Informed and Uninformed Trading with Correlated Assets: An Experimental Study

Philippe Grégoire*, Hui Huang† and Jonathan Coupland‡

June 1, 2008

Abstract

This paper presents the results of an experimental market with two correlated assets. When informed traders are present, they receive information about one asset, asset 1, which also conveys information, albeit less precise, about the value of asset 2. The experimental setup is such that the asset values are gradually revealed to all market participants. We consider a treatment without informed traders, a treatment with informed traders who can freely trade both assets, and a treatment with informed traders who cannot trade in asset 1. We find that the pricing error, as measured by the difference between the transaction price and the asset value, is smaller in asset 1 when informed traders are present and they can trade it, and we find that the pricing error in asset 2 is greater when informed traders are present, restricted or not. Traders in our experiment submit more limit orders early in the game and we find that unrestricted informed traders trade asset 2 more aggressively than asset 1. We also find that imposing restrictions on informed traders significantly reduces market activity.

*Correspondence: Philippe Grégoire, Faculté des Sciences de l'Administration, Université Laval, Québec, QC, Canada, G1K 7P4, philippe.gregoire@fsa.ulaval.ca

†Department of Economics and Finance, University of Victoria at Wellington, Wellington, New Zealand

‡Faculté des Sciences de l'Administration, Université Laval, Québec, QC, Canada, G1K 7P4

1 Introduction

This paper studies the trading behavior of informed and uninformed traders in an environment with two correlated assets. In our setup, informed traders have noisy information on one asset (asset 1) that also conveys information about the other asset (asset 2), the information about asset 1 being more precise than the information about asset 2. The experimental setup is also such that the value of both assets is gradually revealed to all market participants. We consider two cases regarding the flow of public information, namely a case where the information flows continuously, the two asset liquidation values becoming gradually known to all (the continuous case), and a case with a period of time without news that we refer to as the blackout case. Three treatments are analyzed, namely a treatment without informed traders, a treatment with informed traders who can freely trade in both assets (informed traders present, no restrictions), and a treatment where informed traders cannot trade in asset 1 (informed traders present, with restrictions).

We do so by setting up an experimental exchange market where participants trade two assets which values are given by the final score of a game of table tennis (ping pong). That is, each asset represents a player and, if the final score of the game is 11-5 in favor of player 1, say, then asset 1 pays a dividend of 11 at the end of the trading round while asset 2 pays a dividend of 5. Trading operates through a continuous double auction lasting the duration of the ping pong game. The game can be viewed on screens in the trading room and thus information about asset liquidation values is transmitted to traders as the game unfolds. We consider two types of information flow, namely continuous and with a blackout in the middle

of the game. In the continuous case, the table tennis game can be viewed from start to finish whereas in the blackout case, the screens are turned off after some time and are turned back on towards the end of the game. On average, blackouts last one third of the game and take place in the middle of it[1].

The choice of table tennis games to determine asset values is different from the usual case where asset values follow a theoretical distribution as it allows participants to analyze the game, i.e. to do some fundamental analysis. That is, a game of ping pong is not very difficult to understand and can be analyzed just like publicly traded companies can be analyzed. Participants were informed of ping pong trading rules at the start of the experiment and seeing the game being played on screens can be seen as news coming out about companies as a bigger announcement, like an earnings announcement, is drawing closer. When asset values are distributed according to some pre-specified distribution functions, uninformed traders can only perform technical analysis, which is not exactly what traders do in reality. Another advantage of ping pong games is that their average duration, between 3 to 5 minutes, resembles the duration of trading experiments. A game of table tennis ends when one player has made a given number of points[2], and thus the winning player can be seen as a firm maximizing its profits. In a tight game, the second player can also be seen as a firm maximizing its profits. In a sport like hockey where the winning team is the one with the

[1]That is, the first third of the table tennis game is shown, then the screens are turned off and are turned back on at the start of the last third of the game.

[2]A game of table tennis ends when one of the players has made 11 points and there are 2 points separating the players. If the score is 11-10 when the one players first reaches 11 points, the game continues until a difference of 2 points prevails. It is therefore possible that a game ends with a score of 15 to 13, say, as long as the difference is at most 1 when the leading player has between 11 and 14.

most points, teams are not trying to make the maximum number of points and thus the analogy with firms' profits is not the same. In some ping pong games, when one player is way ahead of the other, the loser may sometimes let go, in which case the player is clearly not maximizing his number of points. This behavior, however, can be related to the case of firms that take advantage of bad market conditions to take as many charges as possible in order to show better once economic conditions improve (the "big bath" theory).

Legal literature (Ayres and Bankman, 2001) defines trading in a correlated asset as substitute trading. Such a practice is used when an insider trades stocks of a client, a competitor or a supplier. Even though insider trading is prohibited in section 10(b) of the 1934 Securities Exchange Act, nothing indicates that trading in a substitute is illegal. Economic literature has also addressed the concept of correlated assets, but with a larger application spectrum. Many financial instruments are correlated, the most obvious examples being derivatives contracts. In certain environments, two correlated assets cannot coexist as one of them eventually disappears due to lack of trading (Gorton and Pannacchi, 1993, Bhattacharya, Reny and Spiegel, 1995). Grossman (1998) and Easley, OHara and Srinivas (1998), on the other hand, argue that stocks and stock options can both survive as they appeal to different types of traders.

Theoretical work by Harris (1998) and Foucault (1999) show that informed traders use market orders or limit orders in a way to maximise their information. Harris (1998) shows that informed traders prefer market orders when the market value of the asset is far off its intrinsic value, i.e. trade more aggressively when the fundamentals are in their advantage,

since the non-execution risk would be costly. Likewise, Foucault (1999) finds that market orders are positively correlated with the volatility of the asset and that limit orders are positively correlated with the bid-ask spread. Kaniel and Liu (2006) on the other hand, find that informed traders prefer limit orders. Using a sample of 144 firms traded on the NYSE from November 1990 to January 1991, Anand, Chakravarty and Martell (2005) find that informed traders take liquidity at the beginning of trading period and make liquidity at the end of trading period. Informed traders seem to outperform uninformed traders with limit orders. Bloomfield, OHara and Saar (2005), using an experimental market, that informed traders prefer market orders at the beginning and limit orders towards the end of trading period.

