Original Article

Derivatives pricing and liquidity dominance in alternative trading venues

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ABSTRACT This study examines the quality of derivatives pricing in the market in which liquidity is dominated by an alternative market. We use US interest rate futures from the side-by-side open outcry and electronic markets, in which electronic markets dominate liquidity. We find that the bid-ask spreads in illiquid open outcry markets have increased substantially since electronic markets became a major part of the market liquidity. Accordingly, the implicit trading costs in open outcry markets have significantly increased. We also show that the volatility of bid-ask spreads in illiquid open outcry markets has increased, which is consistent with a decrease in the depth of the market. In addition, we find that the fast rate of price discovery in electronic markets instabilizes the bid-ask spread in open outcry market. Our results are particularly important for practitioners in that the performance of their portfolio and risk managements critically depends on which market dominates liquidity.

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INTRODUCTION

Most newer worldwide exchanges trade as fully automated electronic systems rather than open outcry trading systems, with the objective of effectively handling a large number of trades and enhancing trading efficiency at a low cost.¹ Prior studies, primarily in stock and non-US futures

markets, find that electronic markets possess better market quality because their bid-ask spreads are smaller and the depth of this market is greater than it is for open outcry markets.

In the United States, both the Chicago Board of Trade (CBOT) and the Chicago Mercantile Exchange (CME), unlike the fully automated

systems in other countries, operate both open outcry and electronic trading systems 'side by side'. Since the inception of electronic markets, market liquidity in open outcry markets has diminished significantly. Consequently, questions arise concerning the impact of decrease in liquidity on derivatives prices. This study examines this issue by analyzing the quality of open outcry bid-ask pricing in terms of the size and volatility of the bid-ask spread (the market depth) before and after electronic markets dominate liquidity.

Our results show that the size and volatility of bid-ask spreads in open outcry markets increased substantially as electronic markets dominate market liquidity. Accordingly, implicit trading costs for customers significantly increased. This increase in the spread is consistent with increased market makers' costs from operating risk, adverse selection risk and inventory control risk due to a decrease in the liquidity in the open outcry market resulting from the more efficient and liquid electronic market. With the increased risk from adverse selection and the decreased level of competition in open outcry markets due to fewer limit orders, market makers' (bid-ask) reactions to information asymmetry arising from order flow become larger. Consequently, the volatility of the bid-ask spread increases. Furthermore, we find that price discovery in liquid electronic markets instabilizes the bid-ask spread in illiquid open outcry markets. Our results are particularly important for practitioners in that the performance of their portfolio and risk managements critically depends on which trading venue dominates liquidity. We conclude that the quality of the derivatives bid-ask pricing in open outcry markets deteriorates because electronic markets dominate liquidity.

This article proceeds as follows: the next section discusses the literature on the

characteristics of futures markets in relation to open outcry versus electronic markets. We then construct empirical hypotheses based on this literature in the subsequent section followed by a description of the data. The next section develops the methodologies employed in this article. The penultimate section presents the results. We offer our conclusions in the final section.

ELECTRONIC VERSUS OPEN OUTCRY DERIVATIVES MARKETS

The CBOT open outcry and electronic trading systems are both order-driven markets.² However, the open outcry mechanism provides floor traders unique order flow information on who is trading and related trade size, which is not available in electronic trading systems.³⁻⁶ As off-the-floor traders do not have direct access to the open outcry trading pits, they are not typically privy to order flow information available in these markets. Moreover, incoming large order information often provides floor brokers an opportunity to front-run their clients.^{7,8}

Electronic trading systems do not disclose the identity of counterparty traders or the size of volume, where the size of volume often reflects information (see Easley and O'Hara⁹). Thus, informed traders prefer an electronic trading system, as it provides an anonymous trading environment in terms of trader identity and total volume traded.¹⁰⁻¹⁴ Another important feature of electronic markets is system capacity. With the scalable order matching system, electronic markets can process a great amount of order messages, whereas open outcry trading system can handle only limited amount of orders (see Harris¹⁴). Empirical results in Naidu and Rozeff¹⁵ and Ferris *et al*¹⁶ show the increases in trading volume and liquidity after the exchanges are fully converted into electronic order match

systems from the traditional open outcry systems. This liquid trading environment is crucial for informed trading as the market liquidity helps informed traders hide their information to maximize their profits (see Kyle¹⁷ and Admati and Pfleiderer¹⁸). As informed traders are more likely to trade in electronic markets, price discovery often occurs in an electronic trading system first.^{19–24} As a result, the adverse selection risk to market makers is higher in electronic trading systems than in the open outcry markets. Furthermore, the quality of pricing is more likely better in electronic markets with the increased trading volume, liquidity and consequently higher informativeness.

Prior empirical studies find that electronic markets actually possess a higher quality of pricing than open outcry markets, that is electronic markets possess smaller bid-ask spreads and/or greater market depth.^{25–31} However, these prior studies are for the stock market or non-US futures markets. More important, no prior studies examine the quality of derivatives pricing in the side-by-side traded US derivatives markets. Our article provides new findings on the qualities of pricing between electronic and open outcry markets with the side-by-side traded derivatives. In particular, we report the first analysis on the quality of open outcry bid-ask pricing before versus after electronic markets dominate liquidity for the side-by-side traded derivatives.

HYPOTHESIS CONCERNING ELECTRONIC VERSUS OPEN OUTCRY DERIVATIVES MARKETS

The quality of derivatives pricing in this study is measured by the size and volatility of the bid-ask spread, with the size of the bid-ask spread representing the cost of a transaction for a

customer. Prices in deeply liquid markets change little in response to large volumes, that is, substantial market depth exists. The less the market depth, the larger the volatility of the bid-ask spread. Prior studies use the volatility of price (or the volatility of the bid-ask spread) as a measure of the stability of a market; for example, see Naidu and Rozeff¹⁵ and Ferris *et al.*¹⁶

Theoretically, the existence of electronic trading should reduce the liquidity in open outcry markets, as the electronic trading system is a substitute trading venue for open outcry markets. This decreased liquidity in the open outcry market is expected to increase market makers' open outcry bid-ask spreads because of the following four reasons. First, market makers need to spread their fixed costs of market making over less volume in illiquid markets compared with liquid markets. Second, a market maker in a less liquid market cannot easily spread out their inventory risk, as infrequent trading in the less liquid market reduces the opportunities to quickly layoff inventory imbalances. Third, if liquidity decreases, then the risk of adverse selection increases, causing the adverse selection component of spreads to increase. Finally, if liquidity decreases, then the competition from market makers relative to public limit order traders decreases; consequently, in less competitive markets, market makers often increase their bid-ask spread. Consequently, we examine Hypothesis 1:

Hypothesis 1: The size of the market makers' bid-ask spread in open outcry markets is larger when electronic markets exist relative to before electronic markets existed.

