# BUYER BEHAVIOR AND THE WELFARE EFFECTS OF BUNDLING BY A MULTIPRODUCT MONOPOLIST:

## A LABORATORY INVESTIGATION

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## I. INTRODUCTION

This paper reports the findings of a laboratory test of a number of predictions derived from modern auction theory. The primary focus is on the efficiency and distributional consequences of the common practice of selling a variety of different items in "lots" or "bundles." Recent developments in auction theory allow one to make rather sharp predictions about how allocations are affected by the way the seller chooses to package different items together to form lots. By replicating the environment specified by the model very accurately in controlled laboratory auctions, these predictions are tested. The data are found to provide strong support for many of the theoretical propositions.

A brief verbal description of the auction environment is the following. There are several buyers and one seller. The seller has a set of indivisible items to sell. The seller makes a bundling decision, which is a partition of the set of items into mutually exclusive and collectively exhaustive subsets called bundles. The seller places the bundles for sale using a first-price sealed-bid auction. In each such auction, the seller solicits private, written bids for a bundle from each

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buyer and sells that bundle to the highest bidder at a price equal to the highest bid.

The seller and the bidders may face uncertainty for a variety of reasons, so a key element of the model is the specific type of information structure in these markets which is postulated. The information structure is the following.[1] Each buyer is supposed to have a fixed "valuation" for each item that is known to no other buyer. Each buyer knows only the probability distribution from which the valuations of each of the items for each of the other bidders were independently drawn. Buyers all know their own valuations with certainty. A buyer's valuation for a bundle simply equals the sum of his valuations of the items contained in the bundle. Each buyer also knows how many other buyers are competing in the auction.

Each auction is modeled as a game with incomplete information in which each buyer is a player. A strategy of a player is simply a function which maps valuations into bids.

The (Nash) equilibrium bidding function of values generally depend upon the number of competing bidders and the probability distribution of buyers' valuations of the bundle. Since the probability distribution depends upon the particular way the seller bundles the items, equilibrium bidding behavior is influenced by this bundling decision. Consequently, the final allocation, seller's expected revenue, the efficiency of the final allocation, and the distribution of surplus among the buyers will all depend upon the way the seller partitions the goods into bundles.

In order to provide a clear test of the predictions generated by this model, a number of variables must be measurable and controllable. In particular, reasonable comparisons with the theoretical predictions require a knowledge of the relevant probability distributions, buyer valuations, and the number of competing bidders. In addition, four key assumptions are made in the theoretical model which are particularly difficult to control for. One of these assumptions is that a buyer's valuation for a lot equals the sum of his valuations for the bundle. A second assumption is that there is no aftermarket in which the items may be resold by the winning bidder to the other buyers who participated in the auction. A third assumption is that all of the buyers are risk neutral. A fourth assumption is that the postulated information structure accurately describes buyer information.

The type of data available from real estate auctions, art auctions, and other frequently held auctions can be obtained easily enough, but do not provide enough information to measure and control for all of the parameters and assumptions of the model. In other words, such data would provide at best a very rough test of the theory. For this reason, a series of experimental auctions was designed and carried out in a carefully controlled laboratory environment. The buyers in these laboratories were given complete and accurate information about the distribution from which values were drawn and the number of bidders in each auction. All four key assumptions were met. One of these assumptions, that all buyers are risk neutral, normally would be impossible to control for. However, even though buyers faced risk in each particular auction, each buyer participated in a sufficiently large number of auctions that any risk which existed was judged not likely to be a problem. One of the more useful aspects of using experimental auctions is that it is possible to sell an item twice—once as a single-item bundle and once as part of a two-item bundle. This allows us to directly compare seller revenues, distributional consequences, buyer strategies, and market efficiency in separate as opposed to bundled auctions. This opportunity is fully exploited in this series of experiments.

The use of experiments to test theories about sealed bid auctions is not new. Frahm and Schrader (1970), Smith (1967), Miller and Plott (1979), Belovicz (1977), and Coppinger et al. (1980) have presented results relating to the comparative revenue-generating power of various auction mechanisms. These mechanisms include first-price sealed-bid auctions, second-price sealed-bid auctions, English (oral progressive) auctions, and Dutch (descending bid) auctions. Not surprisingly, some of the aforementioned authors' observations about buyer behavior in first-price sealed-bid auctions were also observed in the experiments discussed below.

## II. THE MODEL

One seller has J indivisible goods (items) to sell. There are n potential buyers. Denote by $v_j^i$ the value of item j to buyer i. These nJ values are independent samples drawn from the same probability distribution, denoted by its cdf, $F(\cdot)$, defined on $[\underline{v}, \overline{v}]$; $F(\cdot)$ is common knowledge to the buyers. Each buyer i observes only his own vector of values $(v_1^i, \ldots, v_J^i)$. The seller conducts an auction in which he solicits n sealed bids, $b_1, \ldots, b_n$, one from each buyer. The buyer who submits the highest bid pays the seller his bid and receives the bundle of all J items. The utility (payoff) to buyer i is $\sum_{j=1}^{J} v_j^i - b^i$ if he wins the auction and is 0 otherwise. Ties are broken randomly. Implicitly we are assuming:

1. Values are additive.
2. Buyers are risk neutral.

This auction is modeled as a game of incomplete information. The strategy of a buyer is a bidding function $b^i$: $(v_1^i, \ldots, v_J^i) \rightarrow \mathbb{R}$. Without loss of generality attention is restricted to functions of the form $b^i$: $\sum_{j=1}^{J} v_j^i \rightarrow \mathbb{R}$. Denote $V_{(J)}^i = \sum_{j=1}^{J} v_j^i$. An equilibrium is a set of functions $(b_1^*, \ldots, b_n^*)$ such that for all i $b_i(V_{(J)}^i)$ maximizes buyer i's expected payoff given $V_{(J)}^i$, where the expectation is over $\{V^i_{(J)}\}^n_{\substack{k=1\\k\neq i}}$, assuming buyer k bids according to $b_k(\cdot)$ for all $k \neq i$. The cdf of $V^i_{(J)}$, $H^J(\cdot)$, is given by the J-fold convolution of $F(\cdot)$ and is the same for all buyers.

Using the results of the aforementioned authors, there exists a symmetric equilibrium $b^1(V^1_{(J)}) = \ldots = b^n(V^n_{(J)}) = b^*(V_{(J)})$ given by

$$b^*(V_{(J)}) = V_{(J)} - \int_{J\underline{v}}^{V_{(J)}} \left[\frac{H^J(x)}{H^J(V_{(J)})}\right]^{Vn-1} dx.$$

The expected payoff to buyer i, $ES^i(V^i_{(J)})$, is $[V^i_{(J)} - b^*(V^i_{(J)})]\,[H(V)^i_{(J)})]^{n-1}$, and so we can write

$$ES^i(V^i_{(J)}) = \int_{J\underline{v}}^{V^i_{(J)}} [H^J(x)]^{n-1}\, dx.$$

The expected winning bid (i.e., expected profit to seller), $E\pi_{(J)}$, is

$$\begin{aligned} E\pi_{(J)} &= \int_{J\underline{v}}^{J\bar{v}} \left\{ x - \int_{J\underline{v}}^{x} \left[\frac{H^J(t)}{H^J(x)}\right]^{n-1} dt \right\} n[H^J(x)]^{n-1} h^J(x)\, dx \\ &= \int_{J\underline{v}}^{J\bar{v}} \left\{ x(H^J(x))^{n-1} - \int_{J\underline{v}}^{x} [H^J(x)]^{n-1}\, dt \right\} nh^J(x)\, dx. \end{aligned}$$

This is sufficient information to compare outcomes from different partitions of the J items into smaller bundles. For example, if the J items are all sold separately, then a buyer's expected surplus in all J auctions is

$$ES^i = \sum_{j=1}^{J} \int_{\underline{v}}^{v^i_j} [F(x)]^{n-1}\, dx$$

and

$$E\pi = J \int_{\underline{v}}^{\bar{v}} \left[ x(F(x))^{n-1} - \int_{\underline{v}}^{x} (F(x))^{n-1}\, dx \right] nf(x)\, dx.$$

With relatively minor algebraic manipulations, we can obtain the following results. These are stated below for the special case of the uniform distribution since this was the distribution used in the experiments. Proofs are not included. For more general and formal statements and proofs, see Palfrey (1980).

**(P1)** *If there are two buyers competing in an auction, then the expected revenue per item generated in a bundled auction is an increasing function of the number of items in the bundle.*

**(P2)** *If there are more than three buyers, then the expected revenue per item generated in a bundled auction is a decreasing function of the number of items in the bundle.*

The intuition behind (P1) and (P2) is that the expected second highest sample out of N draws from the distribution is the seller's expected revenue, where N is the number of bidders. Since the distribution of the value of a given item is a simple mean preserving spread of the distribution of the average value of a bundle of at least two items, then if the expected second highest sample of N draws from the distribution is greater than the mean of the distribution, it will also be greater than the expected second highest sample of N draws from a distribution of the average value of a bundle containing at least two items. Similarly, if the expected second highest value is less than the mean, the opposite will be true.

