WORKING PAPERS

EQUILIBRIA IN THE LABORATORY:

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EQUILIBRIA IN THE LABORATORY: EXPERIMENTS WITH OLIGOPOLY MARKETS WHERE GOODS ARE MADE-To-ORDER*

by

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November 1984

ABSTRACT

This paper is primarily concerned with examining one common practice used in previous studies of laboratory markets. This practice is to test equilibrium models using a data set that includes data from markets that may not have reached an equili-brium. The laboratory markets examined here demonstrate that equilibrium data may be quite different from that data achieved after approximately the number of time periods used in previous studies. For these markets, tests of equilibrium models using equili~rium data would yield quite different results than using the data from the truncated sequence that includes some disequil-ibrium behavior.

1. Introduction

This paper is primarily concerned with examining one common practice used in previous studies of laboratory markets. This practice is to test equilibrium models using a data set that includes data

Fouraker and Siegel [FS]. All of these laboratory markets were oligopoly markets for a homogeneous product where sellers post prices and goods are made-to-order. The primary comparison for this paper only uses the data from my laboratory markets and is between equilibrium behavior and the behavior observed after approximately the same number of market periods used in these two previous studies.
The data from the markets reported on here suggest that using all data available after approximately the same number of market periods as in KSW and FS would lead to significantly different equilibrium test results than restricting tests to equilibrium data. If the sequences of data generated here are truncated to approximately the same number of market periods used in these two studies, significantly different behavior is observed than in

2. Experimental Design and Procedures

The experimental markets reported on here consisted of a sequence of trading periods with identical market structures. The desired characteristics for each subject were induced by the profit structure of these markets, and these profits were paid to the subjects in cash (see Smith, 1976). Each period started with each seller choosing a price to charge for his good and the maximum quantity he was willing to offer to the market. Before these decisions had to be made, each seller had access to his personal cost information and the past history of the market, which consisted of the decisions made by all sellers, the quanti-ties ul timately sold by all sellers, and his own prof it for all previous periods. After the price and quantity choices were made behds.

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behavior. SUbjects sat in front of individual terminals, and all interactions during the experiments were limited to those with the terminal. There was no direct communication between any of the subjects. The subjects themselves were University of Arizona students.
As a primary interest for this research would be with equil-ibrium data, two alternative rules for terminating each experi-mental market immediately suggested themselves. One was to run each market a fixed number of time periods or until a fixed real time limit was met, and later screen out the data from those markets that did not satisfy the operational definition of an equilibrium. Another was to terminate the operation of any market as soon as it satisfied the definition, and assume that

The use of this stopping rule means some of the experimental markets could continue, as some did, for very many periods. These rules, with the large number of time periods possible when using them, could not have been used in the designs chosen by KSW and FS, primarily because of the real time constraint for running one session comfortably. They could not significantly increase the number of time periods run within three hours.
Allowing for a large number of time periods meant that either the length of the sessions had to increase or the real time needed for each market period had to decrease. The former is difficult since fewer students are willing to participate beyond three hour intervals, and running a market across several days is usually not desirable as any communication among subjects within this break in the session is uncontrolled. Here, the time needed for each market period was shortened substantially by simulating the behavior of the buyers, so that in effect the buyers' choices were made instantaneously. Here the buyers were assumed to be acting as perfect competi tors. The cost of using this procedure is the possibility that actual buyers may not behave in the way that has been assumed and the sellers may react differently because of it. Fortunately, this cost now seems acceptable as data from previous experimental markets suggest that in this market environment the buyers do act competitively,

even with a relatively small number of them.4
Figure I illustrates the screen display that was seen by a seller in these markets. The decision box at the top indicates the decisions that had to be entered for each time period. Each seller had to enter the price he was to charge, the quanti ty he

6

DECISIONS FOR FIRM 1 IN PERIOD 163

price =) quantity offered •
quantity you expect to 3elI -

Market History

period firm price qty offered qty 301d profit

162 1 $ 1. 24- 12 3 $ ~.72
2 1. 24- 12 3
161 1 $ 1.24- 12 3 $ B.72
2 1.24- 12 3
16.0' 1 $ 1.24- 12 3 $ 16.72
2 1.24 12 3
159 1 $ t.24- 12 3 $ B.72
2 1.24 12 3
158 1 $ 1.24- 12 3 $ 16.72
2 1. 24- 12 3

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Q)

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0... 2. 1.24- 12 3
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Q) 155 1 $ 1.24 12 3 $ B.72

