# U.K. and U.S. Trading of British Cross-Listed Stocks: An Intraday Analysis of Market Integration

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***This article analyzes intraday patterns for U.K. and U.S. trading of British cross-listed stocks. For each market, the intraday patterns for these stocks closely resemble those of otherwise similar, non-cross-listed stocks. There is a 2-hour period each day when cross-listed stocks are traded both in New York and in London. This overlap is characterized by concentrated trading as private information, originating in New York,gets incorporated into prices in both markets. Cross-border competition for orderflow tends to reduce already declining spreads in London. By contrast, New York specialists maintain***

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***high spreads during the overlap. Overall, the evidence indicates that order flow for cross-listed securities is segmented.***

This article presents an empirical analysis of intraday data for a set of British stocks that were cross-listed on the NYSE and AMEX during 1991. Information from both U.K. and U.S. trading is exploited to examine whether the fact that these stocks are traded in multiple markets significantly affects information flow, trading patterns, and dealer competition as captured by the intraday patterns of volatility, volume, and spreads, respectively. The analysis provides a microscopic view of market integration, defined as prices in both markets reflecting the same fundamental information. There are several reasons why London and New York trading in British cross-listed stocks have the potential of being integrated. First, both London and New York are open trading environments with virtually complete access for foreign investors. Second, no regulatory constraints prevent cross-border arbitrage in cross-listed stocks and the markets are heavily arbitraged by institutional investors. Third, British cross-listed stocks are liquid in both London and New York trading. Finally, since London and New York trade different claims on the same British firms for 2 hours each day, dealers in cross-listed stocks potentially face considerable cross-Atlantic competition for order flow.

Previous empirical research has found U-shaped patterns in intraday securities prices and volume, like those in Figure 1, for singly listed stocks in virtually all time-periods, specific samples, geographic locations, and trading structures. Theoretical models have been developed to explain these empirical regularities as market participants' responses to the nature of information flow, the trading hours of an exchange, and other properties of the trading environment. If the predictions of these models are to carry over to integrated trading of cross-listed stocks, the resulting pattern should look like the thick solid line in Figure 2. The first goal of this study is to examine whether sequential trading of British cross-listed stocks produces such an intraday pattern.

There are, however, several reasons why London and New York trading of British cross-listed stocks might be less than fully integrated. The first is that these stocks trade in the form of dollar denominated American Depositary Receipts (ADRs) in the United States. An ADR is in essence a complex security that packages the claim to the underlying British firm with a service contract. Consequently, the two securities are not necessarily perfect substitutes for all investors. Another factor that might affect the degree of market integration is the costs associated with cross-border arbitrage. ADRs are in principle


**Figure 1**
**Stylized intraday pattern**
The thick solid black line traces out the stylized U-shaped intraday pattern for volatility, trading volume, and percentage spreads.

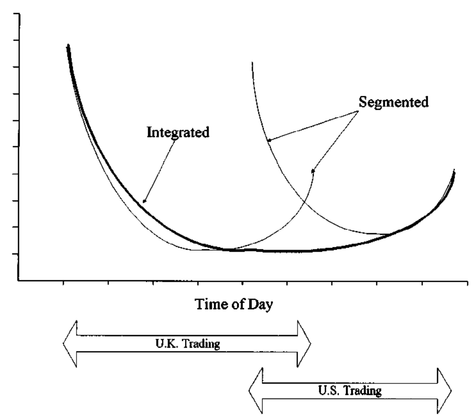


**Figure 2**
**Stylized intraday pattern for cross-listed stocks**
The thick solid black line traces out the elongated U-shape that is the predicted intraday pattern for volatility, trading volume, and percentage spreads under the hypothesis that U.K. and U.S. trading of British cross-listed stocks is perfectly integrated. The thin solid black lines trace out two U-shaped curves that represent the predicted intraday patterns for each market under the alternative hypothesis that trading of British cross-listed stocks is segmented.

fully convertible into the underlying stock, but conversion is not costless. In practice, this is less troublesome since large institutions trade on price differences between London and New York without actually converting underlying stock into ADRs, or vice versa. If an investment house maintains portfolios in both markets, they can quasi-arbitrage price differences by, for example, shorting the ADR in the United States and buying the underlying stock in London. Note, however, that such trades are not riskless.

Recognizing that London and New York trading of British cross-listed stocks might be less than perfectly integrated, the question is to what extent cross-listing affects information flow, trading activity, and spread costs as captured by intraday patterns? If the markets are completely segmented, trading of cross-listed stocks in each market would presumably be characterized by a distinct intraday pattern as indicated by the thin lines in Figure 2. To determine whether cross-listing affects intraday patterns, it is desirable to establish a benchmark pattern for each market. Natural benchmarks are intraday patterns for similar stocks traded in the same market, but that are not cross-listed on a foreign exchange. The second goal of this article is to test whether intraday patterns for British cross-listed stocks as they trade in each market differ significantly from intraday patterns for such control stocks.

If London and New York trading of cross-listed stocks is integrated, the close in London and the open in New York should not exhibit any exceptional levels of volatility, volume, or spreads. The evidence instead shows that trading of British cross-listed stocks generates a distinct and separate intraday pattern for volatility, volume, and spreads for each trading venue. These patterns resemble the U-shaped patterns found in previous work, with the important exception that spreads for cross-listed stocks decline throughout the trading day in each market.

Cross-listed stocks have significantly lower volatility during the early morning London trading compared to non-cross-listed stocks with similar trading volume, consistent with the shorter nontrading period preceding London open for stocks trading in New York. Volatility of quote prices for the underlying stocks increases significantly when New York starts trading the ADR. The explanation is that volatility for the ADRs is very high around, and immediately following, the open in New York, despite the fact that these stocks have been trading continuously for 6 hours in London. This suggests that new information is being revealed through the activity of New York–based traders and shows that there are contemporaneous information links between the markets. Furthermore, the overlap of trading is characterized by high trading volume on both sides of the Atlantic. Spreads are significantly lower for cross-listed stocks in London during the overlap than for non-cross-listed stocks. By contrast, spreads for the ADRs in New York are not significantly different from that of comparable non-cross-listed stocks despite the fact that volume is relatively more concentrated during the overlap (New York morning) for cross-listed stocks.

While no formal tests of a particular theory are conducted in this article, the empirical results are contrasted with predictions from the theoretical literature on intraday price formation and trading patterns. The empirical evidence from London generally supports models of sequential trading where traders have long-lived private information [e.g., Foster and Viswanathan (1990), Freedman (1991), and Holden and Subrahmanyam (1992)]. However, it is difficult to reconcile these models with high volatility, volume, and spreads at, and subsequent to, the New York open. To explain these empirical regularities, it is necessary both to assume a certain degree of market segmentation and to borrow insights from models of specialist market power [e.g., Brock and Kleidon (1992) and Stoll and Whaley (1990)].

This article is among the first to examine international intraday data for securities traded in multiple markets. Related work by DeJong, Nijman, and Röell (1993) and Pagano and Röell (1991) compares the quality of execution for Italian and French stocks that are cross-listed on the International Section of the London Stock Exchange. These studies focus on differences in transaction costs between markets [see Reiss and Werner (1995) for a discussion of transaction costs in London]. Their data differ distinctly from the data studied in this article in that cross-listing within Europe does not create a substantial extension of the available trading hours. Several researchers have recently studied NYSE intraday data for cross-listed securities [e.g., Chan et al. (1995), Forster and George (1993), and Freedman and Terry (1993)]. This study complements their evidence by documenting intraday patterns both in the home (British) market and in the market of foreign listing (United States).[1]

## 1. Data and Methodology

This study uses trade and quote data from the AMEX, NYSE, and London Stock Exchange's SEAQ system for January 1 through December 31, 1991.[2] The British (SEAQ) data are divided into two samples: 23 British stocks cross-listed on the NYSE or AMEX, and 23 British control stocks for NYSE/AMEX-listed British stocks. To be included in the group of cross-listed stocks, a British stock had to have a U.K. trading volume of at least £400 million and also have trades in each market for more than 190 of the 253 trading days in 1991.[3] The British control stocks were selected to match 1991 pound trading volume of

[1] In a companion article [Kleidon and Werner (1995)], we study the impact of both geography and market structure for SEAQ, NASDAQ, and NYSE/AMEX stocks.

[2] London intraday data for 1991 were kindly provided by the Quality of Markets Group at the London Stock Exchange (LSE). Due to data retrieval problems, there are some missing days in the LSE data set. Quotes are missing for January 1–13 (all firms) and October 1–14 [firms not in the Financial Times Stock Exchange (FTSE) 100 index]. Trade data are missing for March 19–31, June 25–30, September 25–30, and December 28–31. Moreover, dates when the time difference between London and New York was not 5 hours were excluded (March 31–April 7, 1991). U.S. data were drawn from the 1991 transaction data tapes distributed by the Institute for the Study of Securities Markets (ISSM).

[3] These rules exclude Attwoods plc.; Beazer plc.; Courtaulds plc.; Huntingdon International plc.; Manpower plc.; and Saatchi & Saatchi plc. from the sample.

British cross-listed stocks in the U.K. as reported in *Stock Exchange Quarterly* (Winter 1991, Table 8C). To ensure that the control stocks did not trade in a major market during the London overnight, British stocks cross-listed in Tokyo were excluded. This way, the nontrading period is always going to be shorter for cross-listed stocks than for their controls.

Similarly, the U.S. data are divided into two samples: 28 British ADRs traded on the NYSE or AMEX, and 28 U.S. control stocks for NYSE/AMEX-listed British ADRs. There are 28 British ADRs because two of the firms have multiple ADRs listed on the NYSE.[4] U.S. control stocks were selected to match 1991 average daily dollar trading volume (and price level) of British ADRs in the United States, calculated using data from the Center for Research in Security Prices (CRSP). S&P 500 stocks were excluded to reduce the risk of attributing to cross-listing any differences in intraday patterns that might be the result of differences in the extent of index trading. The stocks and their 1991 trading volume are reported in the Appendix (Table A1).

Market makers in London are obliged to post firm, two-way quotes from 0830 to 1630 London time. Trading hours for the NYSE and AMEX are 0930 to 1600 New York time. This study focuses exclusively on these "regular trading hours." The trading day in each market is divided into 15-minute time intervals. The length of a time interval was chosen to provide computational efficiency while still enabling detection of any spillovers between markets during the overlap of trading (eight intervals). The first time interval in the British (U.S.) data is 0830–0844 (0930–0944) and the last time interval is 1630–1644 (1600–1614). In other words, there are 33 intervals of 15 minutes for the British data and 27 intervals for the U.S. data. The Appendix outlines how volatility, pound (dollar) volume, and spreads as percent of price were calculated from the raw data for each stock, time interval, and trading day.

The literature does not provide any theoretical guidance for how intraday seasonalities for groups of securities should be measured or summarized. This article uses ordinary least squares regressions (with heteroskedasticity-consistent standard errors) to characterize intraday patterns. Preliminary analysis of the data indicated that there are strong firm-specific effects (see Table 2). The data are also characterized by considerable heteroskedasticity. In this article, two methods are used to correct for firm-specific effects. Both entail expressing intraday patterns as deviations from a benchmark level.

[4] There are five separate ADR issues for Barclays Bank and two separate ADR issues for Royal Bank of Scotland.

The first regression model (Model I) estimates the time-of-day effects, denoted $\gamma_t$ for non-cross-listed stocks and $\gamma_t+\mu_t$ for cross-listed stocks, controlling for firm effects, denoted $\beta_f$. The regressions take the following form:

$$X^j_{f,t} = \sum_{i=1}^{N_{smp}+N_{ctl}} F^f_i \beta_i + \sum_{s\neq\tau} I^t_s \gamma^j_s + \sum_{i=1}^{N_{smp}} \sum_{s\neq\tau} F^f_i I^t_s \mu^j_s + \epsilon^j_{f,t}, \qquad (1)$$

where $X^j_{f,t}$ is the variance of quote prices, variance of trade prices, pound (dollar) volume, or spreads for data from market $j \in$ (SEAQ, NYSE/AMEX); $N_{smp}$ ($N_{ctl}$) is the number of firms in the sample (control group); and $s \in (1, T^j)$ where $T^j$ the number of time intervals per day for market $j$. $F^f_i$ takes the value one if $i = f$ and zero otherwise, $I^t_s$ takes the value one if $s = t$ and zero otherwise, and $\epsilon_{f,t}$ is an error term. In other words, cross-listed firms and their controls are combined into one regression. A significant coefficient $\hat{\mu}^j_t$ means that the time-of-day effect at time $t$ in market $j$ for cross-listed stocks is significantly different from the time-of-day effect for control stocks in that same market. Midday is taken to be $\tau$ = 1215–1230. Note that all time-of-day effects are expressed as *absolute* deviations from the common (group) time-of-day effect at midday.

The second model (Model II) provides an alternative way of correcting for firm effects. Firm-specific means of each variable, $\hat{\omega}^j_f$, are estimated in a first-pass regression that does not control for time-of-day effects:

$$X^j_{f,t} = \sum_{i=1}^{N_{smp}+N_{ctl}} F^f_i \omega^j_i + \nu^j_{f,t}. \qquad (2)$$

Each observation is then normalized by the appropriate firm-specific mean, that is, $Y^j_{f,t} \equiv X^j_{f,t}/\hat{\omega}^j_f$. The following regression is then estimated:

$$Y^j_{f,t} = \sum_{s=1}^{T_j} I^t_s \alpha^j_s + \sum_{i=1}^{N_{smp}} \sum_{s=1}^{T_j} F^f_i I^t_s \nu^j_s + \eta^j_{f,t}, \qquad (3)$$

where time-of-day effects for non-cross-listed stocks are given by $\alpha_t$ and for cross-listed stocks by $\alpha_t+\nu_t$. A significant coefficient $\hat{\nu}^j_t$ means that the time-of-day effect at time $t$ in market $j$ for cross-listed stocks is significantly different from the time-of-day effect for control stocks in that same market. Here, each time-of-day effect is the average of individual firms' time-of-day effect expressed as a *percentage* of the firm-specific intraday level.