In (P1), there are only two bidders, so the expected second highest value is the expected lowest value which is always less than the mean. In (P2), the expected second highest value with more than three bidders is always greater than the mean for any symmetric distribution such as the uniform distribution. Hence bundling will hurt the seller in this case. A general rule, reflected in both (P1) and (P2), is that the absolute difference between the expected revenue per item in a bundled auction and the expected revenue per item in separate auctions is an increasing function of the number of items being bundled.

Another prediction about the seller's revenue is that more buyers increase the seller's revenue.[2]

**(P3)** *The expected revenue from an auction is an increasing function of the number of buyers.*

This is a very well known and intuitively evident theoretical result.

The next set of propositions will lead to specific hypotheses about buyer surplus and the distributional consequences of the seller's bundling decision. One key result from the model is that when there are two buyers then all buyers will prefer separate auctions ex ante. Note that it does *not* imply that a buyer will prefer separate auctions in every state of the world.

**(P4)** *If there are two buyers, then no matter what values a buyer has for the items, the expected surplus to that buyer is greater in separate auctions than in a bundled auction.*

The intuition behind prediction (P4) is that, with a small number of buyers, all buyers are better off as the distribution becomes more spread out. The distribution of values for a bundle is less spread out than the distribution of the component items of the bundle. However, if there are more than two buyers, then a buyer who has extremely high values for a bundle prefers a less dispersed distribution. The logic behind this is that in a less dispersed distribution the probability that such a buyer would have the highest value is greater. Hence, for large numbers of bidders one loses the "unanimity" result of prediction (P4). An even stronger statement of (P4) can be made:

**(P5)** *If there are two buyers, then the expected surplus to a buyer is a decreasing function of the number of items bundled.*

The above argument also leads to several specific predictions about which buyers will prefer a bundled auction if there are more than two buyers.

**(P6)** *If there are more than three buyers, then buyers with relatively high valuations on all items and relatively small variation in valuation will prefer a bundled auction to several separate auctions.*

This prediction expresses the rather obvious notion that in general different buyers are differently affected by the seller's bundling decision. In a similar vein, theory yields the following two propositions, which hold regardless of the number of bidders:

**(P7)** *Buyers with relatively high variation in valuations are relatively worse off when the seller bundles compared to buyers who have the same average valuation but less variation in their values.*

**(P8)** *Buyers with relatively low average valuations are relatively better off when the seller bundles compared to buyers who have the same variation in valuation but have medium valuations.*

As an example to illustrate the intuition behind (P7), consider the following. A buyer has a valuation of $\underline{v}$ on one item and $\bar{v}$ (the maximum possible value) on the second item. If these two items are sold separately, the bidder will (in equilibrium) win the second item with probability 1. However if the two items are bundled and sold together in a single auction, this bidder will probably win neither item. This is particularly obvious if there are many bidders. In addition, in equilibrium the profit he makes in the bundled auction if he wins is less than the equilibrium profit if he wins the second of two separate auctions. Suppose that this buyer's valuations were $\bar{v}/2$ and $\bar{v}/2$ instead. In such a case the bidder is affected not nearly as much by a seller who chooses to bundle.

The next prediction relates to individual bidding behavior and is easily derived theoretically using techniques developed by Vickrey (1961) to calculate the equilibrium bidding functions in single-item and bundled auctions when values of items are distributed uniformly. This prediction is an interesting one to consider because it is a simple qualitative prediction about the effects of bundling on individual bidding behavior and it is an important prediction about bidding behavior that leads to a number of the other theoretical results.

**(P9)** *(Superadditive bidding)* If there are two bidders, then a bidder with a given set of values for a given set of items will bid an amount in a bundled auction which is greater than the sum of his bids if the items were sold in separate auctions.

As in some of the earlier predictions, this is due to the fact that the distribution of values for a single item is a mean-preserving spread of the distribution of sums of values for a bundle of items.

The final prediction addresses aggregate welfare effects of bundling:

**(P10)** *The total surplus per item generated by an auction is a decreasing function of the number of items sold as a bundle in that auction.*

In other words, bundling creates inefficiencies. The intuition behind this is simple. If items are sold separately, in equilibrium the highest bidder in a given auction will have the highest valuation for the corresponding item. This is an efficient allocation. If several items are sold as a bundle, then in equilibrium the highest bidder for that auction will have the highest valuation for the bundles. However, that buyer will not in general have the highest valuation for each separate item in the bundle. This leads to the possibility of ex post gains from trade, i.e., inefficiencies.

## III. EXPERIMENTAL DESIGN

Three series of experiments, using a total of 24 different subjects, were designed and carried out.[3] Each experiment consisted of 240 different auctions in which experimental subjects were buying items from the experimenter. In 120 of these auctions there were two competing buyers, and in 120 of the auctions there were four competing buyers. This divided the auctions into two sets of market sizes according to the number of competing bidders. For each market size there were 40 auctions selling a single item, 40 auctions selling two items bundled together, and 40 auctions selling four items bundled together. Thus the auctions are divided into three sets along the dimension of bundle size. This 2 × 3, or 6-cell, design is summarized in Table 1. The entry in each cell of the table indicates the number of auctions of that type in an experiment. Henceforth, a cell will be referred to

*Table 1.* The Basic 2 × 3 Experimental Design

| | | *Market Size* | |
|---|---|---|---|
| | | *2 Bidders* | *4 Bidders* |
| *Bundle Size* | *1 Item* | I<br>40 | IV<br>40 |
| | *2 Items* | II<br>40 | V<br>40 |
| | *4 Items* | III<br>40 | VI<br>40 |

by the Roman numeral in the upper right hand corner of that cell in Table 1; the buyers in an experiment will be referred to by Arabic numerals 1 through 8.

As one can easily deduce, no buyer competed in all auctions. In particular, each buyer competed in 10 of the 40 auctions in each of cells I, II, and III and 20 of the 40 auctions in each of cells IV, V, and VI. Specification of which auctions a buyer participated in is given in detail later on in this section. However, at this point it will be helpful to describe how buyers' valuations for items were induced.

For each auction in cells I and IV, each participating buyer was given a valuation which was independently drawn at random from the interval \$0.00–\$1.99. All valuations were in penny increments. The values of the bundles for which buyers competed in cells II and V were determined by adding together values which had been randomly drawn for items in cells I and IV. Whichever subset of the buyers competed in two single-item auctions also competed in the corresponding two-item bundled auction. Similarly, the values of the bundles for which buyers competed in cells III and VI were obtained by adding together values of certain pairs of two-item bundles from cells II and V. Again, whichever subset of the buyers competed in a pair of two-item bundled auctions also competed in the corresponding four-item bundled auction.

In order to facilitate smooth operation of the experiment, the 240 auctions in each session were conducted in five different periods. This meant that in each year buyers had to make simultaneous bidding decisions in only 18 auctions rather than make 90 decisions all at once. Conducting the experiment in this fashion also allowed buyers to make adjustments in their strategies after each year if they wished. Of the 18 experiments in which each buyer participated during a market year, there were two each in cells I, II, and III and four each in cells IV, V, and VI. Which auctions were conducted in which year was randomized for each cell.

A potential problem with this particular design is that if a buyer can figure out which bundled auctions correspond to which unbundled auctions that buyer will be able to use information from previous auctions to update his priors about the distribution of competitors' valuations in corresponding auctions which may occur in later years. This problem was avoided in the following way. For each bundle in cells II and V for which a buyer would be competing that buyer was given two new values which were randomly chosen subject to the constraint that the sum of the two values equaled the sum of the two values of the items in the corresponding single-item auctions of cells I and IV. The buyers were not informed that these draws were dependent in this way on earlier draws. This prevented buyers from inferring that there was a connection between the auctions in different cells. Buyers viewed each auction as a completely independent event.

The next problem to overcome involved setting up the auctions so that the same bidders who competed with each other in a bundled auction also competed with each other in the corresponding separate auctions. This was done as follows. In cells I, II, and III buyers only competed in the following pairs: [1,2]; [1,3]; [2,3]; [4,5]; [4,6]; [5,6]; [7,8]. The first six of these groups competed in 5 auctions in each of cells I, II, and III, while the last group, [7,8], competed in 10 auctions in each of these cells. In cells IV, V, and VI the buyers were divided into two groups, [1,3,5,7] and [2,4,6,8]. These two groups each participated in 20 auctions in each of cells IV, V, and VI.

