Title

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Abstract

Each of $n \geq 1$ identical buyers (and $m \geq 1$ identical sellers) wants to buy (sell) a single unit of an indivisible good. The core predicts a unique and extreme outcome: the entire surplus is split evenly among the buyers when $m > n$ and among the sellers when $m < n$; the long side gets nothing. We test this core conjecture in the lab with $n + m = 3$ or 5 randomly rematched traders and minimal imbalances ($m = n \pm 1$) in three market institutions. In the standard continuous double auction, the surplus indeed goes overwhelmingly towards the short side. The DA-Chat institution allows traders to have cheap talk prior to the double auction, while the DA-Barg institution allows the long siders to negotiate enforceable profit sharing agreements while trading. Despite frequent attempts to collude and occasional large deviations from the core prediction, we find that successful collusion is infrequent in both new institutions. A disproportionate fraction of the successful collusions are accompanied by appeals to fairness.

Keywords: core, market, experiment, fairness

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"The notion of the core has attracted the interest of economists for more than 100 years. Much of the core's appeal stems from the intuitive and natural story behind it, the story that first motivated F. Y. Edgeworth in 1881. It runs as follows. An allocation which is not the core is regarded as unstable. It is always the case, given such an allocation, that some individuals will be able to form a coalition and obtain an allocation that each strictly prefers." –Perry and Reny, 1994, p. 795

1 Introduction

The concept of the core is generally regarded as the most important contribution to economics made by cooperative game theory, one of the two major branches of game theory. However, the core as a solution concept is not without controversy, and the following hypothetical example is often used to discredit it (e.g., Perry and Reny, 1994). Consider a market of an indivisible good where each buyer and each seller wants to buy or sell one and only one unit of a good. All buyers have the same value and all sellers have the same cost, which is below buyers' value. The core predicts a unique outcome when there are unequal numbers of buyers and sellers, namely that all the trade surplus goes to the less numerous side (called the short side hereafter) of the market. In particular, one extra buyer drives the buyers' surplus to zero, while one extra seller shifts the entire surplus to the buyers.

Can one extra trader really make all the difference? Skeptics argue that the long side players (the more numerous group, slated to receive zero payoff) will find a way to collude and seize some of the surplus. Or perhaps people's innate sense of fairness will lead them to reject such inequitable allocations. Indeed, the two factors may interact with each other to produce fairness-motivated collusion.

In this paper we take the core conjecture to the laboratory. To give collusion the best shot, we examine small number cases, with two or three players on the long side. The short side has only one fewer player, and sometimes consists of buyers and sometimes sellers. The core doesn't specify the trading institution, so we examine three alternatives: a standard computerized continuous double auction (DA-Std henceforth), an augmented CDA with a chatroom facility (DA-Chat) that provides cheap talk opportunities, and an augmented CDA with a bargaining facility (DA-Barg) that enforces profit sharing among colluding long siders.

Our study falls in a gap between several distinct strands of existing literature. Section 2 first notes the classic theory of the core, and more recent work on noncooperative foundations. It then mentions some of the laboratory studies that examine core predictions in the context of voting, and discusses several laboratory studies that examine market competitivity in various contexts.

Section 3 briefly reviews the theory: the definition of the core, its extreme prediction for the market games, and its implicit underlying assumptions. Section 4 presents the laboratory procedures, including the baseline protocol, the main treatments on market structure and market institutions, and the overall design. It concludes with a list of four testable hypotheses.

Section 5 presents our results, beginning with a graphical overview. The subsequent hypothesis tests and regressions on the whole do support the core conjecture. The surplus indeed skews strongly towards the short side, and in most cases the long side share converges towards zero. Perhaps surprisingly, long siders do not obtain a higher surplus in DA-Barg than in DA-Chat. Successful collusion is infrequent overall, and is correlated with appeals to fairness.

Following a concluding discussion, Appendix A presents supplementary regressions and robustness checks, followed by Appendix B discussing details in the coding of chatroom dialogues and collusion activities, and Appendix C reproduces sample instructions and quiz for the subjects.

2 Related Literature

The core was introduced formally in Shapley (1952) and Gillies (1953), though its intellectual roots go back to Edgeworth (1881). A more recent theoretical literature following Selten (1981) builds noncooperative foundations for the core, and Perry and Reny (1994) is a prominent study in this literature; see the introduction in Yan (2003) for a brief survey.

In these models bargaining typically proceeds one proposal at a time, where each proposal puts forth a feasible allocation for some coalition, and before the next proposal can be made the current proposal is voted on by the members of the proposed coalition. The proposal becomes part of the actual allocation if all the coalition members agree to it, but if one member opposes it then it is discarded and someone can make a new proposal.

Laboratory experiments on the core begin with the classic study of Fiorina and Plott (1978). They found the core did a good job of predicting the outcome of majority rule voting, although Eavey and Miller (1984) found that "fair" alternatives outside the core did better. More recent literature on committees and voting, such as Frechette et al. (2003), is based on the noncooperative model of Barron and Ferejohn(1989), and even these experiments often produce "fairer" (more equal) payoffs than the equilibrium prediction.

For our task, a direct implementation of the noncooperative foundation models would be to ask players to vote on proposed allocations and to impose a unanimity rule. We believe that this would not give collusion and fairness considerations a fair shot, because any short sider could immediately take off the table any attempt by long siders to collude. Our purpose is not to test specific noncooperative models in a general setting, but rather to test a particular class of cooperative games with a natural interpretation in the market setting. Therefore our experiment employs market institutions, in which a trader's bid or offer remains valid until retracted by himself.

Smith and Williams (1990) report early computerized market settings, including several sessions with identical valuations and identical costs. These sessions featured a continuous double auction with 4 multi-unit buyers and 4 multi-unit sellers and sizeable imbalances (either 16 units demanded and 11 units supplied, or the reverse). They found convergence to near the competitive equilibrium, with over 90% of surplus typically going to the short (11 unit) side after 3 or 4 periods. Another series of sessions suggested that two or more traders on one side of the market (and four or more on the other side) was generally was sufficient for convergence to near the competitive equilibrium (CE).

Friedman and Ostroy (1995) report sessions with slightly imbalanced identical valuations and costs, again with 4 buyers and 4 sellers but with essentially divisible goods. They find slow convergence towards the CE price and reasonably high efficiency in CDA markets and also in Call Markets. Issac et al. (1984) allow one side of the market to collude and still find rather competitive outcomes in the CDA, more so than in Posted Offer markets. Joyce (1984) studied collusion in a hybrid market institution with some CDA and some Call Market features, and found that buyers were better than sellers at colluding and extracting surplus.

Our study builds on the predecessors but takes several new directions. For reasons mentioned in the next section, we depart from the usual laboratory convention of private values and costs, and instead publicly announce the (flat) supply and demand configurations. We introduce two new technologies for colluding in laboratory markets, called DA-Chat and DA-Barg, described in section 4. And we examine exceptionally thin markets, with only one or two single-unit traders on the short side and only one more on the long side.[1]

3 Theoretical Background

Intuitively, the core consists of allocations that are stable in the sense that no subgroup of players can break away and achieve better payoffs for all its members.

To formalize, let N denote the set of all players. Any nonempty subset $T \subseteq N$ of players is called *coalition*, and $|T| \geq 1$ denotes the number of players in T. The *grand coalition* consists of all players, $T = N$. A *characteristic function* is a mapping v from the set of all coalitions into $\Re_+$. The number $v(T)$ is called the *worth* of coalition T; it may be interpreted as the size of the surplus available to the members of the coalition T. The pair (v, N) defines a cooperative game with transferable utility.

An *allocation* for coalition T is an element in $\Re_+^{|T|}$, written as $\omega = (\omega_i)_{i \in T}$. It is *feasible* if $\sum_{i \in T} \omega_i \leq v(T)$. A coalition T is said to *block* an allocation for the grand coalition $\omega = (\omega_i)_{i \in N}$ if $v(T) > \sum_{i \in T} \omega_i$. The *core* is the set of all the feasible allocations for the grand coalition that cannot be blocked by any coalition.

[1]Cason and Noussair (2007) also study very thin markets, with only 2 single unit buyers and 3 single unit sellers. But they investigate price dispersion when there are search frictions in Posted Offer markets, an issue almost polar to ours.

3.1 The Buyer-Seller Example as a Cooperative Game

Now let N be the union of two disjoint player subsets, B and S, called buyers and sellers respectively. Let the worth of any coalition of one buyer and one seller be 1, interpreted as the total trade surplus in one transaction. Then set the worth of any coalition T equal to the number of buyer-seller pairs in T, that is, $v(T) = min\{|B \cap T|, |S \cap T|\}$. The game is called a *buyers' market*, and B is called the *short side*, if $|B| < |S|$. The opposite case, $|B| > |S|$, is called a *sellers' market* because now S is the short side. The *long side*, of course, is the other subset of players: S in a buyers' market and B in a sellers' market.

It is easy to show that the core in such games is unique, non-empty, and extreme: the entire surplus goes to the short side players, who divide it equally.

Proposition 1 *A buyers' (sellers') market has a unique core allocation ω. We have $\omega_i = 1$ if player i is a short sider and otherwise $\omega_i = 0$.*

Proof: Consider a buyers' market. We will first show that, fixing any seller i, he must get zero payoff in any core allocation ω. Consider the coalition of the remaining players $T = N\backslash\{i\}$. By the definition of buyers' market, T still contains at least as many sellers as buyers. Hence the specification of v ensures that T has the same worth as the grand coalition, i.e., $v(T) = v(N)$. Hence T blocks any allocation that gives a positive payoff to i. Therefore, any core allocation ω must satisfy $\omega_i = 0$.

We now show that each buyer gets 1. Remember that any coalition consisting of one buyer and one seller has worth 1, so for any $i \in S$ and $j \in B$, we must have $\omega_i + \omega_j \geq 1$. Since $\omega_i = 0$, we must have $\omega_j \geq 1$. But with each buyer getting at least 1, the only feasible allocation is that each buyer gets exactly $\omega_j = 1$.

It is easy to see that no subcoalition blocks ω: for any $T \subseteq N$, we have $\sum_{i \in T} \omega_i = |B \cap T| \geq min\{|B \cap T|, |S \cap T|\} = v(T)$. So the core allocation is indeed unique and as specified.

The sellers' market is symmetric. $\diamond$

The intuition is transparent in a market with one buyer and two sellers. Any proposed allocation that gives either seller a positive payoff leaves a joint payoff of less than one to the buyer and the other seller, who can form a coalition that blocks the proposed allocation.

In a typical market transaction, no transfer is possible between traders on the same side, and this can be captured by restricting feasible allocations to those assigning zero payoffs to redundant long siders. And it is easy to see that Proposition 1 holds for such a partially transferable utility game as well.