The maintained null hypothesis for the statistical tests is that there is no difference between the intraday patterns of cross-listed stocks and controls. Two sets of tests consistent with this null hypothesis are performed. The first is a set of $t$-tests of the null hypotheses $\mu_t^j = 0$ and $\nu_t^j = 0$ for each time interval $t$ during the day in market $j$. The second set of $F$-tests examines the joint restriction $\mu_t^j = \nu_t^j = 0$ for all $t$ in market $j$. Differences in intraday patterns across markets are not formally tested, since such tests would require intraday data on exchange rates, interest rates (to calculate the cost of carry due to differences in settlement rules), and information about commissions and taxes in each market—data that are not publicly available. Standard errors are calculated based on a heteroskedasticity-consistent covariance matrix.[5] The large sample sizes, however, dictate that statistical inferences be both conservative in terms of significance levels and be complemented with an assessment of the economic significance of differences in calculated statistics.

## 2. Levels of Volatility, Volume, and Spreads

This section compares the average levels of intraday securities prices and volume for stocks in the cross-listed (sample) and non-cross-listed (control) groups. Such comparisons provide an assessment of whether the control stocks are reasonable matches for the set of British cross-listed stocks. They also provide an overview of the cross-sectional distribution of volatility, volume, and spreads.

### 2.1 Average volatility, volume, and spreads by group of stocks

The distributions of the statistics calculated from the raw data for sample stocks and controls are reported in Table 1, panels A and B. Statistical tests of differences in means and medians (assuming independence) between sample stocks and control stocks are reported in panel C. Control stocks were chosen to match sample stocks based on mean daily trading volume. Table 1, however, shows that mean trading volume is significantly larger for sample stocks than for their controls. In London, this is a reflection of the fact that cross-listed stocks represent 13 of the 20 highest ranked stocks based on SEAQ trading volume.[6] New York trading volume is matched quite well in terms of medians (not reported), whereas the mean trading volume

[5] See White (1980). It proved computationally infeasible to calculate robust standard errors [Newey and West (1987)] for the regressions in this article. The regressions have up to 370,440 observations and 110 right-hand side variables.

[6] Quality of Markets Companies Book (1992, Table 2).

is higher for cross-listed stocks.[7] Mean trading volume per sample stock in London translates into about £7.9 million per day compared to about £4.7 million per day for controls. New York mean trading volume corresponds to roughly \$4.8 million per day for a typical sample stock compared to roughly \$3.6 million per day for a typical control stock.

These numbers indicate that New York trading volume is a large fraction of total trading volume for British cross-listed stocks. Based on daily 1991 exchange rates, the total London trading volume per stock is approximately \$13.6 million. In other words, roughly one-fourth of the combined U.K.–U.S. volume in British cross-listed stocks is traded in the United States. U.S. trading would represent an even larger fraction of the combined volume if the numbers were corrected for double-counting of dealer-intermediated customer trades as well as the extent of interdealer trading in each market. However, the importance of U.S. trading would diminish somewhat if trading of dollar ADRs in the U.K. was accounted for (see Table A1). The distribution of U.S. order flow shows that British ADRs trade infrequently—less than 50 percent of the 15-minute intervals contain a trade. On the other hand, when trades occur they tend to be large. A similar, albeit less extreme, order-flow pattern is found for U.S. control stocks.

The fact that trading volume for cross-listed stocks exceeds that of controls might affect the average levels of both volatility and spreads. Theoretical models predict, and empirical work confirms, that more liquid stocks *ceteris paribus* are associated with lower volatility and lower spreads [see, e.g., Amihud and Mendelson (1987), Biais (1993), Demsetz (1968), Easley et al. (1995), Ho and Stoll (1981, 1983), and Stoll (1978a,b)]. Mean intraday volatility is indeed significantly lower for sample stocks than for controls during both U.K. and U.S. trading. The volatility difference is larger in magnitude in New York than in London. Median volatility is generally significantly lower for sample stocks. The sole exception is that London quote-price volatility is significantly higher for sample stocks than for controls, although the difference in magnitude is relatively small.

Volatility based on trade prices is an order of magnitude larger than volatility based on quotes during U.K. trading. This pattern might derive from trade prices being excessively noisy due to time-stamping errors.[8] The large difference between trade-price volatility and quote-

[7] The main reason for this is that it is difficult to find a non-S&P 500 stock that matches the trading volume of Glaxo Holdings' ADR. Glaxo Holdings featured on the list of most heavily traded NYSE stocks during our sample period. See further Table A1 in the Appendix.

[8] See, for example, DeJong, Nijman, and Röell (1993) and Reiss and Werner (1995) for discussions of time-stamping errors in U.K. transaction data. This property of the data motivates the use of

**Table 1**
**Descriptive 15-minute statistics**

| | Volatility of quote prices (×1,000,000) | Volatility of trade prices (×1,000,000) | Trading volume thousand (×1,000; pounds or dollars) | Spreads as percent of price |
|---|---|---|---|---|
| **Panel A: U.K. trading** | | | | |
| **Sample stocks** | | | | |
| Mean | 3.51 | 31.36 | 238.77 | 0.90 |
| Standard deviation | 31.29 | 305.53 | 634.28 | 0.50 |
| First quartile | 0.00 | 0.07 | 3.38 | 0.54 |
| Median | 0.02 | 2.77 | 25.70 | 0.79 |
| Third quartile | 1.18 | 24.89 | 195.96 | 1.16 |
| *Number of observations* | *173,920* | *164,822* | *178,194* | *179,378* |
| **Control stocks** | | | | |
| Mean | 4.35 | 41.70 | 142.83 | 1.03 |
| Standard deviation | 30.91 | 187.35 | 478.45 | 0.43 |
| First quartile | 0.00 | 0.11 | 2.12 | 0.74 |
| Median | 0.01 | 5.30 | 13.28 | 0.99 |
| Third quartile | 0.54 | 44.43 | 95.31 | 1.24 |
| *Number of observations* | *174,432* | *161,088* | *173,638* | *179,906* |
| **Panel B: U.S. trading** | | | | |
| **Sample stocks** | | | | |
| Mean | 5.07 | 8.86 | 177.65 | 0.94 |
| Standard deviation | 59.45 | 60.01 | 672.54 | 0.90 |
| First quartile | 0.00 | 0.01 | 0.00 | 0.46 |
| Median | 0.02 | 0.04 | 0.00 | 0.67 |
| Third quartile | 0.65 | 3.07 | 51.80 | 1.06 |
| *Number of observations* | *171,050* | *158,807* | *180,488* | *177,647* |
| **Control stocks** | | | | |
| Mean | 9.67 | 13.79 | 132.31 | 0.99 |
| Standard deviation | 65.23 | 56.41 | 717.22 | 0.65 |
| First quartile | 0.01 | 0.01 | 0.00 | 0.52 |
| Median | 0.04 | 0.07 | 4.83 | 0.86 |
| Third quartile | 3.19 | 9.52 | 55.80 | 1.26 |
| *Number of observations* | *177,459* | *168,351* | *189,952* | *184,288* |

**Table 1**
**(continued)**

| | **Volatility of quote prices** (×1,000,000) | **Volatility of trade prices** (×1,000,000) | **Trading volume thousand** (×1,000; pounds or dollars) | **Spreads as percent of price** |
|---|---|---|---|---|
| **Panel C: Test for differences between samples and controls in each market** | | | | |
| **Student t-test of means** | | | | |
| U.K. sample - U.K. controls = 0 | **−7.90** | **−11.62** | **50.55** | **−88.17** |
| U.S. sample - U.S. controls = 0 | **−21.73** | **−24.22** | **19.83** | **−19.25** |
| **Wilcoxon's test of medians** | | | | |
| U.K. sample - U.K. controls = 0 | **18.21** | **−43.10** | **60.97** | **−121.01** |
| U.S. sample - U.S. controls = 0 | **−81.79** | **−56.32** | **−21.38** | **−76.28** |
| **Panel D: Cross-listed stocks during U.K.–U.S. trading overlap** | | | | |
| **U.K. trading (0930–1130 New York time)** | | | | |
| Mean | 3.66 | 32.62 | 512.31 | 0.86 |
| Standard deviation | 18.76 | 119.44 | 1,384.18 | 0.49 |
| First quartile | 0.01 | 0.10 | 3.99 | 0.51 |
| Median | 0.07 | 3.12 | 52.62 | 0.75 |
| Third quartile | 2.02 | 24.30 | 503.71 | 1.12 |
| *Number of observations* | *43,296* | *41,849* | *47,169* | *48,708* |
| **U.S. trading (0930–1130 New York time)** | | | | |
| Mean | 8.44 | 11.84 | 292.49 | 0.98 |
| Standard deviation | 88.94 | 71.13 | 941.24 | 0.96 |
| First quartile | 0.01 | 0.01 | 0.00 | 0.47 |
| Median | 0.04 | 0.08 | 7.76 | 0.73 |
| Third quartile | 3.23 | 5.74 | 129.44 | 1.14 |
| *Number of observations* | *52,506* | *45,205* | *51,568* | *59,099* |
| **£/$ Exchange rate (1000–1300 New York time)** | | | | |
| Mean | 1.20 | | | |
| Standard deviation | 7.03 | | | |
| *Number of observations* | *249* | | | |

Test statistics significant at the 1 percent level are boldfaced in panel C.

price volatility is also consistent with evidence that quotes on SEAQ move relatively infrequently [see Reiss and Werner (1995)]. However, the fact that quote-price volatility for NYSE/AMEX stocks is of similar magnitude suggests that the problem is the trade data and not the quotes.

Finally, mean and median spreads are significantly lower for sample stocks than for their controls. This is consistent with the negative relationship between percentage spreads and trading volume that has been found in the literature. Moreover, stocks with high volume are also likely to have more competing market makers and, indeed, control stocks have on average one fewer market maker than sample stocks.[9] The U.S. median (mean) spread for sample stocks is slightly lower (higher) than U.K. spreads at 67 (94) basis points. U.S. control stocks have a median (mean) spread of 86 (99) basis points.

### 2.2 Average volatility, volume, and spreads by group of stock during the overlap

Panel D of Table 1 examines the levels of intraday prices and volume for sample stocks during the overlap of trading. To facilitate comparisons between U.K. and U.S. trading, pound volume was translated into dollars using midpoint quotes of daily exchange rates sampled around 1700 London time. These, and other intradaily exchange rates, were retrieved from Tradeline International.[10]

Based on the first column of the table, mean quote-price volatility is higher in New York (8.44) than in London (3.66) during the overlap. These numbers do not, however, correct for the impact of exchange rates. To estimate (roughly) the effect of intraday exchange rate volatility exchange rates were sampled daily at 1000 and 1300. Under the assumption that exchange rate volatility is proportional to time, the estimated mean 15-minute exchange rate volatility is 1.20 with a standard deviation of 7.03 ($n = 249$). This implies that the correlation between the pound/dollar exchange rate and the price of ADRs would have had to be less than -0.94 for New York quote-price volatility, when expressed in pounds, to be lower than the one in London. Thus, stock prices and exchange rates need to have been almost perfectly negatively correlated for the volatility difference to disappear. Trade prices are more volatile in London, but as discussed

volatility based on midpoint quote returns as an alternative measure of information flow.

[9] The median number of market makers is 15 for sample stocks and 14 for controls. These statistics were calculated based on the number of market makers for each individual stock, as of March 29, 1991 [Quality of Markets Companies Book (1991, Table 3)].

[10] Tradeline International reports daily quotes from five separate geographic locations. The quotes are retrieved approximately at 1000, 1300, 1500, 1800, and 2315 GMT each day.

above, this is probably a result of a higher frequency of time-stamping errors for the British data.

Mean and median dollar volume are both considerably higher in London during the overlap. A British cross-listed stock trades on average \$4.1 million in London compared to \$2.3 million in New York during the overlap each day. Thus, the primary (home) market seems to dominate the secondary market while both markets are trading British cross-listed stocks. However, the same caveat that was mentioned in Section 2.1 applies—trading volume for dealer markets and floor trading systems should not be compared without correcting for differences in the extent of dealer-intermediated trading and pure interdealer trading [see Gould and Kleidon (1995)]. However, it seems reasonable to conclude that both markets are highly liquid during the overlap of trading.

As emphasized in Reiss and Werner (1995), it is impossible to compare the spread costs between two markets without correcting for the characteristics of each particular market. Moreover, spread costs represent only part of the costs of trading. Other costs, for example, commissions and turnover taxes, are also likely to affect investors' transaction costs and hence their decision on where to transact. Absent detailed data on other costs of trading, it is impossible to conclude whether London or New York offers significantly lower comprehensive transaction costs. Keeping these caveats in mind, it is nevertheless instructive to compare spread costs between London and New York for British cross-listed stocks. The last column of panel D shows that British cross-listed stocks in London have lower mean spreads, but slightly higher median spreads, than in New York. Mean spreads are 86 basis points in London and 98 basis points in New York. The spread distributions are thus both skewed, with New York being relatively more skewed toward high spreads than London. The four basis point difference in medians is almost negligible in economic terms. Even small switching costs could thus be enough to deter traders from switching from one market to the other for most of the British cross-listed stocks in this sample based on spreads alone.

### 2.3 Average volatility, volume, and spreads by individual stock

The first-pass regressions [Equation (2)] that estimate firm effects can be used to study the cross-sectional distribution of volatility, volume, and spreads. The estimated firm effects are reported in Table 2, panels A and B. All firm effects are significant at the 1 percent level based on a heteroskedasticity-consistent covariance matrix.