Each experiment was conducted in the following way. The eight experimental subjects were each given a folder containing a list of valuations, five information and record sheets (one for each market year, five bidding forms (one for each market year), and a three-page instruction booklet. At the beginning of the experiment, the experimenter read the instructions while the subjects followed along. In these instructions, the subjects were informed that the values of the 210 items on their list of valuations were random draws, uniformly distributed over the range \$0.00–\$1.99. In addition they were told how to figure out the value of a bundle, how to keep records, how to bid, and how to calculate their profits. These simple instructions are given in the Appendix. After the instructions were read and questions were answered, a "practice" year took place which allowed the subjects to become accustomed to the rules and the recording format. No payoffs were made on the basis of outcomes of this practice year. During each real market year each buyer privately submitted to the experimenter written bids for each of the 18 auctions in which the buyer was competing during that year. When all eight buyers had submitted their bidding forms, the experimenter announced the highest *and* the second highest bids in each of the 48 auctions that year. This information was posted so that all subjects could study the information if they wished. Subjects recorded their profit for each auction in which they had participated and then proceeded to the next market year.

To summarize the design, there were three experiments in which a total of 720 auctions were conducted. Perhaps the most important aspect of the design is that each bundled auction corresponds in a very carefully planned way with some set of separate auctions. Because of this, items are essentially sold three times: once in a single-item auction; once in a two-item bundled auction; and once in a four-item bundled auction. This facilitates the analysis of the experimental data tremendously by making it possible to use relatively simple statistical techniques to test the predictions. These techniques, along with the results of the statistical tests, are described in the next two sections.

## IV. HYPOTHESES

This section lists specific testable hypotheses which are stated in a form that allows the data from the experimental auctions to be brought to bear directly on the validity of the propositions of Section II. For each hypothesis, two types of tests are made at two levels of aggregation. First, three comparisons are made, one for each of the three series of experiments, between the results of bundled and separate auctions. Second, aggregate comparisons are also made by pooling the data from all three series of experiments.

In order to test (P1) using the experimental data, comparisons are made between average revenues from auctions in cells I, II, and III of Table 1. Specifically, the statistical hypotheses which are tested using both aggregated and disaggregated data are the following:

**(H1.1)** *The sample mean of differences between revenues generated by two item auctions in cell II and sums of revenues generated in the corresponding single-item auctions of cell I is significantly greater than zero.*

**(H1.2)** *The sample mean of differences between revenues generated by four-item auctions in cell III and the sums of revenues generated in the corresponding single-item auctions of cell I is significantly greater than zero.*

**(H1.3)** *The sample mean of differences between revenues generated by four-item auctions in cell III and sums of revenues generated in the corresponding single item auctions of cell I is significantly greater than the sample mean of differences between revenues generated by two-item auctions in cell II and sums of revenues generated in the corresponding single-item auctions of cell I.*

The following specific hypotheses are used to test prediction (P2):

**(H2.1)** *The sample mean of differences between revenues generated by two-item auctions in cell V and sums of revenues generated in the corresponding single-item auction of cell IV is significantly less than zero.*

**(H2.2)** *The sample mean of differences between revenues generated by four-item auctions in cell VI and sums of revenues generated in the corresponding single-item auctions of cell IV is significantly less than zero.*

**(H2.3)** *The sample mean of differences between revenues generated by four-item auctions in cell VI and sums of revenues generated in the corresponding two-item auctions of cell V is significantly less than zero.*

Prediction (P3) is tested by the following three hypotheses:

**(H3.1)** *The sample mean of revenues generated by auctions in cell I is significantly less than the sample mean of revenues generated by auctions in cell IV.*

**(H3.2)** *The sample mean of revenues generated by auctions in cell II is significantly less than the sample mean of revenues generated by auctions in cell V.*

**(H3.3)** *The sample mean of revenues generated by auctions in cell III is significantly less than the sample mean of revenues generated by auctions in cell VI.*

The testing of (P4)–(P8) predictions about the distributional consequences of bundling, involves a slightly more involved analysis. In each auction in each of cells II, III, V, and VI, each buyer is categorized according to the magnitude of his valuation of items in the bundle and the variation of his valuations of items in the bundle. Specifically, three categories of magnitude (high, medium, and low) are constructed and three categories of variation (high, medium, and low) are constructed. This divides the buyers in each auction in cells II, III, V, and VI into nine categories with approximately equal numbers of buyers in each category. This classification is illustrated in Table 2 where each category is labeled for future reference. Entries for each category are minus the difference

*Table 2.* Categorization of Buyers According to Magnitude and Variation of Valuations for Items in a Bundle

| | | *Variation of Valuations* | | |
|---|---|---|---|---|
| | | *High* | *Medium* | *Low* |
| *Magnitude of Valuations* | *High* | A | D | G |
| | *Medium* | B | E | H |
| | *Low* | C | F | J |

between the mean surplus for buyers in that category in a bundled auction and the mean sum of surpluses for buyers in that category in the corresponding separate auctions.[4]

The predictions we wish to test address questions about the ex ante distribution of buyer surplus, not the ex post distribution of buyer surplus. That is, we wish to investigate how the *expected* surplus a buyer receives varies as a function of the seller's bundling decision *and* that buyer's set of item valuations. Because each individual subject participates in only 10 or 20 auctions in each cell, typically there are only two or three observations for a given subject in each of the nine categories for each cell.This was judged to be too small a number of observations to permit meaningful statistical analysis of expected surpluses at the individual level. Instead, in each category of each cell, observations are obtained pooling across all individual subjects in an experiment.

The following statistical hypothesis is tested to determine the validity of the prediction (P4); again, as in earlier hypotheses, each buyer in each auction is treated as a separate case:

**(H4.1)** *In auctions from cells II and III, entries for all categories, A, B, C, D, E, F, G, H, and J, are significantly greater than zero.*

The following statistical hypothesis is tested to determine the validity of prediction (P5):

**(H5.1)** *Entries for all categories in cell II are each significantly less than the corresponding entries for all categories in cell III.*

The following statistical hypotheses are tested to determine the validity of prediction (P6):

**(H6.1)** *Entries for categories A, B, C, D, E, F, H, and J in cells V and VI are each significantly greater than zero.*

**(H6.2)** *The entry for category G in cells V and VI is significantly less than zero.*

**(H6.3)** *Entries for categories A, B, C, D, E, F, H, and J in cell V are each significantly less than the corresponding entries in cell VI.*

**(H6.4)** *Entries for category G in cell V are significantly greater (less negative) than the corresponding entry in cell VI.*

The hypotheses designed to test prediction (P7) are the following:

**(H7.1)** *In cells II, III, V, and VI, the entries in categories D, E, and F are significantly less than the entries in categories A, B, and C, respectively.*

**(H7.2)** *In cells II, III, V, and VI, the entries in categories G, H, and J are significantly less than the entries in categories A, B, and C, respectively.*

**(H7.3)** *In cells II, III, V, and VI, the entries in categories G, H, and J are significantly less than the entries in categories D, E, and F, respectively.*

The hypotheses designed to test prediction (P8) are the following:

**(H8.1)** *In cells II, III, V, and VI, the entries in categories B, E, and H are significantly greater than the entries in categories A, D, and G, respectively.*

**(H8.2)** *In cells II, III, V, and VI, the entries in categories B, E, and H are significantly greater than the entries in categories C, F, and J, respectively.*

To facilitate analysis of prediction (P9), "bid differences" are calculated. A bid difference equals a buyer's bid for a bundle minus the sum of that buyer's bids in the separate single-item auctions for items contained in the bundle. The hypotheses designed to test prediction (P9) are the following:

**(H9.1)** *The sample mean of the bid differences between cells I and II is significantly greater than zero.*

**(H9.2)** *The sample mean of the bid differences between cells I and III is significantly greater than zero.*

**(H9.3)** *The sample mean of the bid differences between cells I and II is significantly less than the sample mean of the bid differences between cells I and III.*

Hypotheses (H9.1) through (H9.3) are tested at *three* different levels of aggregation: the individual level; the experiment level (aggregating the behavior of 8 buyers); and the fully aggregated level (aggregating the behavior of 24 buyers).

For each auction, efficiency is measured by the valuation of the winning bidder divided by the sum of the highest valuation of each of the separate items being sold in the auction. In other words, we measure efficiency as the percentage of maximum possible total surplus. For each auction in cells II, III, V, VI, an efficiency difference is calculated which equals the percentage of maximum total surplus in separate auctions minus the percentage of maximum total surplus in the corresponding bundled auction. The following hypotheses were designed to test prediction (P10):

**(H10.1)** *The sample mean efficiency differences in cells II, III, V, and VI are each significantly greater than zero.*

**(H10.2)** *The sample mean efficiency difference in cell III is significantly greater than the sample mean efficiency difference in cell II.*

**(H10.3)** *The sample mean efficiency difference in cell VI is significantly greater than the sample mean efficiency difference in cell V.*

In this section, 26 testable hypotheses were outlined. The next section presents the results of the experimental auctions. Some concluding remarks are made in Section VI.