Our experiment combines substitute trading and strategic behavior of informed traders. We study price efficiency, the use of market and limit orders by informed and uninformed traders and the profits of informed traders under three different treatments (no informed traders, informed traders present without restrictions, informed traders present with restrictions) on both correlated assets in two types of environment with respect to the arrival of information: continuous information and sequential.

The remainder of this paper is organized as follows. Section 2 describes the experimental setup, Section 3 analyzes the results and Section 4 concludes.

2 The Experimental Setup

Students at Laval University were recruited to participate in trading experiments taking place over five evenings. Eight students showed up on the first evening and seven students showed up at the remaing four evenings. Participants in the first two sessions were new to the experiment and the last three sessions involved experienced participants, i.e. participants who were present in one of the first two evenings. In a session, at least twelve trading rounds took place, four practice rounds and eight rounds from which we collected data. This ensured that participants were well acquainted with the trading rules and the trading software when the data was gathered. A trading round consisted of a continuous double-auction with two assets. The Carnegie Mellon's Financial Trading System (FTS) was the software used in this experiment. Traders would begin a trading round with an endowment of X units of each asset and an amount $2 \times X$ of experiment money[3]. Endowments were reset to their initial values at the beginning of each trading round and thus losses or gains incurred in one trading round did not have any impact on the following rounds. Final portfolio values at the end of each trading round were given by the cash position plus the number of assets held multiplied by the dividend paid by each asset. Traders could not sell short nor buy on margin.

The dividend paid by each asset in a trading round was determined by the result of a

[3]Endowments for the first two sessions were 1,000 units of each asset and \$20,000 of experiment money while endowments in the last three sessions were 10,000 units of each asset and \$200,000 of experiment money. When compiling the results, we normalized by multiplying by ten the quantities involved in the first two experiments. There were some differences between the results of the first two nights and those of the last three nights but they did not seem to be due to the difference in endowments.

table tennis (ping pong) game. At the beginning of the game, participants were told that asset 1, say, was associated with player A and that asset 2 was associated with player B. If the game ended 11-4 in favor of player A, then participants would receive a dividend of $11 per unit of asset 1 in their portfolio at the end of the game and a dividend of $4 per unit of asset 2 in their portfolio at the end of the game. If, on the other hand, player B won the game 11-8, then asset 2 would pay a dividend of $11 and asset 1 would pay a dividend of $8. The table tennis game from which asset values were derived was played on video screens that all participants could see.

Two cases were considered regarding the flow of information: A continuous case wherein the table tennis game was shown from start to finish without interruption, and a blackout case t wherein the screens were turned off in the middle of the game. In a blackout treatment, participants would see, approximately, the first third of the game, then the video screens were turned off while the second third of the game was played and they were turned back on for the last third of the game. We will refer to the case with continuous flow of information as "Continuous" and to the other case as "Blackout".

The games used have durations ranging from two minutes thirty seconds to six minutes thirty seconds and thus, to make results have been normalized with respect to time to make them comparable. Games of different duration were used to make sure that participants could not anticipate the winner too soon[4].

A game of table tennis usually ends when a player reaches a score of 11, but there must be

[4]If, for instance, all games had a duration of exactly three minutes, then a score of 9-5 after two minutes thirty would leave very little hope of a reversal in the game, i.e. the player ahead would be almost certain to win.

a difference of two points for the game to end. It is therefore possible to have games ending with a final score where one player has more than 11 points as long as there is exactly two points between the score of each player. That is, it is possible to have a game ending with a score of 15-13 but a game ending with a score of 15-12 is not possible. In a game with a score of 15-13, say, assets would still pay dividends according to the score, i.e. one asset would pay a dividend of \$15 and the other asset would pay a dividend of \$13. Participants were informed of the basic rule of table tennis before each experiment.

The ping pong games used were selected from a set of 43 games which characteristics can be seen in Table 1. As we can see, the average winnig score is slightly above 11 (it sometimes exceeds it in order to have at least two points between the winner and the loser) and has a much lower standard deviation than the losing score. The correlation between both scores is positive and equal to 0.7 (Pearson correlation, significant at the 1% level) but this is due to the two-point difference rule. That is, scores where the winner has more than 11 are perfectly correlated whereas scores where the winner has exactly 11 are not correlated. Note the Kolmogorov-Smirnov Z-test does not reject normality for the loser's score but does so for the winner's score. For a trader who does not know who will win the game, each asset has an expected value of 9.239 with a standard deviation of 2.897. A privately informed trader, however, will assign an expected value of 11.364 to the winner and an expected value of 7.114 to the loser. The positive correlation between the winning and the losing score comes from the fact that the loser's score needs to be high when the winner's score is greater than 11 due to the two-point difference rule. Participants were not informed of these average values and

standard deviations but the practice games used were representative of the possible scores.

	All Scores	
Average	9.239	
Standard Deviation	2.897	
Skewness (Std. Error)	−.589 (.257)	
Kurtosis (Std. Error)	−.411 (.508)	
Kolmogorov-Smirnov Z (p-value)	2.569 (.000)	
	Winning Score	**Losing Score**
Average	11.364	7.114
Standard Deviation	.967	2.608
Minimum	11	2
Maximum	16	14
Skewness (Std. Error)	3.400 (.357)	.364 (.357)
Kurtosis (Std. Error)	12.886 (.702)	−.179 (.702)
Kolmogorov-Smirnov Z (p-value)	3.083 (.000)	1.097 (.180)
N	44	44
Correlation	0.70	

Table 1: Statistics of the sample from which the tennis table games used for the experiment were taken.

