Is There Price Discovery in Equity Options?*

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Abstract

This paper presents direct evidence that option price quotes do not contain any information about future stock prices beyond what is already reflected in current stock prices. We use trade and quote data for 39 liquid U.S. stocks and ETFs and options on them, and focus on events when the two markets disagree about the stock price in the sense that the option-implied stock price obtained from the put-call parity relation is inconsistent with the actual stock price. In these disagreement events the options market adjusts bid and ask prices to eliminate the disagreement, while the stock market behaves normally, as if there were no disagreement. The disagreement events are typically precipitated by stock price moves, and often exhibit signed option volume providing pressure to eliminate the mispricing. These results are consistent with the hypothesis that option price quotes do not participate in the price discovery process for the underlying stock price, and stand in contrast to much of the existing literature.

Keywords: Price discovery, equity options, market microstructure, high frequency data, put-call parity.

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Abstract

This paper presents direct evidence that option price quotes do not contain any information about future stock prices beyond what is already reflected in current stock prices. We use trade and quote data for 39 liquid U.S. stocks and ETFs and options on them, and focus on events when the two markets disagree about the stock price in the sense that the option-implied stock price obtained from the put-call parity relation is inconsistent with the actual stock price. In these disagreement events the options market adjusts bid and ask prices to eliminate the disagreement, while the stock market behaves normally, as if there were no disagreement. The disagreement events are typically precipitated by stock price moves, and often exhibit signed option volume providing pressure to eliminate the mispricing. These results are consistent with the hypothesis that option price quotes do not participate in the price discovery process for the underlying stock price, and stand in contrast to much of the existing literature.

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1. Introduction

This paper addresses the fundamental economic question of identifying information flows between the option and stock markets: Do price quotes for equity options contain any "directional" information about the future level of the underlying stock price that is not already reflected in stock price quotes? Using a dataset that contains more than three years of "tick-by-tick" trade and quote data for 39 liquid U.S. stocks and options on them, we address this question by focusing on events when the two markets disagree about the stock price in the sense that the option-implied stock price obtained from the put-call parity relation is inconsistent with the actual stock price quotes. In these disagreement events the options market permanently adjusts bid and ask prices to eliminate the disagreement between the option-implied stock price and the actual stock price. In contrast, the disagreement does not affect the stock market; the behavior of stock price changes conditional on a disagreement event cannot be distinguished from the behavior of stock prices in otherwise similar situations without disagreement. These results indicate that option price quotes do not contain any information that has not already been reflected in the stock market, and thus that option price quotes do not participate in the price discovery process for the underlying stock price.

We obtain these results using a new approach to studying price discovery that involves comparing quote changes in a "treatment" sample of price disagreement events to the quote changes in a matched control sample of otherwise similar observations for which there is no disagreement about the underlying stock prices. The use of the matched sample is necessary because stock and option price quotes can change for reasons other than the price disagreement. This method is accompanied by a test that shows that for the disagreement events option-implied stock price quotes do not predict changes in actual stock price quotes. Consistent with the main results that option price quotes do not contain information that has not already been reflected in stock price quotes, the disagreement events are typically precipitated by stock price moves, and often exhibit signed option volume providing pressure to move the option-implied stock prices toward the actual stock price quotes and thereby eliminate the disagreement. A number of robustness checks ensure the results are not driven by problems with data reporting or other data-related issues.

In interpreting these results within the context of the existing literature, it is important to distinguish between the question of whether some option trades are based on information about underlying stock prices, and the question of whether option quotes contain information about underlying stock prices in addition to that already reflected in the stock price quotes. There are compelling reasons to think that some option trades are executed by informed investors. Black (1975)

argues that the embedded leverage and lack of short-sale restrictions make options attractive for traders with information about future stock prices. More recently, Easley, O'Hara and Srinivas (1998), using a sequential trade model, show that a pooling equilibrium with informed trading in both markets can be observed. On the empirical side, Amin and Lee (1997) and Cao, Chen and Griffin (2005) find evidence of some informed trading in the options market prior to earnings and takeover announcements, respectively.[1] The most convincing evidence comes from Pan and Poteshman (2006), who document that stocks with low put-call ratios computed from the option trades that open new option positions outperform stocks with high put-call ratios computed from opening trades by more than 40 basis points on the next day. (The magnitudes are smaller if only public information on signed volume is used to compute the put-call ratios.)

On the other hand, the evidence on whether option price quotes react to potentially informed trading is mixed. For example, Amin and Lee (1997) show that option bid-ask spreads do not increase during periods of plausibly high information asymmetry, such as prior to earnings announcements, and Vijh (1990) points out that option price quotes do not change after large trades. On the other hand, Chan, Chung, and Fong (2002) extend the approach of Hasbrouck (1991) to multiple markets and find that new information in the options market comes in the form of quote revisions rather than trades. Our results bear on the literature about option price quotes, but do not contradict the evidence in Pan and Poteshman (2006) that some option trading volume is based on information about future stock price movements. Our evidence of signed option volume during the disagreement events is actually direct evidence of a special case of informed high-frequency trading in options, where the information consists of the knowledge that the option quotes are inconsistent with the current stock price.

Our findings bear most directly on the literature on the lead-lag behavior between stock and options markets. This line of research was started by Manaster and Rendleman (1982), who used end-of-day trade prices to show that option prices lead stock prices. However, that paper suffers from a problem with asynchronous trading, because during that paper's sample period options trading continued for ten more minutes after the stock market close. Most of the subsequent literature focused on refining the econometric methodology, starting with simple causality tests by Anthony (1988) and evolving to the vector autoregression error correction models estimated by Chan, Chung, and Fong (2002), Chakravarty, Gulen, and Mayhew (2004), and Holowczak, Simaan, and Wu (2006).[2]

[1] In addition, Easley, O'Hara, and Srinivas (1998) present evidence indicating that options trading volume leads stock trading volume. Enforcement actions by the U.S. Securities and Exchange Commission provide evidence that at least some investors occasionally use options for illegal informed trading.

[2] Other related literature includes Stephan and Whaley (1990), Chan, Chung, and Johnson (1993), DeJong and Donders (1995), Finucane (1999), Diltz and Kim (2005), O'Connor (2005), and Wen-Liang, Chin-Shen, and Shu-Fang (2008). A

Chakravarty, Gulen, and Mayhew (2004) compute option-implied stock prices from call option prices using the binomial model and lagged implied volatilities. Estimating a vector autoregression error correction model for the actual and option-implied stock prices and data from 1988 to 1992, they find that the "information share"[3] of option quotes is 17%. Using the put-call parity relation to compute the option-implied stock price and more recent data from 2002, Holowczak, Simaan, and Wu (2006) obtain somewhat smaller estimates of the information share of option quotes.[4] However, their estimates of the error correction coefficients estimated for different stocks imply that for NYSE-listed stocks and the overall sample, on average actual stock prices react more strongly to the one-second-lagged differences between stock and option prices than do option-implied stock prices. Additional results in Holowczak, Simaan, and Wu (2006) show that the options quotes become more informative when there are large price movements, large numbers of options trades, or significant signed order flow in the options market.

Chakravarty, Gulen, and Mayhew (2004), Holowczak, Simaan, and Wu (2006), and most other papers that study the lead-lag relation assume that the joint option and stock price dynamics can be well-described by a particular econometric model.[5] Therefore, this approach is subject to the joint hypothesis problem. For example, if the econometric results indicate that one market follows the other, it can be because it indeed follows, or because the econometric model is not well-specified.

We take an alternative approach by introducing a clean identification scheme that is valid under mild assumptions. As indicated above, we use the put-call parity relation to compute option-implied stock prices. In doing this, we explicitly take account of the large bid-ask spread found in the options markets, because the commonly used approach of using the bid-ask midpoint or average can

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recent literature review is provided by Afef, and Olfa (2009). Finucane (1991) was the first to apply call-put parity to study lead-lag behavior between the option and stock markets.

[3] The information share of a market is introduced by Hasbrouck (1995) as "the proportional contribution of that market's innovations to the innovation in the common efficient price," and is computed by decomposing the variance of the innovations to the long run price into the components due to the two markets. See also Hasbrouck (2002, 2003).

[4] Holowczak, Simaan, and Wu (2006) also use the common factor loading approach of Harris, McInish, and Wood (2002a, 2002b). For their sample of stocks, the average common factor loading estimate on the options market is larger than the corresponding Hasbrouck information share estimates.

[5] Bhattacharya (1987), who further examines the findings of Manaster and Rendleman (1982), does not rely on a specific econometric model and is the closest study to ours. Using 15-minute quote snapshots for 32 stocks and options on them, he simulates a trading strategy in which stock is bought (sold) when it is quoted below (above) the option-implied stock price by at least the threshold amount. The position is held open for 15 minutes, and then closed. The average profitability from this strategy is close to zero and becomes negative after bid-ask spread costs are considered, providing no evidence that options lead stocks. Similarities between Bhattacharya's approach and ours are that both focus on the cases in which stock prices are inconsistent with the option prices, not the full sample, and both explicitly recognize the bid-ask spread. However, a critical aspect of Bhattacharya's test design is that it can only detect whether the option market leads the stock market and not vice-versa. Moreover, the motivation for the test designs differs. Bhattacharya points that in the full sample his trading strategy is *a priori* loss-making, while we focus on the cases of disagreement because these are cases when one can be confident that the prices in the two markets reflect different information.

misrepresent a market's beliefs about the fair price. Instead, we assume that the fair stock and option prices can be anywhere between the bid and ask prices, and compute option-implied bid and ask prices for the underlying stock. The assumption that the fair price can be anywhere between the bid and the ask implies that if the bid-ask ranges for the actual and option-implied stock prices overlap, then the two markets potentially agree about the fair price of the stock. In the other case, when the bid-ask ranges do not overlap, the two markets disagree about the fair stock price. These cases of disagreement are the focus of our analysis. They are of particular interest because at the moment of disagreement the fair price could be the actual stock price, the option-implied stock price, or somewhere between the two. No-arbitrage conditions imply that in frictionless markets mispricing will be immediately eliminated by arbitrageurs. However, market frictions such as short-sale costs,[6] latency,[7] price impact, margin requirements, and execution uncertainty allow for price disagreements without creating arbitrage opportunities.

The sample of disagreements is large enough to conduct the analysis on a stock-by-stock basis rather than by pooling the stocks together. In the sample, the actual and option-implied prices for a given stock are inconsistent on average several times per day. With three years of data, a sample of more than 107,000 disagreement events is available. Although the sample size is large, only one percent of two-minute snapshots contain disagreements (as determined by violations of put-call parity). Unsurprisingly, this is a lower frequency than was found in the studies of put-call parity violations by Kamara and Miller (1995) and Ofek, Richardson, and Whitelaw (2004) that use data from earlier periods when the options markets were less liquid.

We compare changes in both the actual and option-implied stock price quotes in a treatment sample of price disagreement events to the quote changes in a matched sample of otherwise similar observations for which there is no disagreement about the underlying stock prices. Using both a classical average treatment effect analysis and looking at average effects conditioning on control variables, we find that option-implied stock prices move toward the actual stock prices, but actual stock prices do not move toward the option-implied prices. Rather, the behavior of the actual stock prices when there is a disagreement cannot be distinguished from their behavior in the absence of a disagreement. Examination of histograms summarizing the distributions of changes in option-implied and actual stock price changes reveal that the disagreement events involve a shift in the entire distribution of option-implied quotes, and essentially no alteration in the distribution of actual stock prices. The visual examination of the histograms is corroborated by quantile regression analyses.

[6] See the discussion in Ofek, Richardson, and Whitelaw (2004).
[7] Latency is the length of time it takes for a packet of data to get from one designated point to another.

This finding that option price quotes do not participate in the price discovery process for the underlying stock price stands in contrast to the existing literature on the lead-lag relation between the options and stock markets. While this existing literature finds that most price discovery occurs in the stock market, the results have been interpreted as evidence that option price quotes contribute to price discovery in the stock market in a meaningful way. (For example, Chakravarty, Gulen, and Mayhew (2004) and Holoczwak, Simaan, and Wu (2006).)

Consistent with our findings that option quotes either agree with or lag the stock, the disagreement events are typically precipitated by stock price moves. In addition, the disagreement events often exhibit signed option volume providing pressure in the direction that will tend to move option price quotes to eliminate the disagreement, consistent with stock prices leading option prices. In addition, the signed option volume during the disagreement events is compelling evidence that the events are not an artifact of data problems.

The remainder of this paper is organized as follows. The next section describes the novel data employed in the paper. Section 3 describes how we define and identify the disagreement events and the construction of the matched control sample, and then presents some relevant summary statistics about the disagreement events. Section 4 contains the main results of the empirical analysis of quote changes, while Section 5 presents the results of several supplemental analyses showing that the main results are also found in various subsets of the data and are not an artefact stemming from possible data problems. Section 6 briefly concludes. A short appendix summarizes the recent history of the option market structure.

2. Data Description

The primary data used in this research are tick-by-tick trade and quote data for 36 liquid U.S. stocks and 3 ETFs along with their options from April 17, 2003 to October 18, 2006, a total of 882 trading days.[8] This is a larger and more recent sample than used in previous studies of the lead-lag relation. The data were obtained from Nanex, which provides real-time option and stock price data to its customers via its NxCore product. The data were archived by Nanex as they arrived from the exchanges at Nanex's server, and time-stamped by Nanex to 25 millisecond precision as they arrived.[9] The data come from all U.S. exchanges where a given contract is traded. For trades, transaction price, size, exchange code, and some other information are available. For quotes, exchange-level best quotes

[8] Data are not available for several days during the period, so the total of 882 days does not match the number of trading days from April 17, 2003 to October 18, 2006, inclusive.
[9] The Trade and Quote (TAQ) database available from the NYSE time stamps trades and quotes to only 1 second precision.

and volumes are available. That is, the data include each instance when any exchange adjusts its best quote or quoted volume, even if it this change does not change the national best bid and offer (NBBO). The main reason for limiting the sample size to 39 stocks and ETFs was a data storage limitation. The size of the compressed database exceeds 1,400 GB.

The underlying stocks are listed in Table 1. The selected stocks were those with the highest option market volume during March 2003, and the list of tickers was never changed in order to avoid survivorship bias. These stocks cover a significant share of total volume in the options market. Some of the stocks merged, e.g. America Online, or changed a ticker, e.g. Morgan Stanley. For these stocks, data are available only up to the date of the ticker change. This resulted in five stocks (AOL, CPN, MWD, SBC, and NXTL) dropping from the sample prior to the end date. In addition, the QQQ ticker for the NASDAQ 100 ETF dropped from the sample when it was replaced by the QQQQ ticker.

Dividend and split data are taken from the Ivy DB database available from Option Metrics LLC. The Ivy DB database includes dividend amounts as well as declaration, ex-dividend, and payment dates. The risk-free rates are also from Option Metrics, which compute them from "cash" LIBOR quotes and LIBOR forward rates estimated from the prices of Eurodollar futures contracts.

Some analyses use estimates of signed volume for the options or their underlying stocks, and some use estimates of the delta-equivalent signed volume of the options transactions. For stocks, the required trade direction indicator is inferred using the Lee and Ready (1991) algorithm. For options, trade direction is inferred by first applying the quote rule to the NBBO. If the trade is at the midpoint of the NBBO, the quote rule is applied to the BBO from the exchange at which the trade occurs. Based on six months of data from 1995, Savickas and Wilson (2003) show that the quote rule works better for options than other common algorithms. Also, unlike stocks, in our data approximately 80% of the options transactions occur at the best bid or ask, which suggests that the quote rule will provide reasonable results for the options. Options delta, needed to estimate delta-equivalent signed volume, is computed using the Black-Scholes-Merton formula and the previous days' implied volatility estimates from Option Metrics.

Earnings announcement data are needed for one analysis. Earnings announcement dates are taken from First Call, and the times of the earnings announcements are hand-checked using LexisNexis.[10]

3. The Disagreement and Matched Control Samples

We focus on "disagreement" events in which the stock and options markets disagree about the

[10] Time data in First Call are unreliable.

stock price in the sense that the option-implied stock price quotes obtained from the put-call parity relation are inconsistent with the actual stock price quotes. In these price disagreement events, either the actual stock bid price exceeds the option-implied ask price, or the actual ask price is less than the option-implied bid price. We compare the movement of both the actual stock price quotes and option-implied stock price quotes following the beginning of a disagreement event to the movement of the corresponding quotes during otherwise similar "control" events during which there is no disagreement about the underlying stock prices. Differences in the movement of the quotes between the disagreement and matched control events allow us to draw inferences about the markets in which price discovery occurs.

The motivation for focusing on price disagreements has two parts. First, the common approach of using the quote midpoint as an estimate of the fair price ignores the discreteness of price quotes, e.g. for options priced below three dollars option price quotes were integer multiples of five cents during our sample period. (For options priced above three dollars option price quotes were integer multiples of 10 cents.) The minimum possible option bid-ask spread of five cents implies a 10-cent minimum option-implied spread for the stock when the put-call parity is used to compute option-implied bid and ask prices for the stock. Even this lowest possible value of 10 cents constitutes a sizable 0.25% of a typical stock price, compared to a one-cent (0.025%) spread for liquid common stocks.

