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Do Buyer-Size Discounts Depend on the Curvature of the Surplus Function? Experimental Tests of Bargaining Models

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Abstract: A number of recent theoretical papers have shown that for buyer-size discounts to emerge in a bargaining model, the total surplus function over which parties bargain must have certain nonlinearities. We test the theory in an experimental setting in which a seller bargains with a number of buyers of different sizes. We generate nonlinearities in the surplus function by varying the shape of the seller's cost function. Our results strongly support the theory. As predicted, large-buyer discounts emerge only in the case of increasing marginal cost, corresponding to a concave surplus function.

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1 Introduction

The issue of large-buyer discounts has generated considerable interest for antitrust policymakers, business journalists, and academic economists. A common approach to the issue is to imagine that buyers negotiate with a seller over the price of the good and to posit that large buyers are somehow better bargainers than small buyers.[1] A theoretical literature emerged that derived the formal implications from such a bargaining model for buyer-size discounts, a literature that includes Horn and Wolinsky (1986), Stole and Zwiebel (1996a, 1996b), Chipty and Snyder (1999), Inderst and Wey (2003), and Raskovich (2003). The conclusion reached by this literature is that large-buyer discounts are not a foregone conclusion; whether such discounts are observed depends on the curvature of the total surplus function over which the parties bargain.

The logic of the theoretical argument is captured in Figure 1. Suppose for simplicity that buyers are final good consumers or are downstream firms which sell their output on separate markets. The total surplus function over which the parties bargain, $W(Q)$, is equal to total benefits (downstream consumer surplus or revenue) minus total costs (upstream and downstream production costs) as a function of the quantity, Q, sold to buyers who reach an agreement with the seller. Suppose a buyer with demand for q units trades with the seller. Assuming that others come to an efficient agreement with the seller, the buyer may be regarded as the marginal player, contributing marginal surplus A to the total.[2] In Figure 1A, with a concave total surplus function, A is quite small, and so whatever the sharing rule implicit in the bargaining process, the buyer will not obtain very much surplus per unit. Translated in terms of prices, the buyer will have

[1]Other approaches include models in which collusion is difficult to sustain in the presence of a large buyer (Snyder 1996, 1998), models in which large buyers' credible threat of backward integration limits prices charged to them (Katz 1987, Scheffman and Spiller 1992), and models in which downstream product market competition affects firms' negotiations with an input supplier (Horn and Wolinsky 1988, McAfee and Schwartz 1994, Dobson and Waterson 1997).

[2]In Stole and Zwiebel (1996a, 1996b), disagreement between a seller and a buyer can trigger a cascade of renegotiations out of equilibrium, so buyers' payoffs are a weighted average of the marginal surplus plus a series of inframarginal surpluses. Since the weight is greatest on the marginal surplus and declines over the series of inframarginal surpluses, one obtains a similar insight about the importance of the ratio of the marginal to inframarginal surplus.

to pay a relatively high price. Now consider a second buyer who is twice as big as the first, having demand for $2q$ units. The relevant marginal surplus over which the large buyer and seller bargain becomes $A+B$, which is much greater per unit than A due to the concavity of the surplus function. Hence, the large buyer pays a lower per-unit price than the small one.

Contrast this result with the case of a linear total surplus function as in Figure 1B. Taking the small buyer to be the marginal player, the surplus over which he bargains to satisfy his q units of demand is A. Taking the large buyer to be the marginal player, to fulfill his $2q$ units of demand, he bargains over the surplus $A + B$, which is twice as large as A by the linearity of the surplus function. Thus, the large and small buyer contribute the same marginal surplus per-unit demand and, as a result, pay the same per-unit price.

The case of a convex total surplus function, as in Figure 1C, is more complicated. The surplus over which the small buyer bargains, A, is much larger per unit than that over which the large buyer bargains, $A + B$. Hence we might expect large-buyer premia to emerge in equilibrium. However, buyers' contributions to surplus at the margin may be so high that the low prices they pay as a result are insufficient to cover the seller's costs. Multiple equilibria may arise with one buyer or another paying more to prevent the seller from taking his outside option not to produce. As we will analyze rigorously in Section 3, the set of equilibrium outcomes may range from large-buyer premia, to prices independent of size, to large-buyer discounts.

To summarize, the theory indicates that large-buyer discounts should emerge in the bargaining model when the total surplus function is concave and that the per-unit price should be the same for large and small buyers when the total surplus function is linear. There are multiple equilibria with a convex total surplus function, and so it is an empirical question whether on average there are large-buyer discounts, small-buyer discounts, or no discounts at all.

We test this theory in an experimental setting with three treatments corresponding to markets with concave, convex, and linear total surplus functions. Each market involves a single seller and both large and small buyers, allowing us to measure the buyer-size discount directly. We generate curvature in the total surplus function in a natural way, namely, by varying the seller's marginal cost function, with increasing marginal costs leading to a concave total surplus function, constant marginal costs leading to a linear total surplus function, and decreasing marginal costs leading to a convex total surplus function.

Our results provide strong support for the theory. Substantial large-buyer discounts are observed in the increasing marginal cost treatment (i.e., concave total surplus function), as predicted by theory. Large buyers' per-unit bids are 12 percent lower on average than small buyers' in this treatment. Sellers are also more likely to accept low bids from large buyers than from small buyers. Thus, the large-buyer discount is larger, 14 percent, for accepted bids. In the cases of constant and decreasing marginal costs, large and small buyers bid virtually the same per-unit price on average, and seller's acceptance probabilities are not different for large and small buyers. Exactly as the theory predicts, large-buyer discounts emerge only under certain conditions related to the curvature of the total surplus function.

The strong support our results provide for the theory is somewhat surprising given a number of factors that might lead some to question the practical merit of the theory. (a) The business press suggests large-buyer discounts are pervasive (see, among numerous examples, Schiller and Zellner 1992 and Ferguson 1999), without any qualification that these discounts might depend on an esoteric condition on second derivatives. This might lead one to expect to find large-buyer discounts across all of our treatments, which we do not find. (b) It might be heroic to assume that experimental subjects play like the rational agents of theory, with buyers regarding themselves as marginal in just the right way depending on their size. One might instead expect buyer-size discounts not to emerge, or if they do, not to vary with the aforementioned esoteric condition on second derivatives. But in fact we find size discounts vary precisely as the theory indicates. (c) There is an alternative body of formal theory showing that large-buyer discounts may emerge even with linear or convex total surplus functions if bargaining parties are assumed to be risk averse (Chae and Heidhues 1999a, 1999b; DeGraba 2003). Our results show that large-buyer discounts are limited to the case of concave surplus functions.

To our knowledge, ours is the first direct test of the bargaining literature cited above (Horn and Wolinsky 1986; Stole and Zwiebel 1996a, 1996b; Chipty and Snyder 1999; Raskovich 2003; and Inderst and Wey 2003). There have been a few empirical papers that provide indirect tests, analyzing whether large-buyer discounts are observed in the presence of a monopoly seller or whether competition among sellers is required (Sorensen 2001, Ellison and Snyder 2002). In the particular industries studied, large-buyer discounts were found in markets with competing suppliers but not with monopoly suppliers. While this result does not support the bargaining literature cited above, it is not a direct rejection since the theory does not say large-buyer discounts must emerge in equilibrium—large-buyer discounts may not emerge if the total surplus function is not concave. The empirical section in Chipty and Snyder (1999) provides estimates of the curvature of the total surplus function in cable television. Together with the theory, these estimates could be used to determine cable operators' incentives to merge, but they are not a direct test of the theory.

While ours is the first experimental study of size as a source of buyer discounts, there have been several previous experimental papers that study other sources of buyer discounts. Ruffle (2000) examines buyers' use of dynamic demand-withholding strategies to extract price concessions from competing sellers. Engle-Warnick and Ruffle (2002) study the effect of buyer concentration on prices. Neither study varies buyer size within a market to measure buyer-size discounts, nor do they vary the shape of the total surplus function to test the bargaining theories cited above, as we do in the present paper.

The structure of the paper is as follows. Section 2 provides a detailed description of our experimental design. In Section 3 we formally derive the subgame-perfect equilibria of our experimental game. This requires several new propositions since, to keep the experiment as simple as possible for the subjects, our bargaining game is somewhat different from those adopted in the related theoretical literature cited above. The equilibrium outcomes and their implications for buyer-size discounts are the benchmark against which we compare our results in Section 4. Section 5 concludes.

2 Experimental Design

This section provides a detailed description of our experimental design. To test for the relationship between the curvature of the surplus function and buyer-size discounts, we designed three separate markets or treatments. The three treatments differ only in the shape of the seller's marginal cost function: a treatment with an increasing marginal cost function (IMC), constant marginal cost function (CMC), and decreasing marginal cost function (DMC). In each market, three buyers face a single seller. Two of the buyers are small, with unit demand for the fictitious commodity, and the other buyer is large, with demand for two units. The buyers' per-unit gross surplus is $v_i = 100$, implying total gross surplus of $V_i = 100$ for a small buyer and $V_i = 200$ for the large buyer. The seller can supply up to four units to the buyers, so there is no binding capacity constraint.

The seller's cost function in each of the three treatments is displayed in Figure 2. We controlled for the total cost of supplying all four units by setting it equal to 80 in all three treatments. In the IMC treatment, the seller's first unit of production costs 0, the second unit costs 5, the third unit 15, and the fourth 60. The DMC treatment uses the same numbers but in reverse order, so the first unit costs 60, the second unit 15, the third 5, and the fourth 0. In the CMC treatment, all four units have the same marginal cost of 20. Putting together the sellers' cost functions with buyers' valuations yields the total surplus functions graphed in Figure 3. Note that the cost and valuation parameters of the IMC treatment correspond to a concave surplus function, CMC to a linear surplus function, and DMC to a convex one. The logic of the theoretical literature cited in the Introduction would lead one to expect large-buyer discounts in the IMC treatment, no discounts in the CMC treatment, and one of a range of possible outcomes in the DMC treatment.

(We will verify these claims formally in the next section.)