Three different treatments were considered regarding private information: A treatment without informed traders, a treatment where two traders were informed and could trade any of the two assets, and a treatment with two informed traders who could not trade in asset 1. The informed traders were randomly chosen at the beginning of a trading round and

were being told who the winning player (asset 1) was (and thus about the asset that would pay the highest dividend). Given table tennis rules, knowing the winner of a game indicates that the dividend of the asset representing the winner is at least \$11 and it also provides information about the other asset. An informed trader would then have noisy information about both assets, her information about asset 1 being more precise than her information about the asset 2. Also, the type of information received by informed traders is similar to obtaining good news about one company and bad news about the other. We will refer to the case without informed traders as "No Informed", the second treatment will be referred to as "Informed Present, no Restrictions" and the last treatment will referred to as "Informed Present, with Restrictions".

Participants were paid \$10 per hour on each trading night and trading on each night took place during one hour and thirty minutes. Hence, for their time, participants were paid \$15 per evening. For each game played, \$1 was divided amongst participants according to their performance. With eight games played each night, a trader could earn a bonus of up to \$8 on top of the \$15 paid for her time. Overall, payoffs ranged from \$18 to \$25 per night for all participants.

Using sports games to determine asset values allows participants to analyze the information coming from the screens showing the evolution of the game, which contrasts from asset markets where final asset values are randomly determined from a pre-defined distribution. Moreover, even though business students are usually taught statistics courses, forming expectations about an asset value drawn from a distribution is far from obvious, whereas

forming expectations about the ending score of a table tennis game is an exercise everybody can make with reasonable accuracy as the game moves on. Hence our setup provides an environment where traders can perform some fundamental analysis using the flow of information coming from the screens showing the game. The following section shows the results of our experiment.

3 Results

In total, the trading data comprises over 10,000 observations (limit orders, market orders, cancellations) The asset representing the winner of each table tennis game is always represented by Asset 1[5]. This asset is then the asset wherein there are informed traders. To compare the evolution of limit and market orders through time, we have divided each trading into three equal periods and computed the average value of each variable of interest in each of these periods. Since trading rounds had different durations due to the different length of time of the games being played on the video screens, and since there was a group with one more trader than the others, limit and market orders are expressed per trader per unit of time, the unit of time for an entire game being three minutes and the unit of time for a period being one minute. In what follows we discuss, in turn, the pricing error, the quantities of limit and market orders and the profits of informed traders.

[5]This is to ease the presentation only. Withing the trading software used in the experiment, assets were represented by Stock 1 and Stock 2, and the winning asset could either be Stock 1 or Stock 2.

3.1 Pricing Error

The pricing error in the present work is calculated by taking the volume-weighted average absolute difference between the price of a transaction and the true value of the asset. That is, if a transaction i in asset 1 (buy or sell) is characterized by a quantity $q_{i,1}$ and a price $p_{i,1}$ while the value of asset 1 is v_1, then the volume-weighted average pricing error in asset 1 during a period with I transactions is given by

$$\text{VWPE}_1 \;=\; \sum_{i=1}^{I} \frac{q_{i,1}\,|p_{i,1} - v_1|}{\sum_{i=1}^{I} q_{i,1}}$$

where $|\cdot|$ is the absolute value operator[6].

Table 2 shows the volume-weighted pricing error in each asset for each treatment as well as p-values for the differences between assets and treatments. Throughout this paper, non-parametric tests have been used to compare different means due to the small number of observations for each treatment. Note, however, that the Kolmogorov-Smirnov tests that were performed on average pricing errors within asset-treatment-period subgroups did not formally reject the normal distribution[7].

As can be seen in Table 2, the average pricing error for an entire game (second column of Table 2) is always smaller in asset 1 than in asset 2 but this difference is only significant in the presence of informed traders. However, the presence of informed traders appears to increase the pricing error in asset 2 instead of decreasing the pricing error in asset 1, according to the

[6]This way of measuring the pricing error is different from the measure used in Bloomfield, O'Hara and Saar (2005) wherein the measure used is the difference between the middle point of the bid and ask prices and the true asset value

[7]When comparing differences in means using t-tests, the results obtained were similar to the ones given by non-parametric tests in terms of significance.

p-values shown in the boxes "Pricing Error in Asset 1 across Treatments" and "Pricing Error in Asset 2 across Treatments". In Table 3, we separate the results obtained with the first two groups, wherein all participants were new to the experiment, from the results obtained with the last three groups, which were composed of returning participants more acquainted with the experiment. In Table 3, we can see that the pricing error in asset 1 with experienced participants (sessions 3 to 5) is much smaller in the presence of informed traders than in the absence of the latter. But we still observe an increase of the pricing error in asset 2 when informed traders are present. Hence the presence of informed traders improves price efficency in the asset with private information but reduces it in the substitute. As we will see when we look at order submissions, informed traders trade a lot more aggressively than uninformed traders even in asset 2.

Preventing traders from trading in asset 1 does not significantly affect the pricing error in that asset when we take all sessions together. With experienced traders, however, the pricing error in asset 1 without restrictions on informed trading is much smaller than the pricing error in the same asset when informed traders cannot trade it. Hence imposing restrictions on informed trading does appear to decrease price efficiency.

Tables 2 and 3 also look at the improvement in pricing error throughout the game, the last column of each table showing the Mann-Whitney U-test p-value for the difference between the pricing error in the first period and the pricing error in the third period. In this respect, there seems to be an improvement in the pricing error of asset 2 only, i.e. there does not seem to be any improvement in the pricing error of asset 1.

Table 4 separates the case where information flows continuously to traders (the continuous case) from the case with a blackout in the middle of the game (the blackout case). As one would expect, the pricing errors in the blackout cases are almost always greater than the pricing errors in the continuous case, and price discovery is more important in the blackout case than in the continuous case. However, these two cases do not yield very different results so we will not insist too much on their differences.

3.2 Limit versus Market Orders

Tables 5-11 show the average quantities of limit and market orders in each treatment for entire trading rounds et per periods. Since the ping pong games used did not have the same length of time and since there was an evening with 8 participants instead of 7, the quantities shown have been normalized per trader per unit of time. For an entire game (a trading round) the unit of time used is three minutes whereas we used one minute for a period. For instance, the average quantity of limit orders in asset 1 in an entire trading round of the treatment without informed traders amounted to 754 units of asset 1 per trader per period of three minutes, and the average quantity of limit orders in period 1 of this treatment amounted to 257 units of asset 1 per trader per period of one minute.

