SETS, arbitrage activity, and stock price dynamics

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Abstract

This paper provides an empirical description of the relationship between the trading system operated by a stock exchange and the trading behaviour of heterogeneous investors who use the exchange. The recent introduction of SETS in the London Stock Exchange provides an excellent opportunity to study the impact of an electronic trading system upon traders who use the exchange. Using the cost-of-carry model of futures prices we estimate (non-linearly) the transaction costs and trade speeds faced by arbitragers who take advantage of mispricing of FTSE100 futures contracts relative to the spot prices of the stocks that make up the FTSE100 stock index. We divide the sample period into pre-SETS and post-SETS sample periods and conduct a comparative study of arbitrager behaviour under different trading systems. The results indicate that there has been a significant reduction in the level of transaction costs faced by arbitragers and in the degree of transaction cost heterogeneity. Finally, generalised impulse response functions show that both spot and futures prices adjust more quickly in the post-SETS...
period. These results suggest that both spot and futures markets have become more efficient under SETS. © 2000 Elsevier Science B.V. All rights reserved.

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### 1. Introduction

Exchanges throughout the world have introduced (for example, London and Frankfurt) or are about to introduce (for example, Sydney) electronic trading systems. There remains some uncertainty, however, concerning the benefits (or otherwise) of such systems versus traditional trading systems. This paper provides empirical evidence on the cost and efficiency improvements brought about by electronic trading systems. More specifically, the paper will measure the transaction costs and stock price dynamics associated with arbitrage activity in spot and futures markets in the UK before and after the introduction of an electronic trading system. These measures will be of particular importance to those who organise financial markets with the hope of improving their efficiency.

On October 20, 1997, the London Stock Exchange introduced a new electronic trading system (SETS). The system enables traders to place buy or sell orders for any FTSE100 shares in an electronic order book. These orders are then automatically matched with other orders placed. Before the introduction of this system orders were advertised on computer terminals but actual trades were carried out over the telephone. Under this old system market-makers would absorb the impact of large trades by putting their own capital at risk. Such generosity was compensated for by large bid–ask spreads. Gemmill (1998) reports a 39 basis point spread for large companies and a 79 basis point spread for small companies before the introduction of SETS. By contrast, the respective spreads after the introduction of SETS were 32 basis points and 53 basis points.

The reduction in average bid–ask spreads should have an effect on all arbitrage activity. The activity examined in this paper concerns those trades that are conducted in order to lock into risk-less profits that arise because of perturbations in the contemporaneous relationship between FTSE100 spot and futures prices. Arbitrage activity involves simultaneous positions in both the spot and futures index. The length of time these positions are held depends upon whether or not it is profitable to unwind the position before the maturity of the contract. Brennan and Schwartz (1988, 1990) thus consider such a position as both an arbitrage position and an option to unwind the position when positive profits can be obtained. As Neal (1992) and Sofianos (1993) find that...
most arbitrage positions are not held until maturity it follows that the option to unwind must have some positive value. This additional value presumably lowers the absolute value of the bounds outside which it is profitable to trade. Moreover, as the cost of exercising the option is the difference between the buy and sell prices of the security then any decrease in bid – ask spread lowers the cost of unwinding the position and, thus, the arbitrage bounds.

The introduction of SETS offers an opportunity to study how arbitrage activity and stock price dynamics are affected by a change in transaction costs. In this paper we consider whether the introduction of SETS has changed the trading bounds outside which arbitrage activity takes place and whether markets have become more efficient. The paper is organised as follows. The next section outlines an economic model of arbitrager behaviour based on the cost-of-carry model. Section 3 describes the specific econometric model used. Section 4 provides a description of the data used. The penultimate section contains the empirical results while some concluding remarks are given in Section 6.

