Equilibrium discovery and preplay communication in an experimental market

Bruno Biais, Christophe Bisière and Sébastien Pouget[1]

Toulouse School of Economics

July 2007

Abstract

This paper offers an experimental investigation of equilibrium discovery and coordination in three market mechanisms: i) a pure call auction, ii) a call auction preceded by a non–binding preopening period, and iii) a call auction preceded by binding preopening orders. The non binding preopening period offers traders the opportunity to place manipulative orders. After observing attempts to manipulate, participants learn to distrust cheap talk. Hence, preplay communication does not enhance coordination on Pareto dominant outcomes. In contrast, when preopening orders are binding, they improve significantly the ability to coordinate on high gains from trade.

[1] We gratefully acknowledge the financial support of Paris Europlace. We are also grateful for insightful comments to the participants of the joint UCL-Birbeck theory seminar and the Mannheim University Symposium on Behavioral Economics.

Equilibrium discovery and preplay communication in an experimental market

1 Introduction

Discovering equilibrium prices and orders at the opening of stock markets is a difficult task, especially because liquidity externalities can create equilibrium multiplicity.[2] To facilitate discovery, several bourses start with a preopening period where investors can place orders and indicative prices are set and disseminated. Biais, Hillion and Spatt (1999) document the information content of these prices in the Paris Bourse. But, to the extent that preopening orders can be cancelled, traders can use them to manipulate the market. This could prevent the preopening from facilitating coordination. Market designers have introduced certain features to deter such manipulation. For example, as is the case on Xetra, the German computerzied stock exchange, the exact time of the opening can be random.[3] Or cancellations can be costly. This paper offers an experimental investigation of three market mechanisms, inspired by those prevailing in actual stock exchanges: i) a pure call auction, ii) a call auction preceded by a non–preopening period, and iii) a call auction preceded by binding preopening orders.

We start from a simple game where, according to parameter values there is one or two pure strategy equilibria. In the first case, corresponding to low liquidity, the only equilibrium generates low gains from trade. In the second case, one of the pure strategy equilibria involves low liquidity and low gains from trade, while the other involves high liquidity and high gains from trade. The former is risk–dominant, while the latter is Pareto dominant. In that context, coordinating on equilibrium is likely to be difficult. We study under what conditions preplay communication can facilitate such coordination.

When there is a unique, low liquidity, equilibrium, our game is a simple prisoner's dilemma, while with two equilibria, it is a simple stag–hunt game. Our analysis of the latter is directly in line with previous experimental investigations, especially Cooper, DeJong, Forsythe and Ross

[2] Pagano (1989), Admati and Pfleiderer (1988) and Dow (2004) analyze liquidity externalities.

[3] In the description of the Xetra market model, one can read: "The call phase has a random end after a minimum period in order to avoid price manipulation" (Deutsche Borse, 2004, page 20).

(1992), Blume and Ortmann (2007) and Charness (2000) who find that, in coordination games, preplay communication via non–binding cheap–talk generates good coordination on the Pareto dominant equilibrium. Our paper is also related to the experimental analysis of Clark et al (2001).

The two major differences between our analysis and these papers are the following. First, we consider the following three market mechanisms:

- A pure one–shot call auction where buyers and sellers submit limit orders and the uniform price is set to clear the market.

- A call market preceded by a non–binding preopening period. In this treatment, the call market is held twice in each replication of the experiment. At time 0, participants place non–binding orders and purely indicative prices are set and disseminated. But no trade takes place. Then these orders are cancelled and, at time 1, participants place firm orders, which are taken into account to determine the price and the trades.

- A call market preceded by a binding preopening period. In that game, traders have the option to place orders at time 0. If they do so, those orders are firm and cannot be cancelled. Alternatively, the traders can wait until time 1 to participate in the call auction.

While our experimental setting is admittedly extremely simple and stylized, we have designed these three market mechanisms to capture some salient features of the opening of real stock exchanges, namely the ability to place orders prior to the opening and the fact that cancelling these orders can be more or less difficult or costly. Thus, comparing the performance of our experimental market structures can offer some insights useful for the design of stock exchanges.

The second major difference between our paper and previous experimental analyses (such as Cooper, DeJong, Forsythe and Ross (1992), Blume and Ortmann (2007), Charness (2000) and Clark et al (2001)) is that we study the effect of history on participants' behaviour.[4] Some traders first start with a game with high potential gains from trade, and then experience a situation with low liquidity and low gains from trade. Other participants experience the opposite sequence. The idea is that in real economic situations, and in particular stock exchanges, market conditions change and potential gains from trade vary. We designed our experiment to involve, in a simple way, such variability.

[4] Schmidt et al (2003) also study the role of history, but without preplay communication.

Our experiment was run in the Toulouse University laboratory, with 68 master students, who each played 15 replications of the game and received financial rewards proportional to their gains. Our main experimental results are the following:

- The opportunity to engage in non–binding preplay communication during the preopening period does not clearly facilitate coordination on the Pareto dominant equilibrium. When parameters are such that there are two equilibria, one risk–dominant and the other Pareto dominant, agents coordinate on the latter 40% of the time in the pure call auction and 46% of the time with a non–binding preopening period.[5] In contrast, the opportunity to use binding preopening orders generates strong coordination on the equilibrium with high liquidity and high gains from trade. With binding preopening orders, players coordinate on the Pareto dominant equilibrium in 85% of the cases.

- When preplay communication is non binding and equilibrium involves low liquidity, participants tend to place manipulative orders during the preopening and then to betray such promises when placing firm orders.[6] After observing this behaviour, participants learn to mistrust nonbinding preplay communication. This results in poor coordination, even when there is a Pareto dominant equilibrium with high gains from trade and liquidity. Thus, when the market moves from a prisoner's dilemma to the situation where equilibrium gains from trade are potentially large, we observe the following: Players coordinate on the Pareto dominant equilibrium 32% of the time in the pure call market and 85% of the time with a binding preopening, but only 25% of the time with a nonbinding preopening period.

