The impact of brokers on the dynamics of a Walrasian auction

December 26, 2012

Abstract

We study the impact of the presence of brokers in an experimental exchange market using the Walrasian tâtonnement mechanism. We find that brokers have a tendency to act as liquidity providers, submitting orders likely to equilibrate supply and demand given the orders they receive from other participants. As a result, average excess demand and prices are less volatile, and markets reach equilibrium more often, when brokers are present compared to the case without brokers. Brokers' liquidity-providing behavior is more pronounced when their compensation includes, in addition to their trading profit, a component related to trading volume when equilibrium is reached. Under-revelation, a strategic behavior inherent to Walrasian auctions, is about the same with and without brokers when markets clear, yielding similar levels of market efficiency, measured as total surplus divided by potential surplus.
Keywords: Brokers, Financial Intermediaries, Stability, Efficiency, Price Tâtonnement, Walrasian Auction
JEL: D44; D53; G12; G14; G24

1 Introduction

In typical financial market experiments, agents trade directly with the market. This is rarely the case in practice where transactions usually involve intermediaries, like brokers, who stand between buyers and sellers. In this paper, we conduct an experiment in the spirit of Joyce (1984, 1998) to investigate the impact of brokers on equilibrium dynamics in the context of a Walrasian, or price tâtonnement, auction. Walras (1874) describes a process whereby an auctioneer first announces a price and buyers and sellers then post the quantities they pledge to trade at this price. If demand differs from supply, the price is adjusted toward excess demand and trade takes place when excess demand is zero. While most exchange markets use the continuous double auction[1], almost all economic models assume equilibrium is reached through tâtonnement, and experiments have shown that exchange dynamics can be associated to price tâtonnement (Plott and George, 1992; Plott, 2000; Hirota et al., 2005; Gjerstad, 2007). The Walrasian auction depicts an exchange market in its purest form and allows us to study the impact of brokers on the equilibrium outcome as well as on the dynamics leading to equilibrium.

A fair amount of theoretical work has shown that middlemen play a productive role in markets, mainly through the reduction of search costs and the resolution of adverse selection problems (Rubinstein and Wolinsky, 1987; Bhattacharya and Yavas, 1993; Biglaiser, 1993; Biglaiser and Friedman, 1994; Yavas, 1994; Li, 1998). Empirical studies have demonstrated that brokers provide liquidity and improve efficiency (Silber, 1984; Berkman and Hayes, 2000; Gabre-Madhin, 2001). Nonetheless, experimental research involving intermediaries has essentially focused on dealer markets (Schnitzlein, 1996; Lamoureux and Schnitzlein, 1997; Theissen, 2000). Our contribution is to investigate, in a controlled experiment, how introducing brokers in an exchange market impacts its performance.

The experiment comprises a treatment without brokers, a treatment with brokers only compensated with their own trading profits, and treatments with brokers compensated with their own trading profits plus volume-based incentives. Brokers are traders who receive and view the pledges of selected participants, determine their own pledge, and submit the combined pledges to the auctioneer. To have the same number of auctions in each treatment, the number of trials per auction is limited. A trial begins with a price posted by the auctioneer and, based on this price, participants

[1] To our knowledge, the Tokyo Grain Exchange is the only non-trivial market operating as a Walrasian auction.

submit pledges to buy or sell. If supply differs from demand, the price is adjusted and a new trial begins. For each auction, the number of trials is limited to twelve, which means an auction may not clear.

We find that brokers have a tendency to act as liquidity providers, a behavior that is amplified in the presence of volume-based incentives. Given the information brokers can infer from the orders they receive, a significant number of their own orders can be associated with an attempt to equilibrate supply and demand. When brokers are rewarded with their trading payoff only, about twenty percent of their orders can be seen as being motivated by market clearing. This proportion increases to forty percent with volume-based incentives. As a result, markets with brokers clear twice as often as markets without brokers, and they exhibit less volatile excess demand and price. Hence our study shows that the presence of brokers improves stability and convergence to equilibrium in a price tâtonnement system[2].

