TRANSACTION COSTS AND MARKET QUALITY: OPEN OUTCRY VERSUS ELECTRONIC TRADING

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On May 10, 1999, the London International Financial Futures and Options Exchange (LIFFE) transferred trading in the Financial Times Stock Exchange (FTSE) 100 Index futures contracts from outcry to LIFFE CONNECT, its electronic trading system. We find lower spreads in the electronic market after the transition. However, the open outcry mechanism has higher market quality (or smaller variance of the pricing error) on the basis of Hasbrouck's (1993) model. Furthermore, employing the Hasbrouck (1991) model, we show that trades in the open outcry market have higher information content. Inventory control considerations also affect the electronic market more than the open outcry market. The over-

The authors thank Robert I. Webb (the editor), two anonymous referees, Erik deVos, Upinder Dhillon, Lisa Flynn, and Frank Samuel for their valuable comments. All errors are the responsibility of the authors. They are grateful to the London International Financial Futures and Options Exchange (LIFFE) for providing the tick data and detailed information of LIFFE CONNECT. This research was financially supported by a summer grant of the School of Management and a minigrant of the Office of Research and Sponsored Programs at Binghamton University.
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Received May 2000; *Accepted January* 2001

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The Journal of Futures Markets, Vol. 21, No. 8, 713–735 (2001)

all results suggest that electronic trading should complement, but not replace, open outcry in futures markets.
Jrl Fut Mark 21: 713–735, 2001

INTRODUCTION

As the number of exchanges worldwide using electronic systems in trading options and futures sharply increased in the 1990s, the London International Financial Futures and Options Exchange (LIFFE) decided to follow suit. On April 12, 1999, it began the rollout schedule for the migration of futures contracts to LIFFE CONNECT, its state-of-the-art electronic order matching system. According to the LIFFE ("LIFFE's platform," 1999), transfer from open outcry to electronic trading was accompanied by an increase of 37% in the trading volume. On May 10, 1999, trading in the Financial Times Stock Exchange (FTSE) 100 Index futures contracts was moved to LIFFE CONNECT.

Although many traders consider the implementation of CONNECT a big success of the LIFFE, there are numerous advocates of open outcry trading in the futures markets. They argue that electronic trading neither possesses the necessary speed and flexibility to execute the complex trading strategies used with futures contracts nor provides liquidity as effectively as open outcry. They also point out that electronic trading does not perform well during times of high volatility.

Earlier studies have used the bid–ask spread as a benchmark for comparison with observable trading prices (e.g., Blennerhassett & Bowman, 1998; Frino, McInish, & Toner, 1998; Pirrong, 1996). This spread is also an approximation of transaction costs; lowering such costs may attract volume to the electronic markets. These studies report lower spreads for the electronic trading system.

Many comparative studies of market performance and regulatory impact also base their analyses on the posted bid–ask spread. However, Hasbrouck (1993) and Grossman and Miller (1988) pointed out problems associated with using the bid–ask spread as the measure of market quality. They indicated that the quoted spread is twice the transaction cost for a market-order trader under numerous restrictive assumptions, including the absence of asymmetric information. Relaxing those assumptions will prevent us from measuring the costs accurately even with an effective spread (an actual return the marketmaker receives from the separated trades on ask and bid sides of the spread).

This article compares the trading costs and market quality for the FTSE 100 Index futures contracts on the LIFFE before and after the transition to the screen trading mechanism. We consider two 3-month periods: February to April 1999 for open outcry trading and June to August 1999 for electronic trading. We attempt to determine which mechanism is more efficient for trading futures contracts by comparing the daily median time-weighted spreads and market quality of Hasbrouck (1993). He proposed that the market price of an asset could be decomposed into a random-walk component and a transient component. It is natural to interpret the random-walk component as the efficient price. Under the assumption of a semistrong form of market efficiency, an innovation to random walk reflects all possible newly released public information. The transient component (or the pricing error) represents implied transaction costs in the form of a discrepancy between the true value of an asset and the price the investor pays.

The model assumes that at any given moment, deviation from the true value is transient, and the market price reverts to the efficient price over time. Thus, if the deviations of the market price from the efficient price are large and/or last for a considerable time, the variance of the pricing error will be high. A lower variance of the pricing error implies greater pricing efficiency and higher market quality.

We further use the model of Hasbrouck (1991) to investigate differences in the information content of trades in the two markets. The two Hasbrouck models share similar assumptions and frameworks, but their foci are different. Although the market quality model uses trade prices, the information content model employs revisions of the bid–ask midquotes in response to trades.

Our results indicate that the median bid–ask spread is lower in LIFFE CONNECT. However, the open outcry market for the FTSE 100 Index futures contracts has higher quality (with a lower variance of the pricing error) than CONNECT. This supports the argument that the spread is not an accurate measure for pricing efficiency. The higher quality of the open outcry market is explained by the speed of floor trading and the ease of adjusting the terms of trade. The electronic market slows down the impounding of information into prices, especially in periods of intensive information arrival. We find a higher degree of information content of trades in the open outcry market and higher inventory costs in the electronic market.

RELATED RESEARCH ON MARKET QUALITY

In an attempt to distinguish between the two trading mechanisms, researchers use various concepts of market quality. One of the earliest articles on this subject (Grünbichler, Longstaff, & Schwartz, 1993) found that futures prices on the electronic market [Deutsche Terminborse (DTB)] of the German stock index Deutscher Aktienindex (DAX) lead prices of the floor traded index. However, Grünbichler et al. compared not only two trading mechanisms but also two different products: cash index and index futures. Therefore, their evidence could be biased by the tendency of the futures markets to lead the cash index markets even when both are floor-traded (Chan, 1992).