To permit within-subject comparisons across treatments, we designed the experiment so all subjects participate in each of the three treatments. Each session involves 12 subjects. At the start of the session, nine of the subjects are randomly selected to play the role of buyer and three to play the role of seller. This role remains fixed throughout the experiment. The experiment consists of 60 rounds. In each round of the experiment, the three markets are conducted simultaneously. Each round, subjects are randomly assigned to one of the three markets. The designation of the large and two small buyers in each market is also randomly determined each round. Hence, for example, the probability that a buyer is assigned the role of small (respectively, large) buyer in the IMC market is 2/9 (respectively, 1/9) for each buyer in any of the 60 rounds, while each of the three sellers has equal probability 1/3 of being assigned to any of the three markets in any of the 60 rounds. Thus, this randomization scheme shuffles the cohort of three buyers and one seller that constitutes a market each round. We selected this design feature to minimize repeated-game effects.[3] Furthermore, the randomization scheme was performed once, prior to conducting any of the experiments. The outcome of the randomization scheme was used for all six sessions. In this way, we minimize between-session differences unrelated to behavior.

Trading takes place in a posted-bid market (first analyzed by Plott and Smith 1978), involving the following sequence of events. First, each subject is informed of the market to which he has been assigned and buyers are told whether they have a demand for one or two units that round. Each buyer i then privately and independently chooses a bid, p_i. A small buyer's bid reflects the price he is willing to pay to fulfill his unit demand, while the large buyer's bid reflects the per-unit price he is willing to pay for the bundle of two units. The large buyer was not given the option of bidding separate amounts for the two units. The seller observes each buyer bid for $x_i \in \{1, 2\}$ units and decides whether to accept ($a_i = 1$) or reject ($a_i = 0$) each one. The seller

[3] Subjects who play together repeatedly even for a known, fixed number of rounds sometimes exhibit supergame-style strategies, especially when the number of rounds is large (Selten and Stoecker 1986).

did not have the discretion to supply one of the large buyer's two units and reject the other.

Buyers earn a payment equal to net consumer surplus $a_i x_i (v_i - p_i)$, and sellers earn a payment equal to total revenue, $\sum_i p_i a_i x_i$, minus the total cost of producing realized sales. Thus, rejected bids yield zero profit for the buyer and the seller; the seller does not incur the cost of unsold units.

Buyers' valuations, seller costs, and the structure of the market were all made common knowledge by reading aloud the instructions (contained in Appendix B) given to the subjects. Subjects were told that cohorts would be randomized in each round, but were not told with whom they were playing in a market. Feedback at the end of a round is minimal, again with the aim of minimizing repeated-game effects or possible collusion. Each buyer learns only whether his bid was accepted and his resulting payoff. Buyers do not observe any other buyers' bids in their own or the other two markets, nor the sellers' decisions. Play proceeds to the next round.

At the completion of 60 rounds, all subjects were paid their experimental earnings in cash. All subjects were given an initial endowment of 1,000 experimental "points" at the beginning of the experiment. For every 250 points accumulated, the subject received £1. In total, 72 subjects participated in one of six experimental sessions conducted in the Experimental Economics Laboratory at Royal Holloway, University of London. Each session, including the instructions, five practice rounds, and a post-experiment questionnaire, lasted between 120 and 160 minutes. On average, sellers earned £22 and buyers £19 each, including the initial endowment.

3 Theoretical Predictions

In this section, we derive the subgame-perfect equilibria of our experimental game. Our experimental setting differs slightly from any of the related theoretical papers because we have adopted a different bargaining game. Rather than Nash bargaining (as in Horn and Wolinsky 1986, Chipty and Snyder 1999, and Raskovich 2003), or specific bargaining procedures giving rise to the Shapley value (as in Stole and Zwiebel 1996a, 1996b; and Inderst and Wey 2003), we adopt a simpler, and thus more tractable, bargaining game for an experimental setting, namely one in which parties make take-it-or-leave-it offers. The equilibrium outcomes are qualitatively similar to those in these other papers, but to derive the equilibria formally requires new propositions. Since these propositions are of some independent interest, we first prove a fairly general version of them, and then proceed to derive their implications for the specific parameters used in our experiment.

Suppose there are N buyers indexed by $i = 1, \ldots, N$. Let $B = \{1, \ldots, N\}$ denote the set of buyers. Each buyer i has inelastic demand for $x_i \in \mathbb{N}$ units, with V_i representing the buyer's total gross surplus for the bundle of x_i units, and $v_i = V_i/x_i$ representing the buyer's gross surplus per unit. Let $X = \sum_{i \in B} x_i$. In the first stage of the bargaining game, each buyer i makes a simultaneous offer of a bid per unit $p_i \in [0, \infty)$ to the single seller in the market. In the second stage of the bargaining game, the seller decides whether to accept the bid of each buyer i, the decision denoted $a_i \in \{0, 1\}$. Equivalently, the seller chooses the set of accepted buyer bids $A = \{i \in B | a_i = 1\}$. Market sales are $Q = \sum_{i \in B} a_i x_i$.

Denote the seller's total cost of producing Q by $C(Q)$, its marginal cost of producing the last of Q units by $MC(Q) = C(Q) - C(Q-1)$, its incremental cost of producing Q_2 on top of Q_1 by $IC(Q_2, Q_1) = C(Q_1 + Q_2) - C(Q_1) = \sum_{j=1}^{Q_2} MC(Q_1 + j)$, and its average incremental cost of producing Q_2 on top of Q_1 by $AIC(Q_2, Q_1) = IC(Q_2, Q_1)/Q_2$. Normalize $C(0) = 0$.

A full characterization of the subgame-perfect equilibria of this game for general parameter configurations turns out to be quite complicated. In our experiments, we chose the parameters so that all buyers are served in equilibrium. This simplifies the characterization of equilibria considerably. We will thus restrict attention to the case in which all buyers are served for the remainder of the section. The following proposition provides a sufficient condition for all buyers to be served in equilibrium. The proof of Proposition 1 and all subsequent propositions are provided in Appendix A.

Proposition 1. *All buyers are served in the subgame-perfect equilibrium (formally, the set of buyers whose bids are accepted A equals the set of all buyers B) if, for all $i \in B$,*

$$v_i > \max_{\{Q \leq X\}} MC(Q). \tag{1}$$

Condition (1) specifies that all buyers' per-unit valuations exceed the marginal cost of producing any unit. If condition (1) holds, but not all buyers are served in a particular outcome, the outcome cannot be an equilibrium. Rather than earning zero profit, an excluded buyer could offer a bid between its valuation and the incremental cost of being served that would be strictly profitable for the seller to accept regardless of which other buyers were also being served. This accepted bid would generate positive profit for the buyer. Note that the condition in the proposition is satisfied by the experimental parameters since $v_i = 100$, which is greater than 60, the highest marginal cost of producing any unit in the experiment.

The next set of propositions characterize the subgame-perfect equilibria in which all buyers are served for marginal cost functions of different shapes.

Proposition 2. *Suppose marginal costs are non-decreasing, i.e., $MC(Q+1) \geq MC(Q)$ for all $Q \in \{1, 2, \ldots, X\}$. Buyer bids $\{p_i | i \in B\}$ form a subgame-perfect equilibrium in which all buyers are served if and only if, for all $i \in B$,*

$$p_i = AIC(x_i, X - x_i) \leq v_i. \tag{2}$$

Proposition 3. *Suppose marginal costs are strictly decreasing, i.e., $MC(Q+1) < MC(Q)$ for all $Q \in \{1, 2, \ldots, X\}$. Buyer bids $\{p_i | i \in B\}$ form a subgame-perfect equilibrium in which all buyers are served if and only if $p_i \leq v_i$ for all $i \in B$ and, for all subsets $S \subseteq B$,*

$$IC\Big(\sum_{i \in S} x_i, X - \sum_{i \in S} x_i\Big) \leq \sum_{i \in S} p_i x_i \leq C\Big(\sum_{i \in S} x_i\Big). \tag{3}$$

Proposition 2 subsumes the cases of strictly increasing marginal costs and everywhere constant marginal costs, which correspond to two of our experimental treatments, as well as marginal cost functions that are strictly increasing over some regions and constant over others. In view of Proposition 2, characterization of the equilibrium with all buyers being served under constant or increasing marginal costs is quite simple. Each buyer bids an amount that exactly covers the incremental cost of being served on top of the other $N-1$ buyers' purchases. Any less than this and the seller would gain by rejecting the bid; any greater than this and the buyer could profitably lower the bid and still not have it rejected by the supplier.

As Proposition 3 shows, characterization of equilibria under decreasing marginal costs is more complicated. There is a continuum of equilibria. Within certain bounds, any set of bids summing exactly to the total cost of serving all buyers forms an equilibrium in which all buyers are served. The bounds on buyers' bids in condition (3) ensure that the seller does not have an incentive to reject a subset of buyer bids and that a buyer does not have an incentive to lower his bid since it would be rejected by the seller.

Next we derive the predictions implied by Propositions 2 and 3 for our experimental parameters. Let p_{s_i} be the equilibrium per-unit bid by small buyer $i = 1, 2$ and p_ℓ that by the large buyer. For the IMC treatment, Proposition 2 implies $p_{s_i} = AIC(1,3) = 60$, $p_\ell = AIC(2,2) = 37.5$, and the seller accepts all the bids. The implication is that the large buyer obtains a substantial discount. Each small buyer earns 40 compared to 125 for the large buyer. The seller earns a positive profit of 115.

For the CMC treatment, Proposition 2 implies $p_{s_i} = AIC(1,3) = 20$, $p_\ell = AIC(2,2) = 20$, and the seller accepts all bids. Thus, large and small buyers make the same per-unit bids in equilibrium, equal to the constant marginal cost. Each small buyer earns 80, the large buyer earns 160, and the seller earns zero.

In the DMC treatment, there exists a range of equilibria. Proposition 3 states that condition (3) must hold for all subsets of buyers. Translated into our experimental setting, for a subset of one small buyer, condition (3) implies $0 \leq p_{s_i} \leq 60$, for a subset of one large buyer $5 \leq 2p_\ell \leq 75$, for a subset of one large and one small buyer $20 \leq 2p_\ell + p_{s_i} \leq 80$, and for all the buyers $80 \leq 2p_\ell + p_{s_1} + p_{s_2} \leq 80$. Combining these inequalities yields the set of equilibria labeled DMC in Figure 4. Figure 4 also graphs the predictions for the IMC and CMC treatments for comparison. Along the 45-degree line in the figure, there are no size discounts, below it large-buyer discounts, and above it small-buyer discounts. As the figure shows, there are multiple equilibria with DMC. Both large-buyer and small-buyer discounts are possible, as well as an outcome in which all buyers pay the same per-unit price of 20. All buyers are served in equilibrium. Buyers' payoffs depend on the equilibrium; the seller earns zero in all cases.

