. The levels shown below are aggregated over all 20 months in the sample.

Table 9

Daily Average Number of Options Traders

CTI	Average number of traders
	Nearby contract
1	28
2	3
3	4
4	43
	First deferred contract
1	22
2	2
3	2
4	27
	Second deferred contract
1	15
2	1
3	2
4	19

This analysis is performed to determine the extent of concentration and competition in the futures market. The daily average number of futures traders per day for the three nearest expirations in the options market is found by first summing the number of traders, where a trader is identified by unique identification number each day. These values are then averaged over the number of trader days in a month to obtain an average daily number of futures traders in each month. The levels shown below are aggregated over all 20 months in the sample.

Table 10

Daily Average Number of Futures Traders

CTI	Average number of traders
	Nearby contract
1	136
2	24
3	23
4	267
	First deferred contract
1	107
2	17
3	12
4	161
	Second deferred contract
1	63
2	8
3	6
4	63

The percentage of trades by customer type in the options market is determined through a frequency analysis of trade combinations across the nearest three expiration contracts to examine the extent of interdealer trading in the options market. Interdealer trades are identified when both the initiator of the trade and the opposite trader are both trading for their personal accounts.

Table 11

Interdealer Trading Options

Trader	Opposite trader	Percentage of trades by customer type
	Nearby Contract	
Personal	Personal	22.82%
Personal	House	3.30%
Personal	Other floor	3.97%
Personal	Customer	64.79%
House	House	0.05%
House	Other floor	0.17%
House	Customer	1.29%
Other floor	Other floor	0.03%
Other floor	Customer	0.62%
Customer	Customer	2.97%
	First Deferred Contract	
Personal	Personal	17.82%
Personal	House	3.42%
Personal	Other floor	2.28%
Personal	Customer	71.30%
House	House	0.07%
House	Other floor	0.09%
House	Customer	1.41%
Other floor	Other floor	0.02%
Other floor	Customer	0.53%
Customer	Customer	3.05%
	Second Deferred Contract	
Personal	Personal	16.33%
Personal	House	2.99%
Personal	Other floor	2.00%
Personal	Customer	72.82%
House	House	0.07%
House	Other floor	0.10%
House	Customer	1.58%
Other floor	Other floor	0.02%
Other floor	Customer	0.60%
Customer	Customer	3.50%

The percentage of trades by customer type in the futures market is determined through a frequency analysis of trade combinations across the nearest three expiration contracts to examine the extent of interdealer trading in the futures market. Interdealer trades are identified when both the initiator of the trade and the opposite trader are both trading for their personal accounts.

Table 12

Interdealer Trading Futures

Trader	Opposite trader	Percentage of trades by customer type
	Nearby contract	
Personal	Personal	11.95%
Personal	House	6.59%
Personal	Other floor	1.36%
Personal	Customer	28.97%
House	House	2.58%
House	Other floor	0.12%
House	Customer	16.27%
Other floor	Other floor	0.01%
Other floor	Customer	0.54%
Customer	Customer	26.78%
	First deferred contract	
Personal	Personal	15.39%
Personal	House	9.34%
Personal	Other floor	1.84%
Personal	Customer	44.58%
House	House	1.79%
House	Other floor	0.12%
House	Customer	14.23%
Other floor	Other floor	0.01%
Other floor	Customer	0.48%
Customer	Customer	27.60%
	Second deferred contract	
Personal	Personal	12.72%
Personal	House	8.53%
Personal	Other floor	1.95%
Personal	Customer	39.90%
House	House	1.16%
House	Other floor	0.12%
House	Customer	10.86%
Other floor	Other floor	0.01%
Other floor	Customer	0.49%
Customer	Customer	24.26%

Using option and futures settlement prices, an implied standard deviation is found, which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls). For each trader, the quantity of trade is summed over the entire trading day and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample.

Table 13

End of Day Risk Parameter Position Levels

Risk parameter	Mean	Median	Minimum	Maximum	Standard deviation
Position delta	0.23	0	-437.63	388.91	57.62
Position gamma	0.65	0	-621.35	416.38	90.46
Position vega	-6.34	0	-285.76	440.51	49.56

Using option and futures settlement prices, an implied standard deviation is found, which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls). For each trader, the quantity of trade conducted over the trading hours of 9 am to 12 pm is summed and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The midday position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample.

Table 14

Midday Risk Parameter Position Levels

Risk parameter	Mean	Median	Minimum	Maximum	Standard deviation
Position delta	2.17	0	-184.61	353.48	37.46
Position gamma	-3.23	0	-1332.97	387.62	96.10
Position vega	-4.43	0	-262.17	258.61	34.98

The trading day is partitioned into five increments. Using the last trade for both options and futures in a time increment, an implied standard deviation is found for each time increment, which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options incremental settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls) in each increment. For each trader, the quantity of trade is summed over the increment and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The positions are marked to market each increment by summing the quantity traded over a particular increment for a trader and using that level as the beginning inventory level for the next increment. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample. The Wilcoxon signed-rank test is performed to test whether the mean averages each month ($n = 20$) are significantly different from zero.

Table 15

Intraday Risk Parameter Position Levels Over Five Time Increments

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position delta			
1	-0.05	0.4524	1.75	52.43	-1022.29	1834.99
2	3.21	0.0153	2.52	101.19	-2973.32	3179.35
3	4.97	0.0484	2.60	107.25	-2996.53	4146.03
4	4.21	0.0049	2.12	97.29	-1676.24	6601.65
5	1.14	0.5217	2.08	100.38	-1926.00	4021.32
			Position delta without futures			
1	0.08	0.7285	1.39	45.21	-1000.00	977.71
2	1.95	0.0441	1.74	59.95	-772.91	3179.35
3	1.57	0.2162	1.64	69.20	-2379.33	4146.03
4	1.01	0.2611	1.36	54.52	-1200.00	853.56
5	-0.90	0.5706	1.04	72.03	-1400.00	4001.32

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position gamma			
1	1.27	0.2024	1.85	98.09	-3525.40	3465.95
2	11.14	< 0.0001	2.73	125.71	-1735.19	3440.48
3	12.12	< 0.0001	2.52	121.54	-1294.19	7068.41
4	13.02	< 0.0001	2.24	168.03	-6888.15	6763.43
5	16.06	< 0.0001	2.20	152.25	-2432.28	3305.11
			Position vega			
1	0.69	0.2455	1.59	42.30	-1214.29	1052.35
2	4.71	0.0003	2.52	71.32	-1615.26	3518.78
3	7.05	0.0002	2.28	87.01	-1653.34	12146.64
4	4.74	< 0.0001	1.98	77.47	-2270.48	3018.74
5	7.44	< 0.0001	1.71	70.78	-1531.87	2880.80

The trading day is partitioned into 5 increments. Using the last buy trades for both options and futures in a time increment, an implied standard deviation is found for each time increment, which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options incremental settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls) in each increment. For each trader, the quantity of trade is summed over the increment and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The positions are marked to market each increment by summing the quantity traded over a particular increment for a trader and using that level as the beginning inventory level for the next increment. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample. The Wilcoxon signed-rank test is performed to test whether the mean averages each month (n = 20) are significantly different from zero.

Table 16

Intraday Risk Parameter Position Levels Over 5 Time Increments for Buys

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position delta			
1	0.62	0.5958	0.04	45.04	-1155.71	681.75
2	6.91	0.0107	0.13	100.09	-4029.85	1432.78
3	5.40	0.0400	0.12	90.29	-1498.83	1339.89
4	5.72	0.1231	0.02	112.37	-2100.00	4028.10
5	1.75	0.5217	0.30	110.10	-4835.00	1115.05
			Position delta without futures			
1	-0.27	0.9854	0.02	42.68	-1155.71	702.19
2	5.62	0.0296	0.09	82.80	-4029.85	913.44
3	3.15	0.1327	0.04	80.90	-1195.00	1684.89
4	3.01	0.0349	0.00	99.25	-2100.00	4263.22
5	-0.19	0.8408	0.13	97.31	-4855.00	1066.65

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
Position gamma						
1	43.10	< 0.0001	7.80	117.48	0.00	3465.95
2	82.36	< 0.0001	14.29	240.74	0.00	6397.74
3	74.07	< 0.0001	13.62	184.17	0.00	3317.14
4	75.80	< 0.0001	11.36	221.24	0.00	5826.77
5	80.77	< 0.0001	12.96	221.02	0.00	10854.02
Position vega						
1	17.66	< 0.0001	3.82	44.63	0.00	1382.39
2	36.27	< 0.0001	6.43	92.97	0.00	2706.24
3	33.96	< 0.0001	6.55	84.46	0.00	4222.78
4	40.25	< 0.0001	5.37	157.02	0.00	15112.40
5	35.91	< 0.0001	5.92	93.27	0.00	2948.87

The trading day is partitioned into 5 increments. Using the last sell trades for both options and futures in a time increment, an implied standard deviation is found for each time increment, which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options incremental settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls) in each increment. For each trader, the quantity of trade is summed over the increment and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The positions are marked to market each increment by summing the quantity traded over a particular increment for a trader and using that level as the beginning inventory level for the next increment. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample. The Wilcoxon signed-rank test is performed to test whether the mean averages each month (n = 20) are significantly different from zero.

Table 17

Intraday Risk Parameter Position Levels Over 5 Time Increments for Sells

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position delta			
1	-0.04	1.0000	0.09	45.98	-962.17	1108.27
2	2.649	0.1536	0.00	99.25490036	-2044.27	1749.612
3	4.67	0.0296	-0.04	96.68	-1132.79	2810.00
4	3.99	0.0532	0.00	94.71	-972.38	2787.908
5	3.39	0.1650	0.06	117.38	-2600.00	4858.49
			Position delta without futures			
1	0.44	0.7841	0.07	42.07	-995.50	899.07
2	1.50	0.3488	0.00	79.51	-1133.38	1429.64
3	1.98	0.3884	0.04	79.86	-1026.59	1350.00
4	1.13	0.5217	0.00	76.27	-990.94	2041.67
5	1.50	0.3118	0.00	96.97	-2600.00	4838.49

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position gamma			
1	-40.90	< 0.0001	-6.13	110.71	-3341.52	0.00
2	20.57	< 0.0001	-0.01	202.15	-2841.91	7918.91
3	22.88	< 0.0001	0.01	152.97	-1827.71	2506.07
4	28.86	< 0.0001	0.04	174.89	-1309.05	5446.03
5	36.91	< 0.0001	0.59	188.65	-3106.14	3501.38
			Position vega			
1	-20.11	< 0.0001	-3.21	57.97	-2401.67	0.00
2	8.48	< 0.0001	0.00	84.45	-1477.12	2968.97
3	8.34	< 0.0001	0.05	64.74	-1085.98	922.01
4	12.81	< 0.0001	0.02	79.76	-1254.90	3039.15
5	17.68	< 0.0001	0.35	80.58	-943.62	3244.91

The daily volume of each option trader identified as conducting a member proprietary trade was found by summing the quantity traded over each day in the sample. The top ten CTI 1 traders were then identified by their daily total volume of trade. The trading day is partitioned into five increments. Using the last trades from the traders in the top 10% of daily volume for both options and futures in a time increment, an implied standard deviation is found for each time increment to minimize the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options incremental settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls) in each increment. For each trader, the quantity of trade is summed over the increment and multiplied by the estimated parameter values to compute the trader’s exposure to portfolio risk as measured by position delta, gamma, and vega. The positions are marked to market each increment by summing the quantity traded over a particular increment for a trader and using that level as the beginning inventory level for the next increment. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample. The Wilcoxon signed-rank test is performed to test whether the mean averages each month ($n = 20$) are significantly different from zero.