We also expect the volatility of the bid-ask spread in open outcry markets to become larger when electronic trading exists. A larger volatility of the bid-ask spread is consistent with a reduction

in market depth. Moreover, if liquidity diminishes in a market, then it becomes difficult for market makers to diversify operational costs and reduce the risk of adverse selection. When the risk of adverse selection emanating from order flow increases because of the disappearance of (smaller) liquidity traders, then market makers' reactions to information asymmetry becomes more pronounced. As a result, the volatility of the bid-ask spread increases. In addition, market makers can increase the size of the change in the spread when liquidity is reduced in the open outcry market (because of the electronic market's existence), as less competition exists for the market maker as public limit orders are removed from the open outcry market. Accordingly, we examine Hypothesis 2:

Hypothesis 2: The volatility of the market makers' bid-ask spread in open outcry markets is larger when electronic markets exist relative to before electronic markets existed.

As we use the value of the bid-ask spread and its volatility as the measures of quality in pricing derivatives, if Hypotheses 1 and 2 are accepted then the quality of derivatives pricing in open outcry markets is less than before electronic trading existed.

METHODOLOGY

Directional models

Theory decomposes the bid-ask spread into the market makers' operational costs, the inventory control costs and the adverse selection costs (see Stoll³² and Huang and Stoll³³). Two primary determinants of the spread that affect the aforementioned three spread components are

volume and asset return volatility (for example, see McNish and Wood³⁴). This study employs trading volume as the proxy for liquidity as done in McNish and Wood.³⁴ First, we examine the appropriate sign of the coefficients relating volume and return volatility to the bid-ask spread. In order to examine the spread empirically, we employ McNish and Wood's³⁴ model, as given in (1), where we add a dummy variable '*D_Elect*' to isolate the effect of electronic trading on the bid-ask spread of the open outcry market:

$$BAS_t = a_0 + a_1 \ln(Volume_t) + a_2 \ln(Volatility_t) + a_3 D_Elect + Weekdaydummies + \varepsilon_t \quad (1)$$

where *BAS* represents the bid-ask spread in open outcry markets, *volume* is the daily open outcry volume, *daily volatility* (the volatility of the return as given in (A2)) is measured by (A7), and *D_Elect* takes on the value of one for the time periods when electronic trading exists and zero otherwise. The significance of electronic trading on open outcry bid-ask spreads is measured by a_3 . If $a_3 > 0$, then we accept Hypothesis 1, namely that the size of the bid-ask spread increases with the existence of electronic markets. Furthermore, as discussed previously, a decrease in open outcry trading volume is associated with an increase in the open outcry bid-ask spread. Therefore, we expect $a_1 < 0$. As for volatility, the volatility of the return of the asset is a proxy for information asymmetry.^{35,36} Therefore, we expect $a_2 > 0$, as bid-ask spreads increase with higher information asymmetry.

Impacts of decrease in liquidity on bid-ask spread

If trading volume in a market decreases significantly, then market liquidity decreases

and the risk of adverse selection increases for market makers. As electronic market dominates trading volume, the decreases in market liquidity and increases in adverse selection risk in open outcry markets are expected to increase the bid-ask spread in open outcry markets. The models given in (2) and (3) include the interaction terms between D_Elect and the volume and volatility determinants of the bid-ask spread in open outcry markets. Equation (2) focuses on open outcry volume:

$$\begin{aligned} BAS_t = & a_0 + a_1 \ln(Volume_t) \\ & + a_2 D_Elect \times \ln(Volume_t) \\ & + a_3 \ln(Volatility_t) \\ & + Weekdaydummies + \varepsilon_t \end{aligned} \quad (2)$$

where BAS is the bid-ask spread in open outcry markets. If volume decreases in the open outcry market (as electronic markets dominate liquidity), then the size of the negative coefficient of open outcry volume in (1) should become smaller during this period. The added $D_Elect \times \ln(Volume)$ variable allows us to examine whether the coefficient(s) related to volume becomes a smaller negative number. Thus, if $a_2 > 0$ in (2), then the negative relation between BAS and volume decreases in size, that is $a_1 < a_1 + a_2 < 0$. Therefore, we expect $a_2 > 0$ in (2). Recall that we detailed the major reasons of increases in spreads due to the decreases in liquidity.

Turning our focus to the volatility of returns, we examine the following equation (3):

$$\begin{aligned} BAS_t = & b_0 + b_1 \ln(Volume_t) \\ & + b_2 \ln(Volatility_t) \\ & + b_3 D_Elect \times \ln(Volatility_t) \\ & + Weekdaydummies + \varepsilon_t \end{aligned} \quad (3)$$

Here, if the trading volume in an open outcry market decreases, then the information asymmetry in order flow in the open outcry market should increase, resulting in an increased risk of adverse selection. Therefore, market makers should take precautions to mitigate adverse selection by increasing the bid-ask spread. Consequently, we expect $b_3 > 0$ in (3), as a larger volatility is a proxy for greater adverse selection.

Impacts of decrease in liquidity on the volatility of bid-ask spread

Now we turn our attention to examine the impact of decreases in liquidity on the volatility of the bid-ask spread, that is, market depth. Recall that this study employs the volatility of the bid-ask spread to examine market depth. Prices in deeply liquid markets change little in response to large volumes, that is, substantial market depth exists. Similarly, the larger the volatility of the bid-ask spread, the less the market depth. In order to analyze this relation, we employ a GARCH-based model.

Mean model:

$$\begin{aligned} BAS_t = & a_0 + a_1 \ln(Volume_t) \\ & + a_2 \ln(Volatility_t) + a_3 D_Elect \\ & + Weekdaydummies + \varepsilon_t \end{aligned} \quad (4)$$

Variance model:

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} + \beta_2 D_Elect_t \quad (5)$$

where BAS presents the bid-ask spread in open outcry markets. D_Elect in the variance model of (5) captures the increment of the volatility of the bid-ask spread in open outcry markets that is due to electronic trading. Therefore, if $\beta_2 > 0$, then Hypothesis 2 is accepted, that is, that bid-ask volatility is larger when electronic markets exist.

In order to examine the impact of changes in volume and adverse selection (the volatility of return in (A7)) in open outcry markets on the volatility of the bid-ask spread, we employ the models in (6) and (7):

$$\begin{aligned}\hat{h}_t = & a_0 + a_1 \ln(\text{Volume}_t) \\ & + a_2 D_Elect \times \ln(\text{Volume}_t) \\ & + a_3 \ln(\text{Volatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t\end{aligned}\quad (6)$$

$$\begin{aligned}\hat{h}_t = & b_0 + b_1 \ln(\text{Volume}_t) \\ & + b_2 \ln(\text{Volatility}_t) \\ & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t\end{aligned}\quad (7)$$

where h_t is the conditional variance of the daily realized half bid-ask spread in open outcry markets obtained from equation (5). As noted previously, if volume decreases in a market, then theoretically the level of liquidity competition for market makers from limit orders will decrease. As a result, a greater volatility in the bid-ask spread by market makers should occur. Therefore, we expect that $a_1 < 0$ and $a_2 > 0$ in (6) such that $a_1 < a_1 + a_2 < 0$, as a_2 represents the relevance of the period when electronic trading exists compared to when it does not. In terms of the volatility measure in (7), since the degree of information asymmetry proxied by the volatility increases from order flow information for market makers if the volume in open outcry markets decreases, the size of the volatility in the bid-ask spread by market makers increases. Therefore, we expect $b_2 > 0$ and $b_3 > 0$ in (7) such that $0 < b_2 < b_2 + b_3$ for the period when electronic trading exists ($D_Elect = 1$).