Another approach to market quality is investigating liquidity and the bid–ask spread as a proxy. The bid–ask spread is commonly called the *price for immediacy*. Pirrong (1996) documented that the spreads of Bund futures in the electronic market (DTB) are not greater than those in the open outcry market (LIFFE). Moreover, Pirrong found that price movements on the DTB exhibit less bid–ask bounce and, therefore, are more informative. This result is consistent with Blennerhassett and Bowman (1998) and Frino et al. (1998), who found that spreads in the electronic markets are lower than those in the open outcry system, if market activity is controlled for. However, this contradicts earlier findings of Shyy and Lee (1995) that the spread is greater on the electronic market.

The quoted spread correctly reflects the marketmaker profit only when a marketmaker simultaneously fills two orders at the two sides of the spread. However, the quoted spread may not be considered a cost for the counterparties of the marketmaker in these transactions. More often, transactions on the opposite sides of the spread are separated in time, and the marketmaker profit becomes a so-called effective spread. However, a seller is only concerned about the bid side of the spread and faces a choice between the market and limit orders; therefore, the effective spread does not correctly approximate the price for immediacy. As Grossman and Miller (1988) pointed out, a customer's choice between limit orders and market orders is thus determined not by the spread but by the likelihood that a buyer will arrive who is willing to pay more than the current bid.

A market is considered liquid only if an asset can be easily traded there at a price close enough to the efficient price approximated by the midquote of the bid and offered prices. However, market imperfections cause market price deviations from the efficient price. Thus, a small spread does not mean that the market price is close to the efficient price. Moreover, narrow spreads do not imply market depth (i.e., substantial volume can be traded at the quoted prices). If the quoted prices are inefficient, traders will not be willing to trade large volumes. In this case, the spreads may rapidly widen as depth at the narrower spreads vanishes. Order withdrawal procedures, coupled with information asymmetry, may cause depth in the electronic markets to be smaller. The small capacity of scalpers, who trade on their own accounts and provide liquidity in the open outcry markets, may also cause depth to shrink there (Pirrong, 1996).

An alternative measure of market quality is the overall volatility of the market price (see, among many others, Dhillon, Lasser, & Watanabe, 1997). However, this measure may not be useful in these circumstances because volatility has different implications for the open outcry and electronic markets.

The pits of the open outcry exchange are characterized by the activity of very short-horizon uninformed speculators trading for their own accounts: scalpers. According to the model of Grossman and Miller (1988), scalpers' profits increase with their inventory positions and returns volatility. The model also implies that, in a competitive open outcry market, marketmakers reduce risk by diversifying it across many marketmakers. Consistent with the model of Admati and Pfleiderer (1988), the number of scalpers on the floor increases at times of high volatility. They are willing to absorb large trading volumes and assume the inventory risk. Thus, investors may benefit from the increased liquidity of the open outcry market under higher volatility.

In contrast, Martens (1998) and Frino et al. (1998) showed that the electronic market pricing efficiency and liquidity deteriorate in volatile periods. The difficulty of order withdrawal from the electronic order book causes marketmakers to charge a higher price for their services (Copeland & Galai, 1983) and providers of limit orders to post smaller orders in fear of being picked out by informed traders. This causes the market depth to shrink and the spreads to widen in electronic markets during volatile periods.

Hasbrouck Models of Market Quality and Information of Trades

The Hasbrouck (1993) model considers pricing error as a measure of the implicit transaction costs that traders pay over the true price of an asset. The market price is closer to the equilibrium price in markets with greater quality than in markets with lesser quality. Hasbrouck defined the measure of overall market quality as the variance of the pricing error, with lower variance implying a market of higher quality and greater pricing efficiency.

The overall market quality of Hasbrouck (1993) provides information on proximity of the market price to the efficient price, avoids problems of imperfect or spurious information transmission, and reflects concepts of liquidity and market depth. Thus, the overall market quality is a better measure than the bid–ask spread for evaluating the pricing efficiency of different trading mechanisms.

Hasbrouck (1993) decomposes the price of a security into a random-walk component and a residual stationary component:

$$p_t = m_t + s_t \tag{1}$$

The random-walk component, $m_t = m_{t-1} + w_t$, is considered the efficient price. The innovation of the serially uncorrelated increment, w_t, captures all public information released between time $t - 1$ and t. The pricing error, s_t, embodies microstructure imperfections and can be viewed as the implicit cost of the trade. It measures costs paid over the efficient price. The transaction price, p_t, is allowed to deviate from the efficient price, but these deviations are transient; that is, the market price reverts to the efficient price over time.

The model provides a framework for joint price change and trade dynamics. The trades are allowed to be endogenous; they are related to the previous price changes and trades. Price changes and trading volume are influenced by the inventory control mechanisms, discrete prices, lagged price adjustments, and price smoothing requirements imposed by the exchange.[1]

Therefore, the joint dynamics are represented in the vector autoregression (VAR) form:

$$\Delta p_t = a_1 \Delta p_{t-1} + a_2 \Delta p_{t-2} + \cdots + b_1 x_{t-1} + b_2 x_{t-2} + \cdots + e_{1,t} \tag{2a}$$

$$x_t = c_1 \Delta p_{t-1} + c_2 \Delta p_{t-2} + \cdots + d_1 x_{t-1} + d_2 x_{t-2} + \cdots + e_{2,t}, \tag{2b}$$

where $\Delta p_t = \log(p_t/p_{t-1})$ is the log price change; x_t is a trade indicator variable ($+1$ for a buy order and -1 for a sell order); and $e_{1,t}$ and $e_{2,t}$ are random disturbances with a covariance matrix, Cov(e).

