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ABSTRACT

This study explores empirically the price dynamics within two distinct market institutions – a double oral auction, which resembles modern asset markets, and a bilateral exchange market, which represents markets that have existed for centuries. To provide a theoretical basis to our investigation, we test and compare the excess supply model (Walras (1874, 1877, 1889, 1896)) and the excess rent model (Smith (1962, 1965)) in both market institutions. Our approach is unique in that we make use of appropriate demand and supply systems coupled with randomization of the main treatment variable to discriminate between the theories. All previous efforts, including Smith's (1965) seminal experiments, use designs that cannot appropriately parse the models. We report several insights, perhaps most importantly, we consistently reject the Walrasian model in favor of the excess rent model, regardless of market institution. This finding has important implications both positively and normatively.

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1. Introduction

The functioning of markets permeates virtually every field of economics. Yet, even the most basic market underpinnings remain unresolved. For example, we know surprisingly little about the adjustment of prices when markets are in disequilibrium.[2] The dominant model to describe price fluctuations is the Walrasian excess supply model. Walras' (1874, 1877, 1889, 1896) work represents the backbone of theoretical inquiries within the economic sciences, and more broadly any modeling approach making use of equilibrium concepts in a market. One important prediction of the excess supply model is that the larger the excess supply, the more vigorous the sellers' attempts and thus the faster the decline in prices. Scores of experimental studies over the past several decades have reported strong support for Walras' model using double oral auctions (see Cason and Friedman (1993) for a review).

During his seminal investigation of the Walrasian mechanism, Smith (1962, 1965) presented a refinement of the excess supply model, which he termed the 'excess rent' model.[3] Excess rent is defined as the total rent that would be obtained if all agents who want to trade at the prevailing price were to trade (i.e., ignoring imbalances in supply and demand) minus the total rent at the competitive equilibrium. The excess rent model predicts that the greater the excess rent, the faster prices approach equilibrium. Smith (1962, 1965) reports evidence in favor of his model, rejecting the Walrasian model using a series of double oral auction markets.

An interesting puzzle therefore arises: how can the Walrasian model find broad support from vast experimental studies whereas Smith's seminal work clearly rejects the Walrasian model in favor of the excess rent model? A second consideration is that the excess supply and excess rent models are both derived intuitively rather than with rigorous microfoundations. Thus, the behavior and resulting predictions potentially apply to a range of market institutions, including constructs quite disparate from the double oral auction.

We tackle these two issues in this study. In dealing with the first issue, our experimental design leverages two important identification issues overlooked in the extant literature. When at least one out of demand and supply is strictly monotonic (which is almost always the case in the literature), then there is a bijective relationship between excess supply and excess rent. Moreover, the broader literature relies upon naturally occurring variation in prevailing prices to identify the treatment effect. By sacrificing the use of randomization to generate variation in prevailing prices, previous studies run the risk of endogeneity bias.

The second consideration is handled by pairing data from two distinct market institutions: double oral auctions (Smith (1962, 1965)), which are similar to modern asset markets, and bilateral exchange markets, which are in the spirit of Chamberlin (1948). Such markets have bilateral decentralized

[2] In economics, 'equilibrium' typically refers to a state where all agents are maximizing expected utility under rational expectations, possibly subject to a consistency/feasibility constraint, with 'disequilibrium' denoting a failure of at least one of these conditions. In this paper, 'disequilibrium' refers to a price that fails to clear a static supply and demand system rather than any alleged breakdown of rationality or feasibility.

[3] This work was prominently cited by the Nobel Prize Committee in 2002.

bargaining between multiple traders with public prices. Much like the theoretical literature of the 1980s, we regard these 'Chamberlin markets' as a realistic description of many markets, providing a substantial source of evidence on models of price dynamics, and an important extension of the markets considered in Smith (1962, 1965).[4]

We report several insights. First, a retrospective exploration of Smith (1965) suggests that his reliance on naturally-occurring data erroneously drove his rejection of the Walrasian model. Second, the bijective relationship between excess supply and excess rent inherent in previous experimental designs suggests one should re-evaluate much of the extant literature. Studies that have found support for the Walrasian model have implicitly also found support for the excess rent model. Third, using appropriate supply and demand systems and randomization of the treatment variable, we find strong support for the excess rent model versus the Walrasian model in both Chamberlin markets and double oral auction institutions.

We conclude that as microfoundations develop, great import should be given to disparate predictions across the excess rent and Walrasian models. Our exercise suggests that as empirical evidence accumulates, the excess rent model will gain broader support. If this hypothesis proves correct, then this would be a fundamental change in direction, as the Walrasian excess supply model remains the cornerstone of much of the literature's analysis of price dynamics. For example, Walrasian tatonnement is the foundation for much of the recent literature on dynamic auction design (see, e.g., Gul and Stacchetti (2000), Ausubel and Cramton (2004), Ausubel (2004), Ausubel (2006).

The remainder of our study is organized as follows. Section 2 presents a brief background of the literature and our experimental design. Section 3 summarizes our empirical results. Section 4 concludes.

2. Background and experimental design

A. Background

Despite the centrality of the market mechanism to the economics discipline, there is a dearth of models that yield testable predictions about price dynamics.[5] Moreover neither the excess supply nor excess

[4] Using strictly monotonic demand and supply systems, several studies have found support for the indistinguishable (see below) predictions of the excess supply and excess rent models (see the seminal work of Hong and Plott (1982), as we well as the studies due to Joyce (1983), List (2004) and List and Price (2005)).

[5] In an important work, Plott and George (1992) consider an alternative to Walrasian stability called Marshallian stability, and in empirical testing they find support for the latter. However the Marshallian model only generates predictions that differ to the Walrasian model when at least one out of supply and demand has a perverse slope. For a deeper look at some testable predictions about other aspects of double oral auctions, see Cason and Friedman (1993) and Cason and Friedman (1996). For an investigation of price dynamics in a double auction with three commodities (rather than the usual case of one commodity) see Anderson et al. (2004). For price dynamics in decentralized markets, see Moreno and Wooders (2002).

rent models have rigorous microfoundations.[6] Building on the theoretical bargaining literature of the 1980s, a large literature on the microfoundations of competitive equilibria emerged to fill this gap. A major strand investigated whether price-taking competitive equilibria could emerge as the outcomes of markets with bilateral negotiation as frictions – such as the discount rate or explicit bargaining costs – tended to zero (see, e.g., Rubinstein and Wolinsky (1985), Wolinsky (1988, 1990), and Gale (1987)). Yet, such models focused largely on the properties of equilibria rather than explicit predictions or explanations of price movements en route to equilibrium.[7] Gjerstad and Dickhaut (1998) provide an important middle-ground in the sense that it delves deeply into the micro behavior in markets but does not apply full rationality – traders are myopic and expectations are not fully rational.[8]

Differentiating the excess supply and excess rent model

We are tempted to use the abundant data from experimental double oral auctions and Chamberlin markets to compare the two models, but there is an important identification issue limiting this approach. When at least one out of demand and supply is strictly monotonic (almost always the case), then there is a bijective relationship between excess supply and excess rent. This presents two options to the researcher.

