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Equilibrium Discovery and Preopening Mechanisms in an Experimental Market

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We experimentally analyze how to design preopening mechanisms facilitating coordination on high equilibrium liquidity and gains from trade. We allow a call auction to be preceded by a preopening or not, preopening orders to be binding or not, and the opening time to be deterministic or random. When the preopening is nonbinding, traders place manipulative orders, reducing the credibility of preplay communication. Random market opening deters manipulation, but also hinders communication by making it costly. Gains from trade are maximized when preopening orders are binding. This enables some traders to place early limit orders, attracting further liquidity.

Data, as supplemental material, are available at http://dx.doi.org/10.1287/mnsc.2013.1787.

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1. Introduction

At the opening of the market, there is large uncertainty about supply, demand, and valuations. Market openings can, therefore, be plagued by informational problems and coordination failures. Abstracting from the former, we focus on the latter. Liquidity externalities generate equilibrium multiplicity (see, e.g., the theoretical analyses of Pagano 1989, Admati and Pfleiderer 1988, and Dow 2004, and the empirical investigation of Ellul et al. 2005). When they anticipate high market liquidity, traders participate actively, so that the market ends up being liquid, confirming the initial expectation. Pessimistic initial expectations, on the contrary, lead to low equilibrium liquidity. The preopening period offers a preplay communication mechanism, which could facilitate coordination on equilibrium high liquidity.

Several bourses start with a preopening period during which investors can place orders and indicative prices are set and disseminated. Euronext and Xetra, as well as the Brazilian and the Australian stock exchanges, for example, feature a preopening period whereby traders can submit or cancel limit orders and tentative prices are set. Biais et al. (1999) document price discovery during the Paris Bourse preopening. Cao et al. (2000) show that NASDAQ market makers communicate via nonfirm quotes posted during the preopening period. The findings of Barclay and Hendershott (2008) suggest that on NASDAQ the preopening can contribute to the efficiency of the opening price provided that a critical threshold of activity is reached.

However, to the extent that preopening orders can be canceled, traders can use them to manipulate the market. For example, Davies (2003) studies manipulative preopening trades on the Toronto Stock Exchange. Manipulative strategies could prevent the preopening period from facilitating coordination. Market designers have introduced certain features to deter such manipulation. We focus on the two main ones:

- In a number of computerized stock exchanges, the exact time of the opening is random. This is, for example, the case on the Frankfurt, Australian, and Irish Stock Exchanges.[1]

[1] For example, in the description of the Xetra market model, "The call phase has a random end after a minimum period in order to avoid price manipulation" (Deutsche Börse 2009, p. 23). Beltran-Lopez and Frey (2006) analyze opening auctions on the Xetra system operating at the Deutsche Börse. The preopening period in the Australian Stock Exchange is studied by Comerton-Forde and Rydge (2006) and Kuk et al. (2009). Kelly (2008) studies the preopening period on the Irish Stock Exchange.

• Other exchanges impose restrictions on the cancellation of preopening orders. For example, on the Tel Aviv Stock Exchange, starting at a specific time of the preopening period, orders can no longer be cancelled if they affect the tentative opening price (for an empirical analysis of the preopening on the Tel Aviv Stock Exchange, see Kalay et al. 2004, Hauser et al. 2009). Similarly, on NASDAQ, orders for the 4:00 P.M. closing call cannot be canceled after 3:50 P.M. (see NASDAQ Stock Market 2007).

The variety of existing market designs as well as the potential for coordination failures and manipulation raise the policy question of how the market opening mechanism should be designed. Without natural experiments, it is hard to disentangle the consequences of different market features using field data. Therefore, to shed light on this policy issue, we adopt a laboratory experimental approach. The experiment is designed to focus on situations where discovery of liquidity could be jeopardized by coordination failures and variability in market conditions. In our controlled experimental setting, equilibrium liquidity and gains from trade are precisely identified in the four opening market mechanisms we compare:[2]

• A pure one-shot call auction, with no preopening period.

• A call market preceded by a nonbinding preopening period, during which traders have the option to place orders that they can cancel or modify before the opening.

• A call market preceded by a binding preopening period, during which traders have the option to place orders that they cannot later modify or cancel.

• A market mechanism with a random opening time.[3]

It is not clear, a priori, which of these structures should maximize liquidity and gains from trade. Traders may need a richer communication mechanism than a simple call auction to achieve equilibrium discovery. On the other hand, the effectiveness of the nonbinding preopening could be undermined by manipulation. Furthermore, the market with a binding preopening period would prove ineffective if agents were reluctant to commit to binding orders at early stages of the opening process. Finally, randomness could help curb manipulative attempts, but could also introduce additional uncertainty, hindering coordination.

To study these issues, we run an experimental market game. This enables us to observe precisely trading in a controlled environment, examine how it is affected by market design, compare actual behavior to that predicted by theory, and measure realized gains from trade. We consider a simple trading game where, depending on parameter values, there are one or two pure-strategy Nash equilibria. In the first case, the unique equilibrium features low liquidity and low gains from trade. In the second case, one of the pure-strategy equilibria involves low liquidity and low gains from trade, whereas the other involves high liquidity and high gains from trade. The former equilibrium is risk dominant, whereas the latter is Pareto dominant. In that context, coordinating on equilibrium is likely to be difficult (see, e.g., Van Huyck et al. 1990 and Battalio et al. 2001, who document experimentally the occurrence of coordination failures). The set of Nash equilibrium allocations is the same in all the market structures we consider. We thus offer an experimental investigation of which market design best facilitates coordination on equilibria with high gains from trade and liquidity.

In practice, there is variation in market conditions. Phases with high potential gains from trade and liquidity alternate with phases where gains from trade are more limited.[4] To examine the effect of such variations in market conditions, we vary the parameters of the market game played by the participants. Some traders first start in a market where gains from trade are potentially high, but there are two equilibria, one with larger gains from trade than the other. Then these participants trade in a market with a unique equilibrium and low gains from trade. Other participants experience the opposite sequence. Thus, our experiment offers an opportunity to study how participants exposed to different histories form different beliefs and realize different outcomes.[5]

Our experiment was run in the Toulouse University laboratory, with 204 master students, who each played 15 replications of the game and received financial rewards proportional to their gains. Interactions were computerized and anonymous, and participants

[2] Our preopening periods are in line with those theoretically analyzed by Vives (1995) and Calcagno and Lovo (2010). Vives (1995) assumes that, during the preopening period, the outstanding orders are executed with a probability that increases over time. He then studies the informational efficiency of preopening prices. Calcagno and Lovo (2010) consider that preopening orders are not sure to reach the market when submitted. They then study the equilibrium selection that operates due to the imperfection in the communication technology.

[3] In practice, communication failures may prevent late order placements or cancellations from reaching the market before the opening call. To the extent that such events are random, they have similar effects on traders' gains as our random opening.

[4] Dewan and Mendelson (2001) offer a model in which liquidity is endogenous and varies over time.

[5] Our analysis is in line with Schmidt et al. (2003), who find that the observed history of play affects subjects' behavior. However, they consider only coordination games, whereas we also consider prisoners' dilemmas. Furthermore, Schmidt et al. (2003) do not consider preplay communication.

were randomly matched at each period to rule out repeated game effects.

Our main experimental results are the following. When there is a unique equilibrium with low liquidity, in all market structures most participants play equilibrium strategies. In contrast, when there are two equilibria (one with low liquidity, the other with high liquidity), outcomes vary markedly with the features of the opening mechanism. The market design with the highest performance in terms of realized gains from trade and liquidity is that with binding preopening orders.[6] Different market designs achieve various outcomes because they allow for different communication strategies, which lead traders to form different beliefs about the strategy of their opponents.

First, compare the market with a nonbinding preopening period to the one-shot call auction. The latter rules out preplay communication, which the former enables. However, when there is a unique equilibrium with low gains from trade, traders tend to place generous orders during the nonbinding phase of the market, and then place opportunistic orders in the opening call auction. Such misleading preopening orders undermine the credibility of the preopening phase. Even when a high-liquidity equilibrium exists, the market with a nonbinding preopening period does not outperform the one-shot call auction. Our experimental result that nonbinding preopening periods can be manipulated is in line with the empirical evidence offered by Kuk et al. (2009) and by Kelly (2008). On the Australian Stock Exchange, Kuk et al. (2009) document the submission of aggressive preopening orders that are cancelled before the opening. Kelly (2008) compares the transparent preopening of the London Stock Exchange to its nontransparent counterpart on the Irish Stock Exchange. Greater volatility on the London Stock Exchange is interpreted as reflecting manipulation during transparent nonbinding preopening sessions.

Second, consider the market with a random opening time. When the probability of early opening is large, traders have little opportunity to engage in manipulations or conduct preplay communication. They realize that their initial orders are highly likely to be executed early. They fear such early execution would be very costly for them if they engaged in manipulations or followed a cooperative strategy but their counterparty offered limited liquidity. Hence they tend to play the risk-dominant strategy equilibrium. This is especially so when participants have been initially exposed to the market with a unique, low-liquidity equilibrium. In that case participants develop pessimistic beliefs, and low gains from trade are realized. When the probability of early opening is lower, however, preplay communication is more manageable. Thus, we find that higher gains are realized. This result echoes the findings of Hauser et al. (2009), suggesting that the introduction of a randomized opening time in the Tel Aviv Stock Exchange enhanced market liquidity.