Our results suggest that preplay communication mechanisms can be fragile. Underscoring this fragility is one contribution of our paper relative to the previous literature. Cooper, DeJong,

[5]One of the reasons for this may be that, in our setup, preplay announcements to play the Pareto dominant equilibrium are not self–enforcing in the Aumann (1990) sense. This differs from the case studied by Cooper et al (1992). Clark et al (2001) study preplay communication in a setting where announces are not self enforcing. They find that cooperation is announced 81% of the time, but played only 42% of the time. Our results on the non–binding preopening period are consistent with these figures.

[6]The analysis of Charness (2001) also covers the case of a prisoner's dilemma. In that case, he finds that cooperation is announced 80% of the time but played only 10% of the time. Our results are in line with his findings.

Forsythe and Ross (1992), Blume and Ortmann (2007) and Charness (2000) find that nonbinding preplay communication fosters coordination on the Pareto dominant equilibrium when the parameters of the game are constant and this equilibrium is always within the reach of the participants. In contrast, we consider the case where participants face varying parameters, some for which coordinating on Pareto dominant outcomes is feasible, others in which such win–win situations are unsustainable. We show that the latter situation generates bitter experiences, which then preclude coordination via nonbinding preplay communication.

The second contribution of our paper is to suggest that an alternative mechanism to pure cheap talk, in which this problem is mitigated. In our experiment, when preopening orders are binding, there is strong coordination on the Pareto dominant equilibrium. And this is robust to bad intial conditions, with low initial gains from trade. In this market structure, indeed, participants don't have the opportunity to make false promises and then breach them. Thus, they can't loose trust in the ability to coordinate on win–win situations.

The next section describes our trading game, the different mechanisms we consider and our hypotheses. Section 3 presents the experimental design. Section 4 presents the results. Section 5 briefly concludes.

2 The trading game

In financial markets, opening prices are often set in uniform price auctions, referred to as a call auctions. This is the case, for instance, in the two major European stock markets: Euronext and Xetra, as well as in other bourses throughout the world, such as, e.g., the Brazilian stock exchange. Recognizing that equilibrium discovery is a difficult task, several market organizers have designed preplay communication mechanisms. Thus, Euronext or the Brazilian stock exchange feature a preopening period whereby traders can submit or cancel limit orders and tentative prices are set (see Biais, Hillion and Spatt, 1999). In this section, we present a stylized trading game designed to capture some important features of such markets. For simplicity, we directly present the numerical example which we use in the experiment. We solve for the equilibria of this simple game and offer conjectures on likely behaviours expected to arise in this context.

2.1 The call auction

The buyer and the seller differ in terms of their private valuation of the asset. The buyer assigns value $v = 4$ to the asset, up to $\bar{q}$ units, and then 0. The cost to the seller of providing the good is $c = 0$ up to $\bar{q}$ units, and then infinity. Potential gains from trade are: $(v - c)\bar{q} = 4\bar{q}$.

In the call auction buyers and sellers can post schedules of limit orders. Thus, they submit demand and supply curves. In our simple game, we assume the limit orders are placed on a discrete pricing grid: $p \in \{1, 2, 3\}$. Once the orders have been placed, the supply and demand curves are confronted and the price is set to maximize the number of shares traded. This is a uniform price double auction, i.e., all orders are executed at the same price. If more than one price maximizes volume, then the transaction price is an arithmetic average of the candidate prices.

For simplicity, we assume the buyer has the choice between two schedules of limit orders only. He can opt for a rather low-aggressivity schedule, which we denote by $B1$. This schedule involves a limit order to buy 8 units if the price is not above 2, and another order to buy $\bar{q} - 8$ additional units if the price is not above 1. Obviously, we assume that $\bar{q} > 8$. Alternatively, he can opt for a more aggressive schedule, which we denote by $B2$. This involves a limit order to buy 8 units if the price is not above 3, and another order, to buy $\bar{q} - 8$ units if the price is not above 2. Symmetrically, the seller can choose between two schedules: $S1$ and $S2$. The former involves a limit order to sell 8 units if the price is not below 2 and another order to sell $\bar{q} - 8$ units if the price is not below 3. The latter involves a limit order to sell 8 units if the price is not below 1 and another order, to sell $\bar{q} - 8$ units if the price is not below 2. The supply and demand curves corresponding to these schedules of limit orders are plotted in Figure 1. The players can also choose not to submit any orders. This is denoted by $S0$ and $B0$ for sellers and buyers, respectively.

If both traders opt for aggressive limit orders (i.e., place schedules $S2$ and $B2$), the market clearing price is 2 and the corresponding volume is $\bar{q}$. If both traders opt for less aggressive orders (i.e., place $B1$ and $S1$), then the price is still 2, but trading volume is lower, and equal to 8. Now turn to the asymmetric cases: If the buyer is aggressive, but not the seller ($B2$ and $S1$ are chosen) then again trading volume is low and equal to 8, but the price is pushed upward to 2.5. If the seller is aggressive, but not the buyer ($B1$ and $S2$ are chosen) then again trading volume is low, but the prices is pushed downward to 1.5.

Thus, each trader faces a trade-off: He can choose to place an aggressive schedule, potentially generating greater gains, but at the risk of an adverse price move. This risk depends on whether or not the other trader aggressively provides liquidity. Thus it can be interpreted as liquidity risk.