Impacts of price discovery in electronic markets on the open outcry bid-ask spread

As mentioned earlier, price discovery is more likely to occur in electronic markets first relative to open outcry markets, as electronic markets provide better trading environments for informed traders. Given the fact that open outcry markets and electronic markets are substitutes for each other for the commonly traded side-by-side products, the behaviors of informed traders in electronic markets may increase the size (and volatility) of spread in open outcry markets. To test this expectation, we use the return volatility in electronic markets to proxy for the information asymmetry caused by the informed trading. Specifically, we use the models in (8) and (9) to check whether the information asymmetry in electronic markets affects the size and volatility of spread (BAS) in open outcry markets, respectively.

$$\begin{aligned}BAS_t = & a_0 + a_1 \ln(\text{Volume}_t) \\ & + a_2 \ln(\text{Volatility}_t) \\ & + a_3 \ln(\text{ElectronicVolatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t\end{aligned}\quad (8)$$

$$\begin{aligned}\hat{h}_t = & a_0 + a_1 \ln(\text{Volume}_t) \\ & + a_2 \ln(\text{Volatility}_t) \\ & + a_3 \ln(\text{ElectronicVolatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t\end{aligned}\quad (9)$$

where *Electronic Volatility* represents the daily return volatility in electronic markets, and h_t is the conditional variance of the daily realized half bid-ask spread in open outcry markets obtained from equation (5). We then test whether the information asymmetry in electronic markets is the dominant factor that affects the size and volatility of spread in open outcry markets by

including the return volatility in open outcry markets in the model as shown in model (10) and (11), respectively.

$$\begin{aligned} BAS_t = & b_0 + b_1 \ln(\text{Volume}_t) \\ & + b_2 \ln(\text{Volatility}_t) \\ & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\ & + b_4 \ln(\text{ElectronicVolatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t \end{aligned} \quad (10)$$

$$\begin{aligned} \hat{h}_t = & b_0 + b_1 \ln(\text{Volume}_t) \\ & + b_2 \ln(\text{Volatility}_t) \\ & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\ & + b_4 \ln(\text{ElectronicVolatility}_t) \\ & + \text{Weekdaydummies} + \varepsilon_t \end{aligned} \quad (11)$$

where $D_Elect \times \ln(\text{Volatility})$ and $\ln(\text{Electronic Volatility})$ are the volatilities obtained for September 2003 to 2006 and are zero, otherwise. The models in (10) and (11) allow us to determine the direct factor between these two variables that affects the size and volatility of spread in open outcry markets when electronic markets exist. If the information asymmetry in electronic markets is the direct factor that affects the size and volatility of spread in open outcry markets, then the coefficients b_4 are expected to be larger than b_3 .

DATA

We employ open outcry and electronic market futures contracts on the 10-year US Treasury notes and the 30-year US Treasury bonds from the CBOT for our analysis of the effect of electronic markets on open outcry markets. The data set provides each price traded during the day, with the associated buy and sell volumes for four types of traders.³⁷ The large majority of volume involves local market makers (CTI1) and off-the-floor traders (CTI4). The open outcry

data available are from 1995 to 2006, with the electronic market data from September 2003 to December 2006. Interest rate futures were the most actively traded futures contracts on the CBOT during this time period. The near-by expirations are the most active contracts until one to two weeks before their expiration. As expiration nears, the deferred contracts become more active. We switch to the first deferred contract when this contract has a consistently larger daily volume.

Table 1 shows the annual total open outcry and electronic trading volume by year for the data employed in this study. The electronic market data appear in parenthesis. Table 1 shows that trading volume (liquidity) in the open outcry markets decreases substantially for recent years, since substantial volume moved to the electronic markets. The decrease in open outcry volume is particularly evident since the CBOT and the CME initiated their common clearing link in 2003. Table 1 also confirms that the measure of information asymmetry (volatility relative to volume) increases remarkably since the electronic markets were introduced. The volatility as computed by (A7) actually declines due to the decreases in transactions in the open outcry market. However, the volatility per volume as the measure of information asymmetry increases as the rate of decrease in volume is higher relative to volatility.

RESULTS

Univariate results on the impact of decrease in liquidity on bid-ask spread

Previous studies on the quality of pricing focus on same period comparisons between open

Table 1: Trend of volume and volatility

<i>Year</i>	<i>Annual volume</i>	<i>Daily Volatility (A)</i>	<i>Daily Volume (B)</i>	<i>Volatility to volume (A)/(B) × 100</i>	<i>Daily log volatility (C)</i>	<i>Daily log volume (D)</i>	<i>Volatility to volume (C)/(D)</i>
<i>Panel A: 10-year T-notes</i>							
1995	16 046 867	190.28	128 375	0.15	5.16	11.66	0.44
1996	15 751 665	186.30	125 013	0.15	5.13	11.64	0.44
1997	17 423 762	157.45	139 390	0.11	4.96	11.74	0.42
1998	23 256 858	167.15	186 055	0.09	4.98	12.02	0.41
1999	22 303 538	159.57	177 717	0.09	4.97	12.00	0.41
2000	41 213 860	148.91	328 397	0.05	4.90	12.54	0.39
2001	54 867 313	182.89	440 701	0.04	5.10	12.89	0.40
2002	18 013 420	195.49	144 107	0.14	5.21	11.79	0.44
2003	10 514 626 (39 672 332)	216.94	84 117	0.26	5.31	11.27	0.47
2004	5 631 739 (153 255 871)	163.91	45 054	0.36	4.98	10.61	0.47
2005	3 112 115 (168 468 875)	131.70	24 897	0.53	4.80	10.02	0.48
2006	2 188 710 (199 844 468)	109.21	17 499	0.62	4.61	9.64	0.48
<i>Panel B: 30-year T-bonds</i>							
1995	73 422 758	277.25	587 382	0.05	5.54	13.19	0.42
1996	72 145 174	287.60	572 581	0.05	5.58	13.17	0.42
1997	87 507 507	249.94	700 060	0.04	5.43	13.36	0.41
1998	95 512 353	275.21	764 099	0.04	5.53	13.44	0.41
1999	71 226 147	258.22	567 539	0.05	5.46	13.15	0.42
2000	61 521 992	238.79	490 215	0.05	5.40	12.90	0.42
2001	59 715 985	276.88	479 646	0.06	5.55	12.94	0.43
2002	13 328 589	299.01	106 629	0.28	5.64	11.50	0.49
2003	6 244 158 (14 751 866)	342.40	49 953	0.69	5.77	10.75	0.54
2004	2 903 421 (53 938 286)	262.66	23 227	1.13	5.46	9.94	0.55
2005	1 690 774 (69 164 371)	225.42	13 526	1.67	5.34	9.40	0.57
2006	1 254 729 (73 568 551)	187.27	10 038	1.87	5.16	9.09	0.57