Third, consider the market with binding preopening orders. This market design rules out manipulative orders and at the same time enables cooperative traders to express their intentions. As a result, high gains from trade are achieved. This good result is robust to bad initial conditions, with low gains from trade. With binding preopening orders, participants do not have the opportunity to make false promises and then breach them. Thus, they cannot lose trust in the possibility to coordinate on win–win situations when that possibility arises. From a policy perspective, our findings suggest that restrictions on order cancellation, such as those imposed on the Tel Aviv Stock Exchange or the NASDAQ, might be useful.

With respect to the previous experimental economics literature on preplay communication, our contribution is twofold:

- On one hand, our results suggest that pure cheap-talk preplay communication mechanisms can be fragile.[7] In contrast with previous literature, we consider the case where participants face varying parameter constellations, some for which coordinating on Pareto-dominant outcomes is feasible, others in which such win–win situations are not equilibrium outcomes.[8] We show that the latter situation generates bitter experiences, which then preclude coordination via nonbinding preplay communication.
- On the other hand, we offer new experimental evidence on the performance of various market designs, which to the best of our knowledge had not been compared so far. We show that a preopening period with binding orders outperforms both markets with random opening times and markets with nonbinding preopenings.

The next section describes the trading games we consider and their equilibria. Section 3 presents the experimental design. Section 4 presents the results. Section 5 concludes. The instructions given to participants are in the appendix.

[6] Our experimental result that the pure call auction market does not lead to high trading volumes is in line with the empirical finding of Ellul et al. (2005). They focus on the London Stock Exchange that opens and closes with a call auction and show that these call auctions suffer from a high rate of market failure.

[7] For the case with a unique, low gains from trade equilibrium, our results are in line with those of Charness (2000) that cooperation is announced 79% of the time but played only 10% of the time.

[8] Cooper et al. (1992), Charness (2000), Blume and Ortmann (2007), Valley et al. (2002), and Forsythe et al. (1999) consider experimental designs where the parameters of the game are held constant. They find that nonbinding preplay communication fosters cooperation.

2. Market Structures and Equilibria

Uniform-price call auctions—often preceded by a preopening period—are commonly used to set opening prices in stock exchanges (see, e.g., Euronext and Xetra). In this section, we present a stylized trading game designed to capture some important features of such markets. For simplicity, the players know the structure and the parameters of the game; that is, we consider a complete information setting.

There is one buyer and one seller who differ in terms of their private valuation of the asset.[9] Our focus on a small number of traders differs from that of other experimental finance studies, such as, e.g., Bossaerts and Plott (2004). This difference in approach reflects a difference in focus. Bossaerts and Plott (2004) investigate asset-pricing issues, asking if the population of investors will conform to the aggregate equilibrium implications of the CAPM. In this context, a competitive equilibrium approach, with a large number of agents, is warranted. In contrast, we investigate market microstructure issues, examining how the strategic behavior of traders is influenced by the market mechanism, i.e., the rules of the game. In that context, a game-theoretic approach, with a small number of agents, is appropriate. Admittedly, considering only two players is quite a simplification. We resort to this feature to make sure the game is simple enough so that traders (and experimenters) can figure out the equilibrium. Considering a somewhat larger number of agents would not qualitatively alter the economic mechanism emphasized in our study.[10] In particular, each trader would still face a tradeoff between the benefits of offering high liquidity (which yields large gains from trade if the other side of the market also decides to offer high liquidity), and those of offering low liquidity (which minimizes adverse price impact when counterparties supply low liquidity). In this context there would still be strategic complementarities, equilibrium multiplicity, and scope for coordination via a preopening period.

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 for $\bar{q}$ units are $(v - c)\bar{q} = 4\bar{q}$. Heterogeneous private values capture in a simple way that other considerations than expected cash flows affect the willingness of investors to hold assets. For example, regulation can make it costly or attractive for certain investors, such as insurance companies, pension funds, or banks to hold certain asset classes.[11] Differences in tax regimes can also induce differences in private values.

2.1. The Call Auction Without Preopening

The pure call auction without preopening period is a simple one-shot game. The buyer and the seller are matched. They simultaneously post schedules of limit orders, and thus demand and supply curves. 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: all the orders submitted by market participants (in our case, in each market, there will be one buyer and one seller only) are executed at the same price. If more than one price maximizes volume, then the transaction price is the arithmetic average of the candidate prices.

In our experimental market, for simplicity, each trader has the choice between two schedules of limit orders only. The buyer can opt for schedule $B1$, with 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, the buyer can opt for $B2$, which 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. As an illustration, the supply and demand curves corresponding to these schedules of limit orders for $\bar{q} = 11$ 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.

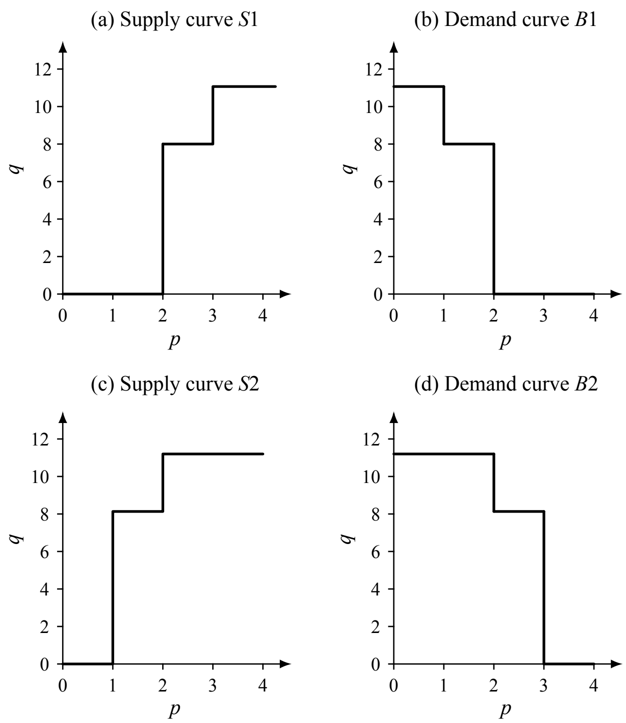
Schedule $B2$ involves limit orders offering to buy more than schedule $B1$. In that sense, $B2$ offers more liquidity than $B1$. Similarly, $S2$ offers more liquidity than $S1$. If both traders offer high liquidity ($B2$ and $S2$), the market clearing price is 2 and the corresponding volume is $\bar{q}$. If both traders offer low liquidity ($B1$ and $S1$), the price is still 2, but trading volume is lower, and equal to 8. If the buyer offers high liquidity, but not the seller ($B2$ and $S1$) then trading volume is 8 and the price is pushed up to 2.5.

[9] Valley et al. (2002) also consider preplay communication in markets with one buyer and one seller. In their setting, traders privately observe their valuations and set quoted prices. However, we consider how play varies according to history and equilibria, and we compare a larger set of market mechanisms.

[10] In an experimental design where the number of participants varied between 6 and 14, Bossaerts et al. (2002) document market illiquidity and study its consequences for portfolio choice. Based on field data from NASDAQ, Biais et al. (2010) document that liquidity issues can arise with a rather large number of traders.

[11] For example, some institutional investors can only hold investment-grade bonds, which they will value at a premium relative to other investors (see Chen et al. 2011).

Figure 1 **Supply and Demand Curves When $\bar{q} = 11$**



Notes. The four panels show the supply or demand curve corresponding to schedules of limit order $S1$, $B1$, $S2$, and $B2$, respectively. Price is denoted by p, and quantity by q.

If the seller offers high liquidity, but not the buyer ($B1$ and $S2$), then again trading volume is 8, but the price is pushed down to 1.5. Thus, each trader faces a trade-off: He can choose to offer high liquidity, potentially generating large trading volume, but at the risk of an adverse price move. This risk depends on how much liquidity the other trader will supply. Hence, it can be interpreted as liquidity risk.

Discarding $S0$ and $B0$, which are weakly dominated, the situation faced by traders in the pure call auction can be represented as the following 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.[12]

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

In the off-diagonal cells, the trader offering low liquidity earns more than his or her counterparty. When $\bar{q} > 8$, the pair of actions that maximizes the total gains from trade is $(S2, B2)$. Will this allocation arise in equilibrium? For the pure call auction, the answer is in the next proposition (whose proof is obvious and omitted).

