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Abstract

This paper examines trading patterns and market integration using laboratory asset markets. Our markets are designed to approximately correspond to the trading day for stocks cross-listed in markets in Europe and North America. Some of our markets feature timing restrictions so that participants cannot trade across markets except during a fully integrated overlap period. Comparison of markets with and without timing restrictions shows that restrictions reduce trading activity and shift transactions to the overlap period. When asset values are extreme, price discovery can be impeded when trading restrictions exist. The measurement of liquidity suggests that trading restrictions increase overall spreads.

I. Introduction

The aim of this paper is to use experimental asset markets to study trading activity, price efficiency, liquidity and adverse selection costs in the context of a perfectly integrated overlapping market in which both informed and liquidity traders participate. This is an important area for study because, as documented by Eun and Sabherwal (2003), Baruch, Karolyi and Lemmon (2007) and Menkveld (2008), there has been a substantial rise in the number of cross-listed securities recently.

An Experimental methodology offers a range of advantages over field market data because impediments exist that prevent full integration across financial markets. Pagano and Roell (1990), DeJong, Nijman and Roell (1993) and Moulton and Wei (2009) show that trading costs differ across markets and trade becomes concentrated in the venue with the lowest costs. Grammig, Melvin and Schlag (2005) demonstrate that trading activity and price movements in overlapping markets are influenced by currency risk. Solnik (1996) and Bacidore and Sofianos (2002) suggest that even in an otherwise integrated market there is a bias towards price discovery taking place in the home market. Moreover, the architecture of the trading system leads to execution preferences. For example, DeJong, Nijman and Roell (1993) show that London has a particular advantage in the execution of larger trades.

Our experimental markets are a perfectly integrated single market, where all participants can trade at any time, share the same market architecture exactly, face no currency risk or impediments to the flow of information. We then impose a single barrier to integration in the form of trade timing restrictions. With timing restrictions, some participants can only trade during the early portion of the market, and others during the late portion of the market, but all participants can trade during an overlap period. The markets are designed so that there are no barriers or costs to trading during the overlap allowing us to make cleaner comparisons between overlap and non-overlap periods.

Each experimental market is subdivided into Early, Middle and Late submarkets. The Middle submarket can be thought of as an overlap period, where both markets are open allowing both Early and Late traders to participate. The use of an experimental methodology allows us to identify trading volume, price discovery, liquidity, and profits of both informed and liquidity traders as well as which type of traders are providing and taking liquidity. We are also able to measure informational efficiency, which cannot be directly observed outside of laboratory markets.

The key contribution of our experimental analysis is that we show how the pattern of trading alters in response to trading restrictions that cause overlapping markets but unlike market based studies we can explain why trading patterns alter. We find that trading restrictions increase average volume per active-trader even though overall volume declines. By comparing markets with and without trading restrictions, our experimental analysis is able to show that there is a shift in both overall volume and per active-trader volume away from the Early market towards the overlap. Therefore, the reason for the rise in volume observed in overlapping markets is because there is a shift in volume from the non-overlapping periods.

Our experimental approach allows us to identify the drivers of this shift in volume. We do this by studying the trading behavior of each kind of trader separately in each type of market. We discover that imposing trading restrictions increases overall limit order submission rates but lowers submission rates during the overlap. Moreover, the lower volume in the Early market is not due to a reduction in the submission of limit orders by either informed or uninformed traders. We measure a trader's aggressively pursued trading volume by calculating the trader's take rate, defined as the number of market orders they submit divided by their total volume. Overall order take rates are not different across treatments but there is a shift in take rates away from the Early submarket to the Middle submarket when trading restrictions are imposed which is apparent for both informed and uninformed traders.

When we examine adverse selection gains to informed traders, we find that the existence of trading restrictions raises overall profits to these traders and makes the Middle market more profitable for the informed. When restrictions apply informed traders are more active in the Middle market where their identity can be hidden more effectively. Thus, the increased volume in the Middle market is also being driven by the informed traders exploiting the most profitable time to trade.

Our experimental result also shows that trading restrictions only lead to higher inefficiency in the Early period but not during the Late or Middle submarkets which is important information for investors and portfolio holders. Moreover, the imposition of trading restrictions leads to higher quoted spreads initially but during the overlap period the different spreads tend to converge. Therefore the benefits of higher liquidity in actual overlapping markets, apparent in empirical studies, appears to be more to do with the information benefits provided by the market opening rather than the overlap itself. Since our markets are by construction fully integrated, it suggests that empirical studies of cross-listed stocks are not studying fully integrated markets.

As well as being important for investors and portfolio holders our results are also important for policy makers and exchanges interested in market design. The overall message of our analysis is that the only way to achieve full integration of markets is to eliminate non-overlapping trading periods by extending the trading day in domestic markets. Yet even this may not always fully integrate markets since investors in widely different time zones have different normal hours of activity. Even if domestic markets were to open 24 hours a day, patterns of trade may still be similar to those observed in our experiments.

The remainder of the paper is organized as follows. Previous research is discussed in Section II. The experimental design, structure of the asset markets, and experimental procedures are presented in Section III. Section IV discusses the results, and the summary and conclusions are in Section V.

II. Previous Research

A U-shaped pattern in intra-day trading, where activity is concentrated at the open or the close of the market, has been found in empirical studies by, for example, Wood, McInish and Ord (1985) and Hameo and Hasbrouck (1995). A comprehensive review of these patterns can be found in O'Hara (1995). Much of this research argues that intraday patterns are driven by the release of public and private information. Kim and Verrecchia (1991), for example, show that volume increases around public news announcements because information is interpreted diversely generating a difference of opinion about future value. Admati and Pfleiderer (1988), (1989) show that intraday patterns can arise when discretionary liquidity traders coordinate trading to reduce costs, causing concentrated activity during some periods. Foster and Viswanathan (1990), (1993) show that when informed traders have private information that dissipates quickly, concentrated bouts of trading arise early on in the day. These concentrated bouts arise as informed traders seek to exploit their information advantage before public announcements and the trading process diminishes its value. Information asymmetry at the start of trading is therefore important for the existence of a U-shaped trading pattern. Empirical evidence by Bessembinder, Chan and Seguin (1996) has shown that both public and private information are important determinants of volume in stock markets.

A. International Trading Patterns and Integration

Werner and Kleidon (1996) analyse intraday volume, volatility and spread patterns for London stocks cross-listed in New York. They argue that if the markets for these securities are fully integrated there will be a bout of concentrated trading coinciding with the open of the first market (London) caused by the accumulation of private information. But, because fully integrated markets allow information to flow from one market to another this trading will cause private information to be reflected in both markets, preventing a further bout of concentrated trading taking place at the open of the second market (New York).[1] Despite London trading for six hours before New York opens they find that each market generates its own U-shaped trading patterns resembling those of control firms that are not cross-listed. This suggests that the markets are not fully integrated as private information accumulates prior to the opening of each market leading to a bout of concentrated trading at the open of each market. They also find that the overlap period attracts a disproportionate amount of trading activity, a feature which is most pronounced for the New York market.

Evidence of concentrated trading is also provided by Menkveld (2008) who examines Dutch shares cross-listed in New York and in European markets. When the NYSE opens, UK volume in Dutch securities rises by as much as 79% but when the UK closes, NYSE volume falls by 96%. In Amsterdam, volume rises by 68% when NYSE opens but NYSE volume falls by 29% when Amsterdam closes. Trade concentration in overlapping markets is also reported by Hupperets and Menkveld (2002) and by Biais and Martinez (2004).

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[1] No concentrated trading takes place as the information advantage of informed traders has dissipated due to trading taking place in the open market.

Menkveld (2008) argues that when some traders face trading restrictions in their home market, trade and price discovery is concentrated during overlaps. This happens because informed traders who are able to trade in both home and foreign markets split their orders across venues to limit the information revealed by their trading activities. Eun and Sabherwahl (2003) study stocks cross-listed on the Canadian and US markets and find that price discovery in the US rises as the US market takes a larger proportion of overall trading.

Baruch, Karolyi and Lemmon (2007) present a theoretical model explaining the variation in trading volume that is attracted to a foreign venue after a cross-listing occurs. Their model shows that the distribution of trading volume in the foreign venue will depend on the correlation of the cross-listed asset returns with the returns of domestic assets traded in the foreign market. When domestic asset returns in the foreign market are correlated with cross-listed returns, market makers can infer prices from the order flow of these securities. Empirically, their predictions are borne out for stocks cross-listed on US exchanges.

Studies of strategic behavior in multiple markets also provide important insights about cross-listed securities. Chowdhry and Nanda (1991) extend the model of Kyle (1985) and Admati and Pfleiderer (1988) to multiple markets. Strategic choices by informed participants leads to trading in markets that are thick with liquidity traders causing a shift in activity to the most liquid market. Migration to overlapping markets because costs are lower is borne out by Werner and Kleidon (1996) and Moulton and Wei (2009) who find that spreads are lower during the overlap period. Karyoli (2006) provides an extensive review of research that examines integration and cross-listed markets.