First, the researcher can simply accept that there is nothing in the theory alone that permits discriminating variation in excess supply/rent.[9] Consequently, studies that have found support for the excess supply model have implicitly also found support for the excess rent model.

Second, the researcher can make functional form assumptions such as linearity, e.g., Alton and Plott (2008). The problem with this approach is that the assumption is arbitrary; while econometricians regularly assume linearity, it is extremely rare that linearity is a necessary condition for identification. Moreover using their data, they find little evidence of the econometric superiority of one model over the other, casting doubt about the usefulness of such arbitrary assumptions.

Smith (1965) sidesteps this problem by noting that in a constant excess demand and supply system (Figure 2) excess supply is constant but excess rent still varies over a range of prices. This allowed Smith

[6] Interestingly, Walras never came up with the idea of a central auctioneer, nor did he even mention any institution that could even vaguely be contorted into a centralized market mechanism (Walker (1996)). Walras' description of the equilibration process clearly corresponded most closely to what we refer to as a Chamberlin market, i.e., bilateral decentralized bargaining between multiple traders with public prices (Chamberlin (1948)).

[7] This was probably at least in part due to the analytical complexity of the models. Another strand of the literature looked at the properties of bilateral bargaining but without taking the limit as frictions go to zero. See for example Cramton (1984), Perry (1986), Chatterjee and Samuelson (1987), Samuelson (1992) and Taylor (1995). Rustichini et al. (1994) and Cason and Friedman (1997) examine similar issues in single call markets rather than bilateral negotiations.

[8] Cason and Friedman (1993) also present insightful models with testable predictions. However they are either based on comparatively stylized forms of bounded rationality or the sharper predictions (such as the order in which traders trade) do not pertain to the path of prices.

[9] Technically, excess supply and excess rent are not variation free (see Heckman (2000)). If either model made specific functional form predictions, then one might still be able to compare them. However both only provide qualitative predictions.

to compare predictions from the competing models using data from experimental double oral auctions. Smith reports broad support for the excess rent model using this institution. While this design is quite elegant, rather than randomizing the prevailing market price, Smith (1965) relied upon naturally occurring variation in prices to differentiate the models. Empirically, such an approach may prove problematic as the key treatment variable of interest (prevailing prices) is endogenously determined.

With this concern in mind, we provide a retrospective look at Smith's (1965) data. Our analysis suggests that Smith's reliance on naturally-occurring data erroneously drove rejection of the Walrasian model. As Smith himself noted, one cannot get too close to the equilibrium price p^* as the excess supply model suffers from a floor effect. This is so because it predicts a constant discrete rate of change of prices χ whatever the prevailing price p_{t-1} unless $p_{t-1} + \chi \leq p^*$, in which case it predicts that prices simply fall to equilibrium (otherwise there would be oscillation). This implies that if identifying variation in p_{t-1} occurs in the range $p_{t-1} \in [p^*, p^* + \chi]$, the excess supply and excess rent models are indistinguishable.

Naturally, if χ is known, then one need only avoid the region $[p^*, p^* + \chi]$. Unfortunately, there are no grounds for reliably specifying χ ex ante. Smith assumed that $\chi \leq \$0.05 = 0.045(v - c)$, i.e., within 4.5% of the trading tunnel's height from the equilibrium price, and he showed that his results were unaffected by dropping data points in the relevant range. Unfortunately, his results are not robust to assuming a larger value of χ.

To see this, we reconstruct Smith's original data.[10] Table 1 is a reproduction of *Table 2* from Smith (1965). In (our) Table 3, we extend the models that Smith estimated.[11] In models 1 and 2, we increase the proportion of prices that Smith dropped from 4.5% to 25%. In one of the two, excess rent loses its statistical significance, and importantly the excess supply model seemingly outperforms the excess rent model.

The picture becomes even more blurred when we note another drawback to Smith's (1965) design. Smith (1965) pooled data from three different constant excess systems: one with a constant excess supply of 2 units, one with 5 units and one with 8 units. This assumption of a homogenous treatment effect is not theoretically motivated. Moreover, it is reasonable to expect that the causal effect is heterogenous across these systems. For example, a prevailing price that is \$12 over equilibrium in a market with an excess supply of 2 units would intuitively generate different price dynamics to a prevailing price that is \$3 over equilibrium in a market with an excess supply of 8 units, even though both imply identical excess rent.

With this in mind, models 3-to-5 in Table 3 replicate model 5 from Table 1 but conditions on one of the three possible constant excess supplies (2 units, 5 units and 8 units). Models 6-to-8 from Table 3

[10] We reconstructed Smith's data from figures in his paper. In principle, all of his data are shown, though the grid has imperfections and therefore the dataset that we have constructed cannot be ensured to be exactly as the original. Nevertheless, using Smith's regression tables as a benchmark, we are able to achieve a high degree of accuracy in our recovered data. Table 1 is a recreation of Table 2 from Smith (1965), and Table 2 is our attempt at reproduction. Visual inspection confirms that our reconstruction is extremely accurate.

[11] Smith (1965) did not use clustered standard errors. To maintain comparability in Table A3, neither do we, though using them does not affect our results.

replicate 3-to-5 from Table 3 but with 25% of the tunnel dropped. Importantly, when we implement these additional controls, only one of the six regressions yields a significant effect of excess rent – calling into question Smith's interpretation of the data.

The homogeneous treatment effect assumption is actually much stronger than just described. A demand and supply system is defined by the values/costs of its participants. Every time a pair of traders strikes a deal and exits the market, the system has changed as there are now two fewer traders. The change is unlikely to be appreciable in real markets with hundreds or thousands of traders, but in a market with below 30 traders, the two traders exiting represent anywhere from 7%-33% of the market.[12] Moreover in non-constant excess systems, where sellers and buyers are not homogenous, the shapes of the supply and demand schedules can change substantially after a pair trade and exit. Smith (1965) and the subsequent literature assume a treatment effect that does not vary with respect to the system by pooling data. Smith did not collect enough data for us to explore if this assumption affects his results, but as discussed below we design our markets to avoid the need for making such assumptions.