Model 2 can be represented in the vector moving average form:

$$\Delta p_t = \alpha_0^* e_{1,t} + \alpha_1^* e_{1,t-1} + \cdots + \beta_0^* e_{2,t} + \beta_1^* e_{2,t-1} + \cdots + \beta_k^* e_{2,t-k} + \cdots \tag{3a}$$

$$x_t = \gamma_0^* e_{1,t} + \gamma_1^* e_{1,t-1} + \cdots + \delta_0^* e_{2,t} + \delta_1^* e_{2,t-1} + \cdots + \delta_k^* e_{2,t-k} + \cdots \tag{3b}$$

[1]The aversion of a marketmaker to the risk of carrying unbalanced inventory may result in a negative autocorrelation in the quote revisions and a positive serial correlation between the trades and lagged quote revisions. Lagged price adjustment and mandatory price smoothing may cause a positive autocorrelation in the trades and a positive serial correlation between the quote revisions and lagged trades.

Beveridge and Nelson (1981) gave the following decomposition:

$$p_t = m_t + s_t \tag{4}$$

$$m_t = m_{t-1} + \sum_{j=0}^{\infty} \alpha_j^* e_{1,t} + \sum_{j=0}^{\infty} \beta_j^* e_{2,t} \tag{5}$$

$$s_t = \sum_{k=0}^{\infty} \alpha_k e_{1,t-k} + \sum_{k=0}^{\infty} \beta_k e_{2,t-k} \tag{6}$$

$$\alpha_k = -\sum_{j=k+1}^{\infty} \alpha_j^* \quad \text{and} \quad \beta_k = -\sum_{j=k+1}^{\infty} \beta_j^* \tag{7}$$

Market quality is defined as

$$\sigma_s^2 = \sum_{k=0}^{\infty} (\alpha_k\, \beta_k)\ \mathrm{Cov}(e) \begin{pmatrix} \alpha_k \\ \beta_k \end{pmatrix} \tag{8}$$

It is clear from Equation 6 that s_t is determined by the price effects of shocks one, two, or more periods after these shocks occur. We also notice that coefficients α_j^* and β_j^* reflect the permanent effect of the shocks on the price, that is, innovation to the efficient price. Thus, Equation 6 suggests that the implication of the news to the equilibrium price is not completely recognized by the market at the instant the news is released. This lagged adjustment produces the pricing error.

The market quality model of Hasbrouck (1993) and the information content of the trades model of Hasbrouck (1991) share a similar VAR framework. However, their purposes are different. The model of market quality employs the actual trade prices, which allow it to measure the total departure of the market price from the efficient price. In Hasbrouck (1991), changes in the midpoint of quoted prices, r_t, reflect a marketmaker's reaction to trades caused by the information content of trades and the inventory control. The model assumes contemporaneous causality running from trades to quote revisions.[2]

The same market microstructure imperfections, as in the market quality model, underlie the VAR model:

$$r_t = a_1 r_{t-1} + a_2 r_{t-2} + \cdots + b_0 x_t + b_1 x_{t-1} + \cdots + v_{1,t} \tag{9a}$$

$$x_t = c_1 r_{t-1} + c_2 r_{t-2} + \cdots + d_1 x_{t-1} + \cdots + v_{2,t}, \tag{9b}$$

where $r_t = \log[(q_t^b + q_t^a)/(q_{t-1}^b + q_{t-1}^a)]$ and q_t^b and q_t^a are the posted bid and ask quotes at time t, respectively. The same microstructure

[2]That is, a marketmaker revises the quotes as a result of the contemporaneous trade and arrival of public information that occurs between the trade order and quote revision.

imperfections that drive Equation 9 disturb the dichotomy that attributes all public information to $v_{1,t}$ and all private information to $v_{2,t}$. We are especially interested in interpreting the coefficients in Equation 9 that relate to the information content or asymmetry of trades and inventory costs.

Coefficient b_0 represents immediate quote midpoint revision in response to a trade. If b_0 is positive and significant, the quote midpoint is immediately increased as a buy order is submitted. The higher the information content of the trade is, the more the marketmaker will revise his or her estimation of the true price upward. Similarly, the quote midpoint is revised downward immediately subsequent to a sell order.

Inventory control considerations of marketmakers are reflected by the coefficients c_i in Equation 9. The negative relation between trades and lagged quote revisions indicates that a marketmaker with an inventory surplus (shortage) would reduce (increase) his or her quotes to elicit more purchases (sales). Therefore, negative values of c_i are consistent with inventory control effects. Positive values of d_i indicate trade persistence, or lagged adjustment to information. However, the effect of inventory control affects these coefficients in the opposite direction. Positive signs of d_i indicate that the effect of lagged adjustment to information prevails.

LIFFE AND LIFFE CONNECT: INSTITUTIONAL DETAILS AND LIQUIDITY

Many earlier studies of differences in trading mechanisms examined the same or closely related assets traded in geographically separated markets (e.g., the DTB and LIFFE Bund futures contracts). Geographical separation, imperfect signal extracting (King & Wadhwani, 1990), home or institutional bias (Huberman, 1997; Tesar & Werner, 1995; Tse, 1999c), and other factors may contaminate conclusions concerning efficiency and quality in these markets.

The FTSE 100 Index futures contracts migrated from the open outcry market (LIFFE) to the electronic market (LIFFE CONNECT) on May 10, 1999. Unlike previous studies, this research considers the same market (and product) operating under two trading mechanisms in two subsequent periods: 3 months before the transition (February to April 1999) and 3 months after the transition (June to August 1999). Our setting assumes that the open outcry and electronic markets have the same underlying efficient price (evolving from the floor trading period to the electronic trading period). For brevity, we refer to the open outcry trading period as P1 and the electronic trading period as Q1. London time is used throughout the article.