3.2 Implementation Issues

The theory is quite abstract, but the intuition and the formalism provide some guidance on how the game might be implemented in the lab.

First, the definition of the core implicitly assumes complete information. For example, the buyer and the other seller must be aware that they can form the blocking coalition just mentioned and split its worth of 1 in a way that leaves both better off than in the proposed allocation. In particular, all buyer values and all seller costs should be public information.

Second, there must be some way to bargain and transact. The formal definitions of the Buyer-Seller example and its core are compatible with most market institutions but do not point to any specific institution. The intuition suggests that players bargain and collude, but again is silent on the specific institutions that they use. Our experiment will investigate three alternative institutions based on the continuous double auction.

Third, the market game uses a special sort of demand and supply configuration, as in Figure 1. Any such configuration has a unique competitive equilibrium (CE) that coincides with the core prediction. But the underlying logic is completely different. The CE theory assumes non-collusive price-taking behavior. That assumption seems reasonable when no one trader can appreciably affect payoffs, but in our case a single (long side) trader can make all the difference. Indeed, for that reason, we shall study buyers' and sellers' markets with just one extra long side trader. We refer to them as $n \times (n+1)$ games, where n is the number of short siders. It is well known that collusion is more difficult when larger numbers of people are involved (see, for example, in the experimental literature, Dufwenberg and Gneezy (2000), Huck et al. (2004), Issac et al. (1984), and Harrison and Mckee (1985)), so we shall focus on $n = 1, 2$.

—-Insert Figure 1—-

Finally, the core analyzes collusion in one-shot interactions. A coalition blocks if it can split its current worth to mutual immediate benefit. Of course, all sorts of collusions are possible in repeated interaction, in which players sacrifice now in the hope of getting greater future gains. Such arrangements, however, are outside the scope of core theory. Thus, in testing the core conjecture, we shall avoid repeatedly matching the same individual buyers and sellers.

4 Laboratory Procedures

We recruited 144 subjects at random from the LEEPS subject pool of over 1000 volunteers, most of them undergraduates at UCSC majoring in Economics, Natural Science or Engineering. None had previous experience in our experiment. On arrival at the laboratory, subjects received printed instructions, reproduced in Appendix C. They then listened to an oral summary with the user interfaces displayed on a wall screen. This is followed by a quiz and a few practice rounds. Then they played 16 to 24 periods of the market games described below over 1 to 2 hours. Most subjects were paid between \$15 and \$25, according to profits earned during the session; average take-home pay was \$21.99.

The matching scheme is intended to discourage repeated game effects. Each period in each session has $k = 2$ or 4 separate marketplaces to accommodate the $(2n + 1)k$ subjects. To maintain anonymity, the messages on screen assign a label to each participant, e.g. buyer or seller A, and the labels are shuffled every period. The matching scheme guarantees that the same group of long siders meet at most twice (also, when $n = 2$, that short siders meet a minimal number of times) and that they have no way of knowing when they do meet again.

Subjects received full information. The written and public oral instructions state the number of participants in each market, e.g., 2 buyers and 3 sellers in a 2×3 buyers' market, and state that all buyers have the same value (always 89 lab dollars) and all sellers have the same cost (55 lab dollars).

The baseline market institution is the Continuous Double Auction (CDA). It is the premier market institution, used widely in practice (e.g. in the Chicago trading pits, the NYSE, and new electronic exchanges) as well as in laboratory experiments. We choose it because it is neutral, in the sense that *a priori* it does not favor either side of the market, and because it typically produces rapid convergence in the lab.

In our standard CDA, sellers and buyers may submit bids and asks at any time, simply by dragging a slider or typing in the desired price, and clicking a Bid or Ask button. These offers are displayed on the screens of every trader in the marketplace, as in Figure 2. Transactions occur immediately whenever a bid and ask overlap, or when a trader selects an offer from the other side of the market and clicks the Buy or Sell button. CDA trading lasts 60 (for 1x2 sessions) or 95 (for 2x3 sessions) seconds each period. See Appendix C for details.

—-Insert Figure 2—-

4.1 Treatments

The first treatment is structural, varying the short side and the number of traders. Thus the experiment examines both 1x2 and 2x3 sellers' markets and buyers' markets.

The second treatment is institutional. The experiment investigates the standard CDA just described, hereafter denoted DA-Std, and also two variants that are more conducive to collusion: a CDA with preplay communication called DA-Chat, and a CDA that also features bargaining with enforceable collusive agreements, called DA-Barg.

In DA-Chat sessions, we begin with two standard CDA periods in order to give long siders experience with low profits. After that, they are more likely to see nontrivial reasons to use the chat facility, which is enabled in period three. Each trading period thereafter is preceded by 2 (for 1x2 markets) or 3 (for 2x3 markets) minutes' preplay communication. Subjects enter a computerized chat room where they may type messages seen by everyone in their marketplace. Such talk is cheap in that it there is no enforcement mechanism. The bids and asks in CDA are shown without revealing the trader's identity, e.g. seller A or B, in order to prevent the short sider(s) from punishing the long sider who initiates collusion in the chatroom.

—-Insert Figure 3—-

DA-Barg enforces agreements in a manner suggested by cooperative game theory. The agreements have the following character: "let's stick to the same price and if someone from the other side chooses to trade with one of us, the lucky one will split the profit with the other(s)". Specifically, DA-Barg opens a parallel collusion market, referred to simply as "Market 2" on traders' screens, in addition to leaving the chat room open throughout each 3-minute trading period. In market 2, as shown in Figure 3, long side traders can negotiate and enforce (or retract) contracts to collude. They click tabs to switch between this market and "Market 1", the standard CDA market. In a 1x2 sellers' market, for example, the two buyers negotiate to have one buyer give up the right to transact in Market 1 in return for some percentage of the profit of the other buyer.[2] The screens reveal the participant labels, e.g., Buyer A or B, and the seller can view their activities in a bulletin board on the CDA screen. The upper left area of the collusion screen is where they send proposals and counter proposals negotiating the percentages and who should give up trading. The computer enforces any agreement active at the time of a transaction.

The collusion agreement is retractable unilaterally by either long side trader without penalty prior to a transaction. As soon as either colluding trader clicks the Retract button, both may resume normal CDA trading, and the retraction is reported in the bulletin board for all to see. Thus the collusion agreement is revocable but is it not cheap talk, because DA-Barg enforces the profit sharing if neither trader retracts.

Why permit retraction? In DA-Std, all bids and asks can be retracted without penalty prior to a transaction. As we see it, core theory requires that profit sharing agreements also be retractable. The theory assumes that players are free to demand and accept more

[2]DA-Chat allows a more limited form of profit splitting. If both long siders in a 1x2 market stick to a preplay collusion agreement to hold the same price, then both have 50% (subjective) probability of being chosen by the buyer for a trade, roughly equivalent to a 50-50 profit sharing agreement in DA-Barg.

profitable offers than existing ones. Core allocations are precisely those that should survive this process. In the example just discussed, the seller's ask represents a more profitable offer to the active long side trader if he retracts, since retraction would allow him to keep the entire profit.

Due to software limitations, DA-Barg is implemented only for 1x2 markets.

4.2 Experimental Design

Table 1 summarizes the laboratory sessions. We have run 7 sessions of 1x2 markets with a total of 84 subjects in 56 markets, each lasting 10 periods, as well as 6 sessions of 2x3 markets with a total of 60 subjects in 24 markets of 8 periods each.

—Insert Table 1—

In each session we run either two 2x3 or four 1x2 markets simultaneously. The periods in the first half, called segment 1, of each session are all buyers' markets (or all sellers' markets). At the halfway point we switch the role of half (in 1x2 sessions) or one third (in 2x3 sessions) of the long siders, so the switchers stay on the long side throughout the session. These subjects are given double showup fees; the instructions say that this is "for their role change." Of course, the other subjects are short siders for segment 1 of the session and long siders for segment 2. Pilot sessions (not reported here) convinced us that subjects could adapt to the strategic environment more readily with this design—a single switch from buyers' markets to sellers' markets (or the reverse) midway through the session—than with alternatives such as simultaneous buyers' and sellers' markets with more rapid rotation of subjects from short side to long side.

4.3 Testable Hypotheses

The experiment allows us to test the following specific hypotheses related to the core conjecture.

1. The core (and CE) predicts that short side traders get a disproportionate share of gains from trade. By contrast, fairness and collusion suggest division closer to an equal split. Normalizing per-transaction surplus ($89 - 55 = 34$ lab dollars) to 1, the equal split benchmark in a $n \times (n+1)$ market is $n/(2n+1)$ since there are n transactions possible, while the unique core prediction is 1.0. The core conjecture is supported when the average short side trader's share significantly exceeds the midpoint $\frac{3n+1}{4n+2}$.

2. One would expect the short siders to get a higher fraction of the surplus in 2x3 than in 1x2 markets based on the stylized fact that it is harder for a larger number of long siders to collude.

3. The DA-Chat and, especially, the DA-Barg market institutions were constructed to give more scope to collusion and fairness considerations. Hence we predict that the core conjecture will fare best in DA-Std and worst in DA-Barg.

4. Given the opportunity, subjects will try to collude, but core theory predicts that such attempts will fail. Therefore we predict that over time, (a) collusion rates will decline and (b) the fraction of the surplus obtained by short siders will increase.

5 Results

To give the reader a general impression of the data, we begin with time graphs of three typical sessions. We then turn to direct tests of the main hypotheses. The rest of the section presents a series of regressions that provide more definitive results. Supplementary regressions are collected in Appendix A.

—-Insert Figure 4—-

5.1 Sample Session Graphs

Figure 4 graphically summarizes the short sider surplus shares (SSS) in three sessions. Panel A shows a 2x3 DA-Std session in which ten subjects rotated through two simultaneous markets. The first 8 periods had two buyers in each market, and the four buyers got the lion's share of the surplus of every transaction, e.g., 94 to 98% in period 8, always far above the equal-split line. The buyer shares were more dispersed in the first 4 periods (the first half of the segment) but all were at least 75%. In period 9, two subjects switched from sellers to buyers, so in periods 9-16 the sellers were short siders and the graph therefore shows sellers' shares of the surplus. These shares again become more tightly bunched above 90% in the last 4 periods (the "second half"). Only two potential trades were missed during the entire session, indicated by the arrows in periods 5 and 9.

Panel B shows a 1x2 DA-Chat session with twelve subjects rotating through four markets. Sellers were the short side in the first 12 periods, and four subjects were switched from buyers to sellers in the remaining 12 periods. As indicated by "No Chat" on the horizontal axis, chat was disabled in two initial periods of each segment. The markets are numbered according to short sider ID and sorted by profitability. It appears that individual short sider's shares are serially correlated, even though different long siders rotated through all four markets in each segment.