The situation faced by traders can be represented in a normal form game, where the payoff of the seller is the first number in each cell, and the payoff of the buyer is the second number in each cell:

Buyer:

Seller:

	$B1$	$B2$
$S1$	$(16, 16)$	$(20, 12)$
$S2$	$(12, 20)$	$(2\bar{q}, 2\bar{q})$

In the off-diagonal cells, the trader with the less aggressive schedule earns greater gains than his or her counterparty. Note also that, since $\bar{q} > q$, the pair of actions which maximizes the total gains from trade is $(S2, B2)$. But will this allocation arise in equilibrium? First note that the situation where each of the traders provide low liquidity $(S1, B1)$ is a Nash equilibrium. Second, note that $(S2, B2)$ is an equilibrium too if a trader anticipating that his counterparty will place an aggressive schedule also prefers to aggressively supply liquidity. This is the case if and only if: $\bar{q} \geq 10$.

So we must consider two cases:

- If $\bar{q} < 10$, we obtain a typical Prisoner's Dilemma game, where $(S1, B1)$ is the unique Nash equilibrium, and the utilitarian optimum is not attained in equilibrium.
- If $\bar{q} \geq 10$, we have a Stag–Hunt game with two pure strategy equilibria: $(S1, B1)$ and $(S2, B2)$. There is also a mixed strategy equilibirum whereby, each trader selects the aggressive schedule, $S2$ or $B2$, with probability $2/3$. Thus, when $\bar{q} \geq 10$, $(S2, B2)$ is a Pareto dominant outcome, but it might fail to emerge, if the traders don't coordinate on this equilibrium.

To study what happens in these two cases, in our experiment we will consider two possible parameter values: $\bar{q} = 9$ and $\bar{q} = 11$. Note that, with such parameter values $(S1, B1)$ is a risk dominant equilibrium. This is obviously the case when $\bar{q} = 9$, but also arises when $\bar{q} = 11$. Suppose the buyer has no clue about the actions of the seller and assigns equal probability to the two possible actions $S1$ and $S2$. Then, when $\bar{q} = 11$, the expected utility of the buyer if he plays $B1$ is:

$$\frac{1}{2}16 + \frac{1}{2}20 = 18,$$

while his utility if he plays $B2$ is:

$$\frac{1}{2}12 + \frac{1}{2}22 = 17.$$

Hence, the buyer prefers to play $B1$.

2.2 The preopening period

Some stock markets operate without formal preopening period. In our simple setup, this corresponds to the case decribed above, where the trading game only involves the call auction. In other bourses, there is a preopening period during which traders can enter limit orders and indicative prices are set and disseminated. There are no trades at these prices, but investors can observe them. This mechanism can be useful if, by observing the indicative prices, investors can progressively coordinate on an equilibrium. But it's not clear whether such preplay communication can deliver useful and reliable information. After all, if traders can costlessly place and cancel orders, they have no clear incentives to reveal their true trading intentions and can attempt to manipulate the market. To cope with this problem, market organizers have designed preopening periods where it can be unattractive or difficult to cancel manipulative orders. This can involve forbidding cancellations, imposing costs for traders cancelling orders, or opening the random market at a random point in time. To study these issues we consider two types of preopening in our simple setup:

- The first preopening mechanism we consider is a pure cheap talk mechanism, with non–binding orders. At time 0 the buyer and the seller can enter orders $S1$ or $S2$ and $B1$ or $B2$. These orders are matched and an indicative price is set, at which there is no trade. All investors observe the outcome of this preopening round. Then, at time 1, the preopening orders are cancelled and the traders have a new opportunity to place orders. These time 1 orders are those which will be used to set the opening prices and will lead to actual trades at this price.

- The second preopening mechanism involves binding orders. It is designed to capture, in a simple way, attempts by market designers to curb manipulation and noisy preopening orders. At time 0 the traders can choose to place limit orders $S1$ or $S2$ and $B1$ or $B2$. Alternatively, they can choose to place no order and wait for $t = 1$ to do so. The outcome of this preopening round is observed by all. At time 1, the orders placed at $t = 0$ are still in the order book, i.e., traders cannot cancel their initial orders. Neither can they place new orders. On the other hand, traders who have not yet placed orders now have the opportunity to place orders $S1$ or $S2$ and $B1$ or $B2$.

How does the presence of this preopening phase alter behaviour and outcomes in our simple trading game? Obviously, the set of equilibrium outcomes is the same in the simple call market and in the call market preceded by a pure cheap talk preopening, with non binding orders. But with binding preopening orders, the set of equilibrium allocations can differ from its pure call market counterpart.

- When $\bar{q} = 9$, $(S1, B1)$ is still the only equilibrium outcome, and it does not matter whether the agents place their orders at time 0 or at time 1.

- When $\bar{q} = 11$, placing $S1$ and $B1$ at time 0 is a Nash equilibrium, and so is placing $S2$ and $B2$ at time 0. There are also two other equilibria with high liquidity: i) In the first one, at time 0 the seller places $S2$ while the buyer initially waits and then at time 1 responds with $B2$. ii) The second equilibrium is symmetric: at time 0 the buyer places $B2$ while the seller waits and then at time 1 responds with $S2$. However, with binding preopening orders, there is no equilibrium in which at time 0 one trader waits while the other plays $S1$ or $B1$. If I anticipate the other to wait at time 0, I am better off playing $S2$ or $B2$ at that time, since I know the other will respond with $B2$ or $S2$ and we will end up in the Pareto dominating outcome. Futhermore there is no mixed strategy equilibrium: First note that if I anticipate the other will randomize at time 0, then I wait until time 1 to play my best response. But if the other anticipates I will wait until time 1, he/she is better off playing $S2$ or $B2$ initially. Second note that if the other is to randomize at time 1, she/he must wait at time 0. But then I am better off immediately playing $S2$ or $B2$. In that case, it will be optimal for the other to respond with $B2$ or $S2$, and he/she will not randomize.