Theoretical analyses of the Walrasian auction have shown that under-revelation, a strategic behavior whereby a trader pledges a sub-optimal quantity in the hope of moving the following trial price in a favorable direction, may spoil the auction's outcome (Dubey, Mas-Colell, and Shubik, 1980; Amir et al., 2000; Hurwicz, 1972; Stoll and Whaley, 1987; Otani and Sicilian, 1990; Medrano and Vives, 2001). When under-revealing, a trader incurs the risk that the auction may clear after a suboptimal pledge, yielding a lower profit and, in turn, an inefficient outcome. To measure market efficiency in a Walrasian auction, we divide the sum of all participants' payoffs by the total payoff earned without under-revelation. Previous experimental studies have found evidence of under-revelation (Joyce, 1984; Joyce, 1998; Bronfman et al., 1996; Pouget, 2007) but field studies provide mixed observations in this respect (Goldberg and Tenorio, 1997; Biais et al., 1996; Eaves and Williams, 2007). When considering all auctions (clearing and non-clearing), we find less under-revelation in the treatment without brokers, a consequence of the greater instability of this treatment. Without brokers, fewer auctions reach equilibrium and, when the twelfth trial approaches, the price tends to bounce back and forth between very high and very low values. At a very high price, sellers submit the largest order they can while buyers remain quiet, and vice versa

[2] Mas-Colell, Whinston and Green (1995, p.620), Ficher (1983) and Bouchaud, Farmer and Lillo (2008) emphasize the importance of paying attention to the dynamics of a system rather than to its equilibrium only. Scarf (1960) and Gale (1963) provide theoretical examples of instability of competitive systems, and Anderson et al. (2004) and Crockett et al. (2011) provide experimental support to these theories.

when the price is very low, behaviors that nourish the system instability given the price adjustment process. However, when considering clearing trials only, there is no significant difference in under-revelation between treatments and, as a result, market efficiency is about the same.

Brokers do not systematically under-reveal more than non-brokers and their trading profits are in line with those of non-brokers with comparable limit prices. When considering brokers' total payoff, i.e. their trading payoff plus the volume-based incentives, brokers earn more than non-brokers with comparable limit prices. Hence brokers were rewarded for providing liquidity to the market.

This paper is structured as follows. The next section provides the details of the experiment, Section 3 exposes the results, Section 4 analyzes in more details brokers' behavior and Section 5 concludes.

2 Methodology

We conduct an experiment simulating a Walrasian auction, following the frameworks of Joyce (1984, 1998) and Bronfman et al. (1996). Four different treatments are implemented: A treatment without brokers, a treatment with brokers and no volume-based incentives and two treatments with brokers and volume-based incentives. Each treatment involves a different group of participants.

2.1 Treatment 1 (T1): No brokers

Ten participants are divided into two groups of five, one group of buyers and one group of sellers of a single good. Envelopes are distributed to participants, indicating their type (buyer or seller) as well as a limit price. The limit price of a buyer (seller) specifies the maximum (minimum) price he/she can pay (must receive) for the good, P_B (P_S), and a buyer (seller) can purchase (sell) at most five units of the good.

An auctioneer opens the auction by writing a price on a blackboard (trial 1). Once the price is announced, subjects indicate, on a slip of paper submitted to the auctioneer, the number of units of the good they would buy or sell at this trial price. If the number of buys equals the number of sells, then equilibrium is reached, the goods are exchanged at the posted price and the auction ends. If there is an imbalance between buys and sells, the auctioneer adjusts the price in the direction of the imbalance, following the formula (Samuelson, 1947):

$$P_{t+1} \; = \; P_t \; + \; k\,(Q_{B,t} - Q_{S,t})\,, \tag{1}$$

where P_t is the price of the commodity in trial t, $Q_{B,t}$ and $Q_{S,t}$ are the aggregate demand and supply, respectively, in trial t, and k is a positive parameter unknown to participants[3]. A pledge cannot be canceled within a trial and all pledges are reset to zero at the start of a new trial.

If, after 12 trials, an auction has not reached equilibrium, it ends without trade[4]. When equilibrium is reached, each participant is rewarded according to the following profit functions:

$$\pi_B \; = \; N_B\,(P_B - P^*) \quad \text{and} \quad \pi_S \; = \; N_S\,(P^* - P_S)\,,$$

where π_B (π_S) corresponds to a buyer's (seller's) profit, P^* to the clearing-trial price, and N_B (N_S) to the number of units demanded (offered) by a buyer (seller). Short sales and margin purchases are not possible.

