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PRODUCT QUALITY SIGNALING IN EXPERIMENTAL MARKETS

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In a series of eleven markets, sellers possessed products that were exogenously designated as either grade "regular" or grade "super." Supers were valued more by buyers but grade could not be observed by buyers prior to purchase. Sellers could add costly units of quality to their products that were observable and valued by buyers. The data are analyzed with perfect information models, signaling equilibrium models, and pooling models. A variety of behaviors are observed across the eleven markets. Signaling is observed in most markets with some markets approaching the most efficient signaling equilibrium. Pooling or partial pooling occurs in a few markets. The performance seems to be sensitive to the relative cost of signaling and the market institutional setting.

1. INTRODUCTION

A continuing area of research in economic theory is the role markets can play in transferring information from one agent to another. In the experimental markets studied in this paper, each seller is the only one who knows all of the relevant characteristics of each of the units of a commodity in his/her possession. If the information known to sellers was also known to buyers, it would affect the value buyers placed on the units. Consequently, sellers have an interest in affecting what buyers know. The work by Akerlof [**1**] suggests that price alone cannot be expected to convey accurately all information from sellers to buyers while also serving a market clearing function. Signaling theory as introduced by Spence [**6**] and Stiglitz [**7**] suggests circumstances in which market processes would allow buyers to extract the sellers' information even though sellers might want to mislead buyers. The experimental markets studied here were designed to explore this latter possibility.

Theoretical discussions of signaling are focused on several issues. Equilibria may not be unique. With the Spence [**6**] formulation, for example, a continuum of equilibria may exist. On the other hand, nonexistence is also a problem (Rothschild and Stiglitz [**5**]), and the discussion of these issues is generally sensitive to the number of agents (Riley [**3**]) and the definitions of equilibrium (Wilson [**8**]; Riley [**4**]). Notions of reputation, gaming, and other aspects of belief structures are also important. Motivated by this literature, our research strategy was first to design markets in which several competing models can be legitimately applied and then to evaluate the models in light of the results.

In addition to questions regarding the relative accuracy of models, several questions of a qualitative nature are posed as implicit features of the overall experimental design. Participants in these markets knew much less than is frequently assumed as part of standard models. Each individual knew only his/her own parameters. The costs of signals to sellers and the value of signals to buyers,

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for example, were not public information. No participant was aware of any of the theory of signaling. Under such circumstances will individuals become aware of the value of the potentials of signals? If each quality level of a product can command a different price, the number of markets must equal the number of levels of signals. If so many markets are open, will the standard demand and supply ideas work? How are multiple markets to be organized? The theory does not provide an operational way of determining the informational content of potential signals, so part of the paper reports on attempts to give the concept of a signal a satisfactory context.

Sellers in these markets possessed commodities that were exogenously designated as either of grade "regular" or grade "super." The latter was valued more by the buyers but grade could not be observed by buyers prior to purchase. Sellers could add units of quality, which were valued by buyers and could be observed prior to purchase. The cost of adding quality to supers was lower than the cost of adding quality to regulars. Given these conditions the possibility of signaling existed. A detailed discussion of the nature of the markets including parameters and experimental procedures is in the next section.

The third section of the paper introduces five competing models. The results are in the fourth section. Four questions are asked of the data in sequence. Does separation occur in the sense that the two grades can be identified statistically by the quality added by the seller? All signaling models predict an affirmative answer whereas certain pooling models predict a negative answer. Is separation, if it exists, due to signaling? The classical Walrasian model, for example, predicts separation but not because of signaling. Do the markets tend to equilibrate? If equilibrium signals are observed, which signaling equilibrium is the most appropriate? Both price data and profit data are used to explore these questions.

Our answers to the above questions, which are detailed in the text, seem to depend upon variables that are not adequately addressed in the theory. A potentially important variable is the magnitude of difference in signaling costs. In markets in which a "substantial" difference exists between the signaling costs of the two basic grades, the system seems to move to near the most efficient signaling equilibrium. If the cost of signals is "too close," pooling seems to occur. We suspect that experience and an awareness of the potential information content of signals are important for signaling and the development of signaling equilibria. A dynamic element not suggested by existing models is detectable. These issues are all outlined in the fourth section.

2. LABORATORY MARKETS

Subjects were undergraduate students from Boston University, California Institute of Technology, and Pasadena City College. In addition, three markets involved high school students attending a Caltech summer science program. The subject pools for each of the eleven experiments are in Table I. A pilot experiment was also conducted but the results are not reported here.

Subjects were recruited from classes and from dorms. They were told they would have an opportunity to earn money. Once subjects were seated in a

TABLE I

EXPERIMENTAL PARAMETERS

		Buyers				Sellers						
				Base Redemption Value			Marginal Quality Cost					
Experiment Index	Subject Pool[a]	Number	1st Unit Bonus	Regular	Super	Number	Regular	Super	Units	Dollars per Franc	Experience[b]	Chalkboard Colors Used
2	CIT	4	1.00	.50	2.50	6	.15	.02	2	1	general market[c]	no
3	PCC	6	2.00	.50	2.50	6	.15	.02	2	1	none	no
4	CIT	4	1.75	.50	2.50	6	.15	.07	2	1	general market	no
5	CIT (HS)	6	.60	.50	2.50	6	.15	.07	2	.40	no	no
6	CIT (HS)	6	1.00	.50	2.50	6	.15	.02	2	.50	no	no
7	CIT (HS)	5	1.50	2.00	4.00	6	.15	.02	2	.25	yes from 5 & 6	period 11 thru period 18
8	BU	5	1.00	.50	2.50	6	.15	.02	2	.50	none	yes
9	BU	2	1.50	2.00	4.00	6	.15	.02	2	.25	none	yes
10	BU	4	1.25	1.00	3.00	4	.15	.02	2	.40	yes from 8 & 9	yes
11	CIT	6	1.50	2.00	4.00	6	.15	.02	2	.40	general market	yes
12	CIT	6	.60	.50	2.50	6	.15	.07	2	.40	yes from 11	yes

[a] *Key:* CIT—California Institute of Technology; PCC—Pasadena City College; BU—Boston University; HS—High School students.
[b] Experience: when people were used in more than one experiment they remained in the same position as a buyer or seller.
[c] General market: experienced from other experimental markets but not this series.

classroom with two large chalkboards, the instructions were distributed and read (see Appendix). A period zero was conducted without payment in order to check the subjects' understanding of the trading rules and accounting. The experiments typically lasted three hours after which subjects were paid. The procedure differed in experiments 11 and 12, in which the same subjects were used and paid for both sessions after the second.

The experience of the subjects differed among the experiments. Caltech undergraduates had experience in laboratory markets but not this particular series, unless otherwise indicated below. All other subjects had no experience at all in laboratory markets aside from this series. In several experiments the subjects had participated in earlier experiments in this series. The object, of course, was to study markets in which participants were already familiar with the market technology, accounting, etc. and could concentrate on the market itself. When subjects were used the second time, they were always assigned the same role, as a buyer or as a seller, that they had previously experienced. In all such experiments the parameters were changed as, contained in Table I.

Preferences were induced in the following manner. Buyer i received a redemption value $V_i(g, q)$ for each unit purchased, which depended upon the grade, g, and the quality, q, of the unit. All buyers had identical redemption value functions but this fact was not public information. The general function was as follows, but subjects saw the discrete approximations in the Appendix which were used to reduce instruction difficulties. Since all buyers had the same redemption schedules the individual subscript is dropped.

$g \in \{R, S\} \equiv \{\text{regular, super}\}$ is an index of the grade of the unit;

$q \in [0, \infty)$ is an index of the units of quality added by the seller;

$$V(g, q) = G(g) + Q(q);$$

$$G(g) = \begin{cases} \$2.50 \text{ if } g = S, \\ \$.50 \text{ if } g = R; \end{cases}$$

$$Q(q) = \begin{cases} \$.205q - \$.005q^2 \quad \text{if } q \leq 20, \\ \$[(.205)(20) - (.005)(20^2)] + \$.01q \quad \text{if } q > 20. \end{cases}$$

$V(g, q)$ is the redemption value of each unit purchased. In addition, the buyer received a bonus (the amounts are in Table I) if at least one unit was purchased.[2] So, except for the first unit, each individual had a horizontal demand function at $V(g, q)$ at all grades and qualities. Of course the buyer observes q but not g at the time of purchase.

The markets proceeded in a sequence of periods. Each period each seller had exactly two units to sell so the total supply was fixed. The basic grades of the units held by an individual seller during a period were the same. Both were

[2] This provided some consumer's surplus and therefore some income for buyers should a competitive equilibrium be attained. In retrospect we think a flat payment per period might have been a better procedure.

regulars or both were supers. For each period the designation of sellers as holding regulars or supers was made randomly subject to the constraint that half of the sellers had supers and half had regulars. While the designation of sellers as supers or regulars was made prior to the experiment, an individual seller did not know his/her designation until just before the period began.[3]

Sellers could add quality, q, to a unit at a cost which depended upon the grade of the unit. In all experiments the marginal cost of adding quality to regulars was constant at \$.15. The marginal cost of adding quality to supers was always lower, at \$.07, in experiments 4, 5, and 12 and \$.02 in all other experiments. Quality could be added "to order" so the seller had no investment decisions. It was as if units were sold to contract and quality was added according to contract specifications after the sale.

Figure 1 is a graph of the unit demand and cost value functions. As can be seen, the value between supers and regulars is a constant \$2.00 for every level of quality. The total cost of a unit expressed as a function of quality is also graphed. Regulars always have a higher marginal cost than supers. The marginal cost of supers is the only financial parameter which varies across experiments.

As can be seen in Table I, the unit of currency was an experimental medium called francs. The dollar value of francs varied across experiments. The experiment and individual incentives were explained to the subjects in terms of francs. The use of francs was incorporated to avoid a possible parameter bias when subjects were used in more than one experiment. For purposes of exposition, however, the discussion and analysis in the paper is in terms of dollars.

The markets consisted of a series of days or trading periods. Each period was identical except the sellers who held supers were different as described above. Bids to buy were tendered by a buyer who would orally indicate his/her letter first, then the quality and then the value of the bid. For example, "*H* bids a 50 at \$6.00."[4] This bid was written on the chalkboard, which had a horizontal quality scale line on it, below the line at the quality 50. The bid was repeated by the auctioneer, after which the floor was open for additional bids and offers. This bid remained until it was accepted or canceled. Offers to sell were announced verbally: "*Q* offers a 75 at \$6.75." These were entered above the line at the proper quality and remained until accepted or canceled. Buyers and sellers could have many bids and offers outstanding, but sellers were required to cancel offers when they had no more units, since bids and offers were commitments to buy or sell. Acceptances could be made at any time and were finalized by the auctioneer, who entered the accepting party's number by the bid or offer and circled it as seen in Figure 2.

[3] The incentive and record charts were stapled together so the chart for period n was not exposed until the chart for $n-1$ was removed.

[4] This sequence has certain logistical advantages. The buyer number first indicates who has the floor should the auctioneer need to call on someone in a tie. The word "bid" alerts the proper side of the market. The quality helps position the auctioneer at the proper location to write the price when (s)he hears it. The auctioneer verbally repeats the tender after it is written and then the floor is open for more bids and offers. This latter feature slows down the process and eliminates congestion and confusion.