Panel C shows a 1x2 DA-Barg session. In period 11, four sellers became buyers, so sellers are the short siders from then onwards. One sees more equal divisions in this treatment, most of them involving buyers 1 and 2 in the first segment. The chatroom transcript suggests that a few short siders offered concessions out of a sense of fairness,[3] and in general the bargaining style of the individual short sider seems to plays an important role. One sees more (approximately) equal splits in this treatment, but there are also many splits that heavily favor the short side. The willing eye may see an upward trend in the SSS in the "second half" of both the buyers' markets and sellers' markets in this session.

Unless otherwise noted, the data analysis to follow will be restricted to "second half" data. As is common for tests of equilibrium theories, the "first half" of each segment (i.e., the first and third quarters of each session) is set aside because it usually is noisier and seems

[3]E.g., in period 12, one seller wrote, "because all the sellers are selling at such a high price that sellers are getting alot more than buyers, which is kinda unfair", and another short sider in Session 2 wrote "if we all did that we should all get fair money[.] That is all I am trying to do[,] make it fair."

to reflect more mistakes and explorations. Appendix A verifies that the inferences from the entire data set are often weaker but generally agree with the inferences presented below.

—-Insert Table 2—

5.2 Direct Tests of Hypotheses

Consistent with Hypothesis 1, the SSS in the three sample sessions were generally much closer to 1.0 than to the red line marking equal division. Table 2 contains more formal results. In each treatment cell, the mean and median SSS exceed the midpoint $\frac{3n+1}{4n+2}$ between equal split and 1.0. Standard tests indicate significance at the 1% confidence level or better, except for the 2x3 DA-Chat treatment at the 5% level.

Of course, the observations are not independent, due in particular to possible serial correlation within short siders, so the confidence levels are perhaps overstated. Independence across sessions can be safely assumed, and the median exceeds the midpoint for buyers' markets in 11 of 13 sessions and for sellers' markets in 12 of 13 sessions. The usual signs test has p-values lower than 0.01. We conclude that the data strongly support the core conjecture.

By contrast, Hypothesis 2 finds no support in the data. The distribution of surplus seems the same in 1x2 markets as in 2x3 markets, in either the DA-Std or DA-Chat treatments, and this impression is confirmed by insignificant standard test statistics (e.g., Fisher's exact test). As noted earlier, our software does not permit 2x3 DA-Barg sessions.

Hypothesis 3 is supported by the fact that median SSS in DA-Std (0.912 in both market sizes) is considerably larger than in either DA-Chat or DA-Barg (those medians are 0.706 and 0.735 for 1x2 and 2x3 DA-Chat, and 0.735 for DA-Barg). The differences are significant at better than the 0.1% level according to Mann-Whitney tests. Two-sample t-tests as well as the median tests give similarly overwhelming results. Regarding the difference between DA-Barg and DA-Chat, while DA-Barg produces marginally significantly more collusion than 1x2 DA-Chat (with a one-side p-value of .102 based on Fisher's exact test), mean and median SSS are in fact slightly (and insignificantly) higher in DA-Barg than in DA-Chat.

Direct tests find no trend in collusion rate to support Hypothesis 4a. For Hypothesis 4b, however, we do find that SSS tends to have higher means and medians in the "second half" data. As shown in Appendix A, the increase is significant at the 1% level in DA-Std sessions, insignificant in DA-Chat sessions, and significant at the one-sided 10% (p=.056)level for DA-Barg sessions. We will present more evidence in support of Hypothesis 4 later in the main text as well as in Appendix A.

—-Insert Table 3—-

5.3 SSS Regression

To control for within-subject correlation, we run regressions with random effects for individual short side subjects. Table 3 presents such regressions of SSS in each completed transaction on treatment dummies, supplemented by dummies for whether the observations come from the second segment (Seg2 = 1), whether there are 3 long siders (D2x3 = 1) or just 2, and for whether the short side is sellers (Smarket=1) or buyers. We focus on regression 1 and 2, regression 3 is included for the sake of robustness, and 4 will be discussed in the next subsection.

Compared to DA-Std, including either a chatroom or a bargaining facility significantly reduces the SSS, consistent with Hypothesis 3. The impact is also economically significant: the enhanced collusion opportunities transfer about 15% of profits to the long siders. Confirming the impression from Table 2, the coefficients for DA-Chat and DA-Barg are almost identical. The Seg2 coefficient estimate is significantly positive, consistent with Hypothesis 4, and suggests the transfer of an additional 5% of surplus to short siders in the second half of each session. Perhaps surprisingly in view of Joyce (1984), sellers tend to extract about 4% more surplus than buyers, other things equal, again significant at the 5% level . The insignificant coefficient estimates for D2x3 corroborate the negative results on Hypothesis 2 noted earlier.

Table 3 presents only the direct effects. Appendix A reports regressions including interactions of all orders. They reveal some nuances—for example, that the buyer-seller asymmetry tends to vanish with experience—but don't alter the basic conclusions.

5.4 Collusion and Missed Trades

Attempts to collude are of interest in their own right. In DA-Chat and DA-Barg sessions, we go through the chatroom and collusion market logs and classify, for each period in each market, whether collusion is proposed, whether appeals to fairness are made, whether there is agreement on a proposal, whether it is bilateral or trilateral, etc; see Appendix B for details. Collusion is deemed successful when there is a transaction and the price conforms to the agreement.

—-Insert Table 4—-

Table 4 gives the summary counts and rates of collusion and fairness appeals. The overall rate of successful collusion is low, only 8.7%, with DA-Barg doing better (at 12.8%) than DA-Chat (at 2.9 - 6.2%). The table also shows the underlying conditional probabilities. Slightly more than half of the time not a single long sider proposes collusion. When a proposal is made, the long siders may disagree on the collusion price or the profit sharing percentage; more than one third of the time, colluders are unable to reach agreement. When they do, nearly two thirds of the time the agreement fails.[4] Of the honored agreements, nearly one sixth were rejected by the short siders and resulted in no trade. Indeed, chatroom conversation show that many subjects anticipate the problems: "that [collusion] never works", "someone will always crack and the other two will scramble for what is left", "this is gross[,] watching people sell each other out"; and one subject in DA-Barg wrote in post-experiment questionnaire that what was on his mind during the experiment was "how not to be screwed by others". This helps to explain the low proposal rate, which is remarkable given the ease of making a proposal, especially with our DA-Barg facilities.

Turning back to Table 3, the last regression shows that collusion and fairness discussion

[4]Probably the conditional failure rate (or rate of cheating) would be even higher if long siders were required to propose collusion. Chat logs confirm that many subjects refuse to entertain collusion proposals because they anticipate cheating.

are associated with lower SSS. In fact all degrees of collusion are highly significant. In particular even unsuccessful attempts at collusion, namely collusion proposals that did not result in an agreement (as captured by the regressor "collusion proposal only") and collusion agreements that were cheated upon[5] are associated with significantly lower SSS. Averaged over all successful collusions in DA-Chat and DA-Barg sessions, the short sider profit is .46, and 95% of the time it is between .35 and .65.

—Insert Table 5—-

Table 5 reports logit regressions that further dissect the collusion process. It includes random session effects to control for the fact that long siders encourage one another to collude[6] and are rematched every period. One sees some evidence consistent with Hypothesis 3 that there tend to be more successful collusions in DA-Barg than in DA-Chat; the relevant coefficient in regression 1 is significant at one-sided 10% level. Notice that Seg 2 has a negative impact on log odds of $-.726$, translating into more than 50% decrease in collusion rate, and this is statistically significant at one-sided 10% level, supporting Hypothesis 4. Again, see Appendix A for a finer-grained comparison.

An important harbinger of success is that the chat mentions fairness. The gross counts noted in the penultimate row of Table 4 are reinforced by regression 2 of Table 5. It reports a highly significant fairness coefficient of 2.5, meaning that the odds of success more than quadruples.

The last two regressions of Table 5 examine efficiency, with missed trades as the dependent variable. Recall from Table 2 that the efficiency levels are fairly high in each treatment; overall, 95.1% of potential trades are realized. Regression 4 indicates that in DA-Chat, honored collusion agreements are a significant cause of missed trades: the coefficient estimate is 2.40, with a p-value of .011, and after controlling for the various collusion and

[5]That even violated collusion agreements are significant follows from the fact that the coefficient estimate of collusion agreement is significant after honored agreements are controlled for.

[6]The chat log shows that, for instance, one long sider in session 12 advocated collusion with every fellow long sider he met and a similar long sider in the same session even asked other long siders to "spread the word".

fairness effects DA-Chat no longer produces significantly more missed trades than DA-Std. On the other hand, as suggested by the highly negative but insignificant interaction term Barg*CollusionHonored in regression 4, collusion does not contribute to missed trades in DA-Barg, and in fact as shown in Table 4 honored collusion agreements in DA-Barg always succeeded. After controlling for the various collusion and fairness effects DA-Barg still produces several times more missed trades than DA-Std, as captured by the coefficient estimate 1.67 on Barg, which is significant at 5%.

Another piece of evidence might be relevant to understanding unsuccessful collusion and missed trades. In DA-Chat sessions for which we have transaction time data, the mean transaction time (54% of the entire trading period) of the successful collusion is no greater than that of the overall average transaction time (55% of the entire trading period). This suggests that the short sider in a successful collusion does not generally try to hold out for the collapse of the collusion.

5.5 Trend Extrapolation

Another way to see how well the core prediction fares is based on fitted values and trends. We focus on the periods in the second half of each session, since they reflect behavior of subjects familiar with the general environment but facing a new situation (e.g., sellers' markets after previously seeing only buyers' markets.) The coefficients come from regression 2 of Table A1 in Appendix A, which pools the sellers' markets with the buyers' markets except in 2x3 DA-Chat, the only case where the buyer-seller asymmetry persists into segment 2.

The fitted values indicate that short siders obtain over 90% of the surplus in the last period of the DA-Std treatments, and that they are on track to obtain virtually 100% five periods later. Similarly in the DA-Barg treatment, they obtain over 84% in the last period and are on track to obtain the rest in seven or eight more periods. DA-Chat is the exception: the last period fitted SSS are 76% in 1x2 markets, and in 2x3 markets are 87% in buyers' markets and 73% in sellers' markets. Furthermore, there is no significant trend, even though the SSS improves appreciably from segment 1 to segment 2 as noted in Appendix A.