To understand why this poses a problem for a lead-lag evaluation, consider an example. Stock ABC is traded at $20.07 bid, $20.08 offer, and the option-implied quotes computed using put-call parity are 20.00 / 20.10. Assume that both markets have access to the same information, so that without tick friction both markets contribute equally to the price discovery. An option market maker believes that the fair price is between 20.07 and 20.08 (the stock bid and offer) and not at the option-implied quote midpoint of 20.05, but the tick size does not allow him to make the option-implied quote midpoint any closer to 20.07 / 20.08. Imagine that the price drifts from 20.07 / 20.08 to 20.01 / 20.02, and when the stock is at 20.01 / 20.02 the option market maker adjusts his quotes to 19.95 and 20.05. Following the change in the option price quotes, the stock price continues drifting downward. Based on the option-implied quote midpoint, the option market leads the stock market during the first part of the episode, and the stock market leads the options market during the second part. However, both conclusions would be incorrect, as by assumption the markets are equally informed at each point in time.

This example illustrates that, although relying on the quote midpoint is convenient, it can be dangerous if the minimum tick size is large. To address this problem, we assume that market maker's estimate of a fair price can be anywhere between his bid and ask prices, and not necessarily at the

midpoint. Then, if the bid-ask range of the actual stock price overlaps with the bid-ask range of the option-implied stock price computed from put-call parity the two markets can potentially have identical estimates of the fair price of the stock. In particular, one cannot rule out the possibility that the two markets agree on the fair price, but that the option market makers cannot center their quotes around it because of the discreteness of price quotes. In this case the markets' fair price estimates are indistinguishable, and it is impossible to compare their relative price discovery. As a result, we focus on the cases when we know that the stock and option markets disagree about the fair price of the underlying stock, because in these cases it is possible to evaluate which market or markets contribute to price discovery.

3.1 *Price disagreement events*

To define a disagreement event, we first construct option-implied bid and ask prices for the underlying stock using the European put-call parity relations

$$\text{Implied Bid}_t = C_t^{\text{bid}} - P_t^{\text{ask}} + PV(D_t(t,T)) + Ke^{-r(t,T)(T-t)} \tag{1}$$

and

$$\text{Implied Ask}_t = C_t^{\text{ask}} - P_t^{\text{bid}} + PV(D_t(t,T)) + Ke^{-r(t,T)(T-t)}, \tag{2}$$

where Implied Bid$_t$ and Implied Ask$_t$ are the option-implied bid and ask prices of the underlying stock, $C_t^{\text{bid}}, C_t^{\text{ask}}$, P_t^{bid}, and P_t^{ask} are the bid and ask prices of the call and put options, respectively, $PV(D_t(t,T))$ is the present value of the dividends with ex-dividend dates falling between the current date t and the option expiration T, K is the strike price of both the call and the put, and $r(t,T)$ is the interest rate for the period from t to T. These relations hold only approximately, as the options in the sample are American, not European, and it can be optimal to exercise deep in-the-money put options prior to expiration, or to exercise in-the-money call options immediately prior to the ex-dividend dates of a large dividend. Recognizing this, we use equations (1) and (2) only with short-term, near-the-money options on stocks for which ex-dividend dates of large dividends do not fall during the lives of the options. For these options the early exercise premia are likely to be small.

Specifically, we use only options that satisfy the following criteria:

(a) The remaining time to expiration $T - t$ is between 10 and 50 calendar days, inclusive.

(b) The option is within 6% of being at-the-money, i.e. the option moneyness $\ln(S/K)$ satisfies $|\ln(S/K)| \leq 0.06$, where S is the average of all trade prices during the day.

(c) The present value of the dividends with ex-dividend dates during the remaining life of the

option satisfies PV($D_t(t,T)$) < 0.05.[11]

(d) The bid price of the option is greater than or equal to 15 cents.

If more than one put-call option pairs satisfies the moneyness criterion (b) all of them are considered independently, potentially resulting in the identification of more than one disagreement event in an underlying stock at a given time *t*. More than 20% of the disagreement events have another event (for a different call-put pair based on the same underlying stock) within the next 20 seconds.[12]

The first two criteria (a) and (b) limit the value of the early exercise premia of both puts and calls, while (c) has the effect of including in the sample only the call options for which the call early exercise premium is almost zero. Criteria (a) also greatly reduces the uncertainty about the dividend estimates used in (c), because dividends typically are announced about a month before the ex-dividend date and do not change from quarter to quarter. This eliminates much of the uncertainty about dividends in the sample of close to expiration options. Moreover, even for stocks that pay quarterly dividends there typically is not a dividend payment during the remaining life of a short-term option.

The criteria (a) and (b) also have the effect of eliminating many of the less liquid options from the sample. Because this is desirable, the reduction in the sample size due to these criteria is not a significant concern.

Criterion (d) has the effect of screening out many cases in which the option bid price becomes unavailable during the evaluation period. Such cases prevent us from computing the change in the option price during the evaluation period. This criterion also contributes to screening out less liquid options.

For each underlying stock and ETF, we search for price disagreement events by comparing the option-implied stock bid and ask prices computed using equations (1) and (2) to the actual bid and ask prices. In this process, we do not consider the quote updates from the first and last 5 minutes of each trading day. At the beginning of the day the markets need some time to aggregate all information accumulated from previous close, while we cannot use disagreements that begin near the close of trading because we are interested in quote changes subsequent to the disagreements. For all other quote updates in the sample, a potential price disagreement event is identified at time *t* if there is a call-put pair that satisfies criteria (a)-(c) above and also:

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[11] This has the effect of screening out stock-date pairs for which the (European) put-call parity relation is not satisfied. The results do not change if we include in the sample the stock-date pairs with large dividends for which the call-put parity relation is satisfied, where in this context "is satisfied" means that for a given call-put pair, the stock and options markets disagree for less than 10% of 2-minute snapshots during the day.

[12] This is unsurprising, as most disagreement events are triggered by movements in the underlying stock price. The application of the filters described below excludes the subsequent events from the statistical analysis.

(i) S_t^{bid} – Implied Ask$_t$ ≥ \$0.02 or (S_t^{bid} – Implied Ask$_t$)/ S_t^{bid} ≥ 0.05%; or

(ii) Implied Bid$_t$ – S_t^{ask} ≥ \$0.02 or (Implied Bid$_t$ – S_t^{ask})/ S_t^{ask} ≥ 0.05%.

These conditions imply that the bid-ask ranges of the actual and option-implied stock prices do not overlap, but rather are separated by a distance that is either \$0.02 or 0.05% of the stock price. The absolute threshold \$0.02 is relevant for high-price stocks, while the relative threshold 0.05% is relevant for low-price stocks.[13] The use of these thresholds minimizes the impact of errors arising from our reliance on the European put-call parity relation. In (i) the price is greater than the implied price, and we call such events {P >IP}-type disagreements; in (ii) the implied price exceeds the price, and we call such events {IP > P}-type disagreements. In the {P >IP}-type disagreements, the actual stock price should decrease and/or the option-implied price should increase to eliminate the disagreement, while in the {IP >P}-type the stock price should increase and/or the implied price should decrease.

We construct the final sample by applying several filters to the events that satisfy (i) and (ii). To avoid interference between multiple events, any potential disagreement that is triggered within a 5-minute period following the start of any previous disagreement event is discarded. Events in which the bid-ask spread for the stock, call option, and put option are not all strictly positive are discarded, and all events with duration of less than half a second are discarded.[14] These filters ensure that the disagreement events that appear in the sample are not merely market "locks," caused by differences in latency, or "blinking" limit orders that are displayed for only a few milliseconds, or otherwise so short-lived that investors are unable to trade on them. Finally, as indicated above we do not search for disagreement events during the first and last five minutes of each trading day.

Our approach involves comparing the movement of both the actual and option-implied stock price quotes following the beginning of a disagreement event to the movement of the corresponding quotes following otherwise similar "control" events during which there is no disagreement about the underlying stock prices. In doing this we examine the quotes either 30 or 60 seconds after the beginning of the events, which we refer to as the evaluation period. Thus, we also associate with each disagreement event the stock and option-implied quotes prevailing 30 and 60 seconds subsequent to the beginning of the event.

Figure 1 illustrates the quote dynamics during a disagreement event. Through the time 10:00:36.200 ABC's ask price is greater than or equal to \$60.00 and the option-implied quotes are \$60.00 / \$60.10. The absolute threshold is 2 cents (the relative one is 3 cents), and is the relevant one.

[13] We obtain similar results and identical conclusions if we use a threshold of 4 cents or 0.1% of the stock price.
[14] The number of these is about 10% of the sample size. Including them in the analysis will strengthen the results.

At the quotes prevailing through 10:00:36.200 the mispricing is only one cent and the disagreement event is not triggered. Then, 200 milliseconds later, at 10:00:36.400, the actual ask quote changes from $59.99 to $59.98. The threshold of 2 cents is met, an {IP>P}-type price disagreement event is triggered, and the time and quotes are stored. In addition, the quotes at 10:01:06.400 and 10:01:36.400 (30 and 60 seconds after the beginning of the disagreement event) are stored for the analysis of quotes changes subsequent to the disagreement event.

3.2 *Matched control sample*

We cannot simply analyze the sample of disagreement events but need to use a matched control sample for two reasons. First, during the evaluation period new information might reach the markets, and prices will move as the information arrives. For example, does a stock price change during a disagreement event mean that the stock market has taken into account the option-implied stock prices, implying that some price discovery about the underlying stock price occurs in the options market? Or is it simply that new information has arrived and been reflected in the stock price? A natural way to control for the arrival of new information and thus distinguish between these two explanations for the stock price movement is to compare the stock price changes during disagreement events to the stock price changes during a matched sample of otherwise similar market conditions for which there is no disagreement. Of course, it is rare to find exact matches to the market conditions. However, one can match on a set of important observable variables, such as the option-implied bid-ask spread and the prior stock return, that are likely to be correlated with stock price movements. With a high-frequency dataset there are enough observations to allow us to locate good matches on these variables.

The same issue is relevant for the other market. Movement in the option-implied stock quotes can be caused by factors other than the price disagreement. Perhaps options quotes always move in a particular fashion, even without price disagreement. For example, during disagreement events the option-implied bid-ask spread is usually smaller than its full sample average, and its reversion toward the full sample mean mechanically reduces the apparent mispricing. Thus, at least part of the apparent decrease in mispricing is due to mean reversion in the bid-ask spread and not due to the options market following the stock market. Therefore, it is necessary to assess what are the "normal" changes in the option-implied quotes during the evaluation period. As in the previous case, a solution is to compare option dynamics under similar market conditions with and without disagreement. The question, therefore, is what variables should be used for matching?

Based on event mechanics, the option-implied bid-ask spread and the pre-event stock return are good candidates. Figure 1 illustrates this. The actual stock bid-ask spread in Figure 1 is narrow,

consistent with the data. Thus, the stock price drifts inside a wide stripe of option-implied quotes, and a disagreement occurs when it gets outside the stripe. The disagreement is more likely to occur when the option-implied bid-ask spread is smaller than its average, because the stock has to move a smaller distance to get outside to option-implied quotes. Thus, the option- implied spread is the first variable to match on. As for the second variable, in our data most of the disagreement events are initiated by the stock market, due to the pre-event return. Because large stock price returns might by themselves predict subsequent movements in stock or option prices, the five minute pre-event stock return is a good variable to use for matching. It is also a proxy for stock volatility at the time of the event.[15]

Based on these arguments, we construct the control sample by matching with respect to two variables, the spread between the option-implied bid and offer quotes at the moment the disagreement event is triggered and the 5-minute pre-event stock return constructed from the actual stock bid-ask midpoints. To facilitate matching, the sample period is divided into 40-day periods. For each disagreement event, a sample of potential matches from that underlying stock is constructed based on quote snapshots at one-minute frequency from the 40 trading day period that contains the disagreement event. We exclude potential matches in which the stock, call, and put bid-ask spreads are not strictly positive, and also exclude potential matches that occur within 5 minutes of the start of any of the disagreement events. Finally, we require that matches for the {P>IP}-type have an actual quote midpoint greater than the midpoint of the option-implied quotes, and vice-versa for the {IP>P}-type.

Each disagreement event is matched with exactly three observations from the set of potential matches. In selecting these three matches we first match on the implied spread, which is a discrete variable taking one of three values 0.1, 0.15 or 0.2 in 99% of the disagreement events, and then find the closest match for the pre-event return.

3.3 *Summary statistics*

Table 1 presents some relevant summary information about the stock' average bid-ask spreads and some characteristics of the disagreement events, on a stock-by-stock basis. The first columns shows the stock ticker symbol, while the second shows the average stock price during the sample period. The third shows the average bid-ask spread (in dollars) in the stock market. The overall average bid-ask spread is only 1.2 cents, which is unsurprising given that most of the stocks are liquid, large capitalization stocks. The maximum of the average spreads is only 2.3 cents, the average spread for Capital One. The fourth column headed "Implied Spread" shows the average spread between the

[15] Table 1 below shows that these variables' means are substantially different for the disagreement and full samples.

option-implied bid and ask prices computed using put-call parity from a pair of options. The overall average implied spread is 15 cents, with the minimum of the average implied spread being 11 cents, the average for Dell Computer. These average spreads justify thinking intuitively of a stock price drifting inside the stripe of option-implied quotes.

There are 89,807 events of the {P>IP}-type and 18,010 of the {IP>P}-type. The largest event suppliers are eBay and Amazon, with more than 8,500 events each. Some of the stocks (e.g., America Online and Calpine) dropped from the sample before the end of the sample period; thus there are few events for them.[16]

The fifth and sixth columns show the median event durations (in seconds) and the implied spread during the event, by stock. The average (across stocks) of the median event durations is 14.2 seconds, with the smallest and largest median durations being 11.15 and 30.16 seconds, respectively. The table compares averages for the matched variables, i.e. the implied spread and per-event stock five minute return, for both event types and the full sample. For both event types the pre-event stock returns are substantially different from the full sample average of zero. Specifically, they are 0.15% for the {P>IP}-type and –0.22% for the {IP>P}-type, consistent with the fact that most price disagreements are precipitated by stock market moves. In fact, only 9% of the disagreements are initiated by the options. The implied spread for the events is 13 cents, which is below the full sample average of 15 cents. This difference is meaningful because the minimum spread is 10 cents. Overall, Table 1 shows that there is little variation in matched variables across stocks. Thus, the stocks can potentially be pooled into one sample; however, for most analyses we do not pool the data. The high-frequency data allow for almost perfect matching.

Figure 2 shows smoothed estimates of the average numbers of {P>IP}-type (the solid red line) and {IP>P}-type events (the dashed blue line) per stock per day. The estimates are constructed by counting the total (across stocks) number of events per day, dividing by the number of stocks and ETF's in the sample on that day, and then smoothing the resulting time series by taking a 20-day moving average. There are about five disagreement events per day on a typical stock. The disagreement frequency has interesting dynamics. In most periods there are more {P>IP}-type events than {IP>P}-type ones. This can be explained by the combination of the behavior of the stock market, which was generally rising and almost doubled during the sample period, and the fact that 91% of the

[16] The numbers of {P>IP} and {IP>P}-type events are not equal, because stock prices generally moved upward during the sample period and (as is shown below) most events were precipitated by stock price moves. If we use a Treasury bill rate as the risk-free rate we obtain 50,534 {P>IP} and 31,322 {IP>P}-type events, respectively. We have performed the main tests with these samples determined using the Treasury bill rate as the risk-free rate and obtained very similar results supporting identical conclusions.

disagreement events were precipitated by stock price moves. During periods when the stock market declined there were relatively more {IP>P}-type events.

The disagreement frequency falls from about 6.5 per day in the beginning of the sample period to about 4.5 per day at the end. There are two possible drivers for this trend. First, volatility as measured by the VIX was falling steadily from 25% in April 2003 to 12% in October 2006. Next, improvements in technology may have made it easier for option market makers to avoid price disagreements.

The duration of the disagreements is another interesting statistic. Figure 3 shows that the cumulative distributions of the duration times are similar for the two event types. Disagreement events have a short life, with 60% of disagreements disappearing in the first 20 seconds, and 90% being eliminated within 100 seconds.[17] Our choice of evaluation periods of 30 and 60 seconds is motivated by these observations. Table 1 reveals that there is not much variation in the median disagreement duration across stocks, and that the mean (across stocks) of the stock median durations is just over 14 seconds.[18]

Figure 4 shows a kernel density estimate of the location of the actual stock quote midpoint relative to the option-implied spread, conditional on the option-implied spread being equal to its most common value of 15 cents. The horizontal axis is the difference between the price and the option-implied bid price, i.e. it is the distance of the price from the bottom of the bid-ask range. The price quotes used to estimate the density are two-minute frequency snapshots from the full sample, excluding cases in which the implied spread is not equal to its most common value of 15 cents. Violations of put-call parity occur when the density function crosses the dotted lines highlighting the locations of the option-implied quotes. Although disagreement events occur regularly, the fraction of time markets spend in disagreement is less than 0.1%.

4. Hypotheses and Main Results

4.1 *Distributions of Quote Changes*

We begin with a visual examination of the differences between the distributions of the quote changes in the disagreement and control samples. For the {P>IP}-type disagreements, the option-implied ask quote is less than the actual bid. The hypothesis that the options follow the stock implies

[17]As discussed above, we exclude from the sample disagreements with durations of less than one-half second. Because some (and perhaps most) of these short-lived disagreements are valid disagreements and not due to differences in latency or data reporting problems, the figure somewhat overstates the typical lengths of disagreement events.