B. Microstructure Experiments

As the survey of experimental studies by Sunder (1995) indicates, a strong focus of experimental asset markets has been on examining information aggregation. Barner, Feri and Plott (2005) create markets where information arrives during the experiment asymmetrically. Their experiment shows that limit orders placed by informed traders early on in the trading period cause private information to be revealed to the market making it informationally efficient. In Bloomfield, O'Hara and Saar (2005) fully informed and uninformed traders with target cash balances, participate in a limit order market. Their objective is to discover which traders provide liquidity to the market as trading evolves. Their results show that high levels of information aggregation take place during the first minutes of trading and that liquidity provision shifts towards informed traders as trading progresses. Bloomfield, O'Hara and Saar (2009) also examine price aggregation but in a market of informed, liquidity and noise traders. They show that noise traders, who have no exogenous reason to trade, add to volume, reduce price impact effects and increase liquidity, but reduce the informativeness of prices.

Qi and Ochs (2009) study information flows between fully segmented markets in an experiment in which there are two markets for an asset that provide identical dividend streams in each market. Participants can view trading in both markets but trade is segregated so that participants can only trade in one. Despite segmentation, information held by insiders passes from one segmented market onto another. Ackert, Mazzotta and Qi (2011) also examine the impact of market segmentation by examining the market for two assets with different dividend claims. They show that when some participants cannot freely trade an asset it commands a higher risk premium, which is necessary to attract unrestricted traders. Both these papers make important contributions to our understanding of segmented markets but do not address the issue of trading patterns in overlap markets or the interaction between informed and uninformed traders in an overlapping market.

III. Experimental Design

Our market sessions utilize a customized program written using the Fischbacher (2007) z-Tree (Zurich Toolbox for Readymade Economic Experiments) to implement twenty experimental computerized double auction markets of three minutes. In each session participants trade a single risky security in a market that is subdivided into Early, Middle and Late submarkets, each one minute in length. In some instances, subjects had trading privileges in only some of the submarkets.[2] During each of the three submarkets, traders could post and accept bids and offers in the double auction. After the Late submarket was completed, the asset value was revealed to all subjects, and all shares of the experimental asset were liquidated. Subjects' earnings for the period were recorded, and the next period would commence.

A. The Experimental Asset and the Information Structure

Before the start of each Early submarket, traders received a supply of shares. All subjects were told that the asset featured four equally likely liquidating dividends amounting to 20, 40, 60 or 80 trading dollars paid at the end of each trading period. In some periods, which for exposition purposes we label as NoInfo, no further information about the liquidating dividend was provided to any trader so that in these periods all traders were uninformed.[3] In other

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[2] Our design with timing restrictions therefore contrasts with Qi and Ochs (2009) who partition markets into a domestic and a foreign venue and prevent traders from participating outside of their designated market, but have no timing restrictions. This difference stems from our diverse objectives. Whereas their aim is to examine a legally separated market, ours is to examine a fully integrated one.

[3] This is a treatment also incorporated into the experiments undertaken by Qi and Ochs (2009).

periods, some traders were perfectly informed and knew the value of the liquidating dividend. The existence of informed traders was publicly announced but both the number and identities of informed traders were not disclosed to the market.

In addition to shares, subjects also received a cash endowment (in trading dollars) before the start of each Early submarket. We induced liquidity trading by giving some subjects cash bonuses or penalties. To encourage some traders to hold more of their wealth in cash and less in the risky asset, some traders received a five percent bonus on their cash balance, paid at the end of the Late submarket, just before the risky asset was liquidated. To encourage other liquidity traders to hold a greater proportion of their wealth in shares, and therefore actively buy more during trading, other traders incur a five percent penalty, also paid immediately prior to liquidation.

Table 1

The starting positions associated with each of the trader roles (liquidity buyers, liquidity sellers, and informed traders) are summarized in Table 1. The role assigned to each subject was randomized over the twenty markets in the session. At the end of each Late market, individual earnings were calculated as a subject's ending cash balance, plus or minus any bonus or penalty, plus the liquidation value of his or her risky assets. At the end of the session, each subject received a cash sum proportional to his or her experimental earnings totaled over the twenty periods.

B. Timing Restrictions

In addition to their roles as informed traders, liquidity buyers or liquidity sellers, subjects were also designated as Early, Late or Both traders. Early traders were allowed to trade in the Early and the Middle submarkets and were prohibited from trading in the Late submarket. Late traders were able to trade in the Middle and Late submarkets but were prohibited from trading in the Early submarket. Both traders were permitted to trade in all three submarkets. Active traders could post and accept bids and offers. Inactive traders could only observe bids, offers and trades. Active and inactive traders saw the same computer screens, but inactive traders had automatically disabled terminals during the inactive period. These timing restrictions are presented in Table 2. In most treatments, there were an equal number of Early traders and Late traders; with equal numbers being assigned to roles as informed, liquidity buyers, and liquidity sellers. In the NoRes treatment all subjects are Both traders.

C. Experimental Structure

The experimental design is summarized in Table 2. The main treatment, labeled IR, allows informed traders to participate but imposes timing restrictions. As control treatments, NoInfo has no informed traders, but does feature timing restrictions and NoRes has informed traders, but no timing restrictions.

Table 2

In addition to the trading restrictions described above, there were also wealth constraints. A subject was not allowed to carry a negative cash balance, i.e., borrow. However there was, in aggregate, sufficient cash to purchase the entire supply of shares, even if the experimental asset trades at a price of $100, considerably higher than the maximum liquidation value. Short sales were permitted but to prevent bankruptcy the seller had to have at least $100 in cash per share shorted.

D. Market Architecture

All traders participate in a continuous double auction market for a single asset. Each trader can submit limit and market orders for one share of the experimental security at a time.

Limit orders are executed strictly on the basis of price then time priority. Market orders are placed and executed by trading against another trader's posted bids (market sell order) or asks (market buy order). Each trader can post bid and ask prices at any time and can post multiple orders either at the same or at different prices if they choose to do so. When posting bid and ask prices, traders do not need to post prices within the inside spread. A trader can cancel an outstanding order at any time.

Throughout each submarket all outstanding bids and asks are visible to every trader, presented on the basis of price then time priority so that the inside bid and ask prices are clearly visible to all market participants along with depth on both sides of the market. As trades arise, they are immediately reported to the market as a whole. Transaction prices appear in chronological order as a list on the screen. The identity of traders posting or accepting quotes is anonymous so that traders cannot tell whether posted quotes come from informed or liquidity traders.

Our experimental design has created a perfectly integrated market during the overlap that is likely to be more integrated than the overlap of actual markets. Our overlap is free from currency risk and information or cost distortions that cause a home country bias. Within the framework we use we allow order flow from Early traders to interact with order flow from Late traders during the overlap ensuring there is no fragmentation of order flow information.[4] The advantage of creating a fully integrated market is that we can examine exclusively the impact that timing restrictions have on trading behavior.

IV. Results

[4] In actual markets cross-listed securities are listed on competing trading platforms that do not allow order flow from one system to interact with another causing a form of fragmentation.

Our results are drawn from eleven sessions, each containing twenty three- minute markets, totaling two hundred and twenty experimental auctions. Each session lasted approximately two-and-a-half hours, including time spent reviewing instructions and watching a software demonstration. Participants for sessions one to seven were drawn from the student population of the University of Cincinnati. Participants for sessions eight to eleven were drawn from Aston Business School. Most sessions used 17 or 18 subjects. However, we also ran two 24-subject sessions as a robustness check. All sessions were conducted using "trading dollars" which were converted to local currency at the end of the session. Typical payouts were between $20 USD and $25 USD per subject.[5]

Our results tables report the average of each variable, such as volume, pricing efficiency and liquidity, by submarket, treatment and cohort. We analyze these data using a within-subjects design repeated-measures ANOVA, which is a conservative but robust procedure for analyzing experimental data. The ANOVA design and results (two-tailed p-values) are beneath each results table. In our core analysis for each dependent variable, the Main Effects that we examine are the timing restriction (2 categories: with timing restrictions and without timing restrictions), the information restriction (2 categories: with informed traders, without informed traders) and the submarket (3 categories: Early, Middle or Late submarket). Interaction Effects between the independent variables allow us to observe whether the effects of timing and information restrictions are dissimilar in different submarkets.[6] The statistical significance of the interaction between the effects of submarket and timing restrictions leads us to undertake additional two-

[5] We do not report session by session results in the paper but these are available from the corresponding author.

[6] As we have no market without informed traders and trading restrictions, our design does not allow estimation of the interaction effect between information and timing.

way ANOVAs to examine the effect of timing restrictions and information restrictions for each submarket separately, and one-way ANOVAs of the effect of submarket for the cases distinguished by timing restriction.[7]

A. Volume

Aggregated trading volume data associated with each session, and the fraction of volume for each submarket and treatment are shown in Table 3.