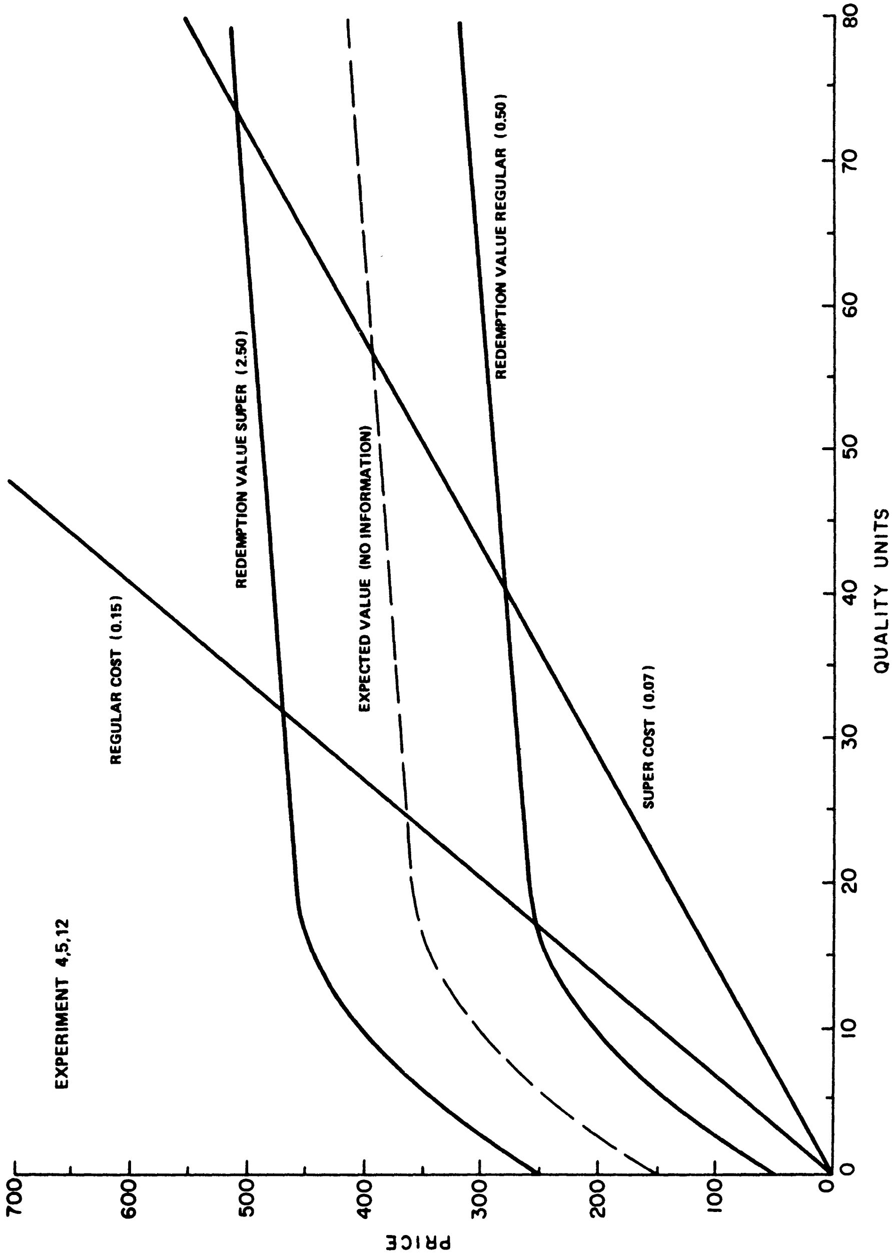
EXPERIMENT 4,5,12
REGULAR COST (0.15)
REDEMPTION VALUE SUPER (2.50)
EXPECTED VALUE (NO INFORMATION)
REDEMPTION VALUE REGULAR (0.50)
SUPER COST (0.07)
PRICE
0
100
200
300
400
500
600
700
QUALITY UNITS
0
10
20
30
40
50
60
70
80

FIGURE 1.

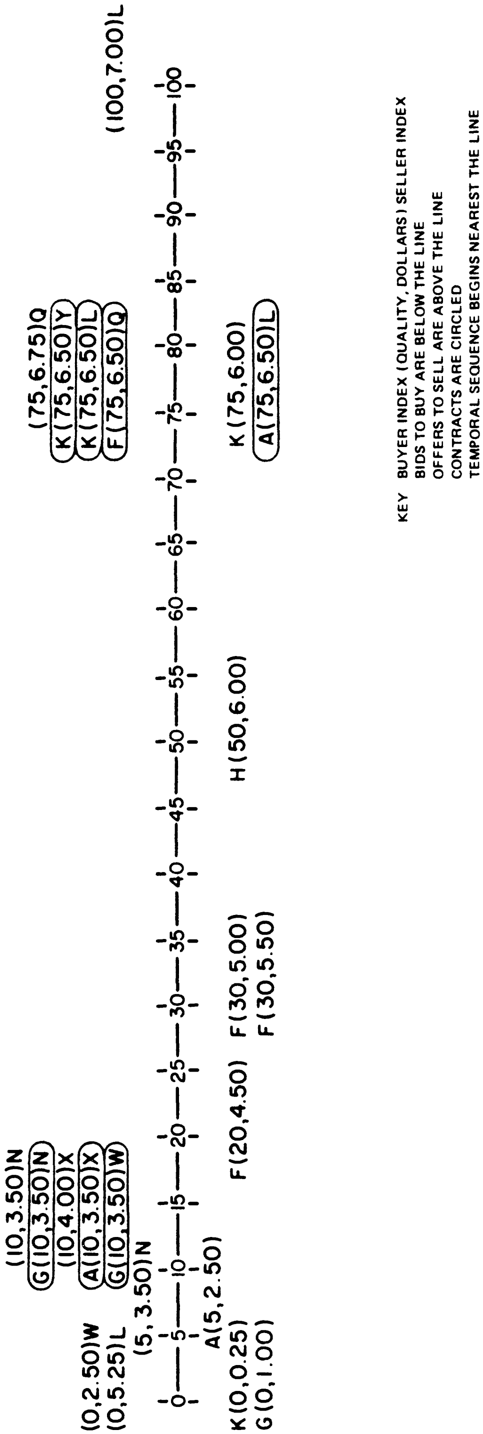

FIGURE 2—Quality line in markets.

As contracts were made they were entered in sequence on a second chalkboard in the vector form (Buyer, Quality, Price, Seller). After the period was over the experimenter announced which sellers were selling regulars and supers so buyers could calculate their profits. This information was carried on the second chalkboard for as many periods back as possible. Thus subjects always had access to the relationship between qualities, prices, and grade from several previous periods.

In addition, starting with period 11 of experiment 7, colored chalk was used to indicate which contracts were for regulars and which were for supers. At the end of a period, as units were indexed as being regulars and supers on the second chalkboard, the auctioneer circled the regulars with green chalk and the supers with red chalk on the primary chalkboard, which contained all bids, offers and contracts. Thus when the markets were separated the left hand side of the chalkboard, with low qualities, had green circled contracts and the right had red. As will be discussed in the final section, this feature was added after it appeared that many agents were unaware of the relationship between basic grade and quality even though it was obvious if the question were asked of the data they had. Many simply never asked the question or were too busy with other aspects of the market to look.

3. MODELS

Five models are to be examined. These will be discussed briefly. The prediction of each model, which may not be unique because of the integer nature of the payoff schedules, is listed in Table II. Several models examined here predict that all regulars will sell at the same price, P_R, and that all supers will sell at the same price, P_S. Furthermore, all models predict that the quality of regulars will be the same at q_R and that the quality of all supers will be the same at q_S. Of course these hypotheses themselves are subject to examination but they will simply be assumed in the discussions below.

A. *The Full Information Model*

Markets will behave as if buyers are fully informed about which sellers have regulars and which have supers. The model can rest on axioms which have sellers wanting a "reputation of honesty" perhaps because the repeated game nature of the market makes such reputations valuable; or because special signals develop in the complicated bidding market which convey this information; or because sellers have a preference for "honesty." The law of supply and demand can be applied directly[5] to obtain the following formal statements:

(1) $V(R, q_R) = P_R;$

(2) $V(S, q_S) = P_S;$

[5] Experiments have not yet been conducted to check the accuracy of this model when the grades of the commodities are known before purchase.

TABLE II

MODEL PREDICTIONS

	Experiment[a]							
	Low Cost No. 2, 3, 6, 8				High Cost No. 4, 5, 12			
	Quality		Price (dollars)		Quality		Price (dollars)	
	R[b]	S[b]	R	S	R	S	R	S
Full Information	[5, 6]	[18, 19]	[1.40–1.55]	[4.57–4.59]	[5, 6]	[13, 14]	[1.40–1.55]	[4.32–4.39]
Naive	[5, 6]	[18, 19]	[2.40–2.55]	[3.57–3.59]	[5, 6]	[13, 14]	[2.40–2.55]	[3.32–3.39]
Polling (Most Efficient)	12		3.24		10		3.05	
Most Efficient Signaling and Rothschild-Stiglitz	[5, 6]	27	[1.40–1.55]	4.67	[5, 6]	27	[1.40–1.55]	4.67
Inefficient Signaling	[5, 6]	$310 \geqq q$ $q > 27$	[1.40–1.55]	$4.67 + .01\,(Q - 27)$	[5, 6]	$55 > q$ $q > 27$	[1.40–1.55]	$4.67 + .01\,(Q - 27)$

[a] For experiments 7, 9, and 11, add \$1.50 to all low-cost dollar numbers. For experiment 10, add \$.50 to all low-cost dollar numbers. Quality predictions remain unchanged.

[b] R—Regular; S—Super.

(3) $$\frac{\partial V(R, q_R)}{\partial q} = \frac{\partial C(R, q_R)}{\partial q};$$

(4) $$\frac{\partial V(S, q_S)}{\partial q} = \frac{\partial C(S, q_S)}{\partial q}.$$

The first two simply say that price of the fixed supply is determined by the (horizontal) demand function. Equations (3) and (4) say that the value of additional quality is equal to the marginal cost of supply. Solutions to these equations for the parameters of this experiment are in Table II.

B. *The Naive Model*

Buyers may never notice that quality carries information about the underlying grade of the unit. Thus, they would treat the purchase as a lottery between the value of a regular and the value of a super at a given level of quality. The system of equations would be (5) and (6) below plus (3) and (4) above. The subjective probabilities are determined by rational expectations.

(5) $$\Pr(R)\,V(R, q_R) + \Pr(S)\,V(S, q_R) = P_R;$$

(6) $$\Pr(R)\,V(R, Q_S) + \Pr(S)\,V(S, q_S) = P_S.$$

Rational Expectations: $\Pr(R) = \Pr(S) = \frac{1}{2}$.

These simply say that price is determined by expected value. For the parameters of the experiment the predictions are in Table II.

C. *The Pure Pooling Models*

Pooling is a situation in which buyers cannot distinguish regulars from supers because the qualities are identical and from this it follows that prices are identical and buyers treat the purchase as a lottery. Sellers on the other hand believe that buyers will accept nothing other than the going quality. Thus equality of quality over all units as indicated in equation (7) and equality of price over all sales, as can be deduced from (7) and (9) or (7) and (10), define a pooling equilibrium at a price level indicated by (8).