6 Discussion

Overall, our laboratory experiment strongly supports the core conjecture. In every treatment, short siders get the lion's share of the gains from trade. In two of the three market institutions (DA-Std and DA-Barg), their share seems to be headed towards 1.0. Moreover, successful collusion is rare, even in the new treatments (DA-Chat and DA-Barg) designed to facilitate collusion.

Neither DA-Chat nor DA-Barg is as efficient as the standard continuous double auction; more mutually beneficial trades are missed in these new institutions even though the subjects had considerably longer time to interact each period.

As anticipated fairness considerations do affect the outcome. Long siders who invoke fairness when attempting to collude tend to be more successful. We detect a tendency of sellers to retain more surplus than buyers, but the asymmetry fades in segment 2.[7]

Our study opens the way to future work. One possibility is to examine other market institutions such as the call market, in which bids and asks are submitted simultaneously and then a market-clearing price is generated to determine all the transactions. Generally the call market is somewhat less efficient than DA-Std, but it is not clear how it would fare in our present setting.

Another possible avenue of new research is to try reducing or eliminating the sense of unfairness in the core allocation, for example by taxing short siders' profits.

What would happen if we allow players, especially the long siders, to keep their collusion agreements secret? The question strays somewhat from our focus on the core, which assumes perfect information, but still seems a natural question.[8] Likewise, it surely would

[7] In fact the only remaining asymmetry in segment 2 is of the opposite sign, that is, sellers retain less surplus than buyers.

[8] In general the core story requires perfect information, in that one needs to observe the noncore allocation in order to block it. But in our setting, since the collusion agreement can be blocked by the long siders themselves through retraction, secrecy probably would not help collusion as much as one might think at first.

be interesting to extend the so-far quite limited experimental literature on noncooperative foundations of the core.

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Appendix A: Supplementary Regressions and Tests

A.1 More on SSS

Table A1 shows regressions of SSS that have one or more of the following features: i) including all interaction terms; i)including all periods; iii) being of random session effects; iv) including a pilot session that has a more symmetric design but has subjects switched between long and short sides.

Tests based on regression 1 of Table A1 show that the buyer-seller asymmetry in SSS vanishes in segment 2 except in 2x3 DA-Chat markets where it changes sign and is significant, that is, the seller's markets have a significantly lower SSS. These tests are not included and are available upon request.

The following results provide further and more nuanced support for Hypothesis 4: i)based on regression 2 of Table A1 in Appendix A, which pools the sellers' markets with the buyers' markets except in 2x3 DA-Chat (the only case that exhibits buyer-seller asymmetry in segment 2), even in the second halves of segment 2 the DA-Barg data still show a significantly positive trend: the sum of the coefficients of Trend, Barg*Trnd, S2*Trnd, and Barg*S2*Trnd is .022 with a two-sided p-value of .028; ii)the overall significant direct effect of Seg 2 as reported in regression 1 of Table 3, when broken down into the three treatments as in regression 8 of Table A1, is insignificant for DA-Std, large and significant for DA-Barg — the sum of the coefficient of Seg 2 and that of Barg*S2 has a value of .118 and a two-sided p-value of .004 —, and marginally significant for DA-Chat — the sum of the coefficient of Seg 2 and that of Chat*S2 is .045 and has a one sided p-value of .085.

Regressions 5 and 6 of Table A1 use all periods data. Regression 5 has trend variables and is comparable to the second half regression, regression 3, and regression 6 has no trend variables and is comparable to the second halves regression, regression 1. One can see that the all periods estimates are in general consistent with those based on the second halves, in the sense that there is not any coefficient whose all periods estimate has the opposite sign of that of the second halves estimate and both estimates are significant. And even the tests on functions of the coefficients generally show consistent qualitative results, with the only notable exception of the trend related estimates as one would expect from the graphs.

We have also run regressions including a pilot session in which buyers' and sellers' markets are run simultaneously and subjects were switched between the long and the short side frequently. We suspected that this design prevented the subjects from learning to collude. Regression 7 of Table A1 confirms that session 1 is indeed highly significantly different from the rest of DA-Chat sessions, and in fact there was not a single successful collusion in this session.

Table A2 shows the means of the first halves and substantiates the claim in the text about the significant increases in SSS from the first to the second halves.

A.2 Collusion, fairness and missed trades

Table A3 shows regressions on the rate of successful collusion i) in DA-Chat with only those observations where the long siders have reached a collusion agreement, and ii) in both DA-Barg and DA-Chat.

What affects the success of a collusion agreement? Our data allows us to probe into collusion success rate when there is a collusion agreement. For DA-Chat sessions, regression 2 in Table A3 reveals that the planned collusion profit, defined as the difference between the agreement price and the cost (or value) of the long side sellers (or buyers), affects success significantly negatively at 5% level. This means that greedy prices are less likely to succeed, both because there is greater temptation to cheat, just as one would expect from game theoretical reasoning, and because the short sider is less likely to agree. For the reader's information, 72 is the modal collusion price, but it happened only 26.3 percent of time and there is a wide spread of the collusion price in general.[9] For DA-Barg sessions, however, regressions (not reported here but available upon request) reveal no significant role played by the collusion profit sharing percentage, apparently due to the fact that it is very narrowly concentrated–it is 87 percent concentrated between 40% to 50% with 50% taking up two thirds of all agreements.

[9]There is a specific price most of the time while on rare occasions the long siders simply agreed to "hold the same price".

We have also done more careful comparisons of the conditional probabilities in Table 4. The last row of Table 4 reveals that the successful collusion rate in DA-Barg is twice as high as in 1x2 DA-Chat, which in turn has twice as high a collusion rate as that in 2x3 DA-Chat. The first of these differences is shown to be statistically significant at one-sided 10% level in regression 1 of Table 5. The second, however, is not. If we trace the probabilities leading to the difference in collusion success between DA-Barg and 1x2 DA-Chat, we see that they have similar unconditional rates of collusion agreements, [10] but half of the collusion agreements in DA-Barg are honored , compared to one third approximately in 1x2 DA-Chat, and this difference is shown to have a two-sided p-value of .075 by Fisher's exact test. This has several explanations: the chat window is open throughout a trading period in DA-Barg, so a cheating subject in DA-Barg may suffer some disutility from seeing criticism in the chat window from the collusion partner; there is also some possible framing effect of our DA-Barg facility, which gives a collusion agreement a more formal aura. Continuing tracing the probabilities we see that an honored agreement always resulted in a trade in DA-Barg whereas nearly half of the honored agreements resulted in no trade in 1x2 DA-Chat, and this difference has a two sided p-value of .022 by Fisher's exact test. One explanation was probably that in the DA-Chat setting, without the framing of collusion as an exchange of trading rights in the bargaining setting, the short sider was less willing to accept the bid or ask coming from a collusion agreement. We also see that fairness discussion appeared twice as often in 1x2 DA-Chat than in 1x2 DA-Barg, and this difference is significant at 1% level by Fisher's exact test. It is plausible to conjecture that the presence of the collusion facility in DA-Barg alleviated the disadvantage felt by the long siders.

And corresponding to the vanishing of buyer-seller asymmetry in SSS in segment 2, we find that the asymmetry in the rate of successful collusion as reflected in regression 1 of Table 5 vanishes as well in every specification based on Fisher's exact tests (available upon request).

How about tacit collusion in DA-Std? Although we find a few clearcut cases of tacit collusion

[10] The unconditional agreement rate is actually lower in DA-Barg than in DA-Chat, a quarter and almost one third respectively, and this is brought about despite the higher proposal rate in DA-Barg by its lower conditional agreement rate.

in 1x2 markets[11], tacit collusion is hard to define in general. The following incidence of relatively low SSS may give a rough idea: in the second halves 8.5 percent of SSS drop below .75, 3.4 percent drop below 2 thirds, none drop below one half. For reference, the average SSS after a successful collusion in a DA-Chat or DA-Barg session is .44. It is easy to see that tacit collusion was not as profitable as explicit collusion and overall it had only a small impact on SSS.

A.3 Robustness

The results presented hitherto are robust to alternative regressions, including random session effects regressions on SSS and probit regressions on collusion and missed trades. One example is regression 7 of Table A1, based on random session effects, and its estimates are consistent with and are of lower precision on the whole than those from the subject effects regression, regression 1 in the same table. The other alternative regressions are available upon request.

[11] There were two cases where the short sider received less than 2 thirds of the surplus and the transaction was made in the last ten seconds.

Appendix B: Coding Collusion and Fairness Discussion

Below we describe in greater details how we coded collusion and fairness from records of the chatroom and the collusion market of DA-Barg.

Fairness discussion is coded as 1 if subjects did any of the following or otherwise made comments obviously related to fairness: i) advocating equal split, including "how about 72?" without any discussion; ii) arguing that any outcome of the market must be fair; iii) making simple comment such as "this (experiment) is so unfair!" iv) arguing that current long siders also had chances of being on the short side.

The following are the main collusion dummies and we explain when they take value 1:

1. "collusion proposal only"

only collusion proposals were sent and no collusion agreement was reached (e.g. due to disagreement about collusion price, or because only one person proposed and the other person did not respond). There are a few special cases worth mentioning. One is that subjects sometimes proposed that they hold the same price until the last 10 seconds. We did not consider this as a collusion proposal since price competition would still be possible in that 10 seconds. Another, rare case is if two long siders first agree to hold the same price without specifying a price, and then one says how about 72, the other says how about 70, and chatroom ends, we consider it absence of an agreement.

2. "collusion agreement" and "nonspecific collusion price"

We code 1 if there is either a bilateral or a trilateral agreement. An agreement is considered reached in DA-Chat if they agree on a specific collusion price or price range, or leave it unspecified (e.g. when they just say "let's hold the same price") and without obvious disagreement over the price, in which case we let the dummy "nonspecific collusion price" take value 1. In particular the following, rare dialogue is considered an agreement without a specific collusion price: "Let's hold the same price.""Ok[.]""How about 72?" and then the chatroom ends. It is natural to feel some arbitrariness about the coding of this example when comparing it to a similar example above, which we interpret as no agreement due to its ending on a counter proposal of "How about 70?". But such cases are so rare that coding them one way or the other does not affect our general results.

3. “honored collusion agreement”

There are two cases, the bilateral and the trilateral agreements. Consider bilateral agreements first. For DA-Chat, when there is a specific collusion price or price range, we consider the agreement honored if nobody posts a price less favorable to the long siders than the agreed price or range. When the subjects only say ”let’s hold the same price”, we consider it a failure if there is any price competition during the trading stage. For DA-Barg, we code 1 if the last collusion agreement of a marketplace is not retracted by either long sider.

In the case of a trilateral agreement, it turns out that in our sessions it was honored by either all three or none.