Table 3

NoRes, NoInfo and IR average trading volume per market are 89.8, 69.5 and 71.2 respectively indicating that the imposition of trading restrictions reduces volume. The similarity of NoInfo and IR mean market volume suggest that it is the trading restriction that is important, not the absence of informed traders. This is confirmed by the ANOVA results as trading restrictions are found to influence market volume ($p<0.001$) but information restrictions do not ($p=0.641$).[8]

The fraction of transactions in the Early, Middle and Late submarkets show how trading restrictions alter the pattern of trading. For the NoRes treatment trading is concentrated in the Early submarket as about 42% of trading occurs in the Early period, 32% in the Middle period

[7] We apply the Tukey Honestly Significant Difference test to identify pair-wise differences between the submarkets with and without timing restrictions. We also examine 4-way ANOVAs, including additionally the cohort as a factor. The results for the original 3 factors (timing, information and submarket) experience negligible changes, while post hoc testing of the homogeneity of the cohorts, also using the Tukey Honestly Significant Difference test, did not point to any systematic differences between the cohorts from the University of Cincinnati and the Aston Business School.

[8] These results are for an ANOVA on the level of volume aggregated across all submarkets, rather than the level of volume in each submarket. In this case, only the main effects of timing restrictions and information restrictions are examined. These results are in the ANOVA results column labelled "Total" below Table 3.

and 26% in the Late period. ANOVA analysis indicates that the NoRes submarkets have statistically different volume ($p<0.001$), with pair-wise tests showing that Early submarket volume is significantly higher than both Middle and Late submarket volume ($p<0.001$), and that Middle submarket volume is significantly higher than Late submarket volume ($p=0.043$), when there are no timing restrictions. These differences are consistent with the intraday trading patterns first discovered by Wood, McInish and Ord (1985).

With trading restrictions, trading becomes concentrated in the Middle submarket. On average for both the NoInfo and IR treatments, trading in the Middle period represents almost 60% of all trading activity and does not conform to the patterns observed by Wood et al. (1985). ANOVA analysis of submarket volume indicates that both timing restrictions and submarket main effects are strongly significant (in both cases $p<0.001$). In contrast, information restrictions do not appear to be significant ($p=0.580$). The significant interaction effect between timing and submarket ($p<0.001$) indicates that the effect of timing restrictions is different in each submarket. This reflects our findings that with timing restrictions, volume is elevated in the Middle submarket, but suppressed in Early and Late submarkets. By analyzing the treatments with trading restrictions (IR and NoInfo treatments), we see that the significant elevation in volume for these treatments in the Middle submarket, relative to the NoRes treatment reflects a statistically significant shift in volume from the Early and Late submarkets to the Middle submarket. For markets with timing restrictions, volume in the Middle submarket is significantly greater than that in each of the Early and Late submarkets ($p<0.001$), and Early submarket volume is also greater than that in the Late submarket ($p=0.030$).[9] Figure 1, Graph A

[9] Separate submarket ANOVAs, show that in the Early submarket only, information restrictions reduce volume significantly ($p=0.054$).

presents the evolution of average volume for each ten-second interval and indicates that the intra-market behavior of NoRes volume is consistent with U-shaped patterns, indicative of elevated volume at the start and end of trading noted by McInish, and Wood (1990) and Hameo and Hasbrouck (1995) for equity markets and by Bloomfield, Easley and O'Hara (2005) on experimental data. When restrictions are in force, Early market average interval volume for the IR and NoInfo treatments are substantially lower than for the NoRes treatment and lower than for intervals in the Middle submarket when IR and NoInfo volume rises.

Figure 1

Table 4 provides average submarket volume information on a per active-trader basis, allowing us to control for differences across treatments caused by the diverse number of traders participating in the submarkets. Average volume per active-trader, for a submarket and treatment, is calculated by dividing the corresponding volume per market by the number of traders in the submarket. Average volume per trader across all submarkets equals the sum of the submarket averages when the number of traders is the same across each submarket, which is the case for the NoRes treatment.[10]

Table 4

While Table 3 indicated that trading activity is suppressed by the imposition of trading restrictions, Table 4 shows that per active-trader volume on average across all sessions and markets is actually higher when trading restrictions apply. Although each individual restricted trader is trading more actively when they can there are fewer active traders during the non-overlap submarkets because of restrictions. The ANOVA results show that the effect of timing

[10] The formulae for the IR and NoInfo treatments are provided in the Appendix.

restrictions is statistically significant (p=0.017), but that the effect of information restrictions is not (p=0.496).

The effect of submarket is significant (p<0.001) and the interaction of submarket and timing restrictions is also significant (p<0.001) mirroring the results for average volume, and reflect the pattern of per active-trader volume across the different treatments and submarkets. As with overall volume, we find that volume per active-trader is elevated in the Middle submarkets but suppressed in the Early submarket, when timing restrictions are in place. Displacement of trading activity, on a per active-trader basis, to the Middle submarket and from both the Early and Late submarkets remains significant for markets with timing restrictions, (p<0.001). Moreover, in the IR treatment, the Early submarket per active-trader volume (1.78 trades) is also higher than in the Late market (1.34 trades). In the NoInfo treatment, however, the per active-trader volume is the same in the Early and Late submarkets (1.50 trades). Overall, our result that timing restrictions displace volume to the overlap submarket is still robust on a per active-trader basis.

Average per active-trader volume associated with the submarkets also confirms the existence of elevated trading activity in the Early submarket when no trading restrictions exist. When there are no timing restrictions, volume per trader during the Early market is significantly higher than in both the Middle submarket (p=0.001) and the Late submarket (p<0.001), while the Middle submarket per active-trader volume is higher than the Late submarket (p=0.052).

Panel B provides a breakdown of trading activity by informed and uninformed traders and shows that without trading restrictions average per trader volume for both uninformed and informed traders declines after the Early market reaching its lowest average value in the Late market. Early traders trade less in the Early market than they do in the Middle market, especially if they are uninformed. Late traders display elevated activity in the Middle market, especially if they are uninformed. For both informed and uninformed traders average per trader volume declines substantially in the Late market. Middle volume appears to be elevated therefore because Early uninformed and informed traders shift their trading to the Middle and because Late traders trade more in the Middle, their first opportunity to trade. Figure 1, Graph B presents the average ten-second interval volume per trader across the Early, Middle and Late submarkets and shows that average volume per active trader is elevated for Middle market interval for treatments with timing restrictions.

B. Submission and Take Rates

In Table 5 and 6 respectively, we provide information about liquidity provision and take rates.[11] Panel A of each table provides average rates for each treatment and each submarket, Panel B decomposes the information by trader type.

Table 5

Figure 2

Panel A of Table 5 shows that, for all three treatments, the submission rates of limit orders peak in the Early submarket, and then decline as we move to the Middle and Late submarkets. The ANOVAs indicate that the presence of timing restrictions increases limit order submission rates in all submarkets, ($p<0.001$), We also find that submission rates decline

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[11]The submission rates are calculated as the total number of limit orders a trader submits (including executed, expired and cancelled) relative to the total number of limit and market orders they submit, within a submarket. This is averaged across each trader by treatment and by session. The take rate is calculated as the number of market orders relative to the total number of executed limit and market orders for each trader, averaged across traders by treatment and by session. The submission and take rates have been calculated exactly as in Bloomfield et al. (2005).

significantly from submarket to submarket, for the treatments with private information ($p<0.001$), but do not decline significantly ($p=0.901$) after the Middle submarket for the treatment without private information.

These differences are strongly influenced by the number of orders that expire without trading activity, which is at a peak during the Early submarket as shown in Figure 2, which provides a breakdown of submarket limits that are executed, expire or are cancelled. Unexecuted orders are high during the Early market for all treatments because price discovery is taking place, encouraging traders to submit more extreme limit orders that are never executed. For example, at the start of trading participants may submit limit order buy (sell) trades at very low (high) prices as traders are very unsure about the final asset value. These orders are never traded as no one wishes to be their counterparty. As trading progresses and prices become more informative fewer extreme orders are placed increasing limit order execution rates.

Figure 2 shows that when trading restrictions apply submitted limit orders are higher in each submarket than when no restrictions apply. When restrictions apply, although the average number of Middle market submitted limit orders falls, there is a rise in the number of executed trades, and it is this rise in the number of executed limits that causes a shift in volume to the Middle market as observed earlier. This suggests that the supressed trading in the Early market associated with trading restrictions noted in Table 3 and 4 is not due to a lack of limit order submissions.

