Production-to-order or production-to-stock:  
the endogenous choice of institution in experimental 
auction markets  

Owen R. Phillips\textsuperscript{a,}\textsuperscript{*}, Dale J. Menkhaus\textsuperscript{b}, Joseph L. Krogmeier\textsuperscript{b}  
\textsuperscript{a} Department of Economics and Finance, University of Wyoming, PO Box 3985, Laramie, WY 82071-3985, USA  
\textsuperscript{b} Department of Agricultural and Applied Economics, University of Wyoming, Laramie, WY 82071-3354, USA  

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Abstract  
Markets are organized so that buyers and sellers have a choice of participating in production-to- 
stock or production-to-order auctions. A production-to-stock (PTS) institution requires the seller 
to hold inventory before trading. Data from computerized double auctions are analyzed. Inven-
tory cost diminishes trading activity. When the choice of institution is endogenous, sales from 
stock are about 15 percent of the total. When there is only a PTS market, econometric estimates 
show sellers as a group seek higher prices and seller surplus is relatively high. A production-to-order 
choice increases buyer surplus and market efficiency. © 2001 Elsevier Science B.V. All 
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1. Introduction  

Often times there exists both a production-to-order (PTO) market and a product-to-stock 
(PTS) market for goods; buying and selling agents can choose to participate in either or both 
types of markets. In a PTS market, the seller has inventory on hand. Production takes place 
in advance of the sale and the buyer usually takes delivery within a short period of time 
after the sale is made. PTO market transactions usually result from long-term contracts. 
Sales are made before output is available. Agents agree on prices and the future delivery of
quantities before a production run begins or it is completed. Many commodities are sold in both PTS and PTO markets. A PTO institution may be thought of as a forward market; a PTS institution is closely akin to a spot market. Cattle, most grains, coal, natural gas, electricity, and even residential housing (custom vs. speculative sales) are examples of goods that have both PTS and PTO trading.

This paper investigates buyer and seller behavior in PTS and PTO markets when the choice to participate in these markets is endogenous. Prices, the quantities traded, and earnings are observed when subjects as market participants buy and sell in computerized double auctions. We are not aware of any other studies that focus on the endogenous choice of a PTS or PTO trading institution, where there is self-selection of the market institution in which agents choose to do business. Other studies have evaluated the efficiency of markets that require advance production, and compared behavior to the widely studied auction institution that does not require an initial inventory stock. Mestelman and Welland (1988) report the results of 10 oral trading sessions that make this comparison. They found the market institution did not significantly affect mean contract prices; but a PTS auction design had somewhat lower levels of sales than those of the PTO type.¹

A disadvantage of advance production is that a seller must carry inventory. The inventory requirement in a PTS market can increase market prices in two ways. First, the restriction that production be at least as great as sales can impose added implicit and explicit expenses that may be thought of as inventory costs. Also, the actual difference between production and sales is random in a given production period. PTS costs therefore will have a random component in the cost function not present in PTO cost functions, and this will cause risk averse sellers to restrict sales.

We refer to the experimental design that allows subjects to choose between the PTO and PTS market institution as a linked O/S institution. Fig. 1 describes the trading sequence or cycle. Agents begin trading in a PTO double auction market. After 3 min the auction ends and sellers make their production decision. At least as many units sold by a seller in this market must be produced, but more can be produced and held in inventory for a double PTS auction that follows. The maximum number of units which may be traded in the PTS market are those units held in inventory. Behavior in this linked design is contrasted with trading in just a PTS market institution and a PTO only market institution. These latter two designs serve as controls. We find that in the linked institution most trades, about 85 percent, occur in the PTO market. Also, relative to a PTS only trading environment, buyers have far greater surplus in the linked markets. Buyer surplus is 60–70 percent greater than that generated in a PTS only market institution. Conversely, sellers fare better in a PTS market, as compared to PTO only trading institution. We provide detail on the experimental design in Section 2. The data are presented in Section 3. Testable hypotheses and econometric results are discussed in Section 4. Section 5 provides some concluding remarks.