To summarize the predictions for the three treatments, large-buyer discounts should be observed in the IMC treatment and no discounts observed in the CMC treatment. The DMC treatment may exhibit a range of outcomes including no discounts. Average bids are predicted to be higher in IMC than the other treatments. Only in the IMC treatment is the seller predicted to earn positive profit; in the CMC and DMC treatments, buyers' bids sum exactly to the seller's total cost of 80.

4 Results

4.1 Buyer Behavior

In this section, we test the equilibrium-bid hypotheses and their implications for buyer-size discounts based on the six experimental sessions we conducted. In analyzing bidding behavior, we will refer to the histograms of buyers' bids by market in Figure 5 and to the descriptive statistics in Table 1. The fixed-effect regressions reported in Table 2 will provide the formal statistical tests. Although the tables also report results based on all 60 rounds, we direct attention to the last 30 rounds of play throughout the discussion. This choice follows from the insight that experimental data is typically noisy in the early rounds as subjects familiarize themselves with the environment, experiment with different strategies and gradually learn to play in a more sophisticated manner. All of our qualitative results are robust to considering the entire 60 rounds of play.

The summary statistics in the first two rows of the last four columns of Table 1 suggest a significant large-buyer discount in the IMC treatment. The mean of large-buyer bids is 39.5 (median=40.0), five points less than the mean small-buyer bid of 44.8 (median=45.0). Figure 5A shows that the distribution of small-buyer bids, represented by the black bars, first-order stochastic dominates the distribution of large-buyer bids, the white bars.

The result from the descriptive statistics and histograms is borne out formally in the fixed-effects regressions in Table 2. Recall from our discussion of the experimental design that all buyers play the role of large and small buyers in each of the three treatments. This allows us to include buyer fixed effects to control for buyers whose bidding behavior might differ systematically from others. The inclusion of round fixed effects accounts for any systematic changes in behavior as play evolves and subjects become more familiar with the game over the course of the experiment. The standard errors are corrected for possible correlation across observations for the same experimental player and also corrected for possible heteroskedasticity following White (1980). In addition to the fixed effects, the regressions include dummy variables for the IMC and DMC treatments, labeled *IMC* and *DMC*, respectively, with CMC as the omitted treatment. To assess the magnitude of buyer-size discounts or premia, interaction terms between each of the treatments and buyer size are included, $IMC \times LARGE$, $CMC \times LARGE$, and $DMC \times LARGE$. The variable *LARGE* equals one for bids made by large buyers and zero otherwise. The coefficient of -4.83 (significant at the one-percent level) on the interaction term $IMC \times LARGE$ in column (b) indicates nearly a five point discount for large buyers in this treatment.

The existence and magnitude of the large-buyer discount in IMC are striking when contrasted with the absence of buyer-size discounts in the other two treatments. Theory predicts that the mean large- and small-buyer bids should be identical in the CMC treatment. The descriptive statistics in Table 1 bear this out: the mean large-buyer bid in this market is 34.6 (median=35.0) compared to 34.5 (median=35.0) for small buyers. The histograms for the two distributions in Figure 5B are nearly identical, except for the few large-buyer attempts to bid below the seller's marginal cost, all of which were rejected. Formal statistical tests from column (b) of Table 2 also show no difference between large and small buyers' bids: the coefficient of -0.88 on $CMC \times LARGE$ is not significantly different from zero.

Turning to the DMC treatment, we again find no difference between large and small buyers' bids. The mean large-buyer bid in DMC is 40.9 (median=40.0) compared to 40.2 (median=40.0) for small buyers. The histograms for the two distributions in Figure 5C are again nearly identical. Formal statistical tests also show no difference between large and small buyer's bids: the coefficient of -0.47 on the interaction term $DMC \times LARGE$ in column (b) of Table 2 is not statistically different from zero.

The results are nearly identical, indeed stronger in the IMC treatment, if we consider the subsample of accepted bids. The justification for focusing on accepted bids is that these would be the prices observed by the empirical researcher in a typical non-experimental market; one would not observe prices for trades that were not executed due to a breakdown in bargaining. (One could counter that for our experimental markets, the theory predicts that all bids are accepted in equilibrium; hence, one should also look at all bids, as we did in the previous paragraphs.) Summary statistics for accepted bids are provided in the last six rows of Table 1. Looking at the mean large and small buyers' accepted bids, the large-buyer discount increases to seven points; the large-buyer discount increases to nine points for the medians. Similarly, the regression coefficient of -5.74 on $IMC \times LARGE$ in column (d) of Table 2 is larger (by one point) than the corresponding coefficient for all bids reported in column (b). By contrast, the means and medians of large and small buyers' bids remain virtually unchanged for the CMC and DMC treatments when we restrict attention to accepted bids and the corresponding regression coefficients measuring a buyer-size discount continue not to be significantly different from zero.

In short, the results for buyer bids are consistent with the underlying theory, the implications of which were summarized in Figure 4. There are large-buyer discounts in the IMC treatment, and no price discounts in the CMC treatment, both consistent with theory. Theory predicts a broad range of possible outcomes for the DMC treatment, one of which involves equal prices across large and small buyers, and this is in fact what the experimental data shows on average.

Next, we compare the levels of buyer bids to the equilibrium predictions, also summarized in Figure 4. In the IMC treatment, the average large-buyer bid of 39.5 is close to the theoretical prediction of 37.5. A one-sample t-test comparing the six session averages of large-buyer bids to the theoretical prediction cannot reject their equality ($t = 0.75$, $p = 0.489$, d.f.$= 5$).[4] On the other hand, the average small-buyer bid of 44.8 is significantly less than the theoretical prediction of 60 in a one-sample t-test using the six session averages of small-buyer bids ($t = 4.79$, $p = 0.005$, d.f.$= 5$). The absence of buyer-size discounts in the CMC and DMC treatments coupled with small buyers' below-equilibrium bidding in IMC make large-buyer discounts in this treatment all the more striking.

To understand small-buyers' below-equilibrium bidding, consider a small buyer who bids strictly less than 60. A seller would certainly reject such a bid if he intended to serve all other buyers. A small buyer might nonetheless submit a bid strictly less than 60 if he expected the other small buyer likewise to bid less than 60, trading off an increased probability of being the one whose bid is rejected for a lower price. Such outcomes unravel in theory as a small buyer seeks to ensure he is not the rejected buyer by bidding slightly above the other. In the next subsection on seller behavior, we will assess the rationality of bidding less than 60 given the experimental

[4] Although we quote a simple t-test, alternative tests yield similar results, for example, weighting the six session averages by the inverse of their standard deviations for the one sample t-test or running a regression of individual large-buyer bids for the last 30 rounds on a constant, accounting for the possible correlation across observations for the same experimental player. The same can be said for the other simple t-tests quoted below. The inclusion of multiple fixed effects in the Table 2 regressions prevents one from using the coefficients from the table directly to test hypotheses involving bid levels.

(rather than theoretical) behavior of subjects.

Average bids in the CMC treatment, around 35, are significantly higher than the theoretical prediction of 20 in a one sample t-test using the six session averages of large-buyer bids ($t = 5.42$, $p = 0.003$, d.f.$= 5$) and similarly for small-buyer bids ($t = 5.55$, $p = 0.003$, d.f.$= 5$). Note that a bid of 20 leaves the seller with no surplus and nets the buyer a surplus of $100 - 20 = 80$ per unit purchased. Ultimatum-bargaining experiments (Güth *et al.*, 1982) reveal that experiments rarely produce such an uneven division of surplus. Indeed, what may be surprising is that our experiments are as close as they are to the theoretical predictions given the observed inequality of surplus distribution. In the CMC treatment, a per-unit bid of 35 yields the seller only 23 percent of total social surplus compared to 77 percent for the buyer, a less-even division than ultimatum-game experiments in which a split closer to 50-50 is typical (see Roth, 1995, for a survey).

Although the theory makes no unique prediction for the large and two small-buyers' bids in our DMC experiments, in all equilibria their bids should sum to 80: with an average large-buyer bid of 40.9 and 40.2 for each of the small buyers, the sum of the three buyers' bids exceeds the theoretical benchmark significantly in a one-sample t-test using the six session averages for the sum of buyers' bids ($t = 9.15$, $p < 0.001$, d.f.$= 5$). Moreover, bids are higher in the DMC than the CMC treatment, although they are predicted to be the same on average (and to provide the seller with zero surplus in equilibrium). The highly significant coefficient of -5.69 on the treatment dummy *DMC* in column (b) of Table 2 indicates that small buyers bid nearly six points more in DMC compared to CMC. Subtracting the coefficient on $\mathit{CMC} \times \mathit{LARGE}$ from the sum of the coefficients on *DMC* and $\mathit{DMC} \times \mathit{LARGE}$ indicates that large buyers also bid about six points more in DMC than in CMC ($F = 22.52$, $p < 0.001$, d.f.$= 1, 53$). The underlying theory also predicts that bids will be higher in the IMC treatment than the other two treatments. The highly significant coefficient of 9.28 (compared to the omitted CMC treatment) and an F-test comparing the *IMC* and *DMC* coefficients support this prediction: small-buyer bids in IMC are more than nine points higher than those in CMC (significant at better than the one percent level) and nearly six points higher than DMC bids ($F = 4.82$, $p = 0.033$, d.f.=$1, 53$). Large-buyer bids are more than five points higher in IMC than in CMC ($F = 15.73$, $p < 0.001$, d.f.$= 1, 53$) but are not significantly greater than in DMC ($F = 0.44$, $p = 0.509$, d.f.$= 1, 53$).

In sum, large buyers' bids in IMC accord on average with the equilibrium prediction, while small-buyers' bids are lower than predicted. Also consistent with the theory, bids in the IMC treatment are higher than the CMC and DMC treatments; however, bids in the CMC and DMC treatments are higher than predicted (though not higher than expected in view of the experimental bargaining game literature).

4.2 Seller Behavior

The distinction between accepted and rejected bids and the question of the rationality of small buyers' bidding below equilibrium in the IMC treatment lead us to examine seller behavior in these markets more closely. The underlying theory predicts that the seller in the IMC treatment should be (weakly) more inclined to accept a large-buyer bid than an equal small-buyer bid since the average incremental cost of supplying the large buyers' two units is lower than supplying the small buyer's single unit. In the CMC treatment, theory suggests that there should be no difference in the accept/reject decision for large- and small-buyer bids since both provide the same per-unit surplus for a given bid. There are no strong theoretical predictions for the DMC treatment in this regard because of the multiplicity of equilibria.