Table 6

Table 6 indicates that the overall average of the take rates vary little across treatments. This is reflected in the ANOVA results that suggest that neither timing restrictions ($p=0.961$) nor information restrictions ($p=0.537$) influence take rates. However, there are significant submarket differences, ($p<0.001$). Without timing restrictions the take rate is highest in the Early market, and falls significantly in the Middle submarket ($p=0.006$) and then falls significantly again in the Late market ($p=0.010$). This pattern is consistent with informed traders more actively exploiting an informational advantage in the Early submarket than during the Middle or Late submarkets when the informational advantage they have is lower. When timing restrictions exist, take rates are lower in the Early market, than when restrictions do not apply ($p=0.014$). These take rates rise significantly in the Middle submarket ($p<0.001$), and fall significantly ($p<0.001$) in the Late submarket. With timing restrictions, some market orders are displaced to the Middle market causing executed orders to rise.

The decomposition of the submission rates by trader type in Panel B of Table 5 shows that when no restrictions exist, the average Early submarket submission rate is 0.60 for both informed and uninformed traders falling to 0.51 and 0.48 respectively in the Middle submarket and to 0.40 and 0.39 in the Late submarket, indicating an elevated number of submissions in the Early submarket for both types of traders. Trading restrictions also appear to cause an elevation in limit order submissions in the Early submarket for these traders. The submission rates for informed and uninformed traders are 0.70 and 0.67 respectively, both more than ten percent higher than was observed in the NoRes treatment. Submission rates of the Early informed and uninformed traders in the Middle submarket are comparable to informed traders that face no restrictions. However, Late traders have elevated average submission rates during the Middle submarket. It is the behavior of Late traders therefore that gives rise to elevated submission rates in the Middle market.

Differences in the take rates for informed and uninformed traders are highlighted in Panel B of Table 6. Without restrictions, the take rate of informed traders is elevated when compared to the uninformed in the Early submarket, but tend to be below those of uninformed traders in the Middle and Late submarkets. This is consistent with informed traders in the Early submarket making use of market orders to exploit their information advantage. However, as trading progresses and this advantage dissipates, take rates decline. When traders are restricted from the Late market their take rates are suppressed in the Early submarket but are higher in the Middle submarket. This suggests that restrictions cause a displacement of market orders from the Early submarket to the Middle submarket and provides some intuition for why the volume shifts of Tables 3 and 4 arise.

In contrast, when traders are restricted from participating in the Early market, informed traders use an elevated number of market orders when they first have an opportunity to trade. This suggests that the restriction on Early submarket trading does not cause a reduction in take rates when these traders get their first opportunity to trade. For unrestricted informed traders the pattern of take rates through the Early and Middle submarkets is similar to the pattern of take rates in the Middle and Late submarkets for informed traders who are restricted from trading in the Early submarket. Uninformed traders facing no trading restrictions take liquidity at a fairly uniform rate in the Early and Middle submarkets but the rate declines in the Late submarket. When there are trading restrictions Early/uninformed traders place market orders at a similar rate in the Early and Middle submarkets, but Late/uninformed traders use an elevated number of market orders during the Middle submarket.

This analysis of trader type suggests that Early traders contribute to the trading patterns we observed in Table 3 and 4 by suppressing take rates in the Early market and raising them in the Middle market relative to NoRes traders, while Late traders raise their Middle market take rates in their first opportunity to trade. Early traders with timing restrictions in the Late market therefore defer some of their trading which prevents Early market trading from being elevated while their activity combined with that of Late traders in the Middle leads to elevated volume in the Middle market.

Figure 3

Figure 3 contains plots of average ten-second limit order submission rates and take rates, respectively. These show that when there are no restrictions the limit order submission and taking rates tend to fall as trading progresses.[12] However, when trading restrictions exist (IR and NoInfo) the limit order submission rate falls until the end of the Early submarket but rises sharply at the start of the Middle submarket, and then continues on a new downward trajectory until the start of the Late submarket when submissions rise once again before falling back towards the end of the Late submarket. Take rates for the IR treatment rise after the first interval and tend to decline until the start of the Middle submarket when the take rate rises sharply. During the Middle market the take rate falls and converges to the take rate of the treatment without restrictions by the end of the Middle market. During the Late submarket the IR take rate follows a similar path to that of the NoRes take rate.

C. Price Discovery

Table 7

Table 7 presents the mean pricing errors for each submarket, calculated as the absolute value of the average transaction price less the asset liquidation value and shows that pricing errors tend to decline as trading progresses from the Early to the Late submarket. With no information, the expected liquidation value is fifty, making it more difficult to detect departures from price

[12] The first interval leads to a rise in the take rate for IR and NoRes treatments and the first three for the NoInfo treatment but after this take rates decline.

efficiency when private information is 40 or 60 so we present results for extreme (20 or 80) and non extreme (40 or 60) signals separately. Panel A contains average pricing efficiency results for the extreme signal and Panel B for the non extreme signals. Comparisons of Panel A and B show that when the asset value is more extreme pricing errors are larger than when the asset value is less extreme, ($p<0.001$).[13]

When the asset value is more extreme, pricing efficiency is higher without trading restrictions ($p=0.033$). Pricing efficiency differences across treatments, caused by timing restrictions, are most pronounced during the Early submarket, ($p=0.068$), but decline in the Middle and Late submarkets ($p>0.319$). For the treatments with timing restrictions, informational efficiency improves significantly between the Early and Middle submarkets, ($p<0.001$) falling from 19.8 to 15.3.

Panel B shows that when the asset value is less extreme, timing restrictions do not lead to lower pricing errors when all submarkets are considered collectively, ($p=0.206$). However, the effect of submarket is strongly significant, ($p<0.001$). Separate analyses of the submarkets indicate that timing restrictions raise pricing inefficiency in the Early submarket, ($p=0.023$). There is a significant improvement in efficiency between the Early and Middle submarkets ($p<0.009$), and this is not affected by timing restrictions.

<u>Figure 4</u>

Figure 4 provides plots of the average pricing error calculated over each ten-second interval. Graph A contains plots for markets with the more extreme asset values and Graph B contains information for markets with the less extreme asset values. Both graphs indicate that as

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[13] This result was obtained by combining the extreme and less extreme cases, which are analyzed separately in Table 5, into a single ANOVA incorporating an extremeness categorical factor.

trading progresses pricing errors fall, a pattern noted in other experimental studies such as those of Schnitzlein (1996) and Bloomfield, Easley and O'Hara (2005). At the start of the Early market, pricing errors are higher when trading restrictions apply but by the start of the Middle market pricing efficiency across treatments converges. At the very end of trading, pricing errors have a tendency to rise but display no clear-cut pattern related to the treatment. Table 7 and Figure 4 indicate that our markets may be less efficient at aggregating information than noted previously in many other studies. A possible explanation is suggested by Schnitzlein (2002) who argues that information aggregation is impeded in markets which allow informed and liquidity traders to interact when participants are unaware of how many informed traders are participating.

D. Liquidity

Hamilton (1979) argued that the increased competition associated with cross-listing will lead to higher liquidity and lower spreads as markets compete for order flow. This appears to be supported empirically. Both Foerster and Karolyi (1998) and Hargis (2000) show that when Toronto and Latin American stocks respectively are cross-listed on a U.S. exchange average spreads decline. Moreover, Werner and Kleidon (1996) show that US-UK cross-listed stocks have lower average spreads than comparable control securities. More recently, Moulton and Wei (2009) have shown that the overlap period itself is important in influencing spreads. Their intraday analysis of quotes for US stocks listed in European markets shows that spreads for these stocks fall at the time the US market opens and rise after the European market closes.

Table 8

Figure 5

Table 8 presents the average time weighted inside spread as defined in McInish and Wood (1992, p. 756), obtained from the Early, Middle and Late submarkets for each session and treatment. Across all sessions the Early submarket displays the highest time-weighted average spread. This is because the open of the market occurs at the start of the Early period and the open of a market is associated with wider posted bid and ask prices due to greater uncertainty regarding prices at this time, see for example McInish and Wood (1992). The ANOVA results show that the main effect of submarket is significant, ($p<0.001$). For each treatment average Early submarket spreads are different to Middle and Late submarket spreads ($p<0.001$) but Middle and Late submarket spreads are not found to be statistically different. The three-way ANOVA shows that timing restrictions increase spreads ($p=0.024$). Early and Middle market spreads tend to converge and are not statistically different.

Figure 5 provides average time-weighted spreads at ten-second time intervals, and shows that during most of the intervals an absence of trading restrictions lowers trading costs, although during the overlap period differences are very small. The average interval spread of all treatments declines rapidly during the Early submarket, falls less sharply during the Middle submarket and rises slightly towards the end of the Late market. A distinctive feature of the IR and NoInfo markets is that at the start of the Late market the spread begins to rise noticeably before receding after the first few intervals.

We find that when overlapping markets are perfectly integrated, restrictions tend to raise spreads. Therefore the benefits of higher liquidity in actual overlapping markets, apparent in empirical studies, appears to be more to do with the information benefits provided by the market opening rather than the overlap itself. Since our markets are by construction fully integrated, it suggests that empirical studies of cross-listed stocks are not studying fully integrated markets.