This table reports the annual total volume, the averages of daily logged and unlogged volume and volatility. The values in parenthesis are the annual total volume for the electronic markets. Electronic data start in September 2003. The daily return volatility is computed by (A7). We compute the proxy of information asymmetry as denoted by ‘volatility to volume’ with the daily volume and volatility values.

outcry and electronic markets.³⁸ Consistent with these studies, we show that bid-ask spreads are lower in electronic markets than in open outcry markets. Importantly, Table 2 shows that the average realized spread of market makers

in electronic markets is less than the spread in the equivalent open outcry market by 3.99 and 8.32 points, respectively, as shown in Panel B (‘Electronic – Open outcry After’). We conclude that the implicit transaction costs are lower

Table 2: Results of univariate analysis of the bid-ask spread

	10-year T-notes			30-year T-bonds		
	Mean	Std Dev	CV	Mean	Std Dev	CV
<i>Panel A: Mean, standard deviation and coefficient of variation of the daily realized half bid-ask spread</i>						
<i>Open outcry before</i>						
1995	1.37	3.65	2.66	1.64	1.43	0.87
1996	2.06	3.72	1.81	2.02	1.88	0.93
1997	1.84	3.66	1.99	1.88	1.48	0.79
1998	1.51	3.27	2.17	1.27	1.84	1.45
Mean	1.69	3.58	2.12	1.70	1.69	0.99
<i>Open outcry after</i>						
2003	7.80	18.40	2.36	7.24	19.59	2.71
2004	4.56	16.97	3.72	11.25	27.85	2.48
2005	5.86	16.13	2.75	11.06	25.43	2.30
2006	5.28	15.11	2.86	11.33	31.38	2.77
Mean	5.49	16.33	2.97	10.82	27.56	2.55
<i>Electronic</i>						
2003	2.50	5.10	2.04	2.60	5.85	2.25
2004	1.57	2.94	1.87	2.11	6.04	2.86
2005	1.45	2.82	1.94	3.29	7.20	2.19
2006	1.15	2.07	1.80	2.05	5.26	2.57
Mean	1.50	3.00	2.00	2.50	6.21	2.48

	10-year T-notes		30-year T-bonds	
	Mean	t-Value	Mean	t-Value
<i>Panel B: Results of the t-tests and F-tests</i>				
Electronic – Open outcry after	–3.99	–6.89***	–8.32	–8.43***
Electronic – Open outcry before	–0.19	–1.20	0.80	3.91***
Open outcry after – before	3.80	7.17***	9.12	10.45***
	Std Dev	F-value	Std Dev	F-value
Open outcry after – before	12.75	20.76***	25.86	265.10***
	CV	F-value	CV	F-value
Open outcry after – before	0.85	1.98***	1.56	5.91***

Panel A shows the mean, standard deviation (Std Dev) and coefficient of variation (CV) of the daily realized half bid-ask spread for the open outcry and electronic markets. The coefficient of variation is defined as the standard deviation divided by the mean. Panel B provides test results for the differences of the measures in Panel A using *t*-tests for the mean difference and folded *F*-tests for the standard deviation and coefficient of variation. We employ three samples: ‘open outcry before’ (from 1995 to 1998), ‘open outcry after’ (from September 2003 to 2006) and the ‘electronic’ trading sample (from September 2003 to 2006), where ‘before’ and ‘after’ stand for before and after the existence of electronic markets.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

in electronic markets than in open outcry markets for side-by-side trading of US interest rate futures markets. Table 2 also shows the

interesting finding that market makers’ realized spreads in electronic markets are not smaller than the spreads they previously earned in the

equivalent open outcry markets. The results in Panel B ('Electronic – Open outcry Before') show that the market makers' realized spreads in electronic markets are not statistically different for T-notes and are larger for T-bonds by 0.80 of a point compared to those in the open outcry markets before electronic markets traded. These empirical results are consistent with prior studies by Pagano and Roell,¹¹ Gramming *et al*¹² and Jain *et al*¹³ in that the risks of adverse selection and price discovery are higher in electronic markets. Although the volume in electronic markets became larger than that the previous volume of open outcry markets, the bid-ask spreads are not smaller than the spreads they previously earned in the open outcry format.

The remainder of this article provides new findings regarding how the quality of derivatives pricing in open outcry markets deteriorates dynamically when electronic markets are introduced and dominate the market liquidity. Table 2 and Figure 1 report the quality of pricing in open outcry markets, as measured by the mean, standard deviation and coefficient of variation of the bid-ask spread. These results show that all three statistics of the market makers' realized spreads in the open outcry markets increased substantially from before to during the period of electronic market trading. The numerical results in Panel B of Table 2 show that the market makers' open outcry spread increased by an average of 3.80 and 9.12 points for T-notes and T-bonds, respectively, from before to during electronic market trading. Meanwhile, the standard deviation of the bid-ask spread during electronic trading became significantly larger, as shown by the F-values of 20.76 and 265.10, respectively. Finally, the mean-adjusted volatility measure (the coefficient

Figure 1: Mean and standard deviation of estimated realized half bid-ask spread in open outcry markets.

Note: The figure shows the annual mean and standard deviation of the daily realized half bid-ask spread measures of market makers for the 10-year T-note and 30-year T-bond futures contracts. The daily realized half bid-ask spread is calculated based on equation (A5) in the Appendix.

of variation) significantly increased during electronic market trading compared to before such trading. These univariate results support our Hypotheses 1 and 2: the quality of the open outcry markets deteriorated during electronic market trading related to when only open outcry markets were available. The following section provides results with multivariate models.

The impact of decrease in liquidity on the quality of bid-ask spread

We provide the results of our multivariate analysis of examining the impact of decrease in liquidity on the quality of pricing in open outcry markets in Tables 3 and 4. Model 1 in Table 3 does not

include the dummy variable for electronic trading in order to examine the relation solely between the bid-ask spread and the independent variables of volume and return volatility. These results confirm the expected negative and positive relations of volume and volatility to the bid-ask

Table 3: Impacts of electronic trading on the bid-ask spread in open outcry markets

	10-year T-notes				30-year T-bonds			
	Model 1		Model 2		Model 1		Model 2	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	9.08	3.69***	8.78	3.59***	16.69	3.96***	16.36	3.89***
Volume	-1.82	-9.53***	-1.81	-9.53***	-2.54	-13.80***	-2.54	-13.82***
Volatility	2.85	6.56***	2.89	6.67***	3.80	5.12***	3.85	5.20***
D_Elect	—	—	3.21	5.30***	—	—	5.72	3.88***
Monday	0.30	0.50	0.55	0.92	-2.74	-2.79***	-2.45	-2.50**
Tuesday	1.75	3.09***	1.76	3.13***	-2.23	-2.38**	-2.23	-2.38**
Wednesday	0.64	1.13	0.56	1.00	-2.50	-2.67***	-2.58	-2.76***
Thursday	0.60	1.06	0.51	0.90	-3.22	-3.43***	-3.36	-3.59***
R-Square (%)	3.49	—	4.39	—	6.56	—	7.03	—
N	3002	—	3002	—	3003	—	3003	—