A few things are worth noting about the cross section of firm effects. There is considerable dispersion of estimated firm effects for all four subsamples. This motivates the correction for firm effects when

**Table 2**
**Estimated firm effects for British cross-listed stocks and their control stocks**

| Sample stocks | | | | | Control stocks | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Code** | **Volatility of quote prices** | **Volatility of trade prices** | **Trading volume** | **Percentage spreads** | **Code** | **Volatility of quote prices** | **Volatility of trade prices** | **Trading volume** | **Percentage spreads** |
| **Panel A: U.K. trading** | | | | | | | | | |
| GLXO | 0.0415 | 0.1748 | 563.6 | 0.45 | GUIN | 0.0218 | 0.1592 | 316.88 | 0.56 |
| HNSN | 0.0285 | 0.2573 | 305.5 | 0.66 | GEC | 0.0322 | 0.3736 | 190.10 | 0.93 |
| BT.A | 0.0215 | 0.0995 | 393.5 | 0.51 | TSCO | 0.0302 | 0.4378 | 170.94 | 0.97 |
| BP. | 0.0327 | 0.2217 | 411.1 | 0.70 | MKS | 0.0361 | 0.3277 | 204.26 | 0.79 |
| ICI | 0.0278 | 0.1255 | 362.8 | 0.42 | BA. | 0.0498 | 0.6581 | 163.18 | 1.34 |
| GMET | 0.0232 | 0.3179 | 357.9 | 0.40 | PRU | 0.0397 | 0.3949 | 140.93 | 0.97 |
| SHEL | 0.0177 | 0.1636 | 362.8 | 0.55 | AYL | 0.0206 | 0.2787 | 136.82 | 0.90 |
| SB.A | 0.0241 | 0.1309 | 274.5 | 0.44 | LLOY | 0.0521 | 0.3354 | 159.24 | 1.05 |
| SB.E | 0.0227 | 0.0569 | 103.7 | 0.81 | LADB | 0.0988 | 0.2602 | 145.34 | 1.10 |
| GAS | 0.0319 | 0.1654 | 362.8 | 0.73 | ROYL | 0.0700 | 0.6647 | 115.75 | 1.40 |
| BATS | 0.0280 | 0.2604 | 255.1 | 0.74 | SBRY | 0.0238 | 0.3250 | 135.30 | 0.88 |
| BARC | 0.0429 | 0.3564 | 243.1 | 0.86 | ANL | 0.0266 | 0.2136 | 143.20 | 0.99 |
| CW. | 0.0332 | 0.5070 | 217.9 | 1.08 | RR. | 0.0639 | 0.5564 | 130.87 | 1.34 |
| NWB | 0.0738 | 0.5076 | 214.8 | 1.15 | KGF | 0.0248 | 0.1733 | 127.18 | 0.74 |
| ULVR | 0.0154 | 0.2447 | 225.5 | 0.75 | BOOT | 0.0239 | 0.2205 | 144.79 | 0.73 |
| BASS | 0.0316 | 0.1808 | 163.7 | 0.68 | MID | 0.1004 | 1.0387 | 127.24 | 1.70 |
| BS. | 0.0850 | 0.8765 | 151.0 | 1.39 | FTE | 0.0634 | 0.5057 | 126.11 | 1.06 |
| RTZ | 0.0241 | 0.3445 | 165.9 | 0.88 | WLMS | 0.0264 | 0.4049 | 82.15 | 1.13 |
| BAY | 0.0584 | 0.5874 | 106.5 | 1.34 | WCM | 0.0470 | 0.2180 | 113.86 | 0.72 |
| VOD | 0.0450 | 0.3549 | 78.8 | 1.32 | HLD | 0.0752 | 0.8441 | 74.72 | 1.66 |
| WILC | 0.0348 | 0.2785 | 62.1 | 1.30 | REED | 0.0285 | 0.2359 | 84.76 | 1.11 |
| RBOS | 0.0373 | 0.5352 | 60.2 | 1.63 | LAND | 0.0174 | 0.2602 | 102.06 | 0.88 |
| NFC | 0.0268 | 0.4132 | 32.5 | 1.83 | RDLD | 0.0271 | 0.2141 | 95.65 | 0.82 |
| **Adjusted $R^2$** | 0.0151 | 0.0141 | 0.1633 | 0.9150 | **Adjusted $R^2$** | 0.0251 | 0.0611 | 0.0915 | 0.9182 |
| ***F*-value** | 117.1 | 103.2 | 1,512.8 | 83,928.1 | ***F*-value** | 196.6 | 456.4 | 759.8 | 87,832.5 |

**Table 2**
**(continued)**

| Code | Sample stocks: Volatility of quote prices | Sample stocks: Volatility of trade prices | Sample stocks: Trading volume | Sample stocks: Percentage spreads | Code | Control stocks: Volatility of quote prices | Control stocks: Volatility of trade prices | Control stocks: Trading volume | Control stocks: Percentage spreads |
|---|---|---|---|---|---|---|---|---|---|
| **Panel B: U.S. trading** | | | | | | | | | |
| GLX | 0.0577 | 0.0764 | 1,932.26 | 0.40 | RN | 0.1653 | 0.4207 | 1,257.08 | 1.23 |
| HAN | 0.0581 | 0.1665 | 517.84 | 0.75 | CVN | 0.1526 | 0.2482 | 396.58 | 0.72 |
| BTY | 0.0241 | 0.0299 | 214.49 | 0.47 | FFC | 0.0216 | 0.0205 | 187.91 | 0.46 |
| BP | 0.0184 | 0.0224 | 466.31 | 0.30 | CIR | 0.1318 | 0.1577 | 381.37 | 0.57 |
| ICI | 0.0224 | 0.0235 | 188.97 | 0.35 | LIT | 0.0348 | 0.0369 | 211.28 | 0.34 |
| GRM | 0.0473 | 0.1045 | 528.41 | 0.55 | PA | 0.1210 | 0.1456 | 388.16 | 0.63 |
| SC | 0.0246 | 0.0395 | 83.52 | 0.54 | PMS | 0.0592 | 0.0600 | 94.77 | 0.68 |
| SBE | 0.0371 | 0.0515 | 697.47 | 0.32 | SLM | 0.0755 | 0.0894 | 690.43 | 0.46 |
| SBH | 0.0287 | 0.0341 | 35.19 | 0.55 | HSB | 0.0554 | 0.0599 | 43.67 | 0.60 |
| BRG | 0.0299 | 0.0418 | 64.01 | 0.71 | ATE | 0.0206 | 0.0599 | 59.29 | 0.64 |
| BTI | 0.0783 | 0.0921 | 84.27 | 1.10 | TDW | 0.2997 | 0.4038 | 66.67 | 1.51 |
| BCS | 0.0536 | 0.1347 | 5.36 | 2.71 | BRE | 0.0376 | 0.0524 | 6.05 | 1.11 |
| BCB.PR.A | 0.0423 | 0.1635 | 14.20 | 0.94 | RJF | 0.1475 | 0.1607 | 17.72 | 1.29 |
| BCB.PR.B | 0.0317 | 0.1245 | 10.64 | 0.90 | NGA | 0.0620 | 0.0765 | 12.02 | 1.35 |
| BCB.PR.C | 0.0228 | 0.1065 | 10.56 | 0.99 | LOG | 0.0795 | 0.1842 | 12.54 | 1.10 |
| BCB.PR.D | 0.0193 | 0.1055 | 26.54 | 0.72 | WPS | 0.0410 | 0.1007 | 27.49 | 0.91 |
| CWP | 0.0408 | 0.0612 | 72.62 | 0.85 | CQ | 0.0629 | 0.0977 | 70.67 | 0.85 |
| NW | 0.0357 | 0.0309 | 6.68 | 1.33 | CSS | 0.0459 | 0.0551 | 5.36 | 1.10 |
| UL | 0.0310 | 0.0422 | 45.17 | 0.64 | OEA | 0.3011 | 0.1246 | 42.72 | 1.00 |
| BAS | 0.0310 | 0.0620 | 5.13 | 1.48 | BKF | 0.0824 | 0.1533 | 8.47 | 1.21 |
| BST | 0.0749 | 0.1850 | 75.99 | 0.88 | CDO | 0.1355 | 0.2032 | 78.82 | 1.06 |
| RTZ | 0.0326 | 0.0344 | 5.99 | 1.35 | RSP | 0.0787 | 0.1091 | 5.12 | 1.89 |
| BAB | 0.0571 | 0.0968 | 176.68 | 0.66 | GNE | 0.1142 | 0.1792 | 210.72 | 0.74 |
| VOD | 0.0447 | 0.0591 | 179.31 | 0.48 | MDA | 0.0315 | 0.0466 | 179.38 | 0.53 |
| WCG | 0.0537 | 0.0583 | 41.06 | 1.11 | KU | 0.0429 | 0.1409 | 44.38 | 0.91 |
| RBS.PR | 0.0357 | 0.1051 | 12.18 | 0.88 | MI | 0.0668 | 0.0843 | 18.45 | 1.28 |
| RBS.PR.B | 0.0093 | 0.0789 | 35.44 | 0.59 | PCL | 0.0699 | 0.1811 | 44.90 | 0.94 |
| NFC | 0.3625 | 0.4256 | 1.61 | 3.59 | III | 0.1893 | 0.2498 | 1.31 | 2.67 |
| **Adjusted $R^2$** | 0.0175 | 0.0358 | 0.2322 | 0.8053 | **Adjusted $R^2$** | 0.0333 | 0.0830 | 0.0943 | 0.8650 |
| ***F*-value** | 110.1 | 211.4 | 1,950.8 | 26,246.0 | ***F*-value** | 219.1 | 545.4 | 707.2 | 42,158.5 |

**Table 2**
**(continued)**

**Panel C: Cross-sectional simple correlations of firm effects**

| **U.K. sample** $n = 23$ | Volatility of trade prices | Trading volume | Percentage spreads |
|---|---|---|---|
| Volatility of quote prices | **0.78** (5.71) | −0.23 (−1.08) | **0.48** (2.51) |
| Volatility of trade prices | | **−0.48** (−2.51) | **0.72** (4.75) |
| Trading volume | | | **−0.81** (−6.33) |

| **U.K. controls** $n = 23$ | Volatility of trade prices | Trading volume | Percentage spreads |
|---|---|---|---|
| Volatility of quote prices | **0.70** (4.49) | −0.18 (−0.84) | **0.74** (5.04) |
| Volatility of trade prices | | −0.24 (−1.13) | **0.91** (10.06) |
| Trading volume | | | **−0.45** (−2.31) |

| **U.S. sample** $n = 28$ | Volatility of trade prices | Trading volume | Percentage spreads |
|---|---|---|---|
| Volatility of quote prices | **0.87** (9.00) | −0.03 (−0.15) | **0.76** (5.96) |
| Volatility of trade prices | | −0.10 (0.77) | **0.72** (5.61) |
| Trading volume | | | **−0.33** (−1.78) |

| **U.S. controls** $n = 28$ | Volatility of trade prices | Trading volume | Percentage spreads |
|---|---|---|---|
| Volatility of quote prices | **0.72** (5.29) | +0.16 (0.83) | **0.41** (2.29) |
| Volatility of trade prices | | **0.45** (2.57) | **0.43** (2.43) |
| Trading volume | | | −0.25 (−1.32) |

The numbers in panels A and B are the estimated firm effects from Equation (2) in the text. All coefficients are significant at the 1 percent level based on a heteroskedasticity-consistent covariance matrix of parameters. Panel C reports correlations calculated based on the cross-section of estimated firm effects in panels A and B. Correlations significant at the 5 percent level are boldfaced. The $t$-values are given in parenthesis below each coefficient.

estimating time-of-day effects. Whereas firm effects explain most of the variation in percentage spreads, they are less successful in explaining the intraday variation in volume and volatility. As indicated in the previous discussion, the firm-by-firm matching on trading volume is considerably closer for U.S. trading in panel B than for U.K. trading in panel A.

There is generally a negative correlation between spreads and trading volume and a positive correlation between spreads and volatility. This impression is confirmed by the correlations reported in panel C of Table 2. Spreads and trading volume are significantly negatively correlated at the 5 percent level in 6 out of 8 cases. Spreads and volatility are significantly positively correlated at the 5 percent level for all cases regardless of whether volatility of quote prices or volatility of trade prices is used. These cross-sectional patterns are consistent with previous evidence in the literature [see, e.g., Stoll (1978b)].

## 3. Intraday Volatility Patterns for Sample Stocks and Controls

Figure 3a shows that volatility patterns based on quote prices are U-shaped for all subsamples (recall that overnight volatility is excluded from the analysis). Quote-price volatility is higher during the morning than at midday. Afternoon volatility is also higher than at mid-day, but the increase is comparatively small in magnitude. This general pattern is well known from previous work on U.S. data [Foster and Viswanathan (1993) and Wood, McInish, and Ord (1985)]. U-shaped volatility has also recently been shown to be a characteristic of British data [Kleidon and Werner (1993), and Abhyankar et al. (1994)]. Several theories have been proposed to explain this empirical regularity. The models are generally more successful in explaining why volatility of prices are initially high and then decline. This pattern could for example be caused by prices only slowly reacting to overnight information as suggested by Amihud and Mendelson (1991), or because imperfectly competitive strategic traders with long-lived private information trade more aggressively on this information early on in the day as suggested by Foster and Viswanathan (1993) and Holden and Subrahmanyam (1992).