[18]Deville and Riva (2007) conduct a detailed statistical analysis of call-put parity violation durations for the French index options market and find that liquidity-linked variables, such as the volumes in the stock and options markets, the imbalance between put and call option volume, and the time to expiration affect violation durations.

that the distribution of the change in the option-implied ask quote for the disagreement sample is to the right of the distribution for the control sample, while the hypothesis that the options do not follow the stock implies that the distribution of the change in the option-implied ask quote for the disagreement sample is either identical to or to the left of the distribution for the control sample. The hypothesis that the stock follows the options implies that for these {P>IP}-type disagreements the distribution of the change in the actual bid quote for the disagreement sample is to the left of the distribution for the control sample, while the hypothesis that the stock does not follow the options implies that the distribution of the change in the actual bid quote for the disagreement sample is either identical to or the right of the distribution for the control sample.

For the {IP>P}-type disagreements, the option-implied ask quote is greater than the actual bid and the predictions for the differences in the distributions are opposite those above. Specifically, the hypothesis that the options follow the stock implies that the distribution of the change in the option-implied ask quote for the disagreement sample is to the left of the distribution for the control sample, and the hypothesis that the stock follows the options implies that the distribution of the change in the actual bid quote for the disagreement sample is to the right of the distribution for the control sample.

Figure 5 consists of six panels comparing the quote change distributions over an evaluation period of one minute for the treatment and control samples aggregated across all stocks. In constructing the figures, for simplicity we replace the actual stock bid price with the bid-ask midpoint because the bid-ask spread in the stock market was typically only one cent and the distribution of changes in the actual bid-ask midpoint cannot be visually distinguished from the distributions of changes in the actual bid and ask prices. The top three panels (A-C) are for the {P>IP}-type disagreements and compare the distributions of changes in the option-implied bid, option-implied ask, and actual stock midpoint for the disagreement and control samples. In each panel, the distribution of quote changes in the disagreement sample is represented by the light-shaded bars, while the distribution of quote changes in the control sample is represented by the dark-shaded bars. The bottom three panels (D-F) also compare the distributions of changes in the option-implied bid, option-implied ask, and actual stock midpoint quotes between the disagreement and control samples, but for the {IP>P}-type disagreements. In all cases quote changes are measured in U.S. dollars, e.g. 0.2 is 20 cents. Note that the distributions of changes in the option-implied bid and ask prices are indeed discrete, as the tick size is five cents.

For the {P>IP}-type disagreements (Panels A-C) the most noticeable difference in the distributions is in Panel B, which compares the distributions of the changes in the implied ask prices for the treatment and control samples. For the control sample (dark-shaded bars), the implied ask stays

the same or decreases more than 70% or the time; it increases and moves toward the actual bid in fewer than 30% of the events. The finding that the implied ask moves toward the bid in some of the events should not be surprising, as in both the disagreement and control samples the option-implied bad-ask spread is less than its unconditional average value, so some spread widening is to be expected. By construction in the control sample, the observed midpoint is closer to the implied ask than to the bid. In contrast, the distribution of changes in the treatment sample shows a much higher frequency of increases in the implied ask price. The implied ask stays the same or decreases in fewer than 30% of the treatment observations, and increases in more than 70%. The mode of the distribution of the treatment sample is five cents, and the mean is close to 10 cents. Thus, the implied ask typically changes by more than enough to eliminate the initial pricing disagreement. Importantly, the whole treatment distribution is to the right of the control distribution, implying that for the disagreement events, the change in the implied ask price is greater at every percentile.

Panel A shows that it is also the case that the distribution of changes in the option-implied bid prices for the disagreement sample is shifted to the right relative to the distribution for the control sample. For the control sample, the probability that the option-implied bid price does not change exceeds 70%, and there are more decreases than increases. This is less movement than was found in the control sample ask prices, which is unsurprising because in the control sample by construction the stock midpoint is closer to the implied ask than to the bid. In contrast, the probability that the option-implied bid increases during the evaluation period is close to 50%. Combined with the movement of the implied ask, this shift in the distribution of the bid prices provides strong evidence that the options market changes its assessment of a fair price during the disagreement events. This implies that the stock market participates in price discovery.

Examining the distributions of changes in the stock price allows us to assess whether the options market participates in price discovery. If the stock price follows the options, then for the disagreement sample the distribution of changes in the actual stock quote midpoint should be shifted to the left relative to the control sample. Panel C reveals that there is no such shift. Rather, the distributions for the treatment and controls samples look quite similar. If anything the treatment distribution is shifted slightly to the right of the distribution for the control sample, and displays slightly more dispersion. This is evidence that the stock market does not follow the options, but rather behaves in a "normal" fashion and is not affected by the disagreement.

The distributions for the {IP>P}-type disagreements in which the option-implied bid exceeds the actual ask are shown in Panels D-F, and are almost a mirror image of the figures for the {P>IP}-type in Panels A-C. The distributions of changes in the option-implied bid and ask quotes for the price

disagreement samples are shifted to the left relative to the corresponding distributions for the control samples, providing evidence that the options follow the stock. The distributions of changes in the actual stock prices are very similar for the treatment and control samples, indicating that the stock does not follow the options. If anything the treatment distribution is shifted slightly to the left of the control distribution, also mirroring the results for the {P>IP}-type disagreements.

The distributions of quotes changes in these six figures are consistent with the hypotheses that option price quotes follow stock price quotes, but not vice-versa. For both disagreement types, both option-implied bid and ask prices tend to change in the directions that reduce or eliminate the disagreement. In striking contrast, stock prices do not change in directions that reduce or eliminate the disagreement. To the extent that the distributions changes in stock prices differ between the treatment and control samples, the stock prices actually change in the directions that increase the magnitude of the disagreement.

4.2 *Comparison of Mean Differences*

After providing strong visual evidence of differences in the distributions of quote changes between the disagreement and control samples, we turn to providing formal statistical tests, beginning with tests for changes in the mean differences between the treatment and control samples.

For the {P>IP}-type disagreements, the option-implied ask quote is less than the actual bid. This suggests a focus on movements in the option-implied ask and the actual bid because these are the quotes most likely to change to eliminate the disagreement. However, for simplicity we use the stock midpoint rather than the bid; this has no effect on our analysis as the bid-ask spread is typically only one cent. The mean changes in the option-implied ask quotes and actual stock midpoints are estimated using

$$\text{Implied Ask}_{t+\tau} - \text{Implied Ask}_{t} = a_{\text{o}} + a_1 D_t + a_2 X_t + \varepsilon_{t+\tau}, \tag{3}$$

and

$$\text{Stock Midpoint}_{t+\tau} - \text{Stock Midpoint}_{t} = b_o + b_1 D_t + b_2 X_t + \varepsilon_{t+\tau}, \tag{4}$$

respectively, where τ is the length of the evaluation period, D is a disagreement dummy that takes the value 1 for disagreement events, and X is a vector of control variables relevant for the option-implied quotes. The estimates of the coefficients a_1 and b_1 are estimates of the mean differences between the treatment and control sample, i.e. they are estimates of the effect of the disagreement on subsequent mean changes in quotes. If the stock market quotes contain information not yet reflected in the option quotes then $a_1 > 0$, interpreted as the options follows the stock; otherwise $a_1 \leq 0$. If the options market

quotes contain information not yet reflected in the stock quotes then $b_1 < 0$, interpreted as the stock follows the options; otherwise we expect $b_1 \geq 0$.

For the {IP>P}-type, we focus on the option-implied bid and the actual midpoint. The mean changes in the option-implied bid and actual midpoint are estimated using

$$\text{Implied Bid}_{t+\tau} - \text{Implied Bid}_{t} = a_0 + a_1 D_t + a_2 X_t + \varepsilon_{t+\tau}, \quad (5)$$

and equation (4) above, where $a_1 < 0$ means that the options follow the stock and in (4) $b_1 > 0$ now means that the stock follows the options.

If the regressions do not include the vector of control variables X then these regressions and hypotheses are equivalent to a classic average treatment effect analysis. Table 2 presents the results of this analysis for each stock in the sample, using an evaluation period of one minute. (The quote changes are calculated at the end of the evaluation period of one minute for each quote type and sample subgroup.) The left-hand half of the table presents the average changes in the option-implied bid, option-implied ask, and stock midpoint for both the treatment and control samples separately for each stock or ETF for the {P>IP}-type disagreements. In the treatment sample, the average changes in the option-implied bid are positive for every stock and ETF. The across-stock average of the stock-by-stock average changes in the implied bid is 4.4 cents, and the minimum of the average changes across stocks is 3.5 cents. For the control sample, the average changes in the implied bids are actually slightly negative for every stock and ETF. The average changes in the implied ask quotes is also positive for every stock in the treatment sample, with the average of the stock-by-stock average change being 8.6 cents and the minimum across stocks being 6.7 cents, respectively. For the control sample, the implied ask increases by an average of 2.1 cents in order to converge to the average bid-ask spread size. Thus, the average difference in the implied ask quote between the treatment and control samples is 6.5 cents, substantially larger than the initial mispricing. This average difference of 6.5 cents is also large relative to the average price of less than two dollars for the at-the-money for call and put options that appear in the sample.[19]

If the stock followed the options, the average change in the stock midpoints in the treatment sample would be negative, and less than the corresponding average changes for the control sample. Inconsistent with this hypothesis, the average changes in the stock midpoint are slightly positive (on average 0.2 cents) for all but three stocks, and in all cases are greater than the average changes in the stock midpoint in the control sample. Together with the corresponding results for the option-implied quotes, these results imply that for the {P>IP}-type disagreements the options follow the stock and the

[19] Through the put-call parity relationship $S = C - P + \text{PV}(K)$, the change in the option-implied stock price S is equal to the change in the difference between the call and put prices $C - P$.

stock does not follow the options.

The right-hand half of the table presents the corresponding average quote changes for the {IP>P}-type disagreements. The average changes in the option-implied bid and ask are now negative and less than the corresponding average changes in the control sample for every stock and ETF, implying that in this case also the options follow the stocks. (Recall that for the {IP>P}-type disagreements the option-implied stock prices exceed the actual stock prices, so that if the options follow the stock the average changes in the option-implied bid and ask prices will be negative.) The overall average change in the implied bid is −11.7 cents, of greater magnitude than the overall average change in the implied ask of 8.6 cents for the {P>IP}-type disagreements, and the overall average change in the implied bid is −6.3 cents, of greater magnitude than the overall average change in the implied bid of 4.4 cents for the {P>IP}-type disagreements. Average changes in stock prices are close to zero for almost all stocks, and to the extent that they differ from zero the average changes are negative, inconsistent with the hypothesis that the stocks follow the options. Overall, this table produces strong evidence that if prices disagree, the options market adjusts to eliminate mispricing, and the stock market does not adjust for *every* stock in the sample. It seems worth emphasizing that the average changes in the option prices are large, and typically larger than the extent of the disagreement, while the average change in stock prices are close to zero. To the extent that the average changes in stock prices are non-zero, the stock prices move to widen the disagreement rather than reduce it.

Table 3 shows that the results are not sensitive to the length of the evaluation period by presenting some summary results for the implied bid, implied ask, and stock midpoint based on a 30-second evaluation period. Specifically the table shows the means and medians across stocks of the stock-by-stock average quote changes, and also presents the averages for the 4^{th} and 36^{th} stocks. For comparison, it also presents the corresponding results for the one-minute evaluation period. Again the left-hand side of the table is for the {P>IP}-type disagreements, while the right-hand side is for the {IP>P}-type disagreements. Consistent with the previous results based on a one-minute evaluation period, the treatment sample changes in the option-implied quotes are positive and greater than the corresponding changes in the control sample for the {P>IP}-type disagreements, while the treatment sample changes in the option-implied quotes are negative and smaller than the corresponding changes in the control sample for the {IP>P}-type disagreements. Unsurprisingly, the magnitudes of the average changes are smaller for the shorter 30-second evaluation period. Also consistent with the previous results, the average changes in the actual stock prices are close to zero.

4.3 *Conditional Mean Differences.*

The high-frequency data provides control observations that match very closely the characteristics of the treatment observations. Nonetheless, the matching is not perfect. In such circumstances, Imbens and Wooldridge (2009) suggest controlling for the differences between the matched and treatment samples by estimating regressions that include as covariates the variables used in matching the samples. Following this advice, we use a vector of control variables X has two elements, the bid-ask spread at the beginning of the event and the return on the underlying stock during the 5 minutes preceding the beginning of the event, and estimate the regressions (3)-(5) separately for each underlying stock and ETF.

Table 4 presents some summary information about the 39 estimates of the dummy variable for the implied bid, implied ask, and stock midpoint based on both the 30-second and one minute evaluation periods. It follows the format of Table 3, and shows the means and medians across stocks of the stock-by-stock estimates of the dummy variable, and also presents the estimates for the 4^{th} and 36^{th} stocks. Again the left-hand side of the table is for the {P>IP}-type disagreements, while the right-hand side is for the {IP>P}-type disagreements. For the {P>IP}-type and using the one-minute evaluation period, for the implied ask the average difference dummy across stocks is 4.2 cents and varies from 2 to 7 cents for different stocks. The mean of the dummy coefficient estimates for the implied bid is 3.4 cents, not much different than the coefficient estimate in the regression explaining theask quote. Thus, an option market marker moves both bid and ask by similar amounts, conditional on matching variables. For the actual stock midpoint, the mean of the coefficient estimates is less than half a penny. These estimates are generally significantly different from zero at conventional levels, with an average (across the 39 regressions) t-statistic of 4.3, but not much weight should be placed on the fact that the estimate are generally significant given the large sample size of 359,228 observations. Importantly, to the extent that the coefficients are non-zero this provides evidence that the actual stock price moves in the direction of increasing the disagreement, not decreasing it.

For the {IP>P}-type, the results are again the mirror image of those for the {P>IP}-type disagreements.

The same conclusion is confirmed one more time: the options market changes both bid and ask quotes to eliminate or reduce the price disagreement, while the stock market does not.

4.4 *Quantile Regressions*

The regressions (3)-(5) allow for statistical inference about only the average and conditional average effects of the disagreement. We provide evidence that the distributional shifts apparent in

Figure 3 are statistically significant by estimating quantile regressions analogous to (3)-(5) for the implied bid, implied ask, and actual stock midpoint for both the {P>IP} and {IP>P}-type disagreements. As with our estimates of (3)-(5), we estimate both versions that include only the disagreement dummy *D*, as well as versions that also include the vector of control variables *X* consisting of bid-ask spread at the beginning of the event and the return on the underlying stock during the 5 minutes preceding the beginning of the event. Because the quantile regressions are more demanding of the data and some of the stocks have relatively few events due to their early departures from the sample, we estimate the quantile regression for the pooled sample that combines the events for the 39 different stocks and ETFs.

Table 5 presents the coefficient estimates and standard errors for the disagreement dummy in regressions for the 10%, 30%, 50%, 70%, and 90% quantiles, for the various regression models and both disagreement types. For the {P>IP}-type disagreements (the left-hand side of the table) the option-implied bid and ask are below the actual stock price, and increases in the implied ask are necessary to eliminate the disagreement. For the implied ask regressions the coefficient on the dummy variable is at least 0.05 (five cents) for all except the 10% quantile, regardless of whether the control variables are included. In the implied bid regressions at the 70% and 90% quantiles the coefficients on the dummy variable are also 0.05. This finding that the coefficient estimates are 0, 0.05, or 0.10 is not surprising: because the quantile regression line by construction passes through two sample points and the left-hand side variable takes values that are almost always low integer multiples of 0.05, when the conditioning variables are not included in the regression the coefficient can be only an integer multiple of 0.05.[20] The reported standard errors are very small and in many cases zero; they are based on 2,500 bootstrap iterations, and in many cases the same coefficient estimate is obtained in all 2,500 iterations.

For the {IP>P}-type disagreements (the right-hand side of the table) the option-implied bid and ask are above the actual stock price and we focus on changes in the implied bid. For these regressions the coefficient on the dummy variable is less than or equal to –0.05 for all except the 90% quantile, and again bootstrapped standard errors are either zero or close to zero. In the implied ask regressions the dummy coefficient is –0.05 at the 10%, 30%, 50%, and also 90% quantiles. These results are consistent with the shifts in the distributions shown visually in Panels A, B, D, and E of Figure 3, and demonstrate that the distribution shifts in those panels are statistically significant.

In contrast, the quantile regressions for changes in the stock price provide no evidence that the stock follows the options. For both the {P>IP} and {IP>P}-type disagreements the estimated

[20] Conditioning on the vector of control variables *X* changes the coefficient estimates only slightly.

coefficient on the dummy is either zero or close to zero at most of the quantiles. To the extent that the estimated dummy coefficients are different from zero, they indicate that during the disagreement events at some quantiles the actual stock price continues moving away from the option-implied stock prices, not toward them. This finding is consistent with the distributions of changes in stock prices shown in Panels C and F of Figure 3.

4.5 *Joint Quote Dynamics*

If the future fair price of stock were known, then a straightforward way to study the joint behavior of the stock and option markets would be to examine which market is better at predicting the future price. This analysis could be implemented as a regression of the end-of-period fair price on the option-implied and actual stock prices at the moment of disagreement. Each of the two regression coefficients, one for the options market and the other for the underlying, could be viewed as the "predictive share" of each of the markets and interpreted as a measure of price discovery. With this interpretation, if the coefficient for one of the markets is zero, then no price discovery occurs in that market.