E. Adverse Selection

<u>Table 9</u>

Table 9 reports average total market dollar gains and average per trade gains to informed traders for the Early, Middle and Late submarkets as well as for the overall market. The gain from a purchase is the liquidation value less the price. For a sale, it is the price minus the liquidation value. Total Gain represents profits from both purchases and sales by all informed subjects measured in trading dollars, on a per period basis, in trades with uninformed traders. The Per Trade column reports the average gain to informed subjects per trade.

Without trading restrictions gains decline as trading progresses in total and on a per trade basis but total gains shift away from the Early submarket to the Middle submarket when trading restrictions exist. When trading restrictions do not exist the uninformed are exploited heavily during Early trading, but with trading restrictions the informed are unable to exploit the uninformed as rapidly. These shifts mirror the patterns associated with volume and appear to support Chowdry and Nanda (1991) who predict that informed traders are more likely to exploit the uninformed in thick markets.

In the NoRes treatment, on either a total gain or per trade basis, profits in the Early submarket are substantially higher than in the Middle submarket ($p<0.001$) and in the Late submarket ($p<0.001$). When timing restrictions apply total gains are significantly higher in the Middle submarket than in the Early submarket ($p=0.015$).[14] On a per trade basis average Early per trade gains are significantly higher than Middle or Late gains (both have a $p<0.001$). Although Early per trade gains are higher than Middle market gains the steep decline in profits observable for markets without restrictions in the Middle market is not as dramatic. Overall, our analysis of adverse selection costs indicates that trading restrictions influence the amount and timing of insider profitability.

[14] Middle submarket profits are also higher than in the Late submarket ($p<0.001$).

V. Conclusions

Our experiments compare asset markets with and without trade timing restrictions. With timing restrictions, some subjects can trade in the Early submarket, some can trade in the Late, but all can trade in the overlap. This corresponds roughly to overlapping markets for cross-listed shares, such as for shares cross-listed on the NYSE and the LSE. However, in our Middle submarket, trading occurs in an integrated, single market. Experimental methodology allows us to study simplified markets without real-world factors such as differential information, cultural differences or any other costs of trading across markets. Despite full integration in the Middle submarket, market quality is not the same as if all markets were open all the time and any subject could trade at any time.

Our main findings pertain to the effect of trade timing restrictions. Without restrictions, trading was heaviest in the Early period, with activity typically declining as the period progressed. When trade timing restrictions are in effect, trading activity is shifted to the Middle submarket. This concentration of activity in the overlap period supports theoretical predictions by Menkveld (2008) and corresponds with empirical findings surveyed by Karolyi (2006). Our analysis of individual trader activity also shows that trading restrictions have different effects in the Early and Late submarkets. Restrictions on Late trading causes trading activity to be delayed from the Early submarket to the Middle submarket while restrictions on Early trading cause more active trading when they can first trade i.e. the Middle market. An important prediction associated with cross-listed stocks is that dual or multiple listings outside the domestic market lead to lower spreads. Our results confirm this as trading restrictions tend to raise spreads. However, in our perfectly integrated experimental market we do not find lower spreads during the overlap.

Trade timing restrictions also influenced price discovery and the profits of informed traders. Price discovery tends to be slower in markets with restrictions when the asset value is more extreme. With restrictions informed traders achieved greater profits and uninformed traders sustained greater losses. Overall trader gains for the informed shift from the Early to the Middle submarket when trading restrictions exist suggesting that informed traders prefer to exploit the uninformed in thicker markets.

Appendix The computation of Volume and Volume per Active-Trader

A. Volume

Let the volume within sub-market m, for all periods (markets) with treatment t, in session s, be denoted $V(m,t,s)$. Let the number of periods (markets) of treatment t be denoted $P(t)$. Then, for Table 3, the average Volume (per period, across all sessions) statistics for a particular treatment are calculated using the following formulae.

Market	Submarket
$\frac{\sum_{m=1}^{3}\sum_{s=1}^{11} V(m,t,s)}{11\times P(t)} = \sum_{m=1}^{3}\left(\sum_{s=1}^{11}\frac{V(m,t,s)}{11\times P(t)}\right)$	$\frac{\sum_{s=1}^{11} V(m,t,s)}{11\times P(t)} = \sum_{s=1}^{11}\frac{V(m,t,s)}{11\times P(t)}$

B. Volume per Active-Trader

Let *N(m,t,s)* be the number of traders in sub-market m, of treatment t in session s, and $V(m,t,s)$ and $P(t)$ remain as defined for the Volume calculations. The Volume per Active-Trader calculations corresponding to the Volume calculations above are given in the Table below. In the Market column, the scaling by three avoids a triple counting of the number of traders across the three submarkets, so that when the number of traders is the same across submarkets (NoRes treatment only), the averages in the Market column are equal to the sum of the Submarket averages.

Market	Submarket
$\frac{\sum_{m=1}^{3}\sum_{s=1}^{11} V(mt,s)}{\sum_{m=1}^{3}(P(t)\times\sum_{s=1}^{11} N(m,t,s))/3}$	$\frac{\sum_{s=1}^{11} V(m,t,s)}{P(t)\times\sum_{s=1}^{11} N(m,t,s)} = \sum_{s=1}^{11}\left(\frac{V(m,t,s)}{P(t)\times N(m,t,s)}\right)$

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Table 1: Trader Roles

At the start of each period, traders receive an initial endowment of shares of the risky asset and cash. Informed traders also learn the liquidation value of the risky asset. Liquidity traders only know the probability distribution of possible outcomes. Liquidity traders also may receive a cash bonus/penalty. The bonus or penalty is applied to the trader's cash balance after the Late submarket, just prior to liquidation of the risky asset.

	Initial Endowment	Cash Bonus/Penalty
Informed Traders	2 Shares \$300	None
Liquidity Buyers	0 Shares \$500	5% penalty
Liquidity Sellers	3 Shares \$200	5% bonus

Table 2: Experimental Design

Our experimental design contains three treatments. The main treatment, IR, has informed traders as well as trading restrictions. Each of the control treatments eliminates one of these features. NoRes eliminates timing restrictions. NoInfo eliminates informed traders.

	Informed Traders Informed traders know the exact asset value prior to the start of the markets. Other traders only know the probability distribution of the asset value.	**No Informed Traders** All traders know only the probability distribution of the asset value.
Timing Restrictions Early traders can trade in both the Early and Middle Submarkets. Late Traders can trade in both the Middle and Late Submarkets	**IR Periods** 1/3 Informed traders 1/3 Liquidity buyers 1/3 Liquidity sellers 1/2 Early traders 1/2 Late traders 10 periods: 3, 4, 5, 8, 9, 10 14, 15, 19, 20	**NoInfo Periods** 1/2 Liquidity buyers 1/2 Liquidity sellers 1/2 Early traders 1/2 Late traders 5 periods: 1, 6, 11, 16, 17
No Timing Restrictions All traders can trade in the Early, Middle and Late Submarkets.	**NoRes Periods** 1/3 informed traders 1/3 liquidity buyers 1/3 liquidity sellers 5 periods: 2, 7, 12, 13, 18	

Trading Restrictions

	Early market 60 seconds	Middle market 60 seconds	Late market 60 seconds
Early traders	Active	Active	Inactive
Late traders	Inactive	Active	Active
Both traders	Active	Active	Active

Table 3: Trade Patterns

Average Volume is the mean number of transactions per market, averaged by treatments. Fraction Early, Middle and Late are the percent of the transactions per market in the Early, Middle and Late submarkets. The ANOVA of submarket volume, using all treatments, sessions and all submarkets, is reported in the All submarkets column of the All treatments block of Panel B Columns Early, Middle and Late report separate ANOVA results using only the volume for that submarket. Column Total uses market volume (the sum of the three submarket volumes). The ANOVAs by treatment use all submarket volumes for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket volumes are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

Treatment	Average Volume	Fraction Early %	Fraction Middle %	Fraction Late %
NoInfo	69.5	21.0	59.5	19.5
NoRes	89.8	41.6	32.3	26.1
IR	71.2	23.7	58.7	17.6

Panel B: **ANOVA (two-tailed p-values)**

	All treatments				
	All submarkets	**Early**	**Middle**	**Late**	**Total**
Timing	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Information	0.580	0.054	0.878	0.379	0.641
Submarket	< 0.001				
Submarket * Timing	< 0.001				
Submarket * Information	0.237				

	By treatment - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	< 0.001	0.030
No Timing	< 0.001	0.001	0.043	< 0.001