Table 18

Intraday Risk Parameter Position Levels Over 5 Time Increments for Top 10 Traders

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position delta			
1	-0.67	0.4524	0.28	79.05	-1022.29	1834.99
2	5.04	0.0266	0.28	152.55	-2973.32	3179.35
3	9.48	0.0897	0.31	157.75	-2996.53	4146.03
4	7.62	0.0215	0.32	141.66	-1676.24	6601.65
5	1.83	0.5706	0.19	144.19	-1926.00	4021.32
			Position delta without futures			
1	-0.55	0.8983	0.12	67.85	-1000.00	977.71
2	3.15	0.1536	0.11	88.08	-772.91	3179.35
3	2.24	0.4304	0.08	100.09	-2379.33	4146.03
4	1.53	0.4524	0.10	77.90	-1200.00	853.56
5	-2.48	0.3884	0.04	102.38	-1400.00	4001.32

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
Position gamma						
1	-0.16	0.6215	-0.01	146.32	-3525.40	3465.95
2	17.75	0.0010	1.07	183.00	-1735.19	3440.48
3	18.19	< 0.0001	1.05	169.63	-1294.19	7068.41
4	19.79	0.0020	0.65	240.38	-6888.15	6763.43
5	23.70	< 0.0001	1.16	207.93	-2432.28	3305.11
Position vega						
1	0.02	0.9273	0.01	62.97	-1214.29	1052.35
2	8.02	0.0064	0.37	105.31	-1615.26	3518.78
3	12.19	0.0010	0.81	125.79	-1653.34	12146.64
4	7.69	0.0012	0.64	110.21	-2270.48	3018.74
5	11.26	0.0006	0.41	98.66	-1531.87	2880.80

The daily volume of each options trader identified as conducting a member proprietary trade was found by summing the quantity traded over each day in the sample. The top 10 CTI 1 traders were then identified by their daily total volume of trade. The remaining traders were partitioned into a separate sub-sample characterized by not falling into the top ten percent in terms of volume on a particular trade day. The trading day is partitioned into 5 increments. Using the last trades from traders not in the top 10 for both options and futures in a time increment, an implied standard deviation is found for each time increment which minimizes the sum of squared errors between the options price estimated by the binomial option pricing model and the observed options incremental settlement price. This implied standard deviation is then used to compute the delta, gamma, and vega for all option strikes and types (puts and calls) in each increment. For each trader, the quantity of trade is summed over the increment and multiplied by the estimated parameter values to compute the trader's exposure to portfolio risk as measured by position delta, gamma, and vega. The positions are marked to market each increment by summing the quantity traded over a particular increment for a trader and using that level as the beginning inventory level for the next increment. The daily position estimates are averaged over all traders on a monthly basis. The values shown below are aggregated over all 20 months in the sample. The Wilcoxon signed-rank test is performed to test whether the mean averages each month (n = 20) are significantly different from zero.

Table 19

Intraday Risk Parameter Position Levels over 5 Time Increments for Traders Not in the Top 10

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position delta			
1	0.25	0.3683	0.03	18.69	-500.00	166.73
2	2.04	0.0009	0.00	29.46	-450.00	537.20
3	1.12	0.1536	0.00	29.45	-511.65	360.84
4	1.57	0.0027	0.00	24.93	-232.93	370.00
5	0.65	0.1650	0.00	26.37	-343.46	434.50
			Position delta without futures			
1	0.49	0.1650	0.01	17.30	-500.00	215.81
2	1.32	0.0532	0.00	23.71	-364.18	617.20
3	0.72	0.0759	0.00	22.75	-511.65	355.00
4	0.57	0.2455	0.00	18.14	-222.93	263.80
5	0.48	0.2455	0.00	19.63	-343.46	315.30

Increment	Mean	Pr > = abs(S)	Median	Average standard deviation	Minimum	Maximum
			Position gamma			
1	2.58	0.0094	0.00	38.43	-759.50	647.29
2	6.25	0.0002	0.01	52.61	-1093.66	807.18
3	7.43	< 0.0001	0.01	50.20	-484.96	2174.05
4	7.47	< 0.0001	0.05	51.92	-704.27	1051.71
5	9.68	< 0.0001	0.07	67.00	-1651.48	1917.21
			Position vega			
1	1.12	0.0083	0.00	17.68	-331.04	383.41
2	2.36	0.0009	0.01	25.61	-502.79	546.44
3	2.73	< 0.0001	0.03	22.31	-354.65	516.53
4	2.50	< 0.0001	0.01	21.74	-511.92	270.58
5	4.23	< 0.0001	0.04	26.87	-612.49	719.17

Table 20 presents a frequency analysis, for the month of September 2005, of the number of traders engaging in trades in both futures and options versus the options market to determine whether options market makers specialize in hedging in only options or in futures. Panel A shows the frequency of trades for those who participate only in the options market, and Panel B shows the frequency of trades for those who participate in both the options and futures market. The top number for each trader in Panel B represents the frequency of trade in the options market while the bottom number represents the frequency of trade in the futures market. The frequency count provides the number of times a particular trader traded while the percent of frequency is computed by taking the frequency count and dividing by the total number of trades in the month over all traders.

Table 20

Frequency Analysis of the Distribution of Traders Across the Options and Futures Markets

Trader number	Frequency count	Percent of frequency
	Panel A: Options trading frequency	
1	4	0.0515
2	66	0.8497
3	1	0.0129
4	1	0.0129
5	21	0.2704
6	8	0.1030
7	9	0.1159
8	63	0.8111
9	14	0.1802
10	2	0.0257
11	4	0.0515
12	9	0.1159
13	3	0.0386
14	2	0.0257
15	5	0.0644
16	4	0.0515
17	6	0.0772
18	1	0.0129
19	10	0.1287
20	18	0.2317
21	11	0.1416
22	20	0.2575
23	2	0.0257
24	2	0.0257
25	9	0.1159
Total	295	3.7981

Trader number	Frequency count	Percent of frequency
Panel B: Options and futures trading frequency		
1	91	1.1716
	218	2.8067
2	22	0.2832
	14	0.1802
3	77	0.9914
	10	0.1287
4	49	0.6309
	4	0.0515
5	78	1.0042
	218	2.8067
6	163	2.0986
	205	2.6394
7	16	0.2060
	2	0.0257
8	54	0.6952
	29	0.3734
9	103	1.3261
	45	0.5794
10	122	1.5707
	139	1.7896
11	17	0.2189
	3	0.0386
12	14	0.1802
	2	0.0257
13	112	1.4420
	150	1.9312
14	27	0.3476
	16	0.2060
15	164	2.1115
	375	4.8281
16	15	0.1931
	3	0.0386
17	71	0.9141
	103	1.3261
18	100	1.2875
	55	0.7081
19	71	0.9141
	538	6.9267

Trader number	Frequency count	Percent of frequency
20	42	0.5407
	4	0.0515
21	61	0.7854
	57	0.7339
22	112	1.4420
	102	1.3132
23	4	0.0515
	2	0.0257
24	12	0.1545
	3	0.0386
25	17	0.2189
	2	0.0257
26	36	0.4635
	154	1.9827
27	225	2.8969
	188	2.4205
28	2	0.0257
	1	0.0129
29	78	1.0042
	154	1.9827
30	77	0.9914
	50	0.6437
31	156	2.0085
	154	1.9827
32	55	0.7081
	153	1.9699
33	67	0.8626
	78	1.0042
34	111	1.4291
	161	2.0729
35	232	2.9870
	216	2.7810
36	50	0.6437
	3	0.0386
37	112	1.4420
	439	5.6521
38	79	1.0171
	7	0.0901
39	63	0.8111
	313	4.0299

Trader number	Frequency count	Percent of frequency
40	63	0.8111
	82	1.0557
Total	7472	96.2019

Table 21 displays the analysis conducted to determine whether traders conducting member proprietary trades prefer to trade in a particular moneyness category. Traders identified a range of values classifying a trade as being OTM, ATM, or ITM. The data analyzed here contain volume information for CTI 1 traders for the nearby contract. For a range of 1%, an at-the-money (ATM) option is one whose strike price is within 1% of the price of the futures settlement price, an out-of-the-money (OTM) option is one whose strike price is above 1% of the futures settlement price, and an in-the-money (ITM) option is one whose strike price is below 1% of the futures settlement price. Moneyness is defined by a range of 1% to 5%, as well as skewed values. Skewed range 1 is 1% for ITM and 4% for OTM; Skewed range 2 is 2% ITM and 5% OTM. The top number is the average daily volume, and the bottom number is the total volume.

Table 21

Average Daily and Total Nearby Volume by Moneyness Levels

Moneyness	1% Moneyness	2% Moneyness	3% Moneyness	4% Moneyness	5% Moneyness	Skewed range 1	Skewed range 2
			CTI 1 traders call options				
OTM	1983	1976	1760	1644	1528	1644	1528
	816158	*782399*	*724700*	*676623*	*628763*	*676623*	*628763*
ATM	235	364	554	700	837	554	731
	84338	*144211*	*222376*	*284270*	*340011*	*223873*	*297113*
ITM	0	183	218	184	164	331	272
	0	*66571*	*81481*	*67664*	*59783*	*128061*	*102681*
			CTI 1 traders put options				
OTM	1980	1656	1725	1589	1484	1980	1855
	806542	*673596*	*702624*	*646918*	*600039*	*806542*	*756128*
ATM	315	427	660	858	1012	476	634
	104099	*170733*	*267372*	*349185*	*411869*	*189561*	*255780*
ITM	494	735	427	374	343	374	343
	221474	*255193*	*162119*	*136012*	*120207*	*136012*	*120207*

Table 22 presents the percentage of trades for September 2005 in each category of option moneyness for traders who trade in all categories, where moneyness is defined by a 3% range. In other words, for a range of 3%, an at-the-money (ATM) option is one whose strike price is within 3% of the price of the futures settlement price, an out-of-the-money (OTM) option is one whose strike price is above 3% of the futures settlement price, and an in-the-money (ITM) option is one whose strike price is below 3% of the futures settlement price.

Table 22

Percentage of Trades in Each Moneyness Category

Category	Percentage of trades
OTM	66.17%
ATM	18.87%
ITM	14.12%

Essay II
Price Discovery in Futures and Options on Futures Markets: A Transaction Based Approach

Introduction

Price discovery can be defined as the process by which new information is absorbed into and revealed by asset prices. Due to the presence of market frictions, one market may reflect new information before another corresponding market; thus, identification of the market that absorbs and reflects new information first is fundamental to the evaluation of where price discovery occurs. In the case of derivative markets, the derivative derives its value from the underlying asset. As such, if markets are dynamically complete and frictionless, options will be redundant securities, [1] and option and underlying security prices will simultaneously reflect new information. If market

[1] For example a call option, when exercised, turns into a long futures contract, whereas a put option, when exercised, turns into a short futures contract.

frictions exist, then options are relevant securities and will contribute to our understanding of the way in which prices absorb new information. Research has established that price discovery straddles both the stock and option markets and that market frictions, such as the relative bid-ask spread, are the source of option markets' contribution to price discovery (Chakravarty, Gulen, & Mayhew, 2004). The question addressed here is whether price discovery occurs in both the option and underlying futures market.