2. The economic model

The (contemporaneous) relationship between spot and forward prices can be described by the cost-of-carry model. This model is also capable of describing the relationship between spot and futures prices providing that the term structure of interest rates is flat and constant. Under the no-arbitrage condition, with no transaction costs, the model has the following specification:

\[ F_t = S_t e^{(r - \delta)(T - t)}, \]  \hspace{1cm} (1)

where \( F_t \) is the futures price, \( S_t \) the spot price, \( r \) the risk-free interest rate, \( \delta \) the expected dividend yield on the underlying asset, and \((T - t)\) is the time to maturity of the futures contract. If the contract is held to maturity then in the presence of proportional transaction costs, \( c \), arbitrage activity will take place when one of the following condition holds:

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1 SETS only pertains to spot positions in any FTSE100 shares. It does not effect the mechanism by which futures contracts in the FTSE100 index are traded. The exchange within which these contracts are traded (LIFFE) currently operates open outcry trading. This difference in trading mechanisms should not detract from the fact that costs of arbitrage trading are likely to be reduced under SETS. This is because mispricing will lead to simultaneous trading in both spot and futures markets. As such, a decrease in the cost of trading the FTSE100 shares in the spot market will reduce overall transaction costs.
As it takes time for arbitragers to take appropriate spot and futures positions, this arbitrage opportunity is necessarily lagged by \( d \) time periods. Therefore, providing \( c \) is small, the above inequalities can be expressed in the following (logarithmic) form:

\[
\frac{F_t}{S_t} e^{(r - \delta)(T - t)} < 1 - c, \tag{2}
\]

\[
\frac{F_t}{S_t} e^{(r - \delta)(T - t)} > 1 + c. \tag{3}
\]

3. The econometric model

Previous empirical studies have concluded that spot and futures stock indices are each non-stationary while the respective basis is stationary (Dwyer et al., 1996; Martens et al., 1998). This implies that spot and futures prices are cointegrated with a cointegrating vector equal to \((1, -1)\). If series are cointegrated, then they necessarily have an error-correction representation (Engle and Granger, 1987). Such an error-correction representation directly links changes in futures and spot prices to deviations from the arbitrage relation (1), that is, to pricing errors. Eq. (4), however, states that arbitrage activity only occurs if it is profitable. Equivalently, arbitrage positions in spot and futures stock markets are taken only when the pricing error is outside a particular bound. Thus, spot and futures prices only adjust to past disequilibria depending on the state or regime of the world one is in. To model this behaviour we use a smooth transition error-correction model (STECM). Ignoring lag dependence in differenced series (for expositional purposes only), the model can be expressed as

\[
\Delta f_t = x_t z_{t-d} F(z_{t-d}) + \epsilon_{1t}, \tag{5}
\]

\[
\Delta s_t = x_s z_{t-d} F(z_{t-d}) + \epsilon_{2t}, \tag{6}
\]

where \( \Delta f_t \) is the differenced logarithmic futures price series, \( \Delta s_t \) the differenced logarithmic spot price series, \( \epsilon_{1t} \) and \( \epsilon_{2t} \) are (possibly) cross correlated i.i.d. series, \( d = \{1, 2, \ldots\} \), and \( F(z_{t-d}) \) is a continuous transition function bounded between 0 and 1. This model allows for smooth transition between low \( z_{t-d} \) dependence \((F(z_{t-d}) = 0)\) and high \( z_{t-d} \) dependence \((F(z_{t-d}) = 1)\). More spec-
cifically, the strength of the relationship between $\Delta f_t$ and $z_{t-d}$ will range from zero to $z_t$ as $F(z_{t-d})$ changes (in a smooth fashion) from 0 to 1. This model is capable of allowing for regime dependent arbitrage as given by Eq. (4). It is expected that for $z_{t-d}$ around zero the value of the transition function will take values close to zero. When $z_{t-d}$ takes relatively large positive and negative values the transition function should take values close to unity. In allowing for smooth transition in $F(z_{t-d})$ the model can allow for heterogeneity in investors exposure to transaction costs.

