# Durable Goods, Coasian Dynamics, and Uncertainty: Theory and Experiments

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This paper presents a model in which a durable goods monopolist sells a product to two buyers. Each buyer is privately informed about his own valuation. Thus *all* players are imperfectly informed about market demand. We study the monopolist's pricing behavior as players' uncertainty regarding demand vanishes in the limit. In the limit, players are perfectly informed about the downward-sloping demand. We show that in all games belonging to a fixed and open neighborhood of the limit game there exists a generically unique equilibrium outcome that exhibits Coasian dynamics and in which play lasts for at most two periods. A laboratory experiment shows that, consistent with our theory, outcomes in the Certain and Uncertain Demand treatments are the same. Median opening prices in both treatments are roughly at the level predicted and considerably below the monopoly price. Consistent with Coasian dynamics, these prices are lower for higher discount factors. Demand withholding, however, leads to more trading periods than predicted.

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## I. Introduction

Theoretical predictions on the dynamic pricing behavior of a durable goods monopolist range from competitive pricing to perfect price discrimination over time. This wide range of predictions suggests an important role for empirical research on this topic, but unfortunately knowledge of empirical regularities in such markets is limited. In this paper, we provide some new evidence on durable goods monopoly pricing in a simple laboratory market. The market is designed keeping in mind the remarkable sensitivity of equilibria to changes in the extensive form game. Our results provide support for Coase's (1972) competitive pricing conjecture in all treatments.

Coase conjectured that a durable goods monopolist, selling a good over time, would price her products at less than the static monopoly price. Theoretical support for the Coase conjecture is by no means unanimous. Gul, Sonnenschein, and Wilson (1986) provide a justification for the conjecture based on a model with a continuum of buyers.[1] Strikingly, Bagnoli, Salant, and Swierzbinski (1989) show that for discrete demand and for sufficiently high discount factors, a monopolist who is perfectly informed about demand is able to "perfectly" price-discriminate.[2] Furthermore, there are no Coasian dynamics.[3] They do, however, point out that other equilibria could also exist.

That equilibrium outcomes may change drastically for apparently small changes in extensive form games has been known for quite some time (see, e.g., Fudenberg, Levine, and Tirole 1985). Furthermore, not much is known about actual structures of extensive form games in real-world durable goods monopolies. As such, our ability to predict pricing patterns in such markets is severely constrained. To compound problems, empirical research is limited, except for Suslow's (1986) analysis of Alcoa's aluminum pricing (motivated by an important antitrust case, *United States v. Aluminum Company of America* [148 F.2d 416, 1945]) and Reynolds' (2000) recent laboratory study.

Our basic objective in this paper is to provide more evidence of durable goods monopoly pricing from simple laboratory markets. Though evidence from experiments has drawbacks because of potential limitations regarding parallelism with the naturally occurring economy, ex-

[1] See Fudenberg and Tirole (1991) for a more complete list of references.

[2] We use the term "perfectly" not in a precise sense since the monopolist charges different prices over time. Hence her profits need to be corrected for the discount factor.

[3] Coasian dynamics will refer to the rate at which the monopolist's (initial) price approaches the perfectly competitive level, as the time period between price offers approaches zero (captured by the discount factor approaching one). Our usage of the term Coasian dynamics differs from that commonly employed in the literature. Authors often use the phrase Coasian dynamics to refer to the situation in which high-valued buyers buy earlier than low-valued ones and there is a pattern of monotonically decreasing prices over time.

periments have the advantage that they provide evidence from exogenously formulated games. Therefore, predictions can be associated with specific extensive form games (or institutions). Nevertheless, a bit of caution may be required in such exercises. In the following paragraph we explicitly state our concern.

In many experiments, as in our case, the experimenter may never be able to completely implement the game of his or her choice in actual laboratory environments. Participants in the laboratory could be playing games "close" to the one structured by the experimenter. Also, the experimenter may not know the "nature" of the nearby game that is played by participants. In such situations, the equilibrium of the exogenously specified game (whose outcome is being tested) should be robust to various types of minor perturbations. To be specific, an equilibrium of a game is said to be robust when the equilibrium outcome of some "nearby" game converges to the equilibrium outcome of the original game as the "distance" between the games converges to zero. Or loosely speaking, the equilibrium outcome of the specified game should not change drastically with (i.e., should not be sensitive to) "small" changes in the original game.

In laboratory markets such as ours, the discrete demand structure of Bagnoli et al. is of particular significance because with a finite number of (human) buyers and a finite number of goods, it is not possible to construct continuous demand curves. Even though one does not expect to see complete extraction of consumer surplus in experiments, we take the Bagnoli et al. result of perfect price discrimination as a benchmark hypothesis. The reason is that their result is robust to at least two kinds of perturbations of their original game. Levine and Pesendorfer (1995) consider a game in which the monopolist observes her sales with noise, so there is uncertainty over realized demand. Though, in general, perfect price discrimination cannot be sustained as an equilibrium outcome, it turns out that for a finite number of buyers and "small" levels of noise, the monopolist's profit is "close" to that under perfect price discrimination. Von der Fehr and Kühn (1995) consider a model in which, consistent with laboratory settings, prices are not fully divisible. Under additional conditions, as indivisibilities are reduced their equilibrium outcome converges to the Bagnoli et al. outcome.

In experimental settings, another perturbation may be of significance. It is quite clear that even if we provide the monopolist with perfect information about buyers' monetary payoffs (as we do in the Certain Demand treatment discussed below), it is impossible to provide perfect information about *utility* over monetary payoffs. Furthermore, as discussed in Fehr, Kirchsteiger, and Riedl (1998), taste parameters such as envy and spite might lead subjects to reject prices that provide them with little or no surplus. The extensive literature on the "ultimatum game" provides ample evidence that subjects reject positive surplus offers when the proposed allocation is highly unequal (see Roth [1995] for a survey). In experimental settings, private information over taste parameters is a norm rather than an exception. This, in our durable goods (experimental) setting, translates to the fact that the monopolist can never be certain about the demand curve (in an a priori sense).

Is the perfectly discriminating equilibrium of Bagnoli et al. robust to perturbations in which the monopolist is uncertain about demand? We address this question theoretically in Section II and show that there exists a unique Nash equilibrium outcome in the Certain Demand game that is robust to uncertainty about the demand curve. This outcome generates Coasian pricing and dynamics, with prices far below the price discrimination equilibrium of Bagnoli et al. Hence, we use the outcome of Coasian dynamics as a second hypothesis for our experiments.

These two hypotheses correspond to the extreme ends of the prevailing theoretical predictions. We are aware that careful consideration of complications such as learning and mistakes would generate additional hypotheses for the experiment. We do not model such complications. So our results, though potentially important for regulatory policies, should be interpreted cautiously.

In our experiment we implement two basic treatments. In the Certain Demand treatment, buyers' monetary valuations are announced and each buyer is assigned one and only one valuation. Announcing buyers' monetary valuations is not the same as announcing utility over these valuations, however, and the monopolist cannot know for certain that buyers would pay prices equal to these known valuations. Thus there is inherent private information even in the Certain Demand treatment. In our second, Uncertain Demand, treatment, buyers know their monetary valuations with certainty but sellers (as well as buyers) are informed that any particular buyer's valuation is a random variable. The probabilities assigned to these variables are announced. The uncertainty (exogenously) induced in this second treatment is "small." Our results show that we can rarely reject the hypothesis that the outcomes are the same in these two treatments. Moreover, the outcomes in both treatments are consistent with Coasian price predictions rather than the high prices of the Bagnoli et al. equilibrium outcome. The experiment implements three different discount factors through different game continuation probabilities. As predicted by Coasian dynamics, and again contrary to the Bagnoli et al. perfect price discrimination outcome, in the Certain Demand treatment, prices shift down toward competitive prices as the discount factor increases.

For readers who would like to skip Section II and go directly to sections on our experiment, here we provide a brief description of the theory presented in Section II. We consider a market with two buyers.

Call the buyers 1 and 2. In the Bagnoli et al. model, buyers 1 and 2 have high valuations for the good with respective probabilities of one and zero. The monopolist is uninformed about the buyers' identity, though she knows that there is one high-valued and one low-valued buyer. So the monopolist and the buyers know with certainty the downward-sloping market demand curve. In our alternative model, each buyer is privately informed about *only* his own valuation, which can be either "high" or "low." As in Bagnoli et al., the seller does not know the identity of the buyers. In particular, in our model the seller as well as the buyers are uncertain about market demand.

The buyers' valuations are drawn from independent distributions, and these distributions along with the seller's valuation are known.[4] Let $\mu_{11}$ and $\mu_{21}$ be the prior probabilities that buyers 1 and 2, respectively, have a high valuation. To keep the monopolist's uncertainty about demand "small," we consider all games in which $\mu_{11}$ and $\mu_{21}$ belong to the intervals (0, 1) and (0, $\alpha^*$), respectively. We explicitly specify a small and positive $\alpha^*$. Thus we consider a set of games in which both buyers are privately and independently informed about their own valuations. These games belong to a fixed open neighborhood of the perfect information game of Bagnoli et al. Our main result is that all games with parameters belonging to this neighborhood have a generically unique perfect Bayesian equilibrium outcome that exhibits Coasian dynamics. This establishes the fact that the Bagnoli et al. result is not robust to perturbations of the kind that we are considering. In other words, consider all sequences of games in which buyers 1 and 2 have high valuations with probabilities that belong to (0, 1). All nontrivial sequences of such kinds will eventually converge to the Bagnoli et al. game through our specified neighborhood. But in this neighborhood, we show that all equilibria exhibit Coasian outcomes.