Unfortunately, the end-of-period fair price is unobservable, rendering this approach infeasible. Instead, we test whether a forecast of a future actual or option-implied quote can be improved by using information from the other market. The tests are based on the idea that if all price discovery occurs in one of the markets, then the information from the other market will not be useful in predicting price changes in the first market. On the other hand, if some price discovery occurs in the other market, then the information from that market should be helpful in predicting the price changes in the first market.

For the {P>IP}-type disagreements we implement this idea via the following regressions, which are estimated using a pooled sample of the disagreement events:

$$\text{Implied Ask}_{t+\tau} - \text{Implied Ask}_{t} = a\,(\text{Bid}_{t} - \text{Implied Ask}_{t}) + \varepsilon_{t+\tau}, \tag{6}$$

and

$$\text{Midpoint}_{t+\tau} - \text{Midpoint}_{t} = b\,(\text{Implied Ask}_{t} - \text{Midpoint}_{t}) + \varepsilon_{t+\tau}. \tag{7}$$

The hypothesis that all price discovery occurs in the options market implies that the location of the actual stock midpoint relative to the option-implied ask does not help predict changes in option quotes, i.e. that $a = 0$ in equation (7). If $a > 0$ then actual stock market quotes help predict future option market quotes. Similarly, the hypothesis that all price discovery occurs in the stock market implies that in equation (8) the coefficient $b = 0$, while if some occurs in the options market, then $b > 0$.

For the {IP>P}-type disagreement the regression equations are

$$\text{Implied Bid}_{t+\tau} - \text{Implied Bid}_{t} = a\,(\text{Ask}_{t} - \text{Implied Bid}_{t}) + \varepsilon_{t+\tau}, \quad (8)$$

and

$$\text{Midpoint}_{t+\tau} - \text{Midpoint}_{t} = b\,(\text{Implied Bid}_{t} - \text{Midpoint}_{t}) + \varepsilon_{t+\tau}, \quad (9)$$

where again positive coefficient estimates indicate that there is an information flow between the markets.

These tests use zero as the benchmark for the expected quote changes, which is a strong assumption. On the other hand, these tests do not rely on the matched control sample. If these tests yield results similar to those obtained above then one can take comfort that the previous results are not driven by some limitation of the matching procedure.

Table 6 presents the estimated regression coefficients and associated *t*-statistics from the four regressions above using evaluation periods τ of both 30 and 60 seconds. The left-hand half of the table presents the results for the {P>IP}-type disagreements. The estimates of the coefficient *a* in equation (6) predicting changes in the implied ask are 1.51 (*t*-statistic 100.0) and 1.75 (*t*-statistic 100.2) for the 30 and 60-second evaluation periods, respectively, and are highly significant. These estimates indicate that the option-implied ask is very strongly affected by the disagreement, with the effect on the implied ask being approximately twice the magnitude of the disagreement. In contrast, the estimates of the coefficient *b* in equation (7) predicting the change in the actual stock midpoint are –0.03 and –0.02 for the 30 and 60-second evaluation periods. While these estimates for the actual stock price movement are significantly different from zero at conventional levels they are small, and more importantly imply that during the evaluation period the stock price tends to move in a way that widens rather than narrows the disagreement. Thus, these regressions indicate that the option quotes have no impact on the price discovery in the stock.

The right-hand side of Table 6 contains the results for the {IP>P}-type disagreements. The estimates of the coefficient *a* in equation (8) reveal that the effect of a disagreement on the implied bid is even larger than the effect of a disagreement on the implied ask. Similar to the results in the left-hand side of the table, the estimates of the coefficient *b* in equation (9) predicting the change in the actual stock midpoint are small, being 0.00 and 0.04 for the 30 and 60-second evaluation periods, respectively. While the coefficient of 0.04 does carry a *t*-statistic of 2.3, this is small in light of the sample size of 18,010 (note that the *t*-statistics in the implied bid regressions are 67.7 and 69.0), and the point estimate of 0.04 is only 0.04/2.22 = 1.8% of size of the corresponding coefficient in the implied bid regression.

To summarize, the results in Table 6 confirm the earlier results that option market quotes do not

participate in the price discovery process for the underlying stock. On the other hand, information in the stock market is very useful in predicting quote changes in the options market. In other words, the options market clearly follows the stock market.

4.6 *Signed Volume During Price Disagreement Events*

We expect to see some "arbitrage" trading during disagreement events. For the {P>IP}-type disagreements, we expect that arbitrageurs will buy call options at their ask prices and perhaps sell puts at their bid prices. For the {IP>P}-type disagreements, we expect that arbitrageurs will buy put options and sell call options. In addition to arbitrage trading, there may be trading by patient options traders who follow the markets and wait for an opportune time to buy options. For example, a trader who wants to buy a call may recognize that a {P>IP}-type disagreement event is an advantageous time to buy. In looking for such arbitrage and other trading we will measure option trading volume using the delta-equivalent share position, i.e. we will compute the delta of each traded option, weight the deltas by the trade sizes, and sum the quantity-weighed deltas to obtain an estimate of the delta-equivalent share position traded in the options market.

In a frictionless market we would also expect to observe trades in the underlying stock. But markets are not frictionless, and the evidence above indicates that the stock leg of the "arbitrage" trade will break even or perhaps lose money[21] before transaction costs, and thus lose money after transactions costs. Thus, traders may elect to trade only in the options and not the stock, and there is no prediction about stock trading during the disagreement events. Because the disagreements tend to close quickly there is relatively little need to buy or sell stock to hedge any options trades, suggesting that there might be no unusual stock trading volume during the disagreement events.

Thus, we focus on option trading volume during the disagreement events. We expect to see positive delta-equivalent volume during the {P>IP}-type disagreement events and negative delta-equivalent volume during the {IP>P}-type disagreement events.

Table 7 presents some summary statistics for the signed volume in the stocks and the delta-equivalent signed volume in the options for the treatment and control samples for both the {P>IP} and {IP>P}-type disagreement events for evaluation periods of 30 and 60 seconds. The statistics are constructed in the following way. First, the mean signed volume and delta-equivalent option volume during the events are estimated for each stock. The table then reports the equally-weighted mean and median of the stock-by-stock means, along with the fourth and 36-th largest of the stock-by-stock

[21] The estimates of the stock price movement indicate that the stock prices have a slight tendency to move so as to widen the disagreements, indicating the stock leg of the transaction will tend to lose money.

means. The table reports the statistics for the signed volume in the underlying stock, delta-equivalent signed volume in all options on the underlying stock, and delta-equivalent signed volume in the pair of options that triggered the disagreement. The results for the {P>IP}-type events are shown in the left half of the table, while those for the {IP>P}-type events appear on the right.

The option volume follows the predictions above. For the {P>IP}-type disagreements, during the first 30 seconds following the beginning of the disagreement, options traders on average buy the equivalent of 1,400 shares, which is almost ten times larger than the delta-equivalent option volume in the control sample. The difference in the stock-by-stock median volume is greater, and the differences in the 4th and 36th highest delta-equivalent option volume are also large. The second panel of the table showing the volumes only in the option pair that triggered the disagreement indicates that more than half of the option volume occurs in the call-put pair that triggered the disagreement. Comparing the volumes during the 30 and 60-second evaluation periods, one can see that for the treatment sample most of the option volume occurs during the first 30 seconds following the beginning of the disagreement.

The results for the delta-equivalent signed option volume during the {IP>P}-type disagreements shown in the right-hand side of the table are similar, except that the signed volumes are negative rather than positive because for these events the option-implied price exceeds the actual stock price. Also, because the delta-equivalent signed volumes are negative the magnitudes of the volumes in the 4th highest volume stock exceed those in the 36th highest volume stock.

Turning to the signed volume in the actual stocks, for the {P>IP}-type disagreements, the mean (of the stock-by-stock means) signed volume is higher by only 60 shares during 30 seconds following the beginning of the disagreement event, or less than one round lot (1.6 round lots for the treatment sample versus 1 round lot for the control sample). The mean volume is 100 shares higher during the 60 second evaluation period. The median, 4th largest, and 36th largest volumes are also slightly higher in the treatment sample. These results are interesting because for the {P>IP}-type disagreements the hypothesis that arbitrage trading takes place in the stock implies that for the treatment sample signed volume in the stock should be *negative* and *less than* in the control sample, not positive and slightly greater than in the control sample. These results for stock trading volume during the {P>IP}-type disagreement events imply that instead of pushing to eliminate mispricing it actually pushes to increase it. Combined with the findings for the delta-equivalent option volume, these results are consistent with the hypothesis that disagreements are triggered by signed volume in the underlying stocks, and then closed following delta-equivalent signed volume in the options.

For the {IP>P}-type disagreements, during the disagreement events signed volume is very

slightly larger during the treatment events than it is during the control events, with the mean difference being 20 shares (0.3 round lot versus 0.1 round lot).

Table 8 provides additional evidence about signed volume during the disagreement events by presenting coefficient estimates from quantile regressions predicting signed volume during both the {P>IP} and {IP>P}-type disagreements. We use a pooled sample that combines both the treatment and control samples for all stocks, and capture the effect of the disagreement with a dummy variable *D* that takes the value of one for the disagreement events. As with the previous quantile regressions predicting quote changes, we estimate both versions that include only the disagreement dummy *D*, and also versions that also include the vector of control variables *X* consisting of bid-ask spread at the beginning of the event and the return on the underlying stock during the 5 minutes preceding the beginning of the event. The results in Table 8 are based on a 30-second evaluation window because the evidence in Table 7 indicates that this is when most of the order imbalance in the options occurs.

Table 8 presents the coefficient estimates and asymptotic *t*-statistics for the disagreement dummy in regressions for the 10%, 30%, 50%, 70%, and 90% quantiles of delta-signed volume in all options, delta-signed volume in just the call-put pair that triggered the disagreement, and signed volume in the underlying stock. For the {P>IP}-type disagreements (the left-hand side of the table), the regressions for signed delta-equivalent volume in all options shows that the disagreement causes large increases in volume at the 70% and 90% quantiles. The effects of the disagreement at the 70% and 90% quantile are 1,630 and 6,420 share equivalents in the regression without control variables, respectively, and 1,690 and 6,590 share equivalents in the regression with control variables. The effect at the median is 370 delta-equivalent shares, both without and with control variables. This effect at the median implies that more than half of the disagreement events display signed volume in the direction that will tend to push prices to close the disagreement. Delta-equivalent volume in the call-put pair that triggered the disagreement is 480 and 2,650 shares at the 70% and 90% quantiles in the regression without control variables, respectively, and similar in the regression with control variables. For the {IP>P}-type disagreements (the right-hand side of the table) the delta-equivalent volumes are negative, and the 30% and 10% quantiles correspond to the 70% and 90% quantiles of the {P>IP}-type disagreements. For these regression the effects at the 30% and 10% quantiles are similar to but slightly larger than the effects are found at the 70% and 90% quantiles for the {P>IP}-type disagreements.

This finding that the effect of the disagreement on signed delta-equivalent option volume is highly skewed is unsurprising because there is no reason to expect that it will always be profitable to trade on or "arbitrage" the disagreement. However, when trading on the disagreement is profitable, one expects arbitragers to trade as many options as possible.

Turning to the quantile regressions for signed volume in the underlying stocks, the coefficients at the 10% and 90% percentiles have opposite signs, indicating that the disagreement events are associated with greater dispersion in signed volume. At the median, for the {P>IP}-type disagreements, the disagreement event increases stock signed volume by about 100 shares relative to the control events, consistent with the results in Table 7 and inconsistent with significant arbitrage selling of the stock. For the {IP>P}-type disagreements, at the median the disagreement event decreases stock signed volume by about 70 shares in the regression without control variables and has no effect in the regression with control variables. This result is similar to that in Table 7, where the difference in medians was also small, though in Table 7 the effect of the disagreement was slightly positive rather than slightly negative.

To summarize, signed option volume in the direction that tends to eliminate the disagreements occurs in more than half of the disagreement events. In a significant fraction of the events, the delta-equivalent signed option volume is large, consistent with "arbitrage" trading exploiting mispricing during the disagreement events. There is no evidence of unusual signed volume in the underlying stocks. For stocks, the increase in signed volume is small and, if anything, is in a direction that increases mispricing.

5. Robustness Checks

5.1 *Analysis of various subsamples*

The stock market initiates 91% of the disagreement events in the sense that, in 91% of the events, a stock market quote update is the proximate cause of the disagreement. It is reasonable to hypothesize that the 9% of events that are initiated by the options market might have different characteristics. Specifically, in these events it might be the case that the actual stock price moves toward the options market quotes, i.e. that price discovery occurs in the options market.

Column 2 of Table 9 shows the estimates of the coefficient on the disagreement dummy in regressions including the control variables explaining the implied bid, implied ask, and observed stock midpoint for the subset of disagreement events that are initiated by the options market.[22] For comparison, the corresponding results for the full sample are shown in column 1. In the top panel showing the results for the {P>IP}-type disagreements one can see that the change in the implied ask is 4.6 cents, not much different from the change of 4.9 cents in the full sample. The change in the actual stock midpoint is –0.3 cents, which is close to zero. In the bottom panel showing the results for the

[22] We obtained similar results in untabulated regressions that do not include the control variables.

{IP>P}-type disagreements the change in the implied bid is −5.9 cents, actually of greater magnitude than the −5.6 cent change for the full sample. The change in the actual stock midpoint is 0.2 cents, close to zero. These results indicate that even when the disagreement is initiated by the options market, the options market moves by about 5 cents in a direction that tends to close the disagreement, and there is only a very small change in the stock price. In untabulated results, we obtain coefficient estimates of zero for the disagreement dummy in robust (median) regressions that explain the stock price change both including and not including control variables.

Table 10 contains results for signed volume. The results in column 2 of that table show less evidence of signed volume in a direction that tends to close the disagreement in the option-initiated disagreements. This is unsurprising, because it is likely that at least some of these disagreements were caused by signed option volume in a direction that tended to open the disagreement. If any of this volume carries over into the disagreement period, these will tend to offset "arbitrage" trades in a direction that tends to close the disagreement. Even so, for the disagreement pair the results show significant signed volume in the direction that tends to close the disagreement.

Earnings announcements are a time when important value-relevant information is often released. Perhaps the options market participates more in price discovery in the period immediately prior to earnings announcements?

Table 9, column 3, shows the average changes in the implied bid, implied ask, and observed stock midpoint for the subset of disagreement events that occur in the two trading days prior to earnings announcements. For both the {P>IP}-type and {IP>P}-type disagreements, the changes in both the implied bid and ask are similar to but slightly larger than the corresponding changes in the full sample. The changes in the stock midpoint are also similar to and slightly larger than those in the full sample. But, recalling that in the full sample the stock price changes tend to increase rather than decrease the magnitude of the disagreement, this result for the stock price changes is actually slightly stronger evidence that the options markets do not participate in price discovery in the period immediately prior to earnings announcements.

The point estimates for signed volume in column 3 of Table 10 for this subsample are very similar to those for the full sample, and actually slightly larger, though the *t*-statistics are smaller because of the smaller sample size.

We also consider the possibility that the markets' reactions to large stock returns differs from the reaction in the full sample, perhaps because large stock returns tend to be overreactions to information. If this is the case, one might expect to see stock price reversals in which stock prices

move toward the unchanged or less changed option market quotes. This would be consistent with some price discovery occurring in the options markets.

Column 4 headed "Pre-Event Return >0.3%" shows the conditional average changes in the implied bid, implied ask, and observed stock midpoint for the subset of disagreement events for which the absolute value of the return during the 5 minutes prior to the beginning of the disagreement event exceeded 0.3%. The results here are very similar to those in column 3 for the two days prior to earnings announcements. For both the {P>IP}-type and {IP>P}-type disagreements, the changes in both the implied bid and ask are similar to but slightly larger than the corresponding changes in the full sample, and the changes in the stock midpoint are also similar to and slightly larger than those in the full sample. Also, in Table 10 the point estimates for signed volume for this subsample are very similar to those for the full sample.

Options market liquidity increased during the sample period, suggesting that perhaps more price discovery might have occurred in the options market during the second half of the sample period. Column 5 of Table 9 addresses this hypothesis by presenting results for the subset of disagreement events that occurred during and after 2004. The average quote changes for this subsample are very close to the averages for the full sample shown in Column 1, providing no evidence of any change over time in the amount of price discovery occurring in the options market. Table 10 reveals that signed delta-equivalent option volume during disagreement events was about 50% greater during this sample relative to the full sample, which is unsurprising given the increase in overall option trading volume during the sample period.

Using a vector autoregression error-correction model, Holowczak, Simaan, and Wu (2006) present evidence indicating that options quotes are more informative during periods in which there are either large numbers of options trades or significant signed order flow in the options market. Column 6 of Table 9 explores whether our methodology also finds a greater informational role of options quotes during periods of high option volume by looking at the subsample of price disagreement events that occurred on days in which option trading volume exceeded the 80^{th} percentile of daily option trading volume for that underlying stock. Greater movement of the actual stock price quotes toward the option-implied quotes would indicate a greater informational role for the options quotes. Focusing on the rows in Panels A and B labeled "Stock" and comparing the results in column 6 to the results for the full sample in column 1, the movement of the stock price quotes during disagreement events that occur on high option volume days is very similar to their movement in the full sample of disagreement events. In both the {P>IP} and {IP>P}-type disagreement events the point estimates in column 6 are similar to those in column 1, and show slight tendency for the stock price to move away from, rather

than toward, the option quotes. Turning to the results for the options in the rows labeled "All Options" and "Disagreement Pair," in both panels the results in column 6 indicate more movement of the option quotes toward the actual stock price quotes than is found in the full sample results reported in column 1.