In conclusion, our retrospective analysis calls into question Smith's (1965) received results, and casts doubt on whether the excess rent model is appropriate. In light of the literature, one might even argue that with this re-analysis, the weight of evidence is now in favor of the Walrasian model. We view this conclusion as premature at this point since the broader literature has difficulty parsing the models, as discussed above.

To facilitate further reassessment, we introduce an important modification to Smith's (1965) design. We manipulate p_{t-1} to ensure that it is well away from the equilibrium. We achieve such manipulation by announcing to traders – immediately prior to the start of trading – that "in a similar market to the one you are about to participate in, a trade occurred at price *X*," where *X* is randomly selected.[13] Naturally, experimenter manipulation and randomization go hand in hand. As we will demonstrate in the results section, our strategy leads to a resurrection of Smith's potentially erroneous siding with the excess rent model.

B. Research questions and identification strategy

Let p_{t-1} denote the prevailing price at time t and let $\Delta p_t = p_t - p_{t-1}$ denote the rate of change of prices at time t.

[12] Smith's constant excess experiments had 11 buyers and either 13, 16 or 19 sellers. See Alton and Plott (2007, 2008) for pioneering ways of modeling a continuous in- and out-flow of traders.

[13] It should be noted that Plott and George (1992) also announce prices prior to the start of trading. However, they do so in a different way and for a different reason. They construct demand and supply systems with multiple equilibrium types to see which are most stable. Natural variation in prices seldom led subjects starting in one of the equilibrium types, precluding a test of its stability. Hence, the authors used announcements to induce the subjects into the desired equilibrium. Thus their motivation had nothing to do with addressing potential endogeneity. Moreover, they never used variation in an induced price as a (randomized) treatment variable.

Research question 1: In a constant excess demand and supply system, what is the causal effect of the prevailing price(p_{t-1}) on the rate of change of prices (Δp_t)?

Aside from the floor effect, Walras' excess supply model predicts a causal effect of zero, while Smith's excess rent model predicts a negative causal effect. Yet, we should note that this method of inquiry has an important caveat. Suppose that the data generating process is:

$$p_t = \alpha + \beta p_{t-1} + u, -1 < \beta < 1$$

Where u is exogenous white noise. This is a stationary process with a mean of $E(p_t) = \alpha/(1-\beta)$. Let p^* be the economically predicted equilibrium price (i.e., the intersection of demand and supply). The excess rent model predicts either convergence from above $(0 < \beta < 1)$ or, in an extreme case, instantaneous equilibration $(\beta = 0, \alpha = p^*)$. The non-equilibrium pure white noise process $(\beta = 0, \alpha \neq p^*)$ is inconsistent with the excess rent model.

If we estimate the model:

$$\Delta p_t = \alpha + \theta p_{t-1} + u$$

Then $\beta = \theta + 1$. Thus, while $-1 \leq \theta < 0$ is necessary for the excess rent model, it is not sufficient. If we find that $(\theta = -1, \alpha \neq p^*)$, then the data generating process is possibly non-equilibrium pure white noise.

Consequently, if we reject $\alpha = p^*$, then to distinguish our findings from white noise, we must demonstrate that $\theta < 0$ *and* $\theta > -1$. This is equivalent to demonstrating that our exogenous price inducement procedure on p_{t-1} has a significant impact on p_t $(\beta > 0)$.

Research question 2: Does the answer to research question 1 depend upon whether the prevailing price (p_{t-1}) is randomly induced versus naturally occurring?

Experimenter control over treatment variables and the concomitant randomization is desirable even if a plausible endogeneity story about natural data fails to spring to mind. However, as discussed above there are explicit grounds for doubting Smith's (1965) results.

A further purpose of the study is comparing the excess rent and excess supply models across different trading institutions. We chose the Chamberlin market and double oral auction principally to extend the domain of testing the models. With respect to the models' testable predictions, we are interested in examining if our conclusions are consonant across both institutions. However, it is interesting to explore for additional differences between Chamberlin markets and double oral auctions as a potential avenue to explore microfoundations. This leads to our third and final research question:

Research question 3: Are there fundamental differences in the distribution of prices or in price dynamics between Chamberlin and double oral auctions markets?

C. Procedure

1. Market structure

To discriminate between the excess supply and excess rent models, we use a constant excess demand and supply system with two buyers with value v and four sellers with cost c, implying a constant excess supply of 2 units. No information about any aspect of the market is given to the subjects beyond generic instructions on how to trade (see the Appendix for the experimental instructions). To ensure that the results are not driven by unfamiliarity with the protocol, we have subjects participate in four distinct markets.[14] This carries the risk of subjects augmenting their learning about the protocol with learning about the values/costs of the market. To account for this possibility, we employ several strategies.

First, values and costs are displaced by a common additive constant between rounds. Thus, for example if in round 1, $v = \$20$ and $c = \$10$, then in round 2 they might be $v = \$75$ and $c = \$65$. This process and the values of the constants are not declared to the subjects. Moreover, the chosen constants ensure no overlap of the bargaining tunnels between any two rounds.

Second, we vary the surplus in each system. For two of the rounds, the available surplus per trade is \$8 (low surplus), while for the other two it is \$16 (high surplus). Unbeknownst to subjects, markets alternate. Having two substantively different systems also serves as a simple robustness check.

Third, in addition to the six 'active' traders, there are four 'inactive' traders in each round. Two are buyers with values that are below c and two are sellers with costs that are above v (see Figure 3). Unbeknownst to subjects, the inactive traders can never trade in the round - only trades that imply weakly positive earnings for both traders are permitted.

Finally, which trader is active or inactive in a particular round changes over the four rounds. It is common knowledge that buyers (sellers) remain buyers (sellers) for all four rounds, but each buyer is active for two, while each seller is active for between two and four.

To summarize, each session has 10 subjects who are randomized an ID (from ID1 to ID10) at the beginning of the session. They then participate in four real rounds of trading with the values/costs in Table 4. Each round has exactly two trades.

To maximize clarity, values/costs are denominated in US\$ and gross earnings for each subject are simply the aggregate of that subject's earnings across all four rounds. Each trader also receives a trading commission of \$0.25 per trade.