These stories have trouble when it comes to explaining the evidence for cross-listed securities. If the volatility pattern were simply caused by information accumulated prior to the start of trading *and* the two markets were integrated in an information sense, the intraday data should be characterized by continuously declining volatility as British stocks are trading first in London and then in New York. It might be overly optimistic to expect this extreme form of market integration to characterize the data. A more modest request for evi-

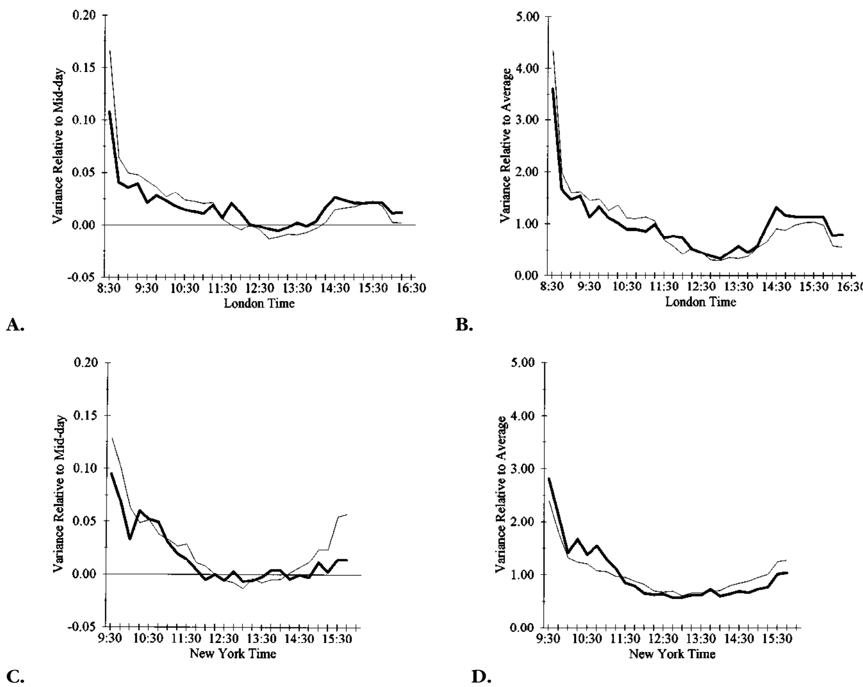


**Figure 3a**
**Intraday quote price variances**
The figures graph the estimated intraday quote price variance patterns. The top panels (A and B) present the results for U.K. trading and the bottom panels (C and D) give the results for U.S. trading. The estimated time-of-day effects for cross-listed stocks are represented by thick solid black lines and the time-of-day effects for non-cross-listed stocks are represented by thin solid black lines. Model I results are reported in panels A and C, while Model II results can be found in panels B and D.

dence of market integration is that the intraday volatility pattern be significantly affected by the fact that stocks are cross-listed. Essentially, the intraday pattern should be “flatter” for cross-listed stocks than for control stocks.

Table 3a reports the results from tests for differences in intraday quote-price volatility for British cross-listed stocks and their controls in each market. Volatility during the first interval of London trading is significantly lower for sample stocks than for controls regardless of model. The magnitude of this difference in terms of normalized time-of-day effects (Model II) is roughly −0.74. Variability of quote prices is low between 1300 and 1400—lunch time in London. As New York open approaches, that is, 1430, volatility picks up for all British stocks. Quotes are significantly more variable for the stocks that are cross-listed in New York than for controls just prior to, and coinciding with, New York open. The difference in normalized time-of-day effects (Model II) is between 0.30 and 0.40. In fact, volatility is relatively more concentrated during the overlap for the British stocks that are also listed in New York. These stocks have 26.1 percent of daily volatility, as measured by the sum of coefficients in a regression estimating only time-of-day effects (not reported), concentrated to the overlap compared to 22.0 percent for control stocks.

The timing of the elevated volatility in London suggests that it is related to the simultaneously ongoing trading activity in New York. Indeed, panels C and D show that quote prices of cross-listed stocks are highly volatile during New York morning trading. The same is true for U.S. controls. While high volatility for control stocks potentially can be explained by a process of price discovery following a nontrading period, this story does not work for cross-listed stocks. These stocks have been trading continuously in London for 6 hours prior to the New York open.

If this were the full story, the results from U.S. trading in Table 3a are somewhat puzzling. Model I results show that New York morning volatility relative to midday is lower for sample stocks than for controls, but the difference for the first 15 minutes is insignificant. Only between 0945 and 1015 are quote prices significantly less variable for cross-listed stocks. In contrast, Freedman and Terry (1993) find that returns of portfolios of dually listed U.S. stocks are significantly less volatile during the first half hour of trading than those of stocks not traded abroad.[11] Moreover, the results from Model II indicate that volatility when measured relative to the firm-specific average is higher for sample stocks than for controls. The difference is significant for a few time intervals during early morning trading, just prior to the London close. Quotes for cross-listed stocks have a relatively larger fraction of their average intraday volatility during the overlap. Based on the estimated time-of-day effects (not reported), British cross-listed stocks have 51.2 percent of their daily volatility during the overlap compared to 42.0 percent for U.S. control stocks. Chan et al. (1995) find a similar pattern for U.S. trading of European and Japanese NYSE/AMEX-listed stocks during 1986 to 1987.

Intraday volatilities for sample stocks and controls are indistinguishable for most of the rest of the New York trading day. There is, for example, no significant increase in New York volatility when London closes at 1130 New York time despite the fact that quote-price volatility in London increases around that time. The explanation is probably

[11] Freedman and Terry (1993) use Fitch data to study 95 U.S. stocks that were listed abroad during 1980 to 1985.

**Table 3a**
**Tests for differences in intraday quote price variance patterns between British stocks cross-listed in the U.S. and their control stocks**

| **U.K. trading** | **Model I** | | **Model II** | | **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control | **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 0830–0845 | **−0.0591** | −6.03 | **−0.7395** | −3.81 | 0930–0945 | −0.0337 | −1.08 | 0.4150 | 0.80 |
| 0845–0900 | **−0.0232** | −2.98 | **−0.3274** | −2.50 | 0945–1000 | **−0.0315** | −2.35 | 0.3285 | 2.15 |
| 0900–0915 | −0.0139 | −1.18 | −0.1313 | −0.76 | 1000–1015 | **−0.0296** | −2.60 | 0.0948 | 1.11 |
| 0915–0930 | −0.0086 | −1.07 | −0.0764 | −0.47 | 1015–1030 | 0.0112 | 0.65 | **0.4397** | 3.61 |
| 0930–0945 | **−0.0204** | −2.40 | **−0.3213** | −2.55 | 1030–1045 | 0.0006 | 0.03 | 0.1709 | 1.66 |
| 0945–1000 | −0.0081 | −1.70 | −0.1550 | −1.49 | 1045–1100 | 0.0107 | 0.74 | **0.4692** | 4.38 |
| 1000–1015 | −0.0035 | −0.75 | −0.0140 | −0.18 | 1100–1115 | −0.0025 | −0.23 | 0.2516 | 2.25 |
| 1015–1030 | −0.0131 | −2.15 | **−0.3398** | −3.04 | 1115–1130 | −0.0070 | −0.71 | 0.1556 | 1.44 |
| 1030–1045 | −0.0092 | −2.03 | **−0.2062** | −2.52 | 1130–1145 | −0.0139 | −1.00 | −0.1027 | −1.32 |
| 1045–1100 | −0.0101 | −2.19 | **−0.2050** | −2.34 | 1145–1200 | −0.0066 | −0.77 | −0.0920 | −1.47 |
| 1100–1115 | −0.0099 | −1.35 | −0.2755 | −1.16 | 1200–1215 | −0.0130 | −1.57 | **−0.1729** | −2.91 |
| 1115–1130 | −0.0028 | −0.28 | −0.0611 | −0.33 | 1215–1230 | n.a. | n.a. | −0.0772 | −1.50 |
| 1130–1145 | 0.0011 | 0.26 | 0.0364 | 0.46 | 1230–1245 | −0.0002 | −0.02 | −0.0386 | −0.50 |
| 1145–1200 | 0.0205 | 1.35 | 0.1961 | 1.06 | 1245–1300 | 0.0108 | 0.97 | −0.1224 | −1.62 |
| 1200–1215 | 0.0157 | 1.52 | 0.3110 | 1.42 | 1300–1315 | 0.0065 | 0.77 | −0.0299 | −0.58 |
| 1215–1230 | n.a. | n.a. | −0.0275 | −0.42 | 1315–1330 | −0.0023 | −0.26 | −0.0480 | −0.81 |
| 1230–1245 | 0.0029 | 0.69 | 0.0026 | 0.03 | 1330–1345 | 0.0051 | 0.51 | −0.0450 | −0.79 |
| 1245–1300 | 0.0064 | 1.83 | 0.0712 | 1.65 | 1345–1400 | 0.0088 | 1.02 | 0.0373 | 0.53 |
| 1300–1315 | 0.0053 | 1.61 | 0.0410 | 1.01 | 1400–1415 | 0.0081 | 0.77 | −0.1092 | −2.27 |
| 1315–1330 | 0.0063 | 1.88 | 0.0979 | 2.09 | 1415–1430 | −0.0062 | −0.75 | **−0.1630** | −2.54 |
| 1330–1345 | **0.0116** | 3.31 | **0.2405** | 3.99 | 1430–1445 | −0.0074 | −0.87 | **−0.1541** | −2.71 |

**Table 3a**
**(continued)**

| **U.K. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1345–1400 | 0.0060 | 1.27 | 0.0725 | 1.13 |
| 1400–1415 | 0.0038 | 0.97 | 0.0273 | 0.56 |
| 1415–1430 | **0.0141** | 3.73 | **0.3046** | 3.93 |
| 1430–1445 | **0.0115** | 2.91 | **0.4034** | 5.62 |
| 1445–1500 | 0.0074 | 1.72 | **0.2794** | 3.87 |
| 1500–1515 | 0.0035 | 0.80 | 0.1586 | 1.77 |
| 1515–1530 | 0.0003 | 0.06 | 0.1087 | 1.35 |
| 1530–1545 | −0.0014 | −0.27 | 0.0959 | 0.99 |
| 1545–1600 | 0.0032 | 0.74 | 0.1477 | 2.05 |
| 1600–1615 | 0.0085 | 1.62 | **0.1946** | 2.34 |
| 1615–1630 | 0.0091 | 1.73 | **0.2371** | 2.72 |
| **Adjusted $R^2$** | 0.0274 | | 0.0371 | |
| ***F*-value** | 91.80 | | 210.55 | |
| ***F*-test** | 0.61 | | 0.41 | |

| **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1445–1500 | −0.0146 | −1.72 | **−0.2254** | −4.03 |
| 1500–1515 | −0.0123 | −1.01 | **−0.2231** | −3.76 |
| 1515–1530 | −0.0213 | −2.10 | **−0.2470** | −3.43 |
| 1530–1545 | **−0.0406** | −3.88 | **−0.2394** | −3.31 |
| 1545–1600 | **−0.0430** | −4.09 | **−0.2444** | −3.20 |
| **Adjusted $R^2$** | 0.0286 | | 0.0216 | |
| ***F*-value** | 97.70 | | 148.70 | |
| ***F*-test** | 2.27 | | 2.90 | |

The table reports estimated time-of-day effects, i.e., $\mu_t$ in Model I and $\nu_t$ in Model II. $t$-values are based on heteroskedasticity-consistent covariance matrices of the estimated parameters. A boldfaced coefficient indicates significance at the 1 percent level ($|t| > 2.33$). For each model, the joint significance of the estimated time-of-day effects reported in the table is tested using an $F$-test. A test statistic above $F = 1.70$ means that the intraday pattern for cross-listed stocks is significantly different from that of controls.

that the magnitude of volatility in London at this time is not large enough to warrant transmission between markets, or that the increase in London volatility is not caused by new information. Volatility for British ADRs is significantly lower than for their controls at the end of the U.S. trading day. The difference in normalized time-of-day effects ranges from $-0.15$ to $-0.25$ (Model II). Based on the $F$-tests reported at the bottom of Table 3a, there is strong statistical support for differences in the volatility pattern between cross-listed stocks and controls during U.S. but not during U.K. trading.

The London morning volatility pattern supports Amihud and Mendelson's (1991) conclusion that a shorter nontrading period tends to reduce price uncertainty. It is also consistent with the theoretical model of security cross-listing developed by Freedman (1991). This model predicts that the primary market volatility (after the opening trade) should be lower for cross-listed stocks since risk-neutral traders with long-lived information spread their trades over both markets.

It is more challenging to find an explanation for why volatility is high during the overlap of trading. There are several candidate explanations for this pattern. The first one follows arguments presented in Stoll and Whaley (1990). They conclude that the monopoly power of specialists on the NYSE is responsible for creating higher levels of volatility around the open than around the close. However, a specialist for cross-listed stocks faces nonnegligible competition from London market makers at the New York open. Only if order flow segmentation is severe will the specialist have enough market power to affect New York opening prices in the way predicted by Stoll and Whaley (1990). In addition, the fact that volatility spills over to London suggests that it is not simply related to the opening mechanism of the NYSE.

A second hypothesis is that higher volatility is caused by a higher level of public information flow for cross-listed stocks during the overlap of trading. While the evidence does not permit a rejection of this hypothesis, the literature does provide some guidance. In an attempt to measure public information arrival using news releases, Berry and Howe (1994) find New York open to have the lowest level of U.S. business-hour information flow. Thus, only if British cross-listed firms have a distinctly different news release pattern can the volatility pattern potentially be explained by new public information flow. It would seem that the most natural way in which British firms might differ when it comes to news release patterns is by disclosing information relative to British business hours in lieu of U.S. business hours. Berry and Howe (1994) find that public information arrival peaks just after the U.S. market close. If British firms follow the same rule, they are likely to release most news after the U.K. market close. This suggests that the volatility increase should take place after 1130

New York time. At that time of day, New York volatility has virtually bottomed out. It thus seems unlikely that morning volatility is caused by a massive arrival of new public information during the overlap of trading.

The third hypothesis, advocated by Chan et al. (1995), is that volatility is high because U.S. investors wait until the New York open to update their priors based on public information released during London (or Tokyo) business hours. Models developed by, for example, Harris and Raviv (1993), Kim and Verrecchia (1991), and Wang (1994) show that differences in how agents interpret public information can generate both higher volume and more volatility. This hypothesis is appealing since the information is public and it can be argued, as do Chan et al. (1995), that U.S. investors do not risk anything by deferring trades based on their revised expectations until New York opens. It would thus not seem necessary to assume that markets are segmented for this story to be consistent with the data. However, if this were the reason, we would not expect volatility in London to increase around the U.S. open.