In general, informed traders or those who have access to private information may choose to invest in either the option or the underlying futures markets. The option market may be the preferred trading venue for informed traders due to the high degree of leverage achievable in addition to the built in downside protection against losses from trading options. However, transaction costs are lower in the futures market, which may lead informed traders to prefer to trade in the cheaper of the two markets. If options are used by informed traders hoping to capitalize on inherent market frictions, then options should significantly contribute to price discovery, and one would expect to see new information about the futures price reflected in the option market first. Conversely, if the futures market is the preferred trading venue for informed traders, one would expect to see the vast majority of price discovery occurring in the futures market.

As shown in Bhattacharya (1987), the speed of adjustment in each market will depend on the inherent frictions as well as the relative risk and return characteristics of each market. Given differences in trading costs, the trading-cost hypothesis indicates that, when information-based trades occur, price discovery tends to occur first in the lowest-cost market, where informed traders are able to produce the highest levels of net profits.

This hypothesis suggests that the underlying futures market should lead the corresponding option market. In this study, a transactions cost approach is taken to study the degree of price discovery in two derivative markets: the NYMEX natural-gas option market and the corresponding NYMEX natural-gas futures market.

One of the most frequently used approaches to studying price discovery is that of Hasbrouck's (1995) information-share approach. Many, including Chakravarty et al. (2004), have applied this method to quantifying the percentage of price discovery attributable to the option market. The research presented here uses this approach to determine the extent of price discovery occurring in the natural-gas option and futures markets. This research adds to the existing literature by estimating the percentage of price discovery attributable to each market by using trader level data that enable a more refined evaluation of market dynamics than previous studies that have used aggregated data.[2] Moreover, option market makers' management of volatility risk in addition to price level risk will affect the price setting process. Thus, relying on the assumption of constant volatility to derive implied futures prices from option prices might result in potentially misleading inferences concerning the contribution of the option market to price discovery. In the analyses that follow, natural-gas option prices are allowed to imply more than the natural-gas futures price by incorporating the implied volatility. The method employed here uses a two parameter binomial process, the Cox, Ross, and

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[2] While several researchers have used transactions data, to my knowledge, no one, with the exception of Battalio and Schultz (2007), who used a very limited set of data from one options market maker, has used trader level data to study price discovery. Using trader data allows for a measurement of the inventory components that will affect the imputation of the option markets perception of the implied futures price. Further, many researchers study price discovery using index options, which, by their design, will tend to have lower volatility because the up and down movements of the individual prices will cancel out one another. To the extent that volatility plays a role in price discovery, their analyses may be downwardly biased.

Rubenstein (CRR) (1979) method. This binomial model enables an inference of both the price and the volatility.

Using the Hasbrouck information-share approach along with a binomial option pricing model to calculate the implied volatilities and implied futures prices, it is found that futures options do significantly contribute to price discovery. On average, between 11% and 12% of price discovery occurs in the futures-option market, which is slightly less than the findings of Chakravarty et al. (2004), who found the option market's contribution to price discovery to be about 17% on average. The estimates for individual months range from 1.45% to nearly 38%.

Further, it may be the case that certain types of options are preferred by informed traders and offer more information about futures market prices. Conflicting evidence has been presented in the literature with regards to which types of options, puts versus calls, as well as various moneyness levels, account for a higher amount of price discovery. These issues are revisited here and the analyses detailed below show that a combined group, consisting of at-the-money and in-the-money options, has a higher information share than out-of-the-money options. Thus, it appears that informed traders may prefer the cost benefits of trading at-the-money and in-the-money options[3] relative to the greater degrees of leverage available with out-of-the-money options. It is also shown that put options contribute greater amounts of price discovery than call options in option markets. This indicates that although put options are traded less frequently than call options, the informational content of put options is higher than that of call options.

The remainder of this essay is organized as follows: Section II provides a thorough review of the various approaches to measuring price discovery; Section III

[3] In-the-money options act like the underlier.

contains information about the data used for this analysis; Section IV provides details regarding the methodology; Section V investigates the price discovery occurring in the options and underlying futures market; Section VI examines the influence of informed trading on price discovery; Section VII concludes.

Price Discovery Literature

A yet-unresolved question is which market leads the other in terms of incorporation of new information into prices. How to identify which market leads the other has been widely argued in the literature. In equilibrium, all markets should react to new information in the same way and at precisely the same time. There have been many different methods by which researchers have tried to extract where the price discovery in capital markets occurs. Those methods, as well as the empirical findings, are reviewed below.

Information-Share Price-Discovery Approach

The information-share price-discovery approach introduced by Hasbrouck (1995) is a useful method for analyzing price discovery because it quantifies the percentage, or range, of price discovery that occurs in a market. In his 1995 study, Hasbrouck examined homogenous, or closely linked, securities that trade in multiple markets to determine where price discovery occurs. Hasbrouck motivated the use of his information-share approach by the finding that lag-lead models of price discovery often imply a “convergent representation” in situations where one does not actually exist, thus causing the models often to be misspecified from an econometric viewpoint. His method of price discovery relies on the assumption of an implicit efficient price which is common to all markets. The sources of variation in the efficient price can be attributed to differences in markets. Price discovery, under this framework, refers to the innovation of the efficient price, while a market's contribution to price discovery is measured by its information share, the proportion of the efficient price innovation variance that can be attributed to that market. Hasbrouck applied this technique to examine the price discovery for NYSE stocks and regional stock exchanges and concluded that price discovery is concentrated at the NYSE with a median information share of 92.7 percent. Hasbrouck (2003) used his 1995 information-share approach to study price formation in U.S. Equity Index markets.

Frijns and Schotman (2004) applied Hasbrouck's (1995) information-share approach to evaluate the price-discovery process in various markets among active dealers by examining two ECNs (Island and Instinet) and the three most active wholesale market makers at 20 NASDAQ actively traded stocks. They modeled the dynamics of quote updates conditional on trade duration, suggesting two measures to summarize the quote-setting behavior of dealers: the first measure considers how dealers incorporate information about the efficient price into their quote innovation, and the second measure considers the contribution of quote innovation to the evolution of the efficient price. The overall evidence suggests that information flow is less at longer trade durations and that more volatility is generated at shorter durations. Further, dealer quotes tend to be more informative when durations are short. Frijns and Schotman found that ECNs tend to dominate the liquid stocks, whereas market makers dominate the less liquid stocks.

Chakravarty et al. (2004) provided evidence that stock-option trading contributes to price discovery in the underlying stock market, with the contribution being related to market frictions such as the relative bid-ask spread. They investigated the relative rate of price discovery to determine whether it is a function of firm characteristics, time, or contemporaneous market conditions such as trading volume, bid-ask spreads, and volatility. Further, they examined how informed trading in the options markets is distributed across strike prices by testing whether the level of price discovery is related to the option's strike price and whether the relative rate of price discovery across different strike prices can be explained by volume and spread differences.

Through the application of a modified version of Hasbrouck's (1995) measure Chakravarty et al. (2004) found that 17% or 18% of price discovery occurs in the options market on average, with estimates for individual securities ranging from 12% to23%. They further found that option-market price discovery tends to be greater when option volume is higher than that of the underlying market and when the effective bid-ask spread is narrow relative to the spread in the stock market. Limited evidence was found to suggest that the information share attributable to the option market is lower when the volatility in the underlying market is comparatively higher. The authors found no significant differences between ATM and ITM options; however, OTM options tend to have increased levels of price discovery that can be attributed to difference in the relative trading volume and bid-ask spreads for those options. These results suggest that leverage may be a primary driving force behind price discovery in the options markets. ATM information shares are found to be higher when these options have high volume and narrow spreads as compared with the OTM options.

The Gonzalo and Granger (1995) permanent/transitory model focuses on the mechanism of the common factor and the error correction process and is related to the Hasbrouck (1995) information-share approach. This method involves only permanent shocks that result in a disequilibrium, as well as decomposition of the common factor into a linear combination of prices. Many researchers have compared the Gonzalo and Granger approach to Hasbrouck's information-share approach with conflicting findings as to which is better at measuring price discovery.[4]

Trading-Strategy-Based Price-Discovery Approach

Much of the early work in price discovery focused on testing ex-ante and ex-post trading strategies to determine whether option markets contained information that stock markets did not possess. Black (1975) first suggested that information traders may prefer trading in option markets due to economic considerations, including reduced transaction costs, capital requirements, and trading restrictions.

Manaster and Rendleman (1982) used Black's option-information trading preferences theory to examine the role of call options as predictors of the equilibrium prices of their underlying stocks, using the BSM model. Differences in implied and observed stock prices should cause arbitrage opportunities that would be quickly eliminated through trading. Manaster and Rendleman rejected the hypothesis that the implied prices of stocks do not contain information about the future movements of the observed prices based on both ex-ante and ex-post testing. Ex-post analysis shows that closing option prices contain additional information that is not fully reflected in closing stock prices. The authors did not determine whether the additional information was due to better information or more recent information, the latter resulting from temporal separations between stock and option closing transactions. The additional information would be due to more recent information because stock and option closing transactions do not always take place at the same time. The alternative is that closing option prices

[4] See Baillie, Booth, Tse, and Zabontina (2002); de Jong (2002); Lehman (2002); Harris, McInish, and Wood (2002); and Hasbrouck (2002).

reflect fundamental information about the equilibrium values of underlying stocks that is not contained in closing stock prices. The ex-ante tests provided similar findings as the ex-post tests, albeit less significant, but the authors were unable to draw conclusions as to whether the information could be used by traders to earn excess returns. Overall, Manaster and Rendleman present evidence that options prices appear to exhibit information that was not reflected in closing stock prices for up to a period of 24 hours.

Bhattacharya (1987) expanded the analysis of Manaster and Rendleman (1982) by using intraday data to test the hypothesis that option prices reveal information not contained in stock prices, while also addressing the speed at which new information is revealed in similar markets. Conditional on the use of the BSM model to compute implied prices and through the use of intraday and overnight holding periods, Bhattacharya found that option and stock prices are nonsynchronous. He indicated that this could be due to misspecification in pricing from the use of the BSM model. Bhattacharya concluded that, while option prices do seem to reflect information not found in stock prices, the overall level is not enough to overcome the bid-ask spread for intraday holding periods, while overnight holding periods can result in excess returns before information search costs and opportunity costs of the exchange seats are considered.[5]

Lead-Lag Price-Discovery Approach

Lead-Lag return regressions have been a common approach to revealing where price discovery occurs and are conducted through paired univariate specifications in which one return is regressed against the leads and lags of the other. The coefficients on

[5] When these costs were included, the null hypothesis of no additional information could not be rejected. Thus, while option prices do contain information not reflected in stock prices, they cannot overcome the inherent costs.

the leads and lags are then used to support general statements about temporal precedence. As Hasbrouck (1995) pointed out, the problem with these models is that they are generally misspecified because convergent representations are assumed in situations where no such representation exists.