We conclude that the finding that the options market does not participate in price discovery about the level of the stock price is a robust one that is found in different subsamples in which it plausibly might not have been found. Given this, we turn to an examination of potential data concerns.

5.2 *Are the Quotes Good?*

As is often the case in the analysis of high-frequency data, data issues are a potential concern. In particular, we calculate price disagreement based on the reported NBBO at each moment, but are the reported quotes valid? Can option market participants actually trade at the reported quotes? While "backing away" from quotes is not a concern with fully electronic exchanges, the frequency of disagreement events is relatively low. It is conceivable that some fraction of the measured disagreement events could be the result of data or data transmission errors, and that such data errors could impact the results.[23]

Before turning to examining the subsamples of likely valid quotes are which option market participants can actually trade, it is first worth emphasizing that the striking evidence of delta-equivalent signed option volume during the disagreement events discussed above is inconsistent with the hypothesis that our results are due to quotes that are not valid because of data errors or other reasons.

We use two approaches to identity quotes that are highly likely to be valid. First, an option best bid (ask) is called "trade confirmed" if there have been trades at exactly this price while the bid (ask) remains the best bid (ask), but not earlier than 200 seconds before the disagreement event. A problem arises because to "trade confirm" an option- implied stock quote, one should confirm both the call and

[23] To understand why data issues can produce spurious results similar to ours, consider an example. Imagine that options are identified by a call-put indicator, maturity date and strike without looking at an option name. Surprisingly, this method can pick more than one option contract in real data. For example, two Citibank call options C_AJ and KYV_AJ have the same strike and maturity but substantially different prices. On January 06, 2004, the first was traded at 0.45/0.5$ while the second was traded at 2.1/2.2 $. The trick is that the second option has special settlement conditions, and its effective strike is different from the stated strike. Thus, almost every quote update for the second option will trigger a price disagreement event. Then, the next quote update for the first option will "eliminate" this fake price disagreement. There is no difference in information---it is just a data feature which will results similar to those in this paper. Less than 2% of the total number of option contracts in our sample has a special settlement and usually the difference in prices is not so dramatic. But, because real price disagreement events are not frequent, such events could account for a significant fraction of the total number. Had we not filtered them out, this issue could have produced spurious results.

put quotes that are inputs to the call-put parity relation. As trading is not frequent in options, this quote confirmation reduces the sample size by a factor of about six. Note, however, that we do not need four options quotes to confirm both the option-implied ask and the option-implied bid, as only one quote is of interest when prices disagree. For example, for the {P > IP}-type it suffices to trade confirm only the option-implied ask quote.

A second way to verify quote validity is to consider only quotes displayed by multiple exchanges. For example, if both the ISE and CBOE quote a call option bid at 1.15, it is more credible than if only the CBOE displays this price. We call an option-implied stock price "two exchange confirmed" if both the call and put quotes used in the put-call parity relation are quoted by market makers on at least two exchanges. As should be expected, this requirement considerably reduces the number of disagreement events that are identified. Option market makers have a strong incentive not to quote call and put prices that are inconsistent with the underlying stock price. The frequency with which market makers at two or more option market makers quote option prices inconsistent with the stock prices is much less than the frequency with which at least one options market maker does so.

Trade and quote confirmations can be combined to increase the sample size. For example, a call price can be "trade confirmed" while a put price is "quote confirmed." We use this approach to increase the size of the sample of confirmed quotes.

Columns 7, 8, and 9 in Table 9 show results for the subsamples in which both the call and put prices used in the put-call parity are "trade confirmed," both the call and put prices are "quote confirmed," and for the combined case in which the call and put prices are either "trade confirmed" or "quote confirmed." In each case, we also use only correspondingly confirmed control observations. Because of the smaller sample size, observations for all stocks are pooled together and a single regression with constant and disagreement dummy is run. The results are similar to those obtained with the full sample. In particular, the estimates of the stock price changes indicate that the stock price tends to move to slightly widen the disagreement, continuing to indicate that the stock price does not participate in price discovery. In Table 10, the coefficient for signed option volume for disagreement pairs is more than two times larger than in the full sample case in Column 1.

5.3 *Differing latencies across markets*

We also entertain the hypothesis that there can be a systematic difference in the recorded times of simultaneous transactions or quote updates in different markets. Consider an example that illustrates the potential problem. At 10:00:00.200 the option-implied quotes for ABC stock are $20.00 / $20.10 and the actual stock observed quotes are $20.03 / $20.04. At that moment, bad news arrives and both

markets change quotes simultaneously to $ 19.90 / $20.00 and $19.03 / $19.04 respectively. Assuming that data processing latency is 200 milliseconds for options and 25 milliseconds for stocks, the option-implied quotes are time stamped "10:00:00.400" and the actual stock quotes are time -stamped "10:00:00.225." Our algorithm identifies a spurious disagreement event at "10:00:00.225," and then this spurious disagreement is eliminated by the options market adjusting at "10:00:00.400."[24]

Is it possible that we find that the options market follows the stock market simply because latency is possibly much larger in the options market? Three considerations make this seem unlikely. First, we are not aware or any systematic or anecdotal evidence that latencies across modern electronic exchanges differ by more than 10 milliseconds. Second, we have no reason to suspect that our data provider introduced additional latency or time-stamp errors. The data provider time-stamped the different quotes as they hit the vendor's server, using a single clock. Moreover, our data provider's business consists of vending real-time data to various high-frequency trading desks, and thus has strong incentives to minimize both latency and errors. Third, the hypothesis that the disagreement events are spuriously created due to differing latencies across the options and stock markets implies that we should not observe significant signed volume pressure in the direction that would eliminate the disagreements. Thus, the signed volume results are a compelling piece of evidence that our results are not spurious.

Nonetheless, we perform one additional test to address this potential data problem. Specifically, we consider the subsample of treatment events in which the option-implied quotes that triggered the disagreement do not change for at least 10 seconds after the event is triggered, and examine the quote changes over a one minute evaluation period. Differing latencies between the options and stock markets cannot drive the results for this subsample, because 10 seconds exceeds any plausible difference in latencies.

The results for this subsample are shown in the column 10 (headed ">10 sec duration") in Table 9. Similar to the results in the full sample, the coefficient estimate for the dummy variable in the regression predicting stock price changes indicates a slight tendency for the stock price to move to widen the disagreement, which again is compelling evidence the options market does not participate in price discovery about the level of the stock price. Also, similar to previous results, the option quotes do move toward the stock price. However, in this subsample the magnitudes of the coefficients are not as large as in the full sample or most of the other subsamples. This result that the average movement in

[24] We do not have to be concerned about the possibility that different exchanges use clocks that might not always agree. The data vendor time-stamps the different quotes as they hit the vendor's server, using a single clock. Thus, the only issue is the possibility of different latencies at different exchanges.

the option quotes is not as large in this subsample is unsurprising, because the criteria used to select this subsample was that the option quotes do not change for at least 10 seconds. Thus, this subsample is likely to be overrepresented with events from market conditions in which quotes are less likely to change.

6. Conclusion

This paper focuses on events in which the stock and options markets disagree about the stock price in the sense that the option-implied stock price obtained from the put-call parity relation differs from the actual stock price. During these disagreement events, the movement of the stock price is virtually identical to the movement of the stock price in otherwise similar events during which there is no disagreement about the underlying stock prices. These results provide compelling evidence that option price quotes do not contain any information that has not already been reflected in the stock market price quotes, and thus that option price quotes do not participate in the price discovery process for the underlying stock price. In contrast, during the price disagreement events the option-implied stock price quotes move toward the actual stock price quotes.

In 91% of the price disagreement events, the disagreement is precipitated by a movement in the underlying stock price quotes. During more than one-half of the events, there is signed order flow in the options market in the direction that will tend to push the option-implied stock price quotes in the direction of the actual stock prices. In some of the disagreement events, the signed order flow in the options market is large, consistent with some option market participants aggressively trading at option price quotes that have been rendered stale by the stock price movement. Overall, our findings suggest a process in which price discovery about the level of the stock price occurs exclusively in the stock market, with the option price quotes following.

Importantly, the approach in this paper requires only weak assumptions. Among other things, it does not require a maintained hypothesis of a particular econometric model, and thus is not subject to the common joint hypothesis problem. In addition, the results are also found in the subsample of events for which the disagreement was precipitated by a change in an option price quote, subsamples in which the option price quotes are confirmed by either trades at the quotes or the presence of an identical quote at another exchange, and a subsample in which the results are almost certain not to be driven by differences in latency across the two markets.

Appendix A. Recent History of Options Market Structure

There was little competition among options exchanges until 1999, as most option series were listed only at one exchange. For example, Dell options were traded only at the Philadelphia Stock Exchange (PHLX). Moreover, unlike for stocks, there was no over-the-counter market for standardized options. Only after the International Securities Exchange (ISE) announced in November 1998 its intention to list the 600 highest volume options upon opening[25] did the other exchanges realize that their monopoly was over. "The great options war" started on August 23, 1999 when CBOE and AMEX started to trade Dell options. As a result, by the end of 2001 all important series, except for some licensed index products, had been cross-listed on all exchanges.

Second, competition at the exchange level was also imperfect because of the large tick size. In early 2001, markets finally switched from fractions to decimals. The tick size for options was reduced to 5 cents (down from $1/16^{th}$ or \$0.0625) for options quoted below \$3 and to 10 cents (down from $1/8^{th}$ or \$0.125) for options quoted above \$3. As most of the trading going in ATM and OTM options is typically priced below two dollars, five cents is as large as 2.5% of the price, and many times larger than the percentage effective spread in stocks. With a large tick size, the bid-ask spread is the same across the options exchanges; that is why option market makers are paying brokers for directing order flow to their exchange. This widespread practice of "payment for order flow" is described in detail in the report SEC (2000).

Third, on January 31, 2003 the SEC finally launched the Options Linkage, which essentially requires that all trades should be executed at national best bid and offer (NBBO). All registered U.S. options markets are linked together on a real-time basis. If a market maker at a "home" exchange does not want to match the NBBO, the order is routed away to an exchange with NBBO quotes. Discussions regarding the Options Linkage started as early as 1998, but it took four years to implement the system.

Finally, market makers still play a very important role in the options market. They are the main providers of liquidity, as most retail orders are market orders. As each stock has up to hundred option classes, market makers are essential for moving liquidity across time and option classes. Not surprisingly, they also have significant privileges relative to other liquidity suppliers. The practice adopted by all exchanges and known as "internalization" requires that a market maker gets 40% of incoming market orders if he is standing at best quote when the order arrives. This percentage can be higher for the orders which a marker maker brings to the exchange.

These developments imply that research results obtained using data from the Berkeley Options

25 ISE launched operations on its options exchange on May 26, 2000

Data Base, which covers the period only through December, 1996, should be projected very cautiously to the contemporary options market.

It is important to note that the microstructure has changed very little during the sample period. The only major event was a launch of the Boston Option Exchange, which joined the option exchange club (CBOE, ISE, AMEX, PHLX, and PSE) on February 6, 2004.

For additional institutional details and a broader historic perspective, there is an excellent book by Gorham and Singh (2009) (pp. 135-137) and the SEC research reports SEC (2000) and SEC (2004).

References

Afef, A. & Olfa, B. 2009, "How Option Markets Affect Price Discovery on the Spot Markets: A Survey of the Empirical Literature and Synthesis", *International Journal of Business and Management,* .

Amin, K. & Lee, C. 1997, "Option trading, price discovery, and earnings news dissemination", *Contemporary Accounting Research,* vol. 14, no. 2.

Anthony, J.H. 1988, "The interrelation of stock and options market trading-volume data", *Journal of Finance,* , pp. 949-964.

Bakshi, G., Cao, C. & Chen, Z. 2000, "Do call prices and the underlying stock always move in the same direction?", *Review of Financial Studies,* vol. 13, no. 3, pp. 549.

Bhattacharya, M. 1987, "Price changes of related securities: The case of call options and stocks", *Journal of Financial and Quantitative Analysis,* , pp. 1-15.

Black, F. 1975, "Fact and Fantasy in the Use of Options", *Financial Analysts Journal,* vol. 31, no. 4, pp. 36-72.

Cao, C., Chen, Z. & Griffin, J.M. 2005, "Informational Content of Option Volume Prior to Takeovers*", *The Journal of Business,* vol. 78, no. 3, pp. 1073-1109.

Chakravarty, S., Gulen, H. & Mayhew, S. 2004, "Informed trading in stock and option markets", *Journal of Finance,* , pp. 1235-1257.

Chan, K., Chung, Y.P. & Fong, W.M. 2002, "The informational role of stock and option volume", *Review of Financial Studies,* vol. 15, no. 4, pp. 1049.

Chan, K., Chung, Y.P. & Johnson, H. 1993, "Why option prices lag stock prices: A trading-based explanation", *Journal of Finance,* , pp. 1957-1967.

Deville, L. & Riva, F. 2007, "Liquidity and arbitrage in options markets: A survival analysis approach", *Review of Finance,* vol. 11, no. 3, pp. 497.

Diltz, J.D. & Kim, S. 2005, "The relationship between stock and option price changes", *Financial Review,* vol. 31, no. 3, pp. 499-519.

Easley, D., O'Hara, M. & Srinivas, P. 1998, "Option volume and stock prices: Evidence on where informed traders trade", *The Journal of Finance,* vol. 53, no. 2, pp. 431-465.

Finucane, T.J. 1991, "Put-call parity and expected returns", *Journal of Financial and Quantitative Analysis,* vol. 26, no. 4, pp. 445-457.

Finucane, T.J. 1999, "A new measure of the direction and timing of information flow between markets1", *Journal of Financial Markets,* vol. 2, no. 2, pp. 135-151.

Gorham, M. & Singh, N. 2009, *Electronic Exchanges: The Global Transformation from Pits to Bits,* Academic Press.

Harris, F. H. deB., T. H. McInish, and R. A. Wood, 2002a, Security Price Adjustment Across Exchanges: An Investigation of Common Factor Components for Dow Stocks," *Journal of Financial Markets* 5, 277-308.

Harris, F. H. deB., T. H. McInish, and R. A. Wood, 2002b, Common Factor Components Versus Information Shares: A Reply," *Journal of Financial Markets* 5, 341-348.

Hasbrouck, J., 1991, "Measuring the information content of stock trades", *The Journal of Finance,* vol. 46, no. 1, pp. 179-207.

Hasbrouck, J., 1995, "One security, many markets: Determining the contributions to price discovery", *The Journal of Finance,* vol. 50, no. 4, pp. 1175-1199.

Hasbrouck, J., 2002, "Stalking the "Efficient Price" in Market Microstructure Specifications: An Overview, *The Journal of Financial Markets* 5, no. 1, pp. 329-339.

Hasbrouck, J., 2003, "Intraday Price Formation in U.S. Equity Index Markets," *The Journal of Finance,* vol. 58, no. 4, pp. 2375-2399.

Holowczak, Richard, Yusif Simaan, and Liuren Wu, 2007, "Price Discover in the U.S. Stock and Stock Options Markets: A Portfolio Approach," *Review of Derivatives Research* 9, Issue 1, pp. 37–65

Hsieh, W.L.G., Lee, C.S. & Yuan, S.F. 2008, "Price discovery in the options markets: An application of put-call parity", *Journal of Futures Markets,* vol. 28, no. 4, pp. 354-375.

Imbens, G.W. & Wooldridge, J.M. 2009, "Recent developments in the econometrics of program evaluation", *Journal of Economic Literature,* vol. 47, no. 1, pp. 5-86.

Jong, F.D. & Donders, M.W.M. 1998, "Intraday lead-lag relationships between the futures-, options and stock market", *Review of Finance,* vol. 1, no. 3, pp. 337.

Kamara, A. & Miller Jr, T.W. 1995, "Daily and intradaily tests of European put-call parity", *The Journal of Financial and Quantitative Analysis,* vol. 30, no. 4, pp. 519-539.

Lee, C.M.C. & Ready, M.J. 1991, "Inferring trade direction from intraday data", *The Journal of Finance,* vol. 46, no. 2, pp. 733-746.

Manaster, S. & Rendleman Jr, R.J. 1982, "Option prices as predictors of equilibrium stock prices", *The Journal of Finance,* vol. 37, no. 4, pp. 1043-1057.

O'Connor, M.L. 2005, "The cross-sectional relationship between trading costs and lead/lag effects in stock & option markets", *Financial Review,* vol. 34, no. 4, pp. 95-117.

Ofek, E., Richardson, M. & Whitelaw, R.F. 2004, "Limited arbitrage and short sales restrictions: Evidence from the options markets", *Journal of Financial Economics,* vol. 74, no. 2, pp. 305-342.

Pan, J. & Poteshman, A.M. 2006, "The information in option volume for future stock prices", *Review of Financial Studies,* vol. 19, no. 3, pp. 871.

