Equity Markets under Stress: Tests for Arbitrage Anomalies in the Stock-futures Basis*

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Abstract

World markets in the 1990s appear to have been subject to greater turbulence and to more shocks than hitherto. At the same time we observe a wide variety of market structures and trading platforms. This raises the question of whether, for a common shock, markets will respond differently. In particular, is it possible to rank the performance of different market structures during turbulent trading conditions? We examine the performance of four equity markets—Frankfurt, London, New York and Toronto—during the stressful trading conditions of October 1997. We propose six econometric tests for normal index arbitrage between spot and futures markets. Counter-intuitive results to these tests are classified as "arbitrage anomalies." A differential concentration of anomalies allows us to rank the robustness of different markets in response to shocks. Tentatively, the tests suggest that during October 1997 markets with a larger dealer component sustained the arbitrage link more robustly than others.

1 Introduction

Twenty or thirty years ago most economists might have argued that prices in financial markets were efficient, fully reflecting all available information and adjusting instantaneously to news. But the gradual emergence of market microstructure ideas questions this, suggesting that the performance of financial mar-

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kets could be "constrained," at least temporarily, by the way they are set up and organised. This seems plausible, given the wide variety of actual market structures that can be seen in operation around the world today. Do these all yield identical outcomes, for given shocks? Or can we rank them in some way?

These are important questions, since in recent years there has been a tendency for organised equity markets to converge on electronic order-books, moving away from traditional dealer structures. What has driven this? There are, from first principles, arguments on the qualities of different market structures. For example, a classic dealer system should prevent liquidity withdrawal and trading halts in times of stress, because, on the back of various privileges, market makers are required to quote continuous two-way prices regardless of market conditions. By contrast, electronic order-matching systems offer open, non-privileged access, with no requirement that participants remain in the market. This, and other aspects of electronic trading like anonymity, could be problematic—particularly in times of stress.

There are a number of practical ways of measuring market performance which we can use to make comparisons of real market structures. A natural episode to evaluate market performance is at times of stress, notably during sharp downward price movements, such as in October 1987 or October 1997. How well did different markets cope with these disturbances? Several possible measures suggest themselves, such as the size of price changes, market turnover (relative to desired trading quantities), or the number of trading halts. But where a futures market exists, the link between the spot and the futures price—the "stock-futures basis"—is a preferable measure because it is readily observable and embodies a simple theoretical underpinning, namely arbitrage principles.

Using data from the market correction in October 1997, this paper tests for the arbitrage link in spot and futures prices for the headline stock indices in four markets—Frankfurt, London, New York, and Toronto. We have chosen these particular centres because they allow a number of interesting comparisons. At the same time we have two North American and two European markets; two "large" and two "small" markets; and an interesting diversity of trading platforms.

The focus of the paper is on trading over the 10 business days from 20 October to 31 October 1997. Since the Correction occurred on 27 October, we have in this sample period 5 days of trading under "stress," and 5 days of "normal" trading from the week before. We also include, for London and New York, data from the October 1987 Crash. These allow us also to assess the impact, not only of different market structures, but also of shocks of differing severity. The underlying *causes* of these shocks are not the concern of this paper. Rather, this is a comparative study of the performance of different market structures, illustrated during times of stress. We draw on the approach of Antoniou and Garrett (1993) to propose six econometric tests for normal arbitrage between spot and futures markets. Counter-intuitive results are classified as "arbitrage anomalies." Any differential concentration of anomalies allows us to rank the robustness of different markets in response to shocks.

The remainder of this paper is divided into four sections. In section 2 we discuss the theory underlying the arbitrage link between spot and futures prices. The details of the econometric methodology used to test for anomalies in the arbitrage link are outlined in section 3. Section 4 begins with a description of the difficult trading conditions encountered during October 1997, before going on to report our econometric results. Section 5 draws some very tentative conclusions. Figures covering all the data are in Annex I. Annex II very briefly describes the market structures in operation during October 1997.

2 Arbitrage and the stock-futures basis

This section defines the stock-futures basis and outlines the kind of arbitrage relationship which can be expected to hold between cash and futures prices in normal trading conditions. In practice, two definitions of the basis are commonly cited: the "theoretical" and the "simple" basis. The theoretical basis is a comparison of the actual futures price, $F_{t,T}$, with the fair value futures price, $F^*_{t,T}$, while the simple basis is the difference between the futures price and the spot price. In the former case the basis is:

$$F_{t,T} - F^*_{t,T} \tag{1}$$

where t is the date the price is quoted and T is the contract expiry date. The definition of fair value is:

$$F^*_{t,T} = S_t.e^{(r-d)(T-t)} \tag{2}$$

S_t is the price of the underlying equity index and (r-d)(T-t) is the cost of carrying the index portfolio to the expiry date of the futures contract: (r-d) being the difference between the risk-free rate of interest, r, and, d, the dividend yield on the equity portfolio. (T-t) is the number of days to expiry. Trading between the two markets occurs if the cost of carry is less than (or equal to) the difference between actual and fair values of the futures contract.

Taking natural logarithms of (2) we can re-write this in terms of the simple basis to get:

$$f^*_{t,T} = s_t + (r-d)(T-t) \tag{3}$$

where lower case letters denote natural logs. In equilibrium the futures market correctly prices the equity portfolio (the contract gives fair value), so:

$$f^*_{t,T} - f_{t,T} = 0. \tag{4}$$

Substituting for $f^*_{t,T}$ in (4) and rearranging for the difference between the future and the spot price we find that the simple basis spread is equal to the cost of carry:

$$f_{t,T} - s_t = (r-d)(T-t) \tag{5}$$

This is the most commonly used measure of the basis in both market practice and in the literature—in the equity market it is usually referred to as the stock-futures basis—and it is the measure used throughout this paper. Since the dividend yield is usually lower than the interest rate on cash, it is expected to be positive.[1] When we come in section 3 to think in econometric terms, it will be convenient to write equation (5) as:

$$f_t = \alpha + \beta s_t \tag{6}$$

That is, the futures price is equal to a constant plus the spot rate. To date empirical studies like that of Antoniou and Garrett (1993) have assumed that the cost of carry is a constant within a single day. I think there is an issue here about the definition (and measurement) of d—which unlike r is not observable in a forward-looking sense. This seems to be a reasonable assumption. We have examined intra-day observations on r during October 1997, and these suggest that within the course of a single day the cost of carry is (approximately) unchanging, so that it can be included in the constant term, α. Notice also that the coefficient, β, on the spot rate equals unity.

In normal conditions basis trading is a form of relative value trading, in that positions taken in one market will be offset in the other; a trader might buy (sell) the cash and sell (buy) the future, but would not simultaneously buy or sell both. In this context, the cost of carry defines a “no-arbitrage window” within which it is uneconomic to undertake new trades. If the spread widens outside this window, i.e., if $|f_t - s_t| \geq \alpha$, arbitrage trading will occur because the expected profit from doing so exceeds the cost of holding the index to delivery.