2.2 Treatment 2 (T2): Brokers without volume-based incentives

The second treatment is identical to the first with the exception that two participants, one buyer and one seller, act as brokers. Like all other participants, a broker is given a limit price and can trade up to five units of the good. But what distinguishes a broker is that he/she receives the pledges of three other participants, namely one buyer and two sellers. Two buyers trade directly with the market, rather than using a broker. This is illustrated in Figure 1. This setup combines direct and brokered trading to prevent brokers from inferring the price adjustment parameter.

A broker observes the direction and the size of the three orders he/she receives. He/she then adds his/her own order and submits an aggregate order to the auctioneer. Profits are calculated as they are in treatment 1.

[3]The parameter k remains constant throughout the experiment.

[4]In Joyce (1988) and Bronfman et al. (1996), an auction can only end when an equilibrium is reached and the price adjustment factor varies during the auction to facilitate convergence. In Joyce (1998), an auction stops after a certain time in order to ensure the completion of the same number of auctions for different treatments. We imposed a limit of 12 trials per auction to ensure that each treatment includes the same number of auctions given our time constraints.

2.3 Treatments 3 and 4 (T3 and T4): Brokers with Volume-Based Incentives

These treatments operate like treatment 2 with the addition of a bonus paid to brokers given the number of shares traded when equilibrium is reached and shares are traded. In treatment 3, ten cents per unit exchanged are paid to each broker on top of his/her own trading profit. In treatment 4, twenty cents per unit exchanged (twice as much as in treatment 3) are paid to each broker on top of his/her own trading profit[5].

2.4 Equilibrium, under-revelation and efficiency

Figure 2 shows the theoretical supply and demand functions induced by the limit prices distributed to buyers and sellers. In Figure 2, a participant is assumed to pledge five units each time his or her limit price is met, a behavior we refer to as full revelation. A fully revealing equilibrium is then such that 25 units are traded at a price between 51 and 52. Such an equilibrium maximizes total surplus and is thus considered efficient. We refer to the price interval [51,52] as the efficient price tunnel.

Given the tâtonnement process, a participant may strategically pledge fewer than five units, or under-reveal his or her type, when his or her limit price is met. The goal of such a behavior is to influence the price in a more favorable direction but this is done at the risk of realizing a lower payoff in the case the market clears following an under-revealing pledge. An equilibrium wherein some participants trade less than five units is inefficient. We measure the level of efficiency of an outcome by dividing the sum of the participants' payoffs by the total payoff of an efficient equilibrium[6].

A Walrasian auction may take some time to equilibrate and thus, given the 12-trial limit that we imposed, it may end without trade. The number of auctions that successfully reach equilibrium in a given treatment then provides another indicator of market performance.

[5]For example, if a total of 18 units are exchanged in an auction, each broker receives \$1.80 in treatment 3 and \$3.60 in treatment 4, on top of their trading profits.

[6]For any price in [51,52], an efficient equilibrium yields a total payoff, or potential surplus, of 75.

3 Results

We recruited two groups of 10 participants for treatment 1 (24 auctions), two groups of 10 participants for treatment 2 (24 auctions), one group of 10 participants for treatment 3 (12 auctions) and one group of 10 participants for treatment 4 (12 auctions).

Table 1 shows the number of auctions that cleared in each treatment as well as average excess demand and average price. Overall, treatments with brokers reached equilibrium twice as often (approximately 60% of the time when combining all treatments with brokers) as the treatment without brokers (approximately 30% of the time). Moreover, the proportion of auctions that cleared increases with the size of volume-based incentives paid to brokers, the treatment with the highest incentives, treatment T4, exhibiting the largest proportion of clearing auctions with 75%. The presence of brokers clearly improved liquidity by generating markets more likely to reach equilibrium within the twelve-trial constraint.

In each treatment, we can see in Table 1 that clearing auctions display less volatile excess demand and prices compared to the average of all auctions. The higher volatility in non-clearing auctions is due to the price process and the twelve-trial constraint. When an auction approaches the twelfth trial and, say, the price is above the efficient tunnel, all sellers have a tendency to submit full orders (orders of five units) while some buyers are out of the money. This translates into a very negative excess demand that sends the next trial price below the efficient tunnel and, this time, all buyers submit full orders while some sellers abstain. This generates a sequence of prices and excess demands seesawing between very high and very low values until the twelfth trial is reached. Consequently, Table 1 also shows that treatments with more clearing auctions have less volatile excess demand and prices when all auctions are considered. Looking at clearing auctions only, we note that treatments with brokers and volume-based incentives have less volatile excess demand and prices than the two other treatments. Hence brokers add stability to a competitive system, and more so when they are compensated with volume-based incentives.