(7) $$q_R = q_S = q;$$

(8) $$\Pr(R)\,V(R, q) + \Pr(S)\,V(S, q) = P;$$

(9) $$P_R - C(R, q_R) = P_S - C(R, q_S);$$

(10) $$P_S - C(S, q_S) = P_R - C(S, q_R).$$

Rational Expectations: $\Pr(R) = \Pr(S) = \frac{1}{2}$.

A glance at the model indicates that while the equations dictate relationships among observables, a unique price and quality is not determined. Many pure pooling equilibria exist. The most efficient pure pooling equilibrium is that which maximizes consumer plus producer surplus subject to the above equilibrium conditions. This particular equilibrium is obtained by the addition of one more equation:

$$\frac{\partial V(R, q)}{\partial q}+\frac{\partial V(S, q)}{\partial q}=\frac{\partial C(R, q)}{\partial q}+\frac{\partial C(S, q)}{\partial q}.$$

The solutions for the experimental parameters are in Table II.

D. *The Partial Pooling Model*

Partial pooling relaxes the requirement that all units trade at a single quality to include the possibility that units trade at two qualities. At one quality, q_R, only grade R units are traded and at another quality, q_M, both grades are traded in a "mix" of grades. The two qualities trade at prices P_R and P_M respectively.

(11) $$P_R - V(R, q_R) \equiv x(R, q_R) = 0;$$

(12) $$\Pr(R|q_M)\, V(R, q_M) + \Pr(S|q_M)\, V(S, q_M) = P_M;$$

(13) $$P_R - C(R, q_R) = P_M - C(R, q_M);$$

(14) $$P_M - C(S, q_M) \geqslant P_R - C(S, q_R).$$

Equations (11) and (12) indicate that prices should increase to the demand price which in the case of (12) reflects the uncertainty. Equation (13) indicates that the holders of regulars are indifferent between selling at the two grades. Equation (14) indicates that holders of supers may sell all units at q_M. The major unspecified variables are the probabilities in (12). The natural principle to apply is the "Principle of Rational Expectations" which in this case is

(15) $$\Pr(S|q_M) = \frac{|S|}{|R|+|S|} \quad \text{and} \quad \Pr(R|q_M) + \Pr(S|q_M) = 1.$$

The partial pooling model, if (15) is included, specifies a price for any given pair (q_R, q_M). However, the model does not dictate a pair (q_R, q_M). So partial pooling equilibria can be identified only through the relationships indicated by the equations applied.

E. *Most Efficient Signaling Equilibrium and Rothschild-Stiglitz*

Signaling equilibria are those for which buyers are aware that there is a relationship between quality and grade.[6] Thus, observing the quality they know the grade for certain. Sellers on the other hand have no incentive to change the quality they are offering given the grade. Generally many levels of quality will have these properties and will thus be signaling equilibria. The most efficient is

[6] The notion of a signaling equilibrium used in this paper is more in accordance with the strong conditions put forward by Stiglitz [7] than the weaker conditions of Spence [6]. The pooling and partial pooling models are consistent with Spence's weaker notion of signaling equilibrium.

the one that maximizes consumer plus producer surplus. Find a (P_R, P_S, q_R, q_S) which maximizes:

$$\max 6V[(R, q_R) - C(R, q_R)] + 6V[(S, q_S) - C(S, q_S)]$$

subject to:

(16) $V(R, q_R) = P_R$;

(17) $V(S, q_S) = P_S$;

(18) $P_R - C(R, q_R) \geq P_S - C(R, q_S)$;

(19) $P_S - C(S, q_S) \geq P_R - C(S, q_R)$.

The number 6 appears in the criterion function because there are six units of each grade, but of course this does nothing to the solution. For the parameters we use, equation (18) should be satisfied by equality at the most efficient signaling equilibrium (modulo the integer problem) and (19) should be a strong inequality. The solutions are in Table II.

Rothschild and Stiglitz [**5**] suggest that conditions in addition to (16)-(19) may be necessary for an equilibrium to be achieved. Sellers may prefer a pooling equilibrium to a most efficient signaling equilibrium and thereby have an incentive to pool. Suppose q_S^* and q_R^* satisfy (16)-(19). An equilibrium in the Rothschild-Stiglitz sense would also satisfy either (20) or (21).[7] That is, for all q, either

(20) $P_S - C(S, q_S^*) > \frac{1}{2}V(R, q) + \frac{1}{2}V(S, q) - C(S, q)$;

or,

(21) $P_R - C(R, q_R^*) > \frac{1}{2}V(R, q) + \frac{1}{2}V(S, q) - C(R, q)$.

The most efficient signaling equilibrium in the market parameters studied here satisfies condition (20) and is therefore a Rothschild-Stiglitz equilibrium as well.[8]

F. *Inefficient Signaling Equilibria*

The inefficient signaling equilibria are the solutions to (16) through (19) with the efficient solution removed. Equilibria computed on the assumption that the quality of regulars is the efficient quality are in Table II. In our parameters the profit equations (18) and (19) will both be strong inequalities at inefficient signaling equilibria. The only possible exception to the strong inequality occurs at the upper bound of qualities but for practical purposes such upper bounds do not exist.

[7] These equations describe only pure pooling equilibria and not partial pooling. The discussion would remain essentially unchanged if the partial pooling possibilities were considered as well.

[8] Because (21) is always satisfied in our parameters, the inequality (20) can be used to define the quantity $W = P_S - C(S, q_S^*) - [\frac{1}{2}V(R, q) + \frac{1}{2}V(S, q) - C(S, q)]$ with q chosen to minimize the expression. W is a measure of how "near" the market is to nonexistence of a Rothschild-Stiglitz equilibrium. As the marginal cost of adding quality of supers ranges over the values .02, .07, .095, .12, the pair (W, q) takes the respective values (.92, 19), (.37, 14), (0, 11), (−.43, 9). Thus, the Rothschild-Stiglitz equilibrium is "closer" to nonexistence in the high-cost markets (.07) than in the low-cost markets (.02).

4. RESULTS

A time series of statistics of all periods of all experiments is contained in Figures 3 through 6. We have included data for all periods because much market behavior that bears on the intuition which motivated the models introduced above is not captured by the models themselves and therefore is not completely represented by summary statistics. In addition, all markets exhibit a process of convergence which we are unable to capture precisely. Thus, the time series itself is an important source of data which helps provide impressions of what is happening in the market beyond those contained in the conclusions below.

Two aspects of the time series are graphed. The first is the excess value of a unit and the second is the quality of the unit. The per period mean values are in the graph.

Excess value is developed from the following notions. Notice that $V(R, q)$ places a lower bound on the redemption value a buyer can receive from a unit. Therefore, if a price $P(q)$ is paid for a unity of quality q then

$$x(q) = P(q) - V(R, q)$$

is the maximum possible loss the buyer can face by purchasing a unit of quality q. If the complications caused by the existence of a first unit bonus are neglected, the quantity, $x(q)$, is a reflection of the buyer's confidence that the unit is a super since it is the amount paid over the unit's value in case the unit is a regular. This quantity, $x(q)$, is called the excess value of a unit of quality q. If $x(q) > 0$ the buyer thinks the unit is possibly an S. At a competitive equilibrium under full information or a signaling equilibrium $x(q) = 0$ for all R and $x(q) = \$2.00$ for all S in all experiments. The naive equilibrium model predicts $x(q) = \$1.00$ for all q and all experiments.

Opportunity cost is a concept necessary to make the profit equations operational. Let $\mathbb{B}(g)$ be the set of observed price-quality pairs traded in the market for grade g units. The profit equations (18) and (19) can then be made operational by studying

$$\Pi_{g_i}(g_j) = \{P - C(g_i, q) | (P, q) \in \mathbb{B}(g_j)\}.$$

This set, $\Pi_{g_i}(g_j)$, is the set of profit numbers that would be generated if grade i units had been sold at the prices and qualities at which grade j units were actually traded. If $i = j$, it is the set of actual profits that occurred. If $i \neq j$, it is a type of opportunity cost that holders of grade i experienced because they did not sell their units in the (price, quality) range in which the other grade was trading. The strategy for using these distributions will be to let a quantity, say, $P_S - C(R, q_S)$, used in the profit equations be equal to the mean of $\Pi_R(S)$. So the mean of $\Pi_R(S)$ is the opportunity cost of selling an R as if it were an S. The mean values of $\Pi_{g_i}(g_j)$ are in Table III. These will be discussed later.

The strategy for reporting the results is dictated by the results themselves. A tree that can be used as a guide through the arguments is found in the concluding section. The first conclusion differentiates ideas about pooling from other ideas. Pooling, it seems, occurs in early periods of many markets but it occurs later,

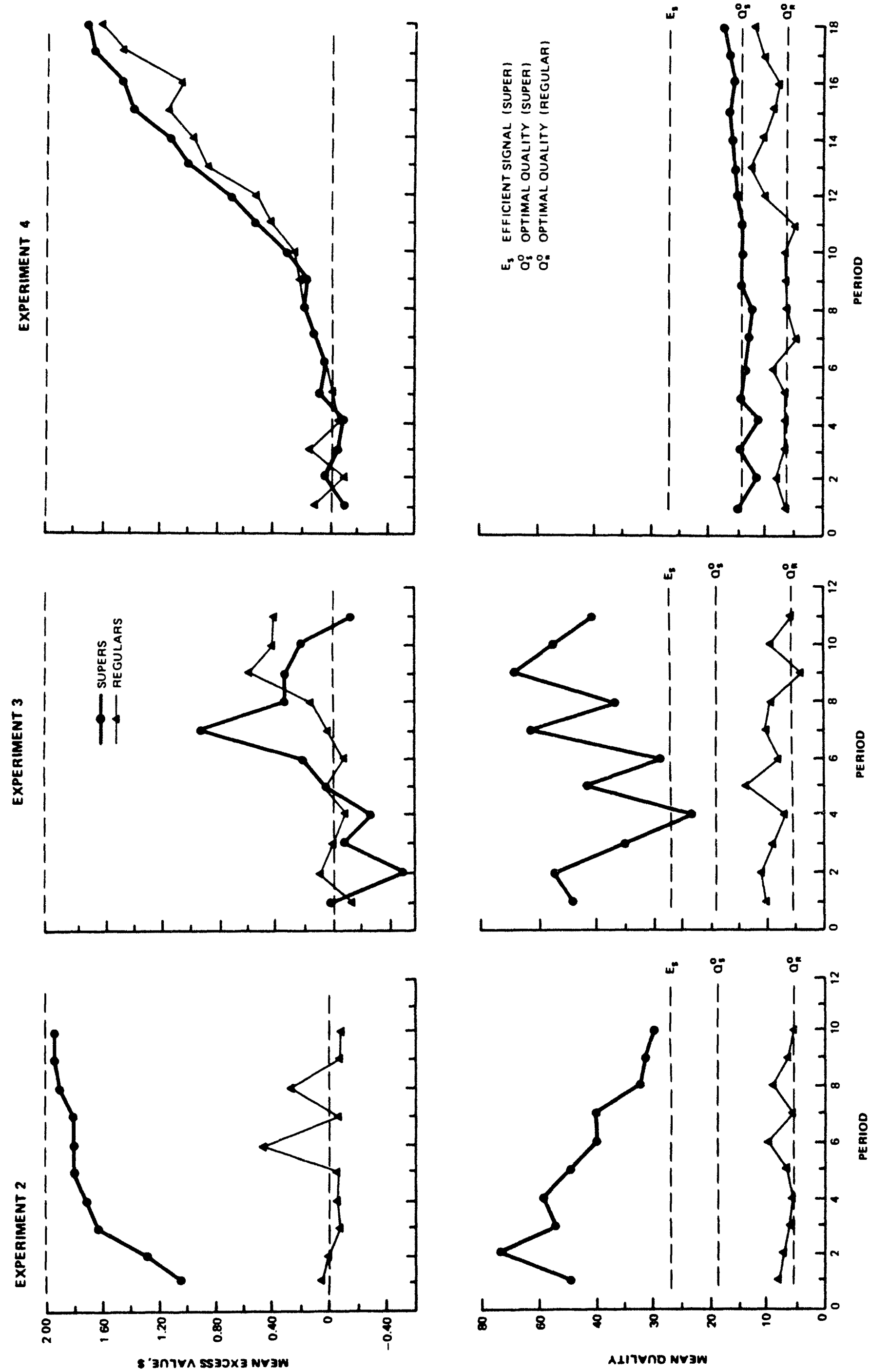
EXPERIMENT 2
EXPERIMENT 3
EXPERIMENT 4
SUPERS
REGULARS
MEAN EXCESS VALUE, $
MEAN QUALITY
PERIOD
E_s EFFICIENT SIGNAL (SUPER)
Q_s^o OPTIMAL QUALITY (SUPER)
Q_R^o OPTIMAL QUALITY (REGULAR)

FIGURE 3.