As shown in tables 5 and 6, we find that traders, both informed and uninformed, submit more limit orders than market orders, which is consistent with Bloomfield, O'Hara and Saar (2005). In the treatment without restrictions, informed traders submit more or limit and market orders than uninformed traders, which could be due to the fact that private

information give confidence to these traders who then behave more aggressively. What is interesting to note is that informed traders submit more orders in asset 2 (the substitute) than in asset 1 (the asset they have information on). Informed traders might strategically trade more aggressively in asset 2 than in asset 1 in order to prevent uninformed traders from discovering too early in the game who is the winning asset.

In Table 6, we can see that market activity dries up when restrictions are imposed on informed trading. That is, both types of traders reduce the number of orders submitted in each asset in this case and these differences are almost all significant, as shown in Table 7. With restrictions, informed traders seem to be behaving very carefully, submitting very few market orders initially in the game. This could be due to the fact that given that they can trade in one asset only, trading too much initially could send a signal to the other traders about which asset is the losing one, which forces them to become more quiet.

Following Bloomfield, O'Hara and Saar (2005), we compute, for each period and each treatment, the submission rate of each different type of trader, as measured by the number of limit orders divided by the sum of market and limit orders submitted, and the results are shown in Table 8. Contrary to Bloomfield et al., we do not find that submission rates increase during the game. We in fact find that submission rates decrease throughout the game, i.e. both types of traders send more limit orders early in the game than at the end, and the difference is stronger when restrictions are imposed on informed trading. These results are consistent with Harris (1998) who shows that the closer the deadline, the greater the likelihood that market orders be submitted. A theoretical explanation as to why informed

traders should submit more market orders early in the game is that the latter trade more aggressively when the value of their information is higher. In the present experimental setup, however, information is progressively revealed to market participants and thus an informed trader trading too aggressive early in the game may induce other traders to rapidly detect which asset is the winning one. Hence informed traders have incentives to be more careful early in the game in order to better profit from their private information.

When separating the first two sessions (inexperienced participants) from the last three sessions (experienced participants), as is done in Table 9, we find very few significant differences between the two groups. We find, however, that experienced traders submit fewer orders than inexperienced ones, and the differences are most often significant in the absence of informed traders.

Table 10 and 11 compare limit and market orders between sessions with continuous flow of information and sessions with a blackout, where we find very little significant differences between the two cases. The observation we can make here is that informed traders tend to submit more orders in asset 1 in sessions with a blackout than in continuous sessions and this is especially true for limit orders early in the game. Hence knowing that it will take more time to other traders to find out who is the winner of the ping pong game seems to induce informed traders to trade more aggressively in the asset they possess information on.

3.3 The Performance of Informed Traders

Tables 12 and 13 show the average value of insiders' trades in each treatment and in each period per treatment. The values shown in these tables represents the total gains realized by both insiders in each period.

When taking all 5 sessions together, the first three rows of Table 12 show that insiders, on average, made money on asset 1, the asset they had information on, but lost money on the other asset (the substitute). In fact, they lost more money in asset 2 than they made in asset 1, netting a loss on average in each game. When we separate the first two sessions from the last three, we find that inexperienced informed traders made money in asset 1 and lost money in asset 2 (rows 4-6 in Table 12), netting an overall loss. When looking at the last three sessions (rows 7-9 in Table 12), we find that experienced traders lost money in asset 1 (although very small amounts) but made enough money on the substitute (asset 2) to net an overall gain. Informed traders also made money in the treatment with restrictions, which involved experienced participants only.

Looking at the results with experienced participants only, we find that informed traders do profit from their information but on the substitute, not on the asset they have information on. Moreover, the absence of restrictions seems to give them a much greater advantage in trading the substitute, as they trade less aggessively when restrictions are imposed. This may explain why informed traders submit more orders in the substitute than in asset 1.

Table 13 may explain why informed traders prefer limit orders to market orders. As we can see in this table, informed traders lose overall with market orders and this even when

they are experienced.

4 Conclusion

In this paper, we analyse the trading behavior of informed traders in the presence of two assets, one for which the private information is more precise and a correlated asset. Asset values are based on the result of ping pong games played on video screens in front of traders and thus the latter can perform some "fundamental" analysis on the assets in place. Informed traders know which player wins the game, whose score gives the value of asset 1, and this provides them with information about the other asset (asset 2) as well.

We find that when informed traders can freely trade either asset, the pricing error in asset 1 is smaller than the pricing error in asset 2. The pricing error in asset 2 increases in the presence of informed traders. When informed traders cannot trade in asset 1, market activity significantly slows down and this adversly affect the pricing error in both assets.

Given the flow of information, traders submit more limit orders at the beginning of a game than at the end of it. Experienced traders trade less frequently then inexperienced ones. Inexperienced informed traders trader very aggressively and lose money on average. Experienced informed traders trade more carefully and make money on average.

References

[1] Anand, A., S. Chakravarty and T. Martell, 2005. Empirical evidence on the evolution of liquidity: Choice of market versus limit orders by informed and uninformed traders, Journal of Financial Markets **8** 289-309.

[2] Ayres, I. and J. Bankman (2001) Substitutes for insider trading, Stanford Law Review **54** 235-294.

[3] Bhattacharya, U., P. Reny and M. Spiegel (1995) Destructive interference in an imperfectly competitive multi-security market, Journal of Economic Theory **65** 136-170.

[4] Bloomfield, R., M. OHara and G. Saar (2005) The "make or take" decision in an electronic market: Evidence on the evolution of liquidity, Journal of Financial Economics **75** 165-199.

[5] Easley, OHara and Srinivas (1998) Option volume and stock prices: Evidence on where informed traders trade, Journal of Finance **LII** 431-465.

[6] Foucault (1999) Order flow comparison and trading costs in a dynamic limit order market, Journal of Financial Markets **2** 99-134.