Floor Trading on the LIFFE in P1 (February to April 1999)

Floor trading in the FTSE 100 Index futures contracts was conducted from 8:35 a.m. to 4:30 p.m. for P1.[3] On the LIFFE, all bids and offers must be announced to the floor before the execution of a trade (see LIFFE Trading Rules 4.10.3 and 4.11.1). A trader can only cry out his quote if it is better than the best current quote on the floor. Thus, all the quoted spreads are also the inside spreads. Scalpers, who provide liquidity through active intraday trading, take positions on both sides of the spread almost simultaneously and, on average, maintain zero inventory balance. As a result, their quoted spreads closely approximate effective spreads. Trading on the open outcry market is not anonymous; the names and behavior of all traders can be observed on the floor. If a trader finds a bid (ask) attractive, he or she simply hits (takes) the price. He or she can also choose with whom to trade when there are several traders with the same bid or ask price.

Trading on LIFFE CONNECT in Q1 (June to August 1999)

At the heart of LIFFE CONNECT is the LIFFE Trading Host, where orders are received and matched. The electronic market consists of the terminals connected to the host. Trading will take place through the submission of orders into the LIFFE CONNECT central order book, which contains all the orders posted in the system. The system is similar to a continuous auction system with automatic order matching in the central order book. "Trading Anonymity is a key aspect of the LIFFE CONNECT market. Traders in the market will not be aware of whose orders they are viewing or trading against, either before or after a trade" ("How the Market Works," 2000, p. 22). The criteria for determining trade priority follow the price and time priority. This ensures that no trade can occur at a price lower than the lowest ask or higher than the highest bid.

Version 2.0 of LIFFE CONNECT for Financial Futures (LCFF2.0) was released on April 12, 1999. The trading day in the FTSE 100 Index

[3]From 14:46 to 6:00 p.m., floor trading is complemented by automated pit trading (APT). We do not consider trades made through APT. As Martens (1998) and Tse (1999a) pointed out, there is a considerable drop in volume during APT. Moreover, the LSE is closed during APT.

futures contracts on LCFF starts at 6:00 a.m. From 6:00 a.m. to 7:15 a.m., traders are allowed to log on to the electronic system and place their orders. In the preopen period (7:15 a.m. to 8:00 a.m.), traders can only submit limit orders and good till cancelled (GTC) orders. Traders are also able to revise orders, submit them, pull them, and so forth. Orders are matched during the market trading period (8:00 a.m. to 4:30 p.m.). At the start of the market trading period, the system calculates the prices for each type of contract at which the maximum number will be traded. During the market trading period, LCFF operates in the style of a continuous auction. The clearing house monitors market activity throughout the day to ensure that the settlement prices fairly reflect the market. After 5:30 p.m., all trade ceases and new orders are not accepted.

Traders on LCFF share access to the electronic order book that allows them to observe the active, pulled, or cancelled orders, market depth,[4] and order event history and to activate or stop market or limit orders. The electronic order book is automatically updated after each order matching, change or cancellation, and GTC expiration. A quote is valid until it is explicitly withdrawn from the system. The order book assists traders in effective management of their inventory and is especially useful in quiet markets, when market information is not easily attainable. Nevertheless, as Martens (1998) pointed out, when the market is volatile, the disadvantage of the order book lies in its slackness of changing prices involving order revisions or new order submissions.

Although the LIFFE claims that LCFF simply automates open outcry, the nature of liquidity supply on LCFF differs from the one in an open outcry market. In particular, as Pirrong (1996) contended, scalpers are the primary suppliers of liquidity in the open outcry markets but not on the automated exchanges. He contrasts costs of becoming a member of an automated exchange with those associated with an open outcry exchange.[5] Costs of entering an automated exchange are prohibitive for scalpers, individuals with relatively low personal capital. If scalpers are squeezed out of an automated exchange, it may lack liquidity.

[4]However, requests for providing full depth are subject to strict limits to prevent degradation of the system.

[5]Pirrong (1996) wrote: "Small local traders are relatively unimportant suppliers of liquidity on automated exchanges due to the structure of the costs incurred to participate in a computerized trading system. Computerized systems require a substantial investment in computer equipment and market analytics. Moreover, most computerized systems charge relatively high fixed fees for the rental of terminals or communication lines. . . . Also, the fixed fees paid to enter an automated market in these ways are largely unrecoverable. This limits the pool of potential locals" (p. 521).

LCFF has designated marketmakers who are obligated to have bid and ask quotes posted during normal trading hours. However, like other traders, marketmakers submit orders to the central order book, and they must abide by the trading anonymity, automatic matching, and price and time trading priority in the order book described previously.[6] Therefore, marketmakers in the LCFF face more severe information asymmetry than scalpers in the face-to-face open outcry market.

Unlike marketmakers in the LCFF, scalpers are attracted to the floor by high volatility. The reason is that they can diversify risk when there are many traders on the floor (see Tse, 1999a). More importantly, quotes are valid only when the "breath is warm" and a simple hand signal can change the quote or order. Thus, during volatile trading hours, liquidity is impaired in the LCFF (because of its slackness of changing prices) but not in the open outcry market.

DATA

The transaction data provided by the LIFFE contain every bid, ask, and trade price stamped to the second. A trade is considered a buy (sell) order when its price matches the prevailing ask (bid) quote. We use the most liquid nearest contracts on the FTSE 100 Index for the two 3-month periods. Stocks constituting the FTSE 100 Index are traded on the London Stock Exchange (LSE). A considerable amount of arbitrage is usually conducted between the spot and futures markets. Therefore, we focus on the trading hours of the LSE, 9 a.m. to 4:30 p.m., to preserve the amount of information transmitted through the arbitrage between these two markets under both trading mechanisms on the LIFFE (see also Chang, Jain, & Locke, 1995; Tse, 1999b).

Table I summarizes the market statistics of the P1 and Q1 periods. There are 61 and 65 trading days in P1 and Q1, respectively. Although average daily trading volumes are similar in the P1 and Q1 periods, the number of trades for the periods of electronic trading is more than three times that for the open outcry period. These results show that the average trade size on the electronic market is smaller. Indeed, the size of 45.8% of the Q1 trades is one contract, the size of 20.8% of the trades is two contracts, and the size of 8.3% of the trades is three contracts. Martens (1998) argued that the adverse selection problem is severe in anonymous electronic trading. Therefore, traders will reduce

[6]If a marketmaker does not wish to trade on one or both sides of the market, he or she can easily do so by posting an unattractive quote.