This table shows the estimation results for the regression model in (1). This regression model is formulated based on McNish and Woods.³⁴

$$\begin{aligned}
 BAS_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 \ln(\text{Volatility}_t) \\
 & + a_3 D_Elect \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{1}$$

BAS stands for the realized half bid-ask spread of the market makers in open outcry markets (see the appendix for the calculation procedure). *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable that takes the value one if the observations belong to years 2003–2006, and zero otherwise. *D_Elect* is orthogonalized due to high negative collinearity between the log of volume and *D_Elect*; the correlation coefficients between $\ln(\text{volume})$ and *D_Elect* are -0.704 and -0.890, respectively. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

spread, respectively.^{39,40} Model 2 includes the dummy variable for the existence of the electronic market, with the results showing that

the bid-ask spread in open outcry markets is directly and significantly related to the existence of electronic trading, that is $a_3 > 0$.⁴¹

Table 4: Impact of electronic trading on the bid-ask spread in open outcry markets from volume and volatility

	10-year T-notes				30-year T-bonds			
	Equation (2)		Equation (3)		Equation (2)		Equation (3)	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	-1.36	-0.44	-1.51	-0.49	4.34	0.85	2.72	0.53
Volume	-0.66	-2.34**	-0.59	-2.01**	-1.10	-2.82***	-0.80	-1.96**
D_Elect × Volume	0.30	5.43***			0.57	4.22***	—	—
Volatility	2.09	4.59***	1.92	4.14***	2.57	3.24***	2.16	2.65***
D_Elect × Volatility	—	—	0.65	5.59***	—	—	1.22	4.77***
Monday	0.52	0.88	0.54	0.92	-2.48	-2.53**	-2.42	-2.47**
Tuesday	1.75	3.11***	1.75	3.11***	-2.25	-2.40**	-2.24	-2.40**
Wednesday	0.55	0.56	0.55	0.98	-2.60	-2.79***	-2.61	-2.80***
Thursday	0.51	0.90	0.51	0.91	-3.37	-3.60***	-3.38	-3.61***
R-Square (%)	4.43	—	4.45	—	7.11	—	7.26	—
N	3002	—	2969	—	3003	—	3003	—

This table shows the estimation results for the regression models found in (2) and (3).

$$\begin{aligned}
 BAS_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 D_Elect \times \ln(\text{Volume}_t) \\
 & + a_3 \ln(\text{Volatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{2}$$

$$\begin{aligned}
 BAS_t = & b_0 + b_1 \ln(\text{Volume}_t) \\
 & + b_2 \ln(\text{Volatility}_t) \\
 & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon
 \end{aligned} \tag{3}$$

BAS stands for the realized half bid-ask spread of the market makers in open outcry markets. *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable which takes the value of one if the observations belong to years from 2003 to 2006, and zero otherwise. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent, respectively.

Table 4 further shows the impact of decrease in liquidity on the bid-ask spread by including in equations (2) and (3) separately the effects of volume and volatility during electronic market periods only. The expectation is that decreased trading volume in open outcry markets (as shown in Table 1) due to electronic markets means a decrease in liquidity competition from limit orders for markets makers in the open outcry market. Our results are consistent with this expectation, that is, that the reduced open outcry trading volume during electronic market trading ($D_Elect \times \ln(Volume)$) increases bid-ask spreads significantly ($a_2 > 0$).⁴² In addition, the results for equation (3) confirm that the adverse selection component of the bid-ask spread increases as the liquidity decreases in the open outcry markets, that is $b_3 > 0$. On the basis of these results for volume and volatility during electronic market trading periods, we accept Hypothesis 1.

Tables 5 and 6 examine the impact of electronic market trading on open outcry markets by measuring bid-ask stability in terms of the volatility of the bid-ask spread (market depth), where the volatility is the conditional variance of the bid-ask spread in open outcry markets obtained by the GARCH model given in (5). The results show that the volatilities of the bid-ask spreads in open outcry markets significantly increased during electronic trading, that is, $\beta_2 > 0$ in Table 5.⁴³

Table 6 further shows the impact of electronic trading on bid-ask spread volatility by examining the inclusion of variables restricted to volume and return volatility during the period of electronic trading. These results for equation (6) show that market makers change bid-ask spreads significantly because of reduced levels of volume liquidity, that is, $a_2 > 0$. In addition, the results for

equation (7) show that market makers change the bid-ask spreads to a greater degree as the risk of adverse selection (return volatility) increases, that is, $b_3 > 0$. These results confirm that the stability of open outcry bid-ask spreads significantly deteriorated because of the existence of electronic markets. Consequently, we accept Hypothesis 2. Overall, our results from these multivariate models support the univariate results that the quality of open outcry markets has decreased since electronic trading began.

The impact of price discovery in electronic markets on the open outcry bid-ask spread

Table 8 shows the results on whether the behaviors of informed traders in electronic markets result in the increased size (and volatility) of spread in open outcry markets. The results in Table 7 show that the volatility in electronic markets (Electronic Volatility) is not a significant determinant of the size of bid-ask spread in open outcry markets. The Electronic Volatility becomes insignificant when the volatility of open outcry market ($D_Elect \times Volatility$) is included in the model for both the T-notes and T-bonds. The results in Table 8 show that the volatility in electronic markets is a significant determinant of the volatility of bid-ask spread in open outcry markets. The Electronic Volatility remains significant even when the volatility of open outcry market ($D_Elect \times Volatility$) is included in the model for both the T-notes and T-bonds. However, the dominant determinant of the volatility of spread in open outcry markets is the volatility in open outcry markets rather than the volatility of open outcry markets, that is $b_3 > b_4$. In sum, price discovery in electronic markets does not directly affect the size of bid-ask spread

Table 5: Impact of electronic trading on the volatility of the bid-ask spread in open outcry markets

	10-year T-notes		30-year T-bonds	
	Coefficient	t-Value	Coefficient	t-Value
<i>Panel B: Mean model (Equation (4))</i>				
Intercept	15.89	7.75***	28.16	14.88***
Volatility	1.83	8.43***	1.15	6.69***
Volume	−1.90	−9.49***	−2.44	−12.55***
D_Elect	3.66	6.80***	8.83	11.01***
Monday	−0.36	−1.33	−1.11	−8.06***
Tuesday	−0.02	−0.09	−0.70	−5.24***
Wednesday	−0.43	−1.59	−0.61	−4.08***
Thursday	−0.15	−0.58	−0.67	−5.22***
<i>Panel B: Mean model (Equation (5))</i>				
ARCH0	0.18	7.78***	0.09	7.25***
ARCH1	0.03	11.97***	0.09	15.11***
GARCH1	0.96	304.69***	0.90	161.00***
D_Elect	2.97	5.97***	20.28	7.3***
R-Square (%)	3.81	—	6.07	—
N	3002	—	3003	—