Anthony (1988) presented similar findings regarding the existence of options prices leading stock prices for studies that used the trading strategy approach, but also found that options do not contain any economically significant information that can be used by traders to exploit the information to earn excess returns. Anthony relied on volume data to test a sequential-flow-of-information hypothesis and was one of the first to begin to look at lead-lag models of price discovery. He used the Granger causality test to find that option-volume Granger causes stock volume but only in 48% of the firms. Although his findings are in line with the sequential-flow-of-information hypothesis of Copeland (1976), Black's (1975) hypothesized option-information trading preference, and the price-based findings of Manaster and Rendleman (1982), Anthony warned that the findings were sensitive to the methodology used and the assumption that trading volume is an appropriate proxy for the arrival of new information.

Stephan and Whaley (1990) took a multivariate time-series approach to studying the intraday relations of price changes and trading volume of options and stocks for a sample of firms whose options are traded on the CBOE during the first quarter of 1986. By transforming call-price changes over 5-minute intervals into implied stock prices, they found that price changes in the stock market lead the options market by as much as 15 minutes, contrary to Anthony (1988) as well as others discussed previously. Their examination of trading volume indicated that the lead may be even longer. They overcame the problems of nonsimultaneity of closing prices in the two markets by using transactions-by-transactions data and focusing directly on the lead-lag relationship rather than using a trading-strategy approach. Thus began the use of multivariate time series analysis to determine the lead-lag relationship between the stock and option markets, which takes the following form:

$\hat{s}_t^0 = \alpha + \sum_{k=-K}^{K} \beta_k s_{t-k}^0 + \varepsilon_t$, where s_t^0 and $\hat{s}_t^0$ are the observed actual and implied stock price changes respectively, ε_t is a random disturbance term that will be affected by market frictions, and K is the arbitrary number of leading and lagging regressors.

Chan, Chung, and Johnson (1993) showed that, if option price changes are based upon spread midpoints rather than trade prices, price moves in the option and stock markets are virtually simultaneous. Although they could confirm the findings of Stephan and Whaley (1990), the results can be explained as spurious leads induced by the infrequent trading of options due to the relatively larger option tick, and, therefore, no arbitrage opportunities are found to exist with the stock lead.

Fleming, Ostdiek, and Whaley (1996) investigated the lead-lag relation between the index option market with that of both the stock index and index futures, simultaneously using a trading-cost explanation for the relative rates of price discovery in each of the markets. Similar to the findings of Stephan and Whaley (1990), they found that stock markets led options markets, which is consistent with the structure of trading costs. Further, when index derivatives were compared to holding a similar stock portfolio, it was found that the derivatives markets led the stock market, also in line with the transactions-cost hypothesis. Finally, it was found that the futures markets led the options markets.

Krinsky and Lee (1997) found results that conflicted with both Stephan and Whaley (1990) and Chan et al. (1993) when they studied the intraday lead-lag relationship of prices and trading activity between the options and stock markets during the period surrounding quarterly earnings announcements. Their results showed trading activity in options markets leading stock markets in pre-earnings and post-earnings announcement periods. Further, using average bid-ask-spread prices, they found no systematic lead of option over stock prices in the days surrounding earnings announcements.

Through the use of variable-length return intervals, Finucane (1999) tested the relationship between CBOE and NYSE options and their underlying stocks in an attempt to reconcile the differing findings of previous studies that all used fixed-time intervals for measuring information flow. His findings suggested that stock quotes lead options quotes, supporting the conclusions of Stephan and Whaley (1990); however, some information flows from the stock to the options market. He also shed light on the lead length with findings of stock leads ranging from a few seconds to 6 minutes and option leads as always less than 3 minutes, which is much shorter than previous researchers had used to study the relationship between the two markets.

Other Price-Discovery Approaches

Other methodologies have also emerged as researchers have tried to sort out the relationship between options and their underlying stocks. Kumar, Sarin, and Shastri (1992) examined the behavior of stock and option prices around large block transactions in stocks using a bootstrap procedure. They found that the options markets exhibit abnormal price behavior starting 30 minutes before a block trade while the price reaction in the stock market leads the block by 15 minutes for downtick block trades and does not lead the block for upticks. Further, it takes the options market up to an hour to reach the new equilibrium price once the block trade has been initiated while the stock markets absorb the change within 15 minutes.

The conflicting results found in Manaster and Rendleman (1982) and Stephan and Whaley (1990) are addressed in a 1996 study by Diltz and Kim, overcame problems of bid-ask bias and non-synchroneity through the use of observed bid-ask-spread data. They used cointegration analysis and an ECM to determine the link between option and stock markets, from which they found that stock markets do indeed lead the option markets. However, the causal link is bidirectional, with option implied stock prices adjusting to the equilibrium intermarket error as well as actual and implied stock prices with a lag up to and including 2 days. O'Connor (1999) also used an ECM approach with similar findings that stock markets lead options markets.

Easley, O'Hara, and Srinivas (1998) investigated the informational role of transactions volume in options markets. They first developed a model based on asymmetric information to examine the impact of the linkage between options and stock markets. They confirmed the findings of Stephan and Whaley (1990) that stock price changes tend to lead option volumes. When they empirically tested their model using intraday data by aggregating option trades into positive-news trades and negative-news trades, they found that negative and positive option volumes contain information about future stock prices. Using Granger causality tests, they found that option volumes respond to stock-price changes with lags of up to 30 minutes while option volumes affect stock-price changes much more quickly.

Data

The data for this research consist of 20 months of transactions-level data in the natural-gas futures and options markets traded on NYMEX, spanning September 2005 through April 2007. This data set is maintained by the U.S. Commodity Futures Trading Commission and comes from the computerized trade reconstruction (CTR) records compiled and maintained by the agency through data feeds from the exchanges.

The data include records of all open-outcry trades and provide information including the price, quantity of the trade, trade date, trade time to the second, trade direction (buy or sell), delivery month and year of the contract, customer type (trade for the member's account, his or her house's account, another member on the floor, or a customer), counterparty's customer type, and the floor trader's identification. The data taken after September 2006 also contain electronic trader data for the futures market. These data contain information on both options and futures trades. A call option, when exercised, results in a long futures position for the holder of the call and a short futures position for the writer. A put option, when exercised, results in a short futures position for the holder of the put and a long futures position for the writer. Options are American style and may be exercised at any time prior to expiration.

The NYMEX trading rules specify the obligations of the floor traders and how trades are to be executed and recorded. The floor trader conducting a sale of a contract, either futures or futures option, is responsible for reporting the transaction to a designated NYMEX exchange employee within one minute of completion. For a futures contract, the report must indicate the price at which the transaction was executed, the name of the trader executing the sale, quantity traded, commodity, delivery month, and the name of the trader conducting the purchase against whom the transaction was executed. If the contract is for an option, the trading member conducting the sale must indicate the premium at which the transaction was executed, the trading member's name, quantity, commodity, strike price, expiration month, whether it was a put or call, and the name of the trader purchasing the contract.

An important responsibility of floor traders on NYMEX is to report on the Trade Allocation System the appropriate CTI and indicator codes for transactions executed on the exchange. There are four categories of trades: (a) CTI 1: This type of indicator code is used for trades executed from a floor trader's personal account, an account he or she controls, or for an account in which he or she has an ownership or financial interest; (b) CTI 2: This type of indicator code is used when a floor trader executes trades for the trading account of a member firm or clearing member; (c) CTI 3: This type of indicator code is used for trades that a floor trader executes for the personal account of another floor trading member or for an account that the floor trading member knows is controlled by another floor trading member; (d) CTI 4: This type of indicator code is used when a floor trading member executes trades for any account other than those in CTI 1-3.

The trading time for the open-outcry natural-gas pits is from 9:00 am to 2:30 pm (ET). The futures contracts trade in units of 10,000 British thermal units (mmBtu) and require physical settlement. The minimum price fluctuation is $0.001 per mmBtu, or $10 per contract. The daily price limit is $3.00 per mmBtu, or $30,000 per contract.

Delivery is conducted through the Sabine Pipe Line Company, Henry Hub in Louisiana, and can take place no earlier than the first calendar day of the delivery month and no later than the last calendar day of the delivery month. The Henry Hub is the nexus of 16 intrastate and interstate natural-gas pipeline systems that serve markets throughout the U.S. east coast, the Gulf coast, and the Midwest up to the Canadian border. The seller is responsible for the movement of the gas through the Hub and pays all Hub fees while the buyer is responsible for movement from the Hub.

The volatility in natural-gas futures prices makes futures and futures options an attractive trading venue for speculators. These markets are also used by a wide variety of companies, from those involved in exploration and the production of natural gas to substantial end users of natural gas, to hedge their price risk. In the U.S. natural-gas market, price peaks and troughs over a market cycle are cyclical and highly dependent upon weather conditions with warmer weather driving prices down and colder weather leading to increases.[6]

The data used in this analysis include only the trades conducted by floor traders who execute trades for their own accounts as indicated as CTI 1 trades in the option market and CTI 1 or 3 trades in the futures market. In order to address issues with nonsynchroneity of trade occurring due to higher trading volume in the futures market and to capture the greatest number of observations a time series of prices is formed by computing a volume-weighted average price over a one minute interval for buys and sells in both the options and the futures markets for the contract expiration with the highest amount of daily volume as follows:

[6] Although seasonal patterns do exist in natural gas prices, I will not control for them here because I am using the underlying futures contracts as a means of comparison. In other words, the relationship between the futures and futures options market should not be seasonal.

$$VWAP = \frac{\sum \#of\ contracts\ purchased\ (sold) * trade\ price}{total\ contracts\ purchased\ (sold)} \quad (1)$$

It should be noted that the prices of the buys and sells will not be identical because the sample partition only contains member proprietary trading. Thus, the difference between the buy price and the sell price in each increment should not be considered a bid-ask spread. The aggregated data are matched across markets by time and account number in order to obtain a time series of data that has an observation for both markets each minute. The observations (minutes) that do not have simultaneous trading in both markets are removed from the sample.

Methodology

Hasbrouck (1995) offered a definition of a market's contribution to price discovery for securities trading in multiple markets, the information share. He considered securities that may be technically different yet linked by arbitrage or short-term equilibrium conditions to be considered the same security. This definition is used here to examine price discovery occurring between futures and futures-option contracts.

Theory suggests that option and futures markets are linked through arbitrage. Violations of put-call parity, resulting from market imperfections, will lead arbitrageurs to enter the market to capitalize on pricing discrepancies between the futures and options markets. When the underlying futures price is less than the options price implied by put-call parity for a particular strike price, arbitrageurs will buy a futures contract and sell the equivalent options portfolio, which will entail selling a call and buying a put. This type of arbitrage is considered quantitative arbitrage because it requires the trader to have a known volatility measure in order to calculate the price in the two markets. Arbitrageurs can also change their holdings based on delta, the change in the option price relative to the change in the futures price, if a temporary disequilibrium in pricing occurs. In either case, buying will drive prices up or selling will drive prices down toward their equilibrium value. A stationary equilibrium between the options and futures market is imposed through these arbitrage strategies, suggesting a cointegration of the implied asset price imbedded in the option prices and the futures price.