TABLE I
Market Statistics

	Open Outcry	*Electronic Trading*
Number of trading days	61	65
Daily trading volume (10e3)	34.1	34.0
Daily open interest (10e3)	19.9	20.5
Daily number of trades (10e3)	17.4	52.5
Variance of daily price changes	0.270	0.281

Note. This table summarizes the market statistics for the periods of open outcry (P1, February to April 1999) and electronic trading (Q1, June to August 1999).

their trade sizes or shorten the average time span for the display of an order in the order book. Because the LIFFE data do not provide transaction volumes in the P1 period, we cannot obtain detailed information of the trade size.

EMPIRICAL RESULTS

Testing for Structural Change

The assumption that the efficient price is the same in the two periods is crucial to our analysis. To ensure that there is no structural change, we conduct a series of Chow tests. First, the tests do not reject the null hypothesis of no structural change in daily price changes of the FTSE 100 between the two periods with a p value of 0.99; that is, there is no structural change. Second, we break period Q1 into two subperiods, June and July to August. We conduct the tests between (1) P1 and June and (2) June and July to August. Neither of the two rejects the null of no structural change, with p values of 0.37 and 0.82, respectively.

We also follow Taylor, van Dijk, Franses, and Lucas (2000, p. 1296) closely to confirm that the subsequent analysis is not sensitive to the particular sample periods used. We test the null hypothesis that the standard deviations of daily price changes are the same in each period by comparing the ratio of sample standard deviations in P1 and Q1. The ratio is 0.98 and is not significantly different from one, suggesting that the daily price changes are equally volatile over the two periods.

Finally, we searched *The Wall Street Journal* and *The Economist*. We found no event that could likely induce structural change. A graph of daily price changes (not reported) also indicated that no significant change occurred.

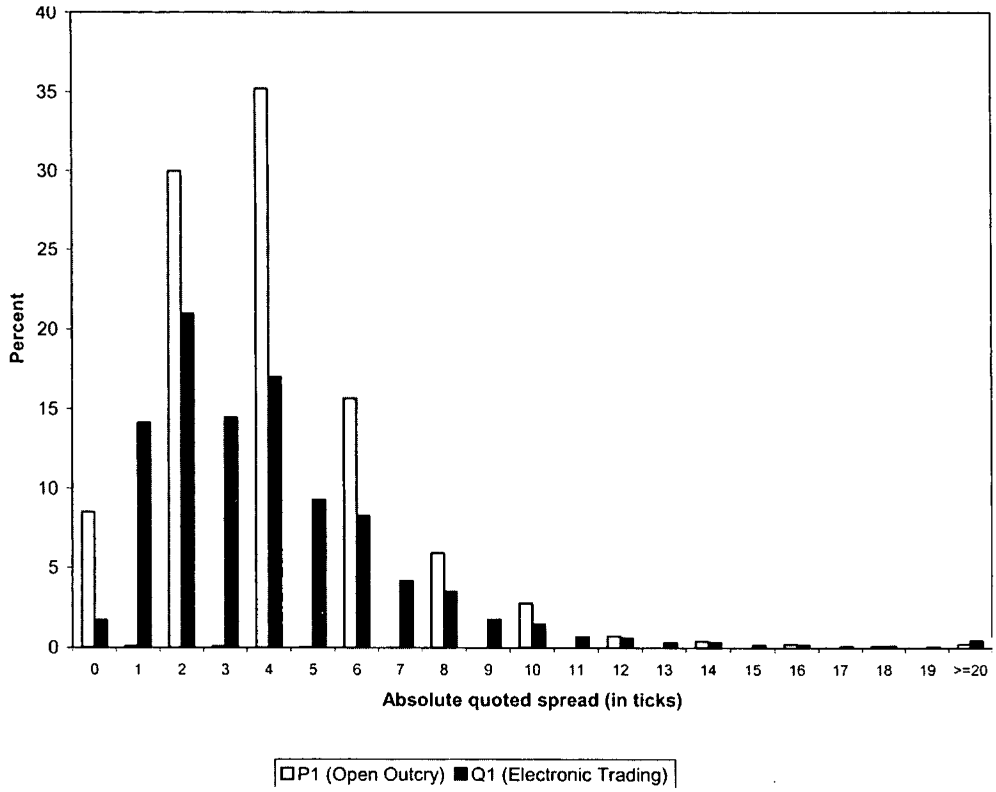

FIGURE 1
Distributions of absolute quoted spreads. The distributions were computed with all absolute spreads of FTSE index futures for P1 (February to April 1999) and Q1 (June to August 1999). The horizontal axis shows spreads in ticks. One tick (or 0.5 in prices) is the minimum price movement. The vertical axis represents the percentage of all spreads that are equal to the specified ticks.

Spreads

We present the frequency distributions of the absolute quoted bid–ask spreads for the two periods (P1 and Q1) in Figure 1.[7] See Tse (1999a) for detailed descriptions of the spreads in futures markets. The figure shows that the spreads in the open outcry market, but not in the electronic trading, clustered at even ticks. A tick is the minimum possible discrete price movement. Pirrong (1996) suggested that the "locals in an open outcry system may be able to collude tacitly to the disadvantage of customers who need to buy or sell large quantities on short notice"

[7]The zero quoted spreads represent the situations when the bid and ask prices are the same. The trade indicator variable, x_t, assumes a value of zero in these situations.