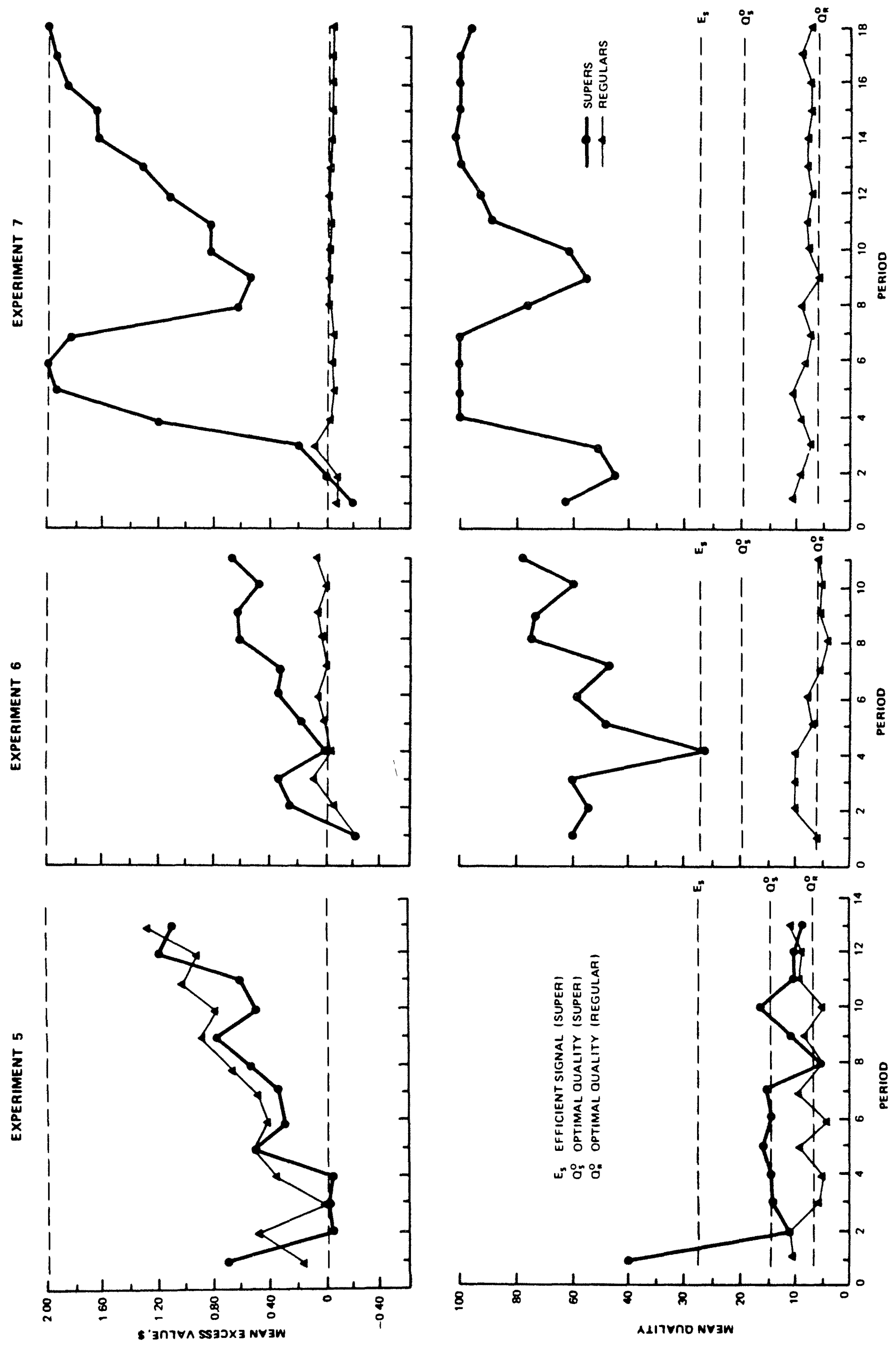
EXPERIMENT 5
EXPERIMENT 6
EXPERIMENT 7
MEAN EXCESS VALUE, $
MEAN QUALITY
PERIOD
SUPERS
REGULARS
E_s EFFICIENT SIGNAL (SUPER)
Q_s^o OPTIMAL QUALITY (SUPER)
Q_R^o OPTIMAL QUALITY (REGULAR)

FIGURE 4.

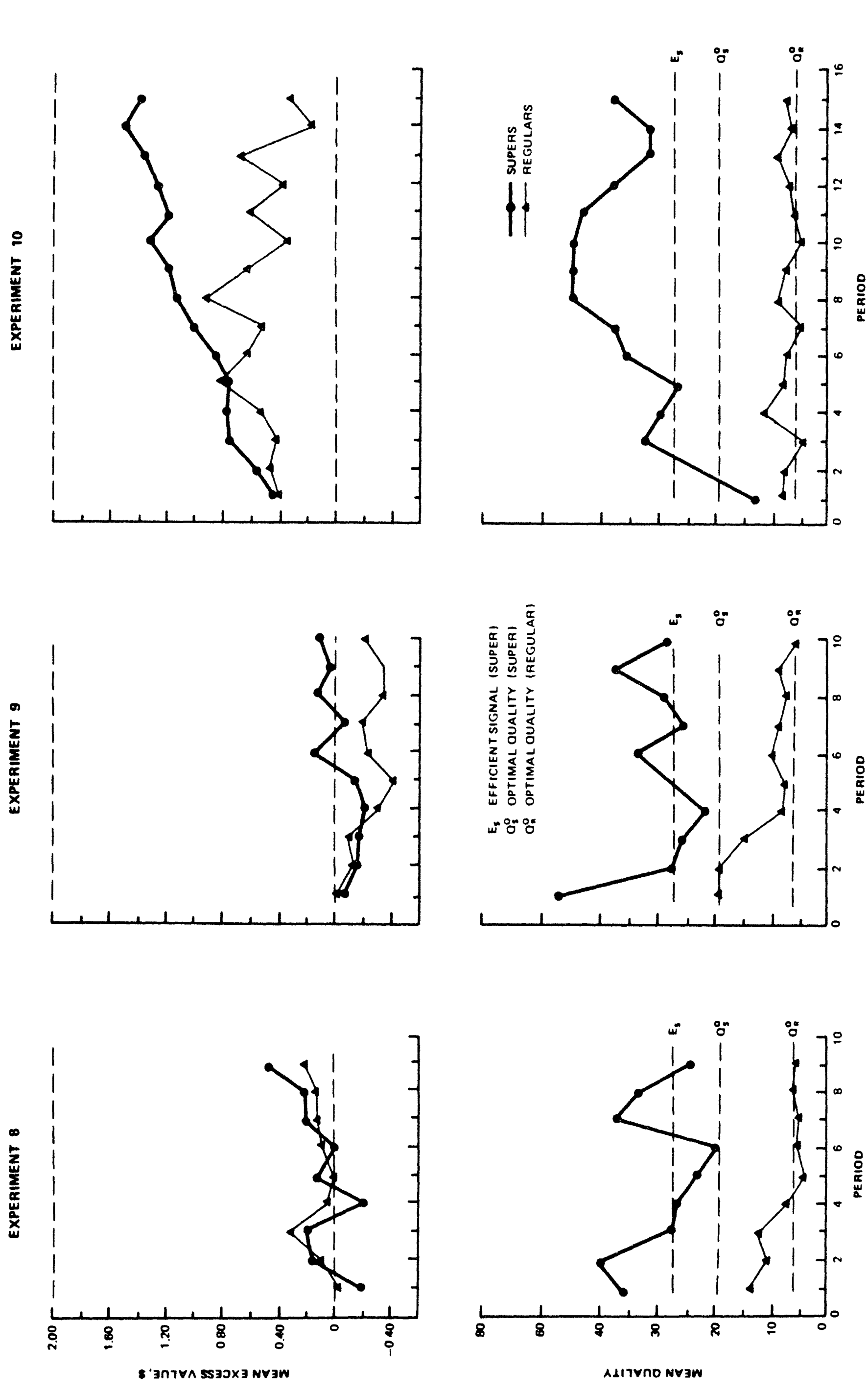
EXPERIMENT 8
EXPERIMENT 9
EXPERIMENT 10
MEAN EXCESS VALUE, $
MEAN QUALITY
PERIOD
SUPERS
REGULARS
E_S EFFICIENT SIGNAL (SUPER)
Q_S^O OPTIMAL QUALITY (SUPER)
Q_R^O OPTIMAL QUALITY (REGULAR)

FIGURE 5.