Table 4: Volume Per Active-Trader

Per Active-Trader Volume, Early, Middle and Late are the mean number of transactions per active-trader per submarket, averaged (across markets) by treatments in the Early, Middle and Late submarkets. Per Active-Trader Volume is the mean number of transactions per trader per market, averaged (across markets and sessions) by treatments. This does not equal the row-wise sum of the sub-market volumes per active-trader, except in the case of NoRes, because the sum of ratios are not generally equal to the ratio of sums, and there are different numbers of traders across the three submarkets in the NoInfo and IR treatments. Panel B decomposes Panel A of the table by trader type. Since each trade has two sides, these statistics are computed out of twice volume. The ANOVA of submarket volume per active-trader, using all treatments, sessions and submarkets, is reported in the All submarkets column of the All treatments block of Panel C. Columns Early, Middle and Late report separate ANOVA results using only the volume per active-trader for that submarket. The ANOVAs by treatment use all submarket volumes per active-trader for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket volumes per active trader are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

Treatment	Per Active-Trader Volume	Per Active-Trader Volume Early	Per Active-Trader Volume Middle	Per Active-Trader Volume Late
NoInfo	5.57	1.50	2.20	1.50
NoRes	4.77	1.98	1.54	1.25
IR	5.70	1.78	2.22	1.34

Panel B

Treatment	Timing	Information	Early	Middle	Late
NoInfo	Early	Uninformed	1.50	2.13	
	Late	Uninformed		2.26	1.50
NoRes	Both	Informed	2.04	1.37	1.07
	Both	Uninformed	1.96	1.62	1.34
IR	Early	Informed	1.86	2.07	
	Early	Uninformed	1.76	2.18	
	Late	Informed		2.11	1.15
	Late	Uninformed		2.41	1.44

Panel C: ANOVA (two-tailed p-values)

	All treatments			
	All submarkets	**Early**	**Middle**	**Late**
Timing	0.017	0.099	< 0.001	0.616
Information	0.496	0.027	0.860	0.296

Submarket	< 0.001			
Submarket * Timing	0.001			
Submarket * Information	0.094			
	By treatment - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	< 0.001	0.001
No Timing	< 0.001	0.001	0.052	< 0.001

Table 5: Limit Order Submission Rates

Limit order submission rates are calculated as the ratio of total submitted limit orders (includes executed, expired and cancelled orders) to total submitted limit and market orders, using all markets. Figures in the All column are the per trader average submission rates across all submarkets, averaged by treatment. Panel B decomposes averages according to the type of trader that posted the limit order. The ANOVA of submarket submission rates, using all treatments, sessions and all submarkets, is reported in the All submarkets column of the All treatments block of Panel C. Columns Early, Middle and Late report separate ANOVA results using only the submission rates for that submarket. The ANOVAs by treatment use all submarket submission rates for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket submission rates for a given treatment are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

Treatment	All	Early	Middle	Late
NoInfo	0.59	0.68	0.56	0.55
NoRes	0.49	0.60	0.49	0.39
IR	0.56	0.68	0.54	0.48

Panel B

Treatment	Timing	Information	Early	Middle	Late
NoInfo	Early	Uninformed	0.68	0.51	
	Late	Uninformed		0.61	0.55
NoRes	Both	Informed	0.60	0.51	0.40
	Both	Uninformed	0.60	0.48	0.39
IR	Early	Informed	0.70	0.51	
	Early	Uninformed	0.67	0.50	
	Late	Informed		0.58	0.47
	Late	Uninformed		0.57	0.48

Panel C: ANOVA (two-tailed p-values)

	All treatments			
	All submarkets	**Early**	**Middle**	**Late**
Timing	< 0.001	< 0.001	0.005	0.001
Information	0.007	0.937	0.216	0.002
Submarket	< 0.001			
Submarket * Timing	0.427			
Submarket * Information	0.075			

	By treatment - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	0.006	< 0.001
No Timing	< 0.001	< 0.001	0.002	< 0.001
Information	< 0.001	< 0.001	< 0.001	< 0.001
No Information	< 0.001	< 0.001	0.901	< 0.001

Table 6: Take Rates

This table presents the take rate, defined as the ratio of all market orders to the sum of executed limit and market orders using all markets and is presented by treatment. Panel B decomposes the averages by the type of trader that accepted a posted limit order. The ANOVA of submarket taking rates, using all treatments, sessions and all submarkets, is reported in the All submarkets column of the All treatments block of Panel C. Columns Early, Middle and Late report separate ANOVA results using only the take rates for that submarket. The ANOVAs by treatment use all submarket take rates for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket take rates for a given treatment are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

Treatment	All	Early	Middle	Late
NoInfo	0.40	0.37	0.44	0.36
NoRes	0.38	0.43	0.38	0.33
IR	0.39	0.40	0.43	0.32

Panel B

Treatment	Timing	Information	Early	Middle	Late
NoInfo	Early	Uninformed	0.37	0.42	
	Late	Uninformed		0.45	0.36
NoRes	Both	Informed	0.49	0.31	0.28
	Both	Uninformed	0.41	0.41	0.35
IR	Early	Informed	0.42	0.38	
	Early	Uninformed	0.39	0.41	
	Late	Informed		0.49	0.28
	Late	Uninformed		0.45	0.34

Panel C: ANOVA (two-tailed p-values)

	All treatments			
	All submarkets	**Early**	**Middle**	**Late**
Timing	0.961	0.014	< 0.001	0.623
Information	0.537	0.235	0.630	0.125
Submarket	< 0.001			
Submarket * Timing	0.007			
Submarket * Information	0.130			

	By treatment - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	< 0.001	< 0.001
No Timing	< 0.001	0.006	0.010	< 0.001

Table 7: Pricing Error by Submarket

Pricing Error is the absolute value of the difference between the average price in a submarket and the liquidation value of the asset, averaged across markets and by treatment. Panels A and B separate the markets that have more extreme (20 or 80), or less extreme (40 or 60) liquidation values. The ANOVA of submarket pricing errors, using both treatments, all sessions and all submarkets, is reported in the All submarkets column of the All treatments block of the ANOVA table. Columns Early, Middle and Late report separate ANOVA results using only the pricing error for that submarket. The ANOVAs by treatment use all submarket pricing errors for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket pricing error are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A: Markets where the asset liquidation value is more extreme (20 or 80)

Treatment	Pricing Error Early	Pricing Error Middle	Pricing Error Late
NoRes	17.0	13.40	12.8
IR	19. 8	15.3	13.9

ANOVA (two-tailed p-values)

	All treatments			
	All submarkets	**Early**	**Middle**	**Late**
Timing	0.033	0.068	0.319	0.340
Submarket	< 0.001			
Submarket * Timing	0.711			

	By treatment - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	0.755	< 0.001
No Timing	0.129	0.264	0.916	0.129

Panel B: Markets where the asset liquidation value is less extreme (40 or 60)

Treatment	Pricing Error Early	Pricing Error Middle	Pricing Error Late
NoRes	5.29	3.05	2.47
IR	7.17	3.02	2.70

ANOVA (two-tailed p-values)

	All treatments			
	All submarkets	**Early**	**Middle**	**Late**
Timing	0.206	0.023	0.772	0.726
Submarket	< 0.001			
Submarket * Timing	0.084			

	By timing restriction - Submarket Main effect			
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	0.946	< 0.001
No Timing	0.001	0.009	0.696	0.001

Table 8: Average Time-Weighted Quoted Inside Spreads by Submarket

The average time-weighted quoted spread in a submarket is the average posted inside spread weighted by how long the quote is outstanding in each interval. These values are averaged by treatment. The ANOVA of submarket inside spread, using all treatments, sessions and all submarkets, is reported in the All submarkets column of the All treatments block of the ANOVA table. Columns Early, Middle and Late report separate ANOVA results using only the spreads for that submarket. The ANOVAs by treatment use all submarket spreads for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket spreads for a given treatment are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

Treatment	Early Submarket	Middle Submarket	Late Submarket
NoInfo	17.91	7.11	5.97
NoRes	13.90	6.23	5.11
IR	16.39	6.95	6.56

Panel B ANOVA (two-tailed p-values)

All treatments				
	All submarkets	**Early**	**Middle**	**Late**
Timing	0.024	0.202	0.434	0.068
Information	0.660	0.351	0.954	0.704
Submarket	< 0.001			
Submarket * Timing	0.560			
Submarket * Information	0.454			

By timing restriction - Submarket Main effect				
	All submarkets	**Early v Middle**	**Middle v Late**	**Early v Late**
Timing	< 0.001	< 0.001	0.629	< 0.001
No Timing	< 0.001	< 0.001	0.206	< 0.001

Table 9: Informed Trader Gains

Trading gains (profits) earned by informed traders are averaged by treatment. Total Gain measures the total profit earned by informed traders through trades with liquidity traders. The total is calculated as the total profit in all submarkets of the treatment divided by the number of markets of the treatment type. The per-trade gain divides the total gain by the average number of transactions per period in the treatment (using all trades, not just trades between informed and liquidity traders). The ANOVAs of submarket total gains and gains per trader, using both treatments, sessions and all submarkets, are reported in the All submarkets column of the All treatments block of the ANOVA tables. Columns Early, Middle and Late report separate ANOVA results using only the gains for that submarket. The ANOVAs by treatment use all submarket gains for a given treatment. The effect of submarket is reported in the column All submarkets, and (two-tailed) pair-wise tests of differences between the submarket gains for a given treatment are given in the columns labeled Early v Middle, Middle v Late and Early v Late.