There is another strength of our result. In general, limits of equilibrium outcomes may depend on the speeds of convergence of various parameters. For example, depending on different speeds of convergence in the Levine and Pesendorfer and von der Fehr and Kühn models, one can alternately get the Coasian and Bagnoli et al. outcomes as robust outcomes. By contrast, in all the games (in the neighborhood) that we consider, and for all discount factors, it turns out that, along the equilibrium path, play lasts for at most two periods. This provides an upper bound on the equilibrium opening price, which is independent of the distribution over valuations. As a result, our convergence result is independent of the speeds of convergence of the discount factor and "uncertainty."

[4] Since we assume that the space of buyers' valuations is discrete, the assumption on the seller's valuation is not necessary for our results.

The intuition behind our result with imperfect information is as follows. It is worthwhile for the monopolist to charge high prices only if buyers with high valuations buy with a (required) positive probability. Along equilibrium, when a good is (supposed to be) bought at a high price, the monopolist updates her beliefs at the beginning of the next period, regardless of whether a good is bought or not. By assumption, there is a low probability that both buyers have high valuations. Hence, posterior beliefs attach a low weight to the event that the remaining buyer(s) has a high valuation. As a result, the monopolist lowers prices in the succeeding period. Off the equilibrium path, if the seller were to charge a very high price in the first period, then each high-valued buyer would wait to buy the good in the succeeding period. But then the monopolist would not be able to sell at the very high price charged in period 1.

The remainder of the paper is organized as follows. Section II presents the theoretical model and collects the theoretical results. Section III describes the experimental design and procedures. Section IV contains the experimental results and relates our findings to the experimental literature. Section V presents conclusions.

## II. The Model

There are two risk-neutral buyers, 1 and 2, and a risk-neutral monopolist whose constant marginal cost is normalized to zero. The monopolist cannot identify the buyers; that is, faced with a buyer, she cannot say whether he is buyer 1 or 2. Let buyer $i$'s valuation be denoted by $v^i$, where $v^i$ can take values $v_1$ or $v_2$. For buyer $i$, $v^i = v_j$ with probability $\mu_{ij}$, $i, j \in \{1, 2\}$. For example, buyer 2 has valuation $v_1$ with probability $\mu_{21}$. Note that $\mu_{i1} + \mu_{i2} = 1$. Each buyer is privately informed about his own valuation and knows the distribution from which his valuation is drawn.[5] The distributions are assumed to be *independent* and to be common knowledge. We assume that $v_1 > v_2 > 0$. The assumption $v_2 > 0$ is quite weak because in the finite case a buyer would have a valuation exactly equal to that of the monopolist with probability zero and the monopolist will never trade with those with valuations below her cost.[6]

There are infinite time periods, and in each time period $t$, the monopolist sets a price in the first stage. Consumers who have not bought previously decide to buy one unit of the good or not buy in that period. Once a consumer buys a good, he leaves the market. For any period $t > 0$, the game may not proceed to $t + 1$ with a positive probability

[5] Our results would not change if we were to assume that buyers know their valuation but not the distribution from which their valuation is drawn.

[6] The assumption also induces a unique perfect Bayesian equilibrium outcome for $\mu_{ij} \in (0, 1)$.

$1-\delta$. All players are indifferent between one unit of payoff at period $t$ and one unit at $t+1$. In what follows in this section, we shall interpret this to be a model in which all players have a common discount factor of $\delta$ and the game proceeds to the next period with probability one. This change is made without loss of generality and is consistent with the cited literature. A date $t$ history for the monopolist is a sequence of vectors $\{(p_n, q_n)\}_0^{t-1}$, where $p_n$ is the price charged in period $n$ and $q_n$ is the number of goods sold through period $n$ (inclusive); for the consumer, a date $t$ history is a sequence $\{(p_{n+1}, q_n)\}_0^{t-1}$. For any particular history $h^t$, let $\mu_{ij}^{h^t}$ denote the belief of the monopolist that buyer $i$ has valuation $v_j$. Similarly, for a given history $h^t$, let $\mu_{ij}^{kh^t}$ be buyer $k$'s belief that buyer $i$ has valuation $v_j$. Let $p_0 = \infty$ and $q_0 = 0$. Note that for any period there are an infinite number of histories. A pure strategy of the monopolist is a price choice for every information set in a period for all periods. Similarly, for the consumers it is a decision "to buy" or "not to buy" for every history in a period for all periods.

We start with the perfect information model of Bagnoli et al., where $\mu_{11} = 1$ and $\mu_{21} = 0$. The concept of equilibrium is that of a subgame-perfect Nash equilibrium. Bagnoli et al. show that there exists an equilibrium in which the monopolist is able to perfectly discriminate for high values of $\delta$. Consider the following consumer strategies. For any period $t$, any period $t$ history, and any price $p_t^*$ charged by the monopolist, consumer $i$ buys the good *iff* $v_i \geq p_t^*$ (hence the consumer's strategy is independent of history and *myopic*). The monopolist uses the following strategy (*Pacman strategy*): For any period $t$, define $v_{\max}(t)$ to be the highest valuation of the set of consumers who have not purchased the good through period $t$. For each period $t$, the monopolist sets $p_t^* = v_{\max}(t)$ and drops this price in future periods *iff* at least one unit of the good is sold at this price (so the Pacman strategy depends on past sales). It is shown that these two strategies constitute an equilibrium when $1 > \delta > 1 - [\Delta/(v_1 + v_2)]$, where $\Delta = v_1 - v_2$. Proposition 1 is taken from Bagnoli et al., and hence we state it without proof.

Proposition 1. The myopic strategy is a sequentially best response for a buyer playing against the Pacman strategy. If all buyers use the myopic strategy, then the Pacman strategy is optimal whenever $1 > \delta > 1 - [\Delta/(v_1 + v_2)]$.

Prices in the Pacman strategy are independent of $\delta$ (in the relevant range). This is sharply at odds with the Coase conjecture. The driving force behind this strategy is the assumption that $\mu_{11} = 1$ and $\mu_{21} = 0$. If it were to be optimal for the monopolist to charge a price equal to $v_1$ in period 1 but if buyer 1 were to deviate from his myopic strategy and not buy, then it is still the case that in period 2, $\mu_{11} = 1$ and $\mu_{21} = 0$. As a result, since it was optimal for the seller to charge $v_1$ in period 1, it is optimal for her to charge $v_1$ in period 2. The deviating buyer is thus punished. Commitment to such punishment arises because of the monopolist's stationary beliefs. Commitment through stationary beliefs is, however, not possible with imperfect information.

In what follows we shall characterize equilibria for *all* games with parameters $0 < \mu_{11} < 1$ and $0 < \mu_{21} < \alpha^* < 1$. The term $\alpha^*$ is a fixed number to be specified later. The concept of equilibrium is perfect Bayesian. The games that we analyze belong to a fixed neighborhood around the Bagnoli et al. game (where $\mu_{11} = 1$ and $\mu_{21} = 0$).

In all the games that we study, in equilibrium the game ends in finite time with probability one. The reason is that the seller updates her beliefs in favor of the low-valued type when there is no sale in a given period. So, after a finite number of periods, either all goods are sold or the monopolist is willing to sell to buyers with the lowest type instead of charging a higher price and waiting for high-valued buyers to buy. Fudenberg et al. (1985) formalize this intuition in a one-buyer, one-seller environment. This "skimming property" of Fudenberg et al. applies almost directly in our environment. The next lemma, which provides a formal statement, is hence stated without proof.

LEMMA 1. In any perfect Bayesian equilibrium, for any period $\tau \leq t$, if a buyer with valuation $v$ is willing to accept an offer $p_\tau$, then a buyer with valuation $v' > v$ accepts the offer with probability one. Furthermore, the game ends with probability one after a finite number of periods.

By lemma 1 the game ends in a finite number of periods. Hence, we can use backward induction to compute equilibria in this game. The next step is to compute equilibria along different kinds of continuation games that may arise.

Consider the continuation game that starts after one good is sold. Since in this game there is only one buyer in the market, it is equivalent to the game studied in Hart (1989). To adapt Hart's result to our framework we need some notation. Let $\theta^t$ in period $t$ be the monopolist's belief that the surviving buyer is buyer 1. Let $\mu^t$ be the monopolist's belief that the surviving buyer has valuation $v_1$. Then $\mu^t = \theta^t\mu^t_{11} + (1 - \theta^t)\mu^t_{21}$, where $\mu^t_{i1}$ is the probability that the $i$th buyer has a valuation of $v_1$. Define $\alpha_1 \equiv v_2/v_1$. Hart's result is as follows.