¹ Other studies have focused on aspects of advanced production in double auction or posted-offer markets or both; e.g., Mestelman and Welland (1988, 1991) and Mestelman et al. (1987). These studies have not made the direct comparison between advanced production markets that have production-to-order as their focus. The production-to-order markets have been widely studied as the standard double auction set up. See Kagel (1995, Chap. 7) for a recent survey of this literature.
2. Experimental design

Ten auction sessions were conducted — four linked O/S sessions, three PTS only, and three PTO only sessions for the same supply and demand schedules. Trading in each of these sessions went through 15 or 16 cycles. Each auction period was 3 min, hence in the linked O/S sessions a trading cycle took 6 min plus time for the production decision as shown in Fig. 1. Sellers in the experiment were made aware of costs before trading and could trade as many units as allowed by the production function. A PTS only session began with a production decision by sellers before trading began. PTS sellers paid all their costs before any trading, and there was no inventory carryover. As in Mestelman and Welland (1988) and in the auction markets studied by Noussair et al. (1995), four buyers and four sellers participated in each market session. Subjects were recruited from upper level undergraduate and graduate economics and business courses.

Buyers were privately given a table which listed the maximum reservation values for each unit purchased; these values were described to buyers as redemption values. Sellers were informed of unit costs. Earnings were denoted on a monetarily convertible currency called tokens. It was explained clearly to subjects that tokens were convertible to cash at the following exchange rate: 100 tokens = $1.00. Redemption values were identical for each buyer and production costs were identical for each seller. Values and costs to participants were strictly private information. The redemption values began at 130 tokens and decreased by 10 tokens for the next unit purchased. Production costs began at 30 tokens per unit and then increased by 10.

Each buyer in each session was allowed to purchase, one at a time, up to eight units in each trading period. Units were purchased in a specified order; with the first unit purchased in each period being the highest valued unit, the second unit purchased being the second
highest valued unit, and so on. Likewise, each seller in a trading cycle was allowed to sell, one at a time, up to eight units. Units were produced and sold in a specified order; with the first unit produced (sold) being the lowest cost unit, the second unit produced (sold) the second lowest cost unit, and so on. The individual demand schedule is given by 
\[ p = 135 - 10q_d \]
and the supply schedule has the form 
\[ p = 25 + 10q_s, \]
where \( q_d \) and \( q_s \) may be the split between the PTO and PTS markets in the linked design. Competitive price theory predicts an equilibrium price of 80 tokens and market sales of 20–24 units/period.

For a buyer, earnings on each unit purchased equaled the redemption value of the particular unit less the price paid to the seller. For a seller, earnings on each unit sold equaled the price received by the seller less the production cost of the particular unit. Earnings accumulated at the end of each trading period and over the sequence of trading cycles, were displayed to each participant on their computer screen. At the conclusion of each session, participants were paid the cash equivalent of these earnings. Each participant was given an initial token balance of 700 ($7.00). Although a nonsalient reward, PTS sellers could lose money on unsold units, or they could make unprofitable sales in order to avoid losing the entire sunk cost of unsold units; the beginning endowment was set large enough to make bankruptcy a remote possibility.

Bids and asks were submitted by typing into the computer the numerical value. A bid or ask price was displayed to the entire market on each individual’s computer screen, but the identity of the subject making the bid or ask was not revealed. Individuals could make a trade by using one of two methods. First, the buyer (seller) could submit a bid (ask) which equaled the currently displayed “best” ask (bid). The match was instantly made by the computer. Second, the individual could simply strike the “A” key on their keyboard, in which case a bid (ask) equaling the current best ask (bid) was automatically submitted. On the computer screen of the two individuals making the trade, the unit number and trade price were recorded. The best bid and ask displayed on everyone’s screen were cleared and individuals were allowed to renew bidding and asking.

3. Description of data

For purposes of describing and summarizing the data we combine observations from three PTS only sessions, the observations from three PTO only sessions, and then the data from four linked O/S sessions. Generally the data will be presented as three time series, but we will also examine separately the behavior in the PTO and PTS markets for the linked design.

Fig. 2 is an average of the prices at which trades are made. After period three the PTS only auction prices are higher than prices in either the PTO only or linked market institutions. It appears average prices in the PTO only and linked sessions are near the competitive equilibrium level, while prices seem to be higher in the PTS only sessions, on the order of 5–6 tokens higher than the other two market institution designs.