3 Six tests for stock-futures arbitrage

3.1 Definitions

We now have to consider how in practice we can model and test the arbitrage link between the future and the spot price. Drawing on Antoniou and Garrett (1993), we suggest six simple tests for normal arbitrage. Since these tests form the backbone of our results in the next section, we will outline each of them in detail below. We can summarise them first in terms of the following six Questions:

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[1] As maturity of the future’s contract approaches, the cost of carry diminishes until at $t = T$ it equals zero.

- *Q.1. Is the stock-futures basis stationary (ADF test)?*
- *Q.2. Is there a long-run relationship between the spot and future (is there a cointegrating vector)?*
- *Q.3. Does the spot price equal the futures price (proportionality test)?*
- *Q.4. Do price changes in the future lead changes in the spot (in terms of (a) the ECM coefficient and (b) "Granger-feedback" effects)?*
- *Q.5. Do shocks to the variances in the GARCH equation persist?*
- *Q.6. Do shocks to the variances in the GARCH equations cointegrate?*

Let us consider each of these in turn, beginning with Question 1. In normal trading, index arbitrage should stabilise prices in both markets. Imagine a situation in which the futures price is below its fair value and outside the no-arbitrage window. The future is cheap, so basis traders will buy the future and sell the spot. If the futures price then rose above fair value (and is again outside of the no-arbitrage window), the reverse trade will be initiated with arbitrageurs buying stock and selling the future. In this way, the futures price should fluctuate around its equilibrium value and the basis will be stationary. This is equivalent to an Augmented Dickey Fuller (ADF) test for a unit root in the basis.

We can begin to explain the remaining Questions in terms of a general econometric model of the pricing relationship between spot and futures markets. That is, consider a VAR-type model like equation (7):

$$\Delta f_t = \mu_0 + \Sigma_i \mu_i \Delta f_{t-i} + \Sigma_j \mu_j \Delta s_{t-j} + \lambda_1 Ecm_{t-1} + \varepsilon_{t1} \qquad (7A)$$

$$\Delta s_t = \gamma_0 + \Sigma_i \gamma_i \Delta f_{t-i} + \Sigma_j \gamma_j \Delta s_{t-j} + \lambda_2 Ecm_{t-1} + \varepsilon_{t2} \qquad (7B)$$

where Δ indicates first differences in the variables and ε_t are white noise residuals. The rationale for this specification is that it restricts the future and spot price, through the error correction term, to converge on their "long-run" equilibrium relationship, while at the same time allowing a wide range of short-run dynamics in the lagged first differences. Thus "Ecm_{t-1}" denotes the error correction model and is essentially the basis as defined earlier in equation (6); that is, $Ecm_{t-1} = (f_{t-1} - \beta s_{t-1} - \alpha)$. Inclusion of the basis in this way is justified theoretically through its role in index arbitrage; econometrically it amounts to an equilibrium condition that keeps f and s in proportion to one another in the long run (without this they would drift apart which would suggest that no arbitrage is taking place and the two markets are trading independently of one another).

In order to include an Ecm term in equation (7), we need to establish first whether f and s are cointegrated; that is, whether there is a linear combination of them that is stationary. This linear combination of f and s is called the cointegrating equation (or vector). If there is no cointegration, this implies there is no equilibrium condition that keeps f and s in proportion in the long run. We will already have some feel for whether f and s are non-stationary from the ADF tests which we have used to examine the basis for Question 1 and indeed cointegration requires the same order of integration in f and s. But we can directly estimate the cointegrating equation using the framework established by Johansen (1991). This approach is advantageous, in that it allows us in addition to test for restrictions on the Ecm term.

We will not here say any more about the well-known details of Johansen estimation, except to add that in a two-variable model there could be up to two cointegrating vectors. If we find a *single* cointegrating vector, this indicates that there is a long-run relationship between f and s and we have an answer to Question 2. But for this relationship to have any economic meaning, we require that the future and spot price are equal, subject to the wedge created by the cost of carry. This recalls equation (5) in section 2 and is equivalent to the null hypothesis that $\beta = 1$ in equation (6). We label this the "proportionality" test.

Moving on to Question 4, an established stylised fact in empirical studies of the link between spot and future is that of price leadership in the futures price (see Holland and Vila (1998) or Schwarz and Szakmary (1994), for example). Since this is an almost universal finding we would expect that, in normal trading, the price of the equity future will move before, i.e. lead, that in the cash market. In equation (7) there are two ways we can consider this. The first, and perhaps usually the clearest, is in terms of the coefficient λ on the Ecm term. From our two pricing equations there will be two versions of the estimated coefficient, λ_1 and λ_2. The smaller of the two will indicate the variable that leads, so we expect $|\lambda_1| < |\lambda_2|$. Intuitively, a smaller coefficient means that for a given shock that variable gets less out of equilibrium and so returns to equilibrium sooner, ahead of the other.

Of course, we can examine the price leadership Question in a classic Granger Causality setting. If, in equation (7A), the lags on the future are statistically zero while those on the spot are not, the spot leads the future; analogously, if equation (7B) contains significant lags only on the future, then the future leads the spot. If both sets of lags are significantly non-zero then a feedback relationship exists.

No estimates of a relationship on very high frequency financial data would be complete without some sort of examination for the effects of volatility in the residuals, i.e. for ARCH and GARCH effects. Where ARCH effects are present we will wish to model these explicitly, including an equation for the conditional variance of the residuals. The commonest form used in the literature is the GARCH(1,1) specification whereby the conditional variance evolves according to:

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad (8)$$

The presence of volatility effects brings us to Questions 5 and 6 which focus on the behaviour of the conditional variance in the spot and futures markets. The work surveyed in Bollerslev *et al.* (1992) indicates that for many financial time series the restriction that $\alpha + \beta = 1$ in the conditional variance equation cannot be rejected such that the conditional variance has a unit root. An interesting aspect of the interaction between conditional variances is the idea of cointegration in variances. Clearly, if the conditional variance is non-stationary, this raises the question as to whether the conditional variances from the separate spot and futures equations cointegrate such that a linear combination of them shows no persistence. If it is apparent that the two are not cointegrated in variance this is a further indication of an anomaly in the arbitrage link between the spot and futures price.

3.2 Interpretation of the arbitrage tests

We have now outlined six Questions which form our tests for normal arbitrage. At the end of the day, we are looking for an interpretation of these which allows us to say something about the effects of market structure. But a breakdown in the arbitrage link could be the result of non-microstructure imperfections—for example, in the way transactions have to be financed or in restrictions on short selling. So we are testing a joint hypothesis where both microstructure and non-microstructure factors will play a role in determining the quality of the arbitrage link.