[7] Gorton and Pennachi (1993) Security baskets and index-linked securities, NBER working paper.

[8] Grossman (1998)

[9] Harris (1998) Optimal dynamic order submission strategies in some stylized trading problems, Financial Markets, Institutions and Instruments **7** 26-74.

[10] Kaniel and Liu (2006) So what orders do informed traders use? Journal of Business **79** 1867-1913.

Average Pricing Error (Volume-Weighted)

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders					
Asset 1	1.90	1.71	1.71	2.28	.650
Asset 2	2.14	2.72	2.02	1.69	.044**
MWU p-value A1 vs A2	.113	.113	.243	.362	
Informed Traders Present, No Restrictions					
Asset 1	1.92	2.07	1.87	1.81	.614
Asset 2	3.99	4.68	4.26	3.02	.479
MWU p-value A1 vs A2	.010***	.169	.001***	.034**	
Informed Traders Present, Restrictions					
Asset 1	2.22	3.05	1.57	2.05	.511
Asset 2	3.84	4.72	4.02	2.77	.169
MWU p-value A1 vs A2	.081*	.243	.022**	.113	
Pricing Error in Asset 1 across Treatments (MWU p-values)					
No Informed vs Informed, NR	.614	.880	.614	.800	
No Informed vs Informed, WR	.448	.311	.448	.880	
Informed, NR, vs Informed, WR	.479	.311	.614	.801	
Pricing Error in Asset 2 across Treatments (MWU p-values)					
No Informed vs Informed, NR	.007***	.479	.001***	.016**	
No Informed vs Informed, WR	.050**	.153	.139	.057*	
Informed, NR, vs Informed, WR	.801	.650	.762	.614	

Table 2: Volume-weighted average pricing error per period, the pricing error being calculated as the absolute difference between the price of a transaction (market order) and the true value of the asset. A row identified as "MWU p-value A1 vs A2" gives the p-value of the Mann-Whithney U-test for the difference between the pricing error of asset 1 and the pricing error of asset 2 within a treatment and the column "MWU 1 vs 3" denotes the p-value of the Mann-Whitney U-test for the difference in the pricing error in period 1 versus the pricing error in period 3 for an asset within a treatment. For the comparisons across treatments, NR denotes "no restrictions" and WR denotes "with restrictions". * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Average Pricing Error (Volume-Weighted)
Differences between Sessions 1-2 and Sessions 3-5

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders					
Asset 1 (Sessions 1-2, $N = 8$)	2.11	1.53	1.71	3.09	.798
Asset 1 (Sessions 3-5, $N = 5$)	1.57	2.01	1.72	0.99	.841
MWU p-value	.435	.943	.724	.524	
Asset 2 (Sessions 1-2, $N = 8$)	2.32	2.64	2.24	2.06	.279
Asset 2 (Sessions 3-5, $N = 5$)	1.87	2.85	1.66	1.10	.151
MWU p-value	.524	.724	.354	.045**	
Informed Traders Present, no Restrictions					
Asset 1 (Sessions 1-2, $N = 8$)	2.78	3.19	2.59	2.56	.878
Asset 1 (Sessions 3-5, $N = 5$)	0.54	0.27	0.73	0.63	.095*
MWU p-value	.011**	.030**	.065*	.093*	
Asset 2 (Sessions 1-2, $N = 8$)	4.03	5.00	3.88	3.21	.798
Asset 2 (Sessions 3-5, $N = 5$)	3.92	4.17	4.87	2.72	.421
MWU p-value	.724	.833	.354	.524	
Informed Traders Present, with Restrictions					
Asset 1 (Sessions 3-5, $N = 13$)	2.22	3.05	1.57	2.05	.511
Asset 2 (Sessions 3-5, $N = 13$)	3.84	4.72	4.02	2.77	.169

Table 3: Volume-weighted average pricing error in sessions 1 and 2 versus sessions 3 to 5, the pricing error being calculated as the absolute difference between the price of a transaction (market order) and the true value of the asset. A row identified as "MWU p-value" gives the p-value of the Mann-Whithney U-test for the difference between the pricing error of an asset during sessions 1 and 2 compared to the pricing error during sessions 3 to 5. "MWU 1 vs 3" denotes the p-value of the Mann-Whitney U-test for the difference in the pricing error in period 1 versus the pricing error in period 3 for an asset within a treatment. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Average Pricing Error (Volume-Weighted)
Continuous (C) vs Blackout (BO)

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders (C:8, BO:5)					
Asset 1–Continuous (C)	1.11	1.27	1.14	0.93	.721
Asset 1–Blackout (BO)	3.16	2.41	2.63	4.45	1.00
MWU p-value C vs BO	.065*	.127	.030**	.093*	
Asset 2–Continuous (C)	2.00	2.16	1.92	1.93	.505
Asset 2–Blackout (BO)	2.37	3.63	2.17	1.32	.056*
MWU p-value C vs BO	.622	.171	.622	.354	
Informed Traders Present, No Restrictions (C:8, BO:5)					
Asset 1–Continuous (C)	1.60	2.09	1.05	1.66	.382
Asset 1–Blackout (BO)	2.43	2.03	3.19	2.06	.841
MWU p-value C vs BO	.435	.354	.093*	.724	
Asset 2–Continuous (C)	4.13	4.91	4.27	3.22	.959
Asset 2–Blackout (BO)	3.76	4.32	4.25	2.72	.222
MWU p-value C vs BO	1.00	.622	.943	.833	
Informed Traders Present, with Restrictions (C:7, BO:6)					
Asset 1–Continuous (C)	1.88	2.79	0.44	2.40	1.00
Asset 1–Blackout (BO)	2.63	3.36	2.90	1.63	.310
MWU p-value C vs BO	.628	.836	.008***	.731	
Asset 2–Continuous (C)	3.59	5.26	3.01	2.50	.383
Asset 2–Blackout (BO)	4.12	4.09	5.20	3.07	.485
MWU p-value C vs BO	.534	1.00	.181	1.00	
Pricing Error in Asset 1 across Treatments (MWU p-values)					
C–No Informed vs Informed, NR	.798	1.00	.721	.505	
BO–No Informed vs Informed, NR	.548	1.00	.421	.548	
C–No Informed vs Informed, WR	.336	.281	.072*	.281	
BO–No Informed vs Informed, WR	.662	.792	1.00	.247	
C–Informed, NR, vs Informed, WR	.694	.397	.189	.694	
BO–Informed, NR, vs Informed, WR	.931	.662	.931	.792	
Pricing Error in Asset 2 across Treatments (MWU p-values)					
C–No Informed vs Informed, NR	.038**	.721	.003***	.161	
BO–No Informed vs Informed, NR	.222	.690	.222	.095*	
C–No Informed vs Informed, WR	.232	.336	.955	.336	
BO–No Informed vs Informed, WR	.177	.537	.052*	.082*	
C–Informed, NR, vs Informed, WR	.613	.613	.336	.613	
BO–Informed, NR, vs Informed, WR	.792	1.00	.537	1.00	