This table shows the estimation results of the GARCH model developed in equations (4) and (5).

$$\begin{aligned}
 \text{Mean model : } BAS_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 \ln(\text{Volatility}_t) \\
 & + a_3 D_Elect \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{4}$$

$$\begin{aligned}
 \text{Variance model : } h_t = & \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 \\
 & + \beta_1 h_{t-1} + \beta_2 D_Elect_t
 \end{aligned} \tag{5}$$

BAS stands for the realized half bid-ask spread of market makers in open outcry markets. *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable which takes the value of one if the observations belong to years from 2003 to 2006, and zero otherwise. *D_Elect* in the mean model is orthogonalized due to high collinearity between log volume and *D_Elect*: the correlation coefficients between log volume and *D_Elect* are −0.704 and −0.890, respectively. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

Table 6: Impact of electronic trading on the volatility of the bid-ask spread in open outcry markets from volume and volatility

	10-year T-notes				30-year T-bonds			
	Equation (6)		Equation (7)		Equation (6)		Equation (7)	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	259.05	21.29***	271.79	22.26***	1456.95	18.62***	1431.06	18.36***
Volume	-22.49	-20.20***	-19.61	-17.06***	-116.87	-19.67***	-105.35	-16.92***
D_Elect × Volume	19.83	92.83***	—	—	49.77	24.09***	—	—
Volatility	6.44	3.62***	-2.95	-1.61	15.85	1.31	-6.76	-0.55
D_Elect × Volatility	—	—	42.39	91.66***	—	—	96.44	24.74***
Monday	-3.75	-1.62	-2.77	-1.18	-22.00	-1.47	-19.40	-1.30
Tuesday	-0.95	-0.43	-0.88	-0.40	-1.46	-0.10	-1.02	-0.07
Wednesday	0.63	0.29	0.68	0.31	-0.90	-0.06	-0.74	-0.05
Thursday	0.74	0.33	1.08	0.49	9.33	0.65	9.98	0.70
R-Square (%)	90.0	—	89.8	—	73.1	—	73.6	—
N	3002	—	3002	—	3003	—	3003	—

The table shows the estimation results from the regression models in (6) and (7).

$$\begin{aligned}
 \hat{h}_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 D_Elect \times \ln(\text{Volume}_t) \\
 & + a_3 \ln(\text{Volatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{6}$$

$$\begin{aligned}
 \hat{h}_t = & b_0 + b_1 \ln(\text{Volume}_t) \\
 & + b_2 \ln(\text{Volatility}_t) \\
 & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{7}$$

h_t stands for the conditional variance of the (average daily) realized half bid-ask spread of the market makers in open outcry markets, as obtained from equation (5). *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable which takes the value of one if the observations belong to years from 2003 to 2006, and zero otherwise. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

in open outcry markets but instabilizes the bid-ask spread in electronic market.

CONCLUSIONS

We provide the first empirical results on the quality of open outcry bid-ask pricing before versus after electronic markets dominate

liquidity for the side-by-side traded derivatives. We employ the bid-ask spread and its volatility as our measures of market quality. The size of the bid-ask spread created by market makers represents the transaction costs for customers and the volatility of the bid-ask spread reflects the market stability and market depth. Prices in deeply liquid markets change little in response to

Table 7: Impact of information asymmetry in electronic markets on the bid-ask spread in open outcry markets

	10-year T-notes				30-year T-bonds			
	Equation (8)		Equation (10)		Equation (8)		Equation (10)	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	3.69	1.13	0.31	0.09	11.31	2.19**	3.33	0.61
Volume	-1.28	-4.43***	-0.73	-2.38**	-2.04	-6.08***	-0.84	-1.96**
Volatility	2.59	5.82***	1.90	4.11***	3.57	4.75***	2.15	2.63***
D_Elect × Volatility			0.81	5.22***			1.26	4.43***
Electronic Volatility	0.31	2.51**	-0.24	-1.52	0.40	1.80*	-0.08	-0.32
Monday	0.45	0.76	0.48	0.80	-2.58	-2.62**	-2.44	-2.49**
Tuesday	1.78	3.14***	1.73	3.07***	-2.19	-2.34**	-2.25	-2.41**
Wednesday	0.63	1.11	0.54	0.96	-2.49	-2.66***	-2.62	-2.80***
Thursday	0.58	1.03	0.50	0.90	-3.23	-3.45***	-3.38	-3.62***
R-Square (%)	3002	—	3002	—	3003	—	3003	—
N	3.69	—	4.56	—	6.66	—	7.27	—

The table shows the estimation results from the regression models in (8) and (10).

$$\begin{aligned}
 BAS_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 \ln(\text{Volatility}_t) \\
 & + a_3 \ln(\text{ElectronicVolatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{8}$$

$$\begin{aligned}
 BAS_t = & b_0 + b_1 \ln(\text{Volume}_t) \\
 & + b_2 \ln(\text{Volatility}_t) \\
 & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\
 & + b_4 \ln(\text{ElectronicVolatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{10}$$

BAS stands for the realized half bid-ask spread of the market makers in open outcry markets. *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable which takes the value of one if the observations belong to years from 2003 to 2006, and zero otherwise. *Electronic Volatility* represents the daily return volatility in electronic markets. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

large volumes, that is, the deeper the market the less the bid-ask spread volatility.

Results show that the trading volume and liquidity in open outcry markets decrease significantly as electronic markets dominate liquidity. Accordingly, we find that the bid-ask spread and their volatilities in open outcry

markets increase substantially when electronic markets exist relative to before electronic trading started. Thus, the quality of open outcry markets deteriorated with the existence of electronic trading. Accordingly, the implicit trading costs for customers have increased significantly on open outcry markets. The

Table 8: Impact of information asymmetry in electronic markets on the volatility of the bid-ask spread in open outcry markets

	10-year T-notes				30-year T-bonds			
	Equation (9)		Equation (11)		Equation (9)		Equation (11)	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	255.04	16.17***	128.70	11.81***	1613.38	19.90***	1129.14	13.84***
Volume	-28.92	-20.77***	-8.38	-8.33***	-156.81	-29.81***	-84.17	-13.10***
Volatility	24.11	11.20***	-1.74	-1.14	83.68	7.11***	-2.49	-0.20
D_Elect × Volatility	—	—	30.24	59.35***	—	—	76.55	17.98***
Electronic Volatility	39.73	67.54***	19.22	36.42***	67.80	19.60***	39.00	10.66***
Monday	1.39	0.48	2.35	1.21	-16.91	-1.10	-8.76	-0.60
Tuesday	2.81	1.03	0.97	0.53	6.04	0.41	2.73	0.20
Wednesday	4.75	1.74*	1.52	0.82	8.86	0.60	1.44	0.10
Thursday	4.59	1.68*	1.63	0.88	20.52	1.40	11.40	0.82
R-Square (%)	3002	—	3002	—	3003	—	3003	—
N	8.47	—	9.30	—	7.18	—	7.45	—