[14] Prior to the four real rounds, subjects also do two practice rounds – one as a seller and one as a buyer – to further promote familiarity with the trading procedure.

2. Trading rules

The 10 subjects are seated facing the monitor. We run principally Chamberlin markets, but to facilitate comparability with Smith (1965) we also run double oral auctions.[15] Chamberlin markets operate according to the following rules. Each trading round lasts 3 minutes. During a trading round, negotiations can take almost any form.[16] Subjects are instructed to approach the monitor after agreeing upon a contract. The monitor ensures that the trade is legitimate (both subjects are earning weakly positive amounts), after which the monitor publicly declares the trade price.[17]

3. Price inducement and treatments

In each round, after value/cost cards are handed to each subject, the monitor makes the following statement:

> "In a similar market to the one you are about to participate in, a trade occurred at price \$$X$. You may now begin trading."

where the prevailing price X is randomized.[18] We view the randomization of prices to be an important design innovation as it affords the research a means to avoid the types of problems discussed in Section 2.A. Of course, there are alternative inducement mechanisms. One is to wait for a certain amount of time after the start of trading and then make a comparable statement. In principle, this decreases the risk of a priming effect of our statement. Another alternative is to introduce confederates and to have them trade at a pre-arranged, randomized price after a certain amount of time.

We reject both these alternatives for the same reasons. First, piloting indicated that the first trade would often happen very quickly (within 20 second or less of the beginning of trading). Second, negotiations were often so vigorous that subjects would not be paying much attention to such a statement by the monitor. In double oral auctions, at most one person is talking at any point and so prices of completed trades are very salient. In the trading-pit environment of a Chamberlin market with excess supply, our chosen method of inducing prices was likely the highest-power method of testing the excess rent model.

Moreover, it should be noted that independent of and simultaneous to our study, Crockett et al. (2009) implemented a different method for generating exogenous variation in the prevailing price to test the Gale model: explicit price controls, i.e., preventing participants from trading below or above certain

[15] See Smith (1965) for the double oral auction procedure used and List (2004) for a more detailed description of the Chamberlin market.
[16] No inappropriate threats, no side payments and no revelation or discussion of values/costs.
[17] The substantive differences in the double oral auctions is that the only communication permitted is bids and offers when called upon by a monitor (the subject must raise his/her hand).
[18] To avoid deception, the induced price was a naturally occurring price obtained from a previous pilot that did not involve any price inducement.

prices.[19] For their study, this method served its purpose well, as they aimed for exogenous trades within a certain range. However, for the purposes of comparing the excess supply and excess rent models, our method adds an important dimension.

Making a price announcement about a trade occurring in a similar market is a good simulation of the information content usually carried by naturally occurring prevailing prices. Traders can look at their values/costs and make an inference about their standing compared to the market, since the prevailing price gives them a lower (upper) bound on the value (cost) of at least one trader. This process is essential to the described mechanics of the excess rent model and therefore it is an important inclusion for its testing. In fact, the alleged superiority of markets to central planning rests on the ability of the prevailing price to transmit relevant information about the state of the market. In contrast, if one were to use purely price controls that were unrelated to any previous market activity, traders learn nothing immediately and must wait to start trading before they can learn something about their standing compared to the remaining traders.

Under the assumption that shifting the values/costs by a common additive constant does not affect market dynamics (an assumption that we test below and fail to reject), our sessions examine two markets only: \$8-per-trade surplus and \$16-per-trade surplus. Another design innovation is that our inference will be based on different prevailing prices (p_{t-1}) in the same demand and supply system. As discussed above, there is nothing in the formulation of either the excess supply or excess rent model that requires structural causal effects to be identical across demand and supply systems. The models make predictions only about causal effects within a system defined in the narrowest possible sense.

All of our identification is based on prevailing prices that vary across identical demand and supply systems. Thus, we compare behavior from the same round between sessions. This raises the question of which induced prices maximize power. The excess rent model predicts a monotonic relationship between excess rent and price movements. Moreover, while there may be heteroskedasticity in price movements, we had no a priori reason to expect any particular form of heteroskedasticity. Thus, the highest power test would be to share the observations equally between the highest and lowest possible trade prices only.

However, as Smith (1965) noted and as discussed above, one cannot get too close to the equilibrium price p^* as the excess supply model suffers from a floor effect. Smith assumed that this floor occurred at 4.5% of the constant per-trade surplus above p^*. We provide extra clearance by selecting a low induced price that is 25% of the constant per-trade surplus above p^*. On the high side we selected an induced price that is 75% of the constant per-trade surplus above p^*. We wanted to avoid the highest possible price because we wanted to be able to check for a priming effect, and this would require trade prices to be both above and below the induced price.

[19] Plott (2000) had previously used price controls, but never to address potential endogeneity bias; rather he was doing it to expand the support of the treatment variable, e.g., to see what happens when prices are near a certain equilibrium. In other words, his is a variant on the method used in Plott and George (1992).

Table 5 details the high and low induced prices used in each round. We ran two session types: in session type 1, the induced price sequence across the four rounds was *low-low-high-high*, while in session type 2 it was *high-high-low-low*.

3. Empirical results

We ran 20 Chamberlin market sessions and 14 double oral auction sessions in two locations (George Mason University and University of Tennessee at Knoxville).[20] Subjects were recruited using campus databases of subjects who had declared an interest in economics experiments. Including check-in and payment processing, sessions lasted approximately 45 minutes and subjects earned an average of roughly $20.

To add structure, we should note that each session had four markets where the active buyers had a common value v and the active sellers an active cost c. And, each market had an induced price p_0, which takes one of two values: a low one, $p_0^L = c + 0.25(v - c)$ and a high one, $p_0^H = c + 0.75(v - c)$. Two trades occur at prices p_1 and p_2. Let $\Delta p_1 = p_1 - p_0$ and $\Delta p_2 = p_2 - p_1$.

- For identification using exogenously induced variation, the treatment variable is p_0 and the outcome variable is Δp_1.
- For identification using naturally occurring variation, the treatment variable is p_1 and the outcome variable is Δp_2.

Table 6 and the accompanying Figure 4 contain a summary of the experimental data. In this summary, to provide a first glimpse of data patterns we have ignored statistical dependencies and pooled over systems where values and costs have been displaced by a common additive constant. As we discuss each result below, we supplement these raw data patterns with a conditional empirical analysis that accounts for data dependencies. We provide a first result:

Result 1a: In a constant excess demand and supply system, the causal effect of the prevailing price (p_0) on the rate of change of prices (Δp_1) is negative in both Chamberlin and double oral auction markets.