Table 4: Volume-weighted average pricing error per period, the pricing error being calculated as the absolute difference between the price of a transaction (market order) and the true value of the asset. MWu denotes the Mann-Whithney U-test for the difference between two pricing errors. For the comparisons across treatments, NR denotes "no restrictions" and WR denotes "with restrictions". * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders					
Asset 1, Limit	754	257	288	209	.762
Asset 2, Limit	665	295	196	173	.418
MWU p-value A1 vs A2	.920	.650	.362	.880	
Asset 1, Market	234	66	90	79	.724
Asset 2, Market	287	116	94	78	.223
MWU p-value A1 vs A2	.762	.153	.880	.479	
Informed Traders Present, No Restrictions					
Asset 1, Limit, Uninformed	836	250	232	353	.418
Asset 1, Limit, Informed	1,382	575	511	296	.362
WRS p-value U vs I	.422	.221	.345	.701	
Asset 2, Limit, Uninformed	797	257	287	253	.579
Asset 2, Limit, Informed	3,733	1,318	1,031	1,383	.072*
WRS p-value U vs I	.007***	.009***	.013**	.382	
Asset 1, Market, Uninformed	295	64	111	120	.125
Asset 1, Market, Informed	707	225	292	190	.687
WRS p-value U vs I	.016**	.075*	.071*	.272	
Asset 2, Market, Uninformed	355	98	133	124	.687
Asset 2, Market, Informed	1,072	113	515	445	.125
WRS p-value U vs I	.311	.959	.753	.249	
Asset 1 versus Asset 2, Uninformed Traders, No Restrictions					
MWU p-value, Limit	.960	.579	.801	.479	
MWU p-value, Market	.579	.311	.545	.920	
Asset 1 versus Asset 2, Informed Traders, No Restrictions					
MWU p-value, Limit	.139	.057*	.139	.418	
MWU p-value, Market	.264	.072*	.223	.801	

Table 5: Average market and limit orders in each treatment from each type of trader for the treatment without informed traders and the treatment with unrestricted informed traders . Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test and WRS denotes the Wilcoxon rank-sum test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders

	Per Game	Per Period 1	2	3	MWU 1 vs 3
Informed Traders Present, with Restrictions					
Asset 1, Limit, Uninformed	392	185	111	97	.029**
Asset 1, Limit, Informed	0	0	0	0	
WRS p-value U vs I					
Asset 2, Limit, Uninformed	509	228	141	141	.044**
Asset 2, Limit, Informed	1,227	574	463	190	.034**
WRS p-value U vs I	.007***	.023**	.006***	.463	
Asset 1, Market, Uninformed	141	31	54	56	.336
Asset 1, Market, Informed	0	0	0	0	
WRS p-value U vs I					
Asset 2, Market, Uninformed	179	63	54	62	.545
Asset 2, Market, Informed	201	28	75	98	.113
WRS p-value U vs I	.753	.116	.972	.701	
Asset 1 versus Asset 2, Uninformed Traders, with Restrictions					
MWU p-value, Limit	.960	.920	.880	1.00	
MWU p-value, Market	.511	.287	.920	.479	

Table 6: Average market and limit orders in each treatment from each type of trader in the case where informed traders cannot trade in asset 1. Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test and WRS denotes the Wilcoxon rank-sum test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders
Differences across Treatments (MWU p-values)

	Per Game	Per Period 1	2	3
No Informed Traders vs Informed Present–NR				
Asset 1–Limit–Uninformed	.418	.960	1.00	.153
Asset 2–Limit–Uninformed	.448	.920	.448	.418
Asset 1–Market–Uninformed	.1.00	.479	.840	.418
Asset 2–Market–Uninformed	.223	.920	.362	.081*
No Informed Traders vs Informed Present–WR				
Asset 1–Limit–Uninformed	.125	.579	.016**	.072**
Asset 2–Limit–Uninformed	.264	.650	.101	.091*
Asset 1–Market–Uninformed	.044**	.057*	.113	.139
Asset 2–Market–Uninformed	.223	.243	.125	.448
Informed Present–NR vs Informed Present–WR				
Asset 1–Limit–Uninformed	.091*	.840	.014**	.006***
Asset 2–Limit–Uninformed	.034**	.418	.034**	.034**
Asset 1–Market–Uninformed	.050**	.687	.186	.101
Asset 2–Market–Uninformed	.029**	.336	.022**	.050**
Asset 2–Limit–Informed	.101	.125	.186	.479
Asset 2–Market–Informed	.223	.724	.362	.336

Table 7: Mann-Whitney U (MWU) test p-values for the difference between the average limit/market order for each type of trader across the different treatments. Informed Present–NR denotes de treatment with informed traders and no restrictions relatively to trading and Informed Present–WR denotes the treatment with informed traders wherein the latter cannot trade in asset 1. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Submission Rates (in %)