(p. 527) Such a collusion is credible because traders interact repeatedly and defecting will result in punishment.[8]

Gwilym, Clare, and Thomas (1998) also reported clustering. They found that 97.8% of the spreads for the FTSE 100 Index futures contracts on the LIFFE are at even ticks. Their evidence is consistent with the negotiation hypothesis of Harris (1991), that in periods of high trading activity and for small trades, traders eliminate odd quotes to minimize the cost of negotiations.

We follow the approach of Skinner (1989) and Kumar, Sarin, and Shastri (1998) to compare the bid–ask spreads of P1 and Q1. For each day, we estimate the daily relative bid–ask spread as the weighted average of all relative spreads in a day, where the weight is the amount of time the quote is valid. The relative bid–ask spread is the difference between the quoted bid and ask prices divided by the midquote of the bid and ask prices. We compare the median daily relative bid–ask spreads for both open outcry and electronic trading. Our results show that the median spread is higher for the open outcry market: 0.0315% for P1 and 0.0244% for Q1.

This finding is consistent with the notion that nominal trading costs decrease under electronic trading. For example, the labor costs of trading the Bund contracts on the DTB are two to three times lower than those on the floor of the LIFFE (Price Waterhouse, 1997). John Foyle, deputy CEO of LIFFE, stated, "[s]creen-based systems don't always end up giving buyers the best prices . . . but they're cheaper to run . . . and they don't require as many esoteric skills" (Freedman, 2000). Sarkar and Tozzi (1998) also pointed out that the overhead costs are smaller in the electronic trading markets. The transparency of the order book in the electronic market allows effective inventory management. Hence, the marketmakers may be able to lower the spreads.

However, the initial capital cost of purchasing the computer equipment and software for trading in the electronic market is larger than the cost of setting up a floor booth. These costs may well be prohibitive for scalpers, individuals with comparatively low personal capital. Thus, they are most likely to be squeezed out of the market by larger brokerage firms. This may cause the average cost of providing liquidity to increase in the electronic market.

Scalpers constitute the major group of traders in the open outcry market. They rarely leave their positions in the market open overnight. If

[8]However, locals may not extract large profits from this collusion; otherwise, profits from defecting may exceed the cost of punishment. In addition, locals face tougher competition from limit orders when they drive the price too high.

the role of scalpers (and their number) has diminished on the LIFFE after the transition to the electronic trading, we would expect to observe a greater number of overnight positions in the electronic market. However, there may be other forces acting in the opposite direction. For example, because electronic markets are characterized by smaller orders (Barclay & Hendershott, 2000), overnight positions may also be adversely affected. Moreover, the adverse selection problem is presumably more important for the electronic markets. Therefore, traders may be more reluctant to leave their positions open overnight.

To assess relative liquidity for the overnight positions, we examined open interest data for the P1 and Q1 periods. Bessembinder and Seguin (1993) suggested open interest as a proxy for liquidity. The average daily open interest for the open outcry period, 198,000 contracts (with an open interest/trading volume ratio of 5.81), is marginally smaller than that for the electronic trading period, 205,000 contracts (with a ratio of 6.03). The evidence, statistically significant at the 5% level, is consistent with the diminished role of scalpers in the electronic market.

In addition, given that the arrival of information is reflected by the price volatility, adverse selection is especially severe in the volatile markets. Traders are unable to cancel or change orders rapidly because of the explicit procedure of order withdrawal from the electronic order book. When new information arrives, traders are unwilling to post orders in the system, fearing that they will be picked out by other traders with superior information. Marketmakers also require a greater price for their services because offering liquidity becomes risky. This may widen the spread. Our evidence suggests that a decrease in the labor and overhead costs and in the costs of managing inventory in the electronic market outweighs the costs of adverse selection.

Market Quality

In the Hasbrouck (1993) model, the overall market quality is measured by the variance of the pricing error. A lower variance suggests greater pricing efficiency and higher market quality. We run the market quality VAR models of Equation 2 with five lags, following Hasbrouck (1991, 1993). The results show that the quality of the open outcry market is greater than that of its electronic heir. For the period P1, the variance of the pricing error is $0.920(10^{-5})$, whereas for the period of electronic trading, Q1, the estimated error variance is $4.70(10^{-5})$.[9] We note that

[9] We also estimate the average daily error variance during each period, and the average in P1 is significantly smaller than that in Q1.

the volatility of changes in the trade price is 0.00046 for P1 and 0.00021 for Q1. Therefore, it is unlikely that the higher error variance in the electronic trading market is induced by the volatility of price changes.

One explanation for these findings is that, in periods of high volatility, when information is arriving at the market, the electronic market fails to incorporate it into the prices. This is because traders are unwilling to submit orders in the system, fearing that they will be unable to change them rapidly enough to cope with the pace of information arrival. In such periods, the market becomes thinner (Frino et al., 1998), and price discovery is impaired (Martens, 1998). Absence of trading creates a dramatic departure of the market price from the rapidly updated efficient price. As a result, the quality of the market decreases.

In contrast, traders on the floor are most active when the market is volatile (see Coval & Shumway, 2000). The return to scalpers increases with their inventory position and the volatility of the market (Grossman & Miller, 1988). Thus, the open outcry mechanism reflects information more efficiently than the electronic market in the volatile periods.

Quality of the open outcry may be weakened in the quiet periods because the only source of information, trading and interaction between traders on the floor, is not available. At the same time, quality of the electronic market may be greater in the quiet periods because of the transparency of the electronic order book. However, a quiet market implies a low level of information, which suggests that the role of these periods in the determination of market quality is not very important.

To show that open outcry is more efficient when the market is more volatile, we partition P1 into two groups, days with high and low trading activities. We compare the average daily pricing error variance in each group. Like Jones, Kaul, and Lipson (1994), among many others, we use the number of trades as a proxy for volatility and trading activity. We find that the average error variance is in the volatile days 2.81 and in the quiet days 3.28. We do a similar analysis for Q1. In contrast to the results of P1, the average error variance in the volatile days is marginally higher than that in the quiet days: 4.67 versus 4.56. Accordingly, for open outcry (electronic market), the market is more efficient with a lower error variance when the market is more (less) actively traded. We also note that the error variance of P1 is significantly smaller than that of Q1 in both high and low volatile periods.