Proposition 1. *Consider the pure call auction. No trade, i.e., $(S0, B0)$, is a Nash equilibrium, but it involves weakly dominated strategies. If $\bar{q} < 10$, then $(S1, B1)$ is the only undominated Nash equilibrium. If $\bar{q} \geq 10$, there are (on top of the no-trade equilibrium) two pure-strategy equilibria: $(S1, B1)$ and $(S2, B2)$, as well as a mixed-strategy equilibrium whereby each trader selects the high-liquidity schedule, $S2$ or $B2$, with probability $2/(\bar{q} - 8)$.*

In our experiment we want to include both the prisoner's dilemma situation, where the unique Nash equilibrium is $(S1, B1)$, and the cooperative situation, where both $(S2, B2)$ and $(S1, B1)$ are equilibria. In the cooperative situation, we further want to have a conflict between risk dominance and Pareto dominance. Thus, we consider two possible parameter values: $\bar{q} = 9$ and $\bar{q} = 11$. In the latter case, $(S2, B2)$ is Pareto dominant, whereas $(S1, B1)$ is risk dominant.[13]

2.2. The Call Auction With a Preopening Period

Whereas some stock markets operate without a formal preopening period, in others there is a preopening period during which traders can enter limit orders and indicative prices are set and disseminated. This mechanism can be useful if, by observing the indicative prices, investors can progressively coordinate on an equilibrium with mutual gains from trade. It is not clear, however, whether the preopening period can generate useful and reliable information. After all, if traders can costlessly place and cancel orders before trading actually takes place, they 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 cancelations, imposing costs for traders canceling orders, or opening the market at a random point in time. To compare these market features, we consider three types of preopening in our simple setup.

2.2.1. Three Preopening Mechanisms. The first preopening mechanism we consider is a pure cheap talk game involving nonbinding orders. At time 0, the buyer and the seller can enter orders $B0$, $B1$, or $B2$

[12] As shown in the appendix, subjects had access to the complete game payoffs. This is standard practice in many experiments (see, e.g., Cooper et al. 1989, McKelvey and Palfrey 1992).

[13] For larger values of $\bar{q}$, the Pareto-dominant equilibrium would also be risk dominant. The intuition for risk dominance is the following. 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 $(1/2)16 + (1/2)20 = 18$, whereas his utility if he plays $B2$ is $(1/2)12 + (1/2)22 = 17$. Hence, the buyer prefers to play $B1$.

and $S0$, $S1$, or $S2$, respectively. These tentative 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 canceled and the traders have a new opportunity to place orders. These time 1 orders are those that are used to set the opening prices at which actual trades occur.

The second preopening mechanism involves binding orders. At time $t=0$, the buyer and the seller can choose to place limit orders $B1$ or $B2$ and $S1$ or $S2$, respectively. Alternatively, they can choose to place no order (denoted by $B0$ and $S0$) and wait for time $t=1$. The outcome of this preopening round is observed by all. The difference with the nonbinding preopening is that when traders have placed orders $B1$, $S1$, $B2$, or $S2$ at $t=0$, they cannot cancel these initial orders and place new ones. On the other hand, traders who have not placed orders at $t=0$ have the opportunity to place orders at $t=1$.

The third preopening mechanism involves a random opening time. At time 0, the buyer and the seller can enter orders $B0$, $B1$, or $B2$ and $S0$, $S1$, or $S2$, respectively. With probability α, the market opens immediately after these orders have been placed. With probability $1-\alpha$, there is a second stage in the opening process: time 0 orders are cancelled, traders have a new opportunity to enter orders $B0$, $B1$, or $B2$ and $S0$, $S1$, or $S2$ and the market opens at time 1. We consider two cases, one in which $\alpha = 1/4$, the other in which $\alpha = 3/4$.

2.2.2. Nonbinding Preopening. When preopening orders are nonbinding, they can be discounted as pure noise by the players. In that case, actions at $t=0$ are irrelevant, and equilibria at $t=1$ are the same as in the market without preopening. Also, when $\bar{q}=9$, $S1$ and $B1$ at time 1 are dominant strategies, and will be played irrespective of preopening orders. On the other hand, when $\bar{q}=11$, players could use preopening orders as communication devices, which would induce a link between orders placed at $t=0$ and orders placed at $t=1$. For example, the agents could agree that, if they played $B2$ and $S2$ at $t=0$, then they should also play $B2$ and $S2$ at $t=1$.[14] Nevertheless, in the market with a nonbinding preopening, the same equilibrium outcomes can be observed at $t=1$ as without preopening. Thus, we can state the following proposition:

[14] A more complex scheme would be for the agents to use a jointly controlled lottery, as in Aumann et al. (1968). For example, the players could mix between $B1$ and $B2$ (or $S1$ and $S2$) at $t=0$ with equal probability. Then, at $t=1$, they would coordinate on $(S2, B2)$ if they played on the diagonal, i.e., $(S1, B1)$ or $(S2, B2)$, at $t=0$. And they would coordinate on $(S1, B1)$ if they played off the diagonal, i.e., $(S1, B2)$ or $(S2, B1)$, at $t=0$.

Proposition 2. *Outcomes* $(S0, B0)$, $(S2, B2)$, $(S1, B1)$, $(S1, B2)$, *and* $(S2, B1)$ *at* $t=1$ *are equilibrium outcomes in the call market preceded by a nonbinding preopening when* $\bar{q}=11$.

2.2.3. Random Opening. Next, consider the random opening mechanism. Again, when $\bar{q}=9$, there are only two equilibria: $(S0, B0)$ and $(S1, B1)$.

When $\bar{q}=11$, at time 1, if the market has not opened yet, all previous orders are cancelled and buyers must choose between $B0$, $B1$, and $B2$, whereas sellers choose between $S0$, $S1$, and $S2$. The situation is very similar to that prevailing with a nonbinding preopening. Orders placed at time 0 can be ignored or considered as communication devices. In particular, if orders placed at time 0 are ignored, we have the same equilibrium outcomes as in the pure call market.

Now turn to the time 0 orders when $\bar{q}=11$. If it is expected that time 0 orders will be ignored at time 1, then participants at time 0 play exactly as in the pure call market, again as in Proposition 1. If, in contrast, time 0 orders are understood as signals of time 1 orders, traders can use the first stage to coordinate, e.g., on the high-liquidity equilibrium. In that case, they will play $B2$ or $S2$ at time 0. Thus, overall, in the market with a random opening, $(S0, B0)$, $(S2, B2)$, $(S1, B1)$, $(S1, B2)$, and $(S2, B1)$ are equilibrium outcomes at time 0 and time 1.

2.2.4. Binding Preopening. Finally, turn to the case where preopening orders are binding. As in the previous market structures, when $\bar{q}=9$, there are only two equilibria: $(S0, B0)$ and $(S1, B1)$, and it does not matter whether agents place their orders at time 0 or at time 1. When $\bar{q}=11$, however, things can be different.

To analyze this case, we focus on subgame-perfect Nash equilibria. Thus, we rule out actions that are strictly dominated at certain nodes of the game. To do this, we first consider the case where, at time 0, the buyer played $B1$ and the seller chose to wait (i.e., played $S0$). Then, playing $S2$ or $S0$ at time 1 would be strictly dominated by the play of $S1$. Second, we turn to the case where, at time 0, the buyer played $B2$ and the seller chose to wait. Then, the play of $S1$ or $S0$ at time 1 is strictly dominated by $S2$. Symmetric arguments apply when the buyer chose to wait while the seller played either $S1$ or $S2$ at time 0. Thus, we can state the following lemma:

Lemma 1. *When* $\bar{q}=11$ *in the market with a binding preopening, the set of choices for the seller that are not strictly dominated is as follows*:

- *Play* $S1$ *at* $t=0$.
- *Play* $S2$ *at* $t=0$.
- *Wait at* $t=0$ *and then respond* $S1$ *if* $B1$ *or* $B0$ *was played at time* 0, *and* $S2$ *if* $B2$ *was played at time* 0. *Denote this by* Σ_1^S.

• *Wait at $t = 0$ and then respond S1 if B1 was played at time 0, and S2 if B2 or B0 was played at time 0. Denote this by Σ_2^S.*

Although the lemma pins down the set of undominated strategies for the seller, similarly the set of choices that are not strictly dominated for the buyer is $B1$ or $B2$ at time 0 and Σ_1^B or Σ_2^B. Note also that the lemma implies that the inefficient no-trade equilibrium is not subgame perfect. Thus, to analyze the subgame-perfect equilibria in the market with a binding preopening, one can focus on the following normal form game:

	$S1$	$S2$	Σ_1^S	Σ_2^S
$B1$	(16, 16)	(20, 12)	(16, 16)	(16, 16)
$B2$	(12, 20)	(22, 22)	(22, 22)	(22, 22)
Σ_1^B	(16, 16)	(22, 22)	(16, 16)	(20, 12)
Σ_2^B	(16, 16)	(22, 22)	(12, 20)	(22, 22)

Inspecting this normal form, one can see that the game admits seven subgame-perfect pure Nash equilibria, as stated in the following proposition:

Proposition 3. *When $\bar{q} = 11$ in the market with a binding preopening, there are seven subgame-perfect pure Nash equilibria:*

- *$(S1, B1)$ at $t = 0$.*
- *$(S2, B2)$ at $t = 0$.*
- *$S2$ at $t = 0$ and Σ_1^B.*
- *$S2$ at $t = 0$ and Σ_2^B.*
- *$B2$ at $t = 0$ and Σ_1^S.*
- *$B2$ at $t = 0$ and Σ_2^S.*
- *(Σ_2^S, Σ_2^B).*

The mixed-strategy equilibria of the game are stated in the next proposition.