## V. DATA

The data support the hypotheses about the effect of bundling on seller revenue. The mean revenue differences for each experiment as well as the pooled mean revenue differences for all three experiments combined are given in Table 3. There is weak support for hypotheses (H1.1), (H1.2), and (H1.3) but the statistical tests for the pooled mean revenue differences between cells I, II, and III are not significant at the 10% level.[5] However, these pooled means have the

*Table 3.* Revenue Differences Attributable to Bundling[a]

| | *Experiment 1* | *Experiment 2* | *Experiment 3* | *Experiments 1–3 (pooled)* |
|---|---|---|---|---|
| cell II − cell I | 1.9<br>(5.0) | 13.9***<br>(3.8) | −8.5<br>(5.6) | 2.5<br>(2.9) |
| cell III − cell I | 12.9*<br>(9.3) | 11.5**<br>(6.3) | −13.3<br>(6.2) | 3.7<br>(4.3) |
| cell III − cell II | 11.0<br>(10.6) | −2.4<br>(7.4) | −4.8<br>(8.4) | 1.2<br>(5.2) |
| cell V − cell IV | −23.2***<br>(4.4) | −13.2**<br>(6.0) | −19.0***<br>(4.0) | −18.5***<br>(2.8) |
| cell VI − cell IV | −57.7***<br>(5.7) | −51.2***<br>(10.6) | −58.5***<br>(6.7) | −55.8***<br>(4.6) |
| cell VI − cell V | −34.5***<br>(7.2) | −39.0***<br>(12.2) | −39.5***<br>(7.8) | −37.3***<br>(5.4) |

[a] Standard errors are in parentheses.
* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

right sign in each case. So in the three experiments conducted, on average the seller was better off bundling when there were two buyers, but not significantly better off.

The data offer very strong evidence that supports hypotheses (H2.1), (H2.2), and (H2.3). When we use a one-tailed test, all three of the pooled mean differences have the right signs[6] and all are significant at the 1% level. In fact all of these mean differences in each of the three experiments are also significantly less than zero at either the 5% or the 1% level. Thus we can state with a great deal of confidence that with four bidders the seller is worse off bundling.

The prediction that seller revenue increases as a function of the number of bidders is also borne out by the data. Table 4 contains the revenue differences.[7] In each experiment, the revenues in cells IV, V, and VI were significantly greater than the revenues in cells I, II, and III, respectively. The significance level was 1%. Thus hypotheses (H3.1), (H3.2), and (H3.3) cannot be rejected.

With few exceptions, the experiments supported the hypotheses about the distributional consequences of bundling. On average, most buyers were made significantly worse off from bundling. Data for the individual experiments are given in Table 5. These differences[8] for all of the experiments pooled are summarized in Table 6.

In cell II, the major exceptions to the above statement are those buyers who have relatively little variation in valuations for items in a bundle. In these exceptions, the signs of the observed mean surplus differences were almost always positive, but not significantly greater than zero at the 10% level. In cell III, only categories G and H (again "low-variation" categories) failed to have significantly positive surplus differences, but again the signs of these means were positive. Each individual experiment also supports these hypotheses. Because there were fewer data points (i.e., fewer auctions), fewer categories showed

*Table 4.* Revenue Differences Attributable to Number of Competing Buyers

| | *Experiment 1* | *Experiment 2* | *Experiment 3* | *Experiments 1–3 (pooled)* |
|---|---|---|---|---|
| cell I − cell IV | −45.925*** | −29.825*** | −18.775*** | −31.250*** |
| cell II − cell V | −62.725*** | −29.025*** | −27.025*** | −41.598*** |
| cell III − cell VI | −113.100*** | −53.500*** | −29.950*** | −65.517*** |
| t-value for I–IV | (6.6) | (7.5) | (5.8) | (3.9) |
| t-value for II–V | (9.9) | (11.2) | (9.8) | (6.2) |
| t-value for III–VI | (13.6) | (14.5) | (11.8) | (8.3) |

*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

*Table 5.* Buyers' Mean Surplus Differences Attributable to Bundling (Experiments 1, 2, 3)[a]

| | *Experiment 1* | | | | *Experiment 2* | | | | *Experiment 3* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* |
| A | 3.46 | 41.70* | −.93 | 3.39 | 23.7* | 61.8*** | 17.5*** | 20.4*** | 6.6 | 37.3*** | −4.9 | 28.7** |
| | (7.87) | (28.22) | (8.24) | (12.26) | (11.1) | (11.4) | (6.8) | (7.2) | (15.6) | (14.0) | (10.9) | (16.6) |
| B | 20.00*** | 57.00*** | 20.65*** | 33.22*** | 26.5*** | 63.3*** | 18.7*** | 41.3*** | 23.0*** | 51.6*** | 15.2*** | 29.9*** |
| | (7.70) | (12.28) | (5.17) | (4.22) | (7.1) | (7.1) | (3.6) | (5.7) | (8.3) | (6.3) | (3.5) | (6.8) |
| C | 7.67 | 28.21*** | 10.89*** | 34.64*** | 11.1** | 35.0*** | 12.3*** | 24.1*** | 11.0** | 61.6*** | 8.2*** | 15.9*** |
| | (6.29) | (8.06) | (4.16) | (9.12) | (4.8) | (9.2) | (4.5) | (4.6) | (6.5) | (7.7) | (2.7) | (3.5) |
| D | 16.14 | 9.86 | −.28 | −7.71 | 25.6** | −1.5 | −15.8 | 29.6** | −.5 | 27.1** | −32.1 | −29.4 |
| | (17.70) | (27.14) | (8.11) | (7.83) | (13.2) | (10.5) | (10.4) | (15.2) | (9.2) | (12.1) | (13.7) | (17.0) |
| E | 0.0 | 51.14** | 6.69** | 24.67** | 1.7 | 32.3*** | 9.0 | 25.6 | 6.7 | 21.0 | 2.3 | 9.3** |
| | (0.0) | (24.25) | (3.73) | (12.39) | (1.7) | (10.5) | (9.0) | (8.1) | (6.7) | (28.0) | (2.8) | (6.8) |
| F | 4.10*** | 25.80*** | 3.33* | 7.29*** | 4.5* | 42.3*** | 1.4*** | 1.5 | 2.5** | 10.0 | 0.0 | 7.4** |
| | (1.43) | (10.53) | (2.32) | (2.30) | (2.9) | (15.8) | (.6) | (1.5) | (1.4) | (10.0) | (0.0) | (3.5) |
| G | −11.25 | 27.25 | −16.00* | −24.64* | 17.3** | 12.5 | 2.3 | −13.0* | 3.3 | −6.1 | − 9.8* | −6.2 |
| | (25.77) | (65.71) | (10.43) | (17.82) | (7.7) | (13.9) | (7.7) | (10.1) | (9.9) | (13.7) | (6.3) | (19.2) |
| H | 1.20 | 7.00*** | −10.25 | 16.83*** | 0.0 | −22.0 | −2.4 | 10.1* | −35.0 | 24.0*** | 3.3 | 6.4 |
| | (19.70) | (0.0) | (5.38) | (5.58) | (8.2) | (0.0) | (2.0) | (6.7) | (35.0) | (4.0) | (2.7) | (5.9) |
| J | −.08 | 3.92*** | 0.0 | 7.82*** | −1.0 | 14.0** | 0.0 | 1.5** | 2.6* | 10.1*** | 0.0 | 4.2* |
| | (.40) | (1.43) | (0.0) | (2.75) | (1.0) | (8.1) | (0.0) | (.7) | (2.0) | (2.8) | (0.0) | (2.8) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

*Table 6.* Buyers' Mean Surplus Differences Attributable to Bundling (All Experiments Pooled)[a]

| | *Cell II* | *Cell III* | *Cell V* | *Cell IV* |
|---|---|---|---|---|
| A | 11.2** (6.3) | 48.3*** (10.1) | 6.7* (4.9) | 17.1*** (6.7) |
| B | 22.9*** (4.4) | 61.7*** (5.3) | 18.5*** (2.5) | 35.2*** (3.1) |
| C | 10.3*** (3.2) | 41.6*** (5.6) | 10.3*** (2.1) | 22.2*** (2.9) |
| D | 9.8* (7.4) | 16.0* (12.8) | -12.3 (6.2) | -4.4 (8.0) |
| E | 3.6 (2.8) | 38.4*** (10.9) | 4.9** (2.3) | 19.2*** (5.0) |
| F | 3.9*** (1.1) | 28.9*** (7.9) | 1.4** (.7) | 6.0*** (1.7) |
| G | 6.5 (6.6) | 2.8 (11.3) | -7.8** (4.5) | -13.4* (10.3) |
| H | -4.9 (9.6) | 8.3 (11.0) | -3.1 (2.4) | 10.5*** (3.6) |
| J | .6 (.7) | 8.1*** (2.1) | 0.0 (0.0) | 4.7*** (1.4) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

significantly positive mean differences; however, most of these sample mean differences had the correct sign. Over all, the experiments strongly support hypothesis (H4.1), which states that if there are two buyers any buyer is better off ex ante when the items are sold in separate auctions regardless of his valuations.