Comparing the number of accepted bids to the total bids (see the last six rows of Table 1), the disproportionate number of rejected bids made by small buyers in the IMC treatment stands out. For the other buyer types, rejection rates range between two percent (large buyers in DMC) and 17 percent (large buyers in CMC). In the case of small buyers in IMC, the rejection rate is 40 percent, with 143 out of 360 bids are rejected. Compare this with large buyers in the same treatment whose bids are rejected at the rate of only ten percent (18 out of 180), despite bidding significantly lower than their small-buyer counterparts.

The probits reported in Table 3 provide a more formal characterization of the seller's accept/reject decision as a function of the buyer's bid, buyer size, and shape of the cost function.[5] In the table, the variable *SMALL* is a dummy for a small buyer bid, equal to $1 - LARGE$, and *BID* is the buyer's per-unit bid. The standard errors on the probits are adjusted for possible heteroskedasticity (White 1980) and for possible correlation in the errors for the same seller across multiple rounds.

In the CMC treatment the results indicate similar acceptance probabilities for large and small buyers, as predicted by the theory. The coefficients on $CMC \times LARGE$ and $CMC \times SMALL$ in column (b), -3.15 and -3.24, respectively, are insignificantly different from each other ($\chi^2 = 0.01$, $p = 0.920$, d.f.$= 1$), as are the coefficients on $CMC \times LARGE \times BID$ and $CMC \times SMALL \times BID$, 0.13 and 0.14, respectively ($\chi^2 = 0.28$, $p = 0.594$, d.f.$= 1$). The probit results for the IMC treatment similarly support the theory: the IMC seller is more likely to reject a small- than a large-buyer's bid, controlling for the amount of the bid. The coefficient on $IMC \times LARGE \times BID$, 0.22, is 88 percent higher than the analogous coefficient on $IMC \times SMALL \times BID$, 0.12, and statistically significantly so ($\chi^2 = 10.55$, $p = 0.001$, d.f.$= 1$). This result suggests that for a given per-unit bid the large buyer's is more likely to be accepted; however, the result is offset somewhat by the fact that the coefficient of -6.40 on $IMC \times LARGE$ is lower than the analogous coefficient of -5.19 on $IMC \times SMALL$, although this difference is not statistically significant ($\chi^2 = 1.37$, $p = 0.241$, d.f.$= 1$). Similarly, in DMC, a comparison of the coefficients on

[5] These are reduced-form probits rather than structural equations, which would condition the acceptance function on other buyers' bids. The reduced forms are more appropriate since we are ultimately more interested in buyers' rational expectations of seller behavior conditional on available information (buyers do not know other buyer bids when bidding) than in a precise characterization of the seller's best-response function. We can use the reduced-form probit results to compute optimal buyer bids given expectations of other players' experimental behavior and to compare these empirically determined optimal bids with the observed bidding behavior characterized in the previous subsection. In any event, the random assignment of buyers to markets each round implies that the distribution of other buyer bids is random, and so the probits in Table 3 will offer insight into the seller's best-response function as well.

DMC × *LARGE* × *BID* and *DMC* × *SMALL* × *BID* would seem to suggest that a large-buyer's per-unit bid has a greater likelihood of acceptance than an equivalent small-buyer bid, but the coefficients on *DMC* × *LARGE* and *DMC* × *SMALL* work in the opposite direction.

These offsetting effects for IMC and DMC and the nonlinearity of the probit make it difficult to interpret the magnitude of the coefficients. Hence, we plot the probability of seller acceptance as a function of the bid for the different buyer sizes and treatments in Figure 6.[6] The seller acceptance functions are nearly identical for the large and small buyers in the CMC treatment, and very similar for the large and small buyers in the DMC treatment. However, the acceptance function for the IMC small buyers lies well below that of IMC large buyers, indicating that the seller is much more likely to accept a large-buyer bid than an equal small-buyer bid. The figure highlights the seller's distinct treatment of IMC small buyers' bids: a bid of 45 by a small buyer in the IMC treatment has less than a 60 percent probability of acceptance, while this same per-unit bid of 45 is accepted with near certainty when submitted by all other buyer types, a difference significant at better than the one-percent level in χ^2-tests in all cases.

By multiplying the acceptance probability times the buyer's surplus conditional on acceptance for each bid level, we generate the expected buyer surplus function displayed in Figure 7. The surplus function is conditional on rational expectations of other experimental subjects' behavior. By looking at the peak of the function, we can determine the optimal strategy for buyers in the experiment (as opposed to the optimal strategy in theory). The optimal bid for a small buyer in the IMC treatment is around 55, greater than that for a large buyer of around 40. Interestingly, these optima are close to the equilibrium predictions. The optimal bids for large and small buyers are about the same in the CMC treatment, around 35, and are the same in the DMC treatment, around 30. A comparison of these optimal with the actual bids reveals that large buyers in IMC and both large and small buyers in CMC bid optimally on average. Large and small buyers in

[6]The figure is based on the coefficient estimates from column (b) of Table 3, i.e., estimates based on the last 30 rounds of bids. The seller acceptance functions are computed using the mean seller and round fixed effects.

DMC bid too high (reflected in the very low rates of rejection), while small buyers in IMC bid too low (reflected in the exceptionally high rates of rejection).

5 Conclusion

An accumulation of results from theoretical bargaining models link the existence of buyer-size discounts to the curvature of the total surplus function over which the seller and buyers negotiate (see Horn and Wolinsky 1986; Stole and Zwiebel 1996a, 1996b; Chipty and Snyder 1999; Raskovich 2003; Inderst and Wey, 2003). In theory, large-buyer discounts emerge if the total surplus function is concave; there are no discounts if the total surplus function is linear, and a range of possible outcomes if the total surplus function is convex. We test the theory in markets in which large and small buyers bargain simultaneously with a single seller. The markets differ in the curvature of the total surplus function. By varying the seller's marginal cost function, we obtain concave, linear, and convex surplus functions from increasing, constant, and decreasing marginal cost curves, respectively. Our results strongly support the theory. Large-buyer discounts are observed where predicted—in the treatment with the concave total surplus function—and only where predicted. The main deviation from theory is that the levels of certain bids differ from the theoretical predictions. These deviations from theory may be explained as the usual sort of deviations observed in related experiments such as the ultimatum game, and in fact our results deviate less from the underlying theory than is typical.

Our results may lead antitrust policymakers, business journalists, and academic economists to place more confidence in the practical relevance of formal bargaining models, in turn increasing their understanding of the logic behind buyer-size discounts and the conditions under which one should expect such discounts to emerge.

Appendix A: Proofs

Proof of Proposition 1 Suppose $v_i > \max_{\{Q \leq X\}} MC(Q)$ for all $i \in B$. Consider any outcome in which there are some buyers whose bids are not accepted by the seller; i.e., $B - A$, the complement of A in B, is nonempty. Let $i \in B - A$. Buyer i earns zero profit in this outcome since its bid per unit, p_i, is rejected. If $p_i > \max_{\{Q \leq X\}} MC(Q)$, the seller's rejecting p_i cannot be subgame perfect. By accepting, the seller could increase its profit by

$$\begin{aligned} p_i x_i - IC\Big(x_i, \sum_{j \in A} x_j\Big) &= x_i \left[p_i - \frac{1}{x_i} \sum_{k=1}^{x_i} MC\Big(k + \sum_{j \in A} x_j\Big) \right] \\ &> x_i \left[p_i - \max_{\{Q \leq X\}} MC(Q) \right], \end{aligned}$$

which is positive by assumption.

Assume therefore that $p_i \leq \max_{\{Q \leq X\}} MC(Q)$. The buyer could raise so that it is in the interval $(\max_{\{Q \leq X\}} MC(Q), v_i)$. If the seller's strategy is subgame perfect, it would accept such a bid by the calculations in the previous paragraph. This bid would be profitable for the buyer since it is strictly less than v_i. *Q.E.D.*

Proof of Proposition 2 Assume

$$MC(Q) \geq MC(Q-1) \quad \text{for all } Q \in \{1, 2, \ldots, X\}. \tag{A1}$$

To prove necessity, consider a set of buyer bids $\{p_i | i \in B\}$ forming a subgame-perfect equilibrium in which all buyers are served. If the seller deviates by rejecting buyer i's bid, its profit changes by

$$p_i x_i - C(X - x_i) + C(X) = x_i[p_i - AIC(x_i, X - x_i)].$$

For this deviation to be unprofitable, $p_i \leq AIC(x_i, X - x_i)$. An argument similar to the proof of Proposition 1 shows that $p_i \leq AIC(x_i, X - x_i)$ or else buyer i could deviate by lowering its price and be assured that this bid is still accepted. Combining these two inequalities yields $p_i = AIC(x_i, X - x_i)$. Finally, for buyer i not to deviate by dropping out of the market (equivalently, bidding $p_i = 0$), $p_i \leq v_i$. This proves (2) must necessarily hold in a subgame-perfect equilibrium in which all buyers are served.

To prove sufficiency, suppose $AIC(x_i, X - x_i) \leq v_i$ for all $i \in B$. Consider the proposed equilibrium in which buyer i bids $p_i = AIC(x_i, X - x_i)$ for all $i \in B$ and the seller accepts the set of bids giving it the highest profit (in case of ties, assume the seller accepts the largest set of such bids). We will argue that this proposed equilibrium is subgame perfect, and the seller serves all the buyers. It is tautological that the seller's strategy is part of a subgame-perfect equilibrium. There remain two claims to be proved: first, that buyers have no incentive to deviate given the seller's strategy and second that the players' strategies lead all buyers to be served. We will prove these claims in reverse order.

To show the seller's strategy leads it to accept all bids, we have to show that the seller cannot gain from rejecting a subset $S \subseteq B$ of them. The change in the seller's profit from so doing is

$$\begin{aligned} IC\Big(\sum_{i\in S} x_i, X - \sum_{i\in S} x_i\Big) - \sum_{i\in S} p_i x_i &\leq \sum_{i\in S} IC(x_i, X - x_i) - \sum_{i\in S} p_i x_i \\ &= \sum_{i\in S} x_i [AIC(x_i, X - x_i) - p_i]. \end{aligned}$$

The first line holds by (A1). The second line holds by algebraic manipulation. The last expression is zero since $p_i = AIC(x_i, X - x_i)$.