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders					
Asset 1	71.29	70.44	72.12	68.42	.650
Asset 2	68.28	71.65	65.50	68.87	.920
MWU p-value A1 vs A2	.579	1.00	.186	.724	
Informed Traders Present, No Restrictions					
Asset 1, Uninformed	69.17	74.64	68.57	69.61	.362
Asset 2, Uninformed	67.35	72.65	64.89	64.54	.311
MWU p-value A1 vs A2	.724	.650	.336	.479	
Asset 1, Informed	51.49	49.01	48.17	51.04	.794
Asset 2, Informed	74.38	89.93	80.63	52.22	.029**
MWU p-value A1 vs A2	.057*	.010***	.037**	.744	
Informed vs Uninformed, Informed Present, no Restrictions					
WRS p-value, Asset 1	.279	.132	.182	.374	
WRS p-value, Asset 2	.345	.047**	.071*	.311	
Informed Traders Present, with Restrictions					
Asset 1, Uninformed	74.90	86.96	64.62	61.21	.004**
Asset 2, Uninformed	69.17	79.41	58.60	56.57	.014**
MWU p-value A1 vs A2	.362	.448	.418	.418	
Asset 2, Informed	84.37	92.07	75.42	59.82	.029**
Informed vs Uninformed, Informed Present, with Restrictions					
WRS p-value, Asset 2	.087*	.101	.221	.753	

Table 8: Average submission rates as measures by limit orders divided by the sum of limit and market orders in each treatment from each type of trader. Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test and WRS denotes the Wilcoxon rank-sum test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders
Differences between Sessions 1-2 (S12) and Sessions 3-5 (S35)

	Per Game	Per Period 1	2	3	MWU 1 vs 3
No Informed Traders					
Asset 1, Limit, S12	939	345	365	229	.382
Asset 1, Limit, S35	458	117	166	175	.841
MWU p-value S12 vs S35	.222	.065*	.171	.833	
Asset 1, Market, S12	260	59	104	97	.161
Asset 1, Market, S35	193	76	67	50	.310
MWU p-value S12 vs S35	.354	.435	.622	.127	
Asset 2, Limit, S12	925	429	263	232	.130
Asset 2, Limit, S35	248	81	89	78	.841
MWU p-value S12 vs S35	.011**	.019**	.171	.019**	
Asset 2, Market, S12	379	157	122	100	.279
Asset 2, Market, S35	140	50	49	41	.690
MWU p-value S12 vs S35	.045**	.065*	.065*	.127	
Informed Traders Present, No Restrictions					
Asset 1, Limit, Uninformed, S12	1,134	339	307	488	.574
Asset 1, Limit, Uninformed, S35	360	109	113	138	.222
WMU p-value S12 vs S35	.171	.127	.065*	.045**	
Asset 1, Market, Uninformed, S12	332	83	142	107	.505
Asset 1, Market, Uninformed, S35	236	34	62	140	.151
WWU p-value S12 vs S35	.524	.622	.284	1.00	
Asset 1, Limit, Informed, S12	1,599	744	575	280	.328
Asset 1, Limit, Informed, S35	1,036	305	409	322	1.00
WWU p-value S12 vs S35	.724	.622	.622	.724	
Asset 1, Market, Informed, S12	750	254	325	171	.574
Asset 1, Market, Informed, S35	637	179	238	220	1.00
WWU p-value S12 vs S35	.724	.833	.943	.622	
Asset 2, Limit, Uninformed, S12	989	321	371	297	.574
Asset 2, Limit, Uninformed, S35	490	155	152	183	1.00
WMU p-value S12 vs S35	.171	.127	.065*	.435	
Asset 2, Market, Uninformed, S12	399	96	145	159	.328
Asset 2, Market, Uninformed, S35	285	101	114	70	.310
WWU p-value S12 vs S35	.524	1.00	.833	.127	
Asset 2, Limit, Informed, S12	5,310	1,810	1,434	2,066	.195
Asset 2, Limit, Informed, S35	1,211	533	388	290	.310
WWU p-value S12 vs S35	.127	.127	.354	.943	
Asset 2, Market, Informed, S12	1,527	132	753	642	.195
Asset 2, Market, Informed, S35	344	82	133	129	.548
WWU p-value S12 vs S35	.524	.724	.065	.354	

Table 9: Average market and limit orders in each treatment from each type of trader divided into the first two evenings (S12, new participants) and the last three evenings (S35, experienced participants). Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders
Continuous (C) vs Blackout (BO)

	Per Game	Per Period 1	2	3	K-W 1-3
No Informed Traders (C:8, BO:5)					
C–Asset 1, Limit	727	279	282	166	.677
BO–Asset 1, Limit	797	221	299	276	.878
MWU p-value C vs BO	.724	.943	.833	.833	
C–Asset 1, Market	230	71	85	74	.912
BO–Asset 1, Market	241	57	98	87	.613
MWU p-value C vs BO	.724	.724	1.00	1.00	
C–Asset 2, Limit	676	301	210	165	.773
BO–Asset 2, Limit	647	287	174	185	.482
MWU p-value C vs BO	.943	.943	.724	1.00	
C–Asset 2, Market	290	129	93	68	.770
BO–Asset 2, Market	282	94	94	93	.277
MWU p-value C vs BO	.943	.833	.943	.724	
Informed Traders Present, No Restrictions (C:8, BO:5)					
C–Asset 1, Limit, Uninformed	996	305	237	171	.724
BO–Asset 1, Limit, Uninformed	582	163	226	192	.827
MWU p-value C vs BO	.284	.354	.833	.435	
C–Asset 1, Limit, Informed	635	220	256	160	.880
BO–Asset 1, Limit, Informed	2,577	1,143	920	514	.280
MWU p-value C vs BO	.065*	.019**	.284	.222	
C–Asset 1, Market, Uninformed	223	35	86	102	.124
BO–Asset 1, Market, Uninformed	411	112	151	148	.811
MWU p-value C vs BO	.354	.127	.435	.622	
C–Asset 1, Market, Informed	670	262	237	171	.668
BO–Asset 1, Market, Informed	765	166	378	221	.967
MWU p-value C vs BO	.724	.622	.943	.833	
C–Asset 2, Limit, Uninformed	893	274	297	322	.854
BO–Asset 2, Limit, Uninformed	643	230	271	142	.185
MWU p-value C vs BO	.622	.943	.524	.435	
C–Asset 2, Limit, Informed	4,222	1,323	1,255	1,643	.104
BO–Asset 2, Limit, Informed	2,952	1,312	673	967	.322
MWU p-value C vs BO	.622	.622	.524	.171	
C–Asset 2, Market, Uninformed	363	77	136	150	.632
BO–Asset 2, Market, Uninformed	343	131	128	84	.595
MWU p-value C vs BO	1.00	.222	.622	.435	
C–Asset 2, Market, Informed	1,615	94	836	685	.070*
BO–Asset 2, Market, Informed	204	143	0	61	.272
MWU p-value C vs BO	.127	.724	.065*	.045**	