The table shows the estimation results from the regression models in (9) and (11).

$$\begin{aligned}
 h_t = & a_0 + a_1 \ln(\text{Volume}_t) \\
 & + a_2 \ln(\text{Volatility}_t) \\
 & + a_3 \ln(\text{ElectronicVolatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{9}$$

$$\begin{aligned}
 h_t = & b_0 + b_1 \ln(\text{Volume}_t) \\
 & + b_2 \ln(\text{Volatility}_t) \\
 & + b_3 D_Elect \times \ln(\text{Volatility}_t) \\
 & + b_4 \ln(\text{ElectronicVolatility}_t) \\
 & + \text{Weekdaydummies} + \varepsilon_t
 \end{aligned} \tag{11}$$

h_t stands for the conditional variance of the (average daily) realized half bid-ask spread of the market makers in open outcry markets, as obtained from equation (5). *Volume* is the number of open outcry contracts traded in a day. *Volatility* is the daily return volatility in open outcry markets as in (A7). *D_Elect* is a dummy variable which takes the value of one if the observations belong to years from 2003 to 2006, and zero otherwise. *Electronic Volatility* represents the daily return volatility in electronic markets. Weekday dummy variables are employed for Monday, Tuesday, Wednesday and Thursday.

*, ** and *** represent statistical significance at the 10, 5 and 1 per cent levels, respectively.

reason for the increased bid-ask spread is that the market makers' costs of operation, their adverse selection risk (cost) and their inventory control costs all increase when liquidity decreases. With the increased risk of adverse selection and the decreased level of competition from retail limit orders, market makers cause bid-ask spreads to be more sensitive to

information asymmetry appearing in order flow. As a result, the volatility of the bid-ask spread increases, that is, market depth decreases. Furthermore, we find that price discovery in electronic markets instabilizes the bid-ask spread in electronic market, although it does not directly affect the size of bid-ask spread in open outcry markets.

We conclude that the quality of derivatives pricing in the US open outcry markets has deteriorated substantially from the existence of electronic trading.

REFERENCES AND NOTES

- For example, the Singapore Stock Exchange in 1989, the Vancouver Stock Exchange in 1989, the Marche a Terme International de France (MATIF) in 1999 and the Sydney Futures Exchange in 1999.
- Market participants use electronic trading systems in three different ways: side-by-side trading (parallel trading to open outcry), off-hours trading and exclusive electronic trading (for example, E-mini futures/options that only trade electronically). In side-by-side trading a trader chooses between open outcry trading and electronic trading systems during regular trading hours.
- Pagano and Röell,⁴ Massimb and Phelps⁵ and Pirrong⁶ point out that floor traders' observations of the bids and asks and trading activity can be used to infer valuable information about the motives for trade, and therefore help determine the size of volume, inventory control and the reduction of adverse selection risk.
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- See Martens,²⁰ Theissen,²¹ Hasbrouck,²² Tse and Zabolina,²³ Kurov and Lasser,⁸ and Tse *et al*²⁴.
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- 25 Refer to Naidu and Rozeff,¹⁵ Pirrong,⁶ Ferris *et al.*,¹⁶ Frino *et al.*,²⁶ Huang,²⁷ Ates and Wang,²⁸ Fung *et al.*²⁹ and Jain *et al.*¹³ Naidu and Rozeff¹⁵ investigate the quality of the market after the open outcry markets were fully converted to an electronic trading system on the Singapore Stock Exchange. Alternatively, Coppejans and Domowitz³⁰ and Ulibarri and Schatzberg³¹ have the opposite findings, that is they show that open outcry markets have lower bid-ask spreads than electronic markets. However, Coppejans and Domowitz's findings do not provide a direct comparison of the market quality between open outcry and electronic markets, since their electronic trading sample data are taken from off-hours trading rather than from side-by-side trading. Ulibarri and Schatzberg do employ a T-bond futures electronic trading sample; however, the sample only uses the first year of side-by-side trading, which was a period of very low electronic trading volume.
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- 34 McNish, T. and Wood, R. (1992) An analysis of intraday patterns in bid-ask spreads for NYSE stocks. *Journal of Finance* 47: 753–763.
- 35 French and Roll³⁶ note that price volatility is a direct measure of risk and an indirect measure of the level of information. Since information asymmetry gets larger as the rate of information arrival increases, the risk of adverse selection rises. However, the information asymmetry given a rate of information arrival decreases if trading volume is large, because trading volume dilutes information asymmetry. Therefore, volatility has to be conditioned on volume. This study uses the ratio of volatility to volume as the proxy of information asymmetry. This measure of information asymmetry is consistent with the idea inherent in the measure of liquidity (volume/volatility) in Naidu and Rozeff.¹⁵ The conditioning between volume and volatility is performed by including $\ln(\text{Volume})$ and $\ln(\text{Volatility})$ in the model. It is well known that the regression coefficient of independent variable captures the relation of the independent variable to the dependent variable conditioning on the other included independent variables.
- 36 French, K. and Roll, R. (1986) Stock return variances: The arrival of information and the reaction of traders. *Journal of Financial Economics* 17: 5–26.
- 37 The Commodity Futures Trading Commission (CFTC) distinguishes traders into four groups by customer trade indicator (CTI): market makers (CTI1), member floor brokers (CTI2), other floor traders (CTI3) and off-the-floor traders (CTI4).
- 38 Refer to Pirrong,⁶ Frino *et al.*,²⁶ Huang,²⁷ Fung *et al.*,²⁹ Jain *et al.*,¹³ Naidu and Rozeff¹⁵ and Ferris *et al.*¹⁶.
- 39 The negative coefficients for volume in Table 3 are consistent with the negative relation between the bid-ask spread and the competition of limit orders for market makers, as well as the effects of the dilution of information asymmetry in order flow. The positive coefficients for volatility are consistent with the positive relation between bid-ask spread and information asymmetry (proxied by the return volatility in (A3)). McNish and Woods³⁴ and George *et al.*⁴⁰ find equivalent results.
- 40 George, H., Wang, K., Yau, J. and Baptiste, T. (1997) Trading volume and transaction costs in futures markets. *Journal of Futures Markets* 17: 757–780.
- 41 The results in Table 3 and 4 show that the average spread is larger on Tuesday and Friday for T-notes and T-bonds, respectively. These results are consistent with the untabulated summary statistics on the spreads in weekdays. The average daily half realized spreads of weekdays from Monday to Friday are 2.76, 4.14, 2.95, 3.03 and 2.70 for T-notes and 4.83, 4.98, 4.99, 5.08 and 5.16 for T-bonds.