Fig. 3 isolates the average PTO price and the average PTS price from the linked market institution. The average PTS price for the first 7–8 periods is lower than average PTO price, but then both price series move toward an average of about 80 tokens. It must be the case that seller earnings are relatively smaller in the linked PTS market, because costs are higher
Fig. 2. Average trading price in PTS, PTO, and linked markets.

Fig. 3. Average trading price in PTS and PTO linked market.
on the marginal units sold. The pattern of PTO and PTS prices in the linked design contrasts with prices in the PTS only and PTO only designs. In the linked sessions it is PTS prices that are relatively low. Just the reverse was observed in comparing the PTS only and PTO only price series in Fig. 2; without the link, PTS average trade prices are relatively high.

Fig. 3 shows that over the trading cycles, adjustments are being made in the linked institution to move prices toward the predicted competitive equilibrium. The relatively higher prices in the PTO market at the beginning of the session suggest that more units should be offered in the PTO auction markets and/or buyers should make relatively more of their purchases in the PTS market. Fig. 4 shows that over time most of the trading activity moves toward the PTO auction. About half way through the linked sessions, PTS sales hold steady at about 10–15 percent of the total linked transactions. Our data show that the total number of linked transactions is near the competitive prediction, and are stable at about 21 units over the 15 trading cycles. PTO only auctions approach this level from below, and after period three the trading pattern becomes almost identical to the linked auction quantities. PTS only markets, in contrast, are always lower and seem to stabilize at an average of about 19 units.

Traders endogenously choose the PTO market as the primary institution through which to conduct business. As we suggested earlier, sellers have an incentive to operate in the PTO market to avoid inventory costs. This may not be obvious to laboratory sellers at the start of a session, because PTO prices in the linked O/S design are relatively high, but as subjects gain experience sellers move toward the PTO market. If buyers are certain of their

Fig. 4. Ratio of average quantity traded in linked PTS markets to total quantity traded.
redemption value, they are not necessarily indifferent about making purchases in a PTS or PTO setting. The PTS market presents buyers with an inelastic supply of the good, once production is decided in a trading cycle. These fixed quantities can be highly variable as Fig. 4 shows. As they fall, trading prices rise, and the PTS market becomes less attractive to buyers. Consequently, trading activity is led by the incentive of buyers and sellers to primarily operate in a PTO market.

Some interesting comparisons can be made by looking at the earnings of buyers and sellers in the three market environments. Fig. 5 shows that buyers do far better in the linked institutional structure than if there is only a PTS auction. Earnings for buyers in the linked markets are about 60 percent higher than those in the PTS only market. We note that buyer surplus levels begin at about the same level, but the trend upward in the linked design leaves little question about which trading environment buyers would prefer, as compared to the PTS only design.

Fig. 6 illustrates average total earnings for the sellers. Over time, these agents do best in the strictly PTS trading environment. After period four, PTS only sellers always earn more than sellers in a PTO only environment. The linked earnings begin relatively high, but trend down a bit and are exceeded by PTS only earnings midway through the session. Total surplus in the linked auctions is always very near 100 percent of that possible. It is a bit less, 98 percent or so for the PTO only sessions. The PTS only sessions begin at a relatively low surplus of about 65 percent and reach a maximum of about 95 percent.
4. Hypotheses and testing

Our control designs are PTO only and PTS only auction trading. We compare behavior in these markets with an institutional structure that places agents in a trading cycle that gives agents the choice of trading in either or both a PTO and PTS market. We can advance our general impressions by studying the convergence processes suggested by the trading activity of agents. We use a convergence model suggested by Ashenfelter et al. (1992) and Noussair et al. (1995) to estimate where prices, quantities traded, and earnings are moving to in the auction markets. These are the estimated stable outcomes in the markets. This model provides an appropriate means to adjust for the statistical problems, as well as the influence of individual agents on market outcomes.