This finding strongly supports the excess rent model over Walras' excess supply model. Evidence to support this result can be seen in Table 6 and Figure 4, where the difference between the *induced price* and *trade price 1* is larger under the high induced price than under the low one. If we normalize the estimated treatment effects so that they correspond to a $1 increase in the induced price, the estimated treatment effects are:

- -$0.87/trade in a low surplus Chamberlin market.
- -$0.64/trade in a high surplus Chamberlin market.
- -$0.64/trade in a low surplus double oral auction.
- -$0.77/trade in a high surplus double oral auction.

[20] Kolmogorov-Smirnov tests confirm that we can pool data across the two locations.

All of these differences are statistically significant at the p < 1% level using Mann-Whitney tests.

These unconditional tests treat observations as IID. As a robustness check, we estimate conditional parametric regression models that include round dummies and session clusters. Empirical results are contained in Table 7. Importantly, they mirror the unconditional results described above.

We have used the absolute rate of change of prices as the outcome variable. Technically, neither the excess supply nor the excess rent models specify using the absolute rate of change of prices, and so one could plausibly use the proportionate rate of change $(\Delta p_1)/p_1$ instead. Doing so does not affect result 1a, so we make these results available upon request.

We have used a mixture of between and within subject variation to estimate causal effects (clustered standard errors are not elixirs). An even more conservative approach is to use the data from the first round of each session only, i.e., exclusively between variation. Since we did not use a full-factorial design, we can only complete this exercise using data from the low surplus Chamberlin and double oral auction markets. Result 1a is again unaffected.

As a final robustness check, recall that we induce the prevailing price by making a statement about an actual trade price in a similar market in a previous session. Since this information is delivered by the monitor, there is a risk of an experimenter demand effect. The subjects could consciously or unconsciously be primed to seek a trade at the announced prevailing price.

To see if result 1a is sensitive to this possibility, we repeat the hypothesis tests omitting either (1) all observations where the first trade price is equal to the induced price, or (2) all observations where the first trade price is within $1 of the induced price. Result 1a remains unaffected.

In all four market-types (high vs. low surplus and Chamberlin vs. double oral auction), using Wald tests, we strongly reject (p < 1%) the hypothesis that $p_1 = p^*$. Thus, to ensure that result 1a is not spurious, we need to demonstrate that p_0 has a treatment effect on p_1. This leads to our next result:

Result 1b: Result 1a is not a spurious reflection of white noise. Trade price 1 (p_1) responds to the induced price (p_0).

Evidence to support this result can be seen in Table 6 and Figure 4, where p_1 is always larger under the high induced price than under the low induced price. In three of the four cases (all but high surplus Chamberlin), Mann-Whitney tests reject the hypothesis that p_0 has a zero causal effect on p_1 (p < 1%, p < 4%, p < 10%; p = 28% in the remaining case). Using the conditional estimates in Table 7, we find similar results if one tests the hypothesis that the coefficient on p_0 is equal to -1.

This also speaks to the effectiveness of our price inducement procedure in simulating a genuine prevailing price. The trade price from a previous session carries substantial information that affects subsequent trade prices. We now turn to our next result:

Result 2: Result 1a is unaffected by using naturally occurring data.

This result shows that in our data, endogeneity bias alone is not driving the insights gained from the naturally-occurring data. Evidence to support this result can be seen in Table 8. Note that in the naturally occurring data, the treatment variable is the first trade price, p_1. Unlike the induced price p_0, this takes many values and hence we are forced to use a parametric model to estimate the causal effect.

In all four markets, the causal effect of the prevailing price on the rate of change of prices is negative. It is tempting to compare the magnitudes of the coefficients from the naturally occurring data to those from the exogenous data. However, these are different markets: there are two less traders, so the demand and supply system has changed.

Similar to result 1a, result 2 is also robust to using proportional rates-of-change in prices, as well as using exclusively between-session variation (round 1 data only).

As the tables and figures make clear, our conclusions are robust to changes in market institution, however, it is informative to test for differences between Chamberlin and double oral auction markets. Upon doing so, a final result emerges:

Result 3: The relationship between the induced price and the first trade price is the <u>same</u> across trading institutions. The relationship between the first and second trade prices <u>differs</u> by trading institution. Specifically, in double oral auctions, the second trade price exhibits greater dependence on the first trade price.

Examining Table 6, if we compare data cells by trading institution using Kolmogorov-Smirnov and Mann-Whitney tests, then we fail to reject equality with only one exception: *trade price 2* is significantly larger in the high surplus Chamberlin market ($3.5) than in the high surplus double oral auction ($2.0). However, even if each cell in Table 6 was identically distributed across trading institution, it would still be possible for the relationships between *induced price* (p_0) and *trade price 1* (p_1), or *trade price 1* (p_1) and *trade price 2* (p_2), to differ substantially.

In Table 7, the differences in the point estimates across trading institution are quite small ($0.24/trade for low surplus and $0.12/trade for high surplus). Pooling the data across institution and including full interaction terms confirms that these differences are statistically insignificant at conventional levels. For parsimony, we make the results available upon request.

In Table 8, the differences in the point estimates across trading institution are large and positive ($0.52/trade for low surplus and $0.70/trade for high surplus). Pooling the data across institution and including full interaction terms confirms that these differences are statistically significant at conventional levels. As such, trade prices are more persistent in double oral auctions, yet it is important to highlight that these behavioral differences do not affect our conclusions concerning the excess supply model versus the excess rent model.

4. Conclusion

Understanding price dynamics within and across market institutions merits serious consideration. If prices do not follow the Walrasian excess supply model, the cornerstone of theoretical inquiries within the economic sciences is directly called into question. While Smith (1965) provides strong support refuting the Walrasian excess supply model using double oral auction markets, there are methodological concerns underlying his fundamental design. Adding to this concern is the fact that scores of experimental studies report evidence consistent with the Walrasian model. An honest appraisal of the literature provides one with the realization that the correct price adjustment model remains largely unknown.

This study attempts to provide clarity to these issues by using randomization in a constant excess demand and supply system across two distinct market institutions. This approach permits us to discriminate between the models using experimental variation of the key variable (the prevailing price). We find strong support for the excess rent model in both Chamberlin markets and double oral auctions. We find that the bijective relationship between excess supply and excess rent inherent in previous experimental designs suggests one cannot make strong inference from the extant literature.