Panel A

	Early		Middle		Late	
Treatment	Total Gain	Per Trade	Total Gain	Per Trade	Total Gain	Per Trade
NoRes	114.10	3.40	20.60	0.65	11.50	0.52
IR	74.90	5.47	120.60	3.38	19.70	2.10

Panel B ANOVA (two-tailed p-values)

All treatments – Total Gains

	All submarkets	Early	Middle	Late
Timing	0.020	0.063	< 0.001	0.241
Submarket	< 0.001			
Submarket * Timing	< 0.001			

By treatment - Submarket Main effect – Total Gains

	All submarkets	Early v Middle	Middle v Late	Early v Late
Timing	< 0.001	0.015	< 0.001	< 0.001
No Timing	0.001	< 0.001	0.863	< 0.001

All treatments – Per Trade Gains

	All submarkets	Early	Middle	Late
Timing	< 0.001	0.090	< 0.001	0.039
Submarket	< 0.001			
Submarket * Timing	0.445			

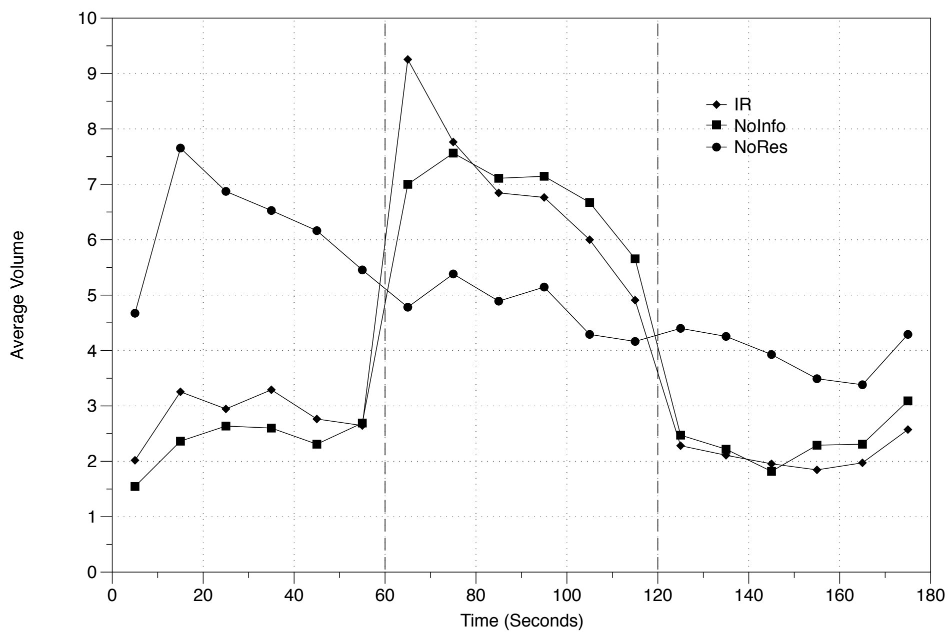
By treatment - Submarket Main effect – Per Trade Gains

	All submarkets	Early v Middle	Middle v Late	Early v Late
Timing	< 0.001	0.015	0.312	< 0.001
No Timing	0.001	< 0.001	0.937	< 0.001

Figure 1: Trading Activity

These charts contain plots of average treatment volume (Graph A) and average treatment per active trader volume (Graph B) calculated at intervals of ten seconds. The first minute coincides with the Early market, the second minute coincides with the Middle market and the final minute coincides with the Late market. NoRes is the treatment with no timing restrictions, IR is the treatment with trading restrictions and NoInfo is the treatment with no informed traders.

Graph A: Intra-market Volume



Graph B: Intra-market Volume per Active Trader

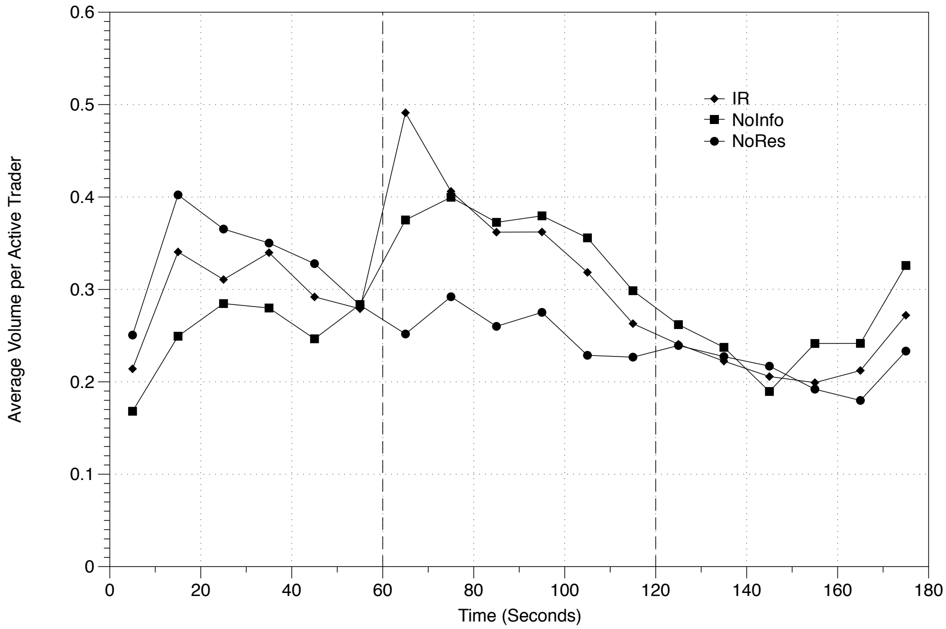


Figure 2: Limit Order Analysis

This figure provides a breakdown of limit order submissions according to whether the limit order expired, was cancelled or executed during the submarket. Limit orders are number of limit order submitted by informed and uninformed traders. Market orders are those limit orders executed as market orders during each sub-market. Expired limit orders are those orders unexecuted during the submarket.

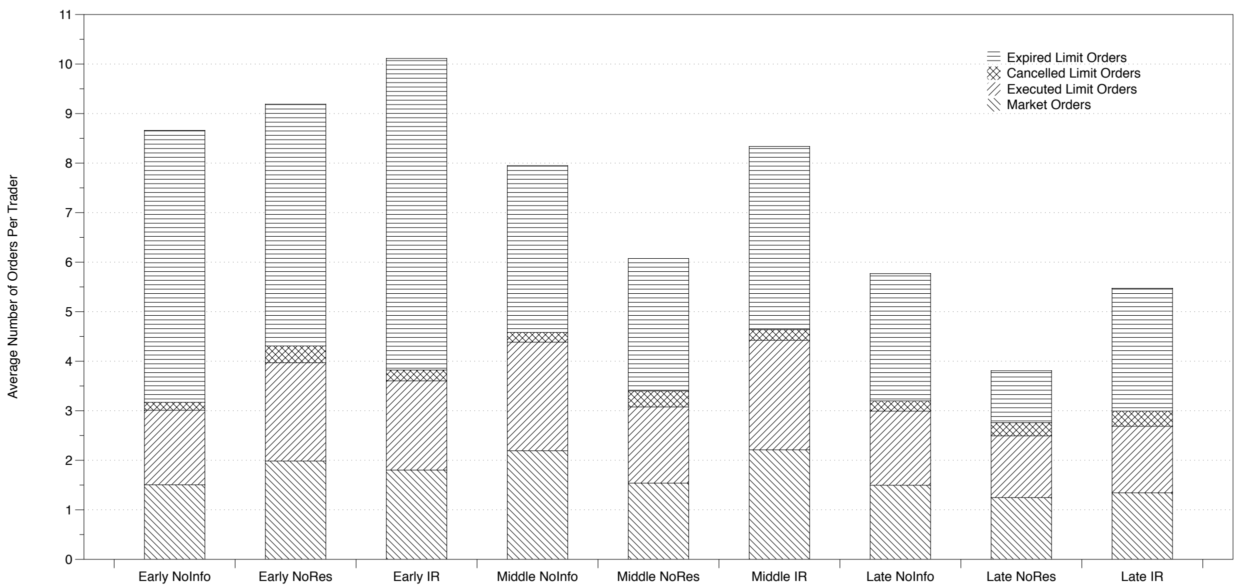
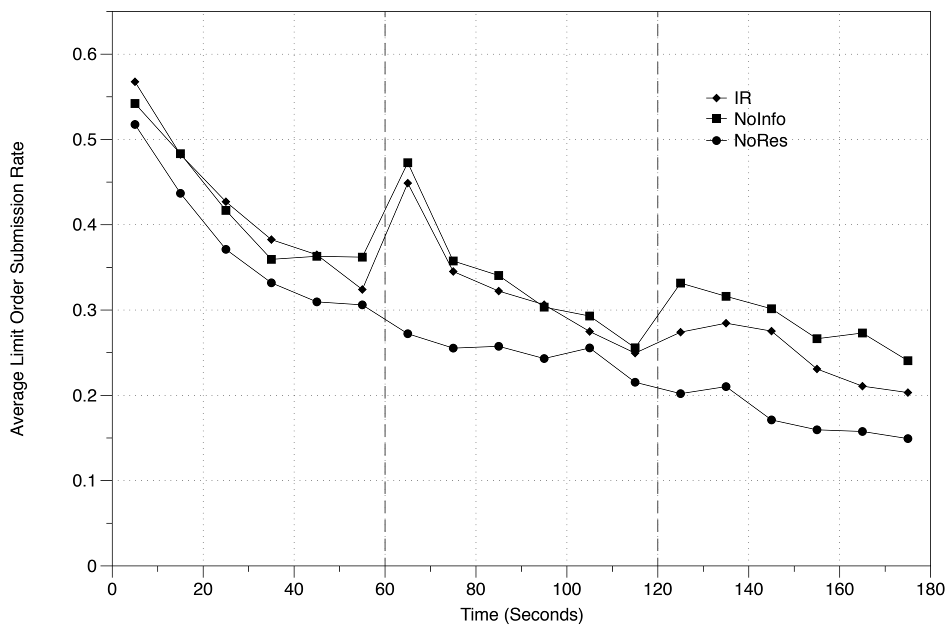