Proposition 4. *When $\bar{q} = 11$ in the market with a binding preopening, there are two mixed-strategies subgame-perfect Nash equilibria*

• *The buyer mixes between B1 at $t = 1$ and Σ_1^B, whereas the seller mixes between S1 at $t = 1$ and Σ_1^S.*

• *The buyer mixes between B2 at $t = 1$ and Σ_2^B, whereas the seller mixes between S2 at $t = 1$ and Σ_2^S.*

Note that, in contrast with the previous market structures, mixing between $B1$ and $B2$ or $S1$ and $S2$ at $t = 0$ or $t = 1$ is not an equilibrium. The intuition is the following. Could the buyer mix between $B1$ and $B2$ at $t = 0$? In that case, the seller would be strictly better off playing $S0$ at $t = 0$ and then, at $t = 1$, playing his best response to the realized action of the buyer. However, anticipating that the seller would wait, the buyer finds it suboptimal to mix at $t = 0$. Also, mixing between $B1$ and $B2$ at $t = 1$ cannot arise in equilibrium. If the buyer plans to mix between $B1$ and $B2$ at time 1, then he waits at time 0. Anticipating this, the seller is better off playing $S2$ at time 0. Observing that decision, the buyer then finds it suboptimal to mix at time 1.

To further sharpen our analysis of the equilibria of this game, we rely on the notion of trembling hand perfection (Selten 1975). With a pure call auction or with a nonbinding preopening, that concept does not rule out any subgame-perfect Nash equilibrium. However, the market with a binding preopening has a sequential flavor that gives bite to the notion of trembling hand perfection. First, note that playing $B1$ (respectively, $S1$) at time 0 is weakly dominated by playing Σ_1^B (respectively, Σ_1^S). Thus, trembling hand perfection rules out the equilibria involving the play of $S1$ or $B1$ at time 0. Intuitively, if there is a small chance that the seller trembles to $S2$, then the buyer is better off playing Σ_1^B than $B1$. This leads to our next proposition.

Proposition 5. *When $\bar{q} = 11$ in the market with a binding preopening, the only trembling hand perfect equilibrium outcome is $(S2, B2)$.*

2.3. Concluding Remarks on the Implications from Theory

There are similarities between the four market structures we consider. In all four markets, Nash equilibrium multiplicity arises when $\bar{q} = 11$, giving rise to high-liquidity and low-liquidity equilibria. In this context, it is an open question whether participants will be able to coordinate on equilibria with high gains from trade, and which market features will best promote coordination.

The market with binding preopening orders, however, has distinct strategic properties. In this market structure, when $\bar{q} = 11$, there is a unique trembling hand perfect equilibrium outcome, $(S2, B2)$. This contrasts with the other market structures where both $(S2, B2)$ and $(S1, B1)$ are equilibrium outcomes, even when one restricts attention to trembling hand perfect equilibria.

3. Experimental Design

The experiment was conducted at the Toulouse University laboratory and programmed with the software *z*-Tree (Fischbacher 2007). The participants were seated in front of computers separated by dividers and we enforced a ban on verbal communication. The experiment involved 204 students from three different master in finance programs at Toulouse University. There were 16 cohorts. The number of participants per cohort varied between 8 and 20. 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. This procedure was orally announced to all 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. Relying on anonymous computerized interaction with a prespecified set of messages, we avoid the confounding effects associated with face-to-face interaction noted by Roth (1995).

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 were informed of the actions of their opponent. 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 behavior, we exposed participants to variations in $\bar{q}$. In 14 of our 16 cohorts, half the participants first played five rounds with $\bar{q} = 11$, followed by five rounds with $\bar{q} = 9$, and then five more rounds with $\bar{q} = 11$. For the other participants in these 14 cohorts, the sequencing was reversed: they first played five rounds with $\bar{q} = 9$, then five rounds with $\bar{q} = 11$, and finally five rounds with $\bar{q} = 9$. We did not tell the participants what the exact process of $\bar{q}$ would be. We just informed them that $\bar{q}$ would vary between 9 and 11 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.

We also wanted to disentangle the pure effect of market structure from its effect combined with history. To do so, for two additional cohorts, we ran the experimental market keeping $\bar{q}$ constant. Because, as will be clear below, experimental outcomes are quite straightforward when $\bar{q} = 9$ and also in the pure call auction, we ran these control experiments only for $\bar{q} = 11$ and for the market structures allowing for a preopening phase. This control treatment enables us to examine the difference between preopening mechanisms in absence of changes in $\bar{q}$.

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 that participants understood the mechanics of the market. At the same time, we carefully avoided giving them any hints as to how they should play. This presentation phase lasted around thirty minutes. Then the market game took place. First, each cohort went through six practice rounds.[15]

Table 1 **Treatments in the Experiment**

Market structure	$\bar{q}$	Number of cohorts	Number of participants
Main treatment:			
Without preopening	9 or 11	2	20
Nonbinding preopening	9 or 11	4	48
Binding preopening	9 or 11	4	48
Random preopening with $\alpha = 1/4$	9 or 11	2	24
Random preopening with $\alpha = 3/4$	9 or 11	2	24
Benchmark case:			
Nonbinding preopening	11	1	20
Binding preopening	11	1	20

Notes. The main treatment involves rounds with $\bar{q} = 9$ and rounds with $\bar{q} = 11$. In the benchmark case, $\bar{q}$ was constant and equal to 11. For each treatment, this table reports the number of cohorts and the total number of participants. In a random opening, α is the probability that the market opens immediately after the preopening orders have been placed.

Then, the 15 "real" rounds took place. At each round, the participants had three minutes to place their orders. In the pure call auction case, this meant they had three 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 realized payment was 17.5 euros, the minimum was 13.2, and the maximum 22.0.[16]

4. Hypotheses and Findings

4.1. Dominant Strategy Equilibrium and Trembling Hand Perfection

When $\bar{q} = 9$, there is a unique undominated equilibrium outcome, whatever the structure of the trading game. Accordingly, we posit the following hypothesis:

[15] Practice rounds were included so that subjects could familiarize themselves with the game. Including practice rounds in experiments is common practice, as indicated by Corrigan et al. (2012), for example. These authors also indicate that practice rounds might have an influence on subsequent play through anchoring effects. To mitigate these potential problems, a subject in our experiment did not have a fixed role during the practice rounds, but instead acted sometimes as a buyer and sometimes as a seller.

[16] The cross-sectional standard deviation of the number of points earned by the participants was 3.9 for the first five periods, 3.5 for periods 6–10, and 3.6 for the last five periods.

Table 2 Actions in the Call Auctions

Order type	Without preopening (%)	Nonbinding preopening (%)	Binding preopening (%)	Random preop. with $\alpha = 3/4$ (%)	Random preop. with $\alpha = 1/4$ (%)
		Panel A: Main treatment, $\bar{q} = 9$			
$B0$ or $S0$	0.7	—	0.8	—	0.6
$B1$ or $S1$	82.0	90.8	88.1	92.8	76.7
$B2$ or $S2$	17.3	9.2	11.1	7.2	22.8
		Panel B: Main treatment, $\bar{q} = 11$			
$B0$ or $S0$	—	—	0.6	0.6	—
$B1$ or $S1$	37.3	43.9	15.6	69.4	41.7
$B2$ or $S2$	62.7	56.1	83.9	30.0	58.3
		Panel C: Benchmark case, $\bar{q} = 11$			
$B0$ or $S0$		1.3	0.3		
$B1$ or $S1$		60.7	26.0		
$B2$ or $S2$		38.0	73.7		

Notes. This table reports the frequencies of the different actions chosen by subjects in the call auctions in the five market structures. Panel A (respectively, panel B) presents the results for subjects who played with $\bar{q} = 9$ (respectively, $\bar{q} = 11$) in the main treatment (in which they were exposed to variations in $\bar{q}$). Panel C presents the results for the benchmark case, where subjects only played $\bar{q} = 11$.