Earlier studies of the relationship between futures prices and spot prices use the threshold error–correction model (TECM), see for example, Dwyer et al. (1996) and Martens et al. (1998). This model allows a very limited number of different regimes and hence transaction costs. The STECM allows for an infinite number of different regimes. As such, the STECM represents a more realistic representation of the heterogeneity of investors that each face different transaction costs. See Anderson (1997) for a more formal treatment of this point.

The following exponential function is used to obtain a parametric specification of the transition function:

$$F(z_{t-d}; \gamma) = 1 - \exp[-\gamma z_{t-d}^2],$$

where $\gamma > 0$. The parameter $\gamma$ measures the speed of transition from no adjustment ($F(z_{t-d}) = 0$) to full adjustment ($F(z_{t-d}) = 1$). Equivalently, $\gamma$ measures the degree of heterogeneity in transaction costs. Low $\gamma$ values imply a wide range of transaction costs faced by investors. By contrast, high $\gamma$ values imply a more uniform transaction cost structure.

The introduction of SETS should lower the transaction costs faced by all investors. Moreover, small (private) investors are expected to face similar transaction costs to those faced by large (institutional) investors. Such transaction cost homogeneity is conveniently measured by a large $\gamma$. It follows that $\gamma$ should be larger after the introduction of SETS. Moreover, if $\gamma$ is larger in the post-SETS period then transaction costs must be lower in this period. This is because the transition function equals zero when there is no pricing error ($z_{t-d} = 0$). As such, a large $\gamma$ value means that the transition function is necessarily above the small $\gamma$ value transition function. The null hypothesis tested in this paper is that $\gamma$ takes the same value in the pre-SETS and post-SETS periods.

Note that the same transition function is used in the equation for futures and spot returns (5) and (6), respectively. This means that the same parameter $\gamma$ enters both equations. Mathematically, it is of course possible to have different parameters, say $\gamma_f$ and $\gamma_s$ in (5) and (6), respectively, implying different transition functions. From an economic perspective, however, this is less plausible in this case. The arbitrage mechanism is triggered by large values of the basis and requires taking a position in both the spot and futures market.
Therefore, the parameter $c$ represents a measure of ‘average’ transaction cost heterogeneity over the two markets. We expect SETS to mainly reduce transaction cost heterogeneity in the spot market, thus lowering the ‘average’ heterogeneity. Given the present testing framework using arbitrage relations across markets, however, we cannot disentangle this average decrease into separate components for the spot and futures markets. This does not mean, however, that we cannot say anything on the relative contribution of SETS to spot and futures market efficiency improvements. In particular, our empirical results show that the efficiency of the spot market has increased relatively more than that of the futures market due to the introduction of SETS, as the post-SETS equilibrium correction parameter $\alpha_s$ for the spot market has increased more than that of the futures market, $\alpha_f$.

4. Data

The futures price of the nearest FTSE100 contract is obtained for every transaction carried out. These data were obtained from LIFFE. The contract is changed when the volume of trading in the next nearest contract is greater than the volume of trading in the nearest contract. To synchronise the futures and spot prices, the futures price series is converted to a price series with a frequency of 1 minute. As one does not know whether the price is a bid or ask price, the average of the last two prices is taken as the futures price. The (spot) level of the FTSE100 index was obtained from FTSE International. The trading hours of the futures market and the spot market are from 8.30 am to 5.30 pm and from 8.00 am to 4.30 pm, respectively. Thus one can obtain overlapping futures and spot data covering the period, from 8.30 am to 4.30 pm. However, since the introduction of SETS it has been noted that spreads are unusually high during the first hour of trading. This is because few institutional orders are entered during this period. For this reason only prices observed between 9.00 am and 4.30 pm are used in the analysis. This results in 451 observations per day. The pre-SETS sample period covers the period from September 8, 1997, to October 17, 1997. To allow traders to adapt to the new system, the post-SETS sample period will start on January 5, 1998 and end on February 13, 1998. These sample periods correspond to six weeks of data both before and after the introduction of SETS. Following Dwyer et al. (1996), and Martens et al. (1998),