.- 2 1.24- 12 3 -L

n::1
Q)

production cost graphed history

Figure I: Sample Screen Display for a Market Period

would offer to the market, and the quanti ty he expected to sell given the previous choices. The remainder of the display indi-cated the information available to the seller before these decisions had to be made. This consisted of cost information and information on the market history. cost information could have been obtained directly by touching the cost box (PLATO has touch sensitive screens), which resulted in going to another display that gave a graph of the cost function and allowed queries about cost for specific quantities. cost information could also have been obtained indirectly as the expected profi t was calculated and shown to the seller once the expected quantity sold was entered. New choi ces caul d have been entered at any time prior to conf

2slrs;mto;d;.0'1 15 COple5

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Summary of Market Parameters

1. 2 sellers
2 •. dynamic environment--1 period information lag
3. goods made-to-order
4. high-to-low rationing rule

ff.ffff
ff • .0' 5 . .0' 1.0' . .0' 15 . .0' 2.0' . .0' 25 . .0' units

5~ Supply & 6. Demand
(Press DATA for more on costs & demand.)
7. parameter shift of $ .0' • .0'.0'
8. entry bonus of $ .0' • .0'.0'

II 2sl rs; mto; d; .0'1 It al

market demand curve intersects (O uni ts, $1.48) and (12 uni ts~ $1.00). The amount demanded from an individual firm was calcu-lated in the following way: if the firm was offering the lowest price, he faced the entire market demand, if both firms were offering the same price, then market demand was split in the same proportions as the amounts offered for sale, if the firm was offering a price higher than his rival, then he received any unsatisfied demand assuming buyers with higher reservation prices purchased first. The quantity actually produced and sold by any firm (i.e. the amount that determined the total cost) was either the quantity demanded from the firm or the quantity offered, whichever was smaller.5

3. Experimental Resul ts

Compared to the resul ts of KSW and FS, one notable pattern emerges from the data. For some markets

of these jumps to a higher price level. Thus, for markets that follow this pattern we observe some behavior prior to an equili-brium that is drastically different from that observed in equili-brium. This pattern is illustrated by the price histories in Figure 3 for copy 1 of the market, where in 3(a) prices which

accompanied a posi tive quanti ty being sol d are graphed, ·0· for
firm 1 and ·x· for firm 2, while in 3(b) all price offers are graphed. (A higher price usually meant no sales.) The data in KSW and FS looks like the ini tial period of this pattern, where the market price falls rather gradually to near the competitive level.
The equilibrium data here appear to be quite different from
the data in KSW and FS. The outcomes here are concentrated around the monopolistic outcome while those in the previous two studies are concentrated around the Nash equilibrium outcome. One possible explanation to reconcile these seemingly large dif-ferences is suggested by the price pattern noted above. If the markets in the previous studies were terminated in some period prior to an equilibrium and the pattern above was followed, prices might be observed that are much lower than prices that would eventually be obtained if the markets were allowed to continue to an equilibrium.
To test this hypothesis we need to consider the outcomes that would be observed if the markets here were truncated to approximately the same number of time periods as in these two previous studies, and then compare this data to the equilibrium data. The markets in KSW with the most similar design are those in their Design II, and these had a last time period that

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$ Price History of Goods Sold

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time periods

$ History of All Price Offers
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between 15, 20, and 25 time periods. The markets in FS with the most similar design are their duopoly and triopoly experiments with incomplete information, and the last period for each

cogy equilibrium outcome periods outcome after

FS implicitly gave each seller information that fully described market demand, while KSW and I gave the sellers no market demand information. FS ran all experiments orally and kept records of transactions by hand, while for KSW and I all experiments were computerized. Instructions were presented differently in each set of experiments. Thus, because of these design differences, many possible explanations will remain as possible causes of any observed differences in behavior.
All of the hypotheses to be tested are conce rned with whe-ther the data from some pair of samples could have come from the same underlying probability distribution. As these outcomes typically lie along the market demand curve, we will only con-sider a one-dimensional description of each outcome -- the price (or an average if there is more than one) associated with some positive level of sales. For these tests we will use a one-tailed Kolmogorov-Smirnov test, a standard non-parametric test of this type of hypothesis. The major advantage of using a non-parametric test such as this is that the statistical assumptions made in any null hypothesis are very weak. with this test the only statistical assumption is one of continuous distribution functions.
The first hypothesis to be tested concerns whether the pattern noted previously appears to be important for these mar-kets. The null hypothesis is that the data from the truncated sequences come from the same probability distribution as the equilibrium data. Using a one-tailed Kolmogorov-Smirnov test, we can reject this hypothesis at a 2% significance level.S For the markets here, this suggests that equilibrium prices are signifi-