At this point, it is important to note that the intuitive derivation of the excess supply and excess rent models means that they only generate one qualitative prediction. And, it is one that they share for most demand and supply systems. In principle, however, they can yield a rich array of testable predictions – predictions that potentially help us gain a more rigorous understanding of price dynamics. We hope that our research will spur explorations of microfoundations, lending deeper insights into predictions across the excess rent and Walrasian models. As this is done, our exercise can be viewed as providing support for the extant predictions of the excess rent model, but richer tests will surely arrive as research intensifies on this issue. In this manner, perhaps the most important area for future research is to flesh out the microfoundations of the models to generate additional testable predictions.

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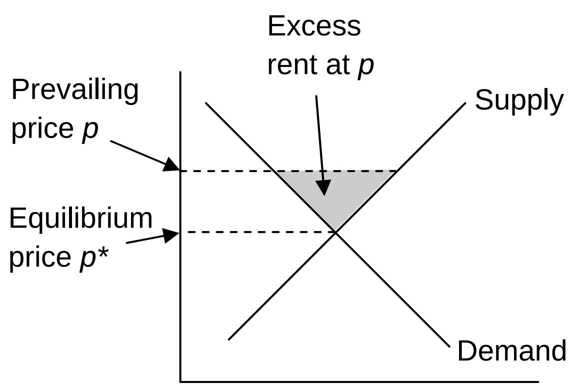

Figure 1: Excess rent

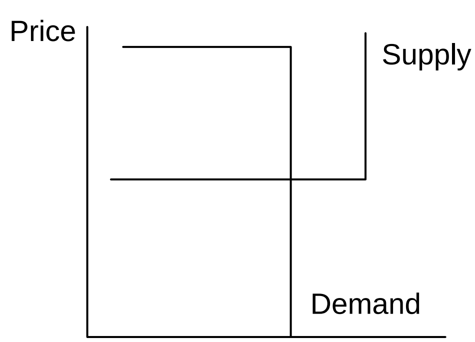

Figure 2: Smith's swastika (constant excess supply) system

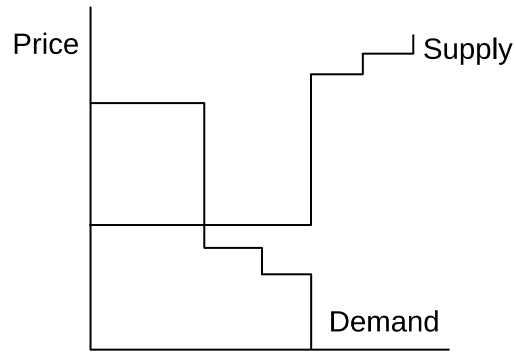

Figure 3: Swastika demand and supply system used in experiments

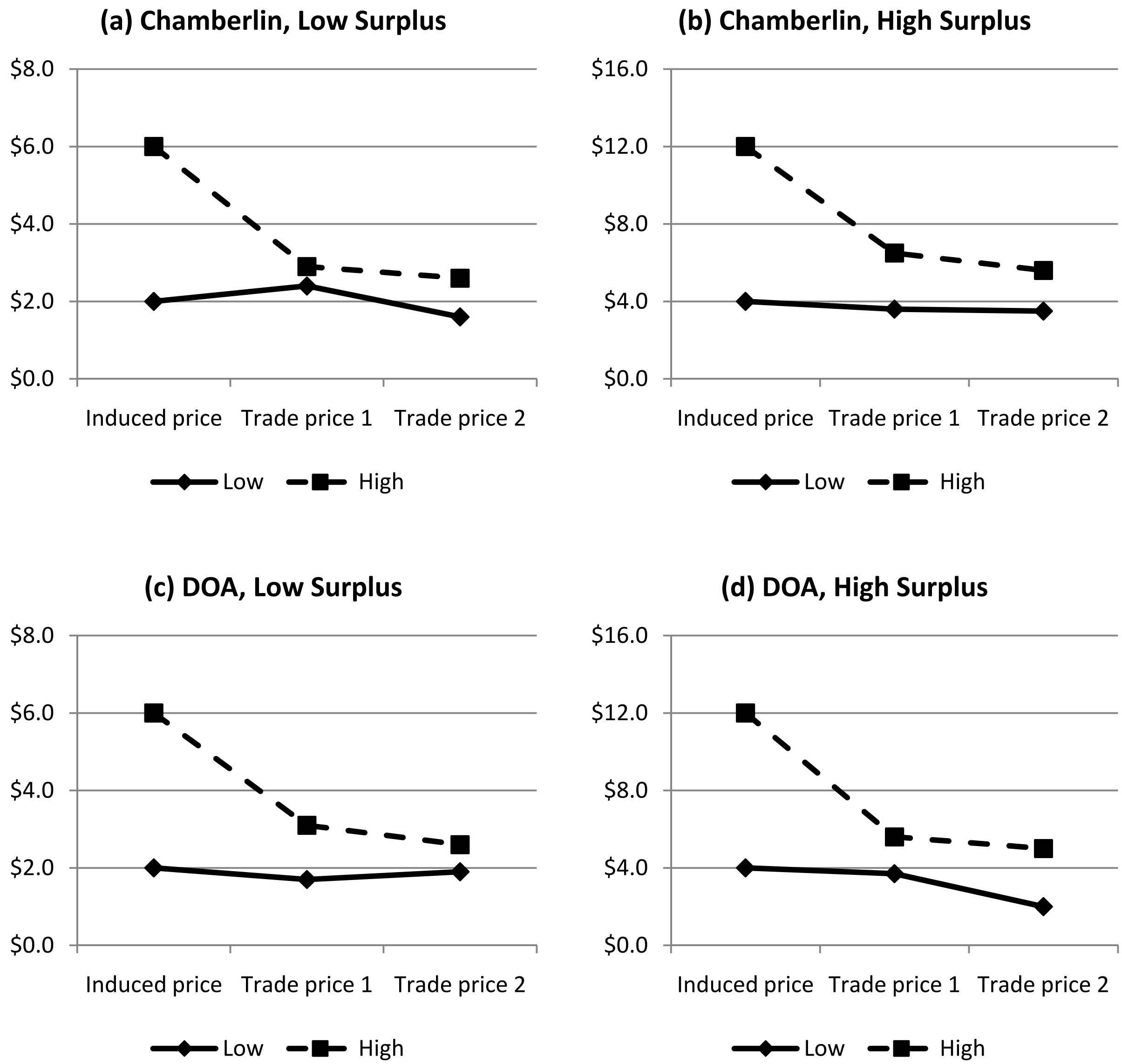

Figure 4: Average trade prices by institution and surplus

DOA denotes double oral auction. Low (high) surplus denotes a market where the per-trade surplus is $8 ($16). All markets have been transformed by an additive constant such that the common seller cost is $0. Figures correspond to data in Table 6.