In this case, the futures-option and futures markets may be linked by arbitrage, but, as in the spirit of Chakravarty et al. (2004), this does not mean that one can find a constant cointegration vector for the time series of futures and option prices. Therefore, the option prices must be converted into implied futures prices. In other words, it is assumed that the futures and futures-options prices follow the following process (focusing on one option price for now):

$$F_t = v_t + \varepsilon_t^f$$

$$C_t = C(v_t, \theta) + \varepsilon_t^o \text{, or,}$$

$$C(F_t^o, \theta) = C(v_t, \theta) + \varepsilon_t^o \qquad (2)$$

where:

F_t represents the futures price,

C_t represents the call price, which depends on the option markets implied futures price as well as other parameters given by the vector theta, including the time to maturity, the risk-free rate of interest, strike price, and volatility. This relationship is highlighted by substituting the function $C(F_t^o, \theta)$.

A two step procedure is used to compute the implied futures price from the option prices. First, the 1979 CRR binomial model is employed to estimate the implied standard deviation which is calculated from the most actively traded, near-the-money call option using the last futures price in an increment (an incremental settlement price), where an increment is defined as one hour of trading time, except the initial increment, which consists of the first 2 hours of trading.[7] A grid search is used to find the implied standard deviation that minimizes the mean-squared error over each increment by comparing the average option premium to the observed premium for each hypothetical sigma. Due to the spread between buy and sell prices, an implied standard deviation is found for buys only and separately for sells.

A set of option prices is compiled from the last observed trade in each strike over a 15 minute interval. Implied buy and sell futures prices are then calculated from this set of option prices by using a bivariate grid search that employs a lagged (by one increment) value of the implied standard deviation found in the previous step in order to minimize the mean-squared error over the set of option prices. This method of using a lagged implied standard deviation in the binomial option-pricing model is similar to the method used by Chakravarty et al. (2004). A time series of implied futures prices results for both buys and sells, which are then matched with the last observed volume-weighted average buy and sell futures prices in each 15 minute interval. This time series can be analyzed to determine whether the four price series (implied futures buy price, implied futures sell price, observed futures buy price, and observed futures sell price) are related through a cointegration analysis.

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[7] Due to the lack of trading in the first hour, the first 2 hours of trade are combined for the incremental analysis.

Whether the two series are cointegrated is tested by establishing, as originally defined by Engle and Granger (1987), whether (a) all components of the price vector, p_t, are integrated of the same order and (b) whether there exists a cointegration vector β such that the linear combination of β'p_t, is integrated of order I(d-b), where b > 0.

The price vector *p* which contains both the observed and implied futures bid and ask prices is denoted as follows:

$$p_t = \begin{bmatrix} F_{B,t} \\ F_{S,t} \\ F_{IB,t} \\ F_{IS,t} \end{bmatrix} = \begin{bmatrix} v_t + e_{B,t} \\ v_t + e_{S,t} \\ v_t + e_{IB,t} \\ v_t + e_{IS,t} \end{bmatrix} \quad (3)$$

Results from the Dickey Fuller test for stationarity reveal that all four price series are unit-root nonstationary. The rank test shows that the series are all integrated of the same order with 3 cointegrating vectors. The system is cointegrated because there is only a single unit root in the vector series and all of the price series are unit-root nonstationary.

As in Hasbrouck (1995), because the assumption of cointegration holds true, these cointegrated prices can be expressed as a vector error correction model (VECM)

$$\Delta p_t = \alpha\beta' p_{t-1} + \sum_{i=1}^{k} A_j \Delta p_{t-i} + e_t \qquad (4),$$

where p_t is a (4×1) vector of prices, A_i is a (4×4) matrix of autoregressive coefficients corresponding to lag i; the error correction vector, α, is a (4×1) column vector, while β′ is the (1×4) cointegrating vector. Alternatively, the price vector can be represented as a vector moving average model

$$\Delta p_t = \psi(L)\varepsilon_t \qquad (5),$$

where ε_t is a 4 x 1 vector of serially uncorrelated disturbances with covariance matrix Ω.

If *I* denotes an *4*x*4* identity matrix, the sum of the moving average coefficient matrices has identical rows ψ. Because ψ reflects the impact of innovations on the permanent price component, the total variance of implicit efficient price changes can be calculated as $\psi\Omega\psi'$. The contribution to price discovery of each market is measured by each market's contribution to this total innovation variance. If price innovations across markets are uncorrelated, the information share of market *j* is given by

$$S_j = \frac{\psi_j^2 \Omega_{jj}}{\psi\Omega\psi'} \qquad (6),$$

where ψ_j indicates the *j*th element of ψ, and Ω_{jj} represents the *j*th diagonal element of Ω.

Typically, price innovations are correlated across markets, resulting in the information share not being uniquely defined. When such is the case, a range of information shares must be computed rather than a point estimate. This computation can be done through retriangularization of the covariance matrix to establish upper and lower bounds. A summary of this approach follows.

If the innovations in the n market prices can be given by the factor structure

$$e_t = Fz_t \qquad (7),$$

where z_t is an *n* x 1 vector of random variables, with $Ez_t = 0$ and $Var(z_t) = I$, and *F* is the Cholesky factorization of Ω (the lower triangular matrix such that $\Omega = FF'$). The lower triangular structure of *F* implies that the random variable $z_{i,t}$ may be interpreted as the normalized residual in the regression of $e_{i,t}$ *on* $\{e_{1,t}, e_{2,t}, ...e_{i-1,t}\}$. The market share of the innovation variance attributed to z_j may be computed as

$$S_j = \frac{([\psi F]_j)^2}{\psi\Omega\psi'} \qquad (8),$$

where $[\psi F]_j$ is the *j*th element of the row matrix ψF. The factorization imposes a hierarchy that maximizes information share on the first price and minimizes information share on the last price. An upper bound for a market's information share may be obtained by permuting ψ and Ω to place that market's price first. A lower bound may be obtained by permuting to place that market's price last.

Analysis of Price Discovery

Adverse selection costs of market makers trading with agents who have superior information is seen as a predominate determinant of the bid ask spread. Thus, as stated in Easley et al. (1998), if alternative markets are available in which informed traders can profit from their information, as in the case of options markets, then where informed traders choose to trade will have important implications for both security-price movements and the behavior of related prices. The conflicting results in the literature on the lead-lag relationship of options and their underlying stocks are revisited in this analysis by estimating the information share for the NYMEX natural-gas futures and futures-option markets.

As discussed in Fleming et al. (1996), for marketwise information, the predictions of the trading cost hypothesis are reversed, and therefore, because trading in futures markets have lower trading costs than futures-option markets, informed trading will tend to migrate toward the cheaper of the two markets resulting in futures price changes leading changes in options prices. If this hypothesis is true, then significant levels of price discovery should not occur in the options market. Of course, while the argument may make sense for futures-versus-index options markets, in the case of natural-gas futures and options, transactions costs are likely to be closer.

H_1: Price discovery in the options market is not significantly different from zero.

In order to compute the information share, a VECM is estimated using a rank of 3 and an AR(1) process each week. The AR(1) process was found to describe the movement of prices best when each week of the sample was analyzed separately using the AIC criterion. The long-term impact of each market's price series is estimated based on a VECM that uses an iteration of 60 lags, allowing one group's innovation to be one and all of the others' to be zero. The covariance matrix is not diagonal (the price innovations being correlated in the VECM); thus, Cholesky factorization is applied to compute the information shares. The order of the price series applied in the model influences the magnitude of the information share in Cholesky factorization. On average, the first price series in the decomposition receives the largest information share while the last price series obtains the smallest information share. With four price series, there are 24 possible combinations when the different orderings are considered. The information share for each group is calculated for each of the different orderings. Hasbrouck (2002) suggested looking at the maximum and the minimum of the distribution resulting from the different observations of the information share for each price series each week to obtain the upper and the lower bounds of the true information share. The mean, maximum, minimum, and midpoint of the distribution of information shares from the 24 combinations each week is presented in Table 5 (see Appendix).

Using the Hasbrouck (1995) information-share approach along with a binomial option-pricing model to calculate the implied volatilities and implied futures prices, it is shown that futures options do significantly contribute to price discovery. On average, between 11% and 12% of price discovery occurs in the futures-option market, which is slightly less than the findings of Chakravarty et al. (2004), who found the option market's contribution to price discovery to be about 17% on average. The estimates for individual months range from 1.45% to nearly 38%. The maximum of the information share in the futures market is approximately 75%, with the maximum of the information share in the option market at about 17%. The minimum of the information share for all groups is zero. Because the maximum information share is about 75% and the minimum is zero, the midpoint is approximately 39% for the futures market. The midpoint for the option market stands at approximately 9%. Thus, applying Hasbrouck's methodology to generate information shares for the two markets and four groups over the 20-month sample period, it is found that options do contribute significantly to price discovery, albeit to a lesser extent than has been found in equity markets using more aggregated data.

Further, to study whether time-series variation occurs in price discovery, the monthly average information-share measure is evaluated to allow for an examination of whether the information share attributable to the option market has increased or decreased over the sample period. As shown in Figure 1, there is a large decline of the mean information share in Month 13, which represents trading in September 2006. In September 2006, Amaranth Advisors, a Connecticut-based hedge fund, incurred losses of $4.5 billion. The losses occurred when natural-gas prices suddenly went lower and apparently went against a wrong-way wager that natural-gas prices would rise. Amaranth traders had bet that the difference, or spread, between the prices of gas futures in the months of March and April in the coming year would increase. Rising gas inventories caused prices to decline, putting Amaranth on the wrong side of the wager. This event apparently caused informed traders to move out of the futures market and into the options market, trying to capitalize on price discrepancies between the two markets. In the following month, the trend reversed itself as informed traders moved back into the futures market, thus increasing the information share attributable to that market.

Informed Traders in Options Markets

Within the option market, traders have their choice of which type of option (put or call) and which strike price to trade. Thus, a study of where informed traders trade must include not only an analysis across markets but also between option types and across moneyness levels. Choice of the informed traders strike price is influenced by many factors, including the amount of leverage offered, width of the bid-ask-spread, commissions, trading volume, and risks as measured by vega. Chakravarty et al. (2004) provided an overview of these competing factors. They posit that out-of-the-money options offer the greatest leverage while also having the widest spreads and the highest commissions. At-the-money options have the lowest spreads and the greatest concentration of volatility trading that can serve to mask the activities of informed traders; however, ATM options also expose the informed trader to the highest amounts of vega risk. Commissions tend to be the lowest for in-the-money options. The literature on informed traders is vast;[8] thus, the discussion to follow focuses on research that evaluates informed traders' preferences across strike prices.

Black (1975) suggested that informed traders would trade in OTM options due to their higher degree of leverage. However, as Kaul, Nimalendran, and Zhang (2002) pointed out, high transaction costs and a lack of liquidity may offset the benefits of trading OTM options. While De Jong, Koedijk, and Schnitzlein (2001) suggested that informed traders may favor ITM options due to their earning higher profits by exercising options with positive intrinsic values, Kaul et al. (2002) found that ATM and slightly OTM spreads are the most sensitive to adverse selection measures in the underlying stock.

Anand and Chakravarty (2007) investigated how price discovery occurs in the options markets through traders' trade-size choice. Through the use of transactions data, they showed that informed traders partition their orders into small trades for low volume contracts and medium trades for high volume contracts. More importantly, when they evaluated how informed traders with private information about a given stock trade across the various option series traded on that stock, they found that: (a) puts do not appear to contribute significantly to price discovery, (b) the largest information share is associated with at-the-money calls, and (c) at-the-money calls are the desired trading vehicle for informed traders.