2 The volume cross-over method of changing futures contracts results in one change in the pre-SETS period and no changes in the post-SETS period. The change involves a switch from the September 1997 contract to the December 1997 contract on September 19, 1997. On this date 1422 September 1997 contracts are traded and 6132 December 1997 contracts are traded. The post-SETS period futures prices make exclusive use of the March 1998 futures contract.
we remove overnight returns. This gives a total of 13,500 (450 \times 6 \times 5) 1 minute frequency returns in each of the sample periods. The analysis is also conducted using 2 and 5 minutes frequency data over the same sample periods.

The pricing error is constructed using the daily demeaned futures and spot prices. This methodology follows Teräsvirta (1994). Subtracting the daily mean from the futures prices ensures that any constant in the logarithmic price due to expected dividends or interest rates is removed. The pricing error is set equal to the difference between the demeaned futures price and the demeaned spot price. Henceforth, the demeaned logarithmic futures and spot prices will be denoted by \( f_t \) and \( s_t \), respectively, while the pricing error will be denoted by \( z_t \).

5. Empirical results

Time series plots of logarithmic futures and spot prices are presented in Fig. 1. Sharp changes in these prices occur when the trading day changes. Problems associated with these price discontinuities are avoided in this paper because only intraday returns are considered.

One of the purposes of SETS is to reduce trading costs in the spot market. One way of measuring these costs is by calculating percentage bid–ask spreads.

![Panel A: Pre–SETS](image1)

![Panel B: Post–SETS](image2)

Fig. 1. FTSE100 futures and spot index levels.
The mean spreads in the pre-SETS and post-SETS periods are given in Table 1. These spreads are calculated by taking the average of end-of-day spreads of all stocks in the FTSE100. The results indicate that there has been a large reduction in average bid–ask spreads since the introduction of SETS. These results confirm the results of more extensive studies, see for example, Gemmill (1998).

It could be argued that the subsequent analysis is sensitive to the particular sample periods used. For instance, one period may be more volatile than the other period. To examine this issue we calculate the standard deviation of daily futures and spot returns in the pre-SETS and post-SETS periods. The results are given in Table 1. Both periods have approximately the same volatility in both periods. One can test the null hypothesis that the population standard deviations are the same in each period by comparing the ratio of sample standard deviations in the pre-SETS and post-SETS periods, with some upper percentile point on a $F(n, n)$-distribution, where $n$ denotes the number of observations. The futures return ratio is 1.0069 and the spot return ratio is 1.0128. Comparing these values with various percentile points on an $F(30, 30)$-distribution leads to $p$-values of 0.4926 and 0.4862, respectively. Therefore, both futures and spot markets are equally volatile over the two periods.

### 5.1. Testing for non-stationarity

Augmented Dickey– Fuller (ADF) tests are performed on various 1 and 5 minute frequency series. In each case a constant is included and the lag lengths are selected on the basis of the Schwarz information criterion (SIC). The 1 minute frequency results given in Table 2 show that futures and spot prices are non-stationary. These prices are not the same prices as those plotted in Fig. 1. The non-stationarity tests are applied to intraday prices. These prices are calculated as follows. First, logarithmic returns are calculated. Second, overnight returns are removed. Third, intraday prices are calculated by numerically integrating the intraday returns. Possible cointegration between these prices is investigated by testing for non-stationarity in the pricing error using

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### Table 1

<table>
<thead>
<tr>
<th>Period</th>
<th>Statistic</th>
<th>$\mu(f)$</th>
<th>$\mu(s)$</th>
<th>$\sigma(f)$</th>
<th>$\sigma(s)$</th>
</tr>
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<tbody>
<tr>
<td>Pre-SETS</td>
<td>0.62</td>
<td>0.23</td>
<td>0.19</td>
<td>1.12</td>
<td>0.94</td>
</tr>
<tr>
<td>Post-SETS</td>
<td>0.43</td>
<td>0.17</td>
<td>0.20</td>
<td>1.13</td>
<td>0.96</td>
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</table>