LEMMA 2. In all continuation games starting from period $t$, with one surviving buyer, the game ends in a finite number of periods. The equilibrium outcome is generically unique. There exists a sequence of numbers $0 = \alpha_0 < \alpha_1 < \alpha_2 < \cdots$ such that, when $\mu^t \in (\alpha_i, \alpha_{i+1}]$, the game lasts for at most $i + 1$ periods. The price charged in period $t$ is $p^t = (1 - \delta^i)v_1 + \delta^i v_2$. The equilibrium price $p^t$ converges to $v_2$ as $\delta$ converges to one.

*Proof.* See Hart (1989).

Lemma 2 sheds light on an interesting aspect of the robustness of one-buyer, one-seller games. Outcomes of the perfect information version may be similar to that of a slightly perturbed version. A perfect information game in which the buyer has valuation $v_2$, that is, $\mu^t = 0$, yields the same outcome as the perturbed version in which the buyer can have valuation $v_1$ ($> v_2$) with probability $\mu^t \in (0, \alpha_1)$ and $v_2$ with probability $1 - \mu^t$. Thus one can say that the outcome in Bagnoli et al. is robust to information perturbations (of our kind) in a one-buyer, one-seller game. Bagnoli et al. (1992) get a similar result when all buyers have the same valuation but the monopolist is uninformed about the valuation. Since all buyers have the same valuation, this case is similar to the case in which there is just one buyer. The Bagnoli et al. result is robust to other perturbations as well. Lemma 3 states that when a buyer is high-valued with a high enough probability (relative to $\delta$), opening prices will be close to $v_1$.

LEMMA 3. Let $\mu^t \in (0, 1)$. For any finite $N$, there exists $\mu^t$ such that the game lasts for at most $N$ periods. The price charged in period $t$ is $p^t = (1 - \delta^N)v_1 + \delta^N v_2$. As $N$ converges to infinity, $p^t$ converges to $v_1$.

*Proof.* It follows from Hart (1989) that the lowest upper bound of the sequence $\{\alpha_i\}_{i=0}^{\infty}$ is one, and furthermore, $\alpha_{i+1} > \alpha_i$ for all $i$. The proof follows from the previous lemma and taking the limit of $p^t$ as $N$ tends to infinity. Q.E.D.

So what happens when there is more than one buyer? The question brings us to the study of another possible continuation game in which equilibrium outcomes may be similar to the Bagnoli et al. outcome (also see Bagnoli et al. 1992).

Consider continuation games in which both buyers are in the market, but with certainty one buyer is known to have the lower valuation of $v_2$. Without loss of generality let $\mu_{21}^t = 0$. Lemma 4 characterizes equilibria along all such continuation games. Since the proof is similar to that of lemma 2, it is omitted.

LEMMA 4. In all continuation games starting from period $t$, with two surviving buyers and $\mu_{21}^t = 0$, the game ends in a finite number of periods. The equilibrium outcome is generically unique. There exists a sequence of numbers $0 = \beta_0 < \beta_1 < \beta_2 < \cdots$ such that, when $\mu_{11}^t \in (\beta_i, \beta_{i+1}]$, the game lasts for at most $i + 1$ periods; $\beta_1 = 2\alpha_1$ and $\beta_2 < 2\alpha_2$. The price charged in period $t$ is $p^t = (1 - \delta^i)v_1 + \delta^i v_2$. The equilibrium price $p^t$ converges to $v_2$ as $\delta$ converges to one.

The two continuation games studied above are quite similar. In both cases, only one buyer has private information. A lemma similar to lemma 3 can also be proved, and one could show that when $\mu_{11}^t$ is "high," that is, the probability that buyer 1 has valuation $v_1$ is high, then the monopolist would charge an opening price close to $v_1$ and buyer 1 buys at this price with positive probability. Following the sale of a good, the monopolist lowers prices to $v_2$, at which price buyer 2 buys with probability one. Thus with positive probability the Bagnoli et al. outcome could occur.

We now study the overall game in which $\mu_{11} \in (0, 1)$ and $\mu_{21} \neq 0$ but is "small." The main difference between the continuation games studied above and the overall game is that both buyers have private information. An interesting result for the overall game is that continuation games, like the ones studied above, do not belong to the equilibrium path. Let us define $\alpha^* = [2/(1 + \alpha_1)]\alpha_1^2$, where $\alpha^* < \alpha_1$ as $\alpha_1 < 1$. We are now in a position to characterize the equilibrium outcomes of the overall game in which there are two buyers, $\mu_{11} \in (0, 1)$ and $\mu_{21} \in (0, \alpha^*)$. Our main result is stated in the next proposition.

PROPOSITION 2. Let $\mu_{11} \in (0, 1)$ and $\mu_{21} \in (0, \alpha^*)$. The game lasts for at most two more periods in equilibrium. All equilibria have a generically unique outcome. Along the equilibrium path, $p^1 = (1 - \delta)v_1 + \delta v_2$ and $p^2 = v_2$ when $\mu_{11} + \mu_{21} > 2\alpha_1$ and $p^1 = v_2$ when $\mu_{11} + \mu_{21} \leq 2\alpha_1$.

*Proof.* The proof, which depends on lemmas 5–8, discussed below, is presented in the Appendix.

Proposition 2 tells us that in the overall game, the price charged in period 1 is either $(1 - \delta)v_1 + \delta v_2$ (when $\mu_{11}$ is high) or $v_2$ (when $\mu_{11}$ is low). The equilibrium outcome is generically unique because there exists only one particular value of $\mu_{11}$ in which the price charged in period 1 can be either $(1 - \delta)v_1 + \delta v_2$ or $v_2$. Thus, for all $\mu_{11} \in (0, 1)$, the game lasts for at most two more periods. Hence, in contrast to lemmas 2 and 4, no matter how close $\mu_{11}$ is to one, opening prices are always bounded above by $(1 - \delta)v_1 + \delta v_2$. It is also the case that the price set in period 1 either is equal to $v_2$ or converges to $v_2$ as $\delta$ converges to one. So for $\mu_{11}$ close to one and $\mu_{21}$ close to zero, that is, when the monopolist is almost certain that she is facing a downward demand curve, the equilibrium induces the following unique outcome. In period 1 the monopolist sets a price equal to $(1 - \delta)v_1 + \delta v_2$. One or both goods are bought at this price with positive probability. Whatever the outcome, the monopolist reduces the price to $v_2$ in the next period. The remaining buyers buy the good at this price and the game ends.

To prove our result we proceed as follows. Proposition 2 claims that, along equilibrium, the game lasts for at most two periods. We shall prove proposition 2 by showing that the set of all equilibrium paths in which the game lasts for more than two periods is empty.

Recall from lemma 1 that in equilibrium the game lasts for a finite number of periods. So consider all finite equilibrium paths along which the game lasts for more than two periods with positive probability. If such paths do exist, then along any such path there has to exist $t$ such that the game goes to period $t + 2$ with positive probability and ends in period $t + 2$ with probability one. Call the set of such paths $\Xi'$. Our objective will be to show that $\Xi'$ is empty. This would then imply that the game lasts for at most two periods. Consider a *subset* of $\Xi'$, where $\mu_{11}^t \in (0, 1)$ and $\mu_{21}^t$ ($\equiv \epsilon^t$) $\in (0, \alpha^*)$ and the game goes to period $t+2$ with positive probability and ends in period $t+2$ with probability one. Call this set $\Xi$. Note that since $\mu_{21} \in (0, \alpha^*)$, Bayesian updating implies that $\epsilon^t \in [0, \alpha^*)$. The set $\Xi$ imposes a restriction on $\Xi'$ in the sense that it does not allow $\epsilon^t = 0$.

Before we go on to prove our result, it might be worthwhile to reiterate the intuition. First note that we require $\mu_{21}$ to be greater than zero. Otherwise we are back to the situation characterized in lemma 4. So $\mu_{21} > 0$ is a *necessary* condition. In other words, for our result it is necessary to have more than one high-valued buyer with positive probability. In this scenario, it is worthwhile for the monopolist to charge high prices only if there exist, with a sufficiently large probability, high-valued buyers and at least one buyer with high valuation buys with a (required) positive probability. When a good is bought at a high price, the monopolist updates her beliefs at the beginning of the next period. By assumption, $\mu_{21} \in (0, \alpha^*)$, and hence there is a low probability that both buyers have high valuations. So once a good is bought, posterior beliefs attach a low weight to the event that the remaining buyer has a high valuation. As a result the monopolist lowers prices. Buyers are now able to take advantage of an externality. A high-valued buyer waits to buy the good because he believes that, with positive probability, there is another buyer who would buy at the high price. But, as a consequence, all high-valued buyers wait, and the monopolist cannot sell at a high price. Note that for buyers to be able to take advantage of this externality, we need at least two high-valued buyers with positive probability.

We prove proposition 2 using a series of lemmas. The sequence of lemmas follows the sequence of logic in the intuition provided in the previous paragraph. All proofs of the lemmas are in the Appendix. Here we provide brief sketches.

First note that when the probability that both buyers have valuation $v_1$ is too low, then the game lasts for one period. The reason is that even if the monopolist were to be able to separate the two buyers and commit to specific prices for each of them, she would still not commit to a price higher than $v_2$ since the probability of executing a sale at this price would be too low. Hence the price charged by the monopolist would be $v_2$. Since the monopolist would never charge a lower price, it becomes worthwhile for all buyers to buy at this price.