11

cantly greater than the prices in the initial period. The only difference between these markets is the number of time periods, so this is presumably the cause of this result.
The next hypotheses to be tested concern the comparisons with the data from KSW and FS. The null hypotheses for these tests must be joint hypotheses that include an assumption that the normalization process is appropriate. The first of these has the null hypothesis that the KSW data and the equilibrium data here come from the same probability distribution (plus the proba-bility distributions are continuous and the normalization is appropriate). Using the one-tailed test, this hypothesis can be rejected at a 0.1% significance level. This test rejects this same hypothesis for the FS duopoly markets at a 0.5% significance level and for the FS triopoly markets at a 0.05% level. These results indicate that the equilibrium prices observed in the markets here are significantly higher than those prices observed in the previous two studies. The data from these previous studies cannot provide an estimate of an equilibrium that is consistent with the equilibrium data here (this may be different from the equilibrium data that would be generated in their markets) •
The second of these comparisons with the previous studies' data has the null hypothesis that the their data and the data from the truncated sequences come from the same probability distribution. The hypothesis for KSW cannot be rej ected at any standard significance levels (>10%), but the hypothesis for the FS duopoly can be rejected at a 3.6% level and for the FS tri-

12

opoly at a 0.1% level. The cause of these results is presumably some of the design differences between the different sets of laboratory markets other than the difference in the number of time periods. While the evidence does not yet make a clear case, the number of sellers is certainly suspected as being one of the contributory causes.
To many researchers conducting

al ternated (in this case every eight periods) choosing (1.20,12) and (1.20,5)

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Th~ data for the experimental markets reported on here demonstrate that restricting tests only to data from markets in equilibrium can affect the results of some tests of equilibrium models. Because of this, for all experimental studies it seems desirable to limit tests of equilibrium models to data from markets in equilibrium, or to run a few markets for a relatively large number of time periods to demonstrate that the estimates of equilibria from the short experiments are similar to the equili-bria actually achieved in the long ones. Such procedures offer an extra measure of control over the data that is to be tested against any equilibrium predictions.
For oligopoly markets where sellers post prices and goods
are made-to-order, this data suggests that ·collusive· behavior may be more likely in equilibrium than previous experimental tests have indicated. It

demand information is varied? Because of the seemingly long time needed for collusive behavior to emerge, will relatively

Footnotes

*. The views expressed here are not to be considered those
of the Commission or of any individual Commissioner. I wish to thank the Bureau of Economics for its support of this experiment-al work1 Vernon

strategies are not fully revealed, such as with mixed strategies or actions that depend upon some previous actions. Using rolling averages of profits over, say, ten periods might be an improve-ment with cyclic patterns and mixed strategies, but for these markets, this was not necessary as their was no indication that mixed strategies were used and those markets that were not termi-nated when this measure was exactly zero for several periods developed an obvious cyclic pattern. I am not sure what criter-ion would be most useful for strategies where actions depend upon the previous history of the market.
4. See the data for the markets considered in Ketcham-Smith-williams (1984) and Isaac-Ramey-Williams (1984). This data was not available when the designs of these previous studies were established, so that simulating buyer behavior would have had a higher cost for these earlier studies than here. These markets, of course, ran for many fewer periods than the laboratory markets here, but the buyers' behavior is likely to satisfy reasonable equilibrium criterion (see fn. 3 as the buyers' actions depend upon the sellers' previous actions), so that their behavior might be expected to continue indefinitely.
5. The program allows quite a variety of oligopoly markets
to be run. There may be: from one to sixteen firms, a dynamic form or a static form of the market, a specified time lag before a firm learns of his rivals' choices, one of several posted-price institutions, one of several rationing rules, any market demand or cost functions, a specified shift of cost and demand curves to disguise them, and a specified lump-sum payment for entering the market.

18

6. All data is available from the author.
7. Prices are normalized so that the monopoly and competi-tive prices of all sets of experiments match. Each price datum in KSW is normalized to give a price equal to .65 times the KSW price plus 1.00. Each price datum in FS is normalized to give a price equal to .08 times the FS price plus .96.
8. It might be that those outcomes with low prices in period 15 also have low prices in equilibrium. These markets may typically require more time to reach equilibrium and be more likely to have frustrated subjects wanting to leave the experi-mental market. If so copies 3, 6, and 14 would be providing a bias to the observed distribution of the truncated series rela-tive to the equilibrium distribution, where they were not in-cluded. If this data is discarded, the null hypothesis is re-jected at a 5.5% significance level.
9. This is similar to the two-arm bandit problem considered
in Rothschild (1974).

19

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