2.3 Hypotheses

We chose to design a simple game, to ensure that participants in the experiments could easily figure out equilibrium strategies. Thus, our first conjecture is that we will observe equilibrium behaviour. When $\bar{q} = 9$, this leads to a simple hypothesis, since there is a unique equilibrium outcome, whatever the structure of the trading game. Accordingly we posit the following hypothesis:

Hypothesis 1 *When $\bar{q} = 9$ we expect the outcome of the game to be $(S1, B1)$ and low liquidity to prevail. Since this is the unique equilibrium outcome and it involves dominant strategies, we expect fast convergence to this situation.*

Note that, when $\bar{q} = 9$, the structure of the market has no impact on the equilibrium outcome. This suggests the presence of a non binding preopening should have no effect on game outcomes. Participants should realize that at time 1 their opponent will always play $S1$ or $B1$, whatever his or her initial order. So they should ignore any other preopening order. At the same time, if participants are unsure whether their opponents conduct such reasoning, they might attempt to manipulate their beliefs. Thus, when $\bar{q} = 9$, they could place misleading orders, $S2$ or $B2$, in the preopening, hoping their opponent would naively respond with $B2$ or $S2$ at time 1. They would opportunistically take advantage of such naive behaviour by placing $S1$ or $B1$ at time 1. In this context we expect that non–binding preopening orders will not predict actual orders placed at time 1, and, correspondingly, preopening prices will have little information content. This is stated in the following hypothesis:

Hypothesis 2 *When $\bar{q} = 9$ and there is a preopening period with non–binding orders, participants may deviate from $(S1, B1)$ at time 0 and place non–credible, manipulative orders.*

When $\bar{q} = 11$, things are more complicated. In all the market structures we consider there are multiple equilibria, with different levels of liquidity and gains from trade. And, while some equilibria are Pareto dominant, one must also bear in mind that the Pareto dominated outcome corresponds to risk dominant strategies. This could make it more difficult for participants to converge to equilibrium.

The first question arising in this context is whether participants can coordinate on one pure strategy equilibrium, be it the low liquidity equilibrium, with outcome $(B1, S1)$, or the high liquidity equilibrium, with outcome ($B2$, $S2$). If the participants fail to achieve such coordination, we will observe frequent mismatches, with outcomes ($B2$, $S1$) or ($B1$, $S2$). However, preplay communication can be expected to foster coordination on pure strategies. Thus we expect that, when there is a preopening period with non binding orders, mismatches should be less frequent than in the pure call market without preopening. Furthermore, we expect mismatches to be even less frequent when preopening orders are binding since in that case such mismatches are not equilibrium outcomes (as there is no mixed strategy equilibrium in that market structure). Thus we posit the following:

Hypothesis 3 *When $\bar{q} = 11$, the frequency of mismatches, whereby one participant plays $B2$ and the other $S1$ or where one participant plays $B1$ and the other $S2$, should be greatest in the pure call market and smallest with binding preopening orders.*

The second question is whether, when $\bar{q} = 11$, the presence of a preopening period could foster coordination on the Pareto dominant equilibrium ($S2$, $B2$). Cooper, DeJong, Forsythe and Ross (1992) and Blume and Ortmann (2007) show experimentally that, in games with multiple Pareto–ranked equilibria, pre–play communication fosters coordination on the most efficient one. Farell (1987) offers a theoretical argument to rationalize this. The intuition is the following: Of course, when non equilibrium or dominated actions are announced, pre-play communication is non credible and players ignore it. But, what if I make an announcement such that if you believe me and respond optimally, then it is in my own interest to stick to my word? Farell (1987) argues that in this case my announcement should be credible. Thus, in our simple trading game, when $\bar{q} = 11$, participants could credibly announce during the preopening their intention to play ($S2$, $B2$) in the call auction. This suggests that the presence of the preopening period should enhance coordination on the Pareto dominant Nash equilibrium. However, Aumann (1990) offers a counterargument. Suppose I announce I will play $S2$ and the buyer believes me. Then he responds with $B2$. Now, I prefer him to choose this response irrespective of whether I really want to play $B2$ or plan to deviate to $B1$. Thus, argues Aumann (1990) my announcement is not *self-enforcing.* This suggests it may not be credible and preplay communication with nonbinding orders may not enhance coordination on the Pareto dominant equilibrium. Whether the preopening period can facilitate coordination in our trading game is therefore in theory an open issue. To set ideas, in line with the experimental results of Cooper, DeJong, Forsythe and Ross (1992), Blume and Ortmann (2007) and Charness (2000) we posit the following hypothesis, under which preopening prices and trading volume should be good predictors of call prices and trading volume.

Hypothesis 4 *When* $(S1, B1)$ *and* $(S2, B2)$ *are both Nash equilibria, the Pareto optimal equilibrium* $(S2, B2)$ *will be more frequent with a preopening period than without.*

The ability for agents to coordinate and the ensuing equilibrium could also depend on the history of the game. If participants start playing in a market where $\bar{q} = 9$, the low liquidity outcome may become a focal point. Thus, the participants would be trapped in the low liquidity equilibrium, even when $\bar{q}$ would go up to 11. On the contrary, if participants start with a more favorable situation ($\bar{q} = 11$), they are more likely to form optimistic beliefs and coordinate on the Pareto dominant equilibrium. To study this point, we will vary the parameter values to which participants will be exposed in the experiment and we will analyze how this affects their behaviour. Accordingly, we posit the following hypothesis:

Hypothesis 5 *If participants start playing the game in the situation where* $(S1, B1)$ *is the only equilibrium, this will reduce their ability to adjust their beliefs and coordinate on the Pareto dominant equilibrium* $(S2, B2)$ *when* $\bar{q}$ *goes up to 11.*

3 Experimental design

To test these hypotheses, we conducted a market experiment at the Toulouse University laboratory. We studied participants behaviour in three treatments: i) a pure call market without preopening, ii) a call auction preceded by a nonbining preopening period, iii) a call auction preceded by binding preopening orders. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2006). The participants were seated in front of computers separated with walls and we enforced a ban on verbal communication. The participants were 68 students from three different graduate finance programs at Toulouse University. There were 7 cohorts. Each cohort played only in one market environment. In each cohort, participants played the market game 15 times. Each time they were randomly and blindly matched with an opponent, and this was orally announced by the experimenter so that it was common knowledge. Anonymity and random matching ensured that each time participants would behave as in a one–shot game.