To show the buyers have no incentive to deviate given the seller's strategy, note first that buyers have no incentive to raise bids because they are all accepted in equilibrium. Buyer i has no incentive to lower its bid since this would lead the seller to reject it by the argument in the second paragraph above. *Q.E.D.*

Proof of Proposition 3 Assume marginal costs are strictly decreasing, i.e.,

$$MC(Q) < MC(Q-1) \quad \text{for all } Q \in \{1, 2, \dots, X\}. \tag{A2}$$

To prove necessity of the conditions in Proposition 3, consider a set of buyer bids $\{p_i | i \in B\}$ forming a subgame-perfect equilibrium in which all buyers are served. As argued in the proof of Proposition 2, $p_i \leq v_i$ is a necessary condition. We then need to show that the two inequalities in (3) are necessary conditions. The seller can deviate by rejecting a subset $S \subseteq B$ of buyer bids. For this deviation to be weakly unprofitable,

$$IC\Big(\sum_{i\in S} x_i, X - \sum_{i\in S} x_i\Big) \leq \sum_{i\in S} p_i x_i. \tag{A3}$$

Thus, the first inequality in (3) is a necessary condition.

To prove that the second inequality in (3) is also necessary, we will proceed in several steps. The first step is to show that the seller makes zero profit in a subgame-perfect equilibrium in which all buyers are served. Suppose to the contrary $\sum_{i\in B} p_i x_i - C(X)$. Let $p_i = \max\{p_j | j \in B\}$. Then this highest-bidding buyer i can deviate to a lower bid $p_i - \epsilon$, where

$$\epsilon = \frac{1}{2} \min \left\{ \frac{1}{x_i} \left[\sum_{j\in B-\{i\}} p_j x_j - C(X) \right], \{MC(Q-1) - MC(Q) | Q = 1, 2, \dots, X\} \right\} \tag{A4}$$

and still have it accepted. To see this, let S' be the set of buyers whose bids are accepted after the deviation by i. The definition of ϵ in (A4), in particular that $\epsilon < [\sum_{j\in B-\{i\}} p_j x_j - C(X)]/x_i$, implies that the seller continues to make strictly positive profit if it continues to accept all buyer bids. Hence S' is nonempty. If $i \in S'$, then i's deviating bid is accepted and we are done. If

$i \notin S'$, then for all $j \in S'$,

$$\begin{aligned} p_i - \epsilon &\geq p_j - \epsilon && \text{(A5)} \\ &\geq AIC\Big(x_j, \sum_{k \in S'} x_k - x_j\Big) - \epsilon && \text{(A6)} \\ &> AIC\Big(x_i, \sum_{k \in S'} x_k\Big). && \text{(A7)} \end{aligned}$$

Condition (A5) holds since p_i is the weakly highest bid. Condition (A6) holds since $j \in S'$, so accepting p_j must give the seller a nonnegative profit at the margin. Condition (A7) holds since

$$\begin{aligned} \epsilon &< MC\Big(\sum_{k \in S'} x_k\Big) - MC\Big(1 + \sum_{k \in S'} x_k\Big) && \text{(A8)} \\ &\leq AIC\Big(x_j, \sum_{k \in S'} x_k - x_j\Big) - AIC(x_i, \sum_{j \in S'} x_j\Big). && \text{(A9)} \end{aligned}$$

Condition (A8) holds by (A4). Condition (A9) holds because the average incremental cost of producing a bundle is weakly less than the marginal cost of the first unit in the bundle and weakly more than the last unit in the bundle by (A2). We have thus shown that i's deviating price exceeds the expression in (A7). But then the seller would gain from accepting buyer i's bid in addition to the bids in S'. Hence buyer i's deviating bid is profitable since it would be accepted. We have thus established that the seller earns zero profit in a subgame-perfect equilibrium in which all buyers are served.

Combining the fact that $\sum_{i \in B} p_i x_i = C(X)$ with the fact that (A3) must hold for the set $B - S$, we have

$$\sum_{i \in S} p_i x_i \leq C\Big(\sum_{i \in S} x_i\Big).$$

Thus, the second inequality in (3) is a necessary condition for a subgame-perfect equilibrium in which all buyers are served.

To show sufficiency, consider a proposed equilibrium in which buyers bids are $\{p_i | i \in B\}$ satisfying $p_i \leq v_i$ and condition (3) and in which the seller accepts the subset of bids giving it the highest profit (in case of ties, assume the seller accepts the largest set of such bids). We will argue that the proposed equilibrium is subgame perfect, and the seller serves all the buyers. It is tautological that the seller's strategy is part of a subgame-perfect equilibrium. There remain two claims to be proved: first, that buyers have no incentive to deviate given the seller's strategy and second that the player's strategies lead all buyers to be served. We will prove these claims in reverse order. To show the seller's strategy leads it to accept all bids, we have to show that the seller cannot gain from rejecting a subset $S \subseteq B$ of them. But this is ensured by the first inequality in (3). To show that the buyers have no incentive to deviate given the seller's strategy, note first that buyers have no incentive to raise bids since they are all accepted in equilibrium.

If buyer i deviates to a lower price $p_i' < p_i$, for any subset of buyers S including i,

$$\begin{aligned} p_i' x_i + \sum_{j \in S - \{i\}} p_i x_i &< \sum_{i \in S} p_i x_i \\ &\leq C\Big(\sum_{i \in S} x_i\Big). \end{aligned}$$

The first line holds since $p_i' < p_i$ and the second by the second inequality of condition (3). Therefore, it cannot be an equilibrium for the seller to accept bids for the buyers in S. In sum, no buyer deviation would be accepted by the seller, establishing sufficiency. *Q.E.D.*

Appendix B: Instructions

This appendix contains the text of the instructions distributed to, and read by, the participants, and read aloud by the experimenter before the start of the experiment.

Introduction This is an experiment in market decision-making. Funds for this experiment have been provided by an external research foundation. Take the time to read carefully the instructions. A good understanding of the instructions and well thought out decisions during the experiment can earn you a considerable amount of money. All earnings from the experiment will be paid to you in cash at the end of the experiment.

Roles and Profit Calculations There are a total of 12 participants in this experiment (you and 11 others). Each participant will be randomly assigned the role of a buyer or a seller of a fictitious commodity. There will be a total of nine buyers and three sellers. A participant's role as a buyer or a seller will remain fixed throughout the experiment.

The experiment takes place over 60 rounds. In each round, there are three separate markets. Each participant is active in one market only in a given round. Each market is composed of three buyers and one seller. Two of the buyers are small in size and one is a large buyer. The distinction between the small buyers and the large buyer is in the number of units of the fictitious commodity that each can profitably purchase. Each of the small buyers can purchase one unit, while the large buyer is able to purchase two units. Each unit is valued at 100 points, no matter whether you are a large or a small buyer. Buyers earn money by purchasing at a price below their valuation. More precisely, they earn the difference between their valuation and the transaction price.

The seller in each of the three markets is able to sell up to four units. Sellers earn money by selling at a price above their cost. More precisely, a seller earns the difference between the transaction price and the cost of the unit on each unit sold. Note that sellers do not pay the costs of unsold units.

Three Different Markets The three markets differ in the shape of the seller's cost function. The following table displays the cost functions of the sellers in each of the three markets:

Market	Unit 1	Unit 2	Unit 3	Unit 4	Total Cost
A	0	5	15	60	80
B	20	20	20	20	80
C	60	15	5	0	80

In market A, the seller's costs increase with the sale of each additional unit. The first unit he sells costs 0 points, the second unit 5 points, the third unit 15 points, and the fourth unit 60 points. In market B, all four of the seller's units cost 20 points each. In market C, the costs of the seller's units are the same as in market A, except the order is reversed. Namely, the first unit costs 60, the second unit 15, the third unit 5, and the fourth unit 0. Notice that the seller's total costs of producing four units are identical in each of the three markets and equal to 80 points.

Assignment to Markets At the beginning of each round, the three sellers are each randomly assigned to one of the three markets. The assignment is completely random, meaning that there is no relation between the market in which the seller participated last round (or any other previous round) and the market to which he will be assigned this round. Each seller has the same 1/3 probability of being assigned to any one of the three markets in any of the 60 rounds.

Similarly, the nine buyers are randomly assigned to one of the three markets and to the role of small or large buyer. Once again, there is no relation between the market in which the buyer participated last round (or any previous round) and the market in which he will participate in this round. This means that the other two buyers in the same market will change from round to round and so will the seller that the buyer faces. Moreover, because there are two small buyers in each market and only one large buyer, a buyer is twice as likely to be assigned the role of a small buyer as a large one. But again, there is no relation between whether a buyer was a small or a large one last round (or any previous round) and whether he will be a small or a large buyer this round.

Transaction Prices At the beginning of each round, each of the three buyers in a market independently decides on a bid price to offer the seller for the purchase of his unit(s). Because the small buyers are able to purchase only one unit each, their bids indicate the price they are willing to pay for the purchase of that unit. The large buyer is able to purchase two units, but his bid reflects the price he is willing to pay per unit (that is, he makes the same bid for each of the two units).

After all three buyers have submitted their bids, the seller in the market observes the bids and decides for each one whether to accept the bid or to reject it. Acceptance of a bid means that the seller agrees to sell to the buyer the specified number of units (one unit for a small buyer and two units for a large buyer) at the specified bid. If a seller accepts a bid, then the transaction takes place. The buyer earns a profit according to his valuation (100 points for small buyers and 200 points for large buyers (that is, 100 points for each of the two units)) minus his bid, while the seller earns the amount of the bid minus the cost of his unit(s) sold. The cost of a unit sold depends on the order in which it is purchased. For example, one can see from the above table that the first unit that a seller in market A sells costs 0 points, the second unit costs 5 points, and so forth.

If a seller rejects a bid, then no transaction occurs between that buyer and the seller and neither participant receives anything. In this sense, a buyer's bid can be thought of as a take-it-or-leave-it offer to the seller.

Each Round A round ends after the seller has responded to each bid by either accepting or rejecting it.

At the end of the round, each buyer sees whether his bid was accepted and his resultant profit from the round. However, a buyer does not observe other buyers' bids or profits or the seller's profit. Moreover, participants do not learn at any time (before, during or after the round), the identities of the other participants in the market.

The experiment does not proceed to the next round until all three sellers have responded to each bid in their respective markets. We need to wait until the completion of all activity in all three markets before proceeding to the next round in order for the assignment of participants to markets to be entirely random.

Except for the random determination of the market in which one participates and one's cohorts in that market, the same process repeats itself in each of the 60 rounds. Namely, each of the three buyers separately decides on a bid. The seller observes the bids and for each bid decides whether to accept or reject it. If the bid is accepted, then the transacting parties profits are calculated as above. If the bid is rejected, then both parties earn zero.