4. “successful collusion”

We code 1 for successful collusion if an hornored agreement leads to at least one transaction. There was only one trilaterally-abided-by agreement in our sessions, and it led to two transactions.

Appendix C: Sample Instructions and Quiz of a DA-Barg Session

GENERAL INSTRUCTIONS

Please read the following instructions carefully. When you are done, you may ask questions. There will also be some practice periods to give you a better idea about how the game works. It is important that you understand how to play the game, so do not hesitate to ask questions after reading the instructions or during the practice periods.

In this experiment you will be interacting anonymously with other subjects as buyers and sellers in a market. You will also be able to "talk" to other traders in your market in a computerized chat room. A trader, say a seller, can also delegate her trading right to another trader on the same side of the market, a seller in this case, for a negotiated percentage of the profits earned by the second seller. Either seller may decide to terminate such a delegation contract at any time.

After you read the instructions, there will be 3 practice runs , then the real game begins. There will be 4 separate markets running simultaneously. For the first half of the session each market has 1 seller and 2 buyers, and for the second half each market has 1 buyer and 2 sellers. Each period you will be assigned to one of the 4 markets. Assignments switch each period so you will face a different set of buyers and sellers each time.

Each period lasts 3 minutes and the remaining time for each period is shown on the top right of you screen. Between periods there is a short interval for review, when you will see the profits earned in all the markets for that period.

Each period each seller and each buyer may sell or buy one and only one unit of a fictitious commodity. The commodity is worth 89 lab dollars to a buyer and it costs 55 lab dollars to a seller. The prices at which you buy or sell in double auction will determine your earnings. The buyer's profit is equal to 89 minus transaction price, and the seller's profit is transaction price minus 55. Buyers and sellers who don't trade earn a profit of 0 that period.

You can keep track of your earnings by jogging down your profit every period. Your total earnings over all periods will be converted into U.S. dollars (1 lab dollar = 0.06 real dollar) and paid to you, privately, in cash at the end of today's session. These earnings are in addition to a $5 show-up fee.

We want to emphasize that your responses throughout today's session will be completely anonymous to other subjects and will be kept confidential, and in fact we will not keep your names on our data.

The following instructions explain trading and earnings for *both* sellers *and* buyers. However, today only some of you will play both roles and the rest of you will be ***either*** a buyer ***or*** a seller for the entire session. Those playing both roles will be a seller in the first half and a buyer in the second half, and to prepare for it they will have a role change halfway through the practice periods. They will also get a double show-up fee at the end of the experiment.

You will be assigned a public ID, or “nickname” that will help remind you of your own activities during each period. A buyer (seller) will be called (unimaginatively) “buyer (seller)” as her public ID if she is the only buyer (seller) in the market, and “buyer A (seller A)” or “buyer B (seller B)” if there are two buyers (sellers). Whether someone is called “buyer (seller) A or B” is completely random and changes from period to period, and it does not affect her performance in any way.

When the experiment begins, your computer screen will tell you which role you play, how many buyers and sellers there are in your market, and the public ID/nickname you are given for each period.

Please use your real name to log in. We will use it to pay you, and we will keep it confidential.

Below we detail the 3 components of this experiment: market 1, for the commodity trade, market 2, for the delegation negotiation, and the chat room, where all players may post messages. You can switch between Market 1 and Market 2 by clicking on the “Market 1” and “Market 2” tabs. The chat room is located in the same window as Market 2. So if you are in Market 1, you need to switch to Market 2 to see or post messages in the chat room. There is a message box located in Market 1 that alerts everybody when there is any activity in either market: e.g. when there is a message in the chat room, a delegation proposal or agreement between two traders, a retraction of the delegation, a price posted by a trader in Market 1, and so on.

Market 1: commodity trade

INSTRUCTIONS FOR SELLERS

How do sellers make money?

Sellers earn money by selling units at prices that are above the cost.
The profit on each unit sold is its transaction price minus the cost. For example since each unit of the fictitious commodity costs 55, if the price Seller A sold it for was 75, her profit was 75 – 55 = 20 if she was the only seller or if she did not have delegation from the other seller, and her profit would be 20 times the agreed-upon percentage if she did have the delegation.

One very important point: **a seller does not incur the cost for a unit until it is sold**. Thus, the profit is zero for a seller who has not sold his unit.

Sellers' Screen (see screenshots at the end)

Who you are

The top of your screen shows your private login name (Alessandra for example), your public ID/nickname, which also indicates your role, a buyer or a seller.

the Market Panel

This panel contains a box for buyers' **Bids**, and a box for sellers' **Asks.** You cannot see the other traders' nicknames, which are replaced with "??". You can see your own nickname next to your ask, as a reminder of your ask price. The **Transactions** box, located on the left right corner, shows the transaction(s) taking place in your market.

Choose-Your-Price Panel

A seller can choose an asking price by typing it in the blank space next to "price", and then clicking the **Ask** button below. You are allowed to ask the same price as asked by the other seller. For example, after seller A asks 59, seller B may also ask 59. Each period a seller may sell only one unit.

Profit Information box

This box is in the right half of the screen, and it shows the (gross) profit (i.e. price – 55) earned on the one unit sold in the current period. This profit is gross when you had delegation from the other seller because you need to pay, out of this money, the agreed percentage to the other seller.

Trading rules

At any time during the period, each seller (who has not already sold one unit or delegated her trading right) may submit an **ask** to sell a unit at a specified price. To replace an existing ask with a new one the buyer needs to retract her existing ask first. To make a ask, the buyer types in the price and clicks the button **Ask**. For instance, if the seller wants to accept the best bid, say

73, he can type 73 and click **Ask** , and then transaction will take place at price 73. Everyone in the market will see his bid (but not his nickname). To retract her ask, she only needs to highlight her ask in the transaction box and hit the **Retract** button.

INSTRUCTIONS FOR BUYERS

How do buyers make money?

Buyers earn money by buying units at prices that are below 89.
The experimenter will redeem each unit purchased at 89 lab dollars. For example, if the price the buyer paid was 75, the profit on the purchased unit was 89 - 75 = 14. This would be the buyer's profit if she was the only buyer or if she did not have delegation from the other buyer, and her profit would be 14 times the agreed-upon percentage if she did have delegation.

One very important point: a buyer does not receive the redemption value for a unit until the unit is bought. Thus, the profit is zero for a buyer with no purchase. Second, you earn negative profits (i.e., lose money) whenever you buy a unit above its value.

Buyers' Screen (see screenshots at the end)

Who you are

The top of your screen shows your private login name (Tai for example), your public ID/nickname, which also indicates your role, a buyer or a seller.

the Market Panel
This panel contains a box for buyers' **Bids**, and a box for sellers' **Asks.** You cannot see the other traders' nicknames, which are replaced with "??". You can see your own nickname next to your bid, as a reminder of your bid price. The **Transactions** box, located on the left right corner, shows the transaction(s) taking place in your market.

Choose-Your-Price Panel

A buyer can choose a bidding price by typing it in the blank space next to "price", and then clicking the **Bid** button below. You are allowed to choose the same bid as submitted by the other buyer. For example, after buyer A bids 59, buyer B may also bid 59. Each period a buyer may buy only one unit.

Profit Information box

This box is in the right half of the screen, and it shows the (gross) profit (i.e. 89- price) earned on the one unit sold in the current period. This profit is gross when you had delegation from the other buyer because you need to pay, out of this money, the agreed percentage to the other buyer.

Trading rules

At any time during the period, each buyer (who has not already bought one unit or delegated her trading right) may make a **bid** to buy a unit at a specified price. To replace an existing bid with a new bid the buyer needs to retract her existing bid first. To make a bid, the buyer types in the price and clicks the button **Bid**. For instance, if the buyer wants to accept the best ask price, say 73, he can type 73 and click **Bid**, and then transaction will take place at price 73. Everyone in the market will see his bid (but not his nickname). To retract her bid, she only needs to highlight her bid in the transaction box and hit the **Retract** button.

Market 2: trading rights delegation

In this market two traders on the same side of the market may negotiate to have one trader delegate his trading right to the other. The delegating party will suspend his trading activities in market 1, and in return he will get the negotiated percentage of the profit when the delegated party makes a trade with the other side of the market. Either party may terminate the delegation unilaterally at any time before a trade takes place. Once a trade takes place, however, both the trade and the delegation agreement become irreversible.

For example, suppose there are two sellers and one buyer. If seller 1 wants to delegate his trading right to seller 2, he can type in the percentage he wants for himself, say 55%, then hit the “Send” button. This proposal will then be subjected to seller 2’s approval, showing up on seller 2’s screen as “I (seller 2) get 45% and you get 55%”. After seller 2 hits “Accept”, a confirmation message will appear in the chat room window as well as in the message box in Market 1, and at the same time the delegator will have all his market 1 buttons frozen. There will be a “Retract” button when there is an outstanding delegation agreement, and hitting the button will result in the termination of the agreement, at which point the delegator may resume his activities in Market 1. The buyer can view all these activities either directly by opening his Market 2 window or by reading the reports from the message box in Market 1.

Profit distribution when there is a trade is shown in the right half of the window. The delegator gets the agreed percentage of the trade profit and this amount shows up as a negative figure on the delegatee’s screen because it will be subtracted from the trade profit when the computer calculates the delegatee’s profit for that period.

Chat Room Instructions

It is similar to typical internet chat rooms (see screenshots at the end). You can "talk" with the other two traders in your market by typing messages and sending them, and your messages will be seen instantaneously by all traders in your market and they will also see your public ID/nickname.

You may not write any messages in an attempt to identify yourself or other subjects. Doing so will be grounds for dismissal and exclusion from this and future LEEPS experiments. With this only exception, you may say anything related to playing the game, and you may say nothing. Your earnings will not be affected by what you say or don't say in the chat room.

Frequently Asked Questions:

1. Is it true that if everybody acts fast and transacts early then you can all go home early?
Answer: No. Each period lasts 3 minutes regardless of how fast you transact.

2. Can you correct mistakenly typed bids and asks after they are already accepted by other players?
Answer: No. All trades are final.

Please take the following quiz to test your understanding of the game rules. We will announce the correct answers shortly.

Quiz

1. Your computer screen shows that you are a seller. You submit an ask of 55, and a buyer accepts it,

a. how much profit do you make?

b. Do the same exercise
i) if your ask is 77;
ii) if you are a buyer and you have bid 89 and 68.

2. You find yourself to be buyer A again after being buyer A in the last period. Can you assume that the buyer B this period is also the same person as in the last period?

You can still ask questions during the practice periods. But PLEASE KEEP QUIET DURING THE REAL GAME!

Thank you in advance for your cooperation.

Are there any questions?