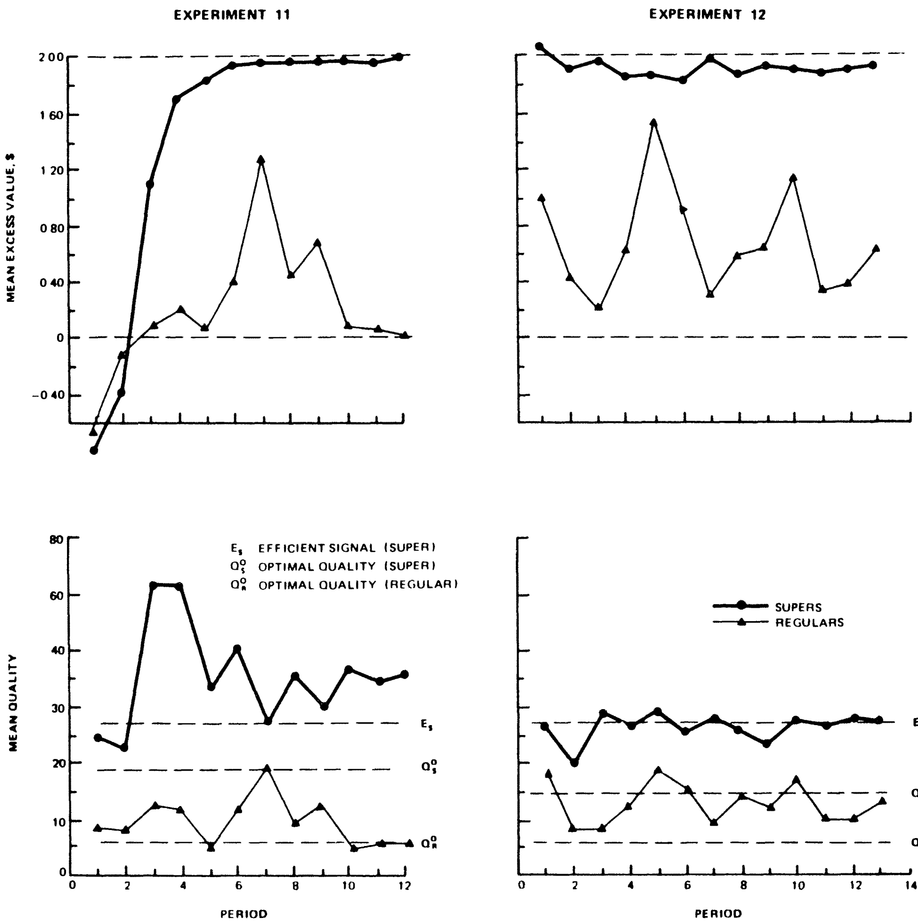

FIGURE 6.

after a few initial periods of adjustment, only in the experiments in which the costs of signaling supers is high ($.07 as opposed to $.02). The discussion of pooling is then postponed until a later section which focuses on those experiments alone. The second set of conclusions is developed for markets in which signaling equilibrium models might apply. These are all the markets with low signaling costs. The conclusions indicate that signaling existed in a substantial proportion of the markets. The analysis then proceeds to differentiate those markets which might be near equilibrium and attempts to ascertain which of the equilibrium models is the most appropriate. The final parts of this section return to the question of pooling and then go on to cover some miscellaneous issues regarding these markets.

TABLE III

MEAN VALUES OF $\Pi_{g_i}(g_j)$, ALL PERIODS, ALL EXPERIMENTS[a]

	Experiment 2				Experiment 3				Experiment 4				Experiment 5			
	(g_i, g_j)				(g_i, g_j)				(g_i, g_j)				(g_i, g_j)			
Period	RR	RS	SS	SR	RR	RS	SS	SR	RR	RS	SS	SR	RR	RS	SS	SR
1	0.65*	−3.56	2.94*	1.69	0.29*	−4.33	1.95	1.66	0.67*	0.03	1.23	1.20	0.70	−2.67	0.51	1.50
2	0.62	−6.79	2.96*	1.53	0.50*	−5.82	1.37	1.97	0.52	0.44	1.36	1.16	0.64	0.39	1.28	1.52
3	0.52*	−3.54	3.50*	1.38	0.44	−2.78	1.68	1.65	0.68*	0.15	1.28	1.21	0.63	0.22	1.34	1.09
4	0.61*	−4.05	3.53*	1.37	0.53	−1.31	1.71	1.49	0.58	0.37	1.30*	1.12	0.93*	0.50	1.62	1.33
5	0.60*	−2.82	3.67*	1.42	0.31*	−3.69	2.01	2.00	0.61*	0.33	1.47*	1.10	0.92	0.38	1.60	1.64
6	0.81*	−1.38	3.82*	2.15	0.53*	−1.47	2.21*	1.63	0.61*	1.34	1.42	1.27	0.99	0.51	1.63	1.38
7	0.60*	−1.64	3.77*	1.34	0.43*	−5.52	2.72*	1.82	0.75*	0.46	1.46*	1.13	0.91	0.49	1.68	1.68
8	0.53*	−0.26	3.97*	1.74	0.73*	−2.63	2.26	1.99	0.81	0.59	1.59*	1.29	1.25	1.19	1.59	1.65
9	0.53	−0.04	4.03*	1.43	1.22*	−6.89	2.10	1.76	0.83*	0.47	1.59	1.33	1.42	1.28	2.14	2.11
10	0.59*	0.13	4.03*	1.33	0.88	−5.39	2.08	2.09	0.88*	0.49	1.68*	1.38	1.37	0.35	1.60	1.77
11					1.02*	−3.55	1.87	1.91	1.02*	0.80	1.93*	1.39	1.50	1.11	1.92	2.22
12									0.98	0.89	2.09*	1.76	1.46	1.71	2.51	2.15
13									1.19	1.08	2.34	2.19	1.76	1.63	2.32	2.60
14									1.37	1.24	2.51	2.23				
15									1.64	1.37	2.71*	2.31				
16									1.58	1.56	2.82*	2.18				
17									1.75	1.72	3.02*	2.58				
18									1.83	1.62	3.03	2.82				

TABLE III—(*cont.*)

	Experiment 6				Experiment 7				Experiment 8				Experiment 9			
		(g_i, g_j)				(g_i, g_j)				(g_i, g_j)				(g_i, g_j)		
Period	RR	RS	SS	SR	RR	RS	SS	SR	RR	RS	SS	SR	RR	RS	SS	SR
1	0.33*	−6.22	1.58	1.08	1.97*	−5.14	2.92	3.27	0.30	−2.70	1.81	1.99	0.69*	−3.69	3.35	3.18
2	0.52*	−5.02	2.02	1.74	1.97*	−2.17	3.46	3.05	0.66*	−2.92	2.15	1.93	1.00	−0.12	3.49	3.47
3	0.62*	−5.72	2.14	1.92	2.10*	−2.92	3.57	2.97	0.75*	−1.21	2.26	2.21	1.52	0.10	3.48	3.47
4	0.53*	−1.24	2.14*	1.82	2.02*	−8.89	4.11*	3.10	0.69*	−1.42	1.93*	1.54	1.81	0.40	3.22*	2.85
5	0.54*	−4.19	2.09*	1.45	2.01*	−8.16	4.84*	3.31	0.57	−0.62	2.23*	1.03	1.68*	−0.17	3.40*	2.66
6	0.62*	−5.42	2.17*	1.61	2.08*	−8.12	4.88*	3.07	0.63*	−0.26	2.17*	1.27	1.72*	−0.63	3.70*	3.02
7	0.59*	−3.81	2.26*	1.26	2.08*	−8.25	4.75*	2.95	0.75*	−2.47	2.19*	1.38	1.89*	0.21	3.57	3.04
8	0.64*	−7.47	2.27*	1.18	2.07*	−5.72	3.82*	3.11	0.74*	−1.92	2.24*	1.41	1.76*	0.03	3.72*	2.71
9	0.64*	−7.22	2.32*	1.31	2.11*	−3.01	3.92*	2.76	0.83*	−0.29	2.61*	1.47	1.59*	−1.32	3.55*	2.74
10	0.60*	−5.50	2.30*	1.25	2.12*	−3.67	4.13*	2.99					1.96*	0.02	3.70*	2.69
11	0.69*	−7.85	2.33*	1.41	2.05*	−7.41	3.86*	2.96								
12					2.14*	−7.80	4.12*	2.92								
13					2.11*	−8.57	4.21*	2.97								
14					2.10*	−8.46	4.54*	2.98								
15					2.12*	−8.22	4.57*	2.90								
16					2.12*	−8.01	4.78*	2.90								
17					2.07*	−7.92	4.87*	3.11								
18					2.10*	−7.39	4.96*	2.88								

TABLE III—(*cont.*)

	Experiment 10				Experiment 11				Experiment 12			
		(g_i, g_j)				(g_i, g_j)				(g_i, g_j)		
Period	RR	RS	SS	SR	RR	RS	SS	SR	RR	RS	SS	SR
1	1.48	0.93	2.59	2.58	1.38*	−0.58	2.67	2.47	0.40	0.72	2.85	1.84
2	1.55*	0.30	3.22*	2.59	1.97*	0.29	3.22	3.01	0.75	1.50	3.10*	1.39
3	1.55	−0.91	3.32*	2.20	1.96*	−3.87	4.36*	3.58	0.71	0.39	2.66*	1.35
4	1.45	−0.54	3.36	2.94	2.08*	−3.25	4.98*	3.60	0.78	0.51	2.64	1.75
5	1.89	−0.30	3.14	2.93	2.22*	1.07	5.40*	2.87	1.30	0.24	2.54	2.77
6	1.69*	−1.29	3.36	2.69	2.26*	−0.01	5.41*	3.72	0.81	0.59	2.66	2.03
7	1.64*	−1.37	3.50*	2.29	2.15	2.01	5.58	4.64	0.73	0.52	2.72*	1.42
8	1.96*	−3.00	3.50*	3.13	2.23	0.83	5.49*	3.40	0.76	0.65	2.72*	1.81
9	1.68*	−2.95	3.55	2.72	2.12	1.66	5.56*	3.77	0.68	1.05	2.92*	1.62
10	1.42*	−2.81	3.69*	2.07	2.23*	0.73	5.50*	2.88	0.83	0.43	2.63	2.13
11	1.75*	−2.37	3.59*	2.53	2.19*	1.05	5.49*	2.88	0.65	0.54	2.67*	1.38
12	1.50*	−1.12	3.75*	2.34	2.14*	0.87	5.52*	2.90	0.79	0.45	2.65*	1.53
13	1.75	−0.16	3.90*	2.92					0.68	0.48	2.67*	1.68
14	1.25	−0.02	4.04*	2.07								
15	1.43*	−1.00	3.88*	2.41								

[a] $\Pi_{g_i}(g_j)$ is the set of profit numbers that would be generated if grade i units had been sold at the prices and qualities at which grade j units were actually sold. For example, mean $\Pi_R(S)$ is the "opportunity cost" of not having sold regulars as supers and is found under column RS.

* denotes a two-tailed t test that $\Pi_{g_i}(g_i) \neq \Pi_{g_i}(g_j)$ is significant at .05 or better.

A. *Pooling vs. Nonpooling*

The first question pits the pooling equilibrium model against all other equilibria. In the pooling model $q_R = q_S$ for all values of parameters studied here. In the equilibria predicted by nonpooling models $q_R < q_S$. Thus, an appropriate test of pooling against nonpooling is equality of quality levels of regulars and supers. The result, as summarized in the conclusion, is that pooling does not occur in markets in which signaling costs are low. When signaling costs are high a pooling hypothesis frequently cannot be rejected. However, the conclusion is sensitive to the test, as is discussed below.

CONCLUSION 1: Quality separation occurs in all markets in which the marginal cost of signaling a super is relatively low (i.e. experiments 2, 3, 6, 7, 8, 9, 10, 11). These markets are not pooled.

Two important definitions are required in order to make this conclusion operational. The first is the test for separation in qualities and the second is the periods to which the test is to be applied. Two tests are used. The first is a range test. Does the range of qualities of grade super overlap the range of qualities for grade regular? If the answer is "no" then the grades are said to be separated. The second test of separation is a t test of the difference between mean quality of supers and mean quality of regulars based on an (obviously incorrect) assumption about normality of the distribution of qualities of each grade.[9]

Four of the last five periods of experiments (2, 3, 6, 7, 8, 9, 10, 11) are separated according to both criteria. Because there is no ambiguity in either test, we think one can safely claim the markets have separated and are not pooled during the last part of the experiments at least.

CONCLUSION 2: Quality separation occurs infrequently or ambiguously in markets in which the signaling costs are relatively high (i.e. experiments 4, 5, 12). These markets are candidates for pooling equilibrium models.