It is also worth saying a little more at this stage on the interpretation of our tests and how we might wish to prioritise the results from each one. Naturally, all of the Questions are related, but we would argue that Questions 1, 2 and 4a are perhaps the most decisive in detecting market anomalies and these could be regarded as our "core" Questions. Question 2 is clearly fundamental, because it addresses the very existence of a (long-run) relationship between the spot and futures price. A negative answer to this Question would suggest that there is no firm, systematic link between the two markets—flatly contradicting the principles of normal arbitrage. Question 1 is important in the same way. A stationary basis implies a continuous process of convergence between the future and the spot, and hence it also implies the existence of a long-run pricing relationship.

Though Question 4a is not motivated by any specific theory, there is plenty of empirical evidence to suggest that, as a stylised fact, the futures price leads the spot (see the early evidence in Kawaller, Koch and Koch (1987), Harris *et al.* (1995) and most recently in Holland and Vila (1998)). There are important practical realities to trading which provide some underpinning to the finding of price leadership. Basket trading the components of a spot index has always proved to be costly because it involves large numbers of transactions in individual stocks—up to 500 in the case of the headline S&P index. On the other hand, trading in the future involves one standard product on a single exchange. For this reason, generic market information tends to be pooled and traded in the futures market first and as a consequence index price discovery occurs in that market first. It is also the case that if investors are capital constrained, they will have incentives to trade first in the future where their initial outlay will be only the margin call on the contract, rather than the full price of the asset as in the cash market. The results of the Granger causality test in Question 4b are based on adjustments in the very short term. The minute-by-minute lags in the equation are likely to be noisy and potentially misleading, since they are merely short-lived deviations around the long-run relationship.

Question 3, the proportionality test, indicates whether the coefficients on the spot and the future are equal. But there are caveats to its interpretation. If there is price leadership, it might be the case in high frequency data that even in the "long run" the spot price is "catching up" with the future. Given this catching-up effect, it is perhaps unlikely that the β coefficient in equation (6) will in practice be precisely equal to one. The existence of transactions costs and other "frictions" in trading will also cause minor departures from exact proportionality. In line with the literature to date, our daily model assumes that the intra-day cost of carry is constant. From the data we have examined, it does appear that the cost of carry is unvarying intra-day. If this were not the case, we would need to model the cost of carry explicitly, rather than in the intercept term. Without this, a time-varying cost of carry would engender an omitted variables problem, biasing our estimate of β and invalidating our hypothesis test for proportionality.

We would not regard Question 5 as a core test because it is not a sign, in itself, of a market anomaly. The literature, for example in Bollerslev *et al.* (1992), has shown that most high frequency financial time series modelled in a GARCH(1,1) setting have a unit root (i.e. $\alpha+\beta=1$). So the finding that in both the future and the spot equation the variance is I(1) is not in any sense unusual. It is more relevant to examine whether the two conditional variances from the GARCH equations cointegrate. Failure to cointegrate can be regarded as a sign of market anomaly.

4 The october 1997 market correction

4.1 Stressful trading conditions

Before describing our results in detail, it is useful to begin Section 4 by providing an overview of the difficult trading conditions encountered in the equity markets during October 1997. In this context, developments in the week beginning 27 October will be described as the "Correction." Later, when we come to discuss the markets in October 1987, we shall refer to the "Crash."

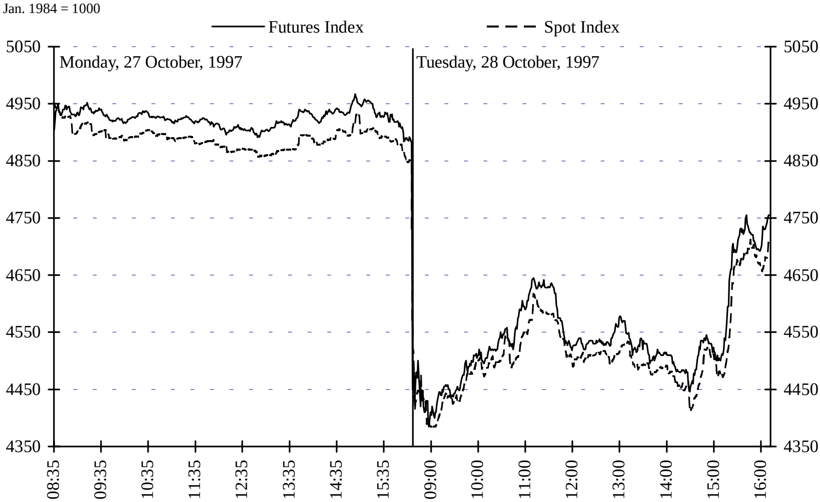
The purpose of this overview is to convey some sense of the practical difficulty that may be faced by basis traders during times of stress—and hence how the markets were tested last year. In London these market problems coincided with an important structural change, the introduction of the new Stock Exchange Trading System ("SETS")—the electronic order book for the top 100 equities—on 20 October.

The conjunctural background to the Correction is interesting. While the Correction began in the US markets on Monday, 27 October, market turbulence generally had been growing since the summer in the east Asian region. World equity prices had been rising steadily since January 1995, more than doubling in the US before the October Correction. Inevitably, this raised questions of valuation—most famously those of Alan Greenspan in his warnings of “irrational exuberance” in December 1996 and March 1997. These set the markets back temporarily, but the trend in prices remained upwards. In London and New York, the equity markets finally peaked in the first week of October 1997 before falling sharply in the second half of the month. Thereafter prices recovered, so that by year-end there was little remaining evidence of a downturn. This recovery from the Correction was mirrored in most non-emerging equity markets by the end of 1997.

The general background of difficult trading during October is reflected in levels of market volatility. The implied volatility from options traded on the S&P 500 future more than doubled to 42% on Monday, 27 October. A sharp increase in volatility on the T35 contract was also recorded in Toronto on the same day. Owing to the time zone differences which saw Europe correct a day later, volatility on the headline indices rose by a third or more in both Frankfurt and London on the 28th. By close of business on the 27th, the S&P 500 spot price was down about 6.3% and the futures price by almost 8% (Figures 3 and A2). As documented in Cochrane (1998), this triggered the New York Stock Exchange’s circuit breaker Rule 80B for the first time since the rule had been adopted in 1988. Trading was halted for half an hour at 2.36p.m.; it resumed at 3.06p.m. before a further halt was invoked at 3.30p.m., closing the US markets for that day. It is clear from Figure 4 that the stock-futures basis became distorted and more volatile during this time, becoming negative in the last period of trading on the 27th and early on the morning of the 28th.

Trading in the European markets ended before the US collapse got into full swing and caught up on Tuesday 28th: in London spot prices opened 6% down on the previous night’s close (Figures 1 and A1). Order-book trading halts were necessary in a few stocks, but the market as a whole functioned without a break. Although the basis spread remained positive, it was clearly very volatile for a short while (Figure 2). Both here and in the US, prices bounced back sharply the day following the Correction, regaining much of the ground they had lost initially (Figures A1 and A2). While price levels recovered rapidly, the sharply increased volatility in the markets persisted for several days.