Given our findings of spread clustering, our estimation of market quality for the open outcry market is lower (i.e., the estimated variance of the pricing error is higher) than what it could be if there were any means to eliminate clustering or prevent locals from collusion. This is because collusion causes choppier prices, which in turn increase the deviation from the efficient price.

Information Content of the Trades

We report the results of Hasbrouck's (1991) model of information content of trades in Table II. In this model, changes in the midquote prices reflect a marketmaker's reaction to trades caused by the information content of trades and the inventory control. The coefficient b_0 in Equation 9a represents immediate quote midpoint revision in response to a trade. For open outcry, b_0 is greater and more significant. More specifically, the quote midpoint is raised $0.859(10^{-4})$ immediately subsequent to a purchase order in P1, but it is raised only $0.305(10^{-4})$ in Q1. We offer several explanations for our finding consistent with the higher information content of trades in the open outcry market.

TABLE II

Estimates of the Information Content of the Trade Model of Hasbrouck (1991): The Bivariate Vector Autoregressive Model

	Open Outcry (P1, February to April 1999)		*Electronic Trading (Q1, June to August 1999)*			*Open Outcry (P1, February to April 1999)*		*Electronic Trading (Q1, June to August 1999)*	
	Coefficient	*t*	*Coefficient*	*t*		*Coefficient*	*t*	*Coefficient*	*t*
a_1	−0.063	−19.43	−0.055	−8.88	c_1	−0.234	−1.59	−0.555	−4.75
a_2	−0.032	−9.54	−0.039	−5.86	c_2	−0.180	−1.20	−0.428	−3.79
a_3	−0.007	−1.97	−0.035	−7.50	c_3	0.086	0.56	−0.253	−1.68
a_4	−0.010	−2.76	−0.025	−6.32	c_4	−0.135	−1.06	−0.080	−0.73
a_5	−0.002	−0.53	−0.020	−3.46	c_5	−0.092	−0.83	−0.120	−0.94
b_0	0.859	135.58	0.305	89.06					
b_1	0.205	29.58	0.071	16.01	d_1	0.186	49.80	0.272	148.86
b_2	0.045	6.39	0.023	5.49	d_2	0.089	23.70	0.066	33.88
b_3	0.002	0.21	0.023	6.27	d_3	0.032	8.42	0.041	21.29
b_4	−0.014	−1.90	0.009	2.42	d_4	0.028	7.55	0.030	15.71
b_5	−0.006	−0.06	0.010	2.61	d_5	0.036	10.30	0.033	17.83
R^2	0.167		0.167			0.086		0.106	
DW	2.000		2.000			2.002		2.002	

Note. $r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5} b_i x_{t-i} + v_{1,t}$ $\quad x_t = \sum_{i=1}^{5} c_k r_{t-i} + \sum_{i=1}^{5} d_i x_{t-i} + v_{2,t}$

$r_t = \log[(q_t^b + q_t^a)/(q_{t-1}^b + q_{t-1}^a)]$, where q_t^b and q_t^b are posted bid and ask quotes at time t (time of a trade), and $x_t = +1$ for a buy order and −1 for a sell order. In the model, changes in the midpoint of quoted prices, r_t, reflect marketmaker reaction to trades caused by the information content of trades and the marketmaker inventory control considerations. Coefficient b_0 represents immediate quote midpoint revision in response to a trade. If b_0 is positive, the quote midpoint is immediately increased as a buy order is submitted. The higher the information content of the trade is the greater the marketmaker revises his or her estimation of the true price upward. Inventory control considerations of marketmakers are reflected by the coefficients c_i. The negative relation between trades and lagged quote revisions indicates that a marketmaker with an inventory surplus (shortage) would reduce (increase) his or her quotes to elicit more purchases (sales). Positive values of d_i indicate trade persistence, or lagged adjustment to information. t statistic at the 0.1% significance level = 3.29. DW stands for Durbin-Watson statistics.

The sequence of events implied in Hasbrouck's (1991) model is as follows. After an order to buy or sell, x_t, is submitted, public information arrives, and then the contemporaneous price midquote revision, r_t, is announced by a marketmaker. Hasbrouck contended that r_t will be caused by the public information and by the private information revealed by x_t. Hence, finding a relationship between r_t and x_t would indicate the private information content of trades. However, the floor traders do not have real-time access to much fundamental information. Therefore, this relationship may indicate that scalpers derive public information from trades.

Miller (1990) asserted that futures prices are influenced by marketwide information such as macroeconomic news. Also, informed investors, if any, are transparent on the floor. Even if a broker trades on behalf of his informed client, scalpers detect information trading, as they know the identities of clients. Scalpers themselves possess no private information and, while on the floor, do not have access to public information. They infer the information from the actions of their peers and brokers on the floor.

Scalpers also heavily rely on looking into each others' eyes and other means of human interaction. Coval and Shumway (2000) found a significant relationship between the level of noise in the trading pit and subsequent movements of price, trading volume, market breadth, and the balance of orders between locals and brokers (Madhavan & Panchapagesan, in press, also showed that New York Stock Exchange (NYSE) specialists find the sound level contains information useful for setting prices). A scalper needs to observe a buy (sell) order to conclude that there is some good (bad) news and revises the quoted prices immediately. Thus, even in the absence of private information in the open outcry market, scalpers are able to rapidly impound public information they derive from trades into the prices.