Model	1	2	3	4	5	6
Excess rent	-0.023***	-0.021***	-	-0.021***	-0.019***	-
Standard error	(0.005)	(0.005)	-	(0.007)	(0.006)	-
Excess supply	0.220	-	0.026	0.152	-	-0.255
Standard error	(0.195)	-	(0.197)	(0.299)	-	(0.268)
Constant	-0.613	0.342	-1.332	-0.682	-0.200	-0.952
Standard error	(1.108)	(0.597)	(0.507)	(1.307)	(0.892)	(1.327)
% of tunnel dropped	None	None	None	4.5%	4.5%	4.5%
Observations	259	259	259	189	189	189

Table 1: Table 2 from Smith (1965)

The dependent variable in all regressions is Δp_t. Asterices denote statistical significance (* = 10%, ** = 5%, *** = 1%).

Model	1	2	3	4	5	6
Excess rent	-0.023***	-0.022***	-	-0.021***	-0.019***	-
Standard error	(0.005)	(0.005)	-	(0.007)	(0.006)	-
Excess supply	0.225	-	0.025	0.152	-	-0.255
Standard error	(0.198)	-	(0.200)	(0.299)	-	(0.268)
Constant	-0.603	0.373	-1.326	-0.682	-0.200	-0.952
Standard error	(1.048)	(0.601)	(1.074)	(1.307)	(0.892)	(1.327)
% of tunnel dropped	None	None	None	4.5%	4.5%	4.5%
Observations	259	259	259	191	191	191
R^2	0.074	0.069	0.000	0.046	0.044	0.005

Table 2: Attempted reconstruction of Table 1 using data inferred from charts

We reconstructed Smith's data by studying the figures in his paper. In principle, they show all the data, though the grid has some imperfections and so the dataset that we have constructed is not exactly the same as the original. Nevertheless, using Smith's regression tables as a benchmark, we are able to achieve a high degree of accuracy in our recovered data. Table 1 is recreation of Table 2 from Smith (1965), and Table 2 is our attempt at reproducing it. The dependent variable in all regressions is Δp_t. Asterices denote statistical significance (* = 10%, ** = 5%, *** = 1%). Visual inspection confirms that our reconstruction is extremely accurate.

Model	1	2	3	4	5	6	7	8
Excess rent	-0.034	-0.026**	-0.019	-0.022	-0.019	-0.229**	-0.030	-0.005
Standard error	(0.025)	(0.012)	(0.021)	(0.013)	(0.012)	(0.092)	(0.040)	(0.054)
Excess supply	0.497	-	-	-	-	-	-	-
Standard error	(1.241)	-	-	-	-	-	-	-
Constant	0.998	1.423	-0.300	-0.175	0.454	18.778**	1.660	-4.109
Standard error	(2.781)	(2.555)	(1.198)	(2.277)	(2.478)	(7.95)	(10.142)	(18.393)
% of tunnel dropped	25%	25%	4.5%	4.5%	4.5%	25%	25%	25%
Excess supply	Pooled	Pooled	2	5	8	2	5	8
Observations	70	70	89	56	46	33	24	13
R^2	0.066	0.064	0.009	0.048	0.048	0.165	0.025	0.001

Table 3: Extended results using data recovered from Smith (1965)

The dependent variable in all regressions is Δp_t. Asterices denote statistical significance (* = 10%, ** = 5%, *** = 1%).

ID	**Role**	**Round 1 value/cost**	**Round 2 value/cost**	**Round 3 value/cost**	**Round 4 value/cost**
1	Buyer	$21	$24	$80	$66
2	Buyer	$21	$41	$81	$49
3	Buyer	$12	$41	$90	$48
4	Buyer	$11	$23	$90	$66
5	Seller	$13	$42	$91	$50
6	Seller	$13	$25	$92	$67
7	Seller	$13	$25	$82	$68
8	Seller	$13	$25	$82	$50
9	Seller	$22	$25	$82	$50
10	Seller	$23	$43	$82	$50

Table 4: Roles, values and costs for the 10 subjects by round

Shaded values correspond to 'active' traders, i.e., those who have a value/cost that actually permits trade. Rounds 1 and 3 are low surplus ($8 per trade) and 2 and 4 are high surplus ($16 per trade).

Session type	Round 1	Round 2	Round 3	Round 4
1	$15 ($13, $21)	$29 ($25, $41)	$88 ($82, $90)	$62 ($50, $66)
2	$19 ($13, $21)	$37 ($25, $41)	$84 ($82, $90)	$54 ($50, $66)

Table 5: Induced prices by round and session type

The first number in each cell is the induced price. The first number in parentheses is the cost of the active sellers, and the second number is the value of the active buyers.

Institution	Surplus	# Obs	Induced price	Trade price 1	Trade price 2
Chamberlin market	Low ($8): c = $0, v = $8	20	Low: $2	$2.4 ($1.7)	$1.6 ($1.3)
		20	High: $6	$2.9 ($1.9)	$2.6 ($1.8)
Chamberlin market	High ($16): c = $0, v = $16	19	Low: $4	$3.6 ($1.9)	$3.5 ($1.4)
		20	High: $12	$6.5 ($3.1)	$5.6 ($3.3)
Double oral auction	Low ($8): c = $0, v = $8	14	Low: $2	$1.7 ($1.2)	$1.9 ($0.9)
		14	High: $6	$3.1 ($2.0)	$2.6 ($2.4)
Double oral auction	High ($16): c = $0, v = $16	14	Low: $4	$3.7 ($2.4)	$2.0 ($1.8)
		14	High: $12	$5.6 ($3.1)	$5.0 ($2.7)

Table 6: Summary statistics

Figures are sample means and standard deviations (in parentheses). All markets have been transformed by an additive constant such that the common seller cost is $0 (formal tests generally fail to reject any pooling). Note that we lost one observation from the high surplus, low induced price Chamberlin market.