At each round, the computer collected all the choices and randomly matched one seller and one buyer within a given cohort. Payoffs were determined according to the normal form game table given above. At the end of each replication, each participant was informed of his or her trading gains. Subjects were not told with whom they were matched, but they knew what their opponent chose. The subjects were not informed of the outcomes of the matches in which they did not participate. When there was a preopening period, the same two players were matched both for the preopening period and the subsequent call market.

To study the effect of history on behaviour, we exposed the participants to variations in $\bar{q}$. Half the participants first played 5 rounds with $\bar{q} = 11$, followed by 5 rounds with $\bar{q} = 9$, and then 5 more rounds with $\bar{q} = 11$. For the other half the sequencing was reversed: they first played 5 rounds with $\bar{q} = 9$, then 5 rounds with $\bar{q} = 11$, and finally 5 rounds with $\bar{q} = 9$. We did not tell the students what the exact process of $\bar{q}$ would be. We just informed them that $\bar{q}$ would vary across rounds and participants. When $\bar{q}$ changed, we clearly warned the participants of this alteration in the parameters via screen messages, to avoid any confusion.

The composition of the cohorts and the treatments are summarized in Table 1. In each cohort, we first explained the game to the participants and gave them an instruction sheet. An example of the instructions, for the pure call auction market, is given in the appendix. We answered questions to ensure the participants understood the mechanics of the market. At the same time we carefully avoided giving them any hints as to how they should play. Then the market game took place. First, each cohort went through 6 practice rounds. Then, the 15 "real" rounds took place. At each round the participants had 3 minutes to place their orders. In the pure call auction case, this meant they had 3 minutes to choose which order to place in the call auction. When there was a preopening, participants had 90 seconds to choose the orders they would place during the preopening and then 90 seconds to place orders in the call auction. We chose this design to ensure that the total decision time would be the same across all treatments. This way, if superior performance was obtained in markets with a preopening period, it could not be due to longer decision time. Overall the market game lasted around one hour and a half for each cohort. The participants were also told that, after the 15 sessions, they would receive a payment in euros equal to their total number of points divided by 15. The average payment was €18, the minimum was 15 and the maximum 21.

4 Experimental results

4.1 Executed orders

First consider executed orders, i.e., the orders that were taken into account to generate trades. In the pure call auction these are simply the limit orders placed by the agents. In the market with non binding preopening orders, these are the orders placed at time 1 in the call auction. In the market with binding preopening orders, these are the orders placed by the participants, either at time 0 during the preopening or at time 1 during the call auction.

Pooling buyers and sellers, Table 2 gives the frequency of three types of orders: $A0$ refers to instances where the participant chose to place no order. $A1$ refers to instances where the participant chose to place non–aggressive orders ($B1$ or $S1$). $A2$ refers to the case where the participant submitted aggressive demand or supply curves ($B2$ or $S2$).

Table 2 Panel A shows that, when $\bar{q} = 9$, consistent with Hypothesis 1, more than 80% of the orders are of type $A1$. This suggests participants easily discover the dominant strategy equilibrium and play accordingly. The table also shows that convergence to this equilibrium is stronger when there is a preopening period, as the frequency of $A1$ is larger. But the effect is not huge. A Chi–square test fails to reject at the 5% level the hypothesis that there is no difference between the frequencies observed without a preopening and with a binding preopening (the Chi–square statistic is 3.52). However, the hypothesis that there is no difference between a pure call auction and a non–binding preopening is rejected at the 5% level (the Chi–square statistic is 24.12).

Table 2, Panel B, shows that the situation is very different when $\bar{q} = 11$. In that case, the majority of the orders are of type $A2$. But frequencies vary strongly across market structures. As shown in Table 2, Panel B, both in the pure call auction and with a non binding preopening, the frequency of $A1$ is around 40%, while that of $A2$ is around 60%.[7] This stands in stark contrast with Hypothesis 4: The pre–play communication opportunities offered by the non–binding pre–opening did not lead to greater coordination on the Pareto dominant Nash equilibrium. This

[7] A Chi–square test fails to reject at the 5% level the hypothesis that there is no difference between the frequencies observed without a preopening and with a non–binding preopening (the Chi–square statistic is 1.26).

also contrasts with the experimental results of Cooper, DeJong, Forsythe and Ross (1992), Blume and Ortmann (2007) who found that cheap–talk fostered coordination on the Pareto dominant Nash equilibrium. In the following we offer more information about the origins of this difference in results. Table 2 Panel B also shows that the market with binding preopening orders strongly differs from its non–binding preopening counterpart. With binding preopening orders, the proportion of $A2$ is very high (91%), i.e., there is strong coordination on the Pareto dominant equilibrium. This is significantly different from the 63% frequency observed in the pure call auction. A Chi square test rejects at the 5% level the hypothesis that there is no difference between these two markets (the Chi–square statistic is 40.69). Such significance is consistent with Hypothesis 4. Thus, while Hypothesis 4 is rejected in its simple version, our results suggest that the preopening facilitates coordination on high liquidity, *if it involves non–binding orders.*

4.2 Mismatches

Next, we study the match between buy and sell executed orders. Table 3, Panel A, shows that, when $\bar{q} = 9$, in the majority of cases order types are matched. In more than 60% of the cases, both the seller's and the buyer's orders are of type $A1$. Interestingly, the proportion of mismatches ($(S1, B2)$ or $(S2, B1)$) is greater when there is no preopening. In that case, the frequency of mismatches is around 30%. In contrast, when there is a preopening, it is around 11 or 12%. Note however that mismatches are not less frequent with a binding preopening than with a non–binding one. Thus, irrespective of whether it is binding or not, the pre–opening period fosters coordination on the dominant strategy equilibrium.