The next hypothesis, (H5.1), states that, when there are two buyers, on average buyers are worse off the more items that are bundled together. Table 7 displays the sample mean surplus differences between cells II and III. In six of the nine categories, the hypothesis is supported at a 1% significance level. The three exceptions are cells D, G, and H. One should note that these are three categories for which such differences are predicted to be quite small. Even so, two of these three categories had means of the predicted sign. Again the results strongly support the theoretical prediction.

Hypotheses (H6.1), (H6.2), and (H6.3) are very strongly supported by the data. In Table 6, categories A, B, C, E, and F have significantly positive entries in cell V. In category J there were no observations other than 0 since none of

*Table 7.* Comparison of Buyers' Mean Surplus Differences with Two-Item Bundles and Four-Item Bundles[a]

| | *Experiment 1* | | *Experiment 2* | | *Experiment 3* | | *Experiments 1–3 (pooled)* | |
|---|---|---|---|---|---|---|---|---|
| | *Cell II – Cell III* | *Cell V – Cell VI* | *Cell II – Cell III* | *Cell V – Cell VI* | *Cell II – Cell III* | *Cell V – Cell VI* | *Cell II – Cell III* | *Cell V – Cell VI* |
| A | 38.2* (29.3) | 4.3 (14.8) | 38.1*** (15.9) | 2.9 (9.9) | 30.7* (21.0) | 33.6** (19.9) | 37.1*** (11.9) | 8.4 (8.3) |
| B | 37.0*** (14.5) | 12.6** (6.7) | 36.8*** (10.0) | 22.6*** (6.7) | 28.6*** (10.4) | 14.7** (7.6) | 38.8*** (6.9) | 16.7*** (4.0) |
| C | 20.5** (10.3) | 23.7*** (10.0) | 23.9** (10.4) | 11.8** (6.4) | 50.6*** (10.1) | 7.7** (4.4) | 31.3*** (6.4) | 11.9*** (3.6) |
| D | 6.2 (33.0) | –7.4 (11.2) | –27.1 (16.9) | 45.4*** (18.4) | 27.6** (15.6) | 2.7 (21.8) | 6.2 (14.8) | 7.9 (10.1) |
| E | 51.1** (24.3) | 18.0* (12.9) | 30.6*** (10.6) | 16.6* (12.1) | 14.3 (28.8) | 7.0 (7.4) | 34.8*** (11.3) | 14.3*** (5.5) |
| F | 21.7** (10.6) | 4.0 (3.3) | 37.8*** (16.1) | .1 (1.6) | 7.5 (10.1) | 7.4** (3.5) | 25.0*** (8.0) | 4.6*** (1.8) |
| G | 38.0 (70.6) | –8.6 (20.6) | –4.8 (15.9) | –15.3 (12.7) | –9.4 (16.9) | 3.6 (20.2) | –3.7 (13.1) | 5.6 (11.2) |
| H | 5.8 (19.7) | 27.1*** (7.8) | –22.0 (8.2) | 12.5** (7.0) | 59.0** (35.2) | 3.1 (6.5) | 13.2 (14.6) | 13.6*** (4.3) |
| J | 4.0*** (1.5) | 7.8*** (2.8) | 15.0** (8.2) | 1.5** (.7) | 7.5** (3.4) | 4.2* (2.8) | 7.5*** (2.2) | 4.7*** (1.4) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

these buyers won any separate or bundled auctions. Category D is a bit of an anomaly since it shows a significantly *negative* sign. In cell VI, all categories except D have positive mean surplus differences and they are significant. Category D is negative but not significant. The data from individual experiments (Table 5) are also supportive of hypothesis (H6.1), but fewer categories are significant due to larger standard errors resulting from a smaller sample size. Thus we conclude that (H6.1) is strongly supported by the data with the exception of category D.

Hypothesis (H6.2) predicts that in cells V and VI the entry for category G should be significantly less than zero. In the pooled data, this is confirmed. This is also confirmed in the individual experiments (Table 5) in the four cases in which the sign of the sample mean is significant.

Hypothesis (H6.3) is supported in all categories except A and D, and hypothesis (H6.4) is not supported (refer to Table 7). Again, with few exceptions this indicates that predictions for most categories are qualitatively very precise. This also appears to be true when we are using the data from the three experiments individually instead of pooled. The signs are generally correct in the individual experiments, but are not always significant because of a small sample problem.

Tables 8 and 9 display the summarized data[9] used to test hypotheses (H7.1), (H7.2), and (H7.3). Using the pooled data (Table 9), hypothesis (H7.1) was strongly supported in all cells and for all categorical comparisons except for the comparison of categories A and D in cell II. Once again the sign was correct but not significant at the 10% level. Hypothesis (H7.2) was significantly supported with one exception: the sign for the comparison between categories A and G was correct but not significant. Hypothesis (H7.3) was also supported by the pooled data, but the evidence was not as convincing as the evidence supporting (H7.1) and (H7.2). In all four cells, the mean surplus difference between categories D and G were not significantly different. This was also true for the comparison of categories E and H in cell III and the comparison of F and J in cell VI. All other signs were correct and significant at the 10% level.

Table 8 shows the sample means and standard errors used to test hypotheses (H7.1), (H7.2), and (H7.3) in each of the three experiments. These data also offer similar support for these three hypotheses, but the support is not as strong because fewer signs are significant due to the smaller sample size. From Tables 8 and 9 we conclude that (H8.1), (H8.2), and (H8.3) cannot be rejected.

The next set of hypotheses, (H8.1) and (H8.2), are tested by comparing sample means of buyers' surplus differences along the dimension of the magnitude of the buyers' valuations for items in a bundle. Table 10 contains the data for each separate experiment, and Table 11 contains the data pooled from all three experiments. For all experiments combined, the signs of the differences were significantly positive, as predicted for all categories in cell VI. In cell V, four of the six categorical comparisons had signs which were significant and consistent with the hypothesis. The exceptions were the differences between categories G

*Table 8.* Comparison of Buyers' Mean Surplus Differences Along the Dimension of Variation of Values (Experiments 1, 2, and 3)[a]

| | *Experiment 1* | | | | *Experiment 2* | | | | *Experiment 3* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* |
| A–D | −12.7 | 31.8 | −.6 | 10.1 | −1.9 | 63.3*** | 33.3*** | −9.3 | 7.1 | 10.1 | 27.2** | 58.2*** |
| | (19.4) | (39.1) | (11.5) | (14.6) | (17.2) | (15.5) | (12.4) | (16.8) | (18.1) | (18.8) | (17.5) | (23.8) |
| B–E | 20.0*** | 5.9 | 13.95** | 8.5 | 24.8*** | 47.0*** | 9.7 | 15.7* | 16.3* | 30.7 | 12.9*** | 20.5** |
| | (7.7) | (27.2) | (6.4) | (13.1) | (7.3) | (12.7) | (9.7) | (9.9) | (10.7) | (28.7) | (4.5) | (9.6) |
| C–F | 3.6 | 2.4 | 7.6* | 27.3*** | 6.6 | −7.3 | 10.9*** | 22.6*** | 8.5 | 51.6*** | 8.2*** | 8.5** |
| | (6.5) | (13.3) | (4.8) | (9.4) | (5.6) | (18.3) | (4.5) | (4.8) | (6.6) | (12.6) | (2.7) | (4.9) |
| A–G | 14.7 | 14.4 | 15.1 | 28.0 | 6.5 | 49.3*** | −15.2* | 33.4*** | 3.3 | 43.4** | 4.8 | 35.0* |
| | (27.0) | (71.5) | (13.2) | (21.6) | (13.5) | (18.0) | (10.2) | (12.4) | (18.5) | (19.6) | (12.6) | (25.4) |
| B–H | 18.8 | 50.0*** | 30.9*** | 16.4*** | 26.5*** | 91.3*** | 21.1 | 31.2*** | 58.0* | 27.7*** | 11.8*** | 23.4*** |
| | (21.2) | (12.3) | (7.5) | (7.0) | (10.8) | (7.1) | (4.1) | (9.0) | (36.0) | (7.5) | (4.4) | (9.0) |
| C–J | 7.8 | 25.3*** | 10.9 | 26.8*** | 12.1*** | 21.0** | 12.3*** | 22.6*** | 8.4 | 51.5*** | 8.2*** | 11.7*** |
| | (6.3) | (8.2) | (4.2) | (9.5) | (4.9) | (12.3) | (4.5) | (4.7) | (6.8) | (8.2) | (2.7) | (4.5) |
| D–G | 27.4 | −17.35 | 15.7 | 16.9 | 8.4 | −14.0 | −18.1 | 42.6*** | −3.8 | 33.3** | −22.3 | −23.2 |
| | (31.3) | (71.1) | (13.2) | (19.4) | (15.3) | (17.4) | (12.9) | (18.2) | (13.5) | (18.6) | (15.1) | (25.6) |
| E–H | −1.2 | 44.1** | 17.0*** | 7.9 | 1.7 | 54.0*** | 11.4 | 15.5* | 41.7 | −3.0 | −1.1 | 2.9 |
| | (19.7) | (24.3) | (6.5) | (13.6) | (8.4) | (10.5) | (9.2) | (10.7) | (35.6) | (28.3) | (3.9) | (9.0) |
| F–J | 4.2*** | 21.9** | 3.3* | −.5 | 5.5** | 28.3* | 1.4*** | 0.0 | −.1 | −.1 | 0.0 | 3.2 |
| | (1.5) | (10.6) | (2.3) | (3.6) | (3.1) | (17.8) | (.6) | (1.7) | (2.4) | (10.4) | (0.0) | (4.5) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