At the completion of 60 rounds, you will be paid your earnings according to the points you accumulated during the experiment. For every 250 experiment points you earn you will be paid £1 in cash. In addition to these earnings, each participant will receive a flat participation fee of £4. While the earnings are being counted for distribution, you will be asked to complete a questionnaire related to the experiment.

Before Beginning Before we begin the actual experiment, there will be five practice rounds with the identical rules and profit calculation as in the real experiment. Your earnings from the practice rounds will not be included in your payment. Rather, the purpose of the practice rounds is to familiarize you with the rules of the experiment, the profit calculation and the computer software.

If you have any questions about the instructions, please raise your hand and an experimenter will come to assist you. Thank you for your participation.

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Table 1: Descriptive Statistics for Buyer Bids

	All Rounds				Rounds 31-60			
	Mean	Median	Std. Dev.	Obs.	Mean	Median	Std. Dev.	Obs.
All Bids								
IMC Large Buyer	39.8	40.0	11.4	360	39.5	40.0	10.1	180
IMC Small Buyer	43.4	42.0	11.9	720	44.8	45.0	9.9	360
CMC Large Buyer	34.1	35.0	10.4	360	34.6	35.0	10.0	180
CMC Small Buyer	34.7	35.0	10.1	720	34.5	35.0	8.8	360
DMC Large Buyer	41.7	40.0	13.6	360	40.9	40.0	11.7	180
DMC Small Buyer	42.0	40.0	13.8	720	40.2	40.0	12.1	360
Accepted Bids								
IMC Large Buyer	41.7	40.0	10.4	316	41.1	40.0	8.9	162
IMC Small Buyer	47.6	50.0	10.8	436	48.0	49.0	9.4	217
CMC Large Buyer	35.9	35.0	9.8	298	36.3	35.0	9.4	149
CMC Small Buyer	35.9	35.0	10.2	617	35.3	35.0	8.7	325
DMC Large Buyer	42.4	40.0	13.5	340	41.1	40.0	11.7	177
DMC Small Buyer	42.7	40.0	13.7	673	40.5	40.0	12.1	347

Table 2: Buyer Bid Regressions

	All Buyer Bids		Accepted Buyer Bids	
	All Rounds (a)	Rounds 31-60 (b)	All Rounds (c)	Rounds 31-60 (d)
IMC	8.73***	9.28***	10.93***	10.51***
	(1.31)	(1.16)	(1.39)	(1.32)
DMC	7.69***	5.69***	7.16***	5.40***
	(1.72)	(1.56)	(1.72)	(1.54)
IMC × *LARGE*	−3.63***	−4.83***	−5.53***	−5.74***
	(0.88)	(0.92)	(1.04)	(1.08)
CMC × *LARGE*	−0.07	−0.88	0.26	−0.39
	(0.71)	(0.70)	(0.78)	(0.74)
DMC × *LARGE*	−1.13	−0.47	−0.83	−0.56
	(1.05)	(0.92)	(1.00)	(0.93)
N	3,240	1,620	2,680	1,377
R^2	0.50	0.64	0.53	0.64

Notes: *CMC* omitted to avoid collinearity, so coefficients reflect comparisons relative to small-buyer bids in the CMC treatment. All regressions include buyer and round fixed effects. The regressions in columns (c) and (d) also include seller fixed effects. The sets of buyer, seller, and round fixed effects are each jointly significantly different from zero at the one-percent level in all regressions. Standard errors reported in parentheses below coefficient estimates are adjusted to account for heteroskedasticity (White 1980) and to account for possible correlation across multiple rounds played by the same buyer. Coefficient significantly different from zero in a two-tailed test at the ***one-percent level, **five-percent level, *ten-percent level.

Table 3: Seller Acceptance Probits

	All Rounds (a)	Rounds 31-60 (b)
IMC × *LARGE*	-4.30^{***}	-6.40^{***}
	(0.64)	(1.40)
IMC × *LARGE* × *BID*	0.15^{***}	0.22^{***}
	(0.02)	(0.04)
IMC × *SMALL*	-3.89^{***}	-5.19^{***}
	(0.56)	(0.81)
IMC × *SMALL* × *BID*	0.09^{***}	0.12^{***}
	(0.01)	(0.02)
CMC × *LARGE*	-3.11^{***}	-3.15^{***}
	(0.62)	(0.95)
CMC × *LARGE* × *BID*	0.12^{***}	0.13^{***}
	(0.02)	(0.03)
CMC × *SMALL*	-2.81^{***}	-3.24^{***}
	(0.62)	(0.82)
CMC × *SMALL* × *BID*	0.12^{***}	0.14^{***}
	(0.02)	(0.03)
DMC × *LARGE*	-1.13^{*}	-1.37
	(0.60)	(1.03)
DMC × *LARGE* × *BID*	0.07^{***}	0.11^{***}
	(0.02)	(0.03)
DMC × *SMALL*	-0.48	-0.10
	(0.61)	(0.77)
DMC × *SMALL* × *BID*	0.05^{***}	0.05^{***}
	(0.02)	(0.02)
N	3,240	1,620
Pseudo R^2	0.39	0.45

Notes: The dependent variable equals one if the seller accepted the buyer's bid and zero otherwise. Probits include seller and round fixed effects. The sets of seller and round fixed effects are each jointly significantly different from zero at the one-percent level in both probits. Standard errors reported in parentheses below coefficient estimates are adjusted to account for heteroskedasticity (White 1980) and to account for possible correlation across multiple rounds played by the same buyer. To facilitate interpretation, probits were run with a complete set of dummies, omitting the constant to avoid collinearity; the equivalent regression omitting one of the dummies and including the constant was run to compute the pseudo R^2. Significantly different from zero in a two-tailed test at the ***one-percent level, **five-percent level, *ten-percent level.