LEMMA 5. In all continuation games starting from period $t$, if $\mu_{11}^t \leq \alpha_1$ and $\mu_{21}^t \leq \alpha_1$, then the game lasts for one period. The monopolist charges $p^t = v_2$ and both buyers buy at the price.

As mentioned above, it should be worthwhile for the monopolist to charge high prices only if at least one buyer with a high valuation buys with a (required) positive probability. We now proceed to formalize this notion. For all elements in $\Xi$ (recall that in this set both buyers have high valuation with positive probability), let consumers 1 and 2 (with valuation $v_1$) buy the good with probabilities $x$ and $y$, respectively, in period $t$. For all other periods $\tau$, we shall refer to these probabilities as $x^\tau$ and $y^\tau$. Since $\epsilon^t$ is "small," consumer 1 has to buy with a probability ($x$) large enough such that the monopolist finds it to her benefit *not to charge a lower price* and ends the game in $t+1$ (recall that in $\Xi$ the game goes to $t+2$ with positive probability). Lemma 6 provides a lower bound on $x$, for all equilibrium paths in $\Xi$.

LEMMA 6. For all elements in $\Xi$, it has to be the case that $x \geq (1 - \delta) + (\delta/\mu_{11}^t)(2\alpha_1 - \epsilon^t) > 0$.

Along all paths in $\Xi$, in period $t$ with $p^t > v_2$, either both goods are bought, one good is bought, or no good is bought. If both goods are bought, then the game ends. If exactly $i$ good is bought, $i \in \{0, 1\}$, then the probability that the surviving buyer is 1 and has a high valuation is $\theta_i^{t+1}\mu_{11}^{t+1}$; similarly, the probability that the surviving buyer is 2 and has a high valuation is $(1 - \theta_i^{t+1})\epsilon^{t+1}$, where

$$\theta_1^{t+1}\mu_{11}^{t+1} = \frac{\mu_{11}^t(1-x)\epsilon^t y}{\mu_{11}^t x(1-\epsilon^t y) + (1-\mu_{11}^t x)\epsilon^t y}, \quad (1)$$

$$(1-\theta_1^{t+1})\epsilon^{t+1} = \frac{\mu_{11}^t x\epsilon^t(1-y)}{\mu_{11}^t x(1-\epsilon^t y) + (1-\mu_{11}^t x)\epsilon^t y}, \quad (2)$$

$$\theta_0^{t+1}\mu_{11}^{t+1} = \frac{\mu_{11}^t(1-x)}{1-\mu_{11}^t x}, \quad (3)$$

and

$$(1-\theta_0^{t+1})\epsilon^{t+1} = \frac{\epsilon^t(1-y)}{1-\epsilon^t y}. \quad (4)$$

Since all paths in $\Xi$ go to $t+2$ with positive probability, it cannot be that the monopolist finds it optimal to end the game in period $t+1$ by charging $v_2$. Therefore, following lemma 5, we have to rule out the case (case 0) in which $\theta_1^{t+1}\mu_{11}^{t+1} < \alpha_1$ and $\theta_0^{t+1}\mu_{11}^{t+1} < \alpha_1$. So, along all paths in $\Xi$, either $\theta_1^{t+1}\mu_{11}^{t+1} \geq \alpha_1$ or $\theta_0^{t+1}\mu_{11}^{t+1} \geq \alpha_1$ (or both). Now, there are two cases in which $\theta_1^{t+1}\mu_{11}^{t+1} \geq \alpha_1$, call them cases 1 and 2, and one more case in which $\theta_1^{t+1}\mu_{11}^{t+1} < \alpha_1$, call it case 3. Note that in case 3, $\theta_0^{t+1}\mu_{11}^{t+1} \geq \alpha_1$.

LEMMA 7. There exists no element in $\Xi$ under which case 1 or case 2 would hold.

Since, by definition of $\Xi$, case 0 is ruled out and the previous lemma rules out cases 1 and 2, it follows that case 3 must be true for all paths in $\Xi$. Now, under case 3, when no good is bought in period $t$, the probability that the surviving buyer is 1 and has valuation $v_1$ has to be high; furthermore, it should be profitable for the monopolist to sell only to the high-valued buyer in $t+1$. But, as it turns out again, this is not possible given the requirement on $x$. As a result, case 3 also cannot hold, and therefore the set $\Xi$, as defined, has to be empty.

LEMMA 8. The set $\Xi = \emptyset$.

From the previous lemma we understand the following. With two buyers in the market, if the game were to go on for three more periods with positive probability and end there with probability one, then it must be the case that the monopolist knows that buyer 2 has valuation $v_2$. That is, $\mu_{21}^t = 0$, and lemma 4 is then applicable. But then if buyer 2 were to be of the high type, he must have bought before at a price higher than $p^t$. Would he do so? He would not because of an externality. Suppose, in equilibrium, that the high-valued buyer 2 is expected to buy in some period $\tau$. But suppose that he decides not to buy. Then he knows that in $\tau + 2$ the price would fall to $v_2$ with positive probability (since the high-valued buyer 1 would buy in $\tau + 1$ with positive probability). So, to induce the high-valued buyer 2 to buy, the price charged in period $\tau$ has to be sufficiently low. It turns out that this price is so low that the high-valued buyer 1 also finds it to his benefit to buy with probability one at this price. Since all high-valued buyers buy at $\tau$, the buyers remaining in period $\tau + 1$ have to have valuation $v_2$. So it is optimal for the monopolist to charge $v_2$ in $\tau + 1$ and end the game. Thus the game can last for at most two periods.

Proposition 2 implies that equilibrium outcomes exhibit Coasian dynamics when the monopolist knows that there exists a buyer (buyer 1) who almost surely has a valuation of $v_1$ and another buyer (buyer 2) who almost surely has a valuation of $v_2$.[7] In particular, the result holds for values of $\mu_{11}$ close to one and $\mu_{21}$ close to zero. Furthermore, our result is invariant to values of $\mu_{11}$ and $\mu_{21}$ in (nontrivial) ranges around one and zero, respectively. This, coupled with the fact that laboratory environments are inherently noisy, leads to the conjecture that (i) experimental treatments with "perfect information" should give us results similar to those with treatments that exogenously impose "small" imperfect information, and (ii) the results should be consistent with Coasian dynamics. The key for this conjecture to hold is that the high-valued buyer 1 (and of course the seller) believes that buyer 2 would pay more than his assigned valuation of $v_2$ with an arbitrarily small (but positive)

[7] Recall that the monopolist does not know the identity of the buyers. Faced with a buyer, the monopolist cannot tell whether he is buyer 1 or buyer 2.

probability. This belief is quite plausible given the nonmonetary payoffs often observed in laboratory markets.[8]

## III. Experimental Design and Procedures

In this durable goods setting the seller has power over price and buyers make only "accept" or "reject" purchase decisions. Therefore, the seller posts prices each period as in the standard posted offer trading institution. Each market includes two buyers and a single seller, and each buyer can purchase up to one unit per trading round. If buyer $i$ with redemption value $v_i^j$ buys at price $p$, she earns $v_i^j - p$ that round. Sellers always face zero marginal costs, and there are no fixed costs. Therefore, if a seller sells a unit at price $p$, she simply earns $p$ on that unit.[9] Since the seller faces two buyers, she can sell at most two units per round. From now on we shall use the term "valuation" instead of "redemption value."

Within each trading round the seller posts one price per "period" across a sequence of periods. The seller also specifies the number of units she is willing to offer at this price, which must equal the number of units she has remaining in inventory for that round (either one or two). Buyers then decide simultaneously whether to execute a transaction by accepting the seller's offer price.[10] In subsequent periods, sellers are free to submit new price offers.

A trading round ends if either ($a$) both buyers purchase their single units or ($b$) the round terminates randomly. At the end of every offer period (after buyer purchase decisions), if at least one buyer has not purchased her unit, a die is rolled in full view of subjects. This die roll implements a continuation probability that we manipulated at three levels across sessions: $\delta = .6$, .75, and .9. For example, when $\delta = .9$, if the outcome of the roll of a 10-sided die is a zero, then the round ends immediately; otherwise the seller posts a new price and the round continues to the next offer period. This continuation probability is fixed across periods within a round and within a session.

Each session employed 12, 15, or 18 subjects, with two buyers for each monopoly seller, organized into one market for each seller. Sixteen of the 25 sessions employed 18 subjects. For example, with 18 subjects, six

[8] For example, buyers in first-price auctions often bid as though they have a (nonmonetary) utility of winning. Some small number of subjects in the present setting could receive a utility from successfully executing a transaction or could simply make mistakes.

[9] Note that redemption valuation and profits are given in monetary terms. They may or may not be equivalent to utility payoffs.

[10] Requiring the seller to offer both units when she has not yet sold any in the round ensures that all buyers are able to purchase in any period. This permits simultaneous acceptance decisions by the buyers rather than requiring buyers to make purchase decisions in a random order, as is frequently done in posted offer experiments.

subjects are sellers, 12 subjects are buyers, and six markets are conducted simultaneously. At the end of each trading round, buyers and sellers are reorganized into new markets with different buyers and sellers for the next round—a so-called strangers design. This random shuffling of subjects each round essentially implements a sequence of one-shot games and has been shown to successfully minimize any repeated game incentives across rounds (e.g., Durham, Hirshleifer, and Smith 1998). Subjects' identities are always concealed, although the sellers and buyers sat on opposite sides of the laboratory, which was obvious to subjects. Usually six trading rounds were conducted in each session. Occasionally only five rounds were possible within the session time period when $\delta = .9$, and we were able to complete more than six rounds sometimes when $\delta = .6$.