Savickas, R. & Wilson, A.J. 2003, "On inferring the direction of option trades", *The Journal of Financial and Quantitative Analysis,* vol. 38, no. 4, pp. 881-902.

Securities and Exchange Commission 2000, “Special Study: Payment for Order Flow and Internalization in the Options Markets”

Securities and Exchange Commission 2004, “Competitive Developments in the Options Markets”, Securities Exchange Act Release No. 49175

Stephan, J.A. & Whaley, R.E. 1990, "Intraday price change and trading volume relations in the stock and stock option markets", *Journal of Finance,* , pp. 191-220.

Vijh, A.M. 1990, "Liquidity of the CBOE equity options", *The Journal of Finance,* vol. 45, no. 4, pp. 1157-1179.

Figure 1. Illustration of a Price Disagreement Event.

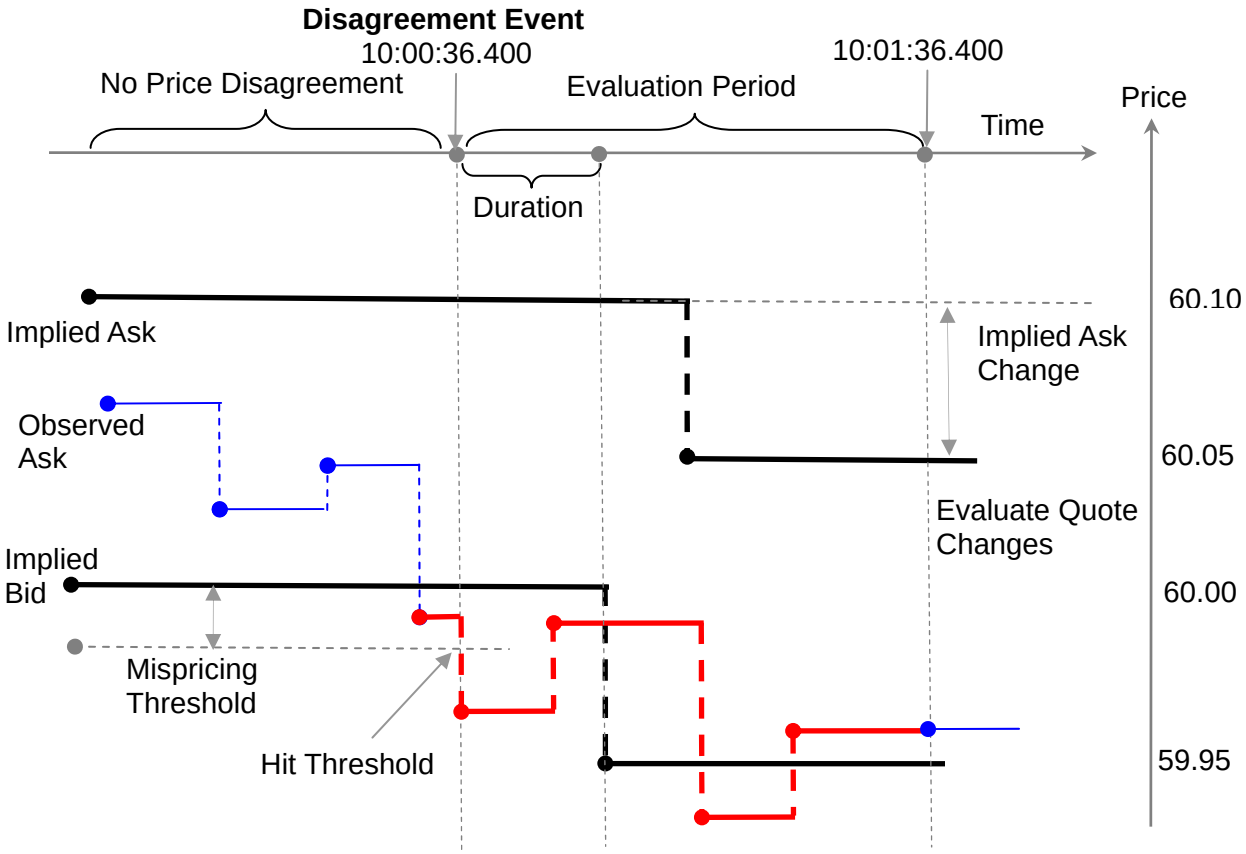

Figure 2. Frequency of disagreement events. The figure presents a smoothed estimate of the average number of events per day per stock during the sample period. The estimate of the number of events per day is constructed by counting the total (across stocks) number of events per day, dividing by the number of stocks in the sample on that day, and then smoothing the resulting time series by taking a 20-day moving average. The solid red line is the smoothed estimate of the number of {P>IP}-type events in which the actual price exceeds the option-implied stock price, while the dashed blue line is the smoothed estimate of the number of {IP>P}-type events.

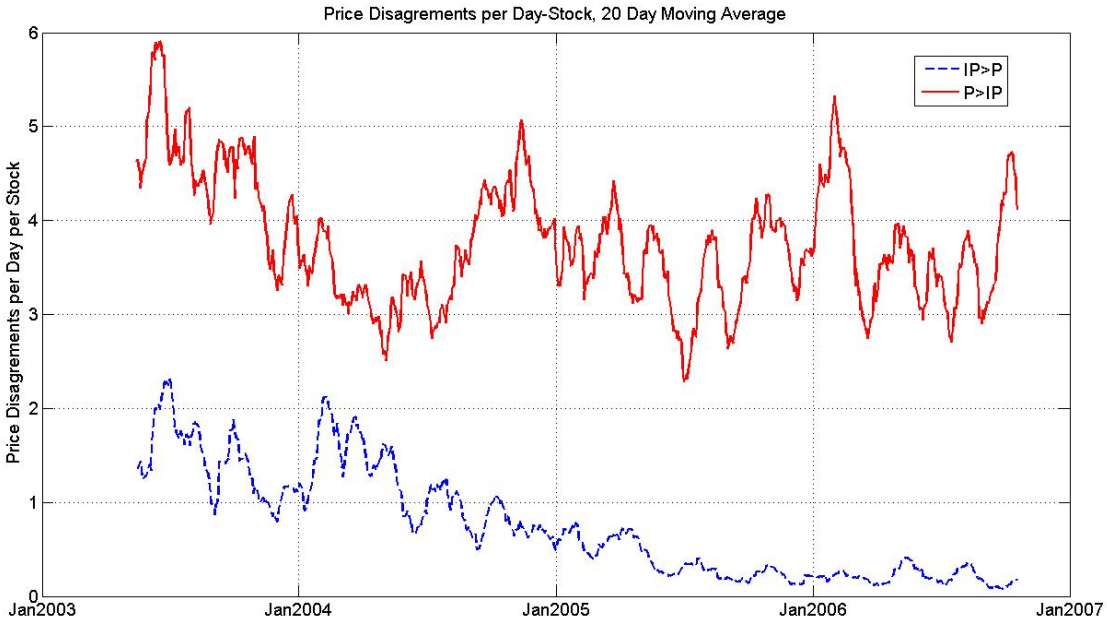

Figure 3. Cumulative distributions of the durations of the two disagreement types. The disagreement duration is the time elapsed from when a disagreement event is triggered to when the actual stock bid-ask range overlaps the option-implied bid-ask range. Durations for the {P>IP} and {IP>P}-type disagreements are shown by the dashed blue and solid red lines, respectively. Disagreements with durations of less than 0.5 second are excluded from the sample.

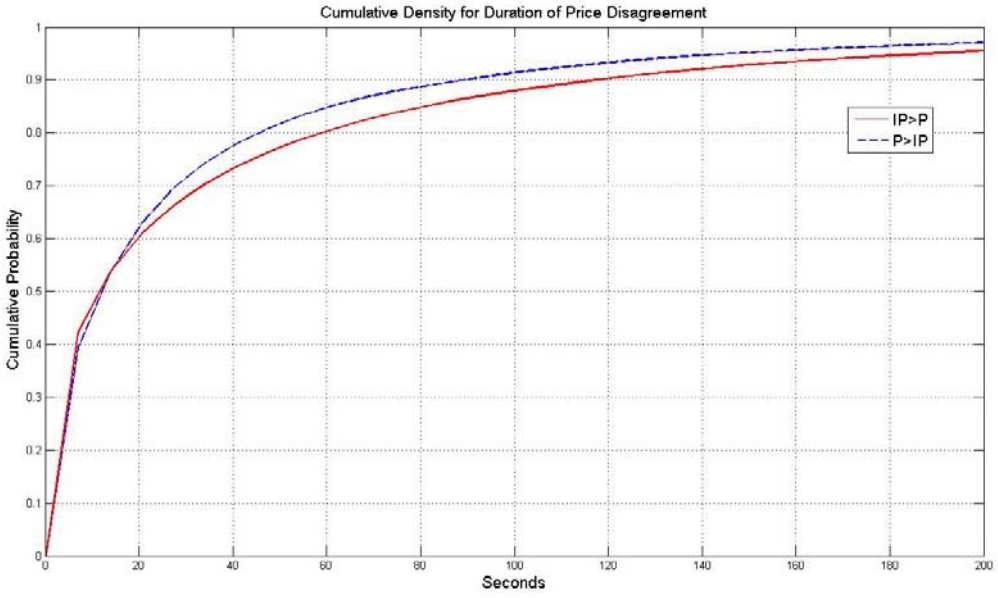

Figure 4. Location of the actual stock midpoint relative to the option-implied bid and ask prices. The figure shows a kernel density estimate of the location of the actual stock quote midpoint relative to the option-implied spread, conditional on the option-implied spread being equal to its most frequent value of 15 cents. The horizontal axis is the difference between the price and the option-implied bid price, i.e. it is the distance of the price from the bottom of the bid-ask range. The price quotes used to estimate the density are two-minute frequency snapshots from the full sample, excluding cases in which the implied spread is not equal to its most common value of 15 cents. The total number of observations is 1,696,175. Violations of put-call parity occur when the density function crosses the green dotted lines highlighting the locations of the option-implied quotes.

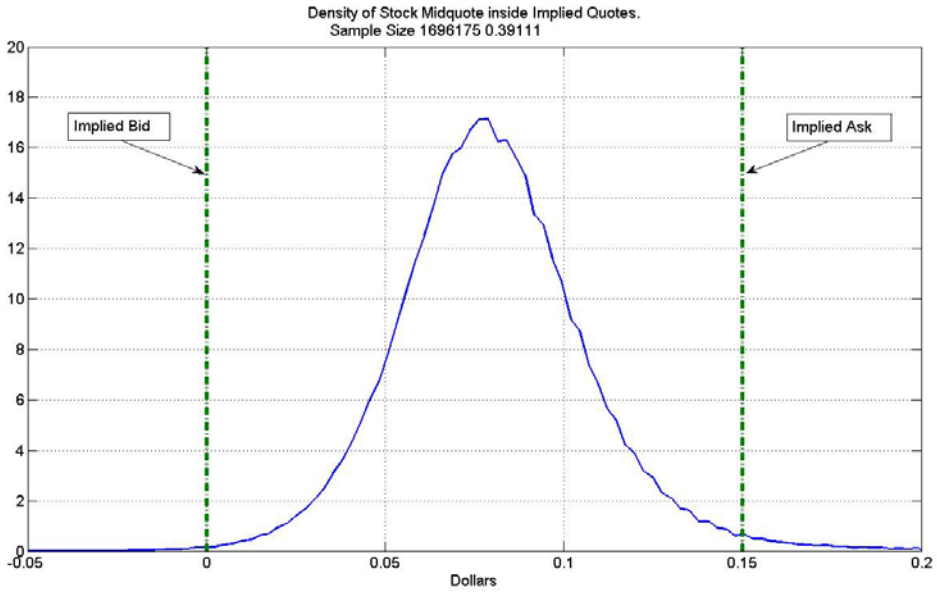

Figure 5. Comparisons of the distributions of quote changes for the disagreement and control samples. Panels (A-C) compare the distributions of changes in the option-implied bid, option-implied ask, and actual stock midpoint for the disagreement and control samples for the {P>IP}-type disagreements, using an evaluation period of one minute. In each panel, the distribution of quote changes in the disagreement sample is represented by the light-shaded bars, while the distribution of quote changes in the control sample is represented by the dark-shaded bars. Panels (D-F) compare the distributions of changes in the option-implied bid, option-implied ask, and actual stock midpoint quotes between the disagreement and control samples for the {IP>P}-type disagreements. In all cases quote changes are measured in U.S. dollars. Panels A, B, D, and E use a bin size of 5 cents, which is the tick size in the options market. Panels C and F showing the distribution of changes in the stock midpoint use a bin size of 2 cents

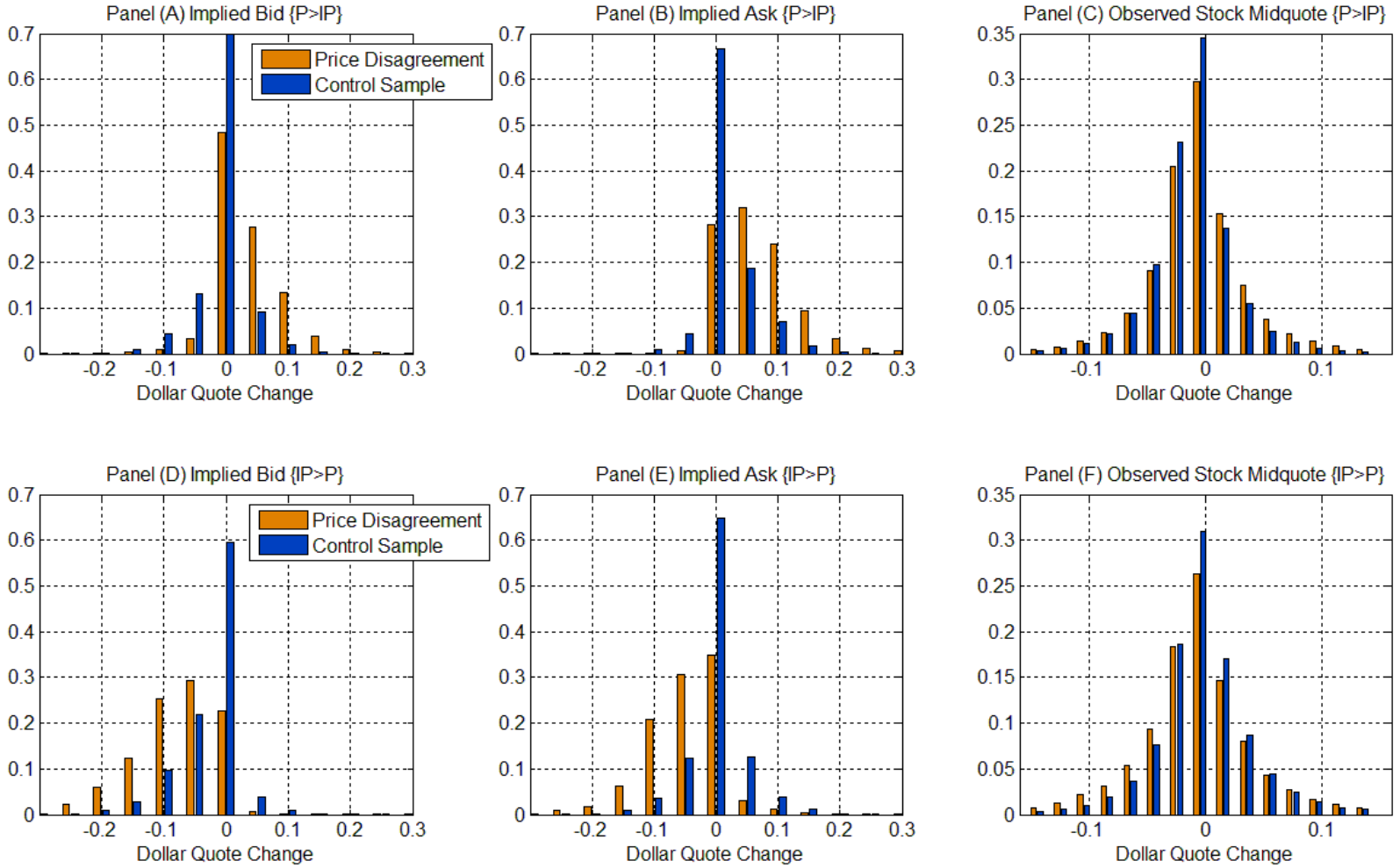

Table 1. Summary statistics for the 36 stocks and 3 ETFs in the sample. The sample in the column headed "Two-Minute Snapshots" is constructed by taking snapshots of the prevailing quotes every two minutes. The implied spread is the difference between the option-implied ask and bid quotes, each computed using the call-put parity relations (1) and (2), in dollars. For the disagreement sample, the implied spread is computed from the option quotes prevailing at the moment a disagreement event is triggered. The column headed "Median Duration" shows the median of the event durations, defined as the time (in seconds) from when a disagreement event is triggered and the first time the actual stock quotes return inside the option-implied quotes. The pre-event return is computed from stock quote midpoints prevailing when each event is triggered and 5 minutes before the event, and is reported in percentage points. The averages in the last row are equal-weighted averages of the stock/ETF averages. Prices and spreads in dollars. Ticker symbols indicated with * dropped before the end of the sample period.