In experiments 4, 5, and 12 the quality ranges of regulars and supers overlap almost every period. For example, overlap exists in the last five periods of all three markets. In experiment 5 the hypothesis that the mean quality of supers equals the mean quality of regulars can be rejected in only one of the last seven periods. In experiments 4 and 12 the hypothesis of equality of quality means can be rejected in three of the last six periods for experiment 4 and in six of the last seven periods of experiment 12. With such ambiguity one cannot say that the markets are separated, nor can one say with confidence that they are pooled. Nevertheless, we will analyze these two experiments along with experiment 5 as those which might be pooled.

[9] In addition, equality of sample variances is assumed in order to sidestep the Fisher-Behrens problem. The results do not appear to change significantly if the degrees of freedom are adjusted to take into account possible differences in these variances.

Another criterion of pooling involves the profit equations (9) and (13). The equations imply an equality between actual profits and opportunity costs (potential profits). An examination of this relationship is reserved for later.

B. *Signaling vs. Nonsignaling*

The analysis now turns to those markets in which qualities are separated (2, 3, 6, 7, 8, 9, 11) and in which signaling equilibrium models might be successfully applied. The signaling models and the naive model all predict quality separation, but the implication of such separation differs among the models in the sense that signaling models suggest that the quality will be used as a signal for the underlying grade, and thus the quality has implications for price beyond the intrinsic value of the quality.

The appropriate tool for differentiating the two classes of ideas is the excess value measure. If regulars and supers are being sold at different levels of quality, and if the quality is used as a signal, then excess value, $x(q)$, should be positively related to quality. Units with high quality will be recognized as supers and the price will be bid upward relative to the value of a regular at that level of quality. The conclusion is that signaling occurs in all of the "nonpooled" markets except two.

CONCLUSION 3: Markets with separated qualities were checked for signaling. Signaling as measured by excess value exists in markets 2, 6, 7, 9, 10, and 11. Signaling does not occur in experiments 3 and 8.

The conclusion is made operational by a difference in means test. The hypothesis that

$$\frac{1}{|S|}\sum_S x(q) - \frac{1}{|R|}\sum_R x(q) > 0$$

was tested for the last periods of experiments 2, 3, 6, 7, 8, 9, 10, and 11. In experiments 2, 6, 7, 10, and 11 the difference is significantly (.05 or better) positive in all of the last five periods and in all periods after the tenth in each of these experiments which had that many periods. On the other hand, in experiments 3 and 8 the difference is significant at .10 in no more than three periods over all periods of each and significant separation at the .05 level occurs only once in each. Thus experiments 2, 6, 7, 10, and 11 appear to be separated while 3 and 8 are not separated. The borderline case is experiment 9, in which only three of the last five periods are separated at the .05 level or better. We chose to analyze it as having been separated.

The result establishes that, empirically, quality separation of grades is not a sufficient condition for the presence of signaling. The natural question is whether one of the other models fits the data. The only remaining model is the naive model, since both pooling and all classes of signaling models, including the perfect information model, can be rejected as capturing the essence of markets 3 and 8.

CONCLUSION 4. The behavior of experiments 3 and 8, the only markets in which the naive model might be successfully applied, are difficult to reconcile with the naive model.

The naive model predicts that the excess value of both supers and regulars should equal $1.00. In both cases the excess value is closer to 0. Risk aversion is consistent with the low price of supers but risk aversion does not account for the high quality level of the supers. The naive model predicts supers at 18 or 19 while the actual qualities are on the order of 30 or more. Thus, the behavior of both of these markets remains a matter of speculation.

C. *Equilibrium vs. Disequilibrium in Signaling Markets*

Experimental markets adjust over time through some yet-to-be-modeled dynamic process. There is also no generally accepted convention for defining when a market is in equilibrium. These facts create difficulties for those who wish to study and apply competing equilibrium models. The proper equilibrium model might be rejected from a competing set of models because the models were applied while the markets were still undergoing substantial adjustment.

Fortunately all signaling models agree on two dimensions of equilibrium behavior. The excess value of supers should be near $2.00 and the excess value of regulars should be slightly below zero. The strategy of model evaulation is to first identify those markets that are close to equilibrium on this criterion and define them as being in equilibrium. In the next section we will then check the quality levels in the equilibrated markets so defined, to evaluate the competing signaling models. All of the signaling models make different predictions about quality.

CONCLUSION 5: Markets 2, 7, and 11 are statistically (.05 level of significance) within $.05 of the predicted equilibria in the last two periods or more. On this criterion they have equilibrated. Markets 6, 9, and 10 have not equilibrated.

In the last two periods of experiments 2, 7, and 11 the compound hypothesis that the excess values of regulars and supers are drawn from distributions with means within $.05 of 0 and $2.00 respectively cannot be rejected at the .05 level of significance. If an assumption is accepted that transaction costs are about .05 then the predictions of the model are expanded to the supported range. Use of $.05 as a transaction cost is not without precedent. Commissions which are normally used to pull the data to exact equilibria are absent in these markets. Of course, one would like a better convention but currently such adjustments to models are all that exist. In experiments 6, 9, and 10 the prices of supers are never close to the equilibrium predictions in a statistical sense.

The visual impression one gets from the time series is that markets 6 and 10 are both converging to some signaling equilibrium. The qualities are well separated and the excess values are moving toward the equilibrium values as the periods replicate. The qualitative aspects of experiment 9 are similar except prices are very low. Market 9 had only two buyers but duopolies are generally unsuccessful in keeping prices far away from competitive levels in experimental markets.

D. *Competing Signaling Models*

Three of the markets appear to be in some sort of signaling equilibrium. The markets are 2, 7, and 11. The question is now which of the three signaling models is most appropriate.

CONCLUSION 6: In markets 2, 7, and 11, both the perfect information model and the efficient signaling equilibrium model can be rejected in favor of the inefficient signaling equilibrium model.

The perfect information model predicts the quality of supers will be eighteen or nineteen units. The efficient signaling equilibirum predicts supers at twenty-seven units while the inefficient signaling equilibrium model predicts super quality at above twenty-seven units. In all three markets and in all of the last few periods the hypothesis that super quality is twenty-seven units or less can be rejected at .05 level of significance. The regulars are near the five to six quality unit level as predicted by all models.

The profit and opportunity cost calculations in Table III support this conclusion. The equality demanded in equation (18) can be rejected (at .1 level) in all periods in all of these experiments except periods 7 and 9 of experiment 11. A difference in means tests for the quality of appropriate values of the means in Table III as dictated by (18) can be rejected. The t statistics for differences are in Table III.

The direction of movement in both experiments 2 and 11 is of interest and perhaps some importance. Notice that the movement of quality levels is toward the most efficient signaling equilibrium. Relative to the distance traveled by the qualities the levels are very close to the signaling equilibrium.

CONJECTURE 1: Both experiments 2 and 11 are converging to the most efficient signaling equilibrium.

In some respects one should conjecture that these experiments are at a most efficient signaling equilibrium. The quality levels are within \$.03 in surplus terms of the most efficient signaling equilibrium. The variance in qualities is low and is actually zero for grades in some periods. Given that information can only be gathered through bids to make risky purchases this might be as close to the efficient signaling equilibrium as can be reasonably expected.

E. *Pooling, Partial Pooling, and "Near" Nonexistence*

The discussion now turns to markets 4, 5, and 12. These are the markets with high signaling cost. None of these three markets have separated grades[10] so some notion of pooling is called for as an explanation. The competing a priori explanations are the pooling equilibrium, the partial pooling equilibrium, and the near nonexistence of a Rothschild-Stiglitz equilibrium.[11] Summarizing the analysis below, experiment 5 is a candidate for the pooling model and experiment 4 is a candidate for partial pooling. Experiment 12 seems to involve a substantially different phenomenon discussed in the next section. As it turns out none of these models provide a completely convincing explanation of what happened in the markets.

CONCLUSION 7: Experiment 5 is a good candidate for the pooling equilibrium model.

Price behavior is the major datum that goes against this conclusion. The pooling model predicts a single quality, q^*, and price behavior such that $x(q^*) = 1$ or perhaps below \$1 because of risk aversion. Contrary to this prediction average excess value is above \$1 in the last two periods. We are at a loss for an explanation.[12] The other predictions of the pooling model seem to be supported. The existence of a single quality, q^*, predicted by the model is supported by the facts that equality of mean quality of regulars and supers cannot be rejected (even at the .2 level) in five of the last six periods; the variance of qualities tend to decrease to within 20 per cent of the mean;[13] and the quality level is near the most efficient pooling quality of ten units. The mean excess values of supers and regulars is never significantly different which suggests the lack of quality signals. The profit equations of the pooling model, (9) and (10), cannot be rejected (Table III). On all dimensions but one the pooling model is supported.

For the next two experiments (4 and 12) both partial pooling and "disequilibrium" concepts are of interest. Partial pooling models drop the assumption of the pooling model that only one quality exists and replace it with an assumption of two qualities (q_R and q_M with $q_R < q_M$). At the lower quality only regulars are traded, and the other quality involves a mix of grades with all supers trading at the higher quality and some number, a, of the regulars trading there as well. The full model is described by equations (11) through (14) and perhaps (15) as well.

CONCLUSION 8: Experiments 4 and 12 have elements of partial pooling equilibrium behavior. The pooling equilibrium model can be rejected for both. However,

[10] A weaker test of separation than was applied above, such as a positive correlation between grade and quality, would almost certainly have these markets separated.

[11] See footnote 8.

[12] We suspect that the bonus paid to the buyers for making at least one purchase plays a role.

[13] The variance in experiments 2, 6, 9, 10, 11 tends to be many times this level.

both experiments exhibit prominent behaviors contrary to the partial pooling models.

The pooling equilibrium model can be rejected in favor of partial pooling on four grounds. In both experiment 4 and experiment 12 the excess values of regulars are separated from the excess values of supers. Pooling requires equality of excess values whereas partial pooling allows inequality. (The t on mean difference is significant at .01 for three of the last four periods.) Second, the excess value of supers in both experiments is considerably above the \$1.00 predicted by the pooling model. Third, an argument can be made that two quality levels, q_R and q_M exist rather than a single quality level. The later periods of both experiments have the low end range of the regulars anchored in the sense that some regulars and only regulars were sold at these low levels. In addition the quality of supers is bounded from below at 15 for experiment 4 and 20 for experiment 12 in the last several periods. Thus in both markets there is a quality below which sales of supers never occurs but sales of regulars do occur there so in both experiments there is a specific quality range in which a regular will be acquired with certainty.

Fourth, the profit data favor partial pooling over pooling. Both the pooling and partial pooling models have equation (13) in common. The data from Table III suggest that the equation is satisfied in both experiments 4 and 12. This condition that sellers of regulars be indifferent between the terms of regular sales and the terms of super sales can never be rejected in experiment 12 and it cannot be rejected in any of the last seven periods of experiment 4. The pooling model through equation (10) requires that sellers of supers should also be indifferent between the terms of regulars and the terms of supers but the partial pooling model, through inequality (14), allows supers to prefer the high quality ranges. In both experiments 4 and 12 the equality of profits demanded by the pooling model is rejected in favor of the inequality of partial pooling. In five of the last seven periods of experiment 4 and in six of the last seven periods of experiment 12 equality can be rejected in favor of the appropriate inequality. Sellers of supers have no incentive to pose as regulars.