The experiment was conducted using the Multiple Unit Double Auction trading software developed at California Institute of Technology (Plott 1991). Although designed initially for conducting experiments using the continuous double-auction trading institution, it is easily adapted for posted offer trading. Sellers post offers in different markets shown on different "pages," which are shown on different screens of the program, and buyers and sellers move to new markets in different rounds using the "page up" or "page down" keys on their keyboards.

As mentioned in the Introduction, for each of the three continuation probabilities, we implement two experimental treatments that varied the composition and information of demand. In the Certain Demand treatment, one buyer in each market has a valuation of 54 pesos and the other buyer has a valuation of 18 pesos. This is explained to all subjects in the instructions. The instructions also explain that buyers' valuations can change between 18 and 54 in different trading rounds, but each market always contains one buyer with each valuation. Furthermore, these valuations remain constant across periods within the same trading round. The ratio of the difference in valuations ($\Delta = 36$) to the sum of valuations (72) is 0.5. If valuations were to be equivalent to utility payoffs, then one could interpret the Certain Demand treatment in the literal sense. If so, then with any continuation probability $\delta > .5$, the Pacman strategy is an equilibrium strategy (proposition 1). As summarized in table 1, if subjects play the Pacman equilibrium, the game should last at most two periods, with the opening price equal to 54 and the second price equal to 18. Note that in this equilibrium, offer prices are independent of $\delta$.

In the Uncertain Demand treatment, each buyer knows his own valuation with certainty, but sellers know only the probability distribution underlying buyer valuations. Buyer 1 has a valuation of 54 pesos with probability .95 and a valuation of 18 with probability .05. Buyer 2 has a valuation of 18 pesos with probability .95 and a valuation of 54 with

TABLE 1

SUMMARY OF EXPERIMENT PARAMETERS AND THEORETICAL PREDICTIONS

A. PARAMETERS

| Certain Demand Treatment | | Uncertain Demand Treatment | |
|---|---|---|---|
| $v_1 = 54$ | $v_2 = 18$ | $v_1 = 54$ | $v_2 = 18$ |
| $\mu_{11} = \mu_{22} = 1$ | $\mu_{12} = \mu_{21} = 0$ | $\mu_{11} = \mu_{22} = .95$ | $\mu_{12} = \mu_{21} = .05$ |

B. EQUILIBRIUM PREDICTIONS

| | CERTAIN DEMAND TREATMENT | | | UNCERTAIN DEMAND TREATMENT | | |
|---|---|---|---|---|---|---|
| $\delta$ TREATMENT | Number of Periods | Price $p^1$ $(=v_1)$ (Pacman Equilibrium) | Price $p^2$ $(=v_2)$ | Number of Periods | Price $p^1$ $(=[1-\delta]v_1+\delta v_2)$ | Price $p^2$ $(=v_2)$ |
| $\delta = .60$ | 2 | 54 | 18 | 2 | 32.4 | 18 |
| $\delta = .75$ | 2 | 54 | 18 | 2 | 27 | 18 |
| $\delta = .90$ | 2 | 54 | 18 | 2 | 21.6 | 18 |

NOTE.—Each session employed two buyers for each monopoly seller. Sellers and buyers were randomly reassigned to new markets each trading round.

probability .05. If one were to assume no divergence between utility and valuation, then in terms of the notation used in Section II, $\mu_{11} = \mu_{22} = .95$ and $\mu_{12} = \mu_{21} = .05$. Therefore, the seller knows that with probability .905 she faces one buyer with a value of 54 and one buyer with a value of 18, as in the Certain Demand treatment. She also knows that with probability .0475 she faces two buyers that both have a value of 54 and with probability .0475 she faces two buyers that both have a value of 18. The experimenters determined the random values prior to the experiment using a 20-sided die, and the same drawn sequence of random values was used in all Uncertain Demand sessions. The instructions also explain that buyers can change between buyers 1 and 2 in different trading periods and that buyer valuations remain constant across periods in the same trading round. Note that $\mu_{21} = .05$, and since $\alpha_1 = \frac{1}{3}$, we have $\mu_{21} = .05 < \alpha^* = \frac{1}{6}$. Further, $\mu_{11} + \mu_{21} = 1 > \frac{2}{9}$ $(= 2\alpha_1)$. So from proposition 2, it follows that the unique outcome is such that the game should last two periods, with the opening price equal to $(1 - \delta)54 + \delta 18$ and the second price equal to $v_2 = 18$. Table 1 summarizes these parameters and price predictions.

As discussed above, the Pacman equilibrium in the Certain Demand treatment may not be robust to the endogenous (or inherent) incomplete information regarding buyer reservation values.[11] Note also that the specific price predictions in the Uncertain Demand treatment are sensitive to $\delta$ but not to the level of uncertainty (by proposition 2 the outcome should not change for all $\mu_{21} \in (0, \frac{1}{9})$ and $\mu_{11}$ such that $\mu_{11} + \mu_{21} > \frac{2}{9}$). So if the endogenous uncertainty in the Certain Demand treatment is small and if adding further noise in the Uncertain Demand treatment does not violate the condition imposed in proposition 2, then there is reason to expect that endogenous uncertainty in the Certain Demand treatment may lead to prices that are similar to prices in the Uncertain Demand treatment.

We report 13 sessions in the Certain Demand treatment and 12 sessions in the Uncertain Demand treatment, employing a total of 408 subjects: 336 subjects were inexperienced and 72 were experienced in a previous session of this series. Table 2 summarizes the number of monopolists in each of the treatments. Experienced sessions were conducted in only the $\delta = .9$ and .6 treatments, where the largest difference in opening prices is expected. Subjects were recruited using in-class

[11] Some readers have suggested an alternative "robot buyers" treatment to test the Pacman equilibrium. In such a treatment, the experimenter would make purchase decisions for the buyers using an announced myopic strategy (i.e., buy one unit at a price no higher than 54 and a second unit at a price no higher than 18). Although we considered such a treatment, we expect that these announced buyer strategies would make the Pacman strategy rather obvious, so little would be learned in such a nonstrategic environment. We therefore chose to devote the scarce resources to pay subjects to the strategic environment with human buyers.

TABLE 2
Number of Monopolists in Each Treatment

| δ Treatment | Certain Demand | Uncertain Demand |
|---|---|---|
| $\delta = .6$ | 27 monopolists (6 experienced) | 22 monopolists (6 experienced) |
| $\delta = .75$ | 18 monopolists | 18 monopolists |
| $\delta = .9$ | 26 monopolists (6 experienced) | 24 monopolists (6 experienced) |

Note.—δ denotes the continuation probability from one period to the next.

announcements from the general undergraduate population at the Instituto Tecnológico Autónomo de México. All experiments were conducted in Spanish.[12] Subjects were paid 50 pesos as an appearance fee plus their profit from trading. Salient earnings per subject ranged from a minimum of 2 pesos to a maximum of 342 pesos, with an average of 107 pesos. The approximate exchange rate when the experiment was conducted was 10 pesos equal to U.S.$1.00, but in terms of local purchasing power, the average earnings considerably exceed the equivalent of U.S.$30. On average, a session required about 105 minutes to complete.

## IV. Results

We organize the results using hypotheses derived from the theory presented in Section II. Subsections *A* and *B* present results from the Certain and Uncertain Demand treatments. Subsection *C* compares the results in these two treatments, and Subsection *D* compares prices for the three δ treatments. Subsection *E* briefly compares the results to the related experimental literature.

### *A. Certain Demand*

Hypothesis 1. Median opening offer prices equal 54—the highest buyer valuation.

Table 3 presents the opening offer prices in the inexperienced Certain Demand sessions, separately by the continuation probability treatment (δ). Nearly all offer prices fall well below 54, rejecting hypothesis 1. In some rounds the mean offer price exceeds the median offer price by a wide margin, because of a few outlying prices. However, over all, only 14 out of 378 opening prices (4 percent) are greater than or equal to 54. The bottom of table 3 indicates that the median offer pooled across rounds is 35 pesos when $\delta = .6$, 30 pesos when $\delta = .75$, and 26 pesos

[12] An English translation of the instructions is available from the authors.

when $\delta = .9$. The medians are, respectively 35, 28, and 25 in round 6. As we discuss below, note that these median offer prices are roughly consistent with the equilibrium predictions of the incomplete information model (which are 32.4, 27, and 21.6, respectively). Figure 1 summarizes the opening prices across the six trading rounds, separately for each $\delta$ treatment. Opening prices tend to fall, and the variance tends to decline across rounds. In every round and in every treatment, a nonparametric Wilcoxon sign rank test rejects the null hypothesis that the median prices equal 54 at the 1 percent significance level.[13]

Figure 2 presents the opening offer prices across the six trading rounds for the experienced sessions. For both $\delta$ treatments, prices are substantially below 54, again rejecting hypothesis 1. For $\delta = .6$, opening prices are remarkably close to the incomplete information model prediction. For $\delta = .9$, opening prices usually exceed the incomplete information model prediction.[14]

Hypothesis 2. Median offer prices after one unit has been sold equal 18—the second-highest buyer valuation.