Hypothesis 1. *When $\bar{q} = 9$, participants are expected to offer low liquidity (i.e., play B1 and S1) in all market structures.*

Pooling buyers and sellers, Table 2 presents the orders that were taken into account to generate trades.[17] For $\bar{q} = 9$, the frequency of $B1$ or $S1$ is 82% in the one-shot call auction, 88.1% with a binding preopening, 90.8% with a nonbinding preopening, and 92.8% and 76.7% in the markets with random opening with $\alpha = 75\%$ and 25%, respectively. For all the market structures, the null hypothesis that these frequencies are not different from 50% (what is expected if the agents put equal probability on all undominated actions) is rejected at the 1% level.[18] These results are summarized below:

Finding 1. *When $\bar{q} = 9$, consistent with Hypothesis 1, the most frequent choices are to offer low liquidity (B1 or S1) in all market structures. The frequency of these actions is significantly greater than 50% (the frequency expected under the null hypothesis that participants choose randomly among actions that are not weakly dominated).*

When $\bar{q} = 11$, with a binding preopening period, there is a unique trembling hand perfect equilibrium outcome. Accordingly, we posit the following hypothesis:

Hypothesis 2. *When $\bar{q} = 11$, participants are expected to offer high liquidity (i.e., play B2 and S2) in the market with a binding preopening.*

In the lab, Hypothesis 2 may fail to hold if the participants play $(S1, B1)$, $(S1, \Sigma_1^B)$, or $(\Sigma_1^S, B1)$, which are subgame-perfect equilibria, but not trembling hand perfect. In that sense, our experimental design offers a test of the predictive power of the concept of trembling hand perfection in a simple context. As can be seen in Table 2, the highest frequency of $B2$ or $S2$ (83.9%) occurs in the market with a binding preopening period, consistent with Hypothesis 2. The lowest frequency of $B2$ or $S2$ (30%) occurs in the market with a random opening time with $\alpha = 75\%$. Intermediary frequencies are observed in the one-shot call auction (62.7%), the market with a nonbinding preopening (56.1%), and the market with a random opening with $\alpha = 25\%$ (58.3%). Taking the same approach as for Hypothesis 1, we test whether these frequencies are significantly different from 50%. The chi-square statistics are such that, when the preopening is binding, one can reject at the 1% level, the hypothesis that buyers (respectively, sellers) play $B1$ or $B2$ (respectively, $S1$ or $S2$) with equal probabilities. In contrast, in the other market structures, the p-values are larger than 5%. Panel C of Table 2 presents the evidence obtained when subjects play all 15 periods with $\bar{q} = 11$. Here again, when the preopening is binding, the frequency of $B2$ or $S2$ (73.7%) is significantly higher than 50% (at the 5% level). This is not the case when the preopening period is nonbinding. These results are summarized below:

Finding 2. *When $\bar{q} = 11$, consistent with Hypothesis 2, in the market with a binding preopening, the frequency of orders offering high liquidity (B2 or S2) is large (83.9%) and significantly above 50%. It is not significantly different from 50% in the other market structures.*

Finding 2 suggests that neither a nonbinding preopening nor a random opening time are particularly conducive to the play of $B2$ and $S2$. These market structures do not outperform the pure call auction, and are strongly outperformed by the binding preopening. These findings suggest that preopening mechanisms can facilitate coordination on high-liquidity equilibria, but only if appropriately designed.

[17] In the pure call auction, these are simply the limit orders placed by the agents. In the market with nonbinding 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. In the market with a random opening time, these are the orders placed at the time the market opened.

[18] This is a chi-square test with one degree of freedom. For each participant, we compute the average frequency with which he or she plays $B1$ or $S1$. For each market structure, we take the average of these frequencies across participants. Thus, in the pure call auction, the average frequency is based on 20 independent observations, i.e., participants. For the markets with a nonbinding and a binding preopening, the number of independent observations is 48. It is 24 for each of the two random opening-time markets.

4.2. Mismatches

When $\bar{q} = 11$, in all market structures, there are multiple subgame-perfect equilibria. Whereas some are Pareto dominant, others are risk dominant. This could make it difficult for participants to coordinate. If they failed to achieve such coordination, we would observe frequent mismatches, with outcomes $(S2, B1)$ or $(S1, B2)$. Preplay communication could facilitate coordination. Thus, we expect mismatches to be less frequent with a preopening than without. Furthermore, with a binding preopening, mismatches are not subgame-perfect outcomes and should therefore be even less frequent. Thus, we posit the following hypothesis:

Hypothesis 3. *When $\bar{q} = 11$, the frequency of mismatches, with one trader offering high liquidity and the other low liquidity (i.e., $(S1, B2)$ or $(S2, B1)$), should be the greatest in the pure call auction and smallest with binding preopening orders.*

Table 3 displays the frequency of each potential match. When $\bar{q} = 11$, $(S1, B2)$ or $(S2, B1)$ occurs 45.3% of the time in the pure call auction, 33.3% with a nonbinding preopening period, 16.7% with a binding preopening period, 35.6% when the opening time is random with $\alpha = 75\%$, and 14.4% when the opening time is random with $\alpha = 25\%$. To test the significance of these results, we use a sign test on five observations. Four observations correspond to the main treatment: we compare the mismatch frequency in the pure call to the one in the four other market structures that include a preopening period (binding, nonbinding, and with two different probabilities of random opening). We also have one observation from the control treatment in which we compare the mismatch frequency in the pure call market to the one in the market structure with a nonbinding preopening period. We run a sign test using as null hypothesis that the mismatch frequency is equally likely to be higher or lower with a preopening period than without. The p-value is $0.5^5 = 3.1\%$. We can thus reject, at the 5% level, the hypothesis that mismatches are as frequent in the pure call market as in a market structure that includes a preopening period. The above results are summarized in the following:

Finding 3. *When $\bar{q} = 11$, consistent with Hypothesis 3, mismatches are significantly more frequent in the pure call auction than in the other market structures.*

Table 3 Matches in the Call Auctions

Order type	Without preopening (%)	Nonbinding preopening (%)	Binding preopening (%)	Random preop. with $\alpha = 3/4$ (%)	Random preop. with $\alpha = 1/4$ (%)
		Panel A: Main treatment, $\bar{q} = 9$			
$(S1, B1)$	66.7	82.2	78.3	86.7	64.4
$(S1, B2)$ or $(S2, B1)$	29.3	17.2	17.8	12.2	23.3
$(S2, B2)$	2.7	0.6	2.2	1.1	11.1
With $B0$ or $S0$	1.3	—	1.7	—	1.1
		Panel B: Main treatment, $\bar{q} = 11$			
$(S1, B1)$	14.7	27.2	7.2	51.1	34.4
$(S1, B2)$ or $(S2, B1)$	45.3	33.3	16.7	35.6	14.4
$(S2, B2)$	40.0	39.4	75.0	12.2	51.1
With $B0$ or $S0$	—	—	1.1	—	—
		Panel C: Benchmark case, $\bar{q} = 11$			
$(S1, B1)$		40.0	16.0		
$(S1, B2)$ or $(S2, B1)$		38.7	19.3		
$(S2, B2)$		18.7	64.0		
With $B0$ or $S0$		2.7	0.7		

Notes. This table reports the frequencies of the different outcomes in the call auctions. An outcome is a pair of actions chosen by a seller and a buyer matched during the experiment. Panel A (respectively, panel B) presents the results for the main treatment, where $\bar{q} = 9$ (respectively, $\bar{q} = 11$). Panel C presents the results for the benchmark case, where subjects only played $\bar{q} = 11$.

4.3. Manipulation

When $\bar{q} = 9$, $S1$ and $B1$ are the only undominated actions. However, participants could play $S2$ or $B2$ at time 0 to lure their opponent into responding $S2$ or $B2$ at time 1. This would be a form of manipulation, to the extent that the trader playing $S2$ or $B2$ at time 0 would then revert to $S1$ or $B1$ at time 1. In the field, market features such as restrictions on preopening orders and random opening times have been designed to curb manipulation. Our experimental setting offers a laboratory to examine the effectiveness of such features by comparing outcomes arising for $\bar{q} = 9$ in the different market structures. We posit the following hypothesis:[19]

Hypothesis 4. *When $\bar{q} = 9$ and preopening orders are not binding, traders place manipulative orders announcing high liquidity at time 0, but then revert to low liquidity ($S1$ or $B1$) at time 1. Such manipulative orders should be most frequent when the preopening period is nonbinding and the opening time deterministic, less frequent when the market opens at time 0 with probability $\alpha = 25\%$, and even less frequent when the market opens at time 0 with probability $\alpha = 75\%$.*

To confront Hypothesis 4 to the data, Table 4 documents the evolution of the orders placed by the same

[19] Hypothesis 4 is in line with the experimental results of Charness (2000), who studies a prisoner's dilemma with nonbinding preplay communication and finds that players tend to announce cooperation but then play defection.