The partial pooling model has some substantial inconsistencies with the data. Table IV gives the average excess value of the lowest quality units for the last several periods of experiments 4, 5, and 12. Since these qualities were always regulars the excess values should converge to slightly below zero as is dictated by equation (11). As can be seen, experiment 12 has this property. In experiments 4 and 5 the movement is in the wrong direction so the partial pooling model can be rejected for both. We have no explanation of this phenomenon other than a possible relationship with the bonuses as was mentioned above in connection with the discussion of experiment 5.

In experiment 12 the prices of supers are "too high" to be consistent with partial pooling. Excess values of supers are near the range of \$1.90 to \$1.95, which is about as close to competitive equilibrium fully informed levels as might be expected with transaction costs. In addition, in experiment 12 the profits of

TABLE IV

AVERAGE EXCESS VALUE OF UNITS TRADING AT THE LOWEST BOUND OF QUALITY RANGES

(*only Regulars trade at these qualities*)

	Period									
Experiment	9	10	11	12	13	14	15	16	17	18
4	.19	.28	.51	.61	.70	.60	1.39	1.00	1.29	1.50
5	.31	.78	.60	.48	1.20					
12	−.04	−.05	−.04	−.05	−.05					

regulars selling at the various quality levels are not equal in a manner that is hidden by a simple comparison of mean profit levels. Some regulars do sell in the super ranges and are much more profitable than regulars selling in the lower (regular) ranges of qualities. Furthermore the supers sell in two ranges of qualities rather than the one predicted by partial pooling. In summary, several aspects of the data do not support partial pooling as a general explanation for the experience of experiment 12 even though the partial pooling model is more accurate than the pooling method.

In summary, the best model is partial pooling. A tempting explanation is that the Rothschild-Stiglitz equilibria do not exist as a practical matter and that the "disequilibrium" behavior we are observing represents a rejection of the most efficient signaling equilibrium model as capturing the proper equilibrium principle in favor of the Rothschild-Stiglitz concept. Two ad hoc explanations compete with that explanation. First, the high prices in experiment 4 suggest unwarranted buyer optimism. If such optimism actually exists, the remainder of the market behavior in experiment 4 can be understood without resort to the Rothschild-Stiglitz equilibrium concept. The behavior of the other perplexing experiment, 12, can be understood in terms of special signals as discussed in the next section. Finally, this "near nonexistence" explanation has difficulty with the fact that the pooling model works so well in experiment 5.

F. *Special Sources of Signals*

Quality is not the only source of signals in a market. Any face-to-face market is rich with possibilities including the tone-of-voice bids or the speed of bids. Such an environment also allows for the possible development of reputations. Two instances in these experiments support the following conjecture.

CONJECTURE 2: The applicability of signaling equilibrium models is sensitive to the market institutional environment. The institutional environment affects both the publicness of the signal and the nature of the signal.

Support for the first part of the conjecture is found in experiment 7 and in the difference between experiment 8 on one hand and 4 and 5 on the other. The key variable here is the experimental procedure of circling of regular contracts and super contracts with different colored chalk after the period was over and the grades were announced. The use of the chalk focused buyers on the possibility that the level of quality actually contained information. We suspect that many agents in experiments without the use of colored chalk never recognized or even suspected a positive relationship existed between quality and grade. Even though the information was in front of them they never looked. We suspect that the fall in excess value in experiment 7, beginning with period 8, reflects in part a lack of awareness on the part of a few buyers and a lack of confidence on the part of others that the quality and grade were related. The increase in excess value of supers after period 11 in experiment 7 is, we feel, due to the use of colored chalk and the information it provided.

We suspect that some sort of public recognition of a signal helps instigate the development of signaling equilibria. We also suspect that experience in the market is also important to this end.

The second instance occurs in experiment 12, in which special signals seem to have developed and generated a different type of equilibrium that reflects a combination of signaling and reputation development. Sellers of supers can make profitable trades that are unprofitable to sellers of regulars. The market institution, which included the possibility of making offers that were not accepted, could thus be used by sellers of supers to make offers that were unprofitable for regulars. Offers of quality 100 at the franc equivalent of $10, for example, began to appear early in experiment 12. These offers were never accepted but the fact that they were made suggested that the seller was a super and since seller identifications were known a reputation could form.[14] The market seemed to be adjusting along these lines with those who made offers of 100 at $10 having established a reputation as selling a super. Then the regulars began making such offers also. Even though regulars would lose considerable money if such an offer was accepted, such transactions never took place because the buyers would have also lost money. Thus a signal developed which established a reputation, seemed to affect prices and qualities, and then eroded as regulars with some perceived risk made the same offers.

Sellers in later periods of experiment 12 began developing a different strategy for reputation formation. By selling their first unit at a price and quality that was clearly reserved for supers their identity as supers became known and their second unit could be sold as if with perfect information in a range that would have been profitable for regulars. This hypothesis explains why, in experiment 12, the profits from regulars differed between the low qualities, as opposed to the price and qualities where supers tended to trade. The identity of the latter as supers was known to buyers who would thus pay high prices. In the last four periods of experiment 12 the first unit of all super sellers was sold (usually as a result of a bid) at a quality of approximately 30 and a price of about $4.50, which was

[14] Subsequent developments in experimental technology now allow trades without traders knowing the identification of the trading partners.

TABLE V

[SALES/ATTEMPTED] SALES AS RELATED TO SELLER REPUTATION
FINAL PERIODS OF EXPERIMENT 12

Period	Sellers of Regulars Reputation? Y	N	Sellers of Supers Reputation? Y	N	All Sellers Reputation? Y	N
10	1/1	1/2	1/2	1/2	2/3	2/4
11	0/0	0/3	3/3	0/3	3/3	0/6
12	0/1	1/2	3/3	0/3	3/4	1/5
13	0/1	1/1	3/3	0/2	3/4	1/3

NOTES: Y: seller had made a sale at a quality of 30 or more; N: seller had not made a sale at a quality of 30 or more. Numerator: number of offers counted in the denominator that were actually accepted; Denominator: number of offers made at quality 20 by sellers with the indicated grade and reputation.

unprofitable for regulars. Regulars never sold on these terms. The second unit was then offered at a quality of 20 at $4.50. Notice the second action was an offer rather than a bid because a bid could be accepted by *any* seller. Offers by other sellers (regulars) existed at (20, $4.50) but were substantially passed over by buyers. Offers by sellers who had sold at (30, $4.50) were taken immediately. The prices at both qualities were near the competitive equilibrium. The variance in quality of regulars in the later periods of the experiment and the high average quality of regulars is due to an occasional "foolish" purchase by a buyer who bought at (20, $4.50) from a seller who had not produced the above signal.

The data in Table V make the point. If sellers have established a reputation by making a sale at a quality above 30, they have a greater probability of having their offers accepted at a quality of 20 than do sellers who have not established such a reputation. The probability of a sale at quality 20, given an attempted sale, is near 1 for those with an established reputation, but it is only near $\frac{1}{4}$ for those without (using the frequencies from the last four periods).

CONJECTURE 3: Seller reputations developed in experiment 12.

G. *Dynamics*

Those markets that seem to equilibrate all have a similar dynamic pattern. The quality of supers initially separates very high above the most efficient level of signaling. The "noise" is thus eliminated. This is followed by a reduction in quality of regulars, an increase in excess values of supers and a reduction in excess values of regulars. The time structure of the latter adjustments is unclear. The quality of supers then begins to adjust downward, increasing the overall market efficiency.

CONJECTURE 4: The dynamics of the signaling equilibrium is for the equilibrium level of the signaling quality to be approached from above.

This conjecture might contain the seeds of an explanation of the failure of the high signaling cost markets to converge to a signaling equilibrium. With low signaling costs the range of qualities which necessarily separate the grades and are feasible from an exchange point of view is larger for the low signaling cost markets. Only the low cost markets might have converged to a separating equilibrium because it was easier for the necessary dynamic process to be initiated.

5. CONCLUSIONS

The tree (Figure 7) gives the structure of the paper and empirical results for all experiments, as we think the weight of evidence and conjectures support. One striking thing about the results of these experiments is the substantial differences in behavior across all experiments. Even though care was exercised to keep conditions the same across experiments no single model accounts for the behavior of all markets.

The method of analyzing the data seems a bit unorthodox. The use of a sequence of criteria to determine the data to which various models will be applied raises an obvious question. What would happen if the criteria were applied in a different order? Given our operational definitions of separation, equilibrium, and the like, the results would all remain as given. All experiments would end up in the same groups. Operational definitions exist, however, for which the final groupings would change with the ordering of application of the criteria. We can only call this problem to the attention of the reader and leave open the basic methodological question of what is the best way to proceed.

The major conclusion is that signaling is a real phenomenon (Conclusion 3); a notion of equilibrium is appropriate (Conclusion 5); and that the most efficient signaling equilibrium can reasonably be expected to emerge (Conjecture 1). The second major conclusion is that quality separation of grades is not a sufficient condition for having observed a signaling equilibrium (Conclusion 3). Third, aspects of pooling can be observed (Conclusion 7) but it is unclear whether or not this pooling behavior involves the type of cycling suggested by the non-existence of a Rothschild-Stiglitz equilibrium (Conclusion 8). The data lead to some interesting speculations. Signaling equilibrium seems to be established through a special type of dynamics (Conjecture 4); an interaction appears to exist between signals and reputation formation (Conjecture 3); and the signaling phenomenon itself seems to be sensitive to market organization and the institutional features of markets (Conjecture 2). Thus theoretical work along the line of these speculations might be productive and investigations of the signaling implications of institutions should be checked when evaluated in the context of policy research.

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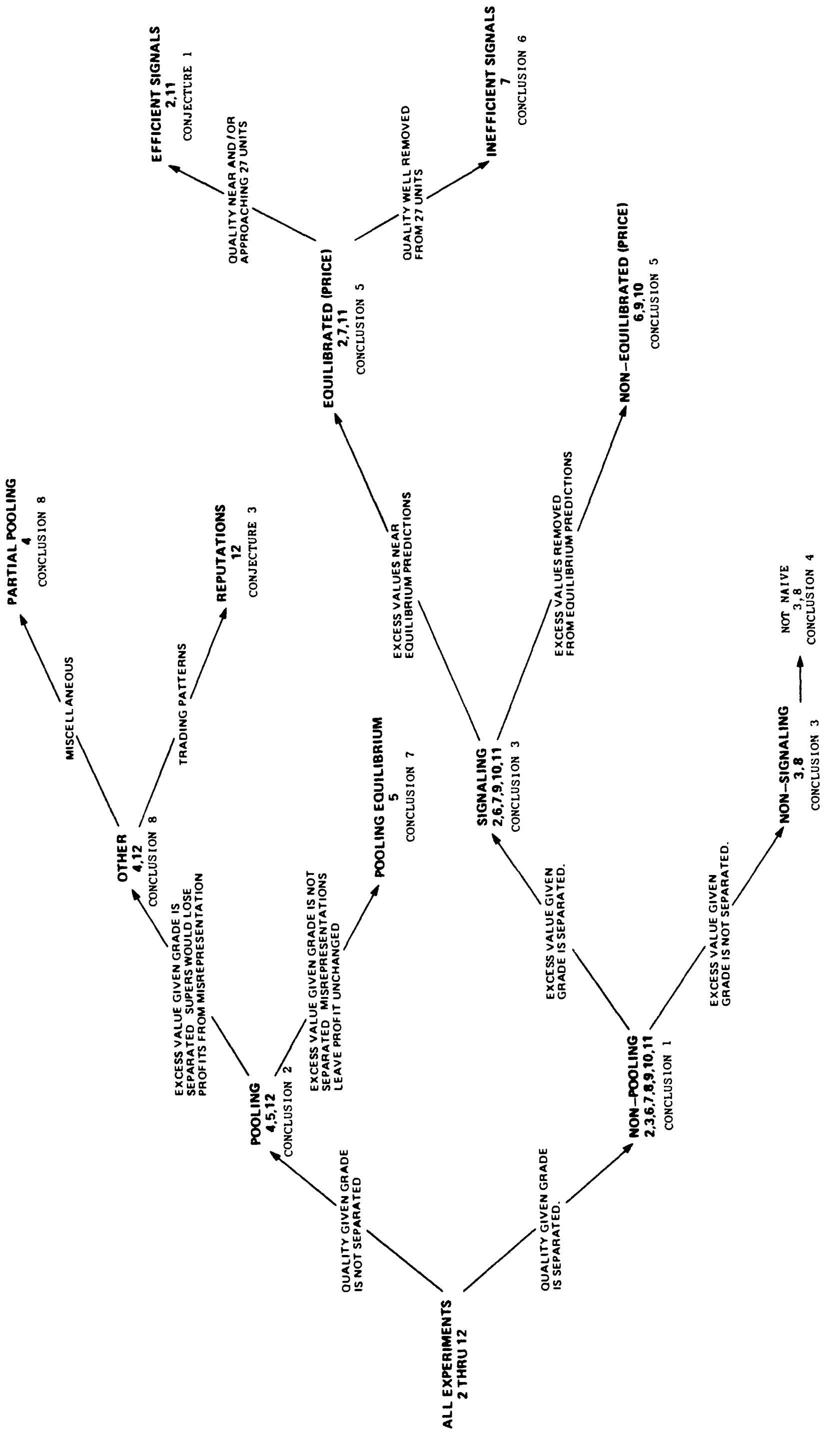