Looking at Table 2, we note that the average quantity traded does not differ materially, in size as well as in volatility, across treatments. The average clearing price lies in the efficient tunnel in all treatments and the number clearing prices outside the efficient tunnel is roughly the same in each treatment[7]. As a result, market efficiency, measured as total surplus divided by potential

[7] In the treatment without brokers, there are two clearing prices outside the tunnel (50.75 and 50.5), there are

surplus, is similar across treatments.

Table 3 shows average under-revelation in each treatment, measured as five minus a participant's pledged quantity when his or her limit price is strictly met[8] (when in the money). Considering all auctions (clearing and non-clearing), we observe that under-revelation is always significantly lower in the treatment without brokers than in any of the treatments with brokers. This is due to the previously explained seesawing pattern of excess demand and prices when a non-clearing auction approaches the twelfth trial, generating a sequence of very high and very low prices that induce in-the-money participants to submit full orders. The treatment without brokers displays this pattern more often than the other treatments and this is why its level of under-revelation is less pronounced when all auctions are considered. When we only consider the auctions that cleared as well as clearing trials, we find that under-revelation is significantly smaller in the treatment with brokers and no volume-based incentives than in the treatment without brokers, but this difference does not remain when volume-based incentives are added to brokers' compensation. The lower under-revelation with brokers and no incentives explains why this treatment exhibits the highest level of market efficiency in Table 2.

4 Broker behavior and market clearing

Why do markets clear more often in the presence of brokers? There are two brokers in our setup, one broker-buyer and one broker-seller. Each broker receives orders from one buyer and two sellers. Let B^i, S_1^i, and S_2^i denote the orders received from the buyer and the two sellers, respectively, by broker $i = b, s$, the superscript b denoting the broker-buyer and the superscript s denoting the broker-seller. If the price announced by the auctioneer is below the broker-buyer's valuation, the latter submits an order between 0 and 5 that we represent by x. The broker-buyer may then infer that the average buy order in the market is $(x+B^b)/2$ and that the average sell order is $(S_1^b+S_2^b)/2$. If the broker-buyer wants the market to clear, he will submit an order $x^* = S_1^b + S_2^b - B^b$, as long as

three in the treatment with brokers and no incentives (52.5, 50.5 and 50.25), there are two in the treatment with brokers/incentives 1 (52.5 and 52.5) and two in the treatment with brokers/incentives 2 (50.75 and 50.75).

[8] For a buyer (seller), under-revelation is calculated as five minus the pledged quantity when the price announced by the auctioneer is strictly below (above) the participant's valuation, or limit price. When the price is equal or above (below) the buyer's (seller's) valuation, the observation is not considered in the calculation. For instance, there are 7 clearing trials in the treatment without brokers but 66 observations for under-revelation rather than 70 (7×10), as there are four cases where the participant would not realize a strictly positive profit by submitting an order.

$0 \leq x^* \leq 5$. Taking into account corner solutions, a clearing-motivated order by the broker-buyer is then such that

$$x^* = \begin{cases} 0 & \text{if } S_1^b + S_2^b - B^b < 0, \\ S_1^b + S_2^b - B^b & \text{if } 0 \leq S_1^b + S_2^b - B^b \leq 5, \\ 5 & \text{if } S_1^b + S_2^b - B^b > 5, \end{cases} \tag{2}$$

whenever his or her limit price is met.

If the announced price is above the broker-seller's valuation, the latter submits an order between 0 and 5 that we represent by y. The broker-seller may then infer that the average buy order in the market is B^s and that the average sell order in the market is $(y + S_1^s + S_2^s)/3$. If the broker-seller wants the market to clear, he will submit an order $y^* = 3B^s - (S_1^s + S_2^s)$, as long as $0 \leq y^* \leq 5$. Including corner solutions, a clearing-motivated order by the broker-seller is then such that

$$y^* = \begin{cases} 0 & \text{if } 3B^s - (S_1^s + S_2^s) < 0, \\ 3B^s - (S_1^s + S_2^s) & \text{if } 0 \leq 3B^s - (S_1^s + S_2^s) \leq 5, \\ 5 & \text{if } 3B^s - (S_1^s + S_2^s) > 5, \end{cases} \tag{3}$$

whenever his or her limit price is met.