Chakravarty et al. (2004) analyzed price discovery of options with differing strike prices, using a definition of ATM options as those being within 5% of the underlying price. While they found no significant differences in information share for ATM and ITM

[8] Examples include Mayhew, Sarin, and Shastri (1995); Easley, O'Hara, and Srinivas (1998); Pan and Poteshman (2003); Cao, Chen, and Griffin (2000); de Jong, Koedijk, and Schnitzlein (2001); Chakravarty and McConnell (1999); Cornell and Sirri (1992); Lee and Yi (2001); Chang, Chung, and Fong (2002).

options, they did find that the information share of OTM options is the highest on average, indicating that leverage may be the driving force behind price discovery. The conflicting results of Chakravarty et al. (2004) with those of Anand and Chakravarty (2007) may be due to the varying definitions of the price series: Chakravarty et al. (2004) used a 5% rule to classify ATM money options and make comparisons across all three groups of moneyness (ATM, OTM, ITM) while Anand and Chakravarty (2007) separated the series by ATM calls, all other calls, and all puts combined.[9]

Thus, it may be the case that trading in certain options is more informative. The differences in price discovery across different subsets of option trades are evaluated depending on moneyness as well as option type. For any futures maturity there are four different categorizations, two levels of moneyness each for puts and calls. The level of analysis does depend on the frequency of trading. The contribution by put options and call options in aggregate and also by moneyness is estimated. The data allow me to mitigate “bid ask” bounce by distinguishing, for both futures prices and futures options implied prices, those trades for which market makers are buying and selling.

This analysis is performed to sort out the conflicting theoretical predictions of which contract informed traders will more likely trade. Chakravarty et al. (2004) found that out-of-the money (OTM) options have a higher average information share than at-the-money (ATM) or in-the-money (ITM) options, and pointed to a higher leverage explanation. In contrast, Anand and Chakravarty (2007) found that ATM options had the greatest amount of information share on average. If the theoretical predictions of Black

[9] Anand and Chakravarty (2007) did not provide a classification rule for ATM call options (i.e., as did Chakravarty et al. (2004) of 5%).

(1975) and the empirical findings of Chakravarty et al. (2004) are correct, then higher levels of price discovery should be found in the OTM options.

H2: Out-of-the money options should have higher levels of price discovery than at-the-money or in-the-money options.

To conduct this analysis, the sample is first partitioned into groups characterized by moneyness. In general terms, *moneyness* describes the relationship between the strike price of an option and the price of the underlying asset. For a call option, an in-the-money contract is one whose strike price is below the price of the underlying asset while, for a put, the strike price is above the underlying securities price. Options are characterized as at-the-money when the strike price is equal to the underlying price. Out-of-the-money call options have strike prices that are above the underlying price, and an out-of-the-money put option is described as having a strike price below that of the underlier. There are, however, varying degrees of moneyness. For example, moneyness can be described as being far in or out of-the-money depending on the distance of the strike price from the underlier's price.

Typically, ranges rather than a point estimate are used to calculate moneyness levels. There is a lack of a universal definition of an appropriate range for each type of moneyness; therefore, several different ranges of moneyness are explored in order to determine the appropriate moneyness level for this sample: Moneyness was defined by a range of 1%, 2%, 3%, 4%, and 5%. In other words, for a range of 1%, an at-the-money (ATM) option is one whose strike price is within 1% of the price of the futures settlement price, an out-of-the-money (OTM) option is one whose strike price is above 1% of the futures settlement price, and an in-the-money (ITM) option is one whose strike price is below 1% of the futures settlement price. Skewed ranges, which use a range of within 1% of the futures settlement price for ITM options and within 4% of the futures settlement price for OTM options, are also examined. The same analysis is conducted using 2% and 5% for ITM and OTM options respectively.

A primary consideration in creating the moneyness groups is ensuring that enough observations are present in each group to enable estimation of the implied futures prices. As is shown in Table 6, the majority of the trades are in out-of-the-money options, for both puts and calls (see Appendix). Following Chakravarty et al. (2004), a moneyness level of 5% is chosen, and at-the-money and in-the-money observations are combined in order to have the greatest range of observations for each moneyness group.

Once the moneyness groups are defined, two implied futures prices for buys and sells are calculated from the set of volume-weighted average option prices, one from the combination of ATM and ITM options prices and one from OTM option prices. The Cox et al. (1979) binomial model is again used to determine the option premiums and implied standard deviations, which are calculated from the most actively traded, near-the-money call options for the last futures price in an increment. A grid search is used to find the implied standard deviation that minimizes the mean-squared error over each increment by comparing the average option premium to the observed premium for each hypothetical sigma.

The trading day is then further partitioned into 15 minute increments in order to find an implied futures buy and sell price from a set of option prices, consisting of ATM and ITM options or OTM options, every 15 minutes. Implied futures prices are calculated every 15 minutes by using a bivariate grid search that employs a lagged (by one increment) value of the implied standard deviation found in the previous step to minimize the mean-squared error over the last option strike prices in an increment. The result is a time series of implied futures prices (one for every 15 minutes in the sample for both buys and sells) for each of the moneyness groups, which are then matched with the last observed volume-weighted average buy and sell futures prices in that same 15 minute increment.

The information share is then computed separately for the combination of ATM and ITM options and OTM options for both buys and sells. The VECM is again estimated using a rank of 3 and an AR(1) process each week. The long-term impact of each market's price series is estimated based on a VECM that uses an iteration of 60 lags, allowing one group's innovation to be one and all of the others to be zero. The covariance matrix is not diagonal; thus, Cholesky factorization is applied to compute the information shares. Presented here are the mean, maximum, minimum, and midpoint of the distribution of information shares from the 24 combinations each week.

Using the Hasbrouck (1995) information-share approach, along with a binomial option-pricing model to calculate the implied volatilities and implied futures prices, it is found that both option groups significantly contribute to price discovery. Contrary to the findings of Chakravarty et al. (2004), the results indicate that informed traders prefer the combination of ATM and ITM options to OTM options, as shown by the higher amounts of price discovery in the combined (ATM/ITM) group. ATM options have the lowest spreads and ITM options provide the lowest commissions; thus, it may be that transactions costs are of greater importance than leverage in the determination of which type of option an informed trader will trade.

As shown in Table 7 (see Appendix), on average between 9.85% and 11.39% of price discovery occurs in out-of-the-money options, while between 14.77% and 14.83% occurs in the combination of at-the-money and in-the-money options. The maximum of the information share for out-of-the-money options is between 15.33% and 16.98% and 20.66% and 21.38% for the combined group. The minimum of the information share for all groups is zero. The midpoint for out-of-the money options is between 7.67% and 8.49% on average, and the midpoint for the combined group is between 10.33% and 10.69% on average. The Wilcoxon signed-rank test is used to examine whether the information shares between the OTM and ATM/ITM groups are different. The results presented in Table 8 (see Appendix) indicate that the differences between the two moneyness groups are all significant at the 1% level. Thus, applying Hasbrouck's (1995) methodology to generate information shares for the two groups over the 20-month sample period, it is found that at-the-money and in-the-money options together contribute more to price discovery than out-of-the-money options. It may also be that informed traders consider option type when making trading decisions; thus, the differences in information share for option types (put versus calls) is also examined.

Due to the conflicting findings by Anand and Chakravarty (2007) and Chakravarty et al. (2004), that put options do not significantly contribute to price discovery and put options have approximately the same information share as call options respectively, the information share for puts and calls are separately examined. If there are differing degrees of price discovery for puts and calls, it may imply that market makers are using one more than the other for hedging purposes; however, due to interaction of all trading within the pit and put-and-call boundaries, similar levels of price discovery are expected in both puts and calls.

H3: Price discovery for puts is not significantly different from that of calls.

To test whether differences exist in the percent of information share for puts and calls, 4 implied futures prices are calculated from the set of volume-weighted average option prices, one for both buys and sells from the option prices associated with puts and one for both buys and sells from the prices for calls. The methodology is the same as is detailed above and employs the Cox et al. (1979) binomial option-pricing model to compute the option premiums and implied standard deviations. Ultimately, a price series consisting of two sets of implied futures prices, one for puts and one for calls, is obtained and is then used in the determination of whether each of the price series are cointegrated with the futures price series. The analysis is run separately for puts and calls, and an information share is obtained for each group with the results displayed in Table 9 (see Appendix).

On average, between 14.17% and 16.92% of price discovery occurs in put options while between 11.66% and 12.98% occurs in call options. The maximum of the information share for put options is between 21.10% and 23.35%, and 17.17% and 18.34% for call options. The minimum of the information share for all groups is zero. The midpoint for put options is between 10.55% and 11.67% on average, and the midpoint for call options is between 8.58% and 9.17% on average. The Wilcoxon signed-rank test is used to examine whether the information shares between puts and calls is different. The results presented in Table 10 indicate that the differences between the two options types are all significant at the 1% level (see Appendix). Thus, applying

Hasbrouck's (1995) methodology to generate information shares for the two groups over the 20-month sample period, I find that put options contribute more to price discovery than call options. This finding contradicts that of Anand and Chakravarty (2007), who found that puts do not contribute significantly to price discovery, and is more in line with the findings of Chakravarty et al. (2004).

Conclusion

A transaction-based approach is taken to study whether price discovery—or the incorporation of new information into asset prices—occurs in the options or in the underlying futures markets using 20 months of transactions-based data from the NYMEX natural-gas option and futures markets. Due to the link between options and futures markets through arbitrage, price discovery should, theoretically, take place in both markets with new information reflected in asset prices at precisely the same time. However, due to inherent market frictions, one market will typically lead the other in terms of incorporation of new information into prices.

The hypothesis that futures markets contain a significant portion of price discovery due to lower transactions costs is examined using a transactions cost based approach to Hasbrouck's (1995) information share. Whether the implied futures price series and the observed futures price series are cointegrated is examined in order to compute the information share attributable to the option and futures markets. It is found that, on average, between 11% and 12% of price discovery occurs in the futures-options market, which is lower than the estimates found by previous researchers studying the contribution of options in equity markets to the price-discovery mechanism, using more aggregated data.

Also evaluated is whether certain types of options are preferred by informed traders. Conflicting evidence has been presented with regards to which types of options, puts versus calls, as well as various moneyness levels account for a higher amount of price discovery. It is shown that the combined groups of at-the-money and in-the-money options have a higher information share than out-of-the-money options. Thus, informed traders may prefer the cost savings of trading in at-the-money and in-the-money options relative to the greater degrees of leverage available with out-of-the-money options. Further, contrary to previous findings on option-type preferences, it is found that put options contribute a significantly higher amount of price discovery than calls options.

This work serves to enhance understanding of price discovery and adds to the relevance and ultimate importance of option markets. Pending data availability, an extension of this work will include an additional market, that of natural-gas trades on ICE, in order to form a more complete understanding of where and how price discovery takes place. Including the independent electronic exchange as well as the NYMEX trades will have implications on policy and enforcement issues due to discrepancies in the way that the various exchanges are regulated. If a significant portion of price discovery is occurring on ICE, this trading platform may be subject to the same regulatory oversight as NYMEX. With both the NYMEX natural-gas futures and options markets trading electronically, a future direction of this work will evaluate how the change from an open outcry to an electronic trading platform affects the flow of information and where price discovery occurs.