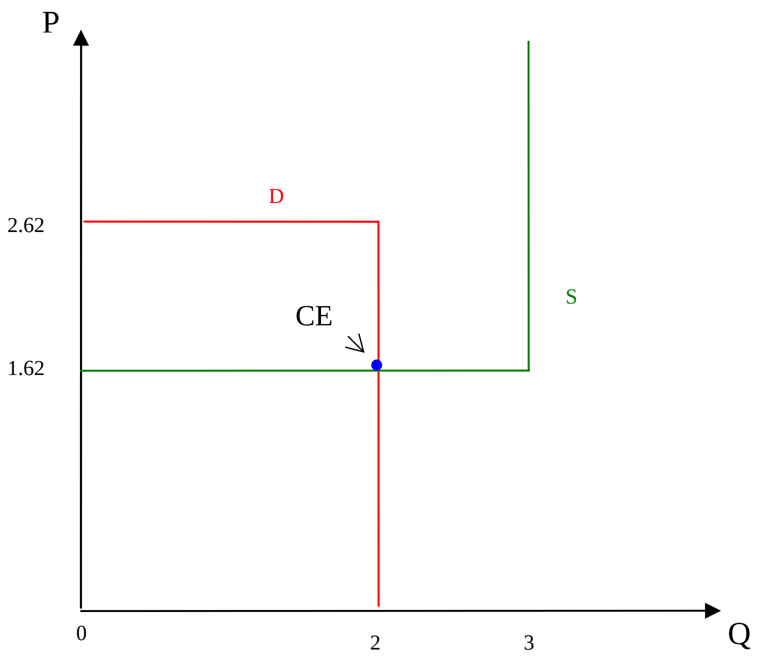
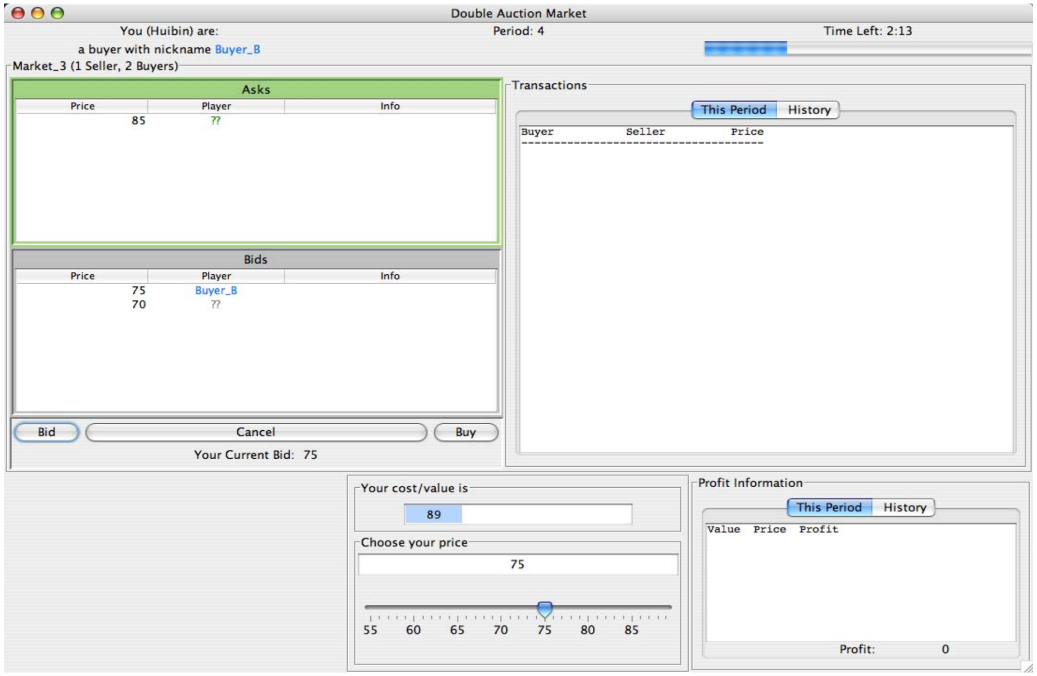


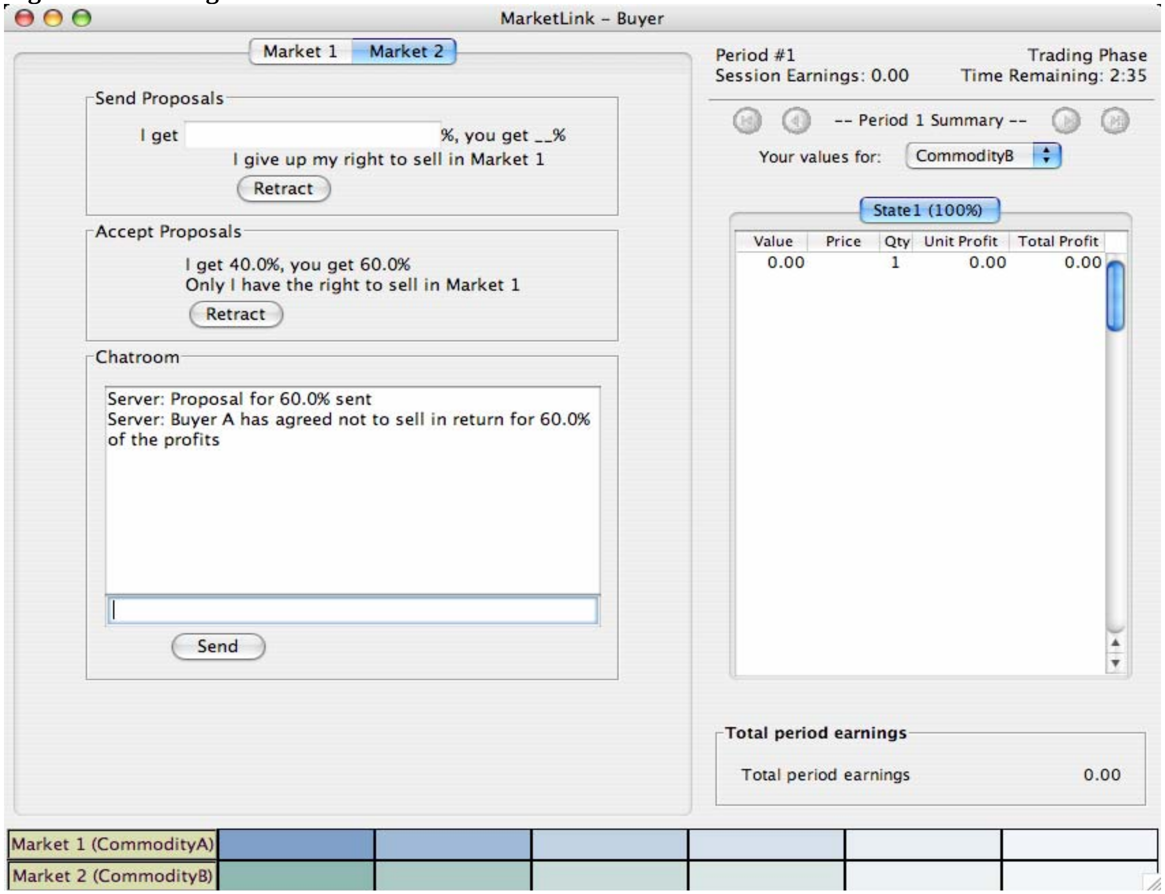
Figure 1: Demand, Supply and the Competitive Equilibrium in a 2 x 3 Buyer's Market.

Figure 2 : DA-Std User Interface



DA-Std trading screen is shown for a buyer (ID code Buyer_B, actual name Huibin). She can post a bid by either typing the desired price or by dragging the slider to the desired value in the "Choose your price" box and then clicking the Bid button. The value of 89 is shown nearby against a blue shaded background. The large box at upper left, labeled "Market 3 (1 Seller, 2 Buyers)," shows all current bids by both buyers and asks by the seller. The buyer transacts by either clicking on an ask or by waiting for the seller to click on her bid. The "Transactions" box shows the current period transactions in her local market; by clicking on the History tab the previous period's transactions are shown. The "Profit Information" box at the bottom right of the screen shows Buyer_B's previous transactions and profit. The History tab details trading profits and transactions in earlier periods. Sellers' trading screens are similar, with Ask and Sell buttons in the center box, costs instead of values, etc.