Table 4 shows the number of times brokers submitted clearing-motivated orders in each treatment when in the money. The first row of each panel shows the number of clearing-motivated orders in all auctions, the second row only considers auctions that reached equilibrium, and the third row only considers the trials where equilibrium was reached. For example, in the treatment with brokers and no incentives (T2), the broker-buyer was in the money 144 times and submitted 41 orders consistent with (2), namely 28.5% of the time. In the same treatment, the broker-seller was in the money 167 times and submitted 18 orders consistent with (3).

Overall, we can see in Table 4 that clearing-motivated orders are non-negligible, representing at least 19% of brokers' orders (panel 1, column 4, row 1 in Table 4) and reaching 39% (panel 3, column 4, row 1 in Table 4) when all auctions are considered. They seemingly contribute to the attainment of equilibrium since treatments with the most clearing trials are also the ones with the most clearing-motivated orders. With the highest volume-based incentives (treatment T4), clearing-motivated orders represent more than half the orders submitted by brokers during trials that reached equilibrium. Without volume-based incentives, the broker-buyer is more likely to submit clearing-motivated orders than the broker-seller but this relationship is reversed in the presence of volume-based incentives.

Table 5 looks at under-revelation by trader type, where a client denotes a participant whose orders transit through a broker and "direct" denotes a participant whose orders are submitted directly to the market. From this table, we cannot say that a broker under-reveals more or less than other participants.

How do brokers fare in terms of payoff? Table 6 shows that only in T3 do brokers realize a higher trading payoff than comparable participants[9], and this because of their lower under-revelation in clearing trials of that treatment. We cannot say, however, that this behavior is a consequence of clearing-motivated orders. In T3, brokers submitted 3 under-revealing, clearing-motivated, orders (clearing-motivated orders smaller than five) out of a total of 12 in clearing trials, hence 25% of the time. This proportion was 17% (4/23) in T2 and and 44% (8/18) in T4. Treatment T4 exhibits the most under-revealing, clearing-motivated, orders in clearing trials yet brokers under-reveal more, on average, in this treatment. Adding the volume-based compensation to brokers' trading payoff, the latter did much better than their comparable peers.

5 Conclusion

Theoretical and empirical studies have concluded that intermediaries have a positive impact on market performance. In this paper, we use a controlled laboratory experiment designed to observe the impact of brokers on a market's performance and its traders' behavior. Our market design follows a Walrasian tâtonnement mechanism. We find that introducing brokers in the auction process substantially improves the likelihood that an auction will reach equilibrium, and brokers reduce market risk through lower price and excess-demand volatility. This result is even stronger when brokers' compensation includes a bonus linked to trading volume. Analyzing brokers' trades, we find that the latter adjust their orders in a manner that increases the likelihood of reaching equilibrium, and this behavior intensifies with volume-based incentives. Strategic under-revelation is slightly higher when brokers are compensated with volume-based incentives but this effect fades off as the market approaches equilibrium, and so does not reduce market efficiency compared with the base case.

[9] The broker-buyer had a limit price of 52.5 and the broker-seller had a limit price of 50.5. The broker-comparable participants are the two buyers with limit prices of 52 and 53 and the two sellers with limit prices of 50 and 51.

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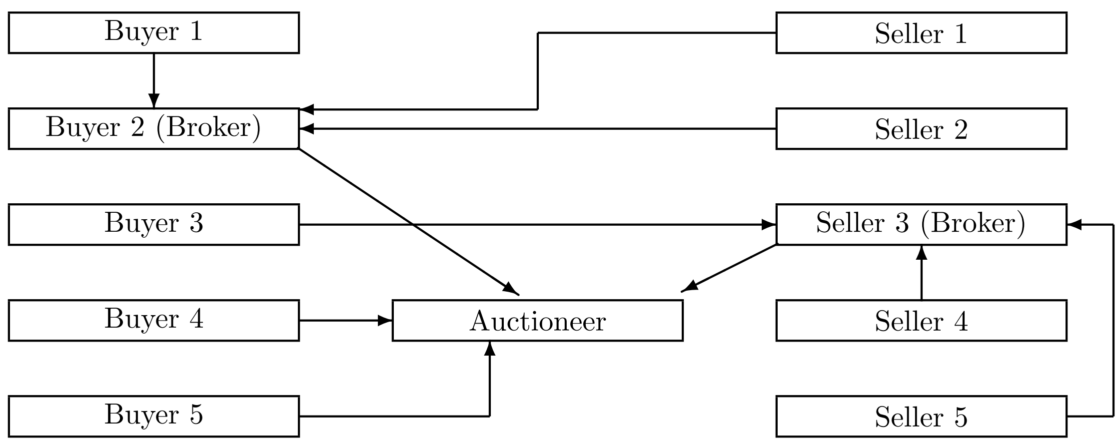