Figure 1: The UK equity markets FT-SE 100 index: Spot and futures price Monday, 27 October, 1997 and Tuesday, 28 October, 1997



Source: FTSE International and LIFFE

Figure 2: The UK equity markets: The stock-futures Monday, 27 October, 1997 and Tuesday, 28 October, 1997

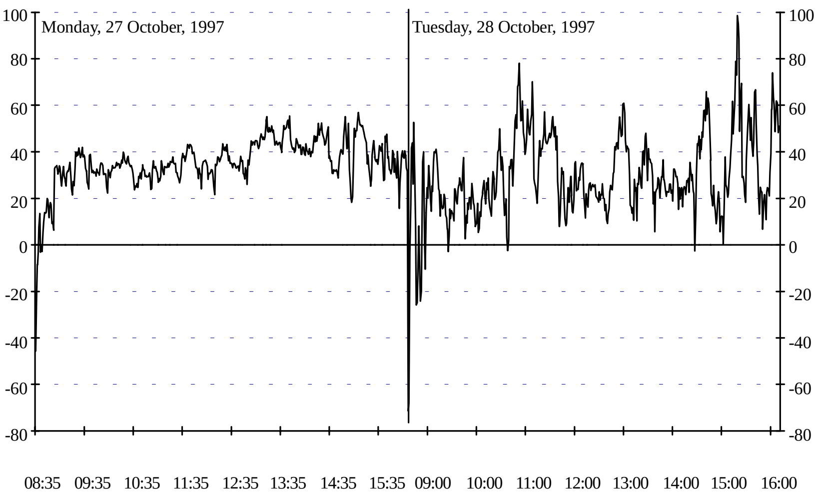
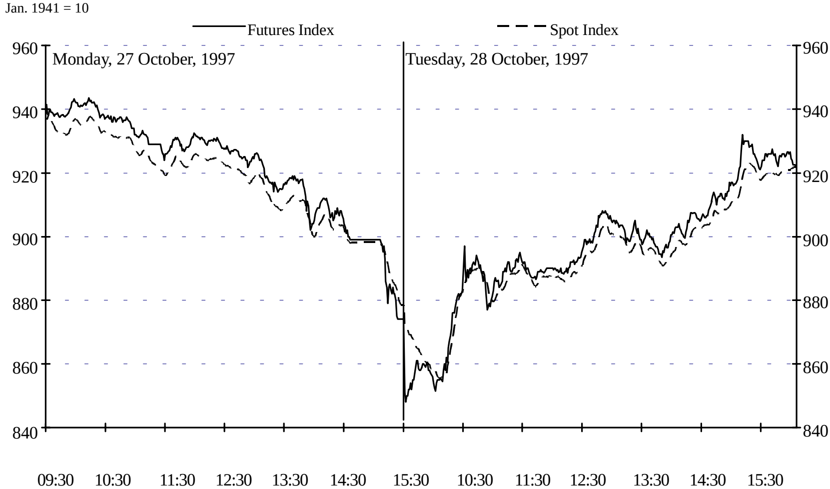
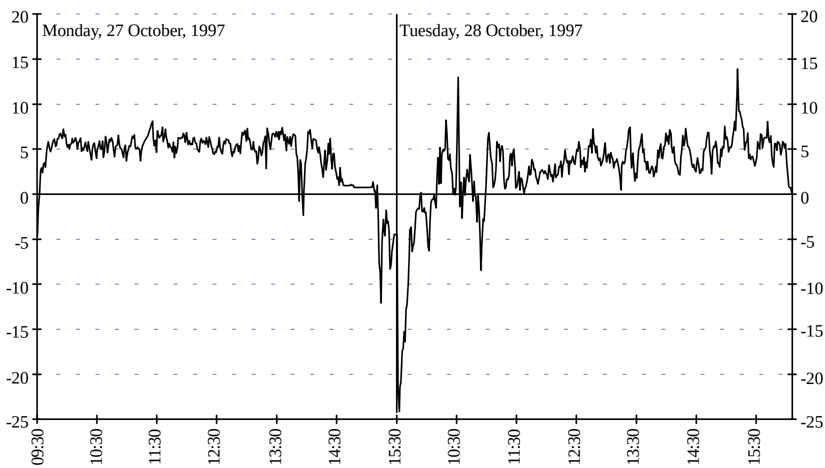


Figure 3: The US equity markets S&P 500 index: Spot and futures Monday, 27 October, 1997 and Tuesday, 28 October, 1997



Source: Federal Reserve Bank of New York

Figure 4: The US equity markets: The stock-futures basis Monday, 27 October, 1997 and Tuesday, 28 October, 1997



4.2 Econometric answers to Questions 1 to 6

Our sample is made up of end-minute observations on the spot and the near-contract futures price for the headline stock indices in each market, covering the five days before and after the October 1997 shock; that is, from Monday 20 to Friday 31 October. We estimate a separate pricing model for each day and in addition we estimate a “pooled” model which examines the aggregate relationship over all ten days. The estimation of separate daily models before and after the shock on the 27th allows us to make a comparison between market performance in the “stressful” conditions of the Correction with the more normal trading the week before.[2] On each day we initially estimate a Vector Error Correction Model (VECM) to test for cross correlation between the errors in the spot and futures equations. Based on this we have identified an appropriate lag length to use in a single equation approach. In most cases we have used a 10-lag specification.[3] For the October 1987 Crash we have included data on London and New York for two trading days: Monday 19 and Tuesday 20. Due to a trading halt which occurred around noon on the Chicago Mercantile Exchange, the data for Tuesday 20 are split into two trading sessions.

Estimation of the Ecm term in the daily model requires that the interest rate and the dividend yield are constant throughout the day and hence that the intra-day cost of carry is constant. The data suggest that this is a valid assumption. Obviously, over several days the cost of carry will vary and so we have allowed for discrete day-by-day changes in the cost of carry in a pooled, 10-day model. One of the purposes of the pooled model is to provide a counterfactual against which to judge the stability of the daily estimates. With this in mind we have estimated a full pooled model on all 10 days and a second version which dummies out the shock day (that is, 28th in London and Frankfurt and 27th in New York and Toronto).[4] It turns out that this adjustment has little impact on the pooled model in either London or New York.

The results to Questions 1 to 6 are very bulky to report in full, so we have condensed them for each market into the summary Tables 1 to 4 reported below. The full results are available from the authors on request. We will discuss London and New York first, referring to Tables 1 and 2, respectively.

London and New York

[2] It is worth observing that some or all of the characteristics of stressful trading conditions (wider spreads, more volatility) might be evident in very quiet trading periods, for example around seasonal lulls like Christmas Eve.