FIGURE 7—Partitioning of experiments according to consistency with competing models.

APPENDIX: INSTRUCTIONS

General

This is an experiment in the economics of market decision making. Various research foundations have provided funds for this research. The instructions are simple and if you follow them carefully and make good decisions you might earn a considerable amount of money, which will be paid to you in cash at the end of the experiment.

In this experiment we are going to conduct a market in which some of you will be buyers and some of you will be sellers in a sequence of market days or trading periods. Attached to the instructions you will find some sheets, labeled Buyer or Seller, which describe the value to you of any decisions you might make. *You are not to reveal this information to anyone.* It is your own private information.

The type of currency used in this market is francs. All trading and earnings will be in terms of francs. Each franc is worth __ dollars to you. Do not reveal this number to anyone. At the end of the experiment your francs will be converted to dollars at this rate, and you will be paid in dollars. Notice that the more francs you earn, the more dollars you earn.

Specific Instructions to Buyers

During each market period you are free to purchase from any seller or sellers as many units as you might want. The value of a unit depends upon its type and its quality. There are two types (Super and Regular) and the value of a Super for any given quality is much greater than the value of a Regular. At the time you buy a unit you will not know the type but you will know the quality. At the end of a trading period you will be told the type of each unit you bought.

The redemption value of a unit is obtained by adding its base value to its quality value. The quality value for each quality level appears in Table IA. So the value of quality is the same for both types but the base value differs.

Your payoffs are computed as follows: You will receive the difference between the redemption value of the units and the total amount you paid for the purchases. Also, you will receive a bonus for each period in which you purchase a unit.

Suppose, for example, that you buy one unit with a quality level of 1000 at a price of 1000. Assume that according to Table IA the quality value for a quality level of 1000 is 1500. Assume further that the base value of a Super is 1250 and a Regular is 200. If at the end of the period you are told that your unit was a Super, your earnings would then be:

$$\text{earnings} = 1500 + 1250 - 1000 = 1750.$$

Or, if you are told it is a Regular your earnings would be:

$$\text{earnings} = 1500 + 200 - 1000 = 700.$$

In addition, you would collect the bonus for purchasing at least one unit that trading period.

At the time you make the purchase you should enter the quality value in row 2 of your buyer sheet and the price you paid for the unit in row 4. At the end of the period when you are told what type of units you have bought, you should enter the base value of these units in row 1. You can then calculate the total redemption value (row 1 + row 2) and enter this value in row 3. The profit for each unit is then row 3 − row 4 and this number is entered in row 5. The first unit you purchase in a trading period should be entered in the first column of your buyer sheet for that period, the second unit should be entered in the second column, and so on. If you make any purchases in a trading period, you also collect the bonus which appears in the last column. After you have calculated the profit (or loss) for each unit, record the total earnings in the blank at the bottom of your buyer sheet. When the period ends remove this sheet to reveal the buyer sheet for the next period.

Your total payoffs will be accumulated over several trading periods and the total amount will be paid to you after the experiment.

Specific Instructions to Sellers

During each market period you are free to sell to any buyer or buyers up to a total of __ units. You are free to choose the quality level of all units you sell, but quality is added at a cost to you. The type of unit you will sell during a market period is given at the top of the seller sheet for that period. If the unit you are selling is a Super, the cost for each additional level of quality will be __. If the unit you are selling is a Regular, the cost for each additional level of quality will be __. As you can see it is much easier to supply quality if you are selling a Super than it is if you are selling a Regular.

The cost of the first unit you sell *during a trading period* should be entered in row 2 of your seller sheet at the time of the sale. The table labeled Super gives the cost when you are selling a Super unit, and the table labeled Regular gives the cost when you are selling a Regular unit. If you sell a second unit, the cost of this unit should also be found in the appropriate table and entered in row 5 of your seller sheet. *Under no conditions may you sell a unit at a price below the cost of the unit.* For each unit sold your earnings (profits) are calculated as follows:

[your earnings = (sale price of unit) − (cost of the unit)].

Suppose, for example, that you sell the first unit at 2000 with a quality of 1400 and the second unit at 1900 with a quality of 1000. Suppose further that at a quality of 1400 your cost is 1000 and at a quality of 1000 your cost is 500. Then, your earnings are:

earnings from 1st = 2000 − 1000 = 1000,

earnings from 2nd = 1900 − 500 = 1400,

total earnings = 1000 + 1400 = 2400.

The blanks on your seller sheet will help you record your profits. The sale price of the first unit you sell during the 1st period should be recorded on row (1) *at the time of sale.* Also, the quality level and the cost of the unit should be entered in row (2). You should then record the profits on this sale as directed in row (3). At the end of the period record the total profit on the last row on the page. Subsequent periods should be recorded similarly.

Your total profits for a trading period, which are yours to keep, are computed by adding up the profits on sales made during the trading period.

At the end of each period remove the seller sheet for that period to reveal the seller sheet for the next period. Do not look at any seller sheet until its period is announced.

Market Organization

The market for this commodity is organized as follows. The market will be conducted in a series of trading periods. Each period lasts for at most __ minutes. Any buyer is free at any time during the period to make a verbal bid to buy the commodity at a specificed price and at a specified quality level, and any seller with units to sell is free to accept or not accept the bid. Likewise, anyone wishing to sell a unit is free to make a verbal offer to sell one unit at a specified price and quality level. If a bid or offer is accepted, a binding contract has been closed for a single unit at the specified price and quality level, and the contracting parties will record the contract price and quality level. Any ties in bids or acceptances will be resolved by random choice. Except for the bids and their acceptance or cancellation you are not to speak to any other subject. There are likely to be many bids that are not accepted, but you are free to keep trying. You are free to make as much profit as you can.

Trading period 0 will be a trial period to familiarize you with the procedure, and will not count toward your cash earnings.

Final Observations

1. Each period there will be exactly three sellers offering Supers and three sellers offering Regulars. Which sellers offer Supers and Regulars has been determined independently and randomly each period.
2. Each individual has a large folder. All papers, instructions, records, etc. should be put into this folder. Leave the folder with us before leaving. *Take nothing home with you.*
3. We are able to advise you a little on making money. First, you should remember that pennies add up. Over many trades and a long period of time very small amounts earned on individual trades can add up to a great deal of money. Secondly, you should not expect your earnings to be steady. You will have some good periods and some bad periods. During bad times try not to become frustrated. Just stay in there and keep trying to earn what you can. It all adds up in the end.

Some people rush to trade. Others find it advantageous to "shop" or spread their trading over the period. We are unaware of any particular "best" strategies and suggest that you adapt accordingly.

The record forms sometimes lead people to think in terms of "markup" and "markdown" strategies. While we see no general problems here, they can lead to occasional mistakes in computing the returns from decisions.

4. Under no circumstances may you mention anything about activities which might involve you and other participants after the experiment (i.e., no physical threats, deals to split up afterwards, or leading questions).
5. Each individual will be paid in private. Your earnings are strictly your own business.

TABLE IA

Buyer________
Period(s)________

Table I

Quality	Quality Value	Additional Value of last Quality Level
0	$0.00	
1	0.20	0.20
2	0.39	0.19
⋮	⋮	⋮
19	2.09	0.02
20	2.10	0.01
21	2.11	0.01
⋮	⋮	⋮
48	2.38	0.01
49	2.39	0.01
50	2.40	0.01
⋮	⋮	⋮
99	2.89	0.01
100	2.90	0.01

For Quality over 100
Value = 2.90 + .01 for each level over 100.
For example,
Quality = 2000 means Quality value = 21.90.
Quality = 5000 means Quality value = 51.90.

Seller________
Periods________

Table: REGULAR

Quality	Cost	Quality	Cost
0	0.00	50	7.50
1	0.15	51	7.65
2	0.30	52	7.80
⋮	⋮	⋮	⋮
47	7.05	98	14.70
48	7.20	99	14.85
49	7.35	100	15.00

Each additional quality level, cost = 0.15. For example, for a quality of 2000 the cost is 300. For a quality of 5000 the cost is 750.

Seller________
Periods________

Table: SUPER

Quality	Cost	Quality	Cost
0	0.00	51	1.02
1	0.02	52	1.04
2	0.04	53	1.06
⋮	⋮	⋮	⋮
48	0.96	99	1.98
49	0.98	100	2.00
50	1.00		

Each additional quality level, cost = 0.02. For example, for a quality of 2000 the cost is 40. For a quality of 5000 the cost is 100.

TABLE IA—(*cont.*)

Base Value of Super ______
Base Value of Regular______

BUYER______ PERIOD______

	Unit	1st	2nd	3rd	4th	5th	Bonus
1	Base value						
2	Quality value						
3	Total value (row 1 + row 2)						
4	Price paid						
5	Profit (row 3 − row 4)						
6	Total per period earnings						

REGULAR SELLER______

Unit Sold		Trading Period Number	
1	1	1st unit sale price	
	2	Cost of unit = ____ × ____ = (quality)	
	3	Profit (row 1 − row 2)	
2	4	2nd unit sale price	
	5	Cost of unit = ____ × ____ =	
	6	Profit (row 4 − row 5)	
	7	Total per period earnings	

SUPER SELLER______

Unit Sold		Trading Period Number	
1	1	1st unit sale price	
	2	Cost of unit = ____ × ____ cents =	
	3	Profit (row 1 − row 2)	
2	4	2nd unit sale price	
	5	Cost of unit = ____ × ____ cents =	
	6	Profit (row 4 − row 5)	
	7	Total per period earnings	

Name______ Soc. Sec. No.______ Total Payment______
Address______

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