		Two-Minute Snapshots		Both {P>IP} and {IP>P} disagreements		{P>IP}-type disagreements		{IP>P}-type disagreements	
Ticker	Price	Stock Spread	Implied Spread	Median Duration	Implied Spread	No. of Events	Pre-event Return (%)	No. of Events	Pre-event Return (%)
AIG	63.9	0.017	0.18	11.15	0.13	1,599	0.14	296	-0.19
AMAT	18.3	0.008	0.13	12.13	0.13	1,796	0.13	749	-0.23
AMGN	65.7	0.013	0.17	13.10	0.12	5,398	0.16	622	-0.22
AMR	14.4	0.013	0.16	14.06	0.12	2,871	0.15	202	-0.21
AMZN	40.6	0.012	0.16	11.52	0.12	7,119	0.15	1,416	-0.23
AOL	15.6	0.011	0.13	24.21	0.13	91	0.16	55	-0.23
BMY	24.7	0.012	0.14	14.01	0.13	700	0.16	110	-0.23
BRCM	34.7	0.011	0.16	13.41	0.12	5,099	0.17	1,578	-0.23
C	46.6	0.012	0.14	11.60	0.13	1,304	0.14	246	-0.20
COF	72.5	0.023	0.21	13.51	0.13	2,577	0.14	222	-0.21
CPN	4.8	0.011	0.12	30.16	0.13	106	0.16	23	-0.18
CSCO	20.0	0.008	0.12	12.32	0.13	1,807	0.13	686	-0.23
DELL	32.8	0.009	0.13	12.99	0.12	4,794	0.17	383	-0.18
EBAY	59.2	0.013	0.18	10.10	0.12	8,173	0.15	1,566	-0.23
EMC	12.6	0.011	0.13	12.21	0.13	652	0.16	299	-0.19
F	11.4	0.010	0.12	26.10	0.13	222	0.17	48	-0.21
GE	31.9	0.011	0.12	12.12	0.13	858	0.16	174	-0.21
GM	35.3	0.013	0.16	11.65	0.13	1,492	0.14	134	-0.23
HD	37.0	0.012	0.14	11.66	0.13	1,429	0.14	142	-0.22
IBM	86.1	0.018	0.17	11.59	0.13	1,708	0.14	201	-0.21
INTC	24.4	0.008	0.11	13.78	0.12	2,484	0.14	1,444	-0.23
JPM	37.0	0.012	0.14	11.57	0.13	1,304	0.14	184	-0.21
KLAC	47.7	0.013	0.17	13.41	0.12	4,007	0.17	902	-0.24
MMM	85.3	0.020	0.19	12.87	0.13	1,085	0.15	130	-0.23
MO	61.1	0.015	0.17	11.48	0.13	1,386	0.14	215	-0.21
MSFT	26.3	0.008	0.11	13.20	0.13	1,124	0.14	626	-0.22
MWD	52.2	0.017	0.18	13.97	0.13	936	0.15	70	-0.24
NXTL	24.5	0.009	0.14	12.99	0.13	1,115	0.14	616	-0.22
ORCL	12.7	0.008	0.12	14.61	0.13	456	0.16	305	-0.19
PFE	29.3	0.011	0.13	12.05	0.13	756	0.15	349	-0.18
QCOM	44.7	0.011	0.15	13.60	0.12	4,707	0.17	1,000	-0.24
QLGC	34.5	0.015	0.17	14.11	0.12	2,682	0.15	1,000	-0.24
QQQ	34.2	0.004	0.12	13.23	0.12	5,319	0.16	32	-0.17
QQQQ	38.7	0.009	0.12	13.60	0.12	4,430	0.17	38	-0.20
SBC	24.3	0.012	0.14	22.46	0.13	295	0.18	64	-0.23
SMH	35.0	0.011	0.14	14.09	0.12	2,742	0.15	639	-0.22
TYC	27.4	0.012	0.14	12.40	0.13	1,070	0.15	225	-0.21
XLNX	29.0	0.011	0.16	12.77	0.12	2,373	0.14	957	-0.24
XOM	54.8	0.012	0.15	11.95	0.13	1,741	0.14	62	-0.24
Average or sum	37.2	0.012	0.15	14.22	0.13	89,807	0.15	18,010	-0.22

Table 2. Mean quote changes in the disagreement and control samples. For each stock and ETF, the table presents the mean changes (in cents) of the option-implied bid quote, option-implied ask quote, and actual stock midpoint for the disagreement and the control samples, for both the {P>IP}-type and {IP>P}-type disagreements. The evaluation period is set to one minute. The averages in the last row are equal-weighted averages of the stock/ETF averages. The units of all variables are dollars. Ticker symbols indicated with * dropped before the end of the sample period.

	{P > IP}-Type Disagreements						{IP > P}-Type Disagreements					
	Treatment Sample			Control Sample			Treatment Sample			Control Sample		
Ticker	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint
AIG	4.7	9.4	0.2	-0.8	2.2	-0.5	-13.5	-6.7	0.1	-3.6	0.0	0.6
AMAT	4.4	9.0	0.1	-0.8	2.1	-0.5	-9.3	-5.2	0.0	-2.5	-0.1	0.5
AMGN	3.8	7.2	0.2	-0.6	1.7	-0.4	-10	-5.3	0.0	-2.7	-0.1	0.5
AMR	3.8	7.5	0.1	-0.7	1.8	-0.4	-14.1	-7.1	0.0	-4.0	-0.3	0.4
AMZN	3.9	7.4	0.2	-0.6	1.7	-0.4	-8.3	-4.8	-0.1	-2.4	0.0	0.3
AOL *	4.4	9.1	0.9	-1.2	3.2	-0.5	-12.9	-6.8	-1.0	-4.8	0.1	0.2
BMY	4.7	9.4	-0.2	-1.2	2.4	-0.5	-12.1	-6.7	0.1	-3.7	-0.1	0.3
BRCM	3.8	7.2	0.2	-0.6	1.7	-0.4	-8.5	-5.1	-0.2	-2.5	-0.1	0.3
C	4.8	9.7	0.2	-0.9	2.2	-0.5	-13.8	-7.2	-0.2	-3.9	-0.2	0.4
COF	3.8	7.8	0.0	-0.8	1.9	-0.4	-13.9	-7.1	0.0	-4.0	-0.2	0.3
CPN *	4.4	8.5	0.7	-1.5	3.0	-0.6	-13.7	-8.9	-2.2	-5.0	0.2	0.7
CSCO	4.4	9.0	0.1	-0.8	2.1	-0.4	-9.6	-5.3	0.0	-2.6	-0.1	0.5
DELL	3.7	7.1	0.2	-0.6	1.7	-0.4	-13.1	-6.4	0.3	-3.4	-0.1	0.6
EBAY	3.9	7.6	0.2	-0.7	1.7	-0.4	-8.5	-5.1	-0.2	-2.5	-0.1	0.3
EMC	4.8	9.5	-0.2	-1.1	2.4	-0.5	-13.5	-6.7	0.1	-3.6	0.0	0.6
F	4.9	9.3	0.6	-1.7	2.4	-0.9	-13.2	-7.1	-1.6	-5.1	0.0	0.1
GE	5.0	9.8	0.1	-1.2	2.2	-0.7	-14.2	-7.4	-0.1	-4.0	-0.4	0.3
GM	4.8	9.5	0.2	-0.8	2.3	-0.5	-12.1	-6.7	0.6	-3.8	0.0	0.3
HD	4.8	9.6	0.2	-0.8	2.3	-0.5	-12.1	-6.6	0.6	-3.7	0.0	0.4
IBM	4.5	9.1	0.1	-0.8	2.2	-0.5	-14.1	-7.1	-0.1	-4.0	-0.3	0.4
INTC	3.9	7.9	0.1	-0.8	1.9	-0.4	-8.3	-4.9	-0.1	-2.4	0.0	0.3
JPM	4.8	9.7	0.2	-0.9	2.2	-0.5	-14.6	-7.4	-0.3	-3.9	-0.4	0.5
KLAC	3.5	6.7	0.0	-0.5	1.6	-0.3	-8.6	-5.0	0.0	-2.3	-0.1	0.4
MMM	4.7	9.4	0.1	-1.0	2.2	-0.6	-11.9	-6.5	0.9	-3.8	-0.1	0.3
MO	4.9	9.7	0.2	-0.8	2.3	-0.5	-14.0	-7.0	0.0	-4.0	-0.3	0.3
MSFT	4.7	9.4	0.2	-1.0	2.2	-0.6	-9.9	-5.3	0.0	-2.7	-0.1	0.5
MWD*	4.9	9.6	0.2	-1.1	2.3	-0.7	-12.6	-7.0	-0.8	-4.4	0.0	0.1
NXTL*	4.7	9.4	0.2	-1.0	2.2	-0.6	-10.0	-5.4	0.0	-2.7	-0.1	0.5

Table 2 (continued)

	{P > IP}-Type Disagreements						{IP > P}-Type Disagreements					
	Treatment Sample			Control Sample			Treatment Sample			Control Sample		
Ticker	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint	Implied Bid	Implied Ask	Stock Midpoint
ORCL	4.5	9.2	-0.2	-1.4	2.2	-0.7	-13.4	-6.7	0.0	-3.6	0.0	0.7
PFE	4.9	9.8	0.0	-1.3	2.2	-0.7	-13.2	-6.5	0.5	-3.5	-0.1	0.6
QCOM	3.7	7.0	0.2	-0.6	1.7	-0.4	-8.3	-4.9	0.0	-2.3	-0.1	0.4
QLGC	3.8	7.7	0.0	-0.7	1.8	-0.4	-8.3	-4.9	0.0	-2.3	-0.1	0.4
QQQ *	3.8	7.2	0.2	-0.6	1.7	-0.4	-12.3	-6.9	-1.6	-4.9	0.4	0.4
QQQQ	3.5	6.8	0.1	-0.5	1.7	-0.4	-12.6	-6.7	-1.4	-5.5	-0.1	0.0
SBC *	5.0	9.6	0.6	-1.5	2.4	-0.7	-13.0	-7.0	-0.7	-4.6	-0.2	-0.1
SMH	3.8	7.6	0.0	-0.7	1.8	-0.4	-9.8	-5.3	0.0	-2.7	-0.1	0.5
TYC	4.7	9.4	0.1	-1.0	2.2	-0.6	-13.8	-7.0	0.1	-4.0	-0.2	0.3
XLNX	3.9	8.1	0.0	-0.8	1.9	-0.5	-8.4	-4.9	0.0	-2.3	-0.1	0.4
XOM	4.5	9.1	0.1	-0.8	2.2	-0.4	-13.1	-7.0	-0.8	-4.7	-0.3	-0.1
Average	4.4	8.6	0.2	-0.9	2.1	-0.5	-11.7	-6.3	-0.2	-3.6	-0.1	0.4

Table 3. Comparison of mean quote changes in the disagreement and control samples for 30-second and one minute evaluation periods. The table presents summary information about the mean changes (in dollars) of the option-implied bid quote, option-implied ask quote, and actual stock midpoint for the disagreement and the control samples, for both the {P>IP}-type and {IP>P}-type disagreements. The columns headed "Mean" and "Median" present the mean and median, respectively, across the 39 stocks and ETFs, of the mean quote changes computed for the 39 stocks and ETFs. The columns headed "4-th" and "36-th" present the fourth and 36th largest of the mean quote changes across the 39 stocks and ETFs.

Variable	Evaluation Period	Subsample	{P > IP}-Type Disagreements				{IP>P}-Type Disagreements			
			Mean	Median	4-th	36-th	Mean	Median	4-th	36-th
Implied Bid	30 seconds	Treatment	0.038	0.039	0.033	0.043	-0.098	-0.105	-0.123	-0.068
		Control	-0.005	-0.004	-0.010	-0.003	-0.029	-0.030	-0.041	-0.018
	1 minute	Treatment	0.044	0.045	0.037	0.049	-0.117	-0.126	-0.141	-0.083
		Control	-0.009	-0.008	-0.014	-0.006	-0.036	-0.037	-0.049	-0.023
Implied Ask	30 seconds	Treatment	0.073	0.075	0.060	0.083	-0.057	-0.060	-0.065	-0.044
		Control	0.018	0.019	0.014	0.021	-0.002	-0.002	-0.004	0.001
	1 minute	Treatment	0.086	0.091	0.071	0.097	-0.063	-0.067	-0.072	-0.049
		Control	0.021	0.022	0.017	0.024	-0.001	-0.001	-0.003	0.000
Actual Stock Midpoint	30 seconds	Treatment	0.003	0.003	0.002	0.004	-0.005	-0.002	-0.016	-0.001
		Control	-0.003	-0.002	-0.004	-0.002	0.000	0.001	-0.004	0.003
	1 minute	Treatment	0.002	0.002	0.000	0.006	-0.002	0.000	-0.014	0.005
		Control	-0.005	-0.005	-0.007	-0.004	0.004	0.004	0.001	0.006

Table 4. Estimates of the mean effect of disagreement, controlling for the variables used in matching. The table presents summary information about the coefficient estimates on the disagreement dummy in regressions of quote changes on a constant, the disagreement dummy, and the two variables used in matching (the option-implied spread and the 5-minute pre-event return). The columns headed "Mean" and "Median" present the mean and median, respectively, across the 39 stocks and ETFs, of the coefficient estimates on the disagreement dummy and their associated *t*-statistics (in parentheses). The columns headed "4-th" and "36-th" present the fourth and 36th largest of the coefficient estimates, again with the associated *t*-statistics. The *t*-statistics are based on White heteroscedasticity-consistent standard errors. Because each disagreement event is matched to three control events, sample sizes for individual regressions are four times the number of disagreements for each stock reported in Table 1.

		{P > IP}-Type Disagreements				{IP>P}-Type Disagreements			
Variable	Evaluation Period	Mean	Median	4-th	36-th	Mean	Median	4-th	36-th
Implied Bid	30 seconds	0.028	0.024	0.017	0.044	-0.039	-0.032	-0.070	-0.018
		(30.6)	(36.2)	(27.9)	(39.8)	(-13.5)	(-9.7)	(-32.1)	(-6.4)
	1 minute	0.034	0.030	0.020	0.050	-0.049	-0.042	-0.083	-0.024
		(30.4)	(38.9)	(11.2)	(48.6)	(-14.5)	(-18.5)	(-13.7)	(-7.4)
Implied Ask	30 seconds	0.036	0.030	0.020	0.060	-0.038	-0.037	-0.058	-0.018
		(32.4)	(36.6)	(46.2)	(64.9)	(-15.6)	(-35.5)	(-31.7)	(-8.8)
	1 minute	0.042	0.036	0.022	0.066	-0.046	-0.044	-0.065	-0.026
		(33.3)	(24.7)	(6.3)	(59.6)	(-15.0)	(-21.7)	(-7.5)	(-5.3)
Actual Stock Midpoint	30 seconds	0.003	0.002	0.000	0.006	-0.002	-0.003	-0.009	0.004
		(4.3)	(3.9)	(0.3)	(8.1)	(-1.7)	(-3.4)	-4.7	(1.1)
	1 minute	0.004	0.003	0.000	0.008	-0.003	-0.005	-0.011	0.005
		(4.3)	(2.8)	(0.5)	(8.1)	(-1.7)	(-2.8)	-5.2	(1.1)

Table 5. Estimates of coefficients on the disagreement dummy in quantile regressions, for various quantiles. The table presents the coefficient estimates on the disagreement dummy in quantile regressions of quote changes in specifications that include either only the disagreement dummy and a constant, or that also include the two variables used in matching (the option-implied spread and the 5-minute pre-event return). Each coefficient estimate in the table is from a separate regression for the pooled sample. Only the coefficient for the disagreement dummy is reported. Standard errors (in parentheses) are based on 2,500 bootstrap iterations. There are 89,807 and 18,010 observations for the {P>IP}-type and {IP>P}-type disagreements, respectively.

		{P > IP}-Type Disagreements					{IP>P}-Type Disagreements				
	Quantile:	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%
Without Control Variables	Implied Bid	0.050	0.000	0.000	0.050	0.050	-0.100	-0.050	-0.050	-0.050	0.000
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Implied Ask	0.000	0.050	0.050	0.100	0.100	-0.050	-0.100	-0.050	0.000	-0.050
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Actual Stock Midpoint	0.000	0.000	0.000	0.005	0.015	-0.020	-0.010	0.000	0.000	0.005
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.0003)
Including Variables Used in Matching as Controls	Implied Bid	0.050	0.000	0.000	0.050	0.084	-0.062	-0.050	-0.050	-0.050	0.000
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.0033)	(0.00)	(0.00)	(0.00)	(0.00)
	Implied Ask	0.000	0.050	0.050	0.087	0.080	-0.050	-0.050	-0.050	0.000	-0.050
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Actual Stock Midpoint	-0.003	0.001	0.001	0.005	0.015	-0.022	-0.010	-0.002	-0.001	0.006
		(0.0003)	(0.0001)	(0.00)	(0.00)	(0.0004)	(0.001)	(0.00)	(0.0002)	(0.0003)	(0.0009)

Table 6. Analysis of joint quote changes. Estimated regression coefficients and associated *t*-statistics from four regressions that predict quote changes in the stock and options markets using information from the other market over evaluation periods τ of both 30 and 60 seconds, for both types of disagreement events. In each regression, observations of all disagreement events of the indicated type are pooled together and a single regression is estimated.