Table 4 Preopening Orders and Subsequent Actions by the Same Subject

	My play at $t=1$ (%)				
My play at $t=0$	$B0$ or $S0$	$B1$ or $S1$	$B2$ or $S2$	No. of obs.	% of obs.
Panel A: Nonbinding preopening, $\bar{q}=9$					
$B0$ or $S0$	—	92.3	7.7	26	7.2
$B1$ or $S1$	—	86.7	13.3	105	29.2
$B2$ or $S2$	—	92.6	7.4	229	63.6
Panel B: Random preopening with $\alpha=1/4$, $\bar{q}=9$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	1.1	92.0	6.9	87	64.9
$B2$ or $S2$	—	70.2	29.8	47	35.1
Panel C: Random preopening with $\alpha=3/4$, $\bar{q}=9$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	95.7	4.3	47	97.9
$B2$ or $S2$	—	100.0	—	1	2.1
Panel D: Binding preopening, $\bar{q}=9$					
$B0$ or $S0$	1.1	93.2	5.7	280	100.0
Panel E: Nonbinding preopening, $\bar{q}=11$					
$B0$ or $S0$	—	45.8	54.2	24	6.7
$B1$ or $S1$	—	66.7	33.3	48	13.3
$B2$ or $S2$	—	39.9	60.1	288	80.0
Panel F: Random preopening with $\alpha=1/4$, $\bar{q}=11$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	87.5	12.5	40	33.3
$B2$ or $S2$	—	28.8	71.3	80	66.7
Panel G: Random preopening with $\alpha=3/4$, $\bar{q}=11$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	77.3	22.7	22	84.6
$B2$ or $S2$	—	50.0	50.0	4	15.4
Panel H: Binding preopening, $\bar{q}=11$					
$B0$ or $S0$	1.3	28.1	70.6	160	100.0
Panel I: Benchmark case, nonbinding preopening, $\bar{q}=11$					
$B0$ or $S0$	10.0	70.0	20.0	10	3.3
$B1$ or $S1$	1.5	76.1	22.4	67	22.3
$B2$ or $S2$	0.9	55.6	43.5	223	74.3
Panel J: Benchmark case, binding preopening, $\bar{q}=11$					
$B0$ or $S0$	0.7	38.2	61.0	136	100.0

Notes. This table reports the frequencies of the different actions chosen by a subject during call auctions ($t=1$), conditional on the action the same subject has chosen during the corresponding preopening ($t=0$). Because this table only reports actions chosen at $t=1$, actions set by binding preopening orders are excluded from this table. The table is broken down by market structure and maximum quantity traded $\bar{q}$.

player at $t=0$ and then $t=1$.[20] The relevant panels are A, B, and C, corresponding to the outcomes for $\bar{q}=9$ in the markets with (i) a nonbinding preopening, (ii) a random opening with $\alpha=25\%$, and (iii) a random opening with $\alpha=75\%$, respectively. The frequency with which participants play $B2$ or $S2$ at time 0 is 63.6% when the preopening is nonbinding and the opening deterministic, and 35.1% and 2.1% when the opening time is $t=0$ with probability $\alpha=25\%$ and $\alpha=75\%$, respectively. Furthermore, after playing $B2$ or $S2$ at time 0, traders at time 1 play $B1$ or $S1$ 92.6% of the time when the preopening is nonbinding and the opening deterministic, and 70.2% and 100% of the time when the opening time is $t=0$ with probability $\alpha=25\%$ and $\alpha=75\%$, respectively. In the treatment with random opening and $\alpha=75\%$, there is only one case in which $B2$ or $S2$ was played at time 0, and the preopening turned out not to be binding. We thus aggregate all the data corresponding to a random opening: the frequency with which traders play $B2$ or $S2$ at time 0 is 26.4%, and these traders at time 1 play $B1$ or $S1$ 70.8% of the time.

We measure the frequency of manipulations by the frequency of $B2$ or $S2$ at time 0 multiplied by the frequency of $B1$ or $S1$ at time 1 conditional on $B2$ or $S2$ at time 0 (and conditional on the preopening not being binding). The frequency of manipulations is 58.9% when the preopening period is nonbinding, and 18.7% when the opening is random. These proportions are significantly different at the 1% level according to a chi-square test. Our results are summarized as follows.

Finding 4. *Consistent with Hypothesis* 4, *when* $\bar{q}=9$, *manipulative orders are frequent in the market with a deterministic nonbinding preopening, and less frequent in the market with a random preopening. Thus, the random opening time is quite effective at deterring manipulative orders.*

Are traders lured after observing manipulative orders at time 0? Common knowledge of rationality implies that traders believe their opponents will not play $B2$ or $S2$ at time 1 when $\bar{q}=9$, irrespective of what they played at time 0. Hence, manipulative attempts should not prove successful, which we state in the following hypothesis.

Hypothesis 5. *When* $\bar{q}=9$, *the announcement of high-liquidity supply at time* 0 *should not induce the opponent to offer high liquidity* (*i.e., play* $B2$ *or* $S2$) *at time* 1.

To confront Hypothesis 5 to the data, Table 5 documents how a player responded at time 1 to the order placed by his opponent at time 0. The relevant panels are A, B, and C, corresponding to the outcomes for $\bar{q}=9$ in the markets with (i) a nonbinding preopening, (ii) a random opening with $\alpha=25\%$, and (iii) a random opening with $\alpha=75\%$, respectively. For the reason indicated above, we again pool all the data with a random opening. After observing their opponent play $B2$ or $S2$ at time 0, participants responded by playing $B1$ or $S1$, 90.8% of the time in the market with a nonbinding preopening and a deterministic opening time, and 75% in the markets with a random opening. The hypothesis that these frequencies

[20] Tables 4 and 5 report actions actually *chosen* at $t=1$. Any action imposed by a binding order in $t=0$ is thus excluded from the data reported in these tables.

Table 5 Response to Preopening Orders

	My play at $t=1$ (%)				
My opponent at $t=0$	$B0$ or $S0$	$B1$ or $S1$	$B2$ or $S2$	No. of obs.	% of obs.
Panel A: Nonbinding preopening, $\bar{q}=9$					
$B0$ or $S0$	—	96.2	3.8	26	7.2
$B1$ or $S1$	—	89.5	10.5	105	29.2
$B2$ or $S2$	—	90.8	9.2	229	63.6
Panel B: Random preopening with $\alpha=1/4$, $\bar{q}=9$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	1.1	89.7	9.2	87	64.9
$B2$ or $S2$	—	74.5	25.5	47	35.1
Panel C: Random preopening with $\alpha=3/4$, $\bar{q}=9$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	95.7	4.3	47	97.9
$B2$ or $S2$	—	100.0	—	1	2.1
Panel D: Binding preopening, $\bar{q}=9$					
$B0$ or $S0$	1.4	92.4	6.2	210	75.0
$B1$ or $S1$	—	96.1	3.9	51	18.2
$B2$ or $S2$	—	94.7	5.3	19	6.8
Panel E: Nonbinding preopening, $\bar{q}=11$					
$B0$ or $S0$	—	41.7	58.3	24	6.7
$B1$ or $S1$	—	85.4	14.6	48	13.3
$B2$ or $S2$	—	37.2	62.8	288	80.0
Panel F: Random preopening with $\alpha=1/4$, $\bar{q}=11$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	90.0	10.0	40	33.3
$B2$ or $S2$	—	27.5	72.5	80	66.7
Panel G: Random preopening with $\alpha=3/4$, $\bar{q}=11$					
$B0$ or $S0$	—	—	—	0	—
$B1$ or $S1$	—	81.8	18.2	22	84.6
$B2$ or $S2$	—	25.0	75.0	4	15.4
Panel H: Binding preopening, $\bar{q}=11$					
$B0$ or $S0$	1.7	38.3	60.0	60	37.5
$B1$ or $S1$	—	100.0	—	6	3.8
$B2$ or $S2$	1.1	17.0	81.9	94	58.8
Panel I: Benchmark case, nonbinding preopening, $\bar{q}=11$					
$B0$ or $S0$	—	100.0	—	10	3.3
$B1$ or $S1$	3.0	82.1	14.9	67	22.3
$B2$ or $S2$	0.9	52.5	46.6	223	74.3
Panel J: Benchmark case, binding preopening, $\bar{q}=11$					
$B0$ or $S0$	1.8	66.1	32.1	56	41.2
$B1$ or $S1$	—	81.8	18.2	11	8.1
$B2$ or $S2$	—	8.7	91.3	69	50.7

Notes. This table reports the frequencies of the different actions chosen by a subject during call auctions ($t=1$), conditional on the action chosen by his or her opponent at time $t=0$. The table is broken down by market structure and maximum quantity traded $\bar{q}$.

are equal to 50% is rejected at the 1% level by chi-square tests. Thus, subjects are not manipulated and play their dominant strategy at time 1 ignoring "cooperative messages" sent by their opponents at time 0.

Documenting the link of a player's action at time 1 with both his action and his opponent's one at time 0 with a contingency table would be cumbersome. Instead, we examine this link by regressing the indicator that the trader plays $B2$ or $S2$ at time 1 on explanatory variables. The latter include the indicator that this trader played $B2$ or $S2$ at time 0, the indicator that the opponent played $B2$ or $S2$ at time 0, the interaction of these two variables, an indicator for the last five periods, as well as the interaction of all the variables. We run three versions of the regression. The first one is a logistic regression. The second one is a stratified logistic regression, which enables us to take into account individual effects. In the third one, we add to the regressors the indicator that there was a random opening.[21] When including that variable, we cannot run a stratified regression, because no trader played both with and without a random opening.

The estimates of the parameters of these regressions for $\bar{q}=9$ are in panel A of Table 6. For the three versions of the regression, when the trader *and* his or her opponent played $B2$ *and* $S2$ at time 0, this significantly increases the likelihood that they play $B2$ or $S2$ at time 1. This suggests that traders interpret such a coordinated liquidity provision as a signal of the propensity to cooperate on the Pareto-dominant outcome, in spite of the fact that it is not a Nash equilibrium. In contrast, if the trader or his opponent was the only one to play $B2$ or $S2$ at time 0, this has a negative impact on the likelihood of $B2$ or $S2$ at time 1. After observing such miscoordinated outcomes during the preopening, traders opt for the Nash equilibrium strategies at time 1. When the indicator that the opening is random is not included in the regressors, this negative impact is nonsignificant. It becomes significant when we include the indicator that the opening is random. In that case, however, the interaction between the fact that the trader played $B2$ or $S2$ at time 0 and the fact that the opening is random is strongly positively significant. When the trader played $B2$ or $S2$ at time 0 in the market with a random opening, she knew her order could get executed. However, she chose to place a cooperative order, and, at time 1, she does the same again.