*a The mean daily spread in the FTSE100 stocks is denoted $s_r$, the mean daily returns to futures returns ($f$) and spot returns ($s$) and the standard deviation of daily returns are denoted $\mu(\cdot)$ and $\sigma(\cdot)$, respectively. All statistics are measured in percentage terms.
the ADF test. Van Dijk and Franses (1999) show that unit root tests such as the ADF test perform well in the presence of non-linearity in the adjustment process. The results indicate that the null hypothesis of non-stationarity can be rejected with a high level of confidence. Therefore, the cointegrating vector provides a combination of non-stationary futures and spot prices that is stationary. As such, these prices have an error-correction representation.

5.2. Testing for non-linearity

It is possible to test the null hypothesis that returns follow a linear error-correction process against the alternative that returns follow a smooth transition error-correction process. The testing procedure used in this paper is based on Luukkonen et al. (1988), Swanson (1999) and Van Dijk and Franses (1999). Observation of the transition function given by (7) shows that the null hypothesis of linearity is equivalent to testing the null hypothesis that equals zero. Moreover, if the transition function is replaced by a third-order Taylor approximation then the STECM for futures returns can be expressed as

\[
\Delta f_t = \phi'_1 w_t + \phi'_1 \bar{w}_t z_{t-d} + \phi'_2 \bar{w}_t^2 z_{t-d} + \phi'_3 \bar{w}_t^3 z_{t-d} + \epsilon_t,
\]

where \( w_t = (1, \bar{w}_t)' \), \( \bar{w}_t = (z_{t-d}, \Delta f_{t-1}, \ldots, \Delta f_{t-p}, \Delta s_{t-1}, \ldots, \Delta s_{t-p})' \), \( \phi \) is a \((m + 1) \times 1\) vector of coefficients, \( \phi_1, \phi_2, \) and \( \phi_3 \) are \( m \times 1 \) vectors of coefficients, and \( m = 2p + 1 \). The original null hypothesis of linearity, \( H_0 : \gamma = 0 \), is equivalent to the null hypothesis that all coefficients of the auxiliary regressors, \( \bar{w}_t z_{t-d}^j, j = \{1, 2, 3\} \), equal zero, that is, \( H_0 : \phi_1 = \phi_2 = \phi_3 = 0 \). An LM-type test is used to test this hypothesis. The 1 minute frequency results are presented in Table 3 for \( p = 1 \) and \( d = \{1, 2, 3, 4, 5\} \). The results indicate that the null hypothesis can be rejected with a high degree of confidence. There is little to choose between each of the \( d \) values. In each case there is a clear rejection of the null hypothesis except when \( d = 4 \) in the post-SETS futures equation.

\[3\] The same approach is followed for the spot return series.
5.3. Estimating the error-correction models

Exponential transition function error-correction models are estimated in both the pre-SETS and post-SETS periods. In both cases \( p = 1 \) and \( d = \{1, 2, 3, 4, 5\} \). The exponential transition function error-correction model is specified as follows: \(^4\)

\[
\Delta f_t = \pi_1^t w_t^* + \pi_2^t w_t^* F(z_{t-d}; \gamma) + \alpha_t z_{t-d} F(z_{t-d}; \gamma) + \eta_t, \tag{9}
\]