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Appendix 1: Tables

A Dickey-Fuller unit root test is performed for each week in the sample to test for stationarity. The results of the Dickey-Fuller unit root test are presented for the futures bid and ask and the options bid and ask price series for the first week of the sample for illustrative purposes. The results suggest that we cannot reject the null hypothesis that the price series have unit roots.

Table 1

The Dickey-Fuller Unit Root Test for the Price Series

Variable	Type	Rho	Prob < Rho	Tau	Prob < Tau
Futures Bid	Zero Mean	-0.0400	0.6716	-0.7300	0.3995
	Single Mean	-6.0200	0.3330	-2.0800	0.2531
	Trend	-7.0200	0.6448	-1.7900	0.7000
Futures Ask	Zero Mean	-0.0400	0.6717	-0.7200	0.4003
	Single Mean	-6.0000	0.3342	-2.0800	0.2546
	Trend	-7.1200	0.6367	-1.8000	0.6959
Options Bid	Zero Mean	-0.1000	0.6580	-0.4100	0.5306
	Single Mean	-43.8500	0.0007	-4.6700	0.0002
	Trend	-44.8700	0.0002	-4.7500	0.0013
Options Ask	Zero Mean	-0.1100	0.6557	-0.3800	0.5454
	Single Mean	-33.9700	0.0007	-4.0900	0.0018
	Trend	-35.5600	0.0008	-4.1300	0.0088

The Johansen trace test is used to estimate the rank in the VECM for the price series for each week in the sample. The results from the first week in the sample are presented here for illustrative purposes. According to the trace values and the critical values, the rank for the VECM is three for the four price series.

Table 2

The Cointegration Rank Test

H_0: Rank = r	H_1: Rank > r	Eigenvalue	Trace	Critical value	Drift in ECM	Drift in process
0	0	0.5947	141.7747	39.7100	NOINT	Constant
1	1	0.4774	74.9483	24.0800		
2	2	0.2966	26.9243	12.2100		
3	3	0.0120	0.8912	4.1400		

The covariance matrix for the price innovations is derived from the VECM for each week in the sample. The results from the first week in the sample are presented here for illustrative purposes.

Table 3

Covariance and Correlation Matrices of the Price Innovations in the VECM

	Futures Buy	Futures Sell	Options Buy	Options Sell
Futures Buy	0.00362	0.00337	-0.00009	0.00379
Futures Sell	0.00337	0.00345	-0.00121	0.00359
Options Buy	-0.00009	-0.00121	0.12908	0.01748
Options Sell	0.00379	0.00359	0.01748	0.14241

The correlation coefficient matrix is computed based on the covariance matrix. The price innovations are slightly correlated.

Table 4

Correlation Coefficient Matrix

	Futures Buy	Futures Sell	Options Buy	Options Sell
Futures Buy	1.00000	0.95092	-0.00511	0.16649
Futures Sell	0.95092	1.00000	-0.05845	0.16170
Options Buy	-0.00511	-0.05845	1.00000	0.12883
Options Sell	0.16649	0.16170	0.12883	1.00000

Because the price innovations in the VECM are correlated, Cholesky factorization is applied to compute the information shares on a weekly basis. There are 24 possible combinations of information shares each week. The maximum, minimum, mean, and midpoint of the range from the 24 different combinations of information share each week are computed and the monthly averages are presented.

Table 5

The information share for the four price series

Month	Futures buy	Futures sell	Options buy	Options sell
		Maximum of the information share		
1	77.49%	84.88%	10.57%	12.29%
2	79.14%	80.08%	17.85%	12.01%
3	78.49%	83.47%	12.19%	12.37%
4	61.93%	70.97%	25.98%	19.82%
5	78.12%	76.10%	15.52%	12.75%
6	84.15%	83.95%	12.29%	17.27%
7	83.75%	79.45%	12.80%	20.95%
8	76.37%	84.77%	14.43%	15.30%
9	65.65%	69.72%	22.65%	19.03%
10	78.60%	71.96%	26.15%	14.80%
11	82.82%	76.82%	16.22%	14.85%
12	76.56%	78.77%	22.82%	9.06%
13	44.01%	46.95%	31.34%	54.31%
14	63.04%	65.70%	19.62%	28.71%
15	90.86%	77.46%	16.28%	3.30%
16	78.16%	86.57%	11.89%	19.02%
17	80.74%	69.51%	10.67%	18.98%
18	82.86%	72.44%	14.95%	13.09%
19	82.11%	84.32%	14.35%	8.45%
20	62.69%	63.93%	18.07%	26.84%
Average	75.38%	75.39%	17.33%	17.66%

Month	Futures buy	Futures sell	Options buy	Options sell
Minimum of the information share				
1	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%
5	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%
7	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%
9	0.00%	0.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	0.00%
11	0.00%	0.00%	0.00%	0.00%
12	0.00%	0.00%	0.00%	0.00%
13	0.00%	0.00%	0.00%	0.00%
14	0.00%	0.00%	0.00%	0.00%
15	0.00%	0.00%	0.00%	0.00%
16	0.00%	0.00%	0.00%	0.00%
17	0.00%	0.00%	0.00%	0.00%
18	0.00%	0.00%	0.00%	0.00%
19	0.00%	0.00%	0.00%	0.00%
20	0.00%	0.00%	0.00%	0.00%
Average	0.00%	0.00%	0.00%	0.00%
Mean of the information share				
1	39.09%	45.88%	7.65%	7.38%
2	39.84%	40.63%	11.80%	7.72%
3	39.61%	43.84%	8.98%	7.57%
4	29.78%	39.00%	17.58%	13.64%
5	40.79%	38.64%	9.99%	10.58%
6	41.44%	41.96%	7.23%	9.37%
7	43.20%	38.15%	6.37%	12.28%
8	36.84%	45.16%	7.67%	10.32%
9	32.43%	36.98%	15.83%	14.76%
10	39.79%	34.49%	14.84%	10.88%
11	42.47%	37.17%	11.62%	8.73%
12	37.78%	40.39%	15.88%	5.95%
13	19.11%	21.20%	21.73%	37.96%
14	29.91%	32.50%	13.62%	23.97%
15	50.74%	38.30%	9.52%	1.45%
16	38.36%	44.65%	6.13%	10.86%
17	45.42%	34.40%	6.05%	14.13%
18	46.84%	36.13%	9.13%	7.90%
19	42.48%	46.09%	7.69%	3.74%
20	34.97%	36.84%	7.54%	20.65%
Average	38.55%	38.62%	10.84%	11.99%

Month	Futures buy	Futures sell	Options buy	Options sell
		Midpoint of the information share		
1	38.75%	42.44%	5.28%	6.15%
2	39.57%	40.04%	8.93%	6.00%
3	39.25%	41.73%	6.09%	6.19%
4	30.97%	35.48%	12.99%	9.91%
5	39.06%	38.05%	7.76%	6.37%
6	42.08%	41.97%	6.14%	8.63%
7	41.87%	39.72%	6.40%	10.48%
8	38.19%	42.39%	7.21%	7.65%
9	32.83%	34.86%	11.33%	9.51%
10	39.30%	35.98%	13.08%	7.40%
11	41.41%	38.41%	8.11%	7.42%
12	38.28%	39.39%	11.41%	4.53%
13	22.01%	23.47%	15.67%	27.16%
14	31.52%	32.85%	9.81%	14.36%
15	45.43%	38.73%	8.14%	1.65%
16	39.08%	43.28%	5.94%	9.51%
17	40.37%	34.76%	5.33%	9.49%
18	41.43%	36.22%	7.48%	6.55%
19	41.06%	42.16%	7.18%	4.23%
20	31.34%	31.96%	9.04%	13.42%
Average	37.69%	37.70%	8.67%	8.83%

This analysis is conducted in order to determine the band of moneyness that will provide the optimal number of observations to be used in estimation procedures. The data analyzed here contain volume information for CTI 1 traders for the nearby contract. For a range of 1%, an at-the-money (ATM) option is one whose strike price is within 1% of the price of the futures settlement price, an out-of-the-money (OTM) option is one whose strike price is above 1% of the futures settlement price, and an in-the-money (ITM) option is one whose strike price is below 1% of the futures settlement price. Moneyness is defined by a range of 1% to 5% ,as well as skewed values. The skewed range 1 is 1% for ITM and 4% for OTM. The skewed range 2 is 2% ITM and 5% OTM. The top number is the average daily volume and the bottom number is the total volume.

Table 6

Average Daily and Total Nearby Volume by Moneyness Levels

Moneyness	1% Moneyness	2% Moneyness	3% Moneyness	4% Moneyness	5% Moneyness	Skewed range 1	Skewed range 2
Volume by moneyness for CTI 1 traders call options							
OTM	1983	1976	1760	1644	1528	1644	1528
	816158	*782399*	*724700*	*676623*	*628763*	*676623*	*628763*
ATM	235	364	554	700	837	554	731
	84338	*144211*	*222376*	*284270*	*340011*	*223873*	*297113*
ITM	0	183	218	184	164	331	272
	0	*66571*	*81481*	*67664*	*59783*	*128061*	*102681*
Volume by moneyness for CTI 1 traders put options							
OTM	1980	1656	1725	1589	1484	1980	1855
	806542	*673596*	*702624*	*646918*	*600039*	*806542*	*756128*
ATM	315	427	660	858	1012	476	634
	104099	*170733*	*267372*	*349185*	*411869*	*189561*	*255780*
ITM	494	735	427	374	343	374	343
	221474	*255193*	*162119*	*136012*	*120207*	*136012*	*120207*

Because the price innovations in the VECM are correlated, Cholesky factorization is applied to compute the information shares on a weekly basis. The implied futures prices are computed using the combination of both at-the-money (ATM) and in-the-money (ITM) options and out-of-the-money (OTM) options separately. There are 24 possible combinations of information shares each week. The maximum, minimum, mean, and midpoint of the range from the 24 different combinations of information share each week are computed and the monthly averages are presented.