Figure 1: Flow of orders in the treatment with brokers. The two brokers are buyer 2 and seller 3. Buyer 2 receives the orders of buyer 1 and sellers 1 and 2, adds his/her own order and submits an aggregate order to the auctioneer. Seller 3 receives the orders of buyer 3 and sellers 4 and 5, adds his/her own order and submits an aggregate order to the auctioneer. Buyers 4 and 5 submit their orders directly to the auctioneer.

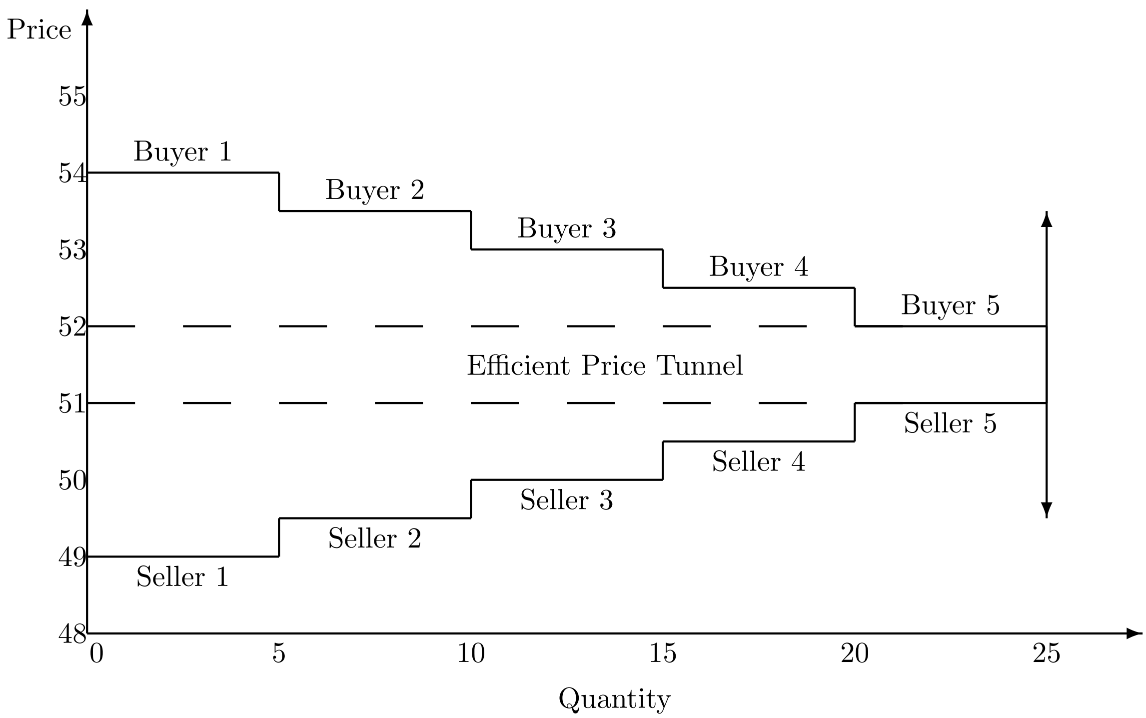

Figure 2: Theoretical supply and demand functions given participants' limit prices.