4.1. Prices

We test for differences in average prices for the PTS and PTO market institutions, whether the markets be independent or linked. Let \( p_s \) be the average PTS only price in a 3 min trading period and \( p_o \) be the average PTO only price. Similarly we use the notation \( p_{sl} \) and \( p_{ol} \) for the linked PTS and PTO prices, respectively. We are interested in pairwise comparisons between these prices. Several null hypotheses are tested. Specifically we focus on: \( H_01: p_s = p_o \); \( H_02: p_{sl} = p_{ol} \); \( H_03: p_s = p_{sl} \); \( H_04: p_o = p_{ol} \) tested against the two-sided alternative that these prices are unequal. The data are organized as a cross-section time series. One set
includes the PTS only and PTO only prices, and the other is the linked O/S prices. Over the 15 or 16 periods in a session we have a different number of observations, where each observation is a trade at an agreed price. In the control sessions with only one auction market, there will be on the order of 15–22 trades made by different subject pairs during each trading period in the session. The linked design will have about this many trades spread over the PTO and PTS trading auctions. Individual subjects in the linked design are typically involved in several trades over a 3 min auction period and participate in both auction institutions. Some subjects are more active traders than others. The \( i \)th trade price in period \( t \) will be written as \( p_{it} \).

We see from the figures that there appear to be convergence patterns in average prices that will not be picked-up by a linear model. To estimate asymptotes from the data, for the two data sets, we use the model

\[
p_{it} = a_0 \left( \frac{t-1}{t} \right) + a_1 \left( \frac{1}{t} \right) + a_2 (\text{dinst}) \left( \frac{t-1}{t} \right) + a_3 (\text{dinst}) \frac{1}{t} + \epsilon_{it} \tag{1}
\]

where \( \text{dinst} \equiv \text{dummy variable for market institution that takes a value of 1 for a PTS market. Convergence in the PTO market is the } a_0 \text{ coefficient estimate. If the PTS market has a significantly different asymptote, then } a_2 \text{ should be significantly different from zero. The model is run using ordinary least squares. Heteroscedasticity is corrected for using White’s (1980) method and an AR(1) process is used for autocorrelation. We find that for the control data set with the PTS only and PTO only observations } \hat{a}_0 = 76.8950 \text{ and } \hat{a}_2 = 7.3277 \text{ with } t\text{-values of 169.314 and 11.344, respectively. Hence, convergence patterns in these markets are significantly different; PTS only prices are moving to a level that is about seven tokens greater than prices in the PTO only market. The first hypothesis, } H_{01}, \text{ is rejected.}

When the model is estimated for the linked auctions, we find \( \hat{a}_0 = 80.9040 \text{ and } \hat{a}_2 = -3.3742 \text{ with } t\text{-statistics that are 125.822 and } -2.131, \text{ respectively. Therefore prices are significantly different in these markets and the null hypothesis, } H_{02}, \text{ is rejected. PTO prices in the linked auction markets are converging to a point that is very close to the competitive prediction. Interestingly, PTS prices have a trend pattern that lies below the PTO price by about three tokens. The linked institutional market structure results in PTS price trends that are about seven tokens (8–10 percent) lower than when trades are made only in a PTS market. PTO prices are trending relatively higher in the linked design than when PTO only trades are made. We therefore observe a reversal of PTS and PTO price relations when the markets become linked through a single trading cycle.}

We test for differences in PTS prices and PTO prices across the market institutions with a simple \( t\)-test, using the standard errors of the estimates. \(^2\) In the PTO markets the hypothesis \( H_{04} : p_o = p_{1t} \) is rejected with a \( t\)-statistic of \(-7.8769\). In the PTS markets the hypothesis

\(^2\) The \( t\)-statistic is the ratio of the estimated coefficient differences to the square root of the sum of the reported standard errors squared. The PTO market coefficients are derived from a dummy coefficient in the above models. The reported standard errors for these dummies along with the PTO asymptote standard errors are used to construct the PTS price standard errors. The standard error of the PTS price estimate is \( \sigma_t = \sigma_o + \sigma_d - 2\sigma_o\sigma_d, \) where \( \sigma_d \) is the standard error of the PTS dummy coefficient in either the PTS only or linked markets.
Table 1
Variance of dummy coefficients in fixed effect regressions