Table 3, Panel B shows that, when $\bar{q} = 11$, mismatches are more frequent than when $\bar{q} = 9$. This is natural since there are multiple equilibria in the former case and not in the latter. Consistently with Hypothesis 3, when $\bar{q} = 11$, mismatches are most frequent in the pure call auction (45%), less frequent with a non–binding preopening (27%) and least frequent with a binding preopening period (12%).

Thus, the ability to place binding preopening orders enhances the ability of participants to coordinate on the Pareto dominant outcome. The non–binding preopening period also enhances coordination, but it sometimes fosters coordination on the risk–dominant, low liquidity, equilibrium. Indeed, the frequency of (S1, B1) matches is greater for the market with non–binding preopening (27%) than for the pure call auction (around 15%) or the market with binding pre–opening orders (3%).

4.3 Orders placed during the preopening period

First consider preopening orders placed when $\bar{q} = 9$, documented in Table 4, Panel A. The difference between the binding and the non–binding preopening periods is striking (the null that the two are equal is strongly rejected, with a Chi–square statistic of 118.06)

- When preopening orders are non binding, the vast majority (62%) is of type $A2$. As reported above, such preopening orders are inconsistent with the orders actually executed in the ensuing call auction, since 90% of the latter are of type $A1$. Thus, participants placing non–binding preopening orders often make non credible promises, to which they will not stick at the call market stage. This is consistent with Hypothesis 2, which raised the possibility that participants would place manipulative orders at time 0.

- In contrast, when preopening orders are binding, participants very rarely play $A2$ at time 0 when $\bar{q} = 9$. In the vast majority of the cases (80%), participants choose to place no order during the preopening and to wait until time 1 to place their orders. They realize that, when $\bar{q} = 9$, there is no way they could coordinate on $A2$ and commiting at time 0 can't help.

Now turn to the case where when $\bar{q} = 11$, which is documented in Table 4, Panel B. Here again the binding and non–binding preopenings give different results (and again a Chi square test rejects the null that the two are equal, with a high Chi–square statistic: 118.01.)

- When preopening orders are non binding, the pattern is apparently not very different from that observed when $\bar{q} = 9$. The proportion of orders of type $A2$ is higher (80% instead of 62%). But of course these orders are now credible.

- In contrast, when preopening orders are binding, the patterns observed when $\bar{q} = 11$ are strikingly different from those observed when $\bar{q} = 9$. In the latter case most participants chose to not participate in the preopening period, while in the former in the vast majority of cases (64%) orders of type $A2$ are placed in the preopening.

4.4 History dependence

Table 5 and Table 6 present the frequencies of different matches for the two sequences of $\bar{q}$ that occurred in the experiment. Table 5 documents the case where $\bar{q}$ was equal to 9 in the first 5 rounds, then went up to 11 for the next 5 rounds and finally reverted to 9 for the last 5 rounds. Table 6 documents the other case, where $\bar{q}$ was first equal to 11, then to 9 and finally to 11.

Panel A of Table 5 and Panel A of Table 6 present the frequencies observed during the first 5 rounds. For these rounds there is no variation in $\bar{q}$, so that agents play in a stationary environment. This enables one to observe the pure effect of the three market settings for the two values of $\bar{q}$. In line with our discussions above, we see that i) when $\bar{q} = 9$, $(S1, B1)$ prevails for all market structures (consistently with Hypothesis 1), ii) when $\bar{q} = 11$, the preopening period reduces the frequency of mismatches (consistently with Hypothesis 3), and iii) preplay communication enhances coordination on the Pareto dominant equilibrium only when preopening orders are binding (which contradicts to some extent Hypothesis 4 and stands in contrast with previous experimental results.) In these early rounds of the game, when the preopening is not binding and $\bar{q} = 9$, participants often announce $A2$ but then playing $A1$. This is in line with Aumann's argument. Participants announcing $A2$ at $t = 0$ hope their opponent will respond with $A2$ at $t = 1$. They prefer such a response whatever their intended action at $t = 1$, i.e., irrespective of whether they play $A2$ or $A1$ at $t = 1$, they are better off if their opponenty plays $A2$ at $t = 1$. And indeed, they often turn out playing $A1$ at $t = 1$, after announcing $A2$ at $t = 0$. Such behaviour is likely to ruin the credibility of nonbinding preopening announces.

Now consider Panel B, in Table 5 and Table 6, documenting what happens in the next 5 rounds of the game. When $\bar{q}$ goes dozn to, agents coordinate on the dominant strategy unique Nash equilibrium. When $\bar{q}$ moves up to 11, Panel B of Table 5 shows that the occurrence of $(S2, B2)$ is minimized for the market with a non–binding preopening. For this market only 25% of matches are $(S2, B2)$. This is below the corresponding frequencies for the pure call market (32%) and the market with binding preopening orders (85%). Why does such a pattern emerge? Remember that, when $\bar{q}$ was equal to 9 during the first five rounds, participants sent many non credible manipulative preopening orders announcing $S2$ or $B2$ and breached their promises during the call by playing $S1$ or $B1$. Observing such orders, participants learned to distrust preopening orders. Thus, even when $\bar{q}$ moved up to 11, they continued to hold pessimistic beliefs about the ability to coordinate on high liquidity and gains from trade. Hence they sticked to the risk dominant equilibrium $(S1, B1)$. Such “breach of trust” ruins the credibility of preplay communication. In contrast, when preopening orders are binding, breach of trust is ruled out. This facilitates coordination on the Pareto dominant equilibrium.

Finally, Panel C of Table 5 and Table 6 presents what happened during the five last rounds. As can be seen in Panel C of Table 6, when $\bar{q} = 11$, in the market with binding preopening orders coordination on the Pareto dominant equilibrium is very strong (90% of the matches are $(S2, B2)$). In contrast, the performance of the market with non–binding preopening orders is relatively poor, with only 50% of the matches of type $(S2, B2)$. Once again, this reflects that, during periods where $\bar{q}$ was equal to 9, players attempted to take advantage of their opponents by playing $A2$ during the preopening, and then $A1$ during the call. After such experiences, participants form pessimistic beliefs and often play the risk dominant strategy $A1$.