[3] Most of the relevant literature using minute-by-minute data, e.g. Holland and Vila (1998), uses a 10-lag specification. The only exceptions in our own results are the 23rd and 28th in the US and the 20th, 23rd and 30th in the UK where we have used 20 lags to remove cross-correlation between the residuals of the future and the spot equation.

[4] Figure A1 in the appendix shows that London reopened on Tuesday down about 6% with respect to the previous day. That is the main reason why we have dummied out the 28th rather than the 27th.

The London spot market switched from a traditional dealer market to a new order book system, SETS, on 20 October, 1997. A lot of bilateral trading has continued, off order book, in the "upstairs" market, but the spot index is calculated from SETS trades. The futures index was traded on LIFFE in a traditional open-outcry format.[5] Based on the answers to Questions 1 to 6, it appears that there is little evidence of arbitrage anomalies during the October 1997 Correction in the UK equity markets. It is worth noting that the answer to what we have called the three core questions (1, 2, 4a) is always intuitive. That is, the basis is stationary, there is a long-run relationship between the two indices and the futures market always leads the spot. Apart from the mixed picture that appears from Question 3 and Question 5, the only anomalies we have observed are on 29 October, where the future fails to Granger-cause the spot, and on the 20th where the shocks in the variances do not cointegrate.[6]

The picture in the London markets ten years earlier, during the 1987 Crash, is completely reversed. On both 19 and 20 October that year the basis is non-stationary and the tests for the existence of a cointegrating vector give borderline results. In line with the findings of Antoniou and Garrett, the situation appears to be worse on the 19th. On this day we clearly reject the proportionality test,[7] and the spot market leads the futures market, both in the long-run analysis (ECM term) and the short-term one (Granger lags). One reason for this sharp difference might be the magnitude of the two events: the 1987 Crash was a much severer test for the market than the 1997 Correction (see Figure 1 and Figure A5). It is worth noting that in October 1987 the future traded at a lower price than the spot throughout both days in the sample, while in October 1997 the futures contract is always traded at a price above the spot, except in the first few minutes after opening on 28 October. Of course, a further important difference in explaining events in 1987 and 1997 could be the change in market structure in London. But the introduction of the new electronic order book, SETS, was so recent that this seems unlikely.

[5] Fuller details of how the market operates can be found in Annex II.

[6] The variance in the spot equation is I(0) whereas in the future equation it is I(1).

[7] The coefficient on the spot is 1.27436 as opposed to 1.17652 on the 20 October, 1987 and to 1.0053 in the pooled model in 1997.

Table 1: UK econometric results: Summary of findings

	Questions:						
Dates	**1**	**2**	3	**4a**	4b	5	6
20/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	Yes (No in Future)	*No*
21/10/97	**Yes**	**Yes**	Yes	**Yes**	Yes	N/A	*N/A*
22/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	N/A	*N/A*
23/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	Yes	Yes
24/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	Yes	Yes
27/10/97	**Yes**	**Yes**	Yes	**Yes**	Yes	Yes (Spot N/A)	*N/A*
28/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	Yes	Yes
29/10/97	**Yes**	**Yes**	Yes	**Yes**	*No*	*No* (Spot N/A)	N/A
30/10/97	**Yes**	**Yes**	*No*	**Yes**	Yes	Yes	Yes
31/10/97	**Yes**	**Yes**	Yes	**Yes**	Yes	Yes (Future N/A)	*N/A*
Pooled Model 20th - 31st Oct.	**Yes**	**Yes**	*No*	**Yes**	Yes	*No*	Yes
19/10/87	***No***	**Yes (Borderline)**	*No*	***No***	*No*	*No*	Yes
20/10/87	***No***	**Yes (Borderline)**	Yes	**Yes**	*No*	Yes (Borderline)	Yes
	Yes in 11/13 days	**Yes in 13/13 days**	Yes in 5/13 days	**Yes in 12/13 days**	Yes in 10/13 days	Yes in 13/19 cases (6 in Spot, 7 in Future)	Yes in 7/8 days

Table 2: US econometric results: Summary of findings

Questions:							
Dates	**1**	**2**	3	**4a**	4b	5	6
20/10/97	***Yes***	***Yes (borderline)***	*Yes*	***No***	*Yes*	*N/A*	*N/A*
21/10/97	***Yes***	***Yes***	*No*	***Yes***	*Yes*	*No*	*Yes*
22/10/97	***Yes***	***Yes***	*Yes*	***Yes***	*Yes*	*N/A*	*N/A*
23/10/97	***Yes***	***Yes***	*No*	***No***	*Yes*	*Yes*	*Yes*
24/10/97	***Yes***	***Yes***	*No*	***No***	*Yes*	*N/A*	*N/A*
27/10/97	***Yes***	***No***	*N/A*	***N/A***	*Yes*	*Yes (No in Future)*	*No*
28/10/97	***Yes***	***Yes***	*No*	***No***	*Yes*	*Yes (No in Future)*	*No*
29/10/97	***Yes***	***Yes***	*Yes*	***Yes***	*No*	*Yes (Borderline)*	*Yes*
30/10/97	***Yes***	***Yes***	*No*	***No***	*Yes*	*No (Future N/A)*	*N/A*
31/10/97	***Yes***	***Yes***	*No*	***Yes***	*Yes*	*Yes (No in Spot)*	*Yes*
Pooled Model 20th-31st Oct.	***Yes***	***Yes***	*No*	***No***	*Yes*	*N/A*	*N/A*
19/10/87	***No***	***Yes (Borderline)***	*No*	***Yes?***	*Yes*	*N/A*	*N/A*
20/10/87 a.m.	***No***	***Yes***	*No*	***Yes?***	*No*	*N/A*	*N/A*
20/10/87 p.m.	***No***	***No***	*N/A*	***N/A***	*No*	*Yes (Spot N/A)*	*N/A*
	Yes in 11/14 days	**Yes in 10 or 12/14 days**	Yes in 3/12 days	**Yes in 6/12 days**	Yes in 11/14 days	Yes in 8/14 cases (4 in Spot, 4 in Future)	Yes in 4/6 days

Table 2 shows the results of the arbitrage tests in the US equity markets. Nearly all of the stocks in the S&P 500 are traded on the NYSE. The market there is based around an order book run by a specialist who, where necessary, balances orders on the book. The futures contract is traded in a pit on the Chicago Mercantile Exchange. Compared to London, it seems that there is greater evidence of anomalies in the US data. As far as the core questions are concerned, it is particularly striking that we fail to detect a long-run relationship between the future and the spot (i.e. no cointegrating vector) on Monday, 27th. Other striking anomalies are found in the answers to Question 4a. In 5 cases out of 9, the *spot* market leads the future in the daily models—the pooled models exhibit the same pattern—whereas we find in London that the future always leads in the 1997 data. Other interesting results in the non-core questions are the lack of futures leadership in the short term lags on the 29th, and the lack of a cointegrating vector in the conditional variances on the 27th and 28th. The proportionality test, as for London, gives mixed results.