When all rounds in the inexperienced sessions are pooled, the median offer price immediately after one unit has been sold is 20 pesos when $\delta = .6$, 16 pesos when $\delta = .75$, and 15 pesos when $\delta = .9$.[15] The medians are 18, 16, and 15, respectively, in the final round. According to the Wilcoxon test, median offers are not significantly different from 18 at the 5 percent level in all but two individual rounds. This provides some support for hypothesis 2. In the experienced sessions, when all rounds are pooled, the median offer price immediately after one unit has been sold is 14 pesos when $\delta = .6$ and 15 pesos when $\delta = .9$.

One interpretation of the result that opening prices are substantially below 54 is that subjects—as in most experiments on the ultimatum game—resist highly asymmetric distributions of exchange surplus. The observed opening prices are often in the range of 20–40 pesos, which if accepted lead the monopolist to earn roughly 35–75 percent of the gains from trade. Ultimatum offers are in this same range, although they typically offer no more than one-half of the surplus to the respon-

[13] Here and in what follows we report statistical tests only for the independent markets, separately for each round. We cannot pool observations for this statistical test across rounds because the same seller makes multiple price offers in different rounds, causing the data to be nonindependent when all rounds are pooled.

[14] Statistical tests for individual rounds of the experienced data have low statistical power because only six sellers participated in each treatment for the experienced data. Therefore, we focus on statistical tests for the inexperienced data and usually report only summary statistics for the experienced data to assess if a major shift in behavior occurs as subjects gain experience.

[15] Some of the offers exceed the low valuation of 18, which may reflect mistakes or confusion on the part of sellers when they have already sold a unit at a price above 18 (most probably to their high-valuation buyer). Some sellers, however, may believe (sometimes correctly) that they sold their first unit to the low-valued buyer.

TABLE 3
MEDIAN AND MEAN OPENING PERIOD PRICES IN THE CERTAIN DEMAND TREATMENT WITH INEXPERIENCED SUBJECTS

| | $\delta = .6$ | | | $\delta = .75$ | | | $\delta = .9$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | $N = 21$ per Round[a] | Pacman Equilibrium | Uncertain Demand Equilibrium | $N = 18$ per Round | Pacman Equilibrium | Uncertain Demand Equilibrium | $N = 20$ per Round[b] | Pacman Equilibrium | Uncertain Demand Equilibrium |
| Round 1: | | | | | | | | | |
| Median offer | 45 | 54* | 32.4* | 30.5 | 54* | 27 | 31.5 | 54* | 21.6* |
| Mean offer | 66.8 | | | 31.8 | | | 74.2 | | |
| Standard error | 21.90 | | | 2.12 | | | 38.31 | | |
| Round 2: | | | | | | | | | |
| Median offer | 40 | 54* | 32.4* | 30 | 54* | 27* | 30 | 54* | 21.6* |
| Mean offer | 43.3 | | | 32.3 | | | 31.65 | | |
| Standard error | 3.80 | | | 2.16 | | | 3.55 | | |
| Round 3: | | | | | | | | | |
| Median offer | 36 | 54* | 32.4 | 30 | 54* | 27* | 27.5 | 54* | 21.6* |
| Mean offer | 35.3 | | | 33.6 | | | 28.5 | | |
| Standard error | 2.08 | | | 2.13 | | | 2.54 | | |
| Round 4: | | | | | | | | | |
| Median offer | 32 | 54* | 32.4 | 30 | 54* | 27* | 25 | 54* | 21.6 |
| Mean offer | 35.2 | | | 30.8 | | | 26.6 | | |
| Standard error | 3.73 | | | 1.46 | | | 2.40 | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Round 5: | | | | | | | | | |
| Median offer | 33 | 54* | 32.4 | 28.5 | 54* | 27 | 25 | 54* | 21.6 |
| Mean offer | 32.1 | | | 29 | | | 25.4 | | |
| Standard error | 1.56 | | | 1.90 | | | 2.02 | | |
| Round 6: | | | | | | | | | |
| Median offer | 35 | 54* | 32.4 | 28 | 54* | 27 | 25 | 54* | 21.6 |
| Mean offer | 43.1 | | | 29.6 | | | 24.7 | | |
| Standard error | 10.00 | | | 1.67 | | | 1.86 | | |
| All rounds pooled: | | | | | | | | | |
| Median offer | 35 | 54 | 32.4 | 30 | 54 | 27 | 26 | 54 | 21.6 |
| Mean offer | 46.2 | | | 31.2 | | | 35.6 | | |
| Standard error | 7.04 | | | .78 | | | 6.80 | | |

[a] Round 6 has only 17 observations.
[b] Round 6 has only 15 observations.
* This equilibrium price prediction is rejected at the 5 percent significance level using a two-tailed Wilcoxon test. This test is not conducted on the pooled rounds data.

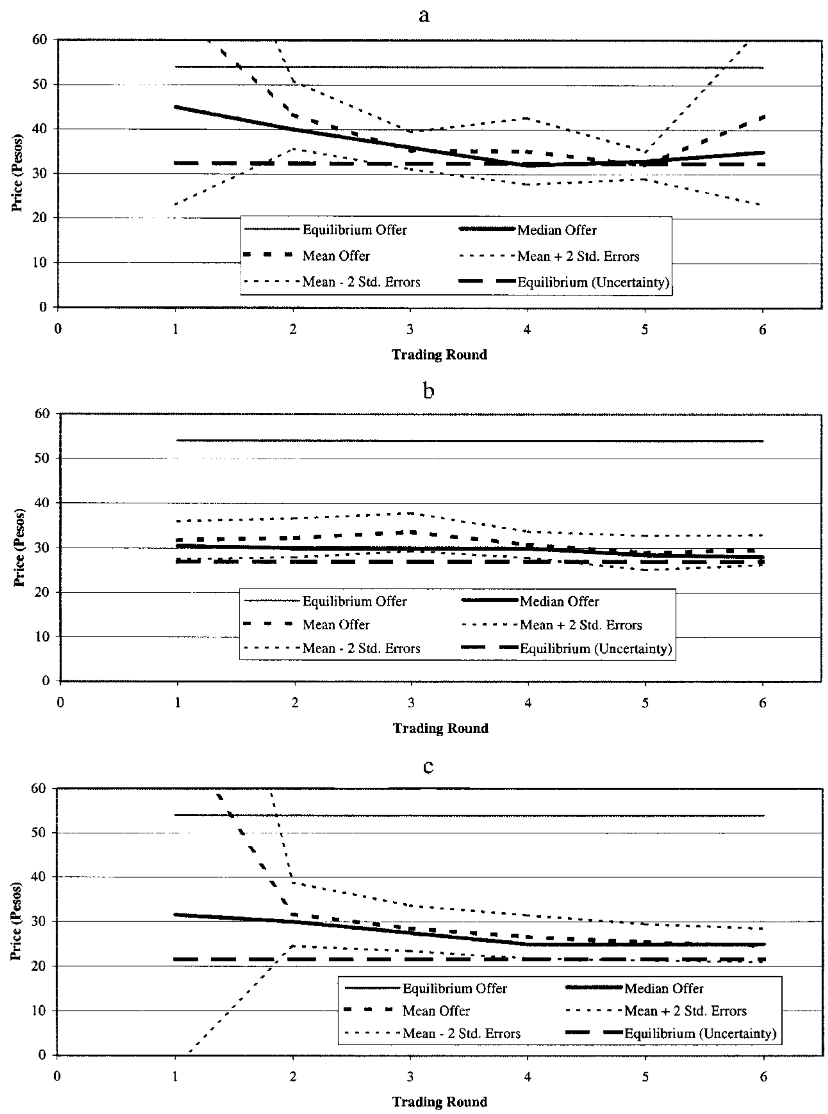


FIG. 1.—Opening offer prices, by trading round, for inexperienced certain demand. *a,* Continuation probability $\delta = .6$; 21 observations per round except round 6 (17 observations). *b,* Continuation probability $\delta = .75$; 18 observations per round. *c,* Continuation probability $\delta = .9$; 20 observations per round except round 6 (15 observations).