Figure 3: Submission and Take Rates

These charts contain plots of the average treatment limit order submission rate (Graph A) and the take rate (Graph B) per trader calculated at intervals of ten seconds. The first minute coincides with the Early market, the second minute coincides with the Middle market and the final minute coincides with the Late market. NoRes is the treatment with no restrictions, IR is the treatment with trading restrictions and NoInfo is the treatment with no informed traders.

Graph A: Intra-market Limit Order Submission Rates



Graph B: Intra-market Take Rates

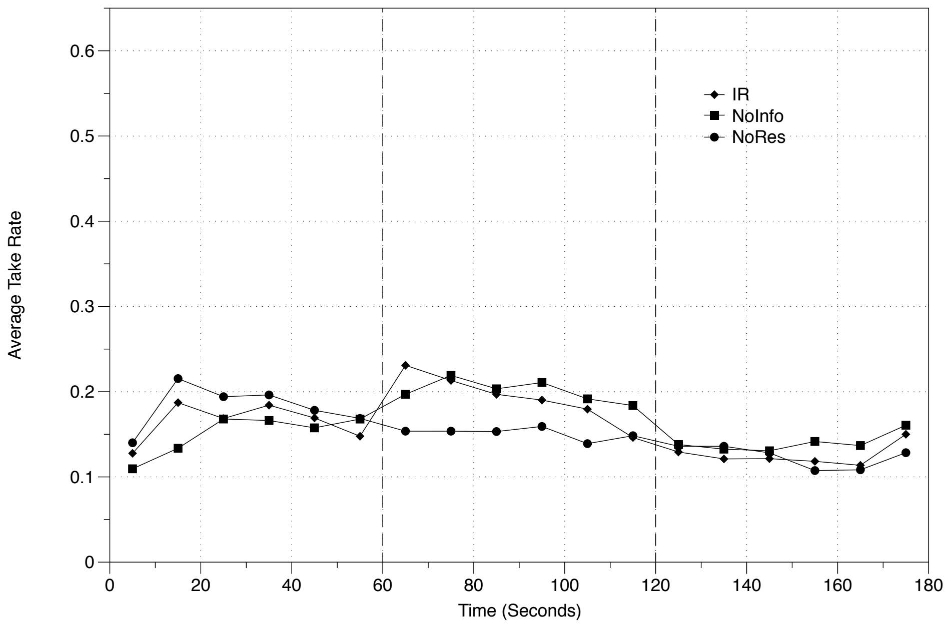
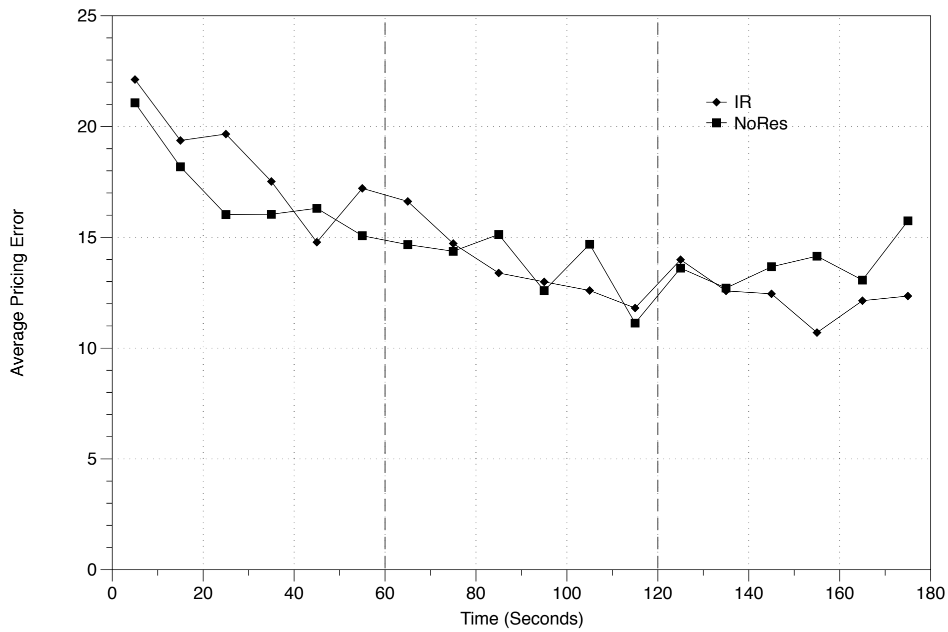


Figure 4: Intra-market Price Efficiency

This chart contains plots of average treatment pricing efficiency calculated at intervals of ten seconds, for markets with extreme asset values (Graph A) and for markets where asset values are not extreme (Graph B). The first minute coincides with the Early market, the second minute coincides with the Middle market and the final minute coincides with the Late market. NoRes is the treatment with no restrictions, IR is the treatment with trading restrictions and NoInfo is the treatment with no informed traders.

Graph A: Extreme Asset Values



Graph B: Non-Extreme Asset Values

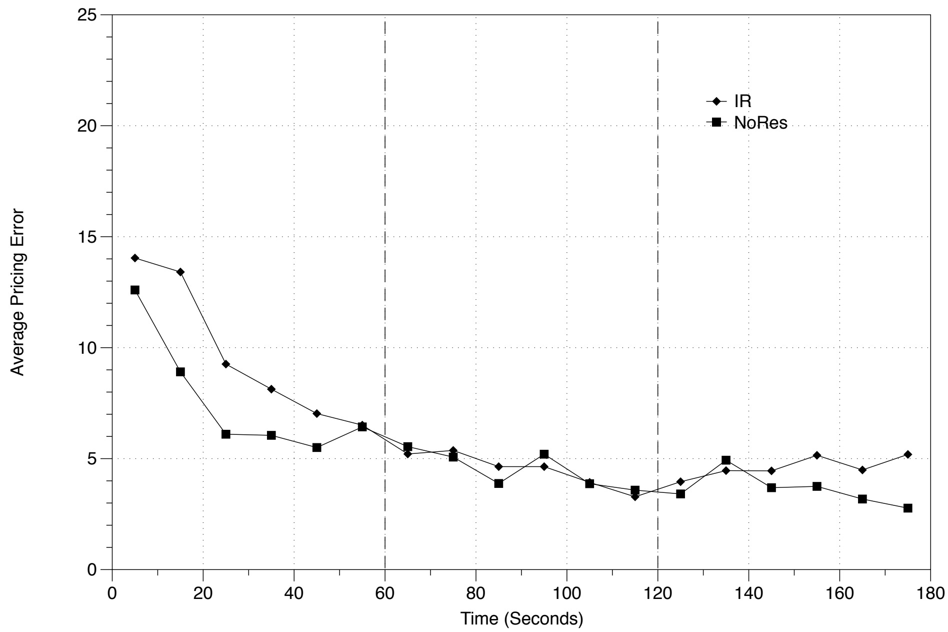


Figure 5: Intra-market Time-Weighted Bid-Ask Spread

This chart contains plots of the average treatment time-weighted bid-ask spread calculated at intervals of ten seconds. The first minute coincides with the Early market, the second minute coincides with the Middle market and the final minute coincides with the Late market. NoRes is the treatment with no restrictions, IR is the treatment with trading restrictions and NoInfo is the treatment with no informed traders.