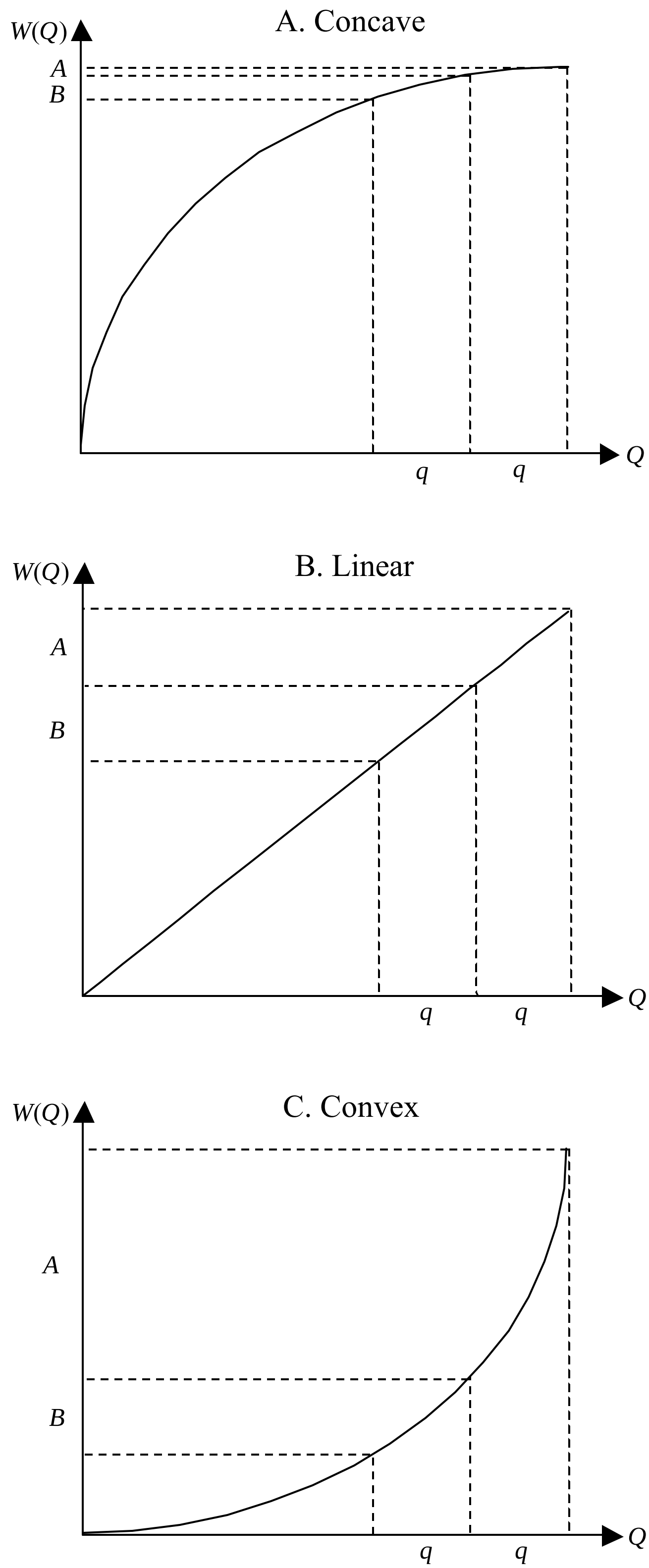

Figure 1: Total Surplus Functions with Different Curvatures

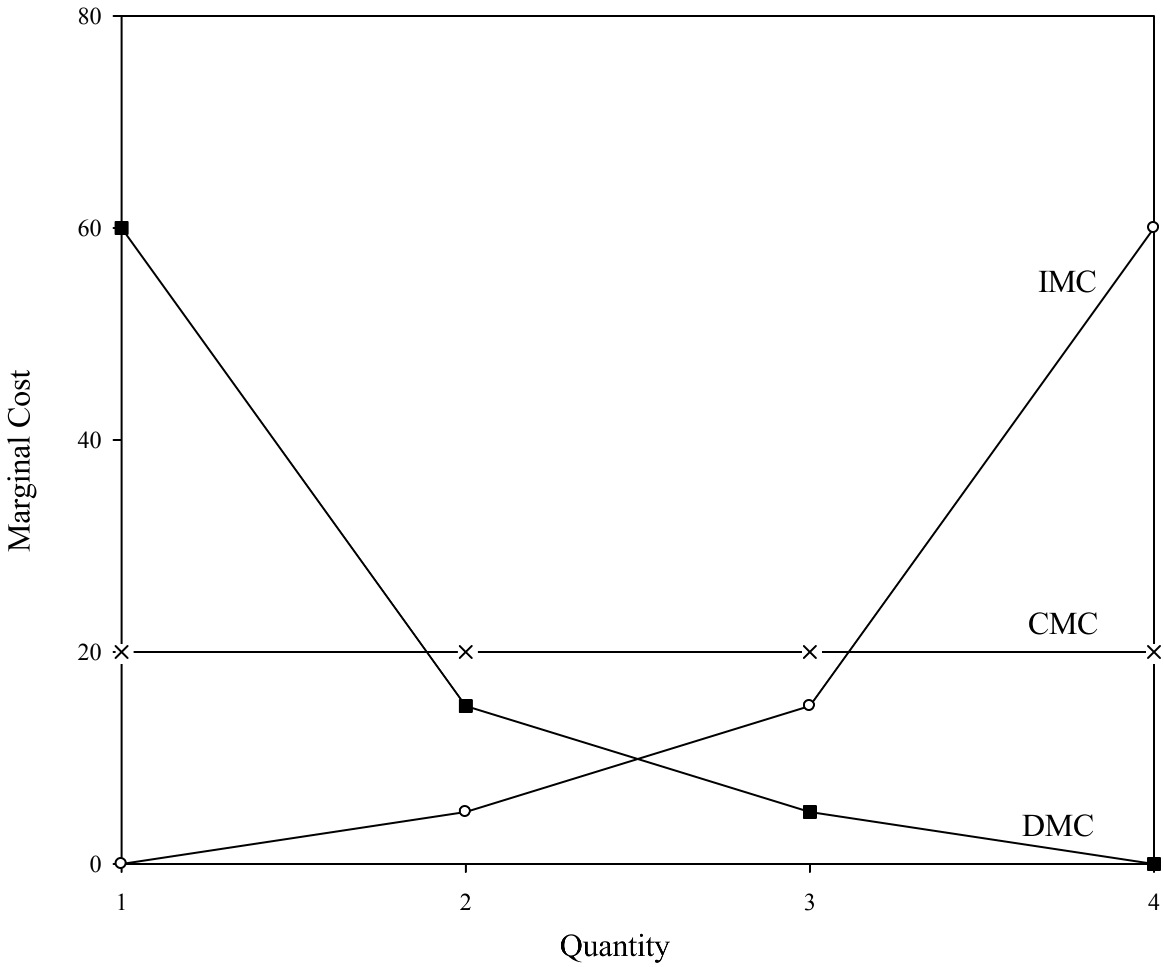

Figure 2: Marginal Cost Functions in Different Treatments

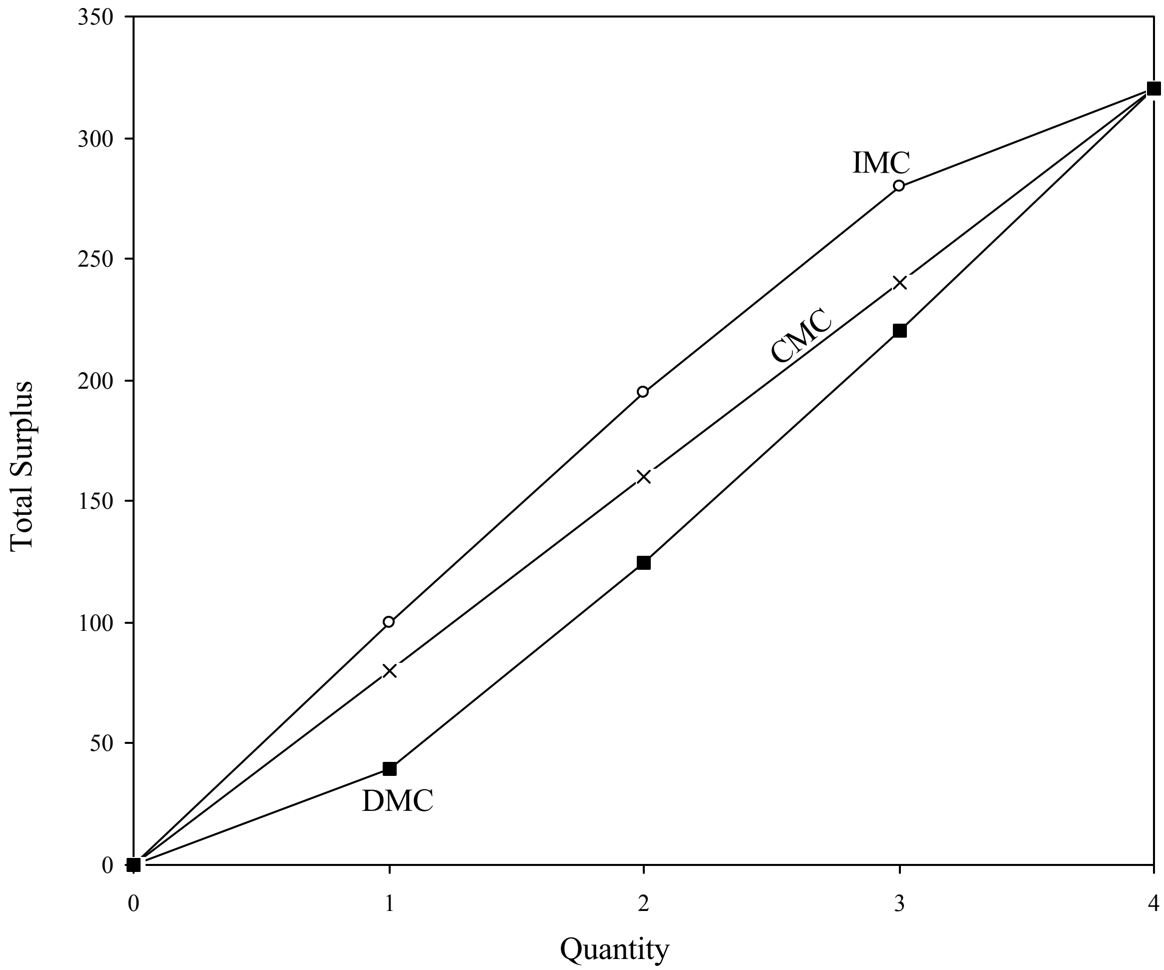

Figure 3: Total Surplus Functions in Different Treatments

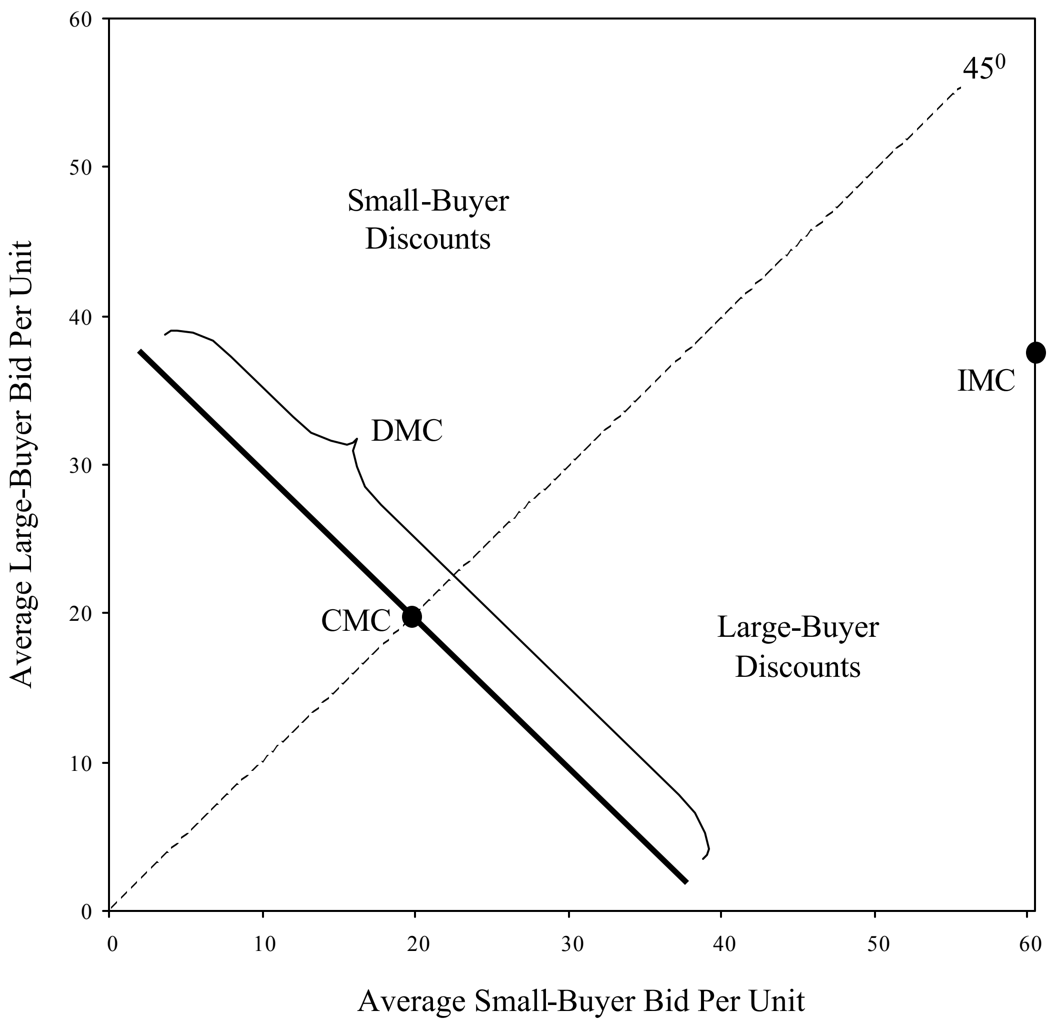