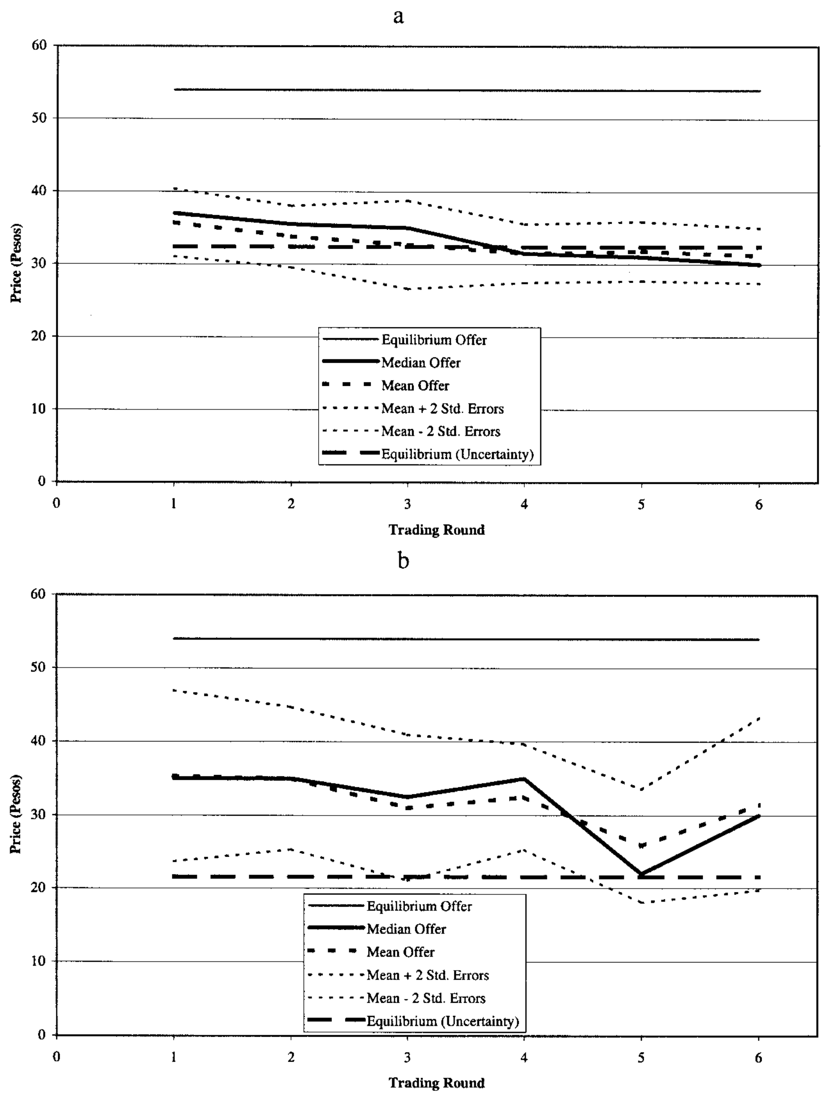


FIG. 2.—Opening offer prices, by trading round, for experienced certain demand. *a,* Continuation probability $\delta = .6$; six observations per round. *b,* Continuation probability $\delta = .9$; six observations per round.

dent (in our case this translates to offer prices greater than or equal to 27). According to this interpretation, our failure to observe prices near 54 is similar to the well-documented failure to observe ultimatum offers near the equilibrium level. The equilibrium offer in the ultimatum game is 1 peso (i.e., a price of 53 pesos), which is the smallest unit of exchange.

There is a problem with this interpretation, however. In our experiments we observe median prices near 18 after one unit has been sold. Median second-unit offers are about 16 pesos, which provides the second buyer with only 11 percent of the exchange surplus. Offers with such extreme earnings distributions are rarely observed in ultimatum game experiments.[16] Moreover, surely fairness considerations alone cannot describe the data, for as formally documented below, sellers strategically change prices as $\delta$ changes.

Hypothesis 3. Both units are purchased after exactly two trading periods have been completed.

This hypothesis is clearly rejected by the data. The random termination rule sometimes exogenously terminates the round after only one trading period, so to test hypothesis 3 we include only those rounds that continued for at least two periods. Table 4 shows that in the inexperienced Certain Demand treatments, both units were purchased by the end of the second period in only 6–22 percent of the rounds that could continue through two periods. In the experienced Certain Demand treatments, both units were purchased by the end of the second period in less than one-third of the rounds. In both experience conditions, the rate at which both units are sold within two periods falls as $\delta$ rises.

To provide some insight into why rounds typically extend beyond two periods, table 5 presents the distribution of opening prices pooled across rounds, along with the number of acceptances by at least one buyer. In the Pacman equilibrium, myopic strategy calls for an acceptance rate of 1.00 for all prices below 54. This is clearly rejected by the data. The acceptance rate tends to be inversely related to opening prices, though it usually remains well below 1.00 except for very low prices. Equilibrium in the incomplete information model implies very sharp cutoffs for acceptable prices, depending on $\delta$. The table highlights in bold the range of prices accepted with probability one in equilibrium. The acceptance rate is rather high for the inexperienced $\delta = .6$ treatment, even for prices slightly exceeding the acceptance threshold (33–35 pesos). But elsewhere the acceptance rates tend to fall below one-half as prices begin to approach the theoretical acceptance threshold from

[16] For example, in the 10 ultimatum game experiments summarized by Fehr and Schmidt (1999), only 4 percent of the offers provide less than 20 percent of the total surplus to the respondent.

TABLE 4

NUMBER OF ROUNDS WITH BOTH UNITS SOLD WITHIN TWO PERIODS

| Treatment and Experience Level | Rounds with Two Units Sold (1) | Total Rounds Not Randomly Terminated after First Period (2) | Rate Two Units Sold (col. 1/col. 2) (3) |
|---|---|---|---|
| | Certain Demand Treatment | | |
| $\delta = .6$: | | | |
| Inexperienced | 17 | 77 | .22 |
| Experienced | 13 | 42 | .31 |
| $\delta = .75$: | | | |
| Inexperienced | 12 | 90[a] | .13 |
| $\delta = .9$: | | | |
| Inexperienced | 6 | 95 | .06 |
| Experienced | 0 | 36 | .00 |
| | Uncertain Demand Treatment | | |
| $\delta = .6$: | | | |
| Inexperienced | 20 | 65[b] | .31 |
| Experienced | 7 | 18 | .39 |
| $\delta = .75$: | | | |
| Inexperienced | 17 | 86[c] | .20 |
| $\delta = .9$: | | | |
| Inexperienced | 5 | 107 | .05 |
| Experienced | 1 | 30 | .03 |

[a] Includes one round with both units sold that terminated after one period.

[b] Includes three rounds with both units sold that terminated after one period.

[c] Includes two rounds with both units sold that terminated after one period.

TABLE 5
Opening Price Offers and Acceptance Rate for Certain Demand Sessions

| | Price Range (Pesos) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | <19 | 19–21 | 22–24 | 25–27 | 28–30 | 31–32 | 33–35 | 36–38 | 39–41 | >41 |
| | Inexperienced Sessions | | | | | | | | | |
| $\delta=.6$: | | | | | | | | | | |
| Opening price frequency | 5 | 13 | 6 | 16 | 18 | 4 | 16 | 5 | 35 | 37 |
| Number accepted | 5 | 12 | 6 | 15 | 14 | 2 | 13 | 1 | 15 | 9 |
| Acceptance rate | **1.00** | **.92** | **1.00** | **.94** | **.78** | **.50** | .81 | .20 | .43 | .24 |
| $\delta=.75$: | | | | | | | | | | |
| Opening price frequency | 5 | 5 | 7 | 24 | 22 | 5 | 12 | 6 | 10 | 12 |
| Number accepted | 5 | 4 | 3 | 13 | 6 | 2 | 2 | 0 | 1 | 1 |
| Acceptance rate | **1.00** | **.80** | **.43** | **.54** | .27 | .40 | .17 | .00 | .10 | .08 |
| $\delta=.9$: | | | | | | | | | | |
| Opening price frequency | 20 | 19 | 5 | 16 | 19 | 2 | 10 | 1 | 3 | 20 |
| Number accepted | 12 | 8 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 1 |
| Acceptance rate | **.60** | **.42** | .00 | .25 | .11 | .50 | .00 | .00 | .00 | .05 |
| | Experienced Sessions | | | | | | | | | |
| $\delta=.6$: | | | | | | | | | | |
| Opening price frequency | 1 | 2 | 2 | 9 | 15 | 3 | 10 | 5 | 7 | 0 |
| Number accepted | 1 | 2 | 2 | 6 | 6 | 1 | 1 | 0 | 0 | 0 |
| Acceptance rate | **1.00** | **1.00** | **1.00** | **.67** | **.40** | **.33** | .10 | .00 | .00 | … |
| $\delta=.9$: | | | | | | | | | | |
| Opening price frequency | 3 | 8 | 1 | 4 | 2 | 0 | 5 | 0 | 6 | 7 |
| Number accepted | 1 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Acceptance rate | **.33** | **.25** | .00 | .00 | .50 | … | .20 | … | .00 | .00 |

Note.—The incomplete information model predicts acceptance rates of 1.00 in the bold highlighted regions and acceptance rates of .00 elsewhere.

below. These high rejection rates cause the rounds to extend beyond two periods quite frequently.