<table>
<thead>
<tr>
<th></th>
<th>Variance of buyer dummies</th>
<th>Variance of seller dummies</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTS only (11 dummy coefficients)</td>
<td>7.94</td>
<td>11.11</td>
</tr>
<tr>
<td>PTO only (11 dummy coefficients)</td>
<td>8.94</td>
<td>4.54</td>
</tr>
<tr>
<td>PTS linked (15 dummy coefficients)</td>
<td>7.35</td>
<td>4.66</td>
</tr>
<tr>
<td>PTO linked (15 dummy coefficients)</td>
<td>7.96</td>
<td>6.03</td>
</tr>
</tbody>
</table>

$H_{01}: p_s = p_o$ is rejected with a $t$-statistic of 6.3413. These results come as no surprise since a summary of the data has shown a reversal in the relative levels of prices across the auction institutions.

A fixed effect bias can result from different beliefs and levels of trading activity by agents. To take account of this possible bias and gain further insight into the trading behavior of agents, the independent PTS and PTO markets are given a dummy variable for each buyer and seller in the six PTS only and PTO only auctions. Since there are four buyers in each of these markets, to avoid singularity, we have 11 buyer dummies, and 11 seller dummies. The same is done for the linked O/S markets. Here we have 15 buyer dummies and 15 seller dummies. All dummies are weighted by $(t - 1)/t$. We estimate two models, one that describes seller activity and the other taking account of buyer activity in the four institutional environments.

We use this model to focus on the variance of the estimated buyer and seller asymptotes as reported in Table 1. These dummy coefficients reveal the level of “disagreement” among agents in the markets. We measure disagreement by the variance in the dummy coefficients. In the PTS only market we observe that sellers have a larger variance in their asymptotes than buyers. In the linked markets sellers seem to be in more agreement about where the market is going than buyers. And for all trades, compared to the variances of asymptotes in Table 1, the linked sellers appear to be more stable in their convergence patterns than sellers in the independent markets. Overall the linked asymptote variances are lower than those in the independent markets.

4.2. Trades

We are interested in how the PTS or PTO market institutions affect the number of trades. We test the hypothesis that trade activity is the same against the alternative that it is not for the PTS only, PTO only, and linked auction markets, i.e. there is a set of pairwise hypotheses we test: $q_s = q_o$; $q_o = q_o$; $q_s = q_o$; $q_0 = q_o$. Tests are two-sided. If the number of trades is explained by the competitive model we expect the auctions to produce between 20 and 24 trades per period. Our results show that the average number of trades in the PTS only and PTO only markets start below the competitive prediction, but that quantities in both market institutions move toward the predicted level. The linked quantities are relatively stable at the competitive prediction.

We test for convergence, weighting with a time factor $(t - 1)/t$ or $1/t$ as before. We have 92 observations in the six experiments in the control sessions. For the number of trades or
Table 2
Estimates and t-statistics for the quality coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>PTO only/PTS only</th>
<th>Linked design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>t-statistic</td>
</tr>
<tr>
<td>$b_0$</td>
<td>22.5970</td>
<td>40.9900</td>
</tr>
<tr>
<td>$b_1$</td>
<td>15.0050</td>
<td>16.9540</td>
</tr>
<tr>
<td>$b_2$</td>
<td>-2.8038</td>
<td>-3.6760</td>
</tr>
<tr>
<td>$b_3$</td>
<td>0.1350</td>
<td>0.1060</td>
</tr>
</tbody>
</table>

$R^2 = 0.54711$  

Estimates are corrected for heteroscedasticity and an AR(1) process is used for autocorrelation.

Sales in a period $q_t$

$$q_t = b_0 \left[ \frac{t - 1}{t} \right] + b_1 \left( \frac{1}{t} \right) + b_2 (\text{dinst}) \left[ \frac{t - 1}{t} \right] + b_3 (\text{dinst}) \left( \frac{1}{t} \right) + \epsilon_t$$ (2)

Estimates are corrected for heteroscedasticity and autocorrelation as before. The coefficients show that the PTO only market converges to a competitive number of trades, 22.5970 (40.9900), and that the PTS only market converges to a significantly different amount at 19.7932 units per period. Specifically, the estimate on $b_2$ is $-2.8038 (-3.6760)$. Hence we reject the hypothesis that the number of trades is the same for the PTS only and PTO only market institutions.