Finding 5. *In general, when $\bar{q}=9$, if one trader offers high liquidity and the other low liquidity at time* 0, *this does not significantly increase the likelihood of high liquidity* ($B2$, $S2$) *at time* 1. *However, if both traders offer high liquidity at time* 0, *then high-liquidity offers* ($S2$ *or* $B2$) *are significantly more likely at time* 1. *Furthermore, when the opening is random, when a trader offers high liquidity at time* 0, *she tends to choose the same action at time* 1.

4.4. Communication and Cooperation

The nonbinding preopening is a cheap talk mechanism. When time 0 orders are binding or when the market opening time is random, the preopening period offers a communication mechanism in which

[21] For random preopening, data for which the market actually opened at $t=0$ are excluded.

"talk is not cheap." Our trading game offers an experimental setting to compare the performance of these communication mechanisms in achieving high gains from trade when $\bar{q} = 11$. Before presenting the findings, we discuss the hypotheses.

Hypotheses for the Market with a Nonbinding Preopening. Cooper et al. (1992), Charness (2000), and Blume and Ortmann (2007) offer experimental evidence where, in games with multiple Pareto-ranked equilibria, nonbinding preplay communication fosters coordination on the most efficient one. Farrell (1987) and Farrell and Rabin (1996) offer a theoretical argument to rationalize this. Suppose I make an announcement, and you believe me and respond optimally. If in that case it is in my own interest to stick to my word, then my announcement should be credible. Thus, in our game, when $\bar{q} = 11$, participants could credibly announce during the preopening their intention to play ($S2$, $B2$) in the call auction. This suggests the preopening period should enhance cooperation and leads to the following hypothesis.

Hypothesis 6. *When $\bar{q} = 11$ with a nonbinding preopening period*, (a) *sellers tend to offer high liquidity, i.e., play $S2$ at time 0 and time 1, and* (b) *buyers respond to this with high liquidity, i.e., $B2$ at time 1* (*the symmetric argument applies to the other side of the market*).

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 $S2$ or $S1$. 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.[22]

Hypotheses for the Market with a Random Opening Time. When the opening time is random, traders submitting $B2$ or $S2$ orders at time 0 run the risk of being executed. Traders who think their opponent might well play $B1$ (respectively, $S1$) will be reluctant to play $S2$ (respectively, $S2$) at time 0. They are more likely to play $B1$ or $S1$ (the risk-dominant equilibrium), especially if α is large. Thus, we posit the following hypothesis:

Hypothesis 7. *When $\bar{q} = 11$, the frequency of high-liquidity offers ($S2$ or $B2$) at time 0 is highest when the preopening is nonbinding, lower when the market opening is random with $\alpha = 25\%$, and even lower with $\alpha = 75\%$.*

[22] That in our setting preplay announcements are not self-enforcing in the Aumann (1990) sense differs from Cooper et al. (1992), but is in line with Clark et al. (2001), who consider a game where the Aumann critique applies. They find that cooperation is played 42% of the time but announced 81% of the time.

On the other hand, in the market with a random opening time, the play of $B2$ (respectively, $S2$) at time 0 signals that the buyer (respectively, seller) is quite confident his counterparty will play cooperative. This suggests he is likely to play $B2$ (respectively, $S2$) again at time 1, which in turn, increases the incentives of his counterparty to behave cooperatively at that time. Thus, we posit the following hypothesis.

Hypothesis 8. *When $\bar{q} = 11$ and the opening time is random, traders will tend to* (a) *play $S2$* (*respectively, $B2$*) *at time 1 after playing $S2$* (*respectively, $B2$*) *at time 0, and* (b) *respond $S2$* (*respectively, $B2$*) *at time 1 to the play of $B2$* (*respectively, $S2$*) *at time 0, especially when α is large.*

Findings. To confront Hypotheses 6 and 7 to the data, we focus on panels E, F, G, and I of Table 4. The frequency of $B2$ or $S2$ at time 0 is 80% with a nonbinding preopening (and 74.3% in the benchmark case where $\bar{q}$ is always 11), 66.7% in the random opening market with $\alpha = 25\%$, and 15.4% in the random opening market with $\alpha = 75\%$. This frequency is significantly lower than the two others at the 5% level. We summarize these findings as follows.

Finding 6. *Consistent with Hypothesis 6(a), when $\bar{q} = 11$, participants often announce high liquidity ($S2$ or $B2$) at time 0 if they are sure the preopening orders will not bind.*

Finding 7. *Consistent with Hypothesis 7, when $\bar{q} = 11$, traders are more reluctant to offer high liquidity at time 0 when the opening is random, especially when α is high.*

To confront Hypothesis 8(a) to the data, we focus on panels E, F, and G of Table 4. In the nonbinding preopening, after the trader played $B2$ or $S2$ at $t = 0$, she plays $B2$ or $S2$ 60.1% of the time at $t = 1$. In the random opening market with $\alpha = 25\%$, this frequency is raised to 71.3%. For $\alpha = 75\%$, it is 50% only. Thus, there is no clear evidence in favor of Hypothesis 8(a).

Next, consider the link between an agent's action at $t = 1$ and his opponent's play at $t = 0$. As shown in panels E, F, and G of Table 5, in the market with a nonbinding preopening period, after observing that his opponent played $B2$ or $S2$ at time 0, a subject will play $S2$ or $B2$ at time 1 62.8% of the time. In the market with a random opening, this frequency is 72.5% when $\alpha = 25\%$ and 75% when $\alpha = 75\%$. This suggests, in line with Hypothesis 8(b), that when the opening time is random, traders tend to respond $S2$ (respectively, $B2$) at time 1 to the play of $B2$ (respectively, $S2$) at time 0.

To examine these hypotheses in more depth, we regress the indicator that the trader plays $B2$ or $S2$ at time 1 on explanatory variables. As in the previous subsection, we consider three specifications: a logistic regression, a stratified logistic regression, and a logistic regression conditioning on whether the opening time is random. The results are in Table 6, panel B. The indicator that the trader played $B2$ or $S2$ at time 1 is never significant. Similarly, the indicator that the opponent played $B2$ or $S2$ at time 1 is significant only in the simple logistic regression without stratification and insignificant in the two other specifications. In contrast, in all specifications, after observing $B2$ *and* $S2$ at time 0, traders are significantly more likely to play $S2$ or $B2$ at time 1. This effect, however, is muted during the last five rounds of the market, as discussed in the next subsection. In contrast, the effect is stronger and more significant when there is a random opening time. Our findings are summarized below:

Finding 8. *In contradiction with Hypothesis* 6(b), *when* $\bar{q} = 11$, *when only one trader announces high liquidity at* $t = 0$, *this does not increase the likelihood that his or her opponent will offer high liquidity at time* 1, *if the preopening is nonbinding. In contrast, for all market structures, when* both *traders offer high liquidity at* $t = 0$, *this significantly increases the likelihood of high liquidity at* $t = 1$. *In line with Hypothesis* 8, *this effect is stronger when the opening time is random.*

Thus, well-coordinated cooperative preopening messages favor the emergence of the Pareto-dominant equilibrium, but one pessimistic message is enough to trigger low gains from trade.

4.5. History

To design their strategies, players need to form beliefs about the moves of their opponents. Such beliefs are likely to be shaped by the observation of past actions, thus generating history dependence. In this context, low initial gains from trade can induce pessimistic beliefs. As discussed above, when the preopening is nonbinding and $\bar{q} = 9$, agents tend to announce high liquidity ($S2$ or $B2$) at $t = 0$, hoping to manipulate their opponent, and then offer low liquidity ($S1$ or $B1$) at $t = 1$. This could reduce the willingness of traders to offer high liquidity and undermine the credibility of preplay communication. After such experiences, even when $\bar{q}$ goes back to 11, players might no longer respond positively to high-liquidity offers at time 0. Accordingly, we posit the following hypothesis:

Hypothesis 9. *Traders who have participated in markets with* $\bar{q} = 9$ *are less likely to offer high liquidity when* $\bar{q} = 11$, *and are also less likely to respond positively to cooperative time* 0 *messages.*

To confront Hypothesis 9 to the data, consider Table 6, panel B, corresponding to the market with a nonbinding preopening when $\bar{q} = 11$. As mentioned above, this table presents the estimates for the logistic regression where the dependent variable is the indicator taking the value 1 if the subject plays $B2$ or $S2$ at time 1. Whereas, in the previous subsection, we already discussed some of the results in this table, we now focus on the role of the indicator variable taking the value 1 for the last five periods of the market.