The final candidate explanation is that private information gets impounded into prices through the trading activity of U.S. investors. In other words, U.S. order flow is informative. This hypothesis implicitly assumes a reluctance of U.S. investors to trade in London—that is, some degree of order flow segmentation. A U.S. investor would potentially benefit from trading earlier, that is, in London, on private information. By combining the evidence from U.K. and U.S. trading of cross-listed stocks, it is possible to infer whether volatility is caused by old public or new private information. Specifically, the fact that volatility in London is significantly higher for cross-listed stocks around 1430 London time suggests that the explanation, at least in part, is related to information not previously incorporated into London prices. The data thus strongly suggest that U.S. order flow conveys information not previously incorporated into London prices.

For completeness, the results for intraday trade-price volatility are reported in Table 3b. The estimated time-of-day effects are graphed in Figure 3b. At first blush, trade-price volatility seems to be U-shaped in London. Closer scrutiny of the plotted time-of-day effects in panels A and B, however, shows that the afternoon increase in volatility is entirely due to the last interval. According to London dealers, this pattern is likely to result from the practice of prearranged so-called protected trades. These trades involve a dealer who at some point during trading agrees to give a customer the better of the prevailing quote, and either an average best price or the single best price available for a specific (subsequent) period of the day. The trade is typically booked at close. Its price will tend to differ from that of previously recorded

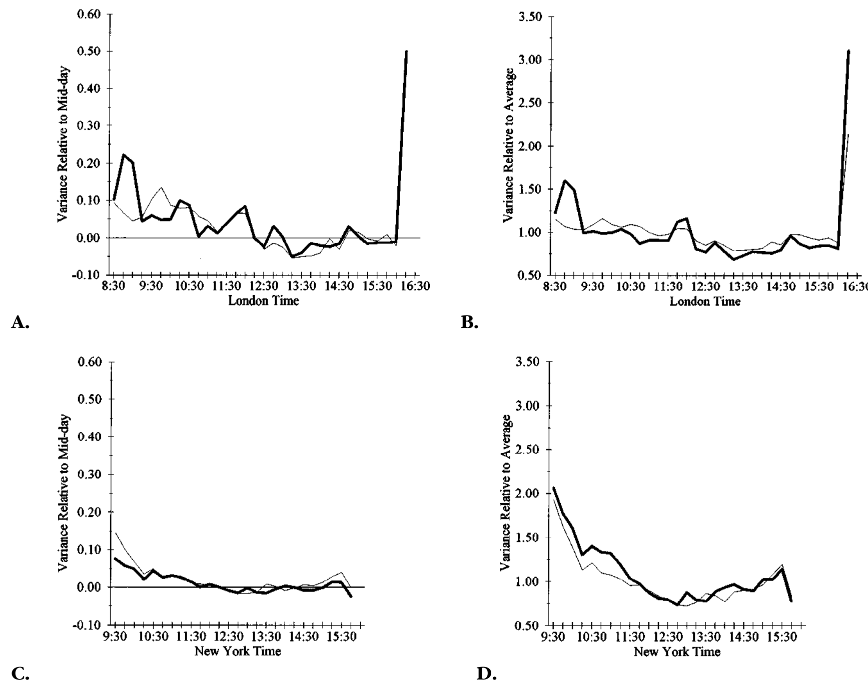


**Figure 3b**
**Intraday trade price variances**
The figures graph the estimated intraday trade price variance patterns. The top panels (A and B) present the results for U.K. trading and the bottom panels (C and D) give the results for U.S. trading. The estimated time-of-day effects for cross-listed stocks are represented by thick solid black lines and the time-of-day effects for non-cross-listed stocks are represented by thin solid black lines. Model I results are reported in panels A and C, while Model II results can be found in panels B and D.

regular trades, hence the large volatility estimate for the last interval. Panels C and D and the U.S. trading part of Table 3b indicate that the trade-price volatility of control stocks in the United States is U-shaped, but there is less afternoon volatility increase for British ADRs than for control stocks.[12]

Results from Model I for U.K. trading in Table 3b confirm the impression from panel A that there is no significant difference between volatility for sample stocks and their controls. Some significant coefficients appear in Model II, but there is no distinct pattern except for a high volatility at the close. Given the reservations about time stamps for the British data, this result is not particularly surprising. In con-

[12] The volatility decline in the last interval is due to forward-filling of trade prices. Few trades occur at 1630 both for sample and control stocks.

**Table 3b**
**Tests for differences in intraday trade price variance patterns between British stocks cross-listed in the U.S. and their control stocks**

| **U.K. trading** | **Model I** | | **Model II** | | **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control | **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 0830–0845 | 0.0088 | 0.31 | 0.0792 | 1.66 | 0930–0945 | **−0.0697** | −3.44 | 0.1334 | 1.00 |
| 0845–0900 | 0.1569 | 1.01 | 0.5344 | 1.10 | 0945–1000 | **−0.0418** | −2.59 | 0.1507 | 1.38 |
| 0900–0915 | 0.1554 | 1.05 | 0.4548 | 0.99 | 1000–1015 | −0.0183 | −0.96 | 0.2182 | 2.21 |
| 0915–0930 | −0.0111 | −0.36 | −0.0402 | −0.87 | 1015–1030 | −0.0141 | −0.99 | 0.1728 | 2.12 |
| 0930–0945 | −0.0439 | −0.96 | −0.0809 | −1.38 | 1030–1045 | −0.0057 | −0.29 | **0.1890** | 2.34 |
| 0945–1000 | −0.0889 | −1.37 | −0.1695 | −2.11 | 1045–1100 | 0.0038 | 0.26 | **0.2326** | 3.19 |
| 1000–1015 | −0.0389 | −0.74 | −0.0989 | −1.39 | 1100–1115 | −0.0004 | −0.03 | **0.2457** | 3.30 |
| 1015–1030 | 0.0200 | 0.24 | −0.0223 | −0.22 | 1115–1130 | 0.0040 | 0.25 | 0.1585 | 2.01 |
| 1030–1045 | 0.0050 | 0.06 | −0.1140 | −1.10 | 1130–1145 | 0.0038 | 0.27 | 0.0787 | 1.29 |
| 1045–1100 | −0.0530 | −1.63 | **−0.1975** | −3.27 | 1145–1200 | −0.0084 | −0.63 | 0.0143 | 0.22 |
| 1100–1115 | −0.0143 | −0.40 | −0.0926 | −1.66 | 1200–1215 | 0.0026 | 0.15 | −0.0216 | −0.34 |
| 1115–1130 | −0.0037 | −0.15 | −0.0564 | −0.95 | 1215–1230 | n.a. | n.a. | −0.0272 | −0.49 |
| 1130–1145 | 0.0024 | 0.06 | −0.0800 | −1.57 | 1230–1245 | 0.0023 | 0.16 | 0.0144 | 0.27 |
| 1145–1200 | −0.0015 | −0.04 | 0.0685 | 0.71 | 1245–1300 | 0.0007 | 0.05 | −0.0051 | −0.12 |
| 1200–1215 | 0.0199 | 0.57 | 0.1144 | 1.19 | 1300–1315 | 0.0139 | 0.94 | 0.1518 | 1.71 |
| 1215–1230 | n.a. | n.a. | −0.0962 | −2.21 | 1315–1330 | −0.0006 | −0.05 | 0.0282 | 0.52 |
| 1230–1245 | 0.0058 | 0.23 | −0.0817 | −1.78 | 1330–1345 | −0.0237 | −1.59 | −0.0859 | −1.10 |
| 1245–1300 | 0.0459 | 0.78 | −0.0224 | −0.23 | 1345–1400 | −0.0077 | −0.54 | 0.0425 | 0.60 |
| 1300–1315 | 0.0279 | 0.52 | −0.0672 | −0.77 | 1400–1415 | 0.0108 | 0.76 | 0.1562 | 2.11 |
| 1315–1330 | 0.0027 | 0.11 | **−0.1002** | −2.79 | 1415–1430 | 0.0009 | 0.06 | 0.0800 | 0.90 |
| 1330–1345 | 0.0094 | 0.35 | −0.0615 | −1.26 | 1430–1445 | −0.0148 | −1.06 | 0.0100 | 0.15 |

**Table 3b**
**(continued)**

| **U.K. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1345–1400 | 0.0336 | 1.15 | −0.0256 | −0.46 |
| 1400–1415 | 0.0191 | 0.76 | −0.0485 | −1.35 |
| 1415–1430 | −0.0234 | −0.86 | **−0.1346** | −3.34 |
| 1430–1445 | 0.0151 | 0.61 | −0.0619 | −1.61 |
| 1445–1500 | 0.0109 | 0.39 | −0.0174 | −0.32 |
| 1500–1515 | −0.0106 | −0.36 | −0.1088 | −2.02 |
| 1515–1530 | −0.0137 | −0.54 | **−0.1172** | −2.99 |
| 1530–1545 | −0.0052 | −0.21 | −0.0715 | −1.83 |
| 1545–1600 | −0.0232 | −0.86 | −0.0909 | −1.90 |
| 1600–1615 | 0.0100 | 0.40 | −0.0676 | −1.49 |
| 1615–1630 | 0.0103 | 0.16 | **0.9554** | 5.09 |
| **Adjusted $R^2$** | 0.0283 | | 0.0245 | |
| ***F*-value** | 89.00 | | 129.01 | |
| ***F*-test** | 0.86 | | 2.95 | |

| **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1445–1500 | −0.0122 | −0.92 | −0.0197 | −0.35 |
| 1500–1515 | −0.0141 | −1.05 | +0.0587 | 0.78 |
| 1515–1530 | −0.0148 | −0.91 | −0.0596 | −0.97 |
| 1530–1545 | −0.0277 | −2.00 | −0.0533 | −0.85 |
| 1545–1600 | −0.0219 | −1.73 | −0.0568 | −0.90 |
| **Adjusted $R^2$** | 0.0614 | | 0.0629 | |
| ***F*-value** | 202.78 | | 423.12 | |
| ***F*-test** | 2.65 | | 2.59 | |

The table reports estimated time-of-day effects, i.e., $\mu_t$ in Model I and $\nu_t$ in Model II. $t$-values are based on heteroskedasticity-consistent covariance matrices of the estimated parameters. A boldfaced coefficient indicates significance at the 1 percent level ($|t| > 2.33$). For each model, the joint significance of the estimated time-of-day effects reported in the table is tested using an $F$-test. A test statistic above $F = 1.70$ means that the intraday pattern for cross-listed stocks is significantly different from that of controls.

trast, the U.S. trading results in Table 3b and panels C and D show that British ADRs have signficantly lower trade-price volatility than their controls during the first 15 to 30 minutes of trading in New York. This parallels the results for quote-price volatility based on Model I. Again, the difference based on Model II is positive and insignificant. Volatility patterns based on trade prices and quote prices are thus very similar for U.S. data. A similar conclusion was reached by Chan et al. (1995).

## 4. Intraday Volume Patterns for Sample Stocks and Controls

Figure 4 shows that trading volume is strongly U-shaped for both sample stocks and controls in each market. Note that the opening minute and the closing minute are estimated separately. Opening and closing volumes are multiplied by 15 to make them comparable to the level of time-of-day effects estimated for other intervals. Similar volume patterns for U.S. stocks were first documented by Jain and Joh (1988).[13] Closer scrutiny of panels A and B (Figure 4) shows that the London volume pattern actually has more of a "two-humped" shape than a simple U-shape. In contrast to evidence from the United States, neither the open nor the close in London is associated with exceptionally high trading volume compared to adjacent time periods. This intraday pattern is a general feature of British data [see Kleidon and Werner (1993)]. Instead of volume being exceptionally high adjacent to periods of market closure, the "two-humped" volume pattern for British stocks can be interpreted as evidence for volume being exceptionally low during lunch. It is striking that the volume pattern for cross-listed firms is so similar to that of control stocks. If market closure creates this pattern, integrated trading of cross-listed stocks should result in clustering of trading activity for these stocks only at the start of trading in London and at the close in New York. To explore whether cross-listing at least significantly affects intraday volume patterns, Table 4 reports results from tests for differences in intraday volume patterns between cross-listed stocks and controls.

Both the results from U.K. trading in Table 4 and panels A and B in Figure 4 show that cross-listed stocks have a more strongly "two-humped" shape than their controls when the intraday pattern is estimated using Model I. This seemingly contradicts the notion that a shorter nontrading period prior to London open should reduce the liquidity demand during early trading. In addition, cross-listed stocks are not subject to a period of market closure following the London close. When the estimated time-of-day effects are scaled relative to

[13] See also Foster and Viswanathan (1993).

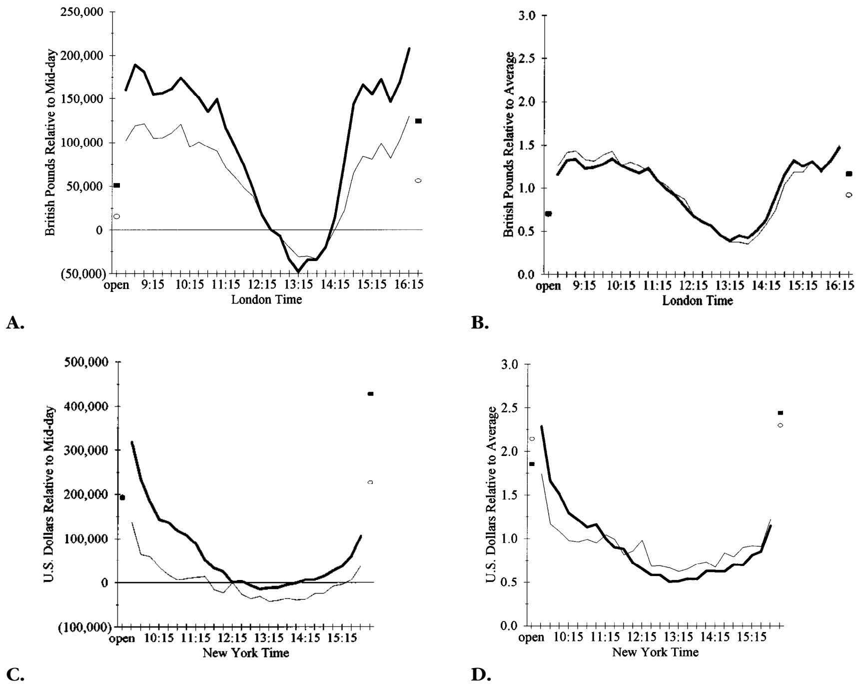


**Figure 4**
**Intraday trading volume**
The figures graph the estimated intraday trading volume patterns. The top panels (A and B) present the results for U.K. trading and the bottom panels (C and D) give the results for U.S. trading. The estimated time-of-day effects for cross-listed stocks are represented by thick solid black lines and the time-of-day effects for non-cross-listed stocks are represented by thin solid black lines. Model I results are reported in panels A and C, while Model II results can be found in panels B and D.

the firm-specific average level (Model II), however, the puzzle disappears. The Model II results suggest that pound trading volume is actually slightly lower, but not significantly so, for cross-listed stocks than for controls during morning London trading. Models I and II give different results because cross-listed stocks have higher average trading volume.