Trading institution Surplus per trade	Chamberlin market Low	Chamberlin market High	Double oral auction Low	Double oral auction High
Prevailing price (p_0)	-0.88***	-0.64***	-0.64***	-0.77***
Standard error	(0.15)	(0.09)	(0.15)	(0.13)
Observations	40	39	28	28
R^2	0.54	0.52	0.50	0.58

Table 7: Regression model of the causal effect of the prevailing price on the rate of change of prices using exogenously induced variation in the prevailing price

The dependent variable in all regressions is Δp_1. All models include a constant and time effects (both omitted from the table). Standard errors are corrected for clustering. Asterices denote statistical significance (* = 10%, ** = 5%, *** = 1%).

Trading institution Surplus per trade	Chamberlin market Low	Chamberlin market High	Double oral auction Low	Double oral auction High
Prevailing price (p_1)	-0.82***	-0.93***	-0.30*	-0.23**
Standard error	(0.18)	(0.21)	(0.15)	(0.08)
Observations	40	39	28	28
R^2	0.55	0.51	0.15	0.16

Table 8: Regression model of the causal effect of the prevailing price on the rate of change of prices using natural variation in the prevailing price

The dependent variable in all regressions is Δp_2. All models include a constant and time effects (both omitted from the table). Standard errors are corrected for clustering. Asterices denote statistical significance (* = 10%, ** = 5%, *** = 1%).

Experimental instructions

Today, we are going to set up a market in which some of you will be buyers and some of you will be sellers. The commodity to be traded is divided into distinct items, or "units". We will not specify a name for the commodity; we will simply refer to units.

Trading will occur in a sequence of trading rounds. The prices that you negotiate in each round will determine your earnings. You will be paid all earnings for the session at the end of the session in cash.

The experiment will consist of 6 rounds. The first 2 rounds will be practice and will not affect your earnings for the experiment.

Every round, you will get a card. The card will indicate whether you are a buyer or a seller for that round. During the practice rounds, you will be both a buyer and a seller. Once we have completed the practice rounds, you will be assigned the role of either a buyer or a seller and will remain in that role throughout the remainder of the session.

Prior to the start of each round, sellers will be provided a seller's card. The number on the sellers' card is known as their "cost". Your cost represents the minimum amount for which you can sell a unit. This information contained on the seller's card is strictly private. A seller's costs may change each round.

Sellers earn money by selling units at prices that are above their cost. Earnings from the sale of each unit are the difference between the sale price and the cost. For example, if a seller has a cost of $10 and sells their unit for $15, they earn $15 – $10 = $5.

If a seller does not sell their unit, they earn exactly zero that round. You will only be allowed to sell at a price equal to or greater than your cost. If you attempt to sell a unit at a price that is less than your cost, your trade will be cancelled.

Prior to the start of each round, buyers will be provided a buyer's card. The number on the buyers' card is known as their "value". Your value is represents the maximum amount for which you can purchase a unit. The information contained on the buyer's card is strictly private and a buyer's value may change each round.

Buyers earn money by buying units at prices that are below their value. Earnings from the purchase of each unit are the difference between the value and the purchase price. For example, if a buyer has a value of $20 and buys a unit for $12, they earn $20 – $12 = $8.

If a buyer does not buy a unit, they earn exactly zero that round. You will only be allowed to buy at a price equal to or below your value. If you violate attempt to purchase a unit at a price that is greater than your value, your trade will be cancelled.

In addition to earnings from buying (selling) at a price that is less than your value (greater than your cost), we will provide a commission of 25¢ to both the buyer and seller for each unit traded.

[Chamberlin markets]

Each trading round will be up to 3 minutes long. During the round, you can approach anyone to negotiate a potential sale/purchase. There are three rules that you must follow during the experiment.

1. You are not allowed to threaten or intimidate other traders.
2. You are not allowed to discuss or disclose your cost or value with any other trader.
3. You are not allowed to discuss post-session side payments with any other trader.

If you violate any of these rules, you will be asked to leave the experiment and will earn nothing for participating.

If you make a trade, you and your partner should approach me immediately and inform me of the trade price to confirm that it is a legitimate trade. Remember that you cannot trade in a way that gives you negative earnings. That means sellers can only trade at a price above their cost and buyers can only trade at a price below their value.

After any pair trade and I have a record of their trade price, I will call out their trade price so that all the remaining participants can hear it.

I will now hand out practice trading cards. Remember: you are not allowed to discuss the information on the cards with any other trader. Please take care not to reveal it accidentally to curious traders looking over your shoulder.

[DOA]

Each trading round will be up to 3 minutes long. Once the market is open, any buyer is free to raise their hand and, when called upon, make a verbal bid to buy at a price that is less than or equal to their value. Likewise, any seller is free at any time to raise their hand and, when called upon, to make a verbal offer to sell at a price that is equal to or above their cost. I will record bids and offers on this board. Any seller is free to accept the bid of any buyer, and any buyer is free to accept the offer of any seller. As soon as a bid or offer is accepted, a binding contract has been closed and the buyer and seller making the deal are to drop out of the market, making no more bids, offers, or contracts for the remainder of that trading period.

Note that buyers cannot withdraw bids and sellers cannot withdraw offers. However after a trade has been completed, I will erase all standing bids and offers from the board.

Except for the bids and offers you are not to speak to any other subject until the experiment is complete. If you violate this rule, you will be asked to leave the experiment and will earn nothing for participating.

If you make a trade, I will confirm that it is a legitimate trade. Remember that you cannot trade in a way that gives you negative earnings. That means sellers can only trade at a price above their cost and buyers can only trade at a price below their value.

After any pair trade and I have a record of their trade price, I will call out their trade price so that all the remaining participants can hear it.

I will now hand out practice trading cards. Remember: you are not allowed to discuss the information on the cards with any other trader. Please take care not to reveal it accidentally to curious traders looking over your shoulder.

We will now do 2 practice rounds. For the practice rounds, earnings will be denominated in $. Earnings from these rounds do not count towards your total earnings for today's session. Rather the practice rounds are designed to provide you familiarity with the trading protocol.

Once we have completed the practice rounds, you will be assigned the role of buyer or seller. Once we have assigned your role, we will distribute the buyer and seller cards for round #1 and begin the portion of the experiment that will influence your earnings for today's session. We will begin the first practice round. You have 3 minutes to trade. Go!

We will now do 4 real rounds. Earnings are denominated in $. Your total earnings for the session will be the sum of your earnings from all 4 rounds. In a similar market to the one you are about to participate in, a trade occurred at price $X. You may now begin trading.