The estimated model for the linked auction markets yields $b_0 = 19.1130 (50.2820)$ and $b_2 = -16.6620 (-29.8280)$. Total sales in the combined auctions are estimated as $19.1130 + 2.4510 = 21.5640$, which is well within the predicted competitive range. The trend however is toward very few PTS market sales; these trend estimates show that slightly more than 11 percent of the sales are made in the PTS market. Clearly, the hypothesis that linked PTO and PTS quantities are equal is rejected. The estimates for all quality coefficients are shown in Table 2.

PTS sales across the different institutions are dramatically different. In the linked design PTS sales average only about 2.5 units. Agents seem to view the PTS alternative as a residual market, while the bulk of the trading action goes on in the PTO linked market. The hypothesis that PTS only and PTS linked quantities are equal is rejected with a $t$-statistic of 38.6102. The PTO quantities are similar across designs, but standard errors are small. PTO linked quantities are smaller because traders have the option of spreading their activity into the PTS market. The hypothesis that PTO only and PTO linked quantities are equal is rejected ($t = 7.6176$).

4.3. Buyer and seller earnings

Sellers fare best in a PTS only market and earn the least in a PTO only market. The linked design offers a middle ground for seller earnings. Earnings rise in the linked institution, relative to the PTO only, because sellers can participate in a PTS market with advance production. Over time the PTS market in the linked setting becomes relatively thin, and as a consequence shows a slow downward trend in seller earnings. Using the model in Eq. (2) the PTO only earnings asymptote for seller is estimated at 135.4900 (31.5430) and the PTS
only earnings asymptote has an added 25.0700 (4.1870) tokens. Seller earnings are therefore estimated at 160.5600 tokens in the PTS only market. In the linked markets the estimated seller earnings are 150.0100 (33.7440). Differences are significant at the 0.01 level.

Buyer earnings are greatest in the PTO only market, and least in a PTS only auction design. Linked earnings lie between the PTS only and PTO only earning levels. The estimated buyer earning asymptotes are 166.2900 (60.8100) in the PTO only auctions; this falls by −41.3340 (−10.8550) in the PTS only market, and the asymptote is 146.4800 (38.8970) in the linked markets. All pairwise differences are significant. Interestingly, the efficiency of trading, i.e. total earnings, is greatest in the PTO only design. Total earnings in the PTO only markets are 301.7800, they are 285.5160 in the PTS only market, and are 296.4900 in the linked auctions. The presence of the PTS only market, while transferring earnings from the buyer to the seller, decreases total earnings for all agents.

5. Concluding discussion

In this study we investigate buyer and seller behavior in PTS and PTO markets when they are linked and the choice to participation in these markets is endogenous. Prices, quantities traded, and earnings generated by agents participating in laboratory double auctions in this linked market institution are compared with those from PTO only and PTS only markets. Results provide the basis for partially understanding the motivation for, and impacts of, transitions which are occurring in some real-world markets. For example, a defining feature of the recent transition in the US food market is a shift from PTS only markets to more direct market channels such as PTO contracts and long-term marketing agreements (Drabenstott, 1994). Buyers favor a PTO option; large buyers as food processors have been successfully moving sellers into more PTO agreements and fewer PTS sales. These changes are also occurring in the sale of natural gas (Tussing and Tippee, 1995) and electricity.

Laboratory results suggest the linked market institution is relatively stable about moving prices and quantities toward the predicted competitive equilibrium. The PTS only market generates higher than predicted prices and lower quantities. Buyer earnings are greatest in the PTO only market, and least in a PTS only institution, whereas the opposite is observed for seller earnings. Earnings for both buyers and sellers in the linked market lie between the PTS only and PTO only designs. The inventory cost in PTS only markets provides an impetus for sellers to seek higher prices, as compared to the PTO only market. This inventory cost, in the PTS market of the linked market setting, does not appear to be as important as in the PTS only market. The risk of loss associated with advance production in the linked case, of course, can be abated by transacting in the PTO market. We observe, in fact, that about 85 percent of the trades occur in the PTO market when the choice of market is endogenous. The PTS market becomes thin in the linked institution.

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