CLEARING AUCTIONS, EXCESS DEMAND AND PRICE

	Average	Standard Deviation	Min	Max	N
Treatment without brokers (T1–2 groups, 24 auctions)					
Number of clearing auctions	7 (29.2%)				
Excess demand, all auctions	−3.52	13.59	−25.00	25.00	247
Price, all auctions	53.11	3.12	48.00	61.50	247
Excess demand, clearing auctions	−2.40	9.43	−18.00	20.00	43
Price, clearing auctions	51.94	2.20	48.00	58.00	43
Treatment with brokers/no incentives (T2–2 groups, 24 auctions)					
Number of clearing auctions	13 (54.2%)				
Excess demand, all auctions	−2.14	10.32	−25.00	21.00	207
Price, all auctions	52.13	2.18	48.25	59.25	207
Excess demand, clearing auctions	−1.85	9.40	−24.00	18.00	75
Price, clearing auctions	52.05	2.05	48.50	58.75	75
Treatment with brokers/incentives 1 (T3–1 group, 12 auctions)					
Number of clearing auctions	7 (58.3%)				
Excess demand, all auctions	−0.82	6.17	−16.00	17.00	90
Price, all auctions	52.21	1.43	50.00	58.50	90
Excess demand, clearing auctions	0.03	2.75	−10.00	7.00	30
Price, clearing auctions	51.73	0.72	51.00	55.00	30
Treatment with brokers/incentives 2 (T4–1 group, 12 auctions)					
Number of clearing auctions	9 (75.0%)				
Excess demand, all auctions	−1.06	5.95	−16.00	15.00	94
Price, all auctions	51.49	1.27	48.75	57.75	94
Excess demand, clearing auctions	−0.88	5.13	−16.00	10.00	58
Price, clearing auctions	51.58	0.99	50.00	55.25	58
Treatments with brokers combined (T2, T3 and T4–4 groups, 48 auctions)					
Number of clearing auctions	29 (60.4%)				
Excess demand, all auctions	−1.58	8.59	−25.00	21.00	391
Price, all auctions	52.00	1.86	48.25	59.25	391
Excess demand, clearing auctions	−1.16	7.18	−24.00	18.00	163
Price, clearing auctions	51.82	1.55	48.50	58.75	163

Table 1: Number of clearing auctions, average excess demand and average price in each treatment.

QUANTITY TRADED, CLEARING PRICE AND MARKET EFFICIENCY

Treatment without brokers (T1–2 groups, 24 auctions)					
	Average	**Standard Deviation**	**Min**	**Max**	**N**
Quantity traded	15.14	4.78	8.00	20.00	7
Clearing price	51.14	0.43	50.50	51.75	7
Market efficiency	0.63	0.18	0.37	0.80	7
Treatment with brokers/no incentives (T2–2 groups, 24 auctions)					
Quantity traded	16.77	1.88	14.00	20.00	13
Clearing price	51.48	0.60	50.25	52.50	13
Market efficiency	0.70	0.07	0.61	0.85	13
Treatment with brokers/incentives 1 (T3–1 group, 12 auctions)					
Quantity traded	15.43	3.41	10.00	18.00	7
Clearing price	51.79	0.51	51.25	52.50	7
Market efficiency	0.65	0.12	0.49	0.77	7
Treatment with brokers/incentives 2 (T4–1 group, 12 auctions)					
Quantity traded	14.56	4.56	7.00	19.00	9
Clearing price	51.14	0.31	50.75	51.50	9
Market efficiency	0.63	0.17	0.35	0.81	9
Treatments with brokers combined (T2, T3 and T4–4 groups, 48 auctions)					
Quantity traded	15.76	3.30	7.00	20.00	29
Clearing price	51.45	0.54	50.25	52.50	29
Market efficiency	0.67	0.12	0.35	0.85	29

Table 2: Average quantity traded, clearing price and market efficiency in each treatment.

UNDER-REVELATION BY PARTICIPANTS

	Average	Standard Error	N	Difference with T1	(*p*-value)
Treatment without brokers (T1–2 groups, 24 auctions)					
All auctions	1.50	0.038	1818		
Clearing auctions	1.84	0.089	347		
Clearing trials	1.98	0.202	66		
Treatment with brokers/no incentives (T2–2 groups, 24 auctions)					
All auctions	1.72	0.036	1642	0.22***	(< .001)
Clearing auctions	1.55	0.058	622	−0.29***	(0.006)
Clearing trials	1.51	0.118	122	−0.47**	(0.030)
Treatment with brokers/incentives 1 (T3–1 group, 12 auctions)					
All auctions	2.04	0.052	788	0.54***	(< .001)
Clearing auctions	2.03	0.067	513	0.19*	(0.085)
Clearing trials	1.76	0.162	66	−0.22	(0.381)
Treatment with brokers/incentives 2 (T4–1 group, 12 auctions)					
All auctions	2.10	0.060	814	0.60***	(< .001)
Clearing auctions	2.04	0.074	518	0.20*	(0.080)
Clearing trials	1.94	0.193	85	−0.04	(0.877)
Treatments with brokers combined (T2, T3 and T4–4 groups, 48 auctions)					
All auctions	1.90	0.027	3244	0.40***	(< .001)
Clearing auctions	1.78	0.041	1425	−0.06	(0.549)
Clearing trials	1.70	0.089	273	−0.28	(0.174)