Table 10: Average market and limit orders in each treatment from each type of trader in the continuous and the blackout cases. Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test and WRS denotes the Wilcoxon rank-sum test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Limit versus Market Orders
Continuous (C) vs Blackout (BO)

	Per Game	Per Period 1	2	3	K-W 1-3
Informed Traders Present, with Restrictions (C:7, BO:6)					
C–Asset 1, Limit, Uninformed	396	199	88	109	.147
BO–Asset 1, Limit, Uninformed	388	169	137	82	.372
MWU p-value C vs BO	.945	.731	.628	.836	
C–Asset 1, Market, Uninformed	173	39	59	75	.560
BO–Asset 1, Market, Uninformed	102	22	47	34	.579
MWU p-value C vs BO	.534	.295	.534	.234	
C–Asset 2, Limit, Uninformed	376	172	111	93	.168
BO–Asset 2, Limit, Uninformed	665	293	177	196	.421
MWU p-value C vs BO	1.00	.731	.445	.534	
C–Asset 2, Limit, Informed	1,150	587	417	146	.195
BO–Asset 2, Limit, Informed	1,318	559	517	242	.372
MWU p-value C vs BO	.628	.945	.366	.628	
C–Asset 2, Market, Uninformed	200	74	57	68	.558
BO–Asset 2, Market, Uninformed	155	49	51	55	.932
MWU p-value C vs BO	.836	.534	.836	.445	
C–Asset 2, Market, Informed	205	28	99	78	.164
BO–Asset 2, Market, Informed	196	28	47	121	.650
MWU p-value C vs BO	.836	.366	.628	.836	

Table 11: Average market and limit orders in the treatment with restricted informed traders under the continuous and the blackout case in terms of flow of information. Each quantity represents an average number of shares per trader per unit of time. The unit of time is one minute for a period and three minutes for a whole game. MWU denotes the Mann-Whitney U test and WRS denotes the Wilcoxon rank-sum test. * denotes 10% statistical significance, ** denotes 5% statistical significance and *** denotes 1% statistical significance.

Value of Insiders' Trades

	Per Game	Per Period 1	2	3
Informed Traders Present, No Restrictions				
Asset 1 (Sessions 1-5, $N = 13$)	1,677	1,760	3,522	$-3,605$
Asset 2 (Sessions 1-5, $N = 13$)	$-6,026$	1,979	3,659	$-11,664$
Total (Sessions 1-5, $N = 13$)	$-4,349$	3,739	7,181	$-15,269$
Asset 1 (Sessions 1-2, $N = 8$)	3,207	2,992	6,096	$-5,880$
Asset 2 (Sessions 1-2, $N = 8$)	$-19,771$	863	129	$-20,763$
Total (Sessions 1-2, $N = 8$)	$-16,564$	3,855	6,225	$-26,643$
Asset 1 (Sessions 3-5, $N = 5$)	-772	-211	-597	36
Asset 2 (Sessions 3-5, $N = 5$)	15,965	3,765	9,307	2,893
Total (Sessions 3-5, $N = 5$)	15,193	3,554	8,710	2,929
Informed Traders Present, Restrictions				
Asset 2 (Sessions 3-4, $N = 13$)	2,968	6,244	$-4,703$	1,427

Table 12: Average gain by insiders per game and per period for each treatment. The gains in each case show the total profit realized by both insiders.

Value of Insiders' Market Orders

	Per Game	Per Period 1	2	3
Informed Traders Present, No Restrictions				
Asset 1–Buy Orders (Sessions 1-5, $N = 13$)	$-5,747$	-832	-868	$-4,047$
Asset 1–Sell Orders (Sessions 1-5, $N = 13$)	$-1,295$	$-1,153$	0	-142
Asset 2–Buy Orders (Sessions 1-5, $N = 13$)	$-22,387$	$-10,292$	-448	$-11,647$
Asset 2–Sell Orders (Sessions 1-5, $N = 13$)	6,697	1,685	2,019	2,993
Asset 1–Buy Orders (Sessions 1-2, $N = 8$)	$-6,497$	$-1,221$	1,041	$-6,317$
Asset 1–Sell Orders (Sessions 1-2, $N = 8$)	$-2,067$	$-1,874$	0	-193
Asset 2–Buy Orders (Sessions 1-2, $N = 8$)	$-34,151$	$-15,000$	-225	$-18,926$
Asset 2–Sell Orders (Sessions 1-2, $N = 8$)	8,675	2,738	2,254	3,683
Asset 1–Buy Orders (Sessions 3-5, $N = 5$)	$-1,218$	-211	-593	-414
Asset 1–Sell Orders (Sessions 3-5, $N = 5$)	-60	0	0	-60
Asset 2–Buy Orders (Sessions 3-5, $N = 5$)	$-3,564$	$-2,760$	-804	0
Asset 2–Sell Orders (Sessions 3-5, $N = 5$)	3,530	0	1,642	1,888
Informed Traders Present, with Restrictions				
Asset 2–Buy Orders (Sessions 3-4, $N = 13$)	$-7,472$	-499	$-6,878$	-95
Asset 2–Sell Orders (Sessions 3-4, $N = 13$)	$-3,114$	-973	$-2,471$	330

Table 13: Average gain by insiders per game and per period for each treatment given buy and sell orders. The gains in each case show the total profit realized by both insiders.