5 Conclusion

Our experiment offers the following policy implications. Market designers should not hope that purely non binding preopening orders will always foster strong coordination on high liquidity and high gains from trade equilibria. Non binding preopening or play communication mechanisms are fragile. In contexts where gains from trade are limited, traders are tempted to to use preplay communication in an opportunistic way and try to manipulate the market. This ruins the credibility of the preopening period and generates pessimistic beliefs and low gains from trade.

But market organizers can strive to design effective communication mechanisms to facilitate coordination. Admittedly, the fully binding preopening orders considered in the present paper are a rather coarse mechanism. In practice, market designers might find it more effective to rely on less simplistic methods. For example, in several markets (e.g. the German stock market XETRA), the actual time of the opening is random. Thus, preopening orders end up being firm orders with some probability, when the market opens before the order could be cancelled. Other methods are to constrain the ability of the traders to revise their orders. For example, in some markets, orders can be cancelled only if they are replaced with new orders providing more liquidity to the market. Or market designers can impose a fee on cancellations that take place during the preopening period. Further experimental studies could be useful to shed more light on the performance of these mechanisms.

References

Admati, Anat R., and Paul Pfleiderer, "A Theory of Intraday Patterns: Volume and Price Variability", *The Review of Financial Studies*, Vol. 1, No. 1 (Spring, 1988), pp. 3–40.

Aumann, Robert, "Nash Equilibria are Not Self-Enforcing, In Gabszewicz, J. J., j.-F. Richard, and L. A. Wolsey, eds., *Economic Decision-Making: Games, Econometrics and Optimisation.* Amsterdam: Elsevier, 1990, pp. 201–206.

Battalio, Raymond, Larry Samuelson, and John Huyck, "Optimization Incentives and Coordination Failures in Laboratory Stag Hunt Games", *Econometrica*, Vol. 69, No. 3, May 2001, pp. 749–764.

Biais, Bruno, Pierre Hillion, and Chester Spatt, "Price Discovery and Learning during the Preopening Period in the Paris Bourse", *The Journal of Political Economy*, Vol. 107, No. 6, Dec. 1999, pp. 1218–1248.

Blume, Andreas, and Andreas Ortmann, "The effects of costless pre-play communication: Experimental evidence from games with Pareto-ranked equilibria", *The Journal of Economic Theory*, Volume 132, Issue 1, January 2007, Pages 274–290.

Charness, Gary, "Self-Serving Cheap Talk: A Test of Aumann's Conjecture", *Games and Economic Behavior*, Vol. 33, No. 2, November 2000, pp. 177–194.

Clark, Kay and Sefton, 2001, *International Journal of Game Theory.*

Cooper, Russell, Douglas V. DeJong, Robert Forsythe, and Thomas W. Ross, "Communication in Coordination Games", *The Quarterly Journal of Economics*, Vol. 107, 1992, pp. 739–773.

Crawford, Vincent, "A Survey of Experiments on Communication via Cheap Talk", *Journal of Economic Theory*, Vol. 78, 1998, pp. 286–298.

Davies, Ryan J., "The Toronto Stock Exchange preopening session", *Journal of Financial Markets*, Vol. 6, No. 4, pp. 491–516.

Deutsche Borse, 2004, "Market model: equities," available on http://deutsche-boerse.com.

Dia, Magueye, and Sébastien Pouget, "Liquidity Formation and Preopening Periods in Financial Markets", working paper, 2005.

Dow, James, "Is Liquidity Self-Fulfilling?", *Journal of Business*, Vol. 77, No. 4, 2004, pp. 895–908.

Farrell, Joseph, "Cheap Talk, Coordination and Entry", *RAND Journal of Economics*, Vol. 18, 1987, pp. 34–39.

Farrell, Joseph, "Communication, Coordination and Nash Equilibrium", *Economics Letters*, Vol. 27, 1988, pp. 209–214.

Farrell, Joseph, and Matthew Rabin, "Cheap Talk", *Journal of Economic Perspectives*, Vol. 10, No. 3, Summer 1996, pp. 103–118.

Fischbacher, Urs, "z-Tree: Zurich Toolbox for Ready-made Economic Experiments", forthcoming *Experimental Economics*.

Forsythe, Robert, Russell Lundholm, and Thomas Rietz, "Cheap Talk, Fraud, and Adverse Selection in Financial Markets: Some Experimental Evidence", *The Review of Financial Studies*, Vol. 12, No. 3, Fall, 1999, pp. 481–518.

Harsanyi, John C., and Reinhard Selten, *A General Theory of Equilibrium Selection in Games*, MIT Press, Cambridge, 1988.

Pagano, Marco, "Trading Volume and Asset Liquidity", *The Quarterly Journal of Economics*, Vol. 104, No. 2, May 1989, pp. 255–274.

Schmidt, David, Robert Shupp, James M. Walker, and Elinor Ostrom, "Playing safe in coordination games: the roles of risk dominance, payoff dominance, and history of play", *Games and Economic Behavior*, Vol. 42, 2003, pp. 281–299.

Appendix: Instructions to participants, in the pure call market (without a preopening.)

In this market you can place buy or sell limit orders in a uniform price call auction. If you play astutely you can make some good money. Buyers start with no share. Each share they buy is worth 4 points for them. Sellers start each trading round with a new endowment of 9 or 11 shares. For them each share is worth 0 point. All traders know how many shares the seller has. There is no link between periods. Cash or shares are not carried over from one period to the next. At the end of each round we compute profits. For buyers this is: number shares bought * (4 – price). For sellers this is: number of shares sold * price. At the end of the experiment you receive in € your profit divided by 15. Only profits matter (as opposed to total wealth) and buyers are assumed to have enough cash to pay for the shares they want to acquire.