where \( F(z_{t-d}; \gamma) = 1 - \exp[-\gamma z_{t-d}^2 / \sigma_{z_{t-d}}^2] \), \( w_t^* = (1, \Delta f_{t-1}, \Delta s_{t-1}) \), \( \pi_1^t \) and \( \pi_2^t \) are \((3 \times 1)\) vectors of coefficients, \( \alpha_t \) is the adjustment coefficient, and \( \sigma_{z_{t-d}}^2 \) is the variance of the pricing error. Inclusion of \( \sigma_{z_{t-d}}^2 \) follows Dwyer et al. (1996) and enables interpretation of \( \gamma \) in a scale-free environment. As such, comparisons of \( \gamma \)s over various sample periods is allowed. Both of these models are estimated using NLS. The estimated adjustment and \( \gamma \) coefficients are presented in Panel A of Table 4. The results of ARCH tests performed on the residuals from the estimated models indicated that there is significant heteroscedasticity present. Therefore, heteroscedastic-consistent standard errors are presented in Table 4.

When using 1 minute frequency returns information criteria are minimised when the delay equals 1 minute in the pre-SETS period and 2 minutes in the post-SETS period. The adjustment coefficients have the expected signs, \( \alpha_f < 0 \) and \( \alpha_s > 0 \). Moreover, adjustment in the spot market is considerably larger, in absolute terms, than adjustment in the futures market during the post-SETS period.

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\(^4\) Spot returns are similarly defined.
Table 4
Estimated STECM parameters

<table>
<thead>
<tr>
<th>Period</th>
<th>$d$</th>
<th>$\hat{d}_t$</th>
<th>$\hat{d}_s$</th>
<th>$\hat{\gamma}$</th>
<th>AIC</th>
<th>SIC</th>
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</thead>
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<td>Panel A: One minute frequency</td>
<td></td>
<td></td>
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<td></td>
<td>(0.0048)</td>
<td>(0.0022)</td>
<td>(0.0864)</td>
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<td>(0.0198)</td>
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<tr>
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<td>Panel B: Two minute frequency</td>
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<td>(0.0099)</td>
<td>(0.1000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SETS 2</td>
<td>-0.0075</td>
<td>0.1976</td>
<td>0.9922</td>
<td>-125.2710</td>
<td>-125.2601</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0102)</td>
<td>(0.0226)</td>
<td>(0.3015)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel C: Five minute frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-SETS 1</td>
<td>-0.0104</td>
<td>0.1033</td>
<td>0.1056</td>
<td>-444.0591</td>
<td>-443.9650</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0638)</td>
<td>(0.0522)</td>
<td>(0.0508)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SETS 1</td>
<td>0.0125</td>
<td>0.4433</td>
<td>0.4443</td>
<td>-443.4842</td>
<td>-443.3901</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0581)</td>
<td>(0.0927)</td>
<td>(0.1335)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The numbers in parentheses are heteroscedastic-consistent standard errors. The last two columns contain values of the Akaike information criterion (AIC) and the Schwarz information criterion (SIC).
5.4. The issue of stale prices

The analysis so far has made use of minute frequency index data. One problem with using such data is that it may be composed of stale prices. The inclusion of such prices occurs when prices are measured at regular intervals but are actually posted at irregular intervals. Such non-synchronous trading effects have been extensively studied, see Fisher (1966) and Scholes and Williams (1977) for early examples. Lo and MacKinlay (1990) show that in a portfolio consisting of homogeneously thinly traded securities the first-order autocorrelation in portfolio returns asymptotically equals the probability of observing a stale individual security price. Moreover, Lo and MacKinlay also show that this autocorrelation decreases rapidly, in a non-linear fashion, when the frequency of the data is decreased.

Non-synchronous trading effects are controlled for in this paper in two ways. First, the STECM given in (9) includes a linear autoregressive component. Thus autocorrelation in returns is explicitly modelled. Second, the frequency of the data is decreased to show that the results are robust to changes in non-synchronous trading effects.