Figure 3: DA-Barg User Interface

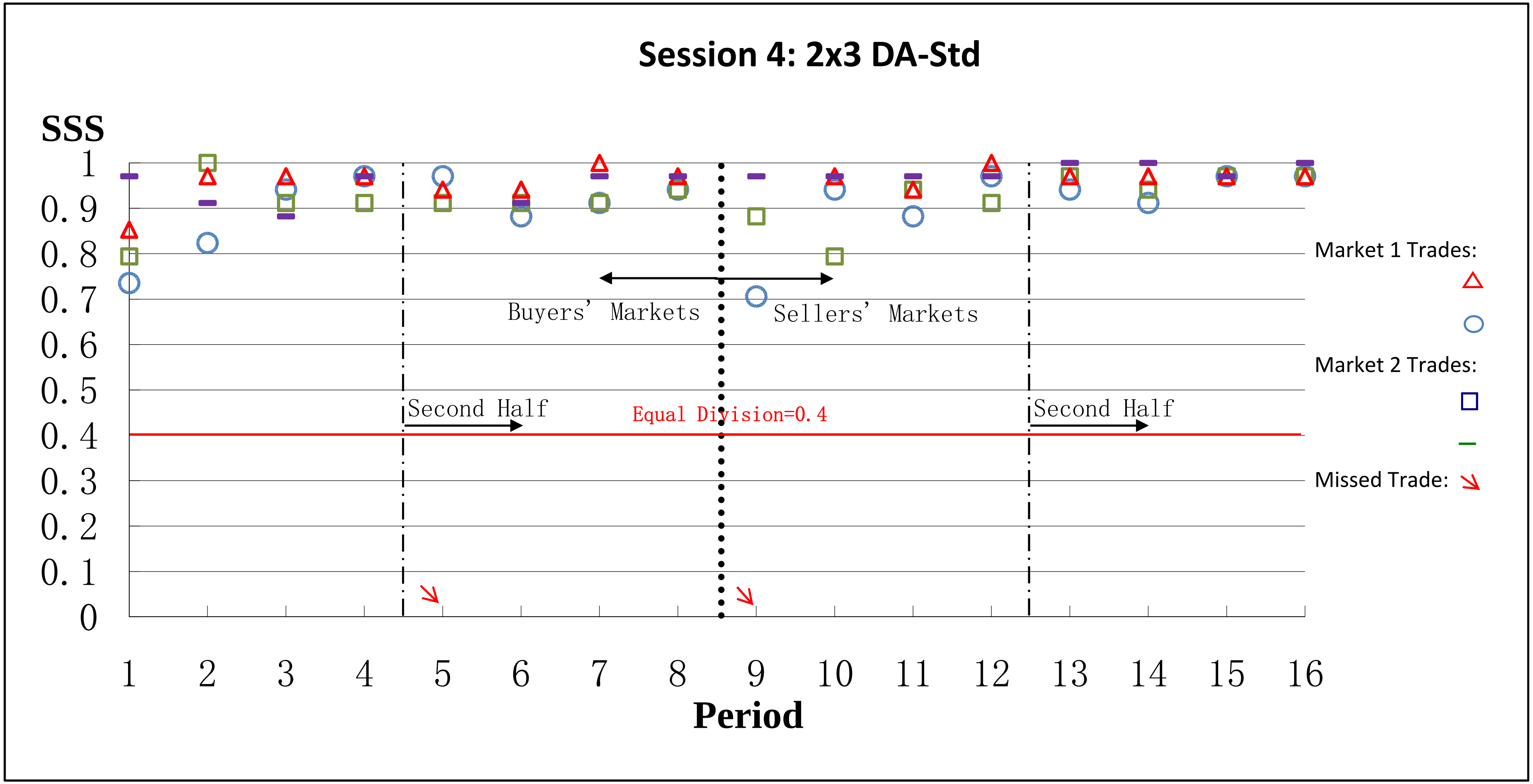


DA-Barg trading screen, tabbed to Market 2, is shown for Buyer_B. The box at upper left allows the buyer to propose (and to retract) an offer to award sole negotiation rights to the other buyer in exchange for a specified share of the profit. Just below is the “Accept Proposals” box, displaying an offer from the other buyer to give up his rights to sell in exchange for 60% of the profit; Buyer_B has accepted that offer but can retract by clicking the button. The Chatroom box below contains automatically generated messages from the server as well as messages sent by the traders (none at present). Earnings are shown on the right side of the screen.

Table 1: Sessions. Notation such as B8S8 indicates that the session included 8 buyers' market periods followed by 8 sellers' market periods, and B(2+10) indicates that 2 periods of ordinary CDA preceded 10 augmented periods (with the Chat facility).

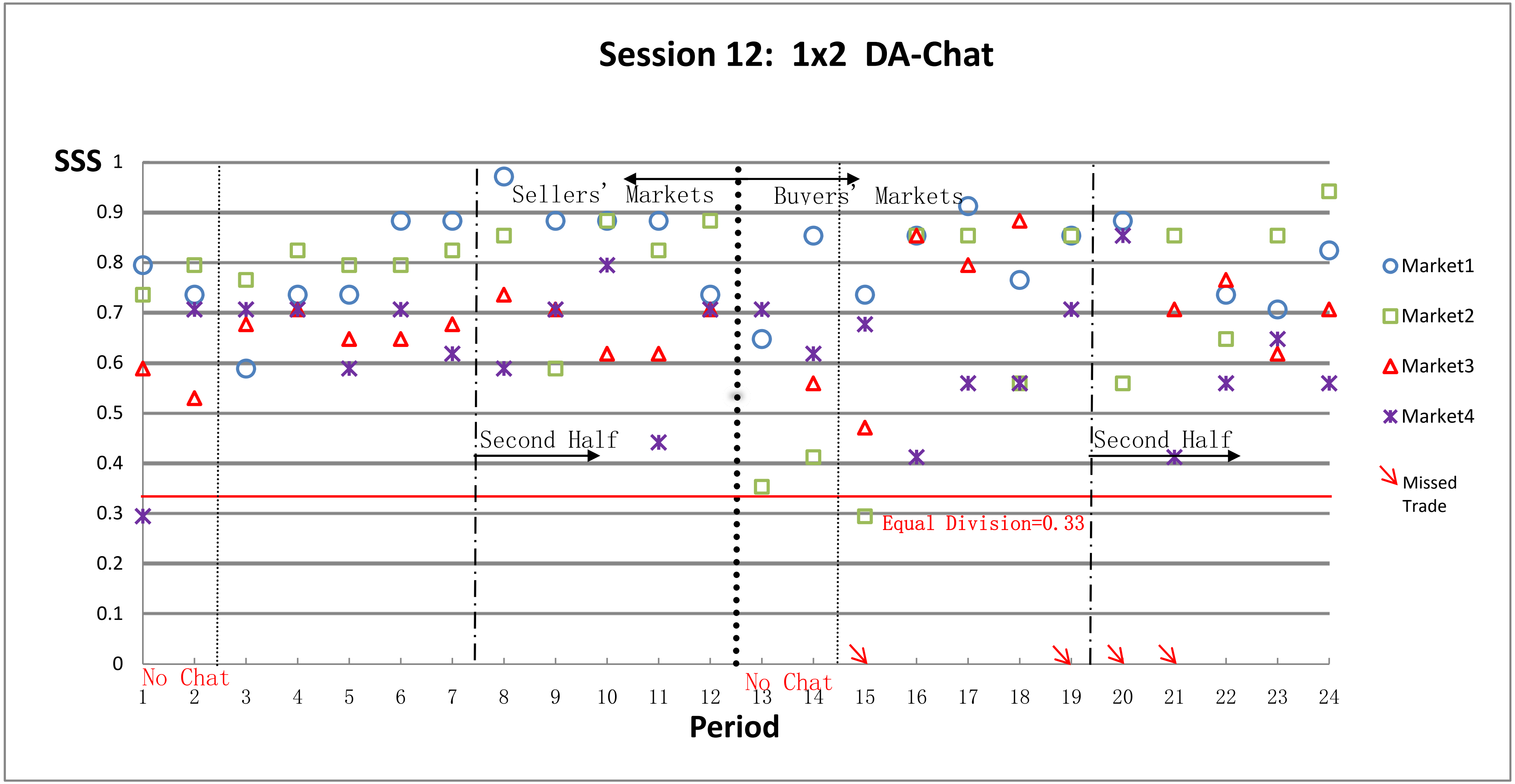
	DA-Std	**DA-Chat**	**DA-Barg**
1x2: 4 mkts per session	2 sessions: B10S10, S10B10	2 sessions: B(2+10)S(2+10), S(2+10)B(2+10)	3 sessions: B10S10, B10S10, S10B10
2x3: 2 mkts per session	3 sessions: B8S8, B8S8, S8B8	3 sessions: B(2+6)S(2+6), B(2+6)S(2+6), S(2+6)B(2+6)	No sessions

Panel A



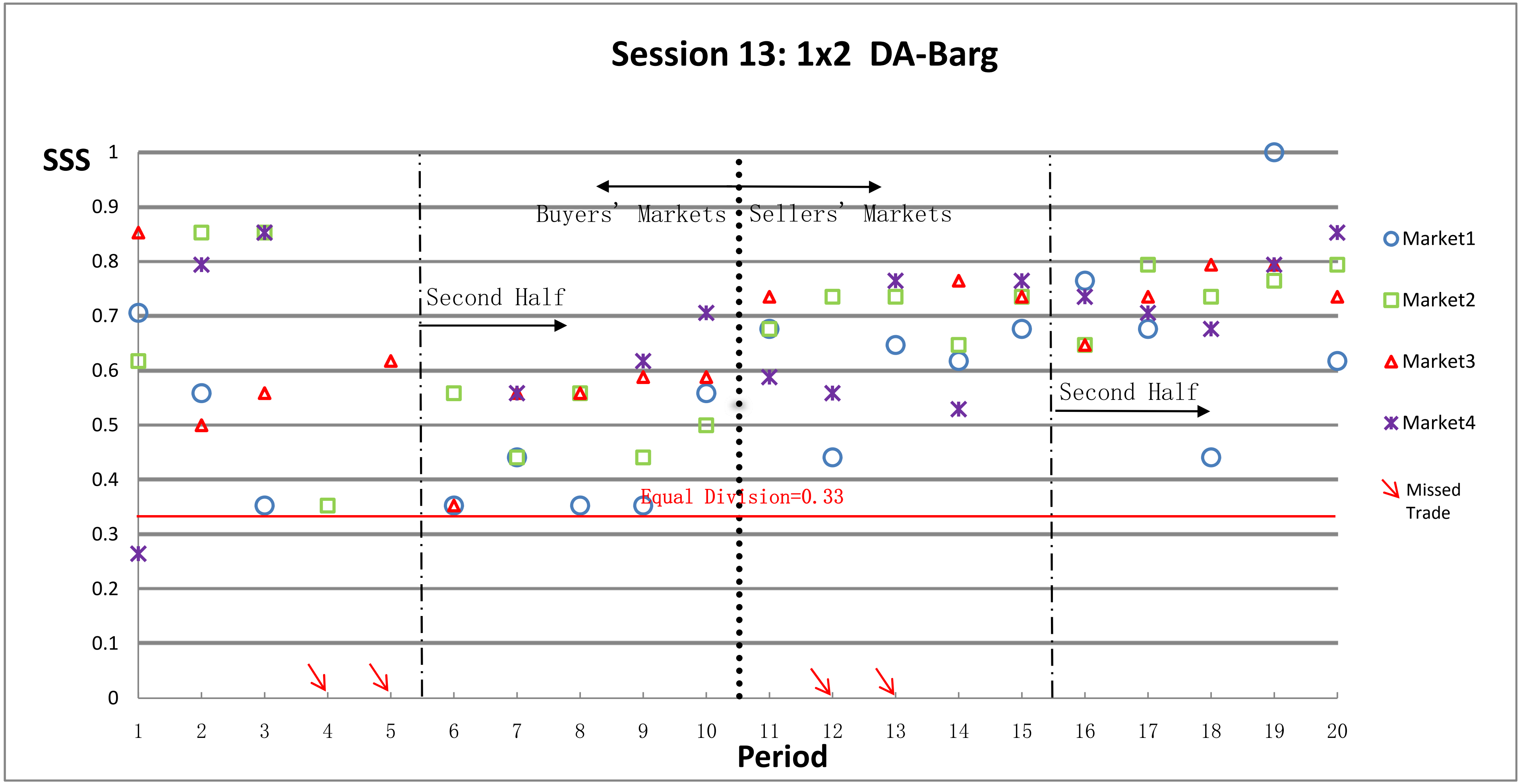
Session 4: 2x3 DA-Std
SSS
1
0. 9
0. 8
0. 7
0. 6
0. 5
0. 4
0. 3
0. 2
0. 1
0
Buyers' Markets
Sellers' Markets
Second Half
Equal Division=0. 4
Second Half
Market 1 Trades:
Market 2 Trades:
Missed Trade:
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Period