Interestingly, pound trading volume is significantly higher for cross-listed stocks just around the time when New York starts trading these stocks, regardless of which model is used. In terms of magnitudes, the difference in normalized time-of-day effects is about 0.15 (Model II). The timing of the relative volume increase strongly suggests that it has something to do with what is simultaneously going on in New York. This conjecture can be confirmed by looking at panels C and D. While the opening minute in New York itself does not have a higher level of trading activity for sample stocks, the average level of

**Table 4**
**Tests for differences in intraday trading volume patterns between British stocks cross-listed in the U.S. and their control stocks**

| **U.K. trading** | **Model I** | | **Model II** | | **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control (thousand pounds) | **t-value** Sample - Control | **Time effect** Sample - Control (fraction of average) | **t-value** Sample - Control | **Time of day** New York time | **Time effect** Sample - Control (thousand dollars) | **t-value** Sample - Control | **Time effect** Sample - Control (fraction of average) | **t-value** Sample - Control |
| open | 35.64 | 1.78 | 0.0049 | 0.05 | open | − 1.86 | −0.05 | −0.2887 | −1.14 |
| 0830–0845 | **57.69** | 3.22 | −0.0937 | −1.44 | 0930–0945 | **182.29** | 6.81 | **0.5373** | 3.76 |
| 0845–0900 | **69.52** | 5.50 | −0.0971 | −1.67 | 0945–1000 | **179.78** | 6.93 | **0.4921** | 5.35 |
| 0900–0915 | **59.32** | 4.42 | −0.0995 | −1.46 | 1000–1015 | **123.44** | 4.69 | **0.4284** | 4.49 |
| 0915–0930 | **49.92** | 4.20 | −0.1058 | −1.95 | 1015–1030 | **108.52** | 4.36 | **0.3142** | 4.26 |
| 0930–0945 | **50.98** | 3.95 | −0.0755 | −1.34 | 1030–1045 | **118.50** | 4.85 | **0.2493** | 3.77 |
| 0945–1000 | **50.17** | 4.12 | −0.1121 | −1.71 | 1045–1100 | **110.93** | 4.61 | 0.1336 | 2.10 |
| 1000–1015 | **52.60** | 4.37 | −0.0877 | −1.58 | 1100–1115 | **97.43** | 4.01 | **0.2031** | 2.58 |
| 1015–1030 | **67.71** | 5.52 | 0.0006 | 0.01 | 1115–1130 | **74.14** | 3.11 | −0.0418 | −0.45 |
| 1030–1045 | **50.39** | 4.19 | −0.0921 | −1.67 | 1130–1145 | 35.76 | 1.51 | −0.0929 | −1.28 |
| 1045–1100 | **40.91** | 3.67 | −0.0854 | −1.74 | 1145–1200 | 48.29 | 2.07 | 0.0647 | 0.81 |
| 1100–1115 | **58.62** | 4.51 | 0.0321 | 0.58 | 1200–1215 | 47.34 | 2.04 | −0.1374 | −1.78 |
| 1115–1130 | **44.86** | 4.10 | −0.0106 | −0.22 | 1215–1230 | n.a. | n.a. | −0.3299 | −2.29 |
| 1130–1145 | **34.93** | 2.92 | −0.0410 | −0.80 | 1230–1245 | 28.81 | 1.20 | −0.0985 | −1.65 |
| 1145–1200 | **26.34** | 2.56 | −0.0215 | −0.48 | 1245–1300 | 29.25 | 1.24 | −0.1086 | −1.72 |
| 1200–1215 | 8.53 | 0.82 | −0.0830 | −1.62 | 1300–1315 | 15.62 | 0.51 | −0.1596 | −1.39 |
| 1215–1230 | n.a. | n.a. | −0.0157 | −0.41 | 1315–1330 | 30.93 | 1.34 | **−0.1136** | −2.64 |
| 1230–1245 | 2.36 | 0.25 | 0.0121 | 0.33 | 1330–1345 | 29.01 | 1.27 | −0.1154 | −1.83 |
| 1245–1300 | 1.04 | 0.11 | 0.0106 | 0.22 | 1345–1400 | 30.07 | 1.27 | **−0.1725** | −2.93 |
| 1300–1315 | −13.61 | −1.66 | 0.0130 | 0.46 | 1400–1415 | 38.36 | 1.67 | −0.1024 | −1.91 |
| 1315–1330 | −17.17 | −2.13 | 0.0139 | 0.53 | 1415–1430 | 44.62 | 1.93 | −0.0462 | −1.00 |
| 1330–1345 | −4.15 | −0.51 | **0.0744** | 2.72 | 1430–1445 | 31.59 | 1.37 | **−0.2149** | −2.94 |

**Table 4**
**(continued)**

| **U.K. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1345–1400 | −0.75 | −0.09 | **0.0669** | 2.70 |
| 1400–1415 | −0.57 | −0.07 | 0.0656 | 2.09 |
| 1415–1430 | 13.15 | 1.47 | 0.0525 | 1.63 |
| 1430–1445 | **55.59** | 5.55 | **0.1507** | 3.79 |
| 1445–1500 | **78.36** | 7.08 | **0.1113** | 2.44 |
| 1500–1515 | **81.41** | 6.88 | 0.1340 | 2.24 |
| 1515–1530 | **74.23** | 6.00 | 0.0674 | 1.20 |
| 1530–1545 | **73.34** | 5.76 | −0.0070 | −0.12 |
| 1545–1600 | **64.04** | 5.78 | 0.0265 | 0.54 |
| 1600–1615 | **65.16** | 5.56 | −0.0141 | −0.25 |
| 1615–1630 | **76.94** | 5.09 | −0.0343 | −0.47 |
| close | **68.51** | 2.46 | 0.2353 | 1.65 |
| **Adjusted $R^2$** | 0.1507 | | 0.1172 | |
| ***F*-value** | 558.50 | | 688.00 | |
| ***F*-test** | 7.85 | | 2.04 | |

| **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1445–1500 | 38.95 | 1.70 | −0.0898 | −1.72 |
| 1500–1515 | 34.87 | 1.49 | **−0.2025** | −3.73 |
| 1515–1530 | 40.87 | 1.69 | −0.1087 | −1.42 |
| 1530–1545 | 52.92 | 2.23 | −0.0597 | −1.04 |
| 1545–1600 | **67.20** | 2.83 | −0.0837 | −0.83 |
| close | **200.46** | 4.14 | 0.1441 | 0.56 |
| **Adjusted $R^2$** | 0.1679 | | 0.0331 | |
| ***F*-value** | 680.57 | | 227.64 | |
| ***F*-test** | 13.47 | | 4.73 | |

The table reports estimated time-of-day effects, i.e., $\mu_t$ in Model I and $\nu_t$ in Model II. $t$-values are based on heteroskedasticity-consistent covariance matrices of the estimated parameters. A boldfaced coefficient indicates significance at the 1 percent level ($|t| > 2.33$). For each model, the joint significance of the estimated time-of-day effects reported in the table is tested using an $F$-test. A test statistic above $F = 1.70$ means that the intraday pattern for cross-listed stocks is significantly different from that of controls.

U.S. trading volume is significantly higher for British ADRs than for their controls following New York open, regardless of which model is used to estimate the pattern.[14] The differences in normalized time-of-day effects during the morning range from 0.20 to 0.50 (Model II). A similar conclusion was reached by Chan et al. (1995).

Curiously, based on Model II there is also a period about 1 hour prior to New York open when London trading volume for sample stocks is significantly higher than for controls. The difference in normalized time-of-day effects is about 0.07. One explanation for this phenomenon, suggested by London market makers, is that British traders in cross-listed stocks are relatively more concerned about the state of their "books" in light of the upcoming period when two markets are going to trade these stocks. While such a period offers opportunities for arbitrage, it also affects transparency because trading is fragmented between two locations. In addition, as shown in the previous section, volatility increases during the overlap. Thus, it can be extra costly for traders to be caught unprepared.

Except for the last 15 minutes of trading, the positive difference between trading volume for sample stocks and controls relative to midday is insignificant during the New York afternoon. Based on Model II, however, trading volume for sample stocks is not significantly higher than for controls around the New York close. Overall, the *F*-tests reported at the bottom of Table 4 indicate that there is stronger support for differences in the intraday patterns of cross-listed stocks and their controls during U.S. trading. However, all patterns are significant at the 1 percent level.

The graphs suggest that New York trading volume in cross-listed stocks is much more concentrated in the morning session than trading volume in U.S. control stocks. We estimate the fraction of daily volume that occurs during the overlap based on coefficients from regressions with only time-of-day effects (not reported). British cross-listed stocks trade 30.9 percent of their daily London volume during the overlap, which is very similar to the fraction traded by British control stocks, 29.2 percent. By contrast, for cross-listed stocks as a group, 47.2 percent of daily New York volume is traded during the overlap compared to 39.7 percent for control stocks. Thus, while both British and U.S. traders have a tendency to skew their trading activity toward the period of overlap, this tendency is much stronger for U.S. traders.

This pattern of concentrated trading volume could have several explanations. The first, proposed by Brock and Kleidon (1992), is

[14] One explanation for the relatively low trading intensity for the opening minute in New York could be a higher frequency of delayed openings for ADRs compared to controls.

that there is more, relatively inelastic, hedging demand adjacent to periods of market closure. For this explanation to be consistent with the fact that volume patterns are distinctly U-shaped in each market, and specifically that volume is concentrated in both markets during the overlap of trading, it has to be the case that at least some British traders take the London close seriously despite the fact that trading continues for another 4.5 hours in the United States. Traders in the United States, on the other hand, must generally view the New York open as the start of trading despite the fact that it occurs after 6 hours of continuous (London) trading. In other words, a substantial part of the order flow for British cross-listed stocks is segmented. The Brock and Kleidon (1992) model does not provide an explanation for the concentration of volatility during the period of overlapping trading.

A second reason for volume to be concentrated during the period of overlap is that prices are more informative at this time, in the sense that they reflect traders' private information. This story follows the model developed by Admati and Pleiderer (1988). It is possible that both discretionary liquidity traders and (privately) informed traders on both sides of the Atlantic are attracted to the overlap; liquidity traders because transaction costs are low and informed traders because they are better able to disguise their trades when volume is high. This prediction is consistent with the high levels of volatility in both markets as discussed in the previous subsection. The model argues that high volatility will result because new information is rapidly incorporated into prices through the concentrated trading activity of competing risk-neutral informed traders. While prices are volatile, they are still attractive in the sense that they are more informative than prices at other times. However, a necessary prerequisite for discretionary liquidity traders to volunteer their order flow at this time is that transaction costs are low. This issue will be explored in Section 5.

A third reason for concentrated volume, focusing on the overlap, is that most of the arbitrage activity between the two markets is likely to be concentrated in periods when both markets are open. Cross-border arbitrage transactions are presumably relatively more abundant if British and U.S. investors either have different opinions about how new public information should affect prices of cross-listed stocks as suggested in, for example, Harris and Raviv (1993) and Wang (1994), or they have different opinions about the value of cross-listed stocks because U.S. investors have private information that is not yet incorporated into London prices. The models also predict that high volume generated by differences in opinion should be associated with volatility increases, which is consistent with the evidence presented in the previous subsection. The fact that London volatility increases significantly during the overlap for cross-listed stocks suggests that the arbitrage activity is primarily motivated by U.S. traders acting on private information. As traders in each market venue react to this new information, prices gradually adjust on both sides of the Atlantic. For the story to hold water, a reluctance for U.S. traders to act on their information prior to New York open is required.

It is of course also possible that concentration of trading during the overlap is entirely motivated by lower transaction costs. Lower transaction costs could, for example, result from competition for order flow between the primary and secondary markets during the overlap. However, for both markets to simultaneously experience concentrated trading, either (comprehensive) transaction costs have to be identical in both markets or market switching costs have to be substantial for a large number of traders. The first condition would support the kind of knife-edge *two-market conjectural equilibrium* that Pagano (1989) derives. The existence of this equilibrium is, however, very sensitive to the equilibrium concept used and Pagano (1989) argues that it is an unlikely outcome. The two-market equilibrium generally does not exist, and traders that are free to choose where to trade would typically concentrate their trades in one market. The second condition is used by Chowdhry and Nanda (1991) to derive an equilibrium in their model of multimarket trading. This equilibrium has the property that as the fraction of institutional investors increases, the correlation between trading volumes in the two markets increases because institutions split trades across markets. This might explain why trading volume is high both in London and in New York during the overlap. Again, a small change in the model would make the equilibrium collapse into one of a single market trading venue. Specifically, if small liquidity traders can choose where to trade, the lowest cost market will dominate. In light of these models, the evidence indicates that at least some traders face prohibitive market switching costs.