*Table 9.* Comparison of Buyers' Mean Surplus Differences Along the Dimension of Variation of Values (All Experiments Pooled)[a]

| | *Cell II* | *Cell III* | *Cell V* | *Cell IV* |
|---|---|---|---|---|
| A–D | 1.3<br>(9.7) | 32.3**<br>(16.3) | 19.0***<br>(7.9) | 21.5**<br>(10.4) |
| B–E | 19.4***<br>(5.2) | 23.3**<br>(12.1) | 13.5***<br>(3.4) | 16.0***<br>(5.9) |
| C–F | 6.4**<br>(3.4) | 12.7*<br>(9.7) | 8.9***<br>(2.2) | 16.3***<br>(3.2) |
| A–G | 4.7<br>(9.1) | 45.6***<br>(15.2) | 14.6**<br>(6.7) | 30.5***<br>(12.3) |
| B–H | 27.9***<br>(10.6) | 53.5***<br>(12.2) | 21.6***<br>(3.5) | 24.8***<br>(4.8) |
| C–J | 9.7***<br>(3.3) | 33.5**<br>(6.0) | 10.3***<br>(2.1) | 17.6***<br>(3.2) |
| D–G | 3.3<br>(9.9) | 13.3<br>(17.1) | –4.5<br>(7.7) | 9.1<br>(13.0) |
| E–H | 8.5<br>(10.0) | 30.1**<br>(15.5) | 8.1***<br>(3.3) | 8.8*<br>(6.2) |
| F–J | 3.3***<br>(1.3) | 20.8***<br>(8.2) | 1.4**<br>(.7) | 1.3<br>(2.2) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

and H and the differences between categories H and J. Considering that the entries in Table 2 for each of the three, G, H, and J, are predicted by theory to be quite small, the fact that the differences between the entries in these three categories were not significantly different from zero is not particularly surprising. In cells II and III combined, only 4 of the 12 signs were significant. All of these signs conformed with the predicted signs. Table 10 also shows that if each experiment is analyzed separately, an overwhelming proportion of the categorical comparisons have the predicted sign and a large number have not only the predicted sign but are also significant.

In all of the hypotheses making comparisons between the nine categories, (H4.1)–(H8.2), the tests have shown more significant comparisons when there are four bidders (cells V and VI) than when there are two bidders (cells II and III). There is a good reason for this. The comparisons in cells V and VI have twice as many observations as the comparisons in cells II and III since there are four bidders instead of two bidders. This results in larger standard errors of the

*Table 10.* Comparison of Buyers' Mean Surplus Differences Along the Dimension of Magnitude of Values (Experiments 1, 2, and 3)

| | *Experiment 1* | | | | *Experiment 2* | | | | *Experiment 3* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* | *Cell II* | *Cell III* | *Cell V* | *Cell VI* |
| B–A | 16.5* | 15.3 | 21.5** | 29.8** | 2.8 | 7.6 | 1.2 | 21.0** | 16.4 | 14.4 | 20.1** | 58.5*** |
| | (11.0) | (30.8) | (9.7) | (13.0) | (13.2) | (13.4) | (7.7) | (9.2) | (17.7) | (15.4) | (11.4) | (17.9) |
| E–D | −16.1 | 41.2 | 7.0 | 32.4** | −23.9 | 33.8** | 24.8** | −4.0 | 7.2 | −6.1 | 34.3*** | 38.7*** |
| | (17.7) | (36.4) | (8.9) | (14.6) | (13.3) | (14.8) | (13.8) | (17.2) | (11.4) | (30.7) | (14.0) | (18.3) |
| H–G | 12.5 | −20.2 | 5.8 | 41.4** | −17.3 | −34.5 | −4.7 | 23.1** | −38.3 | 30.1** | 13.1** | 12.6 |
| | (32.5) | (65.7) | (11.7) | (18.7) | (11.2) | (13.9) | (8.0) | (12.3) | (36.4) | (14.3) | (6.9) | (20.1) |
| B–C | 12.3 | 28.8** | 9.7* | −1.4 | 15.4** | 34.3*** | 6.4 | 17.2*** | 12.0 | −9.9 | 6.9* | 13.9** |
| | (9.9) | (14.7) | (6.7) | (10.0) | (8.0) | (11.6) | (5.8) | (7.3) | (10.5) | (9.9) | (4.4) | (7.6) |
| E–F | −4.1 | 25.3 | 3.4 | 17.4* | −2.8 | −9.9 | 7.6 | 24.1*** | 4.2 | 11.0 | 2.3 | 1.9 |
| | (1.4) | (26.5) | (4.4) | (12.6) | (3.4) | (19.0) | (9.0) | (8.2) | (6.8) | (29.7) | (2.8) | (7.6) |
| H–J | 1.3 | 3.1** | −10.25 | 9.0* | 1.0 | −36.0 | −2.4 | 8.6 | −37.6 | 13.9*** | 3.3 | 2.2 |
| | (19.7) | (1.4) | (5.4) | (6.3) | (8.3) | (8.1) | (2.0) | (7.0) | (35.1) | (4.9) | (2.7) | (6.5) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

*Table 11.* Comparison of Buyers' Mean Surplus Differences Along the Dimension of Magnitude of Values (All Experiments Pooled)[a]

| | *Cell II* | *Cell III* | *Cell V* | *Cell IV* |
|---|---|---|---|---|
| B–A | 11.7*<br>(7.7) | 13.4<br>(11.4) | 11.7**<br>(5.5) | 18.1***<br>(7.4) |
| E–D | -6.2<br>(7.9) | 22.4*<br>(16.8) | 17.3***<br>(6.6) | 23.6***<br>(9.4) |
| H–G | -10.4<br>(11.6) | 5.5<br>(15.8) | 4.7<br>(5.1) | 23.9**<br>(10.9) |
| B–C | 12.6**<br>(5.4) | 20.1***<br>(7.7) | 8.2***<br>(3.3) | 13.0***<br>(4.2) |
| E–F | -.3<br>(3.0) | 9.5<br>(13.5) | 3.6*<br>(2.4) | 13.3***<br>(5.3) |
| H–J | -5.5<br>(9.6) | .1<br>(11.2) | -3.1<br>(2.4) | 5.8*<br>(3.9) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

estimated mean differences in cells II and III than in cells V and VI, so that one would expect fewer of the signs to be significant.