Table 7

The Information Share for OTM and ATM/ITM Options

Month	OTM options buy	OTM options sell	ITM and ATM options buy	ITM and ATM options sell
		Maximum of the information share		
1	5.98%	11.91%	22.01%	18.30%
2	14.00%	19.50%	20.69%	14.10%
3	20.13%	14.09%	19.84%	13.14%
4	11.51%	26.05%	36.62%	16.56%
5	12.26%	18.68%	26.46%	22.58%
6	14.33%	10.62%	10.51%	15.30%
7	7.39%	11.75%	16.83%	31.75%
8	4.94%	12.93%	24.94%	18.65%
9	14.87%	15.12%	28.69%	26.94%
10	22.08%	12.35%	24.55%	19.84%
11	15.24%	11.01%	23.10%	21.21%
12	17.41%	13.20%	23.69%	16.48%
13	23.04%	52.52%	38.79%	55.64%
14	28.23%	19.91%	5.28%	40.02%
15	22.51%	28.53%	19.26%	5.67%
16	8.88%	14.66%	19.52%	20.15%
17	7.29%	11.48%	17.09%	26.63%
18	17.79%	13.60%	17.73%	12.66%
19	4.58%	13.59%	11.91%	8.21%
20	34.17%	8.11%	20.10%	9.33%
Average	15.33%	16.98%	21.38%	20.66%

Month	OTM options buy	OTM options sell	ITM and ATM options buy	ITM and ATM options sell
		Minimum of the information share		
1	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%
5	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%
7	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%
9	0.00%	0.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	0.00%
11	0.00%	0.00%	0.00%	0.00%
12	0.00%	0.00%	0.00%	0.00%
13	0.00%	0.00%	0.00%	0.00%
14	0.00%	0.00%	0.00%	0.00%
15	0.00%	0.00%	0.00%	0.00%
16	0.00%	0.00%	0.00%	0.00%
17	0.00%	0.00%	0.00%	0.00%
18	0.00%	0.00%	0.00%	0.00%
19	0.00%	0.00%	0.00%	0.00%
20	0.00%	0.00%	0.00%	0.00%
Average	0.00%	0.00%	0.00%	0.00%
		Mean of the information share		
1	3.92%	7.01%	17.15%	13.16%
2	8.34%	11.73%	14.57%	8.57%
3	11.86%	8.47%	14.28%	8.92%
4	7.79%	20.26%	28.10%	11.40%
5	8.33%	12.79%	22.28%	16.45%
6	10.02%	5.75%	7.83%	11.31%
7	3.96%	9.07%	11.16%	23.70%
8	2.61%	9.23%	15.41%	12.00%
9	8.76%	12.50%	21.70%	21.47%
10	14.13%	9.09%	15.11%	13.61%
11	10.82%	6.09%	15.69%	14.66%
12	12.06%	6.96%	15.87%	10.08%
13	15.41%	38.90%	26.21%	39.72%
14	18.15%	13.74%	2.73%	35.07%
15	10.32%	16.35%	13.11%	3.43%
16	4.85%	8.72%	13.66%	14.89%
17	3.53%	5.94%	12.11%	21.16%
18	15.34%	11.38%	10.92%	7.14%
19	2.01%	8.76%	6.06%	3.71%
20	24.85%	5.00%	11.53%	6.19%
Average	9.85%	11.39%	14.77%	14.83%

Month	OTM options buy	OTM options sell	ITM and ATM options buy	ITM and ATM options sell
		Midpoint of the information share		
1	2.99%	5.96%	11.00%	9.15%
2	7.00%	9.75%	10.34%	7.05%
3	10.07%	7.04%	9.92%	6.57%
4	5.76%	13.02%	18.31%	8.28%
5	6.13%	9.34%	13.23%	11.29%
6	7.16%	5.31%	5.26%	7.65%
7	3.69%	5.88%	8.42%	15.87%
8	2.47%	6.47%	12.47%	9.33%
9	7.44%	7.56%	14.35%	13.47%
10	11.04%	6.17%	12.27%	9.92%
11	7.62%	5.51%	11.55%	10.61%
12	8.71%	6.60%	11.84%	8.24%
13	11.52%	26.26%	19.39%	27.82%
14	14.12%	9.95%	2.64%	20.01%
15	11.26%	14.26%	9.63%	2.84%
16	4.44%	7.33%	9.76%	10.07%
17	3.64%	5.74%	8.54%	13.32%
18	8.89%	6.80%	8.87%	6.33%
19	2.29%	6.80%	5.95%	4.11%
20	17.08%	4.06%	10.05%	4.67%
Average	7.67%	8.49%	10.69%	10.33%

The Wilcoxon signed-rank test is used to examine whether the information shares between the OTM and ATM/ITM groups are different.

Table 8

The Wilcoxon Signed-Rank Test for Differences Between OTM and ATM/ITM Information Share

	Variable	Pr >= |*S*|
Buy	Max ATM/ITM-max OTM	< 0.0001
	Mean ATM/ITM-mean OTM	< 0.0001
	Midpoint ATM/ITM-midpoint OTM	< 0.0001
Sell	Max ATM/ITM-max OTM	< 0.0001
	Mean ATM/ITM-mean OTM	< 0.0001
	Midpoint ATM/ITM-midpoint OTM	< 0.0001

Because the price innovations in the VECM are correlated, Cholesky factorization is applied to compute the information shares on a weekly basis. The implied futures prices are computed using put options and call options separately. There are 24 possible combinations of information shares each week. The maximum, minimum, mean, and midpoint of the range from the 24 different combinations of information share each week are computed and the monthly averages are presented. The Wilcoxon signed-rank test is used to examine whether the information shares of puts and calls are different.

Table 9

The Information Share for Put and Call Options

Month	Put options buy	Put options sell	Call options buy	Call options sell
Maximum of the information share				
1	18.05%	21.50%	15.28%	15.76%
2	21.50%	23.12%	23.87%	11.22%
3	9.63%	7.15%	22.37%	27.85%
4	17.54%	13.40%	12.49%	33.62%
5	34.37%	20.22%	20.92%	23.38%
6	15.32%	32.49%	14.19%	8.43%
7	21.00%	26.13%	15.30%	15.68%
8	9.57%	28.56%	7.89%	14.51%
9	25.84%	31.25%	31.08%	12.22%
10	27.77%	13.60%	14.48%	11.92%
11	24.36%	25.41%	11.70%	17.23%
12	28.19%	25.79%	25.12%	13.21%
13	39.04%	47.31%	34.89%	46.97%
14	26.06%	39.48%	16.84%	24.71%
15	11.46%	2.96%	13.49%	9.42%
16	24.90%	26.36%	11.73%	24.08%
17	25.03%	20.13%	10.27%	23.54%
18	14.41%	20.03%	16.61%	13.37%
19	8.80%	12.99%	18.04%	7.66%
20	19.19%	29.08%	6.78%	12.03%
Average	21.10%	23.35%	17.17%	18.34%

Month	Put options buy	Put options sell	Call options buy	Call options sell
		Minimum of the information share		
1	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%
5	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%
7	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%
9	0.00%	0.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	0.00%
11	0.00%	0.00%	0.00%	0.00%
12	0.00%	0.00%	0.00%	0.00%
13	0.00%	0.00%	0.00%	0.00%
14	0.00%	0.00%	0.00%	0.00%
15	0.00%	0.00%	0.00%	0.00%
16	0.00%	0.00%	0.00%	0.00%
17	0.00%	0.00%	0.00%	0.00%
18	0.00%	0.00%	0.00%	0.00%
19	0.00%	0.00%	0.00%	0.00%
20	0.00%	0.00%	0.00%	0.00%
Average	0.00%	0.00%	0.00%	0.00%
		Mean of the information share		
1	13.13%	15.95%	12.02%	9.95%
2	13.05%	17.07%	18.57%	8.28%
3	5.79%	3.07%	17.21%	18.18%
4	12.37%	9.68%	8.98%	26.73%
5	25.19%	15.49%	14.86%	17.41%
6	9.94%	22.45%	10.64%	6.08%
7	11.83%	18.83%	10.57%	10.51%
8	5.01%	23.34%	4.79%	9.53%
9	17.40%	28.48%	18.43%	7.68%
10	17.42%	8.21%	10.15%	8.05%
11	16.13%	13.65%	7.24%	13.09%
12	17.95%	16.06%	16.95%	8.64%
13	29.01%	34.21%	24.10%	35.41%
14	17.71%	32.77%	10.53%	20.01%
15	6.86%	1.12%	9.63%	5.61%
16	18.36%	17.19%	7.92%	17.04%
17	18.15%	15.59%	6.80%	15.08%
18	9.41%	12.72%	11.03%	10.54%
19	6.69%	8.74%	8.93%	2.94%
20	12.08%	23.68%	3.77%	8.83%
Average	14.17%	16.92%	11.66%	12.98%

Month	Put options buy	Put options sell	Call options buy	Call options sell
		Midpoint of the information share		
1	9.02%	10.75%	7.64%	7.88%
2	10.75%	11.56%	11.94%	5.61%
3	4.81%	3.58%	11.19%	13.92%
4	8.77%	6.70%	6.24%	16.81%
5	17.19%	10.11%	10.46%	11.69%
6	7.66%	16.25%	7.10%	4.21%
7	10.50%	13.07%	7.65%	7.84%
8	4.79%	14.28%	3.95%	7.25%
9	12.92%	15.63%	15.54%	6.11%
10	13.89%	6.80%	7.24%	5.96%
11	12.18%	12.70%	5.85%	8.62%
12	14.09%	12.89%	12.56%	6.61%
13	19.52%	23.65%	17.45%	23.49%
14	13.03%	19.74%	8.42%	12.35%
15	5.73%	1.48%	6.75%	4.71%
16	12.45%	13.18%	5.86%	12.04%
17	12.52%	10.07%	5.13%	11.77%
18	7.21%	10.01%	8.31%	6.68%
19	4.40%	6.50%	9.02%	3.83%
20	9.59%	14.54%	3.39%	6.01%
Average	10.55%	11.67%	8.58%	9.17%

The Wilcoxon signed-rank test is used to examine whether the information shares between puts and calls is different.

Table 10

The Wilcoxon Signed-Rank Test for Differences Between Put and Call Information Share

	Variable	Pr >= |*S*|
Buy	Max put-max call	< 0.0001
	Mean put-mean call	< 0.0001
	Midpoint put-midpoint call	< 0.0001
Sell	Max put-max call	< 0.0001
	Mean put-mean call	< 0.0001
	Midpoint put-midpoint call	< 0.0001

Appendix 2: Figure

The mean information share each month is plotted across time to evaluate whether any time variation occurred over the sample.

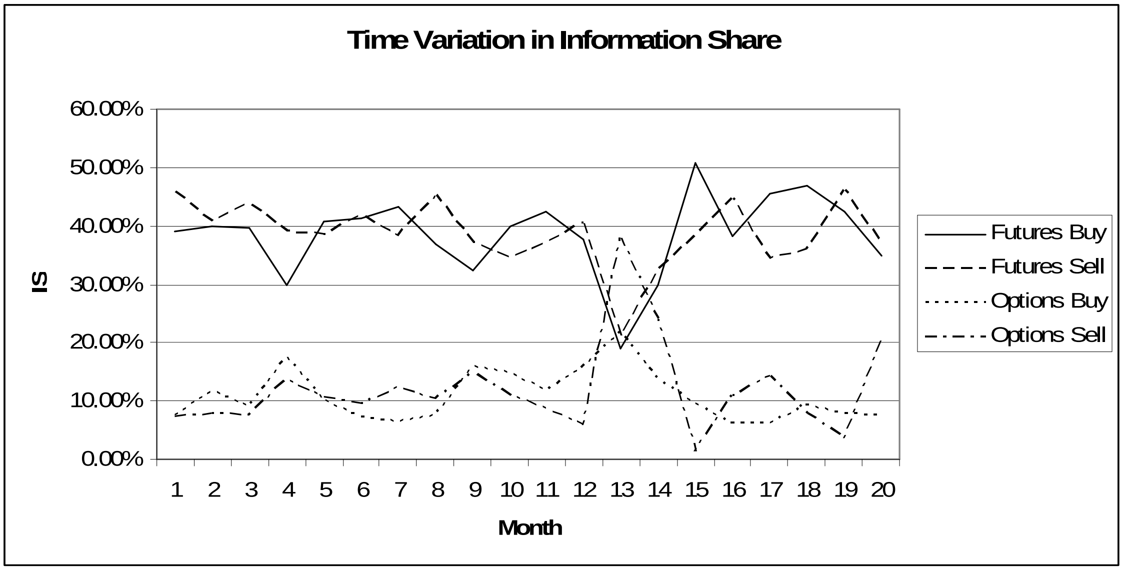

Figure 1. Time variation in information share.