Table 3: Average under-revelation in each treatment. The line "Clearing auctions" considers all trials of auctions that reached equilibrium. The line "Clearing trials" considers the last trial of clearing auctions. These calculations only consider cases where submitting an order by a participant would generate a strictly positive profit. The column "(*p*-value)" gives the *p*-value for the difference between average under-revelation in a treatment and average under-revelation in T1. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

CLEARING-MOTIVATED ORDERS BY BROKERS

Treatment with brokers/no incentives (T2–2 groups, 24 auctions)						
	Broker-buyer		**Broker-seller**		**Combined**	
All auctions	41/144	28.5%	18/167	10.8%	59/311	19.0%
Clearing auctions	23/61	37.7%	7/66	10.6%	30/127	23.6%
Clearing trials	6/12	50.0%	1/11	9.1%	7/23	30.4%
Treatment with brokers/incentives 1 (T3–1 group, 12 auctions)						
All auctions	19/68	27.9%	29/88	33.0%	48/156	30.8%
Clearing auctions	11/27	40.7%	11/30	36.7%	22/57	38.6%
Clearing trials	2/5	40.0%	3/7	42.9%	5/12	41.7%
Treatment with brokers/incentives 2 (T4–1 group, 12 auctions)						
All auctions	28/79	35.4%	32/75	42.7%	60/154	39.0%
Clearing auctions	20/50	40.0%	22/52	42.3%	42/102	41.2%
Clearing trials	3/9	33.3%	7/9	77.8%	10/18	55.6%

Table 4: Number and percentage of clearing-motivated orders submitted by brokers in each treatment. Market-clearing trades are as defined in (2) and (3). The table only considers situations where submitting an order generates a strictly positive profit to a broker. For instance, 13 trials cleared in treatment T2 but 1 of them was such that the posted price was above the broker-buyer's valuation and 2 of them were such that the posted price was below the broker-seller's valuation.

UNDER-REVELATION BY PARTICIPANT TYPE

Treatment with brokers/no incentives (T2–2 groups, 24 auctions)			
	Broker	**Client**	**Direct**
All auctions	1.69	1.79	1.56
Clearing auctions	1.74	1.54	1.42
Clearing trials	1.87	1.40	1.46
Treatment with brokers/incentives 1 (T3–1 group, 12 auctions)			
All auctions	2.13	2.17	1.58
Clearing auctions	1.56	1.96	1.59
Clearing trials	1.17	2.05	1.43
Treatment with brokers/incentives 2 (T4–1 group, 12 auctions)			
All auctions	2.49	1.84	2.51
Clearing auctions	2.46	1.79	2.37
Clearing trials	2.11	1.73	2.33

Table 5: Average under-revelation in each treatment by participant type. The line "Clearing auctions" considers all trials of auctions that reached equilibrium. The line "Clearing trials" considers the last trial of clearing auctions. These calculations only consider cases where submitting an order by a participant would generate a strictly positive profit. A client is a participant whose trades transit through a broker and Direct denotes a participants trading directly with the market.

AVERAGE PAYOFF PER AUCTION BY PARTICIPANT TYPE

	Trading Payoff							
Treatment	**All**	**Broker**	**Client**	**Direct**	**Broker Comparable**	**Average Volume**	**VBI**	**Broker + VBI**
T1	5.76			5.76		15.14		
T2	5.27	2.91	5.22	7.79	3.91	16.77	0.00/unit	2.91
T3	4.85	3.71	4.54	6.93	3.24	15.43	0.10/unit	5.26
T4	4.69	2.60	4.57	7.14	3.49	14.56	0.20/unit	5.51

Table 6: Average payoff per auction by participant type. A client denotes a participants whose trades transit through a broker and Direct denotes a participant trading directly with the market. The column Broker (Trading) only considers a broker's trading payoff. VBI stands for volume-based incentives and Broker + VBI gives a broker's average payoff including his volume-based compensation. The column "Broker Comparable" shows the average payoff to participants with limit prices averaging to those of the brokers. The broker-buyer had a limit price of 52.5 and the broker-seller had a limit price of 50.5. The broker-comparable participants are the two buyers with limit prices of 52 and 53 and the two sellers with limit prices of 50 and 51.