Figure 4: Equilibria for Experimental Parameters

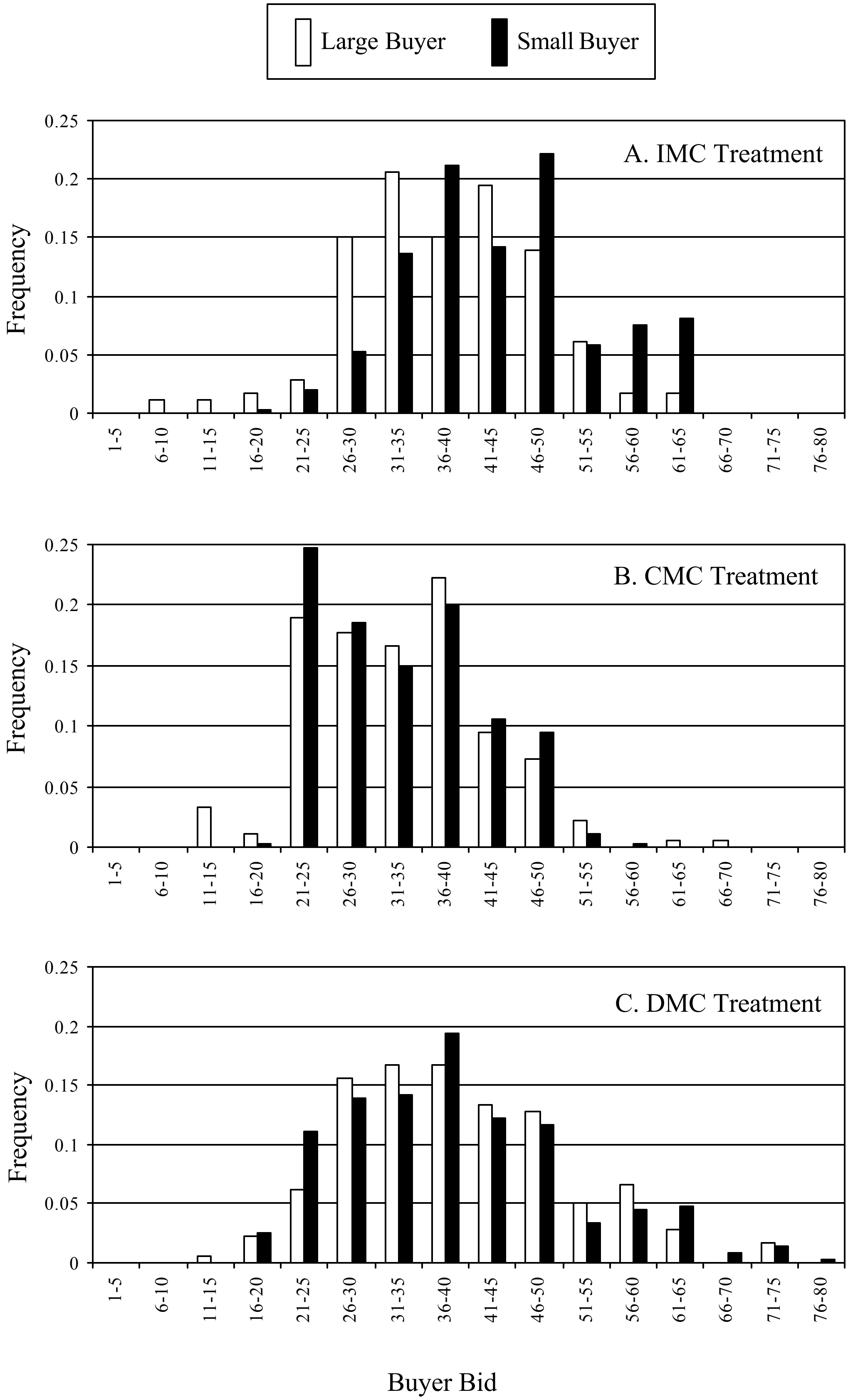

Figure 5: Histograms of Large- and Small-Buyers' Bids, Last 30 Rounds

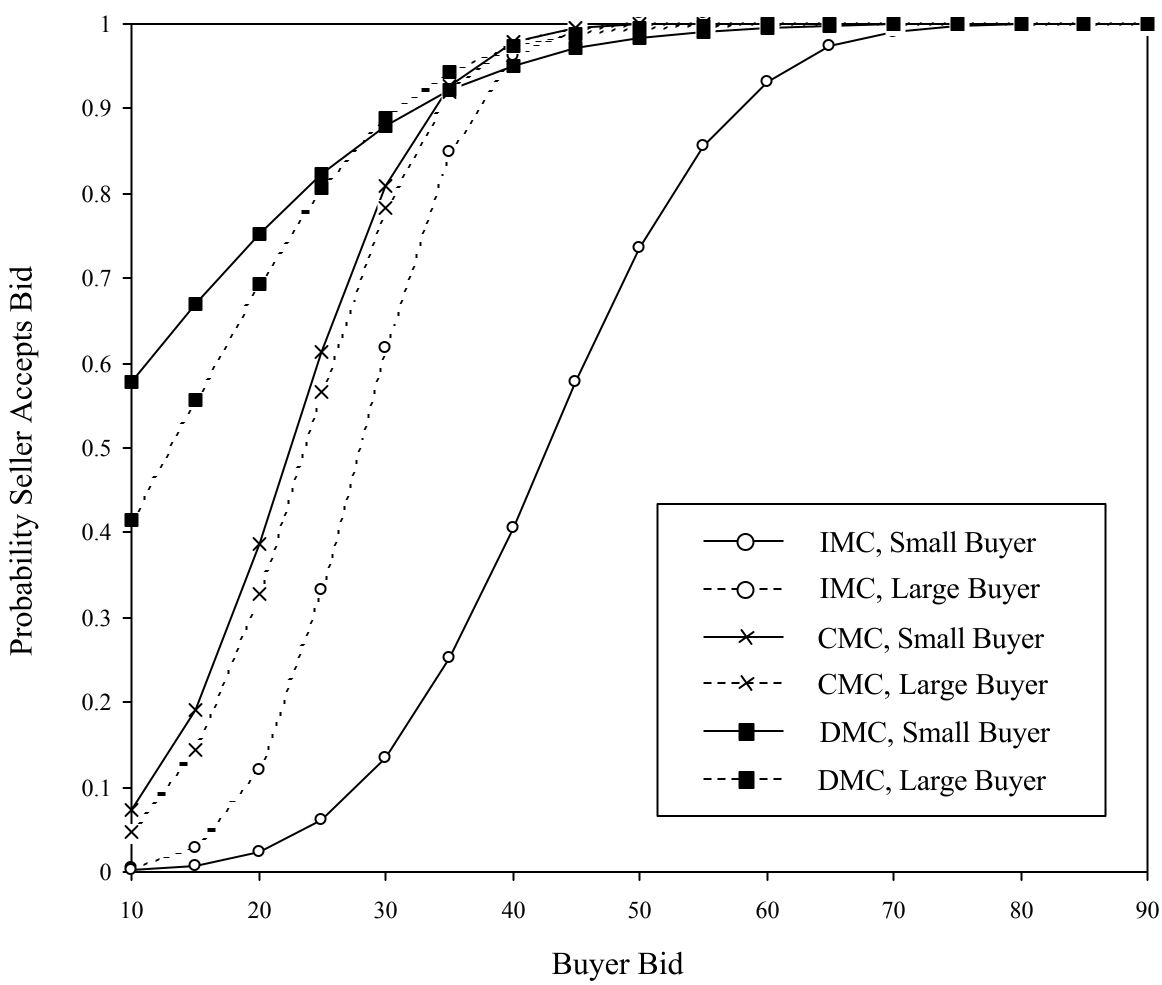

Figure 6: Seller Acceptance Decision from Probit Estimates

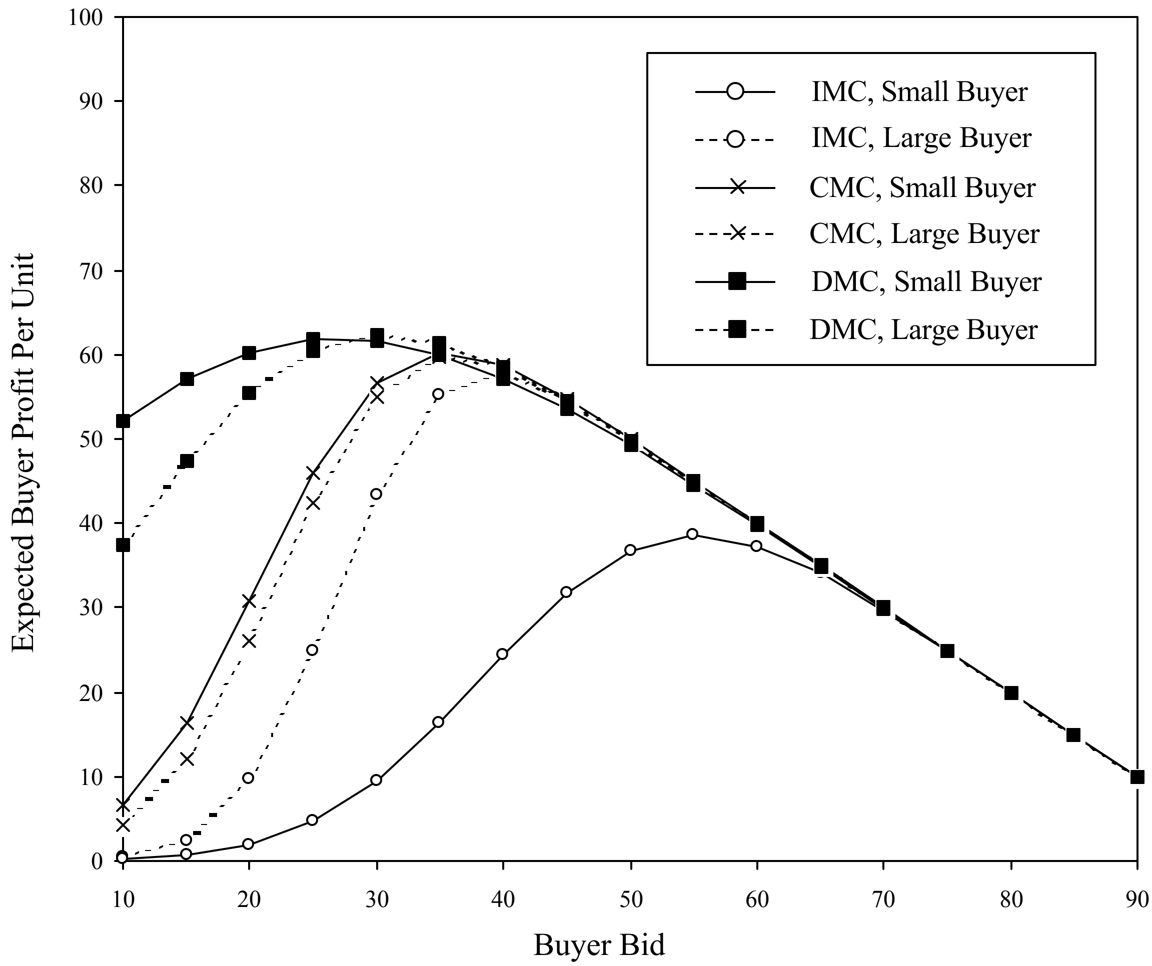

Figure 7: Optimal Buyer Bid Given Others' Experimental Behavior