A comparison of the US markets in October 1987 and October 1997 gives the same picture as in London, in that market performance is much poorer in the 1987 data. Remember that the US data for 20 October, 1987 have been split into two samples (morning and afternoon) following a trading halt in the middle of that day. The afternoon of the 20th is by far the worst period in terms of market performance, although there are probably too few observations to draw firm conclusions. We therefore concentrate on trading on the 19th and in the morning of the 20th. We find that the arbitrage link broke down on both days. The basis is non-stationary, while it is not clear whether there is a cointegrating vector on the 19th, and the proportionality test is rejected.[8]

The overall picture that emerges from Tables 1 and 2 is that there are similarities in a comparison of London and New York in the Crash, but differences during the Correction. Thus in both London and New York the markets seem to be under much more pressure in October 1987, when there is clearer (econometric) evidence of arbitrage breakdown. The reason for this may lie in the difference in the magnitude of the two Crashes.

During October 1997 the London markets appear to trade with less evidence of difficulty than in New York. This may be because the Correction occurred during New York trading hours, whereas it happened overnight in Europe. Consequently, the European markets were able to open a single step down in response to the news rather than undergoing a process of adjustment with greater uncertainty in the middle of the trading day (which might be more disruptive). It is also interesting to observe that the informal split we suggested between normal trading and stressful trading is not accurately reflected in the results. For example, in the US markets the price leadership responses are equally counter intuitive both in the week before and the week of the Correction, rather than during the stressful conditions alone.

Frankfurt and Toronto

We now turn briefly to our results on Frankfurt. Until October 1997, the Frankfurt stock exchange operated a hybrid system of floor trading and an electronic order book called IBIS.[9] Floor trading operated in parallel with the order book from 10.30a.m. to 13.30p.m. While the floor was open, the official DAX 30 prices were calculated from floor trades (rather than from trading in the order book). Our data set includes only floor trades and so our daily model was estimated over this

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[8] The coefficient on the spot is 1.5338 on the 19th and 1.3437 on the 20th in the morning as opposed to 1.0516 in the 1997 pooled model.

[9] This was replaced by the new electronic Xetra system in November 1997.

shorter, 3-hour period, excluding the IBIS trading either side. In the 10 days of the sample period, we find that there are three days which show evidence of weakness in market performance, based on our core Questions. Again, these are not confined to the week of the shock itself. Other than on the proportionality test, the aggregate pooled model performs well.

In Toronto the spot market trades through an electronic order book, CATS (Computer Assisted Trading System); floor trading ended in April 1997. Futures trades are conducted through a traditional open-outcry floor system. Last October trading in the future was not liquid enough to allow minute-by-minute sampling of prices, so we have taken observations every 2 minutes. No daily model is estimated at all on 20 and 21 October, where the future trades too infrequently to allow this, so in the case of Toronto we have 8 daily models rather than 10. Likewise, the pooled model is estimated over 8 rather than 10 days. The overall picture in the intra-day analysis shows many instances of anomalies. With the single exception of 28 October, no long-run relationship can be identified in the data. The pooled model gives rather more favourable results, in that the basis appears to be stationary and there is a cointegrating vector. One possible interpretation of this may be that anomalies in arbitrage will persist over short periods of a day or two but will be removed over one- or two-week horizons (as embodied in the pooled model).

Table 3: Frankfurt econometric results: Summary of findings

	Questions:						
Dates	**1**	**2**	3	**4a**	4b	5	6
20/10/97	**Yes**	**Yes**	*No*	***No***	Yes	N/A	N/A
21/10/97	***No***	***No***	N/A	**N/A**	Yes	Yes (in the Future)	N/A
22/10/97	**Yes**	**Yes**	*No*	**Yes**	*No*	N/A	N/A
23/10/97	***No***	***No***	N/A	**N/A**	Yes	Yes (in the Future)	N/A
24/10/97	**Yes**	**Yes**	*No*	***No***	*No*	N/A	N/A
27/10/97	**Yes**	**Yes**	*No*	**Yes**	*No*	N/A	N/A
28/10/97	**Yes**	**Yes**	Yes	**Yes**	Yes	N/A	N/A
29/10/97	**Yes**	**Yes**	Yes	***No?***	Yes	N/A	N/A
30/10/97	**Yes**	**Yes**	Yes	**Yes**	*No*	N/A	N/A
31/10/97	***No***	***No***	N/A	**N/A**	Yes	Yes (in the Future)	N/A
Pooled Model 20th - 31st Oct.	**Yes**	**Yes**	*No*	**Yes?**	Yes	No	Yes
	8/11 Yes	**8/11 Yes**	3/8 Yes	**5/8 Yes**	7/11 Yes	Yes in 3 cases (3 in Future)	1/1 Yes

Table 4: Toronto econometric results: Summary of findings

	Questions:						
Dates	**1**	**2**	3	**4a**	4b	5	6
22/10/97	**Yes?**	**No**	N/A	**N/A**	No	N/A	N/A
23/10/97	**Yes?**	**No**	N/A	**N/A**	Yes?	Yes (in the Spot)	N/A
24/10/97	**No**	**No**	N/A	**N/A**	Yes	Yes (in the Future)	N/A
27/10/97	**Yes?**	**No**	N/A	**N/A**	No	N/A	N/A
28/10/97	**Yes?**	**Yes**	Yes	**No**	No	Yes (in the Future)	N/A
29/10/97	**No**	**No**	N/A	**N/A**	Yes?	N/A	N/A
30/10/97	**Yes?**	**No**	N/A	**N/A**	Yes	Yes (in the Spot)	N/A
31/10/97	**Yes?**	**No**	N/A	**N/A**	Yes	N/A	N/A
Pooled model 22nd - 31st Oct.	**Yes**	**Yes**	No	**No**	Yes	No	N/A
	7/9 Yes	**2/9 Yes**	1/2 Yes	**0/2 Yes**	6/9 Yes	Yes in 4 cases (2 in Spot, 2 in Future)	

Note: There is no daily model on the 20th and 21st of October because of lack of liquidity in the futures market.

Summary

Taking the four markets as a whole, London seems to produce the best results with little, if any, evidence of a break in the arbitrage link in October 1997. However, it could be argued that the London market—and European markets generally—were not tested to the same extent as those in North America, since the initial shock occurred outside European trading hours. As a consequence, the Correction is for them embodied in a single observation at the Open on Tuesday, 28th. If the Correction had begun during the trading day, providing a continuous period of stress, the picture in London might have been different. However, in both London and New York in the 1987 Crash there is clear evidence of market breakdown in all three core Questions. In New York in 1997 the only real evidence of a problem is on 27 October, the day of the Correction when the market fell over 6%. Frankfurt shows rather more evidence of problems. But still more often than not, the arbitrage link appears to hold. On the criteria we have selected, Toronto is the weakest performer. The lack of a long-run relationship in 7 out of 8 days in the data is striking. We will speculate below whether these conclusions have any clear market structure interpretation.