Panel B



Session 12: 1x2 DA-Chat
SSS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Sellers' Markets
Buyers' Markets
Second Half
Second Half
Equal Division=0.33
No Chat
No Chat
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Period
Market1
Market2
Market3
Market4
Missed Trade

Panel C



Session 13: 1x2 DA-Barg
SSS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Buyers' Markets
Sellers' Markets
Second Half
Second Half
Equal Division=0.33
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Period
Market1
Market2
Market3
Market4
Missed Trade

Table 2: Summary Table: mean and median SSS and efficiency levels , and t- and sign test results

	DA-Std	**DA-Chat**	**DA-Barg**
1x2 **midpoint= .670**	.878 ± .011 (.000) .912 (.000) .975	.722 ± .018 (.003) .706 (0.004) .925	.724 ± .017 (.001) .735(.001) .933
2x3 **midpoint= .700**	.894 ± .009 (.000) .912 (.000) .990	.740 ± .018 (.014) .735 (.000) .931	

Notes: Entries in each cell are as follows:

mean±std error (one-sided p-value of t-test)

median (one-sided p-value of sign test)

efficiency

Table 3: SSS regressions (random short sider effects GLS)

Regression Number	1	2	3	4
constant	.831***±.024	.755***±.041	.705***±.024	.849***±.021
Chat	-.153***±.023	-.163***±.023	-.112***±.021	-.101***±.021
Barg	-.149***±.029	-.146***±.029	-.099***±.027	-.086***±.026
Seg2	.050**±.020	.050**±.020	.021±.019	.040**±.017
Smarket	.042**±.020	.042**±.020	.022±.019	.016±.018
D2x3	.017±.023	.037±.025	.029±.021	.017±.020
Trend		.009**±.004	.015***±.002	
Collusion proposal only				-.061***±.018
Collusion agreement				-.075***±.017
Honored agreement				-.179***±.026
Fairness discussion				-.042**±.017
Range	Second Halves	Second Halves	All Periods	Second Halves
R-sq (overall):	.310	.314	.163	.491
rho	.425	.433	.285	.409
Number of Observations	422	422	846	422

Note: The treatment dummies (Chat, Barg, D2x3, Seg2 and Smarket) are defined in the text. Trend is the number of periods that have lapsed from the beginning of each segment. Precise definitions of the collusion variables in regression 4 can be found in the Appendix. ***, ** and * indicate significance at 1%, 5% and 10% levels respectively and the numbers before and after ± are the coefficient estimate and its standard error respectively.

Table 4: Collusion and fairness counts and rates. Unless noted otherwise, all rates are conditional on the counts in the row above.

		1x2 DA-Barg		1x2 DA-Chat		2x3 DA-Chat		Overall	
Number of Observations		117		80		34		241	
Propose	Fairness Appeal	59 50.4%	18 15.4%	34 42.5%	28 35.0%	15 44.1%	13 38.2%	108 44.8%	59 24.5%
Agreed:		30 50.9%		26 76.5%		11(including 9 trilateral agreements)73.3%		67 62.1%	
Honored		15 50.0%		9 34.6%		1(1)† 9.1% (11.1%)		25 37.3%	
Success		15 100.0%		5 55.6%		1 100.0%		21 84.0%	
Success∩ Fairness	Rate Conditional on Fairness	10	55.6%	4	14.3%	0	.00%	14	23.7%
Success Rate (Unconditional)		12.82%		6.25%		2.94%		8.71%	

† The trilateral agreement was honored all three.

Table 5: Logit Regressions for Collusion and Efficiency. All columns report results from second half data with random session effects.

[1] This dummy takes value 1 where collusion proposals were sent but did not result in an agreement.

Regression number	1	2	3	4
Dependent Variable	Successful Collusion	Successful Collusion	Missed Trades	Missed Trades
Constant	-1.816***±.513	-3.348***±.724	-3.893***±.746	-4.083±.776
Chat			1.523**±.720	.840±.798
Barg	.803†±.555	1.537**±.647	1.409*±.807	1.674**±.842
Seg2	-.726†±.525	-.881±.589	-.097±.439	-.183±.466
Smarket	-1.851***±.651	-1.458**±.695	-.097±.439	.074±.477
D2x3	-.938±1.131	-1.290±1.180	-.294±.635	.059±.653
Collusion proposal only[1]				.061±.673
Collusion agreement[2]				-.270±.744
Honored agreement[3]				2.398**±.944
Fairness discussion[4]		2.509***±.595		.831±.617
Barg*CollusionHonored				-37.779±>1000
Data Range	DA-Barg and DA-Chat	DA-Barg and DA-Chat	All Treatments	All Treatments
Log likelihood	-60.141	-49.721	-85.946	-79.572
rho	0	0	.047	.027
Number of observations	231	231	445	445

[2] This dummy takes value 1 when a collusion agreement, either bilateral or trilateral, was reached. See Appendix B for more details.
[3] This dummy takes value 1 when there was a collusion agreement and the long siders did not deviate from the agreement price. See Appendix B for more details.
[4] This dummy takes value when there were some statements regarding fairness. See Appendix B for more details.
† indicates significance at one-sided 10% level.

Table A1: Regressions of SSS (Random Effects GLS)

Regression number	1	2	3	4	5	6	7	8
Constant	.885***±.041	.757***±.085	.907***±.097	.885***±.041	.706***±.047	.800***±.039	.885***±.091	.850***±.027
Barg	-.289***±.051	-.236*±.124	-.372***±.141	-.289***±.05	.014±.061	-.160***±.049	-.294***±.112	-.201***±.039
Chat	-.238***±.059	.132±.133	-.081±.107	-.238***±.058	.030±.063	-.130**±.056	-.246**±.129	-.169***±.032
Seg2	.003±.059	.100±.109	-.141±.123	.003±.058	-.018±.064	.050±.056	.003±.129	.014±.031
Smarket	-.121**±.059		-.221±.124	-.121**±.058	-.088±.064	-.051±.056	-.119±.129	.039*±.020
D2x3	.045±.051	.058±.085	-.004±.091	.045±.051	.045±.054	.081*±.049	.046±.112	.017±.023
Barg*Odr	.163***±.078	-.001±.164	.161±.223	.163**±.077	-.021±.093	.050±.075	.165±.171	.104**±.051
Barg*Smkt	.317***±.079		.163±.244	.317***±.077	.062±.095	.192***±.075	.317*±.171	
Cht*Odr	.064±.084	-.313*±.188	.033±.089	.064±.082	-.032±.082	-.008±.08	.070±.183	.031±.045
Cht*Smkt	.224***±.083		.204**±.088	.224***±.082	.105±.081	.118±.079	.230±.182	
Cht*S2	-.036±.074	-.145**±.070	-.086±.079	-.036±.073	-.111±.072	-.067±.07	-.028±.159	
Odr*Smkt	.199**±.083		.311*±.175	.199**±.082	.124±.091	.089±.079	.197±.253	
Odr*S2	-.112±.079	-.137**±.064	-.084±.082	-.112±.078	-.211***±.077	-.224***±.075	-.112±.171	
Smkt*S2	.066±.079		.086±.082	.066±.078	-.056±.076	-.063±.075	.063±.171	
Barg*Odr*Smkt	-.351***±.111		-.157±.329	-.351***±.109	-.203±.133	-.233**±.106	-.348±.335	
Cht*Odr*Smkt	-.236**±.118		-.215*±.125	-.236**±.116	-.103±.115	-.115±.112	-.236±.358	
Cht*Odr*S2	.244**±.114	.308***±.108	.266**±.116	.244**±.112	.325***±.109	.314***±.108	.238±.243	
Cht*Smkt*S2	.001±.114		.014±.116	.001±.112	.120±.109	.114±.108	-.007±.243	
Odr*Smkt*S2	-.061±.112		-.084±.116	-.061±.110	.144±.108	.154±.106	-.058±.335	
Cht*Odr*Smkt*D2x3	-.205±.161	-.131**±.062	-.219±.164	-.205±.158	-.352**±.155	-.351**±.153	-.206±.475	
Trend		.008±.010	-.003±.011		.017***±.004			
Barg*Trnd		.009±.014	.010±.016		-.031***±.007			
Cht*Trnd		-.028**±.014	-.016±.010		-.026***±.004			
Trnd*Odr		0±.012	.018±.013		.012**±.005			
Trnd*Smkt			.012±.013		.007±.005			

Trnd*S2		.006±.010	.007±.010		$.012^{***}$±.004			
Barg*Trnd*Odr		.004±.019	.000±.026		.013±.010			
Barg*Trnd*Smkt			.017±.028		$.023^{**}$±.010			
Cht*Trnd*Odr		.026±.019						
Trnd*Odr*Smkt			-.014±.019		-.006±.008			
Barg*Trnd*Odr*Smkt			-.022±.038		-.005±.014			
Session 1				$.269^{***}$±.061				
Ssn1*Smkt				$-.249^{***}$±.086				
Random effect	Subject	Subject	Subject	Subject	Subject	Subject	Session	Subject
Data Range	Second Halves	Second Halves	Second Halves	Second Halves, including Session 1	All Periods	All Periods	Second Halves	Second Halves
R-sq(overall)	.451	.358	.466	.453	.331	.194	.451	.326
rho	.319	.402	.331	.314	.119	.196	.378	.418
Number of Observations	422	422	422	446	846	846	422	422

Table A2: Mean shares of short siders in the first halves

	DA-Std	DA-Chat	DA-Barg
1x2	.767***±.018	.731±.013	.702†±.018
2x3	.739***±.020	.731±.013	

Notes:

i) *** indicates significant difference from second halves at 1% level.

ii) † indicates that the mean is significantly below second half data at one-sided 10% level.

Table A3: Logit Regressions on Successful Collusion (Random Session Effects)

Regression number	1	2
Constant	-1.187*±.585	-38.744±>1000
Barg	1.693**±.681	
Seg2	-.019±.711	-38.744±>1000
Smarket	-1.574*±.850	-.735±.896
D2x3	-.744±1.195	3.348±2.045
Nonspecific collusion price[†]		-42.215±>1000
Planned collusion profit[††]		-7.513**±3.323
Trilaterality of agreement		-1.328±1.250
Random Effects	Session	Session
Data Range	DA-Barg and DA-Chat	DA-Chat only, with collusion agreements
Log likelihood	-34.268	-11.059
rho	0	0
Number of Observations	67	37

†This dummy takes value 1 when there was no specific collusion price and the long siders simply agreed to, for instance, ``hold the same price". See Appendix B for details.

††When the long siders agree on a specific collusion price, the planned collusion profit is defined as the difference between this price and the cost (or value) of a long side seller (buyer) .