At each trading round, each buyer is randomly & anonymously matched with one seller. Prices & trades are set in a uniform price call auction, crossing the buy & sell orders. For each pair, the supply curve of seller & the demand function of the buyer are crossed in a uniform price call auction, setting the price & volume for this round & this pair of traders.

At each round, each seller chooses between 3 schedules of limit orders:

- S0: Don't sell at any price,
- S1: One order to sell 8 shares if price not below 2; another order to sell X additional shares if price not below 3,
- S2: One order to sell 8 shares if price not below 1; another order to sell additional X shares if price not below 2,

and each buyer chooses between 3 schedules of limit orders.

- B0: Don't want to buy at any price,
- B1: One limit order to buy 8 shares if the price is not above 2; another limit order to buy X additional shares if the price is not above 1,
- B2: One limit order to buy 8 shares if the price is not above 3; another limit order to buy X additional shares if the price is not above 2.

When the maximum trade is 11, then X=3. When the maximum trade is 9, X=1.

When the maximum trade is 11 shares, the possible trades and profits are the following:

- B0 or S0: no trade, profits =0.
- B2 & S2: price = 2, volume = 11. Profit of buyer = profit of seller = 22.

- B1 & S1: price = 2, volume = 8. Profit of buyer = profit of seller = 16.
- B1 & S2: price = 1.5, volume = 8. Profit of buyer: 20, profit of seller = 12.
- B2 & S1: price = 2.5, volume = 8. Profit of buyer: 12, profit of seller = 20.

When the maximum trade is 9 shares, the possible trades and profits are the following:

- B0 or S0: no trade, profits =0.
- B2 & S2: price = 2, volume = 9. Profit of buyer = profit of seller = 18.
- B1 & S1: price = 2, volume = 8. Profit of buyer = profit of seller = 16.
- B1 & S2: price = 1.5, volume = 8. Profit of buyer: 20, profit of seller = 12.
- B2 & S1: price = 2.5, volume = 8. Profit of buyer: 12, profit of seller = 20.

We will start with 6 warm up rounds, so that you can familiarize with the game (no points will be earned during these 6 rounds). During these 6 rounds you'll sometimes be a buyer and sometimes a seller. Then, there will be 15 trading rounds, during which you'll earn €. The number of € you will earn will be your total accumulated profit/15. At the beginning of the 15 rounds, you will be assigned a role: buyer or seller, which you'll keep throughout the game. In some rounds the maximum trade will be 9 shares, in others max number of shares traded will be 11. At each round, before players choose orders, the maximum trade will be announced to all.

Table 1: Cohorts and participants in the experiment

Cohort number	Treatment	Number of participants
1	Without preopening	12
2	Nonbinding preopening	12
3	Nonbinding preopening	12
4	Without preopening	8
5	Nonbinding preopening	8
6	Binding preopening	8
7	Binding preopening	8

Table 2: Executed Orders

Table 2, Panel A: Executed orders when $\bar{q} = 9$

Order type	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
A0	1%	0	1%
A1	82%	95%	88%
A2	17%	5%	11%

Table 2, Panel B: Executed orders when $\bar{q} = 11$

Order type	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
A0	0	0	0
A1	37%	41%	9%
A2	63%	59%	91%

Table 3: Matches

Table 3, Panel A: Matches when $\bar{q} = 9$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	3%	0	5%
B2S1 or B1S2	30%	11%	12%
B1S1	67%	89%	82%

Table 3, Panel B: Matches when $\bar{q} = 11$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	40%	46%	85%
B2S1 or B1S2	45%	27%	12%
B1S1	15%	27%	3%

Table 4: Preopening Orders

Table 4, Panel A: Preopening orders when $\bar{q} = 9$

Order type	Call Auction following	Call Auction following
	Non–Binding Preopening	Binding Preopening
A0	10%	80%
A1	28%	15%
A2	62%	5%

Table 4, Panel B: Preopening orders when $\bar{q} = 11$

Order type	Call Auction following	Call Auction following
	Non–Binding Preopening	Binding Preopening
A0	9%	34%
A1	10%	2%
A2	80%	64%

Table 5: Matches for cohorts which played first with $\bar{q} = 9$, then with $\bar{q} = 11$ & finally with $\bar{q} = 9$.

Table 5, Panel A: Matches during the first 5 rounds, when $\bar{q} = 9$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	4%	0	15%
B2S1 or B1S2	36%	10%	20%
B1S1	60%	90%	60%

Table 5, Panel B: Matches during the middle 5 rounds, when $\bar{q} = 11$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	32%	25%	85%
B2S1 or B1S2	52%	32.5%	5%
B1S1	16%	42.5%	10%

Table 5, Panel C: Matches during the last 5 rounds, when $\bar{q} = 9$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	0%	0	0%
B2S1 or B1S2	28%	2.5%	5%
B1S1	68%	97.5%	95%

Table 6: Matches for cohorts which played first with $\bar{q} = 11$, then with $\bar{q} = 9$ & finally with $\bar{q} = 11$.

Table 6, Panel A: Matches during the first 5 rounds, when $\bar{q} = 11$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	60%	62.5%	80%
B2S1 or B1S2	32%	17.5%	20%
B1S1	8%	20%	0

Table 6, Panel B: Matches during the middle 5 rounds, when $\bar{q} = 9$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	4%	0	0%
B2S1 or B1S2	24%	20%	10%
B1S1	72%	80%	90%

Table 6, Panel C: Matches during the last 5 rounds, when $\bar{q} = 11$

Match	Pure Call Auction	Call Auction following	Call Auction following
	Without preopening	Non–Binding Preopening	Binding Preopening
B2S2	28%	50%	90%
B2S1 or B1S2	52%	30%	10%
B1S1	20%	20%	0