The estimated STECM parameters obtained using lower frequency data (2 and 5 minute frequency data) are given in Panels B and C of Table 4. When 2 minute frequency data are used we set \( d = \{1, 2\} \). These correspond to actual delays of 2 and 4 minutes. Using longer time delay is unrealistic given the likely speed of the arbitrage process. The results are very similar to those obtained using minute frequency data. The optimal time delays are \( d = 2 \) (4 minutes) in the pre-SETS period and \( d = 1 \) (2 minutes) in the post-SETS period. In most cases the adjustment coefficients take their expected signs and are significantly different from zero. Similar results are obtained when 5 minute frequency data are used with \( d = 1 \).

5.5. Comparing transaction cost profiles

The results given in Table 4 indicate that when the exponential transition function is used, the degree of transaction cost heterogeneity is greater in the pre-SETS period than in the post-SETS period. That is, \( \hat{\gamma} \) is smaller in the former period. As the transition function must take a value of zero when there is no mispricing then this result implies that the transactions costs faced by arbitragers in the post-SETS period are smaller than those faced in the pre-SETS period.

The profiles presented in Fig. 2 plot the estimated transition function against the pricing error using minute frequency data (Panel A), 2 minute frequency data (Panel B) and 5 minute frequency data (Panel C). This figure shows that there is full adjustment outside a narrow range of mispricing in the post-SETS period. By contrast, this range is considerably larger in the pre-SETS period.
Moreover, there is a sharper change from no adjustment \( F(z_{t-d}) = 0 \) to full adjustment \( F(z_{t-d}) = 1 \) in the post-SETS period than in the pre-SETS period.

To formally test this equality of \( \gamma \) values over the two sample periods a simple \( t \)-test based on heteroscedastic-consistent standard errors is performed for various delay values. In each case the same delay values are assumed in each period. In addition, the optimal delays, as given by the SIC, are used in each period and the \( t \)-statistic is calculated. The results pertaining to various sampling frequencies are presented in Table 5. When minute frequency data are used transaction costs are significantly lower in the post-SETS period when delays of 2 and 5 minutes are assumed and when optimal delays are assumed. When 2 and 5 minute frequency data are used the results indicate that transaction costs are universally significantly lower in the post-SETS period.

5.6. Adjustment in response to pricing error

In using a STECM to model the arbitrage process one can obtain estimates of the adjustment in futures and spot markets for a given pricing error. Using (9), the respective adjustments due to previous pricing errors in futures and spot markets are:
Using 1 minute frequency data and optimal delays, $G(z_{t-d}; \gamma; \alpha_t)$ is plotted against $z_{t-d}$ and presented in Fig. 3. Before the results are discussed consider a few presentation issues. First, as $\alpha_t$ and $\alpha_s$ take different signs the absolute values of $G(\cdot)$ are used. Second, as $|G(\cdot)|$ is symmetric about zero only positive pricing errors are considered. Third, the $y$-axis in the figure is truncated so that a visual comparison of the various adjustments can be achieved.

Fig. 3 shows that the introduction of SETS causes an increase in the level of adjustment in the futures and the spot market given past pricing errors. However, the change in adjustment is greatest in the spot market. Thus prior to the introduction of SETS, prices were not adjusting as swiftly as possible due to prohibitive transaction costs. Since the introduction of SETS spot prices, in

$$G(z_{t-d}; \gamma; \alpha_t) = \alpha_t z_{t-d} F(z_{t-d}; \gamma),$$

$$G(z_{t-d}; \gamma; \alpha_s) = \alpha_s z_{t-d} F(z_{t-d}; \gamma).$$

Table 5
Transaction cost difference tests\(^a\)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>$d$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>SIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1M</td>
<td></td>
<td>0.10</td>
<td>4.00</td>
<td>0.35</td>
<td>0.34</td>
<td>1.33</td>
<td>2.64</td>
</tr>
<tr>
<td>2M</td>
<td></td>
<td>2.81</td>
<td>3.44</td>
<td></td>
<td></td>
<td></td>
<td>1.26</td>
</tr>
<tr>
<td>5M</td>
<td></td>
<td>3.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.00)</td>
</tr>
</tbody>
</table>