Another explanation deals with the possibility of collusion among the scalpers. In quiet periods, there are fewer scalpers on the floor because they are only attracted to the pit by high market activity. Accordingly, scalpers mainly trade with brokers. Pirrong (1996) argued that scalpers are more aggressive when trading with brokers than with other scalpers. Repeated interaction on the floor of the open outcry market and personal acquaintance prevent scalpers from aggressive bidding of the price up or down when trading with each other. Thus, in a quiet market, if scalpers know that a buy order is going to be received, they may collude to drive the price up.

Our findings are also consistent with the inventory control considerations of the scalpers. In a quiet market, scalpers are unusually averse to the risk of carrying unwanted inventory because they are unsure whether they will be able to reverse their positions rapidly. Thus, when an order to purchase (sell) is received, a scalper wants to increase (decrease) the ask (bid) to compensate himself for the imbalance in inventory in advance. Furthermore, scalpers act on both sides of the spread. If the scalper is expecting an order on the other side of the market, he may simultaneously increase (decrease) the bid (ask) to compensate himself for the inventory risk.

In active markets, the scalper's inventory costs are negligible, and collusion is not probable. However, in these cases our evidence is consistent with the scalper's reputation considerations. Trading on both sides of the market almost simultaneously, a scalper builds his reputation by providing a high level of liquidity, that is, by trading with everybody who needs to trade, even if this trade will unbalance his inventory. He will try to correct the imbalance immediately. Thus, when a sell order is received, a scalper will decrease his ask to sell part of the order simultaneously, causing the midpoint of the bid and ask quotes to decrease as well. When a purchase order is received, a scalper may immediately increase his bid to attract inventory if he does not have enough of it on hand to fill the purchase order.[10]

In the electronic market, because of the order change/cancellation procedure, response to an order will be less pronounced than in the rapid, human-intensive open outcry market. Collusion is impossible in the anonymous electronic system. However, finding b_0 positive and highly significant suggests that trades in the electronic market also have strong information content, although it is less than in the open outcry market. These results are consistent with Huang (2000), who examined stock price discovery by the Electronic Communication Networks and NASDAQ marketmakers. Huang argued that the information content of trades in the electronic market is enhanced by informed traders who are enticed by the anonymity of trading but is impeded by liquidity traders who are attracted by lower trading costs.

Inventory Control

For the open outcry market, we find the c_i coefficients insignificant, suggesting no significant effect between trades and lagged quote revisions. In contrast, for the electronic market, we find the coefficients

[10]These trades may not be exactly scratch trades, but they are close to them. In scratch trades, scalpers sell at the same price that they buy the assets. Smith and Whaley (1994) pointed out that scalper profits are less than the bid–ask spread because of such trades.

significantly negative. This negative relation between trades and lagged quote revisions is consistent with inventory control effects. We use a 0.1% significance level because the number of observations is sufficiently large: 106,390 for P1 and 341,374 for Q1.[11]

Our results are consistent with Silber (1984). He found that the average time a scalper's inventory deviates from zero is about 2 min; therefore, scalpers find it very easy to control the level of their inventories. Moreover, according to the model of Grossman and Miller (1988), scalpers can diversify the inventory risk effectively in a volatile market. Because the presence of scalpers is very limited in electronic markets and trading there is not as rapid as in the open outcry, marketmakers in electronic trading are more concerned with carrying the unbalanced inventory.[12]

Like Goodhart, Ito, and Payne (1996) in their study of foreign exchange markets, we find that the c_i coefficients (both for open outcry and for electronic trading) are considerably less significant than those reported by Hasbrouck (1991). These results are consistent with the notion that traders in the market with many competing markets, such as the futures and foreign exchange markets, have much smaller inventory control costs than those on the NYSE.

Positive signs of d_i coefficients indicate trade persistence and imply that the effect of lagged adjustment to information prevails over inventory control considerations. However, both magnitudes and values of the t statistics for d_i coefficients are generally greater for the electronic market. Evidence of slower adjustment to information in the electronic market suggests that deviations of the market price from the efficient price last longer in the electronic market, supporting the finding of lower market quality in electronic trading.

CONCLUSIONS

On May 10, 1999, the LIFFE transferred floor trading in the FTSE 100 Index futures contracts to the electronic trading system CONNECT. Using transaction data provided by the LIFFE, we compared the transaction costs and market quality between open outcry (from February to April 1999) and electronic trading (from June to August 1999). We

[11]Connolly (1989) contended that the significance level should be adjusted downward to ensure that the interpretation of test statistics was not distorted by the large sample size used in the article.

[12]Hasbrouck (1991) also mentioned that finding negative c_i coefficients is also consistent with the model of Leach and Madhavan (1989), in which a marketmaker sets quotes to optimally extract information from the traders.

employed the model of Hasbrouck (1993) to investigate market quality in terms of the variance of the pricing error. We also used the model of Hasbrouck (1991) to investigate the information content of the trades and inventory control effects in the two markets.

We find that the median daily time-weighted spreads are lower in the electronic market. However, open outcry has higher quality and pricing efficiency. We attribute this to the superiority of the open outcry market over the electronic trading market in impounding information into prices. Our results also indicate that trades in the open outcry market have higher information content. The possible reasons are the efficient human intermediation on the floor and the specifics of scalper trading, such as trading on both sides of the spread and building reputations by providing liquidity. Inventory control is higher in the electronic market because scalpers are squeezed out of this market. The average aversion of traders to carrying unbalanced inventory is also higher in the electronic market.

Our results support several earlier studies (e. g., Frino et al., 1998; Martens, 1998) that electronic trading should complement rather than replace open outcry and that open outcry cannot categorically be considered outdated and inefficient. Our results also support the recent restructuring plan of the Chicago Board of Trade (CBOT). It calls for the CBOT to split into two competing for-profit companies, one that will retain open outcry trading and another that will trade electronically. Although both systems are available, most of the CBOT volume remains in open outcry, suggesting that investors prefer its liquidity and efficiency ("Trading is alive and well," 2000).

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