- 42 The value of $a_2 > 0$ is also consistent with increased fixed operational costs of market making, and increased inventory risk due to decreased liquidity in the open outcry markets. Market makers who trade frequently can spread their fixed costs of market making over more volume in liquid markets relative to less liquid markets. However, a market maker in a less liquid market cannot easily spread out inventory risk, since infrequent trading in the less liquid market reduces the opportunities to quickly lay off inventory imbalances.
- 43 Pirrong¹⁵ uses German Bund futures traded simultaneously on the LIFFE (open outcry) and DTB (electronically). He finds that the bid-ask spreads and their corresponding volatilities are less on the DTB than on LIFFE. The signs and magnitudes of estimated coefficients of weekday dummies for T-notes in Table 5 are different from those in Tables 3 and 4. These results occur due to the two main reasons: the GARCH model for Table 5 and the correlation of spread to volatility. The GARCH model incorporates the conditional volatility of the spread into the model. The conditional volatility of spread in the model takes some of the explanatory power from the coefficients of other variables. Meanwhile, the untabulated correlation coefficients show the negative relation of spread to volatility on Monday, Tuesday and Wednesday and the positive relation on Thursday and Friday. As a result of the aforementioned two reasons, when the volatility rises on Friday (results show that the volatility is highest on Friday), the spread also goes up on Friday and goes down in other weekdays. Consequently, as the GARCH model incorporates the conditional volatility of spread, the net spread for the weekday dummies is higher on Friday although the coefficients are not statistically significant.
- 44 Manaster, S. and Mann, S.C. (1996) Life in the pits: Competitive market making and inventory control. *Review of Financial Studies* 9: 953–975.
- 45 Berkowitz, S.A., Logue, D.E. and Noser, E.A. (1988) The total cost of transactions on the NYSE. *Journal of Finance* 43: 97–112.
- 46 Madhavan, A. (2002) VWAP strategies, in transaction performance. In: B.R. Bruce (ed.) *The Changing Face of Trading*. New York: Institutional Investor, pp. 32–38.
- 47 Manaster and Mann,⁴⁸ Locke and Sarajoti⁴⁹ and Choe *et al*⁵⁰ present similar measures of a good trade execution.
- 48 Locke, P.R. and Sarajoti, P. (2004) Interdealer trading in futures markets. *Journal of Futures Markets* 24: 923–944.
- 49 Choe, H., Kho, B.-C. and Stulz, R.M. (2005) Do domestic investors have an edge? The trading experience of foreign investors in Korea. *Review of Financial Studies* 18: 795–829.
- 50 Similarly, a positive (negative) sell return means that the majority volume of CTI1's sales occur at trade prices P_{it} higher (lower) than the naïve benchmark VWAP during day t .

APPENDIX

Determining the realized bid-ask spread using VWAP

This appendix develops the realized half bid-ask spread using the volume weighted average price (VWAP). Manaster and Mann⁴⁴ and Harris¹⁴ employ similar methods. We employ the VWAP as our benchmark for a naïve uninformed trader and from this benchmark develop the resultant measure of the bid-ask spread. Berkowitz *et al*⁴⁵ provide the theoretical justification for using the VWAP as the price that a naïve trader can expect to achieve. More importantly, practitioners use the VWAP to evaluate their performance (Madhavan⁴⁶). If a trader's buy (sell) prices are less than (greater than) the VWAP, then they are considered to possess good trading skills.

Following Berkowitz *et al*⁴⁵, we compute the VWAP as follows. Let V_t be the daily total volume. The daily volume for the CTI1 market makers (V_{1it}) at price level P_i is defined as the sum of the buy volumes (B_{1it}) and sell volumes (S_{1it}) for day t at price P_i for the CTI1 market makers (consequently, this volume is double the reported volume). The total daily volume (V_{1it}) at price level P_i is defined as the sum of the volumes for each CTI (V_{1it}) at P_i . Then the daily benchmark $VWAP_t$ for day t for all price levels i and for all trades made is defined as the following:

$$VWAP_t = \sum_i P_{it} \frac{V_{it}}{V_t} = \sum_i P_{it} v_{it},$$

$$\text{where } v_{it} = \frac{V_{it}}{V_t} \quad (A1)$$

The $VWAP_t$ represents the price level at which the weighted average transaction is made, with the percentage volume share v_{it} being the weighting factor. We define the difference between P_{it} and $VWAP_t$ as the return (r_{it}) relative to the benchmark $VWAP_t$ for the trades that occur at P_{it} as follows:

$$r_{it} = P_{it} - VWAP_t \quad (A2)$$

The daily buy return for the CTI1 market makers (r_{bt}) for day t is defined as^{47,44,48,49}:

$$r_{bt} = - \sum_i (P_{it} - VWAP_t) \left(\frac{B_{1it}}{B_{1t}} \right),$$

where $B_{1t} = \sum_i B_{1it}$ (A3)

where r_{bt} represents the return at which the weighted average buy transactions of CTI1 occur during day t , with a positive r_{bt} representing a relatively profitable return on the market maker's trading activities. Similarly, the daily sell return for the CTI1 market makers (r_{st}) is defined as

$$r_{st} = \sum_i (P_{it} - VWAP_t) \left(\frac{S_{1it}}{S_{1t}} \right),$$

where $S_{1t} = \sum_i S_{1it}$ (A4)

A positive (negative) buy return means that the majority volume of CTI1's purchases occur at trade prices P_{it} lower (higher) than the naïve benchmark VWAP during day t , and therefore the CTI1 market maker performance is superior (inferior) relative to the benchmark VWAP. Similarly for r_{st} .⁵⁰

The daily realized half bid-ask spread for market makers consequently is defined as the volume-weighted average of the buy and sell returns:

$$\begin{aligned} \text{Daily realized half bid - ask spread}_t & \\ & \equiv r_{bt} \left(\frac{B_{1t}}{V_{1t}} \right) + r_{st} \left(\frac{S_{1t}}{V_{1t}} \right) \\ & = \frac{S_t}{V_t} (SELL_t - VWAP_t) \\ & \quad + \frac{B_t}{V_t} (VWAP_t - BUY_t) \end{aligned} \quad (A5)$$

where $SELL_t = \sum_i P_{it} (S_{1it}/S_{1t})$ and $BUY_t = \sum_i P_{it} (B_{1it}/B_{1t})$. Since market makers close their positions at the end of each day, mismatching buy and sell volumes are not an issue. Thus, under the condition that $S_{1t} = B_{1t} = 0.5 V_{1t}$ (A5) takes the same form as (A6):

$$\begin{aligned} \text{Daily realized half bid - ask spread}_t & \\ & = \frac{1}{2} (SELL_t - BUY_t) \end{aligned} \quad (A6)$$

The standard deviation of r_{it} at day t is employed as the measure of the daily volatility of returns in this study:

$$\begin{aligned} \sigma_t & = \sqrt{\sum_i (r_{it} - r_{VWAP_t})^2 v_{it}} \\ & = \sqrt{\sum_i (P_{it} - VWAP_t)^2 v_{it}} \end{aligned} \quad (A7)$$

where $r_{VWAP_t} = VWAP_t - VWAP_t$ is the return of a naïve trader, which is zero.