## 5. Intraday Spread Patterns for Sample Stocks and Controls

Kleidon and Werner (1993) show that the main difference between the intraday patterns for British data compared to U.S. data is that spreads tend to decline throughout the London trading day. This pattern is evident for both sample stocks and controls during London trading as captured in panels A and B of Figure 5. London spreads for sample stocks are higher during the morning and lower in the afternoon than at midday. For British control stocks, the spreads decrease markedly in the afternoon, while spreads during the morning do not deviate noticeably from the level at midday. These results closely resemble the spread pattern found by Chan, Christie, and Schultz (1994) for liquid

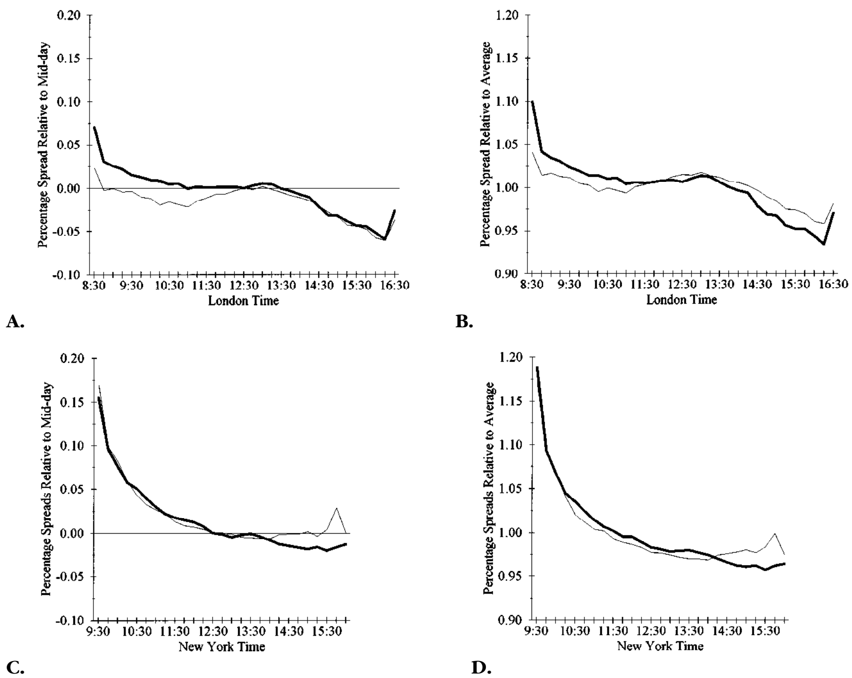


**Figure 5**
**Intraday percentage spreads**
The figures graph the estimated intraday percentage spread patterns. The top panels (A and B) present the results for U.K. trading and the bottom panels (C and D) give the results for U.S. trading. The estimated time-of-day effects for cross-listed stocks are represented by thick solid black lines and the time-of-day effects for non-cross-listed stocks are represented by thin solid black lines. Model I results are reported in panels A and C, while Model II results can be found in panels B and D.

NASDAQ stocks—also a dealer market—suggesting that the difference in part can be attributed to the differences in trading structure.

The trading structure cannot, however, be the entire explanation for the different spread pattern since New York spreads for cross-listed stocks in panels C and D also decline over the course of the trading day. Afternoon sample stock spreads are about one to two basis points lower than at midday. U.S. control stocks do have higher spreads in the morning than at midday, while spreads in the afternoon are similar to the level at midday. Spreads, particularly for cross-listed stocks, contrast with the U-shaped spreads found in earlier studies for NYSE data [see, e.g., Brock and Kleidon (1992), Foster and Viswanathan (1993), and McInish and Wood (1992)].

Higher U.K. spreads in the morning for cross-listed and control stocks alike is generally consistent with the adverse selection story during price discovery as originally proposed by Bagehot (1971). Such spread patterns are also predicted by models of informed traders with long-lived information, for example, Foster and Viswanathan (1993) and Holden and Subrahmanyam (1992). While these models could also explain the spread pattern for control stocks in New York, they are unable to explain the intraday spread pattern for British cross-listed stocks in New York if markets are fully integrated. Specifically, it has to be the case that some (U.S.) traders with private information wait until the New York open to execute their trades. Note that this is consistent with the volatility patterns described in Section 3. As was the case with volatility and volume, spread patterns for cross-listed stocks closely resemble those for control stocks in each market. Table 5 reports the results of tests for differences in intraday spread patterns.

Spreads in London are significantly higher relative to their benchmark level for sample stocks than for controls during morning trading regardless of regression model. The difference ranges from two to six basis points in magnitude. No other individual 15-minute coefficients are significant for U.K. trading based on Model I. Model II results, however, show that sample stocks' spreads are significantly lower during the overlap. In terms of magnitude, the difference is about two basis points. Again, the timing coincides exactly with the start of trading in New York. By contrast, spreads at this time of day are at their highest level in New York, both for sample stocks and controls. Moreover, U.S. spreads are insignificantly different across samples for most of the day. Sample stocks have significantly lower spreads (by about three basis points) during the last 30 to 90 minutes of New York trading. Based on the $F$-tests reported at the bottom of Table 5, there is stronger evidence supporting differences in intraday spread patterns for U.K. trading than for U.S. trading of cross-listed stocks.

This U.S. spread pattern is different from that found for dually listed stocks by Chan et al. (1995). Their data show European cross-listed stocks to have significantly higher spreads at New York open than their U.S. control stocks. That result is puzzling in light of the fact that volume for cross-listed stocks is relatively more concentrated during the overlap. It suggests that U.S. traders are relatively prone to trade during the overlap despite costs being significantly higher at the open in New York. Based on more recent data covering only British ADRs, we find here that while spreads for British ADRs are higher at the open than during the rest of the day, they are not significantly higher than spreads for similar U.S. stocks.

Spreads for cross-listed stocks are perhaps the most interesting feature of the intraday patterns presented in this article. Some guidance for understanding the London spread pattern can be found in Freedman's (1991) model of securities cross-listing. The model predicts that spreads for cross-listed stocks will be relatively higher in the primary

**Table 5**
**Tests for differences in intraday percentage spread patterns between British stocks cross-listed in the U.S. and their control stocks**

| U.K. trading | Model I | | Model II | | U.S. trading | Model I | | Model II | |
|---|---|---|---|---|---|---|---|---|---|
| Time of day London time | Time effect Sample - Control | t-value Sample - Control | Time effect Sample - Control (fraction of average) | t-value Sample - Control | Time of day New York time | Time effect Sample - Control | t-value Sample - Control | Time effect Sample - Control | t-value Sample - Control |
| 0830 | **0.0476** | 5.49 | **0.0587** | 9.14 | 0930 | −0.0146 | −1.16 | 0.0172 | 1.59 |
| 0845 | **0.0329** | 3.88 | **0.0273** | 4.50 | 0945 | −0.0032 | −0.24 | 0.0034 | 0.32 |
| 0900 | **0.0254** | 3.02 | **0.0180** | 3.05 | 1000 | −0.0060 | −0.47 | 0.0018 | 0.20 |
| 0915 | **0.0255** | 3.05 | **0.0175** | 2.98 | 1015 | −0.0011 | −0.09 | 0.0044 | 0.51 |
| 0930 | 0.0185 | 2.20 | 0.0118 | 2.02 | 1030 | 0.0079 | 0.63 | 0.0146 | 1.78 |
| 0945 | **0.0222** | 2.65 | **0.0140** | 2.39 | 1045 | 0.0072 | .0.58 | 0.0124 | 1.54 |
| 1000 | **0.0210** | 2.51 | 0.0111 | 1.90 | 1100 | 0.0036 | 0.29 | 0.0107 | 1.38 |
| 1015 | **0.0275** | 3.30 | **0.0188** | 3.21 | 1115 | −0.0002 | −0.02 | 0.0049 | 0.60 |
| 1030 | **0.0201** | 2.40 | 0.0105 | 1.77 | 1130 | 0.0046 | 0.38 | 0.0088 | 1.14 |
| 1045 | **0.0242** | 2.90 | **0.0142** | 2.41 | 1145 | 0.0059 | 0.48 | 0.0064 | 0.82 |
| 1100 | **0.0211** | 2.52 | 0.0103 | 1.75 | 1200 | 0.0055 | 0.44 | 0.0089 | 1.15 |
| 1115 | 0.0163 | 1.96 | 0.0047 | 0.80 | 1215 | n.a. | n.a. | 0.0060 | 0.78 |
| 1130 | 0.0119 | 1.40 | 0.0014 | 0.23 | 1230 | 0.0031 | 0.25 | 0.0056 | 0.83 |
| 1145 | 0.0079 | 0.96 | −0.0018 | −0.31 | 1245 | −0.0022 | −0.19 | 0.0041 | 0.61 |
| 1200 | 0.0077 | 0.93 | −0.0001 | −0.02 | 1300 | −0.0039 | −0.35 | 0.0036 | 0.53 |
| 1215 | n.a. | n.a. | −0.0043 | −0.74 | 1315 | 0.0026 | 0.23 | 0.0070 | 1.04 |

**Table 5**
**(continued)**

| **U.K. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** London time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control (fraction of average) | **t-value** Sample - Control |
| 1230 | 0.0046 | 0.56 | −0.0089 | −1.52 |
| 1245 | 0.0045 | 0.54 | −0.0041 | −0.70 |
| 1300 | 0.0034 | 0.41 | −0.0041 | −0.71 |
| 1315 | 0.0058 | 0.70 | −0.0016 | −0.28 |
| 1330 | 0.0042 | 0.50 | −0.0055 | −0.96 |
| 1345 | 0.0048 | 0.57 | −0.0066 | −1.15 |
| 1400 | 0.0040 | 0.48 | −0.0094 | −1.60 |
| 1415 | 0.0037 | 0.44 | −0.0084 | −1.44 |
| 1430 | −0.0011 | −0.14 | **−0.0181** | −3.07 |
| 1445 | −0.0034 | −0.40 | **−0.0204** | −3.48 |
| 1500 | 0.0020 | 0.24 | **−0.0167** | −2.86 |
| 1515 | 0.0043 | 0.52 | **−0.0187** | −3.20 |
| 1530 | 0.0006 | 0.08 | **−0.0221** | −3.74 |
| 1545 | 0.0030 | 0.36 | **−0.0180** | −3.08 |
| 1600 | 0.0063 | 0.75 | **−0.0167** | −2.86 |
| 1615 | 0.0011 | 0.13 | **−0.0232** | −3.84 |
| 1630 | 0.0109 | 1.29 | −0.0114 | −1.85 |
| **Adjusted $R^2$** | 0.9172 | | 0.9140 | |
| ***F*-value** | 36,163.80 | | 57,858.48 | |
| ***F*-test** | 3.95 | | 8.40 | |

| **U.S. trading** | **Model I** | | **Model II** | |
|---|---|---|---|---|
| **Time of day** New York time | **Time effect** Sample - Control | **t-value** Sample - Control | **Time effect** Sample - Control | **t-value** Sample - Control |
| 1330 | 0.0046 | 0.40 | 0.0096 | 1.42 |
| 1345 | 0.0022 | 0.19 | 0.0072 | 1.05 |
| 1400 | −0.0021 | −0.19 | 0.0057 | 0.84 |
| 1415 | −0.0110 | −0.97 | −0.0041 | −0.60 |
| 1430 | −0.0139 | −1.23 | −0.0101 | −1.47 |
| 1445 | −0.0155 | −1.36 | **−0.0159** | −2.33 |
| 1500 | −0.0202 | −1.78 | **−0.0198** | −2.92 |
| 1515 | −0.0123 | −1.08 | −0.0151 | −2.20 |
| 1530 | −0.0243 | −2.14 | **−0.0267** | −3.93 |
| 1545 | **−0.0352** | −3.13 | **−0.0375** | −5.55 |
| 1600 | −0.0126 | −1.03 | −0.0106 | −1.30 |
| **Adjusted $R^2$** | 0.8338 | | 0.0836 | |
| ***F*-value** | 16,813.86 | | 34,074.36 | |
| ***F*-test** | 1.51 | | 2.88 | |

The table reports estimated time-of-day effects, i.e., $\mu_t$ in Model I and $\nu_t$ in Model II. $t$-values are based on heteroskedasticity-consistent covariance matrices of the estimated parameters. A boldfaced coefficient indicates significance at the 1 percent level ($|t| > 2.33$). For each model, the joint significance of the estimated time-of-day effects reported in the table is tested using an $F$-test. A test statistic above $F = 1.70$ means that the intraday pattern for cross-listed stocks is significantly different from that of controls.

market (London) because volume is lost to the secondary market (New York). Her model does not explicitly allow for an overlap of trading, but stretching its implications to such a setting would suggest that London spreads for cross-listed stocks are higher, both in absolute terms and relative to spreads of non-cross-listed stocks, during the London morning compared to the afternoon, because volume is relatively more concentrated to the overlap for these stocks. However, Freedman's model also predicts that spreads in New York should be lower for cross-listed stocks than for similar non-cross-listed stocks. The intuition behind this prediction is that the (positive) effect on New York spreads of information-based trading taking place in London instead of New York is likely to outweigh the (negative) effect on spreads of liquidity being lost to London. The evidence instead shows that New York spreads are significantly higher for cross-listed stocks than for controls during the overlap. Since New York volume is relatively more concentrated during the overlap for cross-listed stocks than for non-cross-listed stocks, which should lower trading costs at this time, the results suggest that information trading is abundant in New York during the overlap.

Whether the high New York spreads around the open are generally consistent with models of privately informed investors depends on what one assumes about their attitudes toward risk and the ability of other traders to choose when to trade during the day. If all traders are assumed to be risk neutral and a subset of liquidity traders can choose when to trade based on transaction costs, as in Admati and Pfleiderer (1988), these traders would avoid the New York open and the overlap. Other models of asymmetric information with risk averse investors, for example, Spiegel and Subrahmanyam (1992) and Subrahmanyam (1991), have equilibria where spreads may be positively or negatively correlated with volatility and volume depending on the particular market settings. However, if discretionary liquidity traders were added to these models, they would avoid the overlap, since it is characterized by high spreads, and the clustering of volume at this time of day would break down. Thus, for these models to be supported by the data there has to be some exogenous reason for volume to be clustered during the overlap.