In addition to the above tests of expected surplus differences it is also possible to calculate exactly for each bidder in each auction the ex post surplus predicted by the theoretical model of bidding behavior. These calculated numbers can then be compared to the actual surpluses buyers received, enabling us to examine the effect of bundling on ex post surplus differences. Such comparisons do not test any of the propositions stated in Section II, above, but they are of interest insofar as they relate to open theoretical and empirical questions about individual bidding behavior. Thus, for the sake of completeness, these comparisons were made and are reported here. For each bidder in each bundled auction, a theoretical surplus difference was predicted by subtracting the theoretical surplus for that bidder in that auction from the theoretical surplus in the corresponding separate auctions. The signs (+, 0, −) of these differences were then compared to the signs of the *actual* surplus differences. Table 12 reports the proportion of correctly predicted signs for each cell in each experiment. Using binomial tests, theory predicts the signs significantly better than a model in which signs are predicted by randomly choosing one of the three signs (+, 0, or −). However, if we use a similar binomial test, all proportions are significantly less than 1 according to any reasonable statistical criterion. These results lead us to conclude that, while the ex ante (on average) effects of bundling on the distribution of buyer surplus

*Table 12.* Proportion of Signs of Surplus Differences Predicted Correctly by the Model[a]

| | *Cell II – Cell I* | *Cell III – Cell I* | *Cell V – Cell IV* | *Cell VI – Cell IV* |
|---|---|---|---|---|
| Experiment 1 | .60 (80) | .63 (80) | .68 (160) | .61 (160) |
| Experiment 2 | .59 (80) | .80 (80) | .78 (160) | .75 (160) |
| Experiment 3 | .73 (80) | .76 (80) | .75 (160) | .66 (160) |
| All experiments pooled | .63 (240) | .73 (240) | .74 (480) | .67 (480) |

[a]Numbers of observations are in parentheses.

*Table 13.* Mean Bid Differences (by Individual Buyers)[a]

| *Buyer Number* | *Cell II – Cell I* | *Cell III – Cell I* | *Cell III – Cell II* |
|---|---|---|---|
| 1 | 5.6 (5.6) | 55.3*** (8.0) | 49.7*** (9.8) |
| 2 | 16.5** (7.7) | 9.3 (11.0) | –7.2 (13.4) |
| 3 | 2.1* (1.3) | 3.6*** (1.4) | 1.5 (1.9) |
| 4 | .8 (2.0) | 8.6 (9.2) | 7.8 (9.4) |
| 5 | 14.4*** (4.0) | 56.2*** (7.3) | 41.8*** (8.3) |
| 6 | 6.8 (11.0) | 49.6*** (19.3) | 42.8** (22.2) |
| 7 | 4.4 (5.3) | 32.8*** (7.2) | 28.4*** (8.9) |
| 8 | 12.8*** (4.9) | 50.0*** (18.7) | 37.2** (19.3) |
| 9 | 19.0** (8.5) | 71.2*** (7.9) | 52.2*** (11.6) |
| 10 | 26.1*** (7.3) | 77.5*** (15.6) | 51.4*** (17.2) |
| 11 | 5.5 (6.4) | 32.5*** (7.1) | 27.0*** (9.6) |

*Table 13. (cont.)* Mean Bid Differences (by Individual Buyers)[a]

| *Buyer Number* | *Cell II – Cell I* | *Cell III – Cell I* | *Cell III – Cell II* |
|---|---|---|---|
| 12 | 38.6*** (7.9) | 122.2*** (13.4) | 83.6*** (15.6) |
| 13 | 14.1* (9.0) | 16.0* (11.5) | 1.9 (14.6) |
| 14 | 4.0 (4.9) | 54.0*** (11.2) | 50.0*** (12.2) |
| 15 | 11.5*** (2.8) | 27.0*** (4.5) | 15.5*** (5.3) |
| 16 | 36.7*** (13.5) | 126.6*** (12.3) | 89.9*** (18.3) |
| 17 | 17.0*** (4.7) | 77.0*** (5.5) | 60.0*** (7.2) |
| 18 | 5.1 (5.3) | 11.6 (15.1) | 6.5 (16.0) |
| 19 | -5.0 (17.1) | 19.7* (13.2) | 24.7 (21.6) |
| 20 | 17.0** (7.6) | 46.2*** (9.8) | 29.2*** (12.4) |
| 21 | 6.4 (12.0) | 46.3*** (9.7) | 39.9*** (15.4) |
| 22 | 21.7*** (6.8) | 47.8** (11.4) | 26.1** (13.3) |
| 23 | 3.2 (4.2) | 19.9*** (5.8) | 16.7** (7.2) |
| 24 | 13.4 (11.1) | 46.5*** (9.5) | 33.1** (14.6) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

is predicted quite accurately by the model, actual surplus for a particular bidder in a particular auction is predicted less accurately.

The next set of hypotheses, (H9.1)–(H9.3), addresses the question of superadditivity of buyers' bidding strategies. Table 13 displays these data for individual buyers. Since there were three experiments, there were 24 buyers in all. Each entry is an average measure of superadditivity from a specific buyer. Each row corresponds to a different buyer, and each column corresponds to an average

*Table 14.* Mean Bid Differences (by Experiment)[a]

| | *Cell II – Cell I* | *Cell III – Cell I* | *Cell III – Cell II* |
|---|---|---|---|
| Experiment 1 | 7.9*** (2.1) | 33.2*** (4.6) | 25.3*** (5.1) |
| Experiment 2 | 19.4*** (3.1) | 65.9*** (5.8) | 46.5*** (6.6) |
| Experiment 3 | 9.9*** (3.4) | 39.4*** (4.2) | 29.5*** (5.4) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

difference between an individual's bids in bundled auctions from one cell and sums of that individual's bids in the corresponding unbundled auctions in another cell. Positive entries indicate superadditivity, and negative entries indicate subadditivity. As one can see, nearly all entries (70 out of 72) are positive, as predicted. In fact 39 of the 72 entries in the table are significantly positive at the 1% level. Note that column 1 corresponds to (H9.1), column 2 corresponds to (H9.2), and column 3 corresponds to (H9.3). Referring to column 1, note also that 13 of the 24 buyers satisfy hypothesis (H9.1) at the 10% significance level and all but one of the remaining 11 buyers bid superadditively but not significantly superadditively. The other hypotheses are even more strongly supported by this table. There is not a single entry which is significantly less than zero even at a significance level of 15%. Of the few negative entries, none is more than one standard error less than zero. What is remarkable is that so many entries in this table are significantly positive even though the sample size for each entry is only 10. In Table 14, bid differences are averaged across *all* bidders by experiment. When this aggregation is performed, all entries are significantly positive at the 1% level. The data clearly confirm hypotheses (H9.1)–(H9.3) beyond much doubt.

A final observation about individual bidding behavior should be noted. Buyers did not always bid exactly according to bidding strategies specified by the theory. This observation was also made by Coppinger et al. (1980) on the basis of their experimental data.[10] The fact that, despite this, the predictions from the theory about the aggregate effects of bundling decisions were strongly supported by the experiments described in the present paper indicates that predictions of this sort are quite robust. Nonetheless, this phenomenon points to a weakness in the theory of individual bidding behavior which deserves to be explored in future research endeavors.

The final set of hypotheses, (H10.1)–(H10.3), addresses the loss of efficiency

*Table 15.* Mean Efficiency Differences[a]

| | *Cell I − Cell II* | *Cell I − Cell III* | *Cell II − Cell III* | *Cell IV − Cell V* | *Cell IV − Cell VI* | *Cell V − Cell VI* |
|---|---|---|---|---|---|---|
| Experiment 1 | 4.6*** (1.7) | 9.1*** (2.1) | 4.5** (2.7) | 13.7*** (2.1) | 18.5*** (1.8) | 4.8** (2.8) |
| Experiment 2 | 6.0*** (2.0) | 14.4*** (1.7) | 8.4*** (2.6) | 13.7*** (2.7) | 21.3*** (1.9) | 7.6*** (3.3) |
| Experiment 3 | 8.5*** (2.2) | 11.6*** (1.7) | 3.3 (2.8) | 6.4*** (1.7) | 16.1*** (1.7) | 9.7*** (2.4) |
| All experiments pooled | 6.4*** (1.1) | 11.7*** (1.1) | 5.3*** (1.5) | 11.3*** (1.3) | 18.7*** (1.0) | 7.4*** (1.6) |

[a]Standard errors are in parentheses.
*Significant at 10% level.
**Significant at 5% level.
***Significant at 1% level.

*Table 16.* Average Efficiencies

| | *Cell I* | *Cell II* | *Cell III* | *Cell IV* | *Cell V* | *Cell VI* |
|---|---|---|---|---|---|---|
| Experiment 1 | .971 | .929 | .887 | .966 | .830 | .782 |
| Experiment 2 | .965 | .913 | .829 | .979 | .841 | .765 |
| Experiment 3 | .996 | .911 | .881 | .963 | .899 | .802 |
| All experiments pooled | .977 | .918 | .866 | .969 | .857 | .783 |

due to bundling. Table 15 presents average efficiency differences between cells for each experiment and for all experiments pooled. The efficiency measure used was the percentage of maximum total surplus that was generated by the auction. The average efficiency difference between two cells is equal to the average difference between the percentage of maximum surplus generated in separate auctions and the percentage of maximum surplus generated in the corresponding bundled auction.[11] The evidence presented in Table 15 overwhelmingly supports (H10.1–(H10.3). Bundling creates inefficiencies. Average efficiencies[12] for each cell of each experiment are given in Table 16.