5 Did market structure make a difference?

The results we have presented are of statistical anomalies observed while markets were trading under stress. We need to ask if they are any more than this. In particular, can we plausibly attribute departures from econometric benchmarks to the effects of market structure? This is a tantalising question. On the one hand, there appears to have been a trend towards order-driven trading systems in both spot and futures markets since the mid-1980s. Consider for example the introduction of the CAC system in Paris, its precursor CATS in Toronto, IBIS and latterly Xetra in Frankfurt and SETS in London. In practice, these systems are rarely pure auction markets, but usually incorporate some of the characteristics of a dealer market as well. In London more than half the trading on SETS shares is done bilaterally off order book, while in New York, monopoly specialists take out imbalances in the book. Consequently, the distinction between market structures is in practice blurred, at least relative to text book cleanliness.

So we are forced to make dirty comparisons. Bertero and Mayer (1990) made one such attempt. They observed that while stock markets were responding to a global shock, the price collapse observed during the 1987 Crash varied widely across markets, from under 5% in Austria to over 25% in Singapore. This obviously raised questions about the interdependence of markets and of the link between structure and performance. Their analysis undertook cross-section regressions of price changes on market structure variables, but was unable to find a conclusive link. Based on our own results we would also wish to be tentative in drawing firm conclusions. But the facts of the tests do suggest that during October 1997 the market with the largest dealership component—London—sustained the arbitrage link more robustly than in the other markets in this study. This need not imply that these other markets had profound or terminal difficulties. But at the margin, in difficult trading conditions, they may at least show more noise in the arbitrage link between spot and futures pricing.

Annex I

Figure A1: The UK equity markets FT-SE 100 index: Spot and futures price 20 October, 1997 - 31 October, 1997

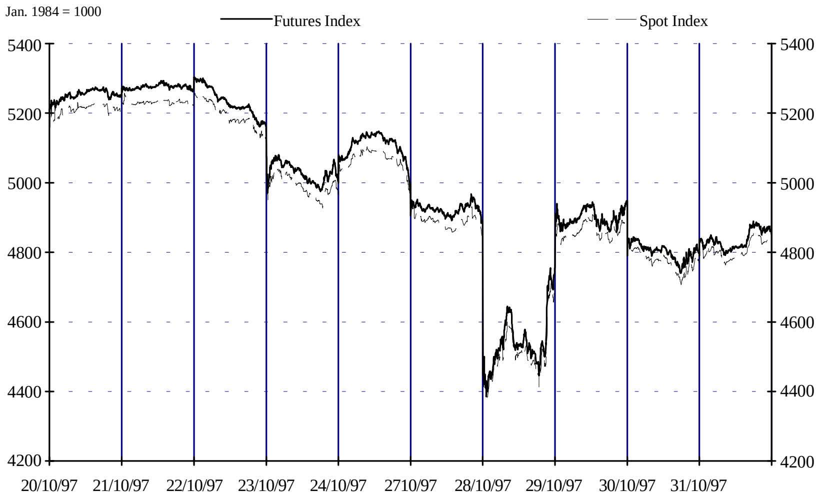

Figure A2: The US equity markets S&P 500 index: Spot and futures prices 20 October, 1997 - 31 October, 1997

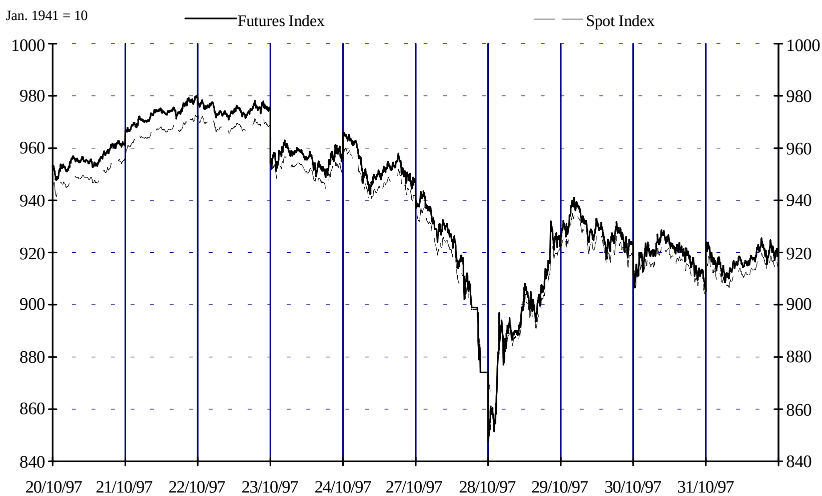

Figure A3: The UK equity markets FT-SE 100 index: Spot and futures price 19 and 20 October, 1987

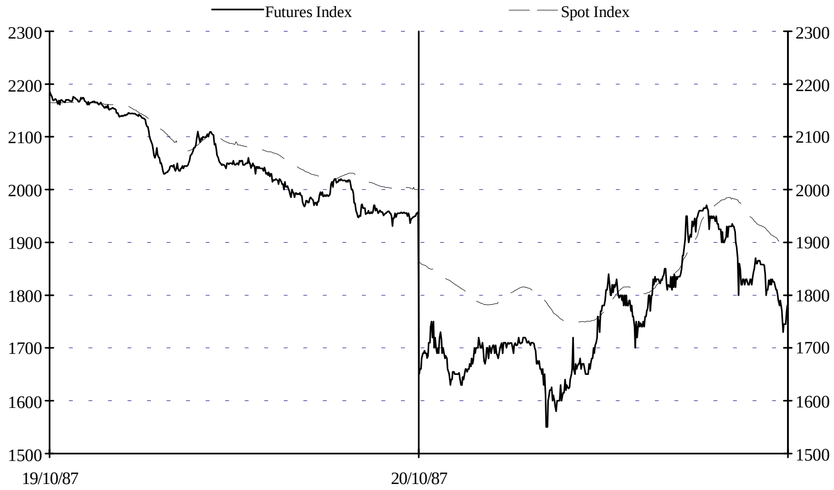

Figure A4: The UK equity markets: The stock-futures basis 19 and 20 October, 1987

Figure A5: The US equity markets S&P 500 index: Spot and futures price 19 and 20 October, 1987