The left-hand half of the table presents the results for the {P>IP}-type disagreement events. For these disagreements, the regression specifications are

$$\text{Implied Ask}_{t+\tau} - \text{Implied Ask}_t = a\,(\text{Bid}_t - \text{Implied Ask}_t) + \varepsilon_{t+\tau},$$

$$\text{Midpoint}_{t+\tau} - \text{Midpoint}_t = b\,(\text{Implied Ask}_t - \text{Midpoint}_t) + \varepsilon_{t+\tau}.$$

For the {IP>P}-type disagreement events for which results are shown in the right-hand half of the table, the specifications are

$$\text{Implied Bid}_{t+\tau} - \text{Implied Bid}_t = a\,(\text{Ask}_t - \text{Implied Bid}_t) + \varepsilon_{t+\tau},$$

$$\text{Midpoint}_{t+\tau} - \text{Midpoint}_t = b\,(\text{Implied Bid}_t - \text{Midpoint}_t) + \varepsilon_{t+\tau}.$$

Positive estimates of the coefficients *a* or *b* indicate that information from one market is useful in predicting price changes in the other market. The *t*-statistics are based on White heteroscedasticity-consistent standard errors. Sample sizes are 89,807 for the {P>IP}-type, and 18,010 for the {IP>P}-type.

		{P>IP}-Type Disagreements		{IP>P}-Type Disagreements	
Evaluation Period		Implied Ask	Stock Midpoint	Implied Bid	Stock Midpoint
30 seconds	Coefficient	1.51	-0.03	1.86	0.00
	t-statistic	(100.0)	(-2.95)	(67.7)	(-0.29)
	R^2	0.08	0.00	0.05	0.00
1 minute	Coefficient	1.75	-0.02	2.22	0.04
	t-statistic	(100.2)	(-1.74)	(69.0)	(2.3)
	R^2	0.07	0.00	0.03	0.00

Table 7. Average signed volume during the disagreement and control events. Signed volume in the underlying stocks is based on the Lee and Ready (1991) algorithm, while a version of the quote rule is used to estimate the direction of options trades. The delta-equivalent volume is computed using the estimates of signed option volume and the options delta from Option Metrics. "All Options" include all option pairs for a given underlying stock, while the "Disagreement Pair" includes only volume in the option pair that triggered the disagreement event. The columns headed "Mean" and "Median" report the mean and median, respectively, of the 39 values for each of the stocks and ETFs. The columns headed "4-th", and "36-th" reports 4-th and 36-th largest of the signed volumes for the 39 stocks and ETFs. The units are round lots of 100 shares, so that "1" means 100 shares. All results are reported for the evaluation periods of both 30 and 60 seconds. The number of disagreements for each stock is reported in Table 1. Because each disagreement event is matched to three control events, the control samples are three times the sizes of the treatment samples.

			{P > IP}-Type Disagreements				{IP>P}-Type Disagreements			
	Sample	Evaluation Period	Mean	Median	4-th	36-th	Mean	Median	4-th	36-th
All Options	Treatment	30 seconds	14.1	14.9	7.9	18.6	-14.9	-14.3	-19.6	-9.2
		1 minute	14.0	16.5	5.5	19.9	-8.5	-12.3	-23.5	11.8
	Control	30 seconds	1.5	1.1	0.7	2.5	-3.1	-3.5	-4.5	-0.8
		1 minute	2.8	2.8	0.4	5.7	-4.9	-4.6	-7.3	-3.3
Disagreement Pair	Treatment	30 seconds	7.8	8.8	2.4	10.3	-7.9	-7.9	-10.8	-4.1
		1 minute	9.3	10.8	3.0	12.3	-8.8	-11.4	-14.1	-0.7
	Control	30 seconds	0.5	0.6	0.2	0.8	-1.8	-1.8	-2.9	-0.8
		1 minute	0.8	0.9	0.4	1.2	-2.1	-1.9	-3.0	-1.1
Stock	Treatment	30 seconds	1.6	1.5	1.1	2.4	0.3	0.2	-2.0	1.8
		1 minute	2.7	2.8	2.1	3.2	1.0	1.0	-1.9	2.8
	Control	30 seconds	1.0	0.8	0.6	1.6	0.1	-0.1	-0.9	1.6
		1 minute	1.7	1.6	1.1	2.2	0.6	0.6	-0.8	2.5

Table 8. Estimates of the coefficient on the disagreement dummy in quantile regressions explaining signed volume. Only the coefficient for disagreement dummy is reported, and each cell in the table is from a separate regression for the pooled sample using an evaluation period of 30 seconds. Signed volume in the underlying stocks is based on the Lee and Ready (1991) algorithm, while a version of the quote rule is used to estimate the direction of options trades. The delta-equivalent volume is computed using the estimates of signed option volume and the options deltas from Option Metrics. "All Options" include all option pairs for a given underlying stock, while the "Disagreement Pair" includes only volume in the option pair that triggered the disagreement event. The columns headed "Mean" and "Median" report the mean and median, respectively, of the 39 stock-by-stock values. The columns headed "4-th", and "36-th" report the 4-th and 36-th largest of the signed volumes for the 39 stocks. The units are round lots of 100 shares, so that "1" means 100 shares. Standard errors (in parentheses) are based on 2,500 bootstrap iterations. The numbers of observations are 89,807 for the {P>IP}-type and 18,010 for the {IP>P}-type.

		{P>IP}-Type Disagreements					{IP>P}-Type Disagreements				
	Quantile:	10%	30%	50%	70%	90%	10%	30%	50%	70%	90%
Including Variables Used in Matching as Controls	All Options	0.5 (0.28)	0.0 (0.00)	3.7 (0.00)	16.3 (0.16)	64.2 (0.89)	-70.3 (1.94)	-20.8 (0.44)	-7.2 (0.00)	0.0 (0.00)	2.3 (0.60)
	Disagreement Pair	-0.8 (0.00)	0.0 (0.00)	0.0 (0.00)	4.8 (0.00)	26.5 (0.25)	-34.6 (0.81)	-8.4 (0.00)	-1.4 (0.00)	0.0 (0.00)	2.8 (0.00)
	Stock	-4.1 (0.25)	0.0 (0.00)	1.1 (0.04)	3.9 (0.10)	11.4 (0.28)	-10.2 (0.60)	-3.8 (0.21)	-0.7 (0.13)	1.5 (0.20)	7.5 (0.53)
Without Control Variables	All Options	0.4 (0.28)	0.0 (0.00)	3.7 (0.00)	16.9 (0.17)	65.9 (0.97)	-70.3 (2.14)	-21.6 (0.43)	-7.2 (0.00)	0.0 (0.00)	2.2 (0.63)
	Disagreement Pair	-0.9 (0.00)	0.0 (0.00)	0.0 (0.00)	4.8 (0.00)	27.2 (0.31)	-35.0 (0.76)	-8.4 (0.00)	-1.4 (0.00)	0.0 (0.00)	2.7 (0.00)
	Stock	-5.0 (0.24)	0.0 (0.00)	1.0 (0.00)	4.0 (0.00)	12.0 (0.00)	-11.0 (0.60)	-4.0 (0.06)	0.0 (0.26)	2.0 (0.31)	8.0 (0.56)

Table 9. Conditional average quote changes in various subsamples. Panels A and B show coefficient estimates for the {P>IP} and {IP>P}-type disagreement events, respectively. In each panel, each column reports the coefficient estimates on the disagreement dummy and the associated *t*-statistics (in parentheses) for regressions explaining the option-implied bid, option-implied ask, and actual stock midpoint for the subsample identified in the column heading. In each subsample, all observations are pooled together and a single regression is estimated. Each column also reports the median disagreement duration, in seconds, and the number of treatment sample events. Because each disagreement event is matched with three control events, the total number of observations is four times the number of treatment events. The evaluation period is one minute, and the *t*-statistics are based on White heteroscedasticity-consistent standard errors.

Results for the full sample are provided in column 1 for comparison. Column 2 headed "Option-initiated" contains the results for the subsample of events (and corresponding matched observations) triggered by changes in options quotes. Column 3 headed "2 Pre-Earnings Days" is for the subsample of events that occur in the 2 days before an earnings announcement, column 4 headed "Pre-Event Return >0.3%" uses the subsample of events for which the absolute value of the 5-minute pre-event stock return exceeded 0.3%, and column 5 headed "Year >2004 " uses events from 2005 and 2006. Column 6 headed "Option Volume > 80th %-tile" is for the subsample of events that occurred on days in which option trading volume exceeded the 80th percentile of daily option trading volume for that underlying stock. Column 7 headed "Trade Conf." is for the subsample of events with "trade-confirmed" quotes, where "trade-confirmed" means that there were trades at both the call and put quotes used to compute the option-implied stock quote that causes the disagreement, while column 8 headed "Exch. Conf." is for the subsample of events with "exchange-confirmed" quotes, where "exchange-confirmed" means that the call and put quotes used to compute the option-implied stock quote that causes the disagreement were quoted by at least two exchanges. Column 9 headed "Trade or Exch." uses the quotes that are either trade or exchange confirmed, i.e. it uses the union of the subsamples used in columns 7 and 8. Column 10 headed "> 10 Sec. duration" includes only events where the violating implied quote does not change in the first 10 seconds after the disagreement is triggered.

Panel A: {P>IP}-Type Disagreements

	1	2	3	4	5	6	7	8	9	10
	Full Sample	Option-Initiated	2 Pre-Earnings Days	Pre-Event Return >0.3%	Year >2004	Option Volume > 80th %-tile	Trade Conf.	Exch. Conf.	Trade or Exch.	>10 Sec. Duration
Implied Bid	0.039	0.027	0.045	0.051	0.034	0.042	0.039	0.033	0.039	0.028
	(194.9)	(42.0)	(33.8)	(72.2)	129.0	(92.2)	(83.5)	(79.0)	(144.6)	(118.8)
Implied Ask	0.049	0.046	0.059	0.060	0.049	0.054	0.039	0.041	0.048	0.026
	(215.0)	(61.3)	(38.9)	(79.2)	(162.20	(105.2)	(71.6)	(86.9)	(157.5)	(96.8)
Actual Stock Midpoint	0.006	-0.003	0.008	0.009	0.004	0.007	0.008	0.005	0.006	0.001
	(31.6)	(-4.5)	(6.5)	(13.5)	(16.5)	(16.2)	(20.0)	(11.8)	(26.7)	(4.0)
Median Duration	13.1	14.6	9.5	6.5	6.925	11.1	35.0	14.6	13.6	44.7
No. of Treatment Events	89,807	8,462	2,558	12,301	43,162	21,424	12,067	17,035	43,876	45,392

Table 9 (continued)

Panel B: {IP>P}-Type Disagreements

	1 Full Sample	2 Option-Initiated	3 2 Pre-Earnings Days	4 Pre-Event Return < -0.3%	5 Year >2004	6 Option Volume > 80th %-tile	7 Trade Conf.	8 Exch. Conf.	9 Trade or Exch.	10 >10 Sec. Duration
Implied Bid	-0.056	-0.059	-0.062	-0.065	-0.057	-0.059	-0.050	-0.041	-0.052	-0.033
	(-94.7)	(-22.5)	(-18.3)	(-54.4)	(-39.2)	(-45.6)	(-44.2)	(-26.5)	(-62.0)	(-46.6)
Implied Ask	-0.050	-0.040	-0.057	-0.058	-0.047	-0.051	-0.051	-0.044	-0.049	-0.039
	(-96.8)	(-17.1)	(-18.6)	(-52.4)	(-36.9)	(-43.7)	(-51.2)	(-31.1)	(-66.3)	(-63.1)
Observed Midpoint	-0.006	0.002	-0.011	-0.010	-0.001	-0.005	-0.008	-0.004	-0.006	-0.003
	(-12.0)	(1.0)	(-3.1)	(-8.6)	(-0.6)	(-4.63)	(-8.9)	(-2.5)	(-7.9)	(-4.8)
Median Duration	13.1	10.7	11.5	8.125	5.125	10.4	21.9	27.3	15.4	35.0
No. of Treatment Events	18,010	1,036	633	5,605	3,065	4,410	3,835	2,072	7,628	9,300

Table 10. Signed volume in various subsamples. Panels A and B show coefficient estimates for the {P>IP} and {IP>P}-type disagreement events, respectively. In each panel, each column reports the coefficient estimates on the disagreement dummy and the associated *t*-statistics (in parentheses) for regressions of either the delta-equivalent signed option volume in a set of options or the signed stock volume on a constant and the disagreement dummy for a separate subsample identified by the column heading. The results in the rows labeled "All Options" use as the left-hand side variable the total delta-equivalent signed volume in all option pairs for a given underlying stock. The results in the rows labeled "Disagreement Pair" use only the delta-equivalent signed option volume for the option pair that triggered the disagreement event, while the rows labeled "Stock" use the signed volume in the underlying stock. In each subsample, all observations are pooled together and a single regression is estimated. The table also reports the median disagreement duration, in seconds, and the number of treatment sample events. Because each disagreement event is matched with three control events, the total number of observations is four times the number of treatment events. The evaluation period is 30 seconds, and the *t*-statistics are based on White heteroscedasticity-consistent standard errors.

Results for the full sample are provided in column 1 for comparison. Column 2 headed "Options-Initiated" contains the results for the subsample of events triggered by changes in options quotes. Column 3 headed "2 Pre-Earnings Days" is for the subsample of events that occur in the 2 days before an earnings announcement, column 4 headed "Pre-Event Return >0.3%" uses the subsample of events for which the absolute value of the 5-minute pre-event stock return exceeded 0.3%, and column 5 headed "Year >2004" uses events from 2005 and 2006. Column 6 headed "Option Volume > 80th %-tile" is for the subsample of events that occurred on days in which option trading volume exceeded the 80th percentile of daily option trading volume for that underlying stock. Column 7 headed "Trade Conf." is for the subsample of events with "trade-confirmed" quotes, where "trade-confirmed" means that there were trades at both the call and put quotes used to compute the option-implied stock quote that causes the disagreement, while column 8 headed "Exch. Conf." is for the subsample of events with "exchange-confirmed" quotes, where "exchange-confirmed" means that the call and put quotes used to compute the option-implied stock quote that causes the disagreement were quoted by at least two exchanges. Column 9 headed "Trade or Exch." uses the quotes that are either trade or exchange confirmed, i.e. it uses the union of the subsamples used in columns 7 and 8. Column 10 headed "> 10 Sec. duration" includes only events where the violating implied quote does not change in the first 10 seconds after the disagreement is triggered.

Panel A: {P>IP}-Type Disagreements

	1 Full Sample	2 Option-Initiated	3 2 Pre-Earnings days	4 Pre-Event Return >0.3%	5 Year >2004	6 Option Volume > 80th %-tile	7 Trade Conf.	8 Exch. Conf.	9 Trade or Exch.	10 >10 Sec. Duration
All Options	23.0	-0.1	23.8	17.9	30.7	23.7	66.6	52.0	38.3	22.1
	(17.1)	(0.0)	(5.2)	(3.7)	(12.9)	(10.6)	(14.3)	(12.8)	16.0)	(9.5)
Disagreement Pair	11.2	7.1	11.6	9.5	14.6	10.2	35.4	27.7	20.1	12.0
	(28.1)	(4.8)	(7.9)	(7.8)	(22.1)	(16.8)	(18.1)	(20.3)	(27.6)	(18.1)
Stock	2.9	-1.2	0.9	1.1	2.0	3.7	5.5	3.4	3.9	2.1
	(16.1)	(-2.0)	(1.4)	(2.5)	(7.9)	(9.2)	(8.1)	(6.6)	(13.3)	(7.8)
Median Duration	13.1	14.6	9.5	6.5	6.925	11.1	35.0	14.6	13.6	44.7
No. of Treatment Events	89,807	8,462	2,558	12,301	43,162	21,424	12,067	17,035	43,876	45,392

Panel B: {IP>P}-Type Disagreements

	1	2	3	4	5	6	7	8	9	10
	Full Sample	Option-Initiated	2 Pre-Earnings Days	Pre-Event Return < -0.3%	Year >2004	Option Volume > 80th %-tile	Trade Conf.	Exch. Conf.	Trade or Exch.	>10 Sec. Duration
All Options	-22.4	-4.1	-27.1	-22.9	-40.3	-19.7	-43.3	-67.5	-37.2	-22.4
	(-16.6)	(-0.9)	(-3.6)	(-10.0)	(-11.7)	(-5.2)	(-9.9)	(-12.8)	(-14.1)	(-11.4)
Disagreement Pair	-12.7	-7.2	-15.8	-11.1	-23.9	-11.5	-30.4	-37.7	-23.4	-12.8
	(-21.9)	(-4.0)	(-5.5)	(-10.7)	(-11.9)	(-9.0)	(-17.3)	(-13.8)	(-20.5)	(-14.9)
Stock	-1.2	1.3	1.6	1.5	-0.1	-0.2	-2.7	-0.1	-1.2	-2.1
	(-3.8)	(1.1)	(0.9)	(2.3)	(-0.1)	(-0.3)	(-3.2)	(-0.1)	(-2.1)	(-5.0)
Median Duration	13.1	10.7	11.5	8.125	5.125	10.4	21.9	27.3	15.4	35.0
No. of Treatment Events	18,010	1,036	633	5,605	3,065	4,410	3,835	2,072	7,628	9,300