## VI. CONCLUSIONS

This series of experiments was designed and carried out with the aim of providing data to statistically test a number of specific predictions generated by a theoretical model. The predictions tested were qualitative in nature and addressed questions of the effect of bundling and the effect of the number of competing bidders on seller revenues, the ex ante distribution of buyer surplus, the strategies of the buyers, and the ex post distribution of total surplus (i.e., efficiency). The following predictions were strongly supported by the data:

1. Seller revenues increase as a function of the number of bidders.
2. Buyers bid superadditively.
3. When there are a large number (four or more) of bidders, the seller is better off not bundling.
4. Bundling creates significant inefficiencies.
5. On average, buyers with relatively more dispersed valuations are affected more adversely under bundling than are buyers with relatively less dispersed valuations.
6. Ex ante, buyers are affected adversely by bundling.
7. If there are a large number (four or more) of bidders, then buyers with exceptionally high valuation benefit, on average, from bundling.

Two other predictions were supported by the data, but not so convincingly as the above predictions:

8. With few competing bidders, the seller is better off bundling.
9. On average, buyers with mediocre valuations are affected more adversely by bundling than buyers with relatively high or relatively low valuations.

## APPENDIX: INSTRUCTIONS

*General Instructions*

This is an experiment in the economics of market decision making. Various research foundations have provided funds for this research. The instructions are simple. If you follow them carefully and make good decisions, you might earn a considerable amount of money. Your earnings will be paid to you in cash at the end of the experiment. In addition, you will also be paid $3.00 at the end of the experiment for your participation.

In this experiment we are going to conduct auctions in which you will be buying items from the experimenter. You will participate in several such auctions in a sequence of 5 market years. In your folder you will find an information and record sheet for each market year, as well as a "list of valuations." These will determine the amount you will be paid if you win an auction. You are not to reveal this information to anyone. It is your own private information.

*Specific Instructions*

During each market year, several auctions are conducted for several lots. Each lot consists of one or more items. At the beginning of each year, you will be asked to submit private, written bids for each of the lots listed in the first column of your information and record sheet. These bids must be in penny increments. You have been provided with bidding forms for this purpose. Each lot consists of the set of items listed in column 2. You will also be told how many of the people in the room (including yourself) will be bidding on each lot. This number is listed in the fourth column of your information and record sheets.

Your *redemption value* for each item may be found in your "list of valuations." You will notice that all of your redemption values are between \$0.00 and \$1.99. Each of these values was drawn perfectly randomly in the range from \$0.00 to \$1.99 for each bidder. Each value for each bidder for each item is equally likely to be anywhere from \$0.00 to \$1.99. Therefore, different bidders will almost certainly have different values for each item. All values are in penny increments. The only values you know for sure are your own, and you are not to reveal any information about these to anyone else.

Remember, each lot may consist of several items. The total value to you of a *lot* equals the *sum* of your redemption values for the items in the lot. For your convenience, your total redemption value for each lot has been calculated for you and is listed in column 3 of your information and record sheet.

*Your Profit*

If someone else submits a higher bid than yours for a particular lot, you neither receive nor pay any money. Your profit for that lot is zero.

If your bid for a lot is higher than any other bid for that lot, then the experimenter will pay you your redemption values for *all* items in that lot minus your bid for that lot. Your profit for that lot, if you win, is equal to the difference between your total redemption value for the lot and your bid for the lot. For example, suppose that lot #2 consisted of items 48, 53, and 117, and your values for these items were \$0.91, \$1.45, and \$0.61, respectively. Then your total redemption value for lot #2 is

$$\$0.91 + \$1.45 + \$0.61 = \$2.97.$$

If you submitted a bid of \$1.29 for lot #2 and this was the highest bid submitted by any bidder for lot #2, then your profit for this lot would be

$$\$2.97 - \$1.29 = \$1.68.$$

If you and at least one other bidder tie for the highest bid on a lot, then your profit equals your total redemption value minus your bid *divided by* the number of winning bidders. In the example above, if one other bidder also submitted a bid of \$1.29 and no one submitted a bid higher than \$1.29, then your profit would be

$$\frac{\$1.68}{2} = \$0.84.$$

Your total profits for the experiment will be the sum of your profits in each auction plus a payment of \$3.00 for your participation.

*Recording Instructions*

Each market year, your bids should be recorded in column 5 of your information and record sheet and on the bidding forms which have been provided for you by the experimenter. When you have completed your bidding form raise your hand and the experimenter will collect it. After everyone has submitted their bidding forms for that year, the experimenter will announce the highest bid and the second highest bid for each lot. Please record the highest bid in column 6 of your information and record sheet. The experimenter will also announce whether there were any ties. When the experimenter has finished this, you should record your profit for each lot in the last column of your information and record sheet. Your total profit for the market year is computed by adding rows 1 through 18. Please record this number in the box at the bottom of the page. When everyone has done this, we will proceed to the next market year.

Are there any questions?

## ACKNOWLEDGMENTS

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## NOTES

1. This model of the bidding process was originally formulated in Vickrey (1961).
2. This is a well-known prediction of Vickrey's bidding model.
3. All subjects were undergraduate students at the California Institute of Technology.
4. The cutoff points to determine in which category a buyer belongs were chosen so that the expected number of cases in each category were approximately equal. Due to correlation between magnitude and variation of values the expected number of cases is not exactly the same across all the nine categories. This results in a small sacrifice of the efficiency of our statistical tests. For cells II and V the categories were divided in the following way: m = magnitude of valuation = (sum of valuations of items in the lot)/(number of items in the lot); s = variation of valuations = (sum of absolute differences between the values of items in the lot and m for that lot)/(number of items in the lot).

| | | |
|---|---|---|
| A | $118.3 < m < 199$ | $s > 30$ |
| B | $81.7 < m < 118.3$ | $s > 30$ |
| C | $0 < m < 81.7$ | $s > 30$ |
| D | $118.3 < m < 199$ | $15 < s < 30$ |
| E | $81.7 < m < 118.3$ | $15 < s < 30$ |
| G | $0 < m < 81.7$ | $15 < s < 30$ |
| F | $118.3 < m < 199$ | $0 < s < 15$ |
| H | $81.7 < m < 118.3$ | $0 < s < 15$ |
| J | $0 < m < 81.7$ | $0 < s < 15$ |

For cells III and VI, the categories were divided in the following way:

| | | |
|---|---|---|
| A | $115 < m < 199$ | $s > 40$ |
| B | $85 < m < 115$ | $s > 40$ |
| C | $0 < m < 85$ | $s > 40$ |
| D | $115 < m < 199$ | $30 < s < 40$ |
| E | $85 < m < 115$ | $30 < s < 40$ |
| F | $0 < m < 85$ | $30 < s < 40$ |
| G | $115 < m < 199$ | $0 < s < 30$ |
| H | $85 < m < 115$ | $0 < s < 30$ |
| I | $0 < m < 85$ | $0 < s < 30$ |

5. These entries are hypothesized to be significantly greater than zero. (In all tables, standard errors are in parentheses below the appropriate sample mean.)

6. These entries are hypothesized to be significantly less than zero.

7. These entries are hypothesized to be significantly greater than zero.

8. All entries in Table 5, 6, and 7 are hypothesized to be significantly greater than zero except for entries for category G in the "Cell V" columns, "Cell VI" columns, and "Cell V − Cell VI" columns, which are hypothesized to be significantly less than zero.

9. All entries in Tables 8, 9, 10, 11, 13, and 14 are hypothesized to be significantly greater than zero.

10. Consistent with findings elsewhere, bidders did generally "overbid" relative to the risk-neutral model when valuations were distributed uniformly (cells I and IV). However, this was *not* generally the case when valuations were not distributed uniformly. In fact, with four bidders when valuations were not distributed uniformly, buyers frequently *underbid* relative to the risk-neutral model.

11. Suppose, for example, exactly three auctions with two bidders were conducted in an experiment—two separate auctions and one *corresponding* bundle auction. If the bidders' values were 1.00 and 1.25 for the first item and 1.00 and .90 for the second item and bids were .50, .75 and .50, .55 in the two separate auctions and 1.50, 1.40 in the bundled auctions, then the efficiency difference would be

$$\left[\frac{1.25 + .90}{1.25 + 1.00} - \frac{2.00}{1.25 + 1.00}\right] \times 100 = [.96 - .89] \times 100 = 7.0.$$

12. Note that average efficiency differences reported in Table 14 are *not* obtained by subtracting one of the entries in Table 15 from another entry in Table 15. (e.g., average efficiency difference Cell I − Cell II $\neq$ average efficiency Cell I − average efficiency Cell II). In the example in note 11, above, the efficiency difference is 7.0 but the difference between average efficiencies is 6.0.

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