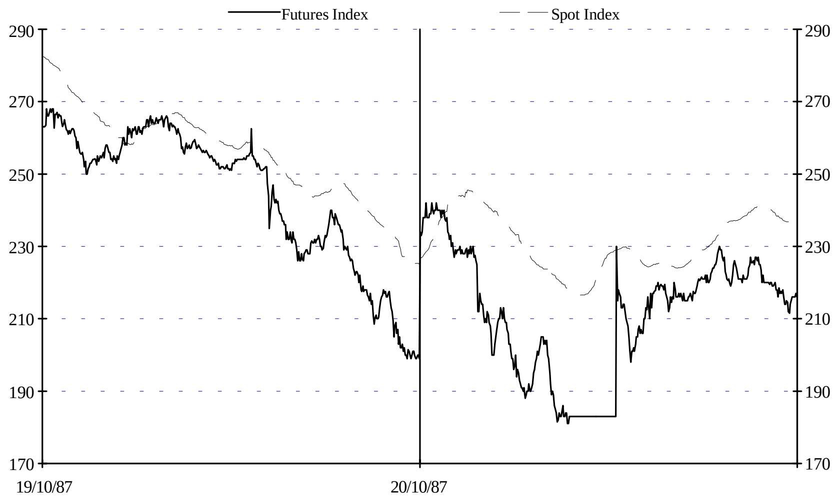

Figure A6: The US equity market: The stock-futures basis 19 and 20 October, 1987

Annex II

Microstructure of the equity markets

The purpose of this Annex is to outline the microstructure of the UK, US, Toronto and Frankfurt equity markets. Trading systems are described as they were in operation during our sample period, i.e. from 20 October, 1997 to 31 October, 1997.

London

London Stock Exchange (LSE)

- Index characteristics: The FT-SE 100 index comprises the top 100 UK-registered companies listed on the London Stock Exchange measured by market capitalisation.
- Trading system: Before 20 October, 1997 the LSE was a quote-driven market, based on competing, dual-capacity market makers who quoted bid and ask prices through SEAQ screens. Trading with customers occurred through bilateral negotiation over the telephone. Market makers were compelled by the Exchange's rules to execute a trade size up to 1 NMS (normal market size = 2.5% of the daily average trading volume) between 8:30 a.m. and 16:30 p.m. at, or within, the quoted ask and bid. Trading among market makers occurred directly over the telephone or indirectly through one of the four inter-dealer broker (IDB) screens which provided an anonymous electronic order-driven trading facility.
- SETS (Stock Exchange Electronic Trading Service) was introduced on 20 October, 1997 and functions in parallel with the traditional telephone-based system. SETS is an order book for trading FT-SE 100 stocks, on which there is no requirement for dealers to post firm bid and ask quotes. The order book opens at 8:00 a.m. for order addition and deletion and then starts execution with an uncrossing process at 8:30 a.m. It closes at 16:30 p.m.

The London International Financial Futures and Option Exchange (LIFFE)

- The FT-SE 100 index future: Contract size: Valued at GBP 25 per full index point.
  Delivery method: Cash settlement.
  Trading hours: 08:35 a.m. – 16:10 p.m.
- Trading system: The FT-SE 100 futures contract is traded through open-outcry negotiation in a pit on the trading floor at LIFFE.

Toronto

Toronto Stock Exchange (TSE)

- Index characteristics: The Toronto 35 index is composed of 35 Canadian blue chip stocks. It is a modified, capitalisation-weighted index (i.e. larger stocks have greater weight). However, there is a ceiling of 10% on the weight of each stock.
- Trading systems: The trading system at the Toronto Stock Exchange used to be a hybrid of order book (called CATS) and floor trading. Stocks were listed either as floor stocks or CATS stocks. Orders were handled according to the type of stock and the nature of the order. The trading floor closed in April 1997 and now all stocks are traded electronically through CATS. Orders for CATS are entered through terminals located in brokerage-firm offices and they are booked in price and time priority. The CATS system is to be replaced by another more advanced electronic system called TOREX.

Toronto Futures Exchange (TFE)

- The Toronto 35 Index (TXF): Contract size: CAD 500 times Toronto 35 Index level.
  Trading hours: 09:15 a.m. – 16:15 p.m.
- Trading system: The trading system of the TFE is an open outcry (last trade market) with floor traders.

Frankfurt

Deutsche Bõrse AG

- Index characteristics: The DAX 30 index comprises 30 German blue chips. It is calculated for both floor trades and for IBIS (now XETRA). Our research in this paper concentrates on the floor-based index.
- Trading system: In our sample period the Frankfurt stock exchange trading system is a hybrid between a floor and an electronic trading system called IBIS. IBIS is a country-wide computer-assisted trading system that allows dealers to trade anonymously between 8:30 a.m. and 17:00 p.m. In 1996, 38.6% of the DAX 30 shares were electronically traded on IBIS. Floor trading is organised as an auction market where market participants (banks, official and unofficial brokers) are responsible for fixing the official daily price (called “einhetskurs” or single price) which is determined once a day commencing at 12:00 noon for shares. The single price is the price that maximises the volume traded after matching supply and demand. Brokers are allowed to trade on their account any imbalance between demand and supply that should arise at the single price. Highly liquid stocks are also traded continuously on the floor in lots of 50

shares between 10:30 a.m. and 1:30 p.m. The residues of orders exceeding the round lot are traded at the single price. Therefore it might happen that a trade is executed at two different prices.

Deutche Terminbõrse (DTB)

- The DAX German Stock index: Contract size: DEM 100 per DAX Index point.
  Trading hours: 09:00 a.m. – 17: 00 p.m.
- Trading system: Trading at the DTB is based on an international electronic network. The system displays best bids and offers, allows traders to query the market for better or additional quotes and matches orders and quotes electronically.

New York

New York Stock Exchange (NYSE)

- Index characteristics: The Standard and Poor's (S&P) Composite Index comprises 500 stocks mostly traded on the NYSE, but also including a few AMEX (American Stock Exchange) and some OTC stocks.
- Trading system: Trading at NYSE is conducted as a centralised continuous auction at a designated location on the trading floor between 9:30 a.m. and 4:00 p.m. The market participants are mainly member-firms than can act both as agent dealer, member-firm broker, independent broker, and, lastly, dealers known as specialists. The specialist's functions are three: as a dealer he trades on his own account—after giving precedence to public orders—when there is an absence of public buyers or sellers; as an agent he executes orders entrusted by other brokers which have arrived electronically; as auctioneer he quotes current bid/ask prices for each of the stocks assigned to him. However, the majority of the trades are processed electronically through SuperDot, an electronic system which links member firms' order processing and trading operations to the specialist post at the floor. The market is subject to circuit breakers if the DJIA (Dow Jones industrial average) falls 350 points from the previous trading day's close. AMEX, which comprises some of the S&P 500 stocks, works with the same principles as NYSE.

There are dual-function specialists and an automated system called PER, which is similar to SuperDot.

The Chicago Mercantile Exchange (CME)

- S&P 500 Index future: Trading unit: USD 500 times S&P 500 index value.
  Trading hours: 08:30 a.m. – 15:15 p.m. (Central time).

- Trading system: Trading is effected in outcry pits. There is also a system for after-hours trading called GLOBEX. This allows trading around the clock, on Sundays and on public holidays.

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