The fact that the spread patterns during the overlap are so different between London and New York reinforces the impression that trading of British cross-listed stocks is at least partially segmented. If a substantial share of the order flow is indeed segmented, and new private information is being revealed through the trading activities of New York investors as suggested by the volatility and volume patterns reported above, a simple adverse selection story might motivate why New York spreads are equally high for cross-listed stocks as for controls during the overlap. By contrast, although London volatility increases significantly at this time as well, the London market does not respond by increasing spreads. On the contrary, spreads are if anything significantly lower for cross-listed stocks than for controls during the overlap. It seems that London dealers are, relatively speaking, less concerned with the risk of facing informed trading at this time of day.

A complementary interpretation of the London spread pattern during the overlap is that London dealers are sensitive to the additional competition for order flow from New York. Their response is to incorporate New York information into their prices which lowers the spread costs for investors choosing to trade in London at this time of day. By contrast, there is virtually no impact of this cross-border competition from London on New York spreads. While dealers in London seemingly worry about losing order flow to New York, the specialist seems to be less concerned with orders flowing in the other direction. Thus, the mere fact that more dealers are actively posting prices during the overlap does not necessarily mean that New York spreads are lower for cross-listed stocks than for control stocks. Indeed, at the New York open, spreads are higher in New York than in London. This evidence lends credence to Brock and Kleidon's (1992) conjecture that New York specialists have some amount of market power that enables them to keep spreads high at the open.

## 6. Summary and Conclusions

This study shows that the intraday patterns for British cross-listed stocks closely resemble those of otherwise similar non-cross-listed stocks. Specifically, London intraday patterns for British cross-listed stocks are to a very limited degree affected by the fact that these stocks have a shorter nontrading period prior to London open and that they continue trading in New York for another 4.5 hours after London close. Perhaps more surprisingly, New York intraday patterns for British ADRs are almost completely unaffected by the fact that British stocks have been trading continuously in London for 6 hours prior to New York open.

The 2-hour period each day when both London and New York are trading British cross-listed stocks is characterized by concentrated trading volume on both sides of the Atlantic. Cross-listed stocks experience a larger fraction of their total daily volatility and trading volume than non-cross-listed stocks during the overlap. This clustering of activity is more pronounced for New York trading than for London trading. There is also evidence that morning volatility originating in New York spills over to the London market. Despite this information spillover, London dealers for cross-listed stocks do not respond by raising their spreads. On the contrary, spreads in London for these stocks are if anything lower than for controls during the overlap of trading. At the same time, New York spreads for British ADRs are as high as they are for other similar NYSE/AMEX-listed stocks. There is no measurable effect on volatility, volume, or spreads in New York of the London close.

The combined evidence from U.K. and U.S. trading of British stocks strongly suggests that each market leaves distinct "footprints" in the data regardless of whether a security is traded in other (overseas) markets. This result is consistent with evidence from the foreign exchange market presented in Hsieh and Kleidon (1994). They find that trading spot \$/DM is characterized by distinct separate intraday patterns in London and New York, respectively. Taken together, the empirical evidence suggests that traders take a much less global view on trading than one might expect given the relative ease by which information is transmitted between markets and given the relatively modest costs of cross-border arbitrage.

By comparing intraday patterns in London and New York during the overlap, a more detailed analysis of market integration is possible. The following five conclusions are drawn from the evidence during the overlap: (i) new private information is being revealed through U.S. trading of the ADR; (ii) the arbitrage activities set in motion as this new information is incorporated into prices on both sides of the Atlantic produces a relatively stronger concentration of volume toward the overlap for cross-listed stocks; (iii) the New York specialist keeps opening ADR spreads high, partly as a response to the increased adverse selection risk associated with information trading around the New York open and partly due to a desire to price discriminate against inelastic liquidity demand at this time of day; (iv) London dealers in the underlying stock at this time of day seem to be concerned about the added competition for order flow represented by New York trading activity; and (v) the strikingly different dealer reactions on either side of the Atlantic are consistent with informed trading at this time of day almost exclusively affecting New York, that is, there is very limited risk that U.S. informed traders take their trades to London after the U.S. market opens. Overall, the evidence suggests that market switching costs are high enough to prevent a substantial share of U.S. informed traders from placing their trades in London.

Theoretical models of intraday price formation, whether they are rational expectations models with asymmetrically informed agents or models of intertemporal trading, have trouble explaining the combined evidence for cross-listed stocks. This does not, however, mean that these empirical regularities could not be caused by private information trading or that a particular market's trading hours are unimportant for interpreting the evidence. It simply suggests that no model has yet fully captured the dynamic interaction between volatility, volume, and spreads.

## Appendix

This appendix describes how the dependent variables of the regression analyses were calculated from the raw data. Minute-by-minute time series of the best bid and offer for each stock were first calculated. For the British data, this entails finding the best bid and offer among up to 18 market makers posting firm two-way prices and volumes. The first price series is taken to be the midpoint of these best bids and offers, sampled at the beginning of each time interval. The percentage spread, defined as the difference between the best bid and the best offer divided by the midpoint quote at the beginning of each time interval, is also recorded. For each British (U.S.) stock ($f$), this gives 33 (27) daily ($d$) time interval ($t$) spreads, $S_{f,d,t}$.

In calculating volatility of returns, quoted prices have the advantage of being continuous and of not being affected by bid-ask bounce, but the disadvantage of possible "staleness." Consequently, also price series based on trade prices, using ordinary bargains from the British data and regular trades from the U.S. data.[15] Trades are time stamped to the second in the U.S. data and to the minute in the British data. The British data include time stamps reported by both buyer and seller. Since settlement in the U.K. is based on the seller's time stamp, this time stamp is used for determining when trades occurred.[16] Trade prices are recorded as missing until the first trade of the day, which is recorded for the corresponding time interval. For subsequent time intervals, the first trade price for that interval is recorded (unless there are multiple trades in the same minute, when the average is used); if no trades occurred, the previously recorded price is retained.

For each time interval, cumulative trading volume, defined as the sum of the pound (dollar) value of ordinary trades during the interval, is also recorded. Volume at 0830 (0930) [open] and 1630 (1600) [close] in the U.K. (U.S.) are recorded separately, giving 34 (28) daily ($d$) time

[15] Intrafirm trades, options related trades, and trades with special condition codes were excluded from the LSE data.

[16] When sorting trades by the seller's time stamp, trade prices sometimes are outside the prevailing quotes. While this seemingly violates the best execution rule of the London Stock Exchange, a more likely explanation for the discrepancy is that the seller's time stamp was misreported. Misclassified trades will primarily affect inferences about the intraday volatility of trade prices. It might also affect the intraday pattern of trading volume.

**Table A1**
**1991 trading volume and security codes for samples and controls**

**British stocks cross-listed on NYSE/AMEX and their British controls**

| Sample stock | U.K. volume (million pounds) | U.K. volume (ex ADRs) | EPIC code | Control stock | U.K. volume (million pounds) | U.K. volume (ex ADRs) | EPIC code |
|---|---|---|---|---|---|---|---|
| Glaxo Holdings | 7,591 | 4,427 | GLXO | Guiness | 3,192 | 3,148 | GUIN |
| Hanson | 5,103 | 2,939 | HNSN | General Electric | 2,287 | 2,287 | GEC |
| British Telecom | 5,015 | 4,259 | BT.A | Tesco | 2,031 | 2,026 | TSCO |
| British Petroleum | 4,774 | 3,596 | BP. | Marks & Spencer | 1,912 | 1,912 | MKS |
| ICI | 3,808 | 3,365 | ICI | British Aerospace | 1,579 | 1,579 | BA. |
| Grand Metropolitan | 3,700 | 3,036 | GMET | Prudential | 1,508 | 1,508 | PRU |
| Shell Transport | 3,667 | 2,962 | SHEL | Argyll | 1,489 | 1,489 | AYL |
| Smithkline Beecham | 3,616 | 2,557 | SB.A | Lloyds Bank | 1,407 | 1,407 | LLOY |
| (combined volume) | | | SB.E | Ladbroke | 1,391 | 1,391 | LADB |
| British Gas | 3,590 | 3,280 | GAS | Royal Insurance | 1,327 | 1,327 | ROYL |
| BAT (AMEX) | 2,959 | 2,527 | BATS | Sainsbury | 1,314 | 1,314 | SBRY |
| Barclays | 2,291 | 2,254 | BARC | Abbey National | 1,311 | 1,311 | ANL |
| Cable & Wireless | 2,253 | 2,253 | CW. | Rolls Royce | 1,270 | 1,270 | RR. |
| National Westminster | 2,198 | 2,170 | NWB | Kingfisher | 1,258 | 1,258 | KGF |
| Unilever | 2,133 | 2,031 | ULVR | Boots | 1,227 | 1,227 | BOOT |
| Bass | 1,878 | 1,846 | BASS | Midland Bank | 1,210 | 1,210 | MID |
| British Steel | 1,850 | 1,475 | BS. | Forte | 1,065 | 1,065 | FTE |
| RTZ | 1,785 | 1,764 | RTZ | Williams Holdings | 1,039 | 1,039 | WLMS |
| British Airways | 1,353 | 1,000 | BAY | Wellcome | 1,037 | 1,037 | WCM |
| Vodafone | 1,123 | 918 | VOD | Hillsdown | 1,010 | 1,010 | HLD |
| Willis Corroon | 667 | 598 | WILC | Reed International | 1,010 | 1,010 | REED |
| Royal Bank of Scotland | 556 | 556 | RBOS | Land Securities | 972 | 972 | LAND |
| NFC (AMEX) | 400 | 400 | NFC | Redland | 971 | 971 | RDLD |
| **Mean** | **2,709** | **2,183** | | **Mean** | **1,427** | **1,425** | |
| **Median** | **2,272** | **2,254** | | **Median** | **1,311** | **1,311** | |

**Table A1**
**(continued)**

**NYSE/AMEX trading of British cross-listed stocks and NYSE/AMEX U.S. controls**

| Sample stock | U.S. volume (million dollars) | U.S. ticker | Control stock | U.S. volume (million dollars) | U.S. ticker |
|---|---|---|---|---|---|
| Glaxo Holdings | 15,260 | GLX | RJR Nabisco | 6,670 | RN |
| Hanson | 2,938 | HAN | C&S Sovran Corporation | 3,108 | CVN |
| British Telecom | 1,261 | BTY | Fund America Enterprise Hldgs. | 1,334 | FFC |
| British Petroleum | 3,140 | BP | Circus Circus Enterprise | 2,688 | CIR |
| ICI | 1,416 | ICI | Litton Industries | 1,294 | LIT |
| Grand Metropolitan | 2,661 | GRM | Primerica Corporation New | 2,739 | PA |
| Shell Transport | 585 | SC | Policy Management Systems | 556 | PMS |
| Smithkline Beecham | 5,173 | SBE | Student Loan Marketing | 4,849 | SLM |
| | 263 | SBH | Hartford Steam | 306 | HSB |
| British Gas | 403 | BRG | Atlantic Energy | 425 | ATE |
| BAT (AMEX) | 609 | BTI | Tidewater Inc | 478 | TDW |
| Barclays | 34 | BCS | BRE Properties | 39 | BRE |
| | 111 | BCB.PR.A | Raymond J. Financial | 123 | RJF |
| | 83 | BCB.PR.B | Associated Natural Gas | 87 | NGA |
| | 78 | BCB.PR.C | Rayonier Timberlands | 91 | LOG |
| | 161 | BCB.PR.D | Wisconsin Public Service | 218 | WPS |
| Cable & Wireless | 505 | CWP | Communications Satellite | 486 | CQ |
| National Westminster | 33 | NW | CSS Industries | 45 | CSS |
| Unilever | 285 | UL | OEA Inc | 293 | OEA |
| Bass | 45 | BAS | Baker Fentress & Co | 50 | BKF |
| British Steel | 491 | BST | Comdisco Inc | 486 | CDO |
| RTZ | 34 | RTZ | Americus Tr. Sears Shares | 33 | RSP |
| British Airways | 1,098 | BAB | Genentech Inc | 1,235 | GNE |
| Vodafone | 835 | VOD | Mapco Inc | 1,116 | MDA |
| Willis Corroon | 310 | WCG | KU Energy Corp. | 331 | KU |
| Royal Bank of Scotland | 97 | RBS.PR | Marshall Industries | 105 | MI |
| | 87 | RBS.PR.B | Plum Creek Timber Creek | 317 | PCL |
| NFC (AMEX) | 8 | NFC | Insteel Industries Inc | 8 | III |
| **Mean** | **1,357** | | **Mean** | **1,054** | |
| **Median** | **356** | | **Median** | **378** | |

U.K. trading volume is customer business January–December 1991 as reported by the Stock Exchange Quarterly (Winter 1991, Table 8C). U.S. trading volume was retrieved from Chicago's Center for Research in Security Prices.

interval ($t$) volume observations, $V_{f,d,t}$, for each British (U.S.) stock ($f$).

Finally, volatility based on quote prices, $\sigma(\text{quotes})^2_{f,d,t}$, and on trade prices, $\sigma(\text{trades})^2_{f,d,t}$, are calculated. The volatility measure is constructed as follows. The return for stock $f$, on day $d$ and time interval $t$ is defined as

$$R_{f,d,t} \equiv ln(P_{f,d,t+1}) - ln(P_{f,d,t}). \tag{A.1}$$

This produces 32 (26) return observations per stock and trading day for the British and U.S. data, respectively. Note that the overnight volatility is excluded, so the first observation is for 0830 to 0845 in the U.K. and for 0930 to 0945 in the United States. For each stock and each time interval, volatility is measured as the squared deviation from the stock- and interval-specific mean return,

$$\sigma^2_{f,d,t} = (R_{f,d,t} - \bar{R}_{f,t})^2. \tag{A.2}$$

where $\bar{R}_{f,t} = \sum_{d=1}^{D_f}(R_{f,d,t}/D_f)$ is the mean across $D_f$ trading days.

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