\(^a\)Frequencies of one minute (1M), two minutes (2M), and five minutes (5M) are considered. The null hypothesis that the $\gamma$ coefficient in the pre-SETS period equals the $\gamma$ coefficient in the post-SETS period is tested against the alternative that the pre-SETS $\gamma$ is less than the post-SETS $\gamma$. The $t$-statistics associated with the difference between the pre-SETS $\gamma$ and the post-SETS $\gamma$ are reported. The standard error of this difference is calculated using the heteroscedastic-consistent standard error. The numbers in parentheses are the $p$-values associated with this test.
particular, are rapidly and fully adjusting to past mispricing because of lower transaction costs in the spot market. In this sense both spot and futures markets have become more efficient since the introduction of SETS.

5.7. Generalised impulse responses

Generalised impulse response functions are calculated using the smooth transition error-correction models estimated in the pre-SETS and post-SETS periods. In both cases, 1 minute frequency data are used and the delay \( d \) is selected by the SIC. Shocks equal to \(-0.4, -0.35, -0.3, \ldots, 0.35, \) and 0.4 are assumed to affect both spot and futures markets. The effects that these shocks have on subsequent spot and futures returns are measured at various points within the pre-SETS and post-SETS sample periods. The distribution of these innovations is estimated using a quartic kernel function at various time periods after the shock hits the system. A uniform distribution taking values between \(-0.4\) and 0.4 (inclusive) is observed when the shock occurs. Subsequent distributions are less uniform and have a smaller range as the effects of the shock gradually disappear. This rate of decay gives an indication of the speed of adjustment in the respective markets. The estimated distributions at 2 and 5 minutes after the initial shock occurs are presented in Figs. 4 and 5.

The introduction of SETS causes more rapid adjustment in both spot and futures markets. This can be observed by comparing Panels A and C with B and D, respectively in Figs. 4 and 5. In each case the range of values taken by the innovations is smaller in the post-SETS period than in the pre-SETS period. Moreover, in the pre-SETS period the adjustment in the futures market is faster than adjustment in the spot market. That is, after 2 and 5 minutes the range of the innovations in the futures equation is smaller than the range of innovations in the spot equation. By contrast, adjustment is similar in both markets in the post-SETS period. This increased speed of adjustment to exogenous shocks in the post-SETS period is clear evidence of improved efficiency under the new trading system.

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5 This estimation process is based on a sub-sample of the pre-SETS and post-SETS periods. The ‘histories’ used in the current context equal the 1st, 101st, 201st, \ldots, 13301st, and 13401st observations. These histories are selected from a sample consisting of 13500 observations. Selection of these histories is based on a need to reduce the computation time.

6 For further details of kernel functions and the optimal bandwidth used see Eq. 3.31 of Silverman (1986).

7 Similar distributions are estimated at 1, 3, and 4 minutes after the initial shock occurs and when 2 and 5 minute frequency data are used. These figures are available upon request.
Fig. 4. Generalised impulse response distributions (2 minutes after shock).

Fig. 5. Generalised impulse response distributions (5 minutes after shock).
6. Conclusion

The transaction costs faced by arbitragers trading the FTSE100 spot and futures markets have been significantly reduced since the introduction of SETS. As such, both markets have become more efficient. Analysis of generalised impulse response functions leads to two additional findings. First, shocks to the futures and spot markets have less effect in the post-SETS period. Indeed, the effects of such shocks almost disappear after 5 minutes. Second, the futures market is less affected by shocks than the spot market in the pre-SETS period. However, both markets appear to be equally affected in the post-SETS period. These two findings are consistent with the objectives of SETS. That is, to improve the efficiency of the FTSE100 market.

The results are also encouraging with respect to LIFFE’s introduction of the Connect trading system covering the FTSE100 futures market in May 1999. Analysis of the impact of this system upon transaction costs will be the subject of future research. In particular, one would expect an increase in the level of adjustment in the futures market equal to that seen in the spot market since the introduction of SETS.

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