When $\bar{q} = 11$ during the last five periods, participants played with $\bar{q} = 9$ in the previous five periods. According to Hypothesis 9, this should reduce the frequency of $B2$ or $S2$ at time 1. In contrast, for all three specifications of our logistic regression, the coefficient of the indicator of the last five periods is significantly positive at the 10% level. This is puzzling, especially since in the benchmark case where participants only played with $\bar{q} = 11$, the indicator of the last five periods is nonsignificantly negative. Thus, our finding does not merely reflect an end-of-game effect. Maybe, in contrast with our hypothesis, when participants are again confronted with $\bar{q} = 11$, after having played with $\bar{q} = 9$, this increases their propensity to offer high liquidity.

What *is* significantly lower in the last five periods with $\bar{q} = 11$, however, is the positive impact on cooperation of the fact that both traders offered high liquidity at time 0. This suggests that, in line with Hypothesis 9, previous exposure to manipulative attempt with $\bar{q} = 9$ does reduce the credibility of preopening announces to offer high liquidity. Note that in the benchmark case, there is no decline in the credibility of joint high-liquidity offers at time 0.

We summarize these findings as follows:

Finding 9. *Traders who have previously been exposed to* $\bar{q} = 9$ *are not less likely to offer high liquidity when* $\bar{q} = 11$. *These traders are, however, giving significantly less credibility to preopening announcements to offer high liquidity when* $\bar{q} = 11$.

5. Conclusion

This paper offers an experimental comparison of different preopening mechanisms. We compare a one-shot call auction to markets with various types of preopening periods, binding or not, and with deterministic or random opening times. We measure the gains from trade arising in each of these market structures, which reveal to which extent traders have been able to coordinate on equilibria with high liquidity and high gains from trade.

We find that, when the preopening is nonbinding, traders tend to place manipulative orders. This reduces the credibility of preplay communication and, in turn, the ability to coordinate on Pareto-superior equilibria. When the market opening is random, this deters manipulation. Unfortunately, it also hinders communication by making it costly. We find that gains from trade are maximized when preopening orders are binding. In this market, some traders place early

Table 6 When Do Participants Play $B2$ or $S2$ at Time 1?

	Trader played $B2$ or $S2$ at $t=0$	Counter-party played $B2$ or $S2$ at $t=0$	$(B2, S2)$ at $t=0$	Last 5 rounds	$(B2, S2)$ at $t=0$ and last 5 rounds	Random opening	Trader played $B2$ or $S2$ and random opening	Counter-party played $B2$ or $S2$ and random opening	$(B2, S2)$ at $t=0$ and random opening	Intercept
Panel A: Nonbinding or random preopening, $\bar{q}=9$										
A1: Logistic regression (542 obs.)										
Estimate	−0.5532	−0.2822	1.3313	−0.4206	−0.6438					−2.0465
Std. err.	0.4784	0.4441	0.6393	0.4146	0.7664					0.3093
p-value	0.2476	0.5251	0.0373	0.3103	0.4009					<0.0001
A2: Stratified logistic regression (542 obs., 93 subjects)										
Estimate	−1.0970	−0.6547	2.2112	−1.3533	−0.4541					
Std. err.	0.8108	0.6766	0.9454	0.5925	1.0286					
p-value	0.1761	0.3332	0.0193	0.0224	0.6588					
A3: Logistic regression with random opening indicator (542 obs.)										
Estimate	−1.8641	−1.0682	1.9918	−0.6043	−0.3764	−1.4223	2.6818	0.8989		−1.1178
Std. err.	0.5983	0.5143	0.6840	0.4304	0.8010	0.5224	0.7276	0.7220		0.4259
p-value	0.0018	0.0378	0.0036	0.1603	0.6384	0.0065	0.0002	0.2131		0.0087
Panel B: Nonbinding or random preopening, $\bar{q}=11$										
B1: Logistic regression (506 obs.)										
Estimate	0.1745	0.8135	1.7452	0.7290	−1.1481					−1.5921
Std. err.	0.4348	0.4150	0.5361	0.3462	0.4385					0.3537
p-value	0.6881	0.0500	0.0011	0.0352	0.0088					<0.0001
B2: Stratified logistic regression (506 obs., 87 subjects)										
Estimate	−1.1510	0.5125	3.0281	1.2165	−2.1472					
Std. err.	1.0025	0.8431	1.0465	0.6734	0.8113					
p-value	0.2509	0.5433	0.0038	0.0709	0.0081					
B3: Logistic regression with random opening indicator (506 obs.)										
Estimate	−0.0489	0.6357	1.3358	0.6329	−1.0726	−0.8980	−0.1840	−0.2606	3.9779	−1.0530
Std. err.	0.5815	0.5680	0.6776	0.3549	0.4521	0.6918	0.9761	0.8988	1.3494	0.5079
p-value	0.9330	0.2631	0.0487	0.0745	0.0177	0.1943	0.8505	0.7718	0.0032	0.0382
Panel C: Nonbinding preopening, benchmark case, $\bar{q}=11$										
C1: Logistic regression (300 obs.)										
Estimate	−1.4761	−0.4519	3.2379	−0.8471	−0.1385					−0.6989
Std. err.	0.7215	0.6401	0.8435	0.6001	0.6910					0.5452
p-value	0.0408	0.4802	0.0001	0.1581	0.8411					0.1998
C2: Stratified logistic regression (300 obs., 20 subjects)										
Estimate	−0.9125	−0.4649	3.0622	−0.9722	−0.1016					
Std. err.	0.8036	0.7238	0.9209	0.6260	0.7468					
p-value	0.2562	0.5207	0.0009	0.1204	0.8917					

Notes. This table reports the estimates of a logistic regression where the dependent variable is the indicator that the trader played $B2$ or $S2$ during the call auctions (i.e., at $t=1$) preceded by a nonbinding preopening, or by a random preopening for which the market opened at $t=1$. Regressors include the indicators that the subject played $B2$ or $S2$ at $t=0$, the counterparty played $B2$ or $S2$ at $t=0$, the trade occurred during one of the last five rounds, and the preopening was random. Regressors also include interactions between these indicators.

limit orders, offering liquidity. This attracts further liquidity from the other side of the market.

Thus, although preopening mechanisms can facilitate coordination on high-liquidity equilibria, they can also be ineffective if they are not properly designed. Our experiment suggests that restrictions on the cancellation of preopening orders can play a useful role.

For simplicity, our experiment focuses on strategic uncertainty, i.e., uncertainty about the strategies of the other players, while ruling out asymmetric information about the fundamental value of the security. With information asymmetries, preopening mechanisms would be exposed to additional problems.

In the present setting, traders can be reluctant to offer high liquidity (by placing orders $B2$ or $S2$) because they fear their counterparty will offer low liquidity (by placing orders $B1$ or $S1$). If traders observed private signals about the common value of the asset, this problem would be worsened. Limit orders to sell a large amount (such as $S2$) could signal bad news rather than the intention to realize mutually beneficial gains from trade. However, as long as the magnitude of the adverse selection problem would remain limited relative to that of the gains from trade, coordination on high-liquidity equilibria via preopening mechanisms should remain feasible. In a setting with asymmetric information, Pouget (2007a) experimentally shows that a Walrasian tatonnement enables more gains from trade to be extracted than a pure call auction, possibly because of adaptive learning

(Pouget 2007b). It would be interesting to study learning under asymmetric information in a preopening mechanism. We leave this analysis to further research.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2013.1787.

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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 four 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 the number shares bought × (4 − price). For sellers this is the 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 and anonymously matched with one seller. Prices and trades are set in a uniform-price call auction, crossing the buy and sell orders. For each pair, the supply curve of the seller and the demand function of the buyer are crossed in a uniform-price call auction, setting the price and volume for this round and this pair of traders.

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

- $S0$: Do not sell at any price.
- $S1$: One order to sell 8 shares if price is not below 2; another order to sell X additional shares if price is not below 3.
- $S2$: One order to sell 8 shares if price is not below 1; another order to sell additional X shares if price is not below 2.

And each buyer chooses between three schedules of limit orders.

- $B0$: Do not 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.
- $B2$ and $S2$: price = 2, volume = 11. Profit of buyer = profit of seller = 22.
- $B1$ and $S1$: price = 2, volume = 8. Profit of buyer = profit of seller = 16.
- $B1$ and $S2$: price = 1.5, volume = 8. Profit of buyer = 20, profit of seller = 12.
- $B2$ and $S1$: 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.
- $B2$ and $S2$: price = 2, volume = 9. Profit of buyer = profit of seller = 18.
- $B1$ and $S1$: price = 2, volume = 8. Profit of buyer = profit of seller = 16.
- $B1$ and $S2$: price = 1.5, volume = 8. Profit of buyer = 20, profit of seller = 12.
- $B2$ and $S1$: price = 2.5, volume = 8. Profit of buyer = 12, profit of seller = 20.

We will start with six warm-up rounds, so that you can familiarize with the game (no points will be earned during these six rounds). During these six rounds you will sometimes be a buyer and sometimes a seller. Then, there will be 15 trading rounds, during which you will 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 will keep throughout the game. In some rounds the maximum trade will be 9 shares, in other rounds, the max number of shares traded will be 11. At each round, before players choose orders, the maximum trade will be announced to all.

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