Although the finding that the rejection rate generally increases with increases in the offer price is reminiscent of the standard ultimatum game, table 5 highlights several ways in which the present experiment differs from the ultimatum game. First, the fraction of "fair" opening offers that provide the seller and the high-valued buyer with at least 40 percent of the exchange surplus ranges between 19 and 54 percent in our various $\delta$ and experience treatments. This is well below the overall rate of 71 percent in ultimatum games (Fehr and Schmidt 1999). Second, note that the acceptance rate for prices in various ranges of table 5 changes significantly as $\delta$ changes. Although the acceptance threshold is clearly not as sharp as implied by the incomplete information model, acceptance rates decline as $\delta$ increases; for example, the inexperienced sessions' acceptance rate for the price range 25–27 is 94 percent when $\delta = .6$, 54 percent when $\delta = .75$, and 25 percent when $\delta = .9$. Statistical tests for individual, independent periods are not possible because of

TABLE 6
MEDIAN AND MEAN OPENING PERIOD PRICES IN THE UNCERTAIN DEMAND TREATMENT WITH INEXPERIENCED SUBJECTS

| | $\delta=.6$ | | $\delta=.75$ | | $\delta=.9$ | |
|---|---|---|---|---|---|---|
| | $N=16$ per Round | Uncertain Demand Equilibrium | $N=18$ per Round | Uncertain Demand Equilibrium | $N=18$ per Round | Uncertain Demand Equilibrium |
| Round 1: | | | | | | |
| Median offer | 39 | 32.4* | 35 | 27* | 32.5 | 21.6* |
| Mean offer | 50.4 | | 59.6 | | 42.4 | |
| Standard error | 9.36 | | 23.65 | | 7.52 | |
| Round 2: | | | | | | |
| Median offer | 37 | 32.4 | 30 | 27 | 35 | 21.6* |
| Mean offer | 40.4 | | 32.1 | | 40.2 | |
| Standard error | 4.94 | | 2.96 | | 6.95 | |
| Round 3: | | | | | | |
| Median offer | 33.5 | 32.4 | 27 | 27 | 25 | 21.6* |
| Mean offer | 34.1 | | 28.2 | | 28.3 | |
| Standard error | 3.54 | | 2.32 | | 2.40 | |
| Round 4: | | | | | | |
| Median offer | 30 | 32.4 | 28 | 27 | 26 | 21.6* |
| Mean offer | 30.1 | | 28.6 | | 29.3 | |
| Standard error | 2.32 | | 1.95 | | 2.65 | |
| Round 5: | | | | | | |
| Median offer | 25 | 32.4* | 26 | 27 | 25 | 21.6* |
| Mean offer | 25.7 | | 28.9 | | 26.1 | |
| Standard error | 2.14 | | 3.20 | | 1.78 | |
| Round 6: | | | | | | |
| Median offer | 25 | 32.4* | 26 | 27 | 26 | 21.6* |
| Mean offer | 24.6 | | 25.8 | | 26.3 | |
| Standard error | 1.86 | | 2.13 | | 1.87 | |
| All rounds pooled: | | | | | | |
| Median offer | 30 | 32.4 | 28 | 27 | 28 | 21.6 |
| Mean offer | 33.9 | | 33.9 | | 32.1 | |
| Standard error | 1.96 | | 4.15 | | 1.92 | |

* This equilibrium price prediction is rejected at the 5 percent significance level using a two-tailed Wilcoxon test. This test is not conducted on the pooled rounds data.

small sample sizes, but the overall pattern is clear in most price ranges shown in table 5.

### *B. Uncertain Demand*

HYPOTHESIS 4. Median opening offer prices equal 32.4, 27, and 21.6, respectively, when $\delta = .6$, .75, and .9.

Table 6 presents opening offer prices in the inexperienced Uncertain Demand treatment for each $\delta$.[17] The median offer pooled across rounds is 30 pesos when $\delta = .6$, 28 pesos when $\delta = .75$, and 28 pesos when $\delta = .9$. The medians are 25, 26, and 26, respectively, in the final round. Figure 3 shows the opening offer prices across the six trading rounds,

[17] We exclude from our analysis one obviously confused seller in the inexperienced Uncertain Demand, $\delta = .9$, treatment. This seller nearly always set an opening offer price greater than 54 pesos (his mean opening offer price was 308 pesos, with a median of 204 pesos). These are prices that are very unlikely to be accepted.

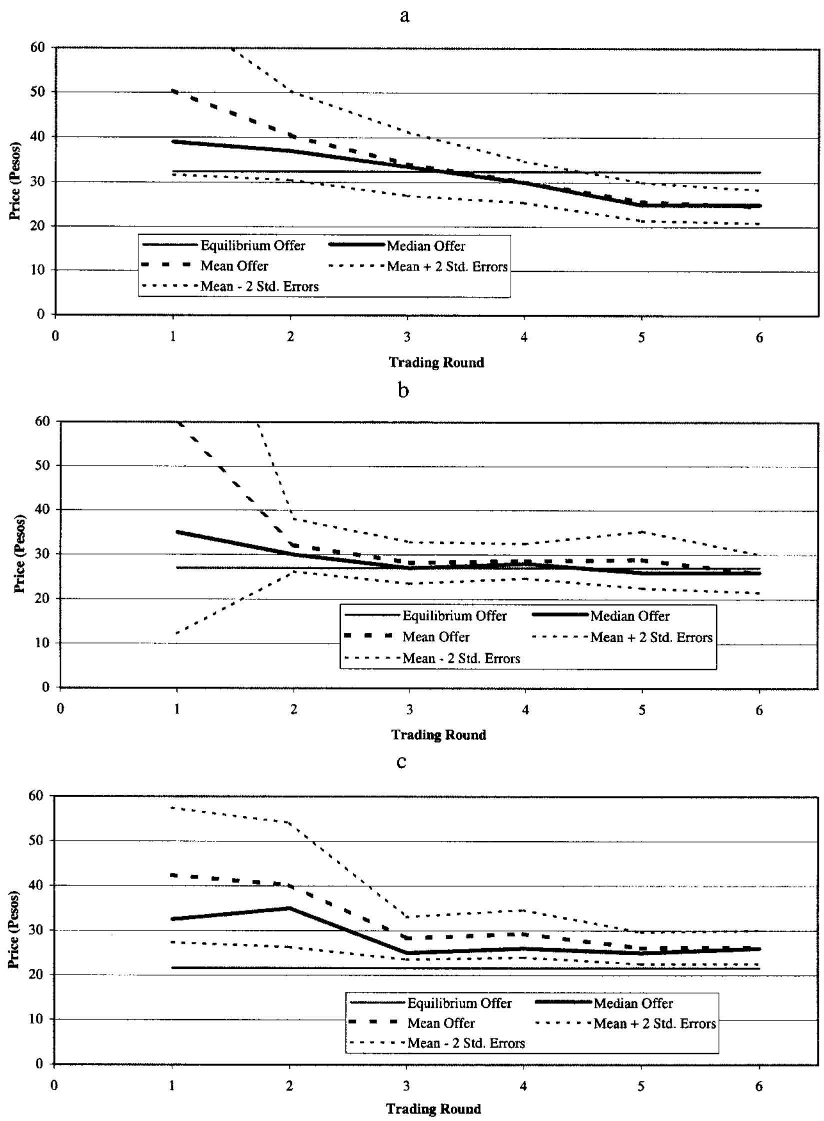


FIG. 3.—Opening offer prices, by trading round, for inexperienced uncertain demand. *a,* Continuation probability $\delta = .6$; 16 observations per round. *b,* Continuation probability $\delta = .75$; 18 observations per round. *c,* Continuation probability $\delta = .9$; 18 observations per round.

separately for each $\delta$ treatment. As in the Certain Demand treatment, opening prices tend to fall and the variance tends to decline across rounds. Note that the first-round median prices are ordered according to the comparative static prediction for changes in $\delta$, with first-round medians of 39, 35, and 32.5 for $\delta = .6$, .75, and .9. By the final round, however, opening offer prices are (statistically) identical in the three $\delta$ treatments (see Subsection *D* below for details). According to a two-tailed Wilcoxon test, at the 5 percent significance level, the median opening offer price is significantly below the equilibrium level in rounds 5 and 6 for $\delta = .6$ and significantly above the equilibrium level in round 1 for $\delta = .6$, in round 1 for $\delta = .75$, and in all but round 5 for $\delta =$ .9. Hypothesis 5 therefore receives support in the inexperienced data only when $\delta = .75$.

For the experienced Uncertain Demand opening offers shown in figure 4, mean and median prices closely correspond to the equilibrium prediction of 32.4 when $\delta = .6$. However, mean and median prices remain above the lower equilibrium prediction of 21.6 when $\delta = .9$.

Hypothesis 5. Median offer prices in the second period equal 18 —the second-highest buyer valuation.

When all rounds are pooled, the inexperienced sessions' median offer price in the second period is 20 pesos when $\delta = .6$, 20 pesos when $\delta = .75$, and 25 pesos when $\delta = .9$. These medians are 17, 12, and 21, respectively, in round 6. According to the Wilcoxon test, median offers are not significantly different from 18 at the 5 percent level in any round when $\delta = .75$ and are not significantly different from 18 in all rounds except round 1 when $\delta = .6$. The inexperienced data therefore provide support for hypothesis 5 when $\delta = .6$ and $\delta = .75$. When $\delta = .9$, however, median second-period price offers are significantly *greater* than 18 at the 5 percent level according to the Wilcoxon test in rounds 1, 2, 3, 5, and 6.[18]

The experienced sessions' median offer in the second period is also higher than the equilibrium of 18 only for $\delta = .9$. It is equal to 20 pesos for pooled inexperienced rounds with $\delta = .9$ and 16 pesos for pooled experienced rounds with $\delta = .6$.

Hypothesis 6. Both units are purchased after exactly two trading periods have been completed.

[18] In the incomplete information model, the monopolist's equilibrium strategy is to reduce the price to 18 in the second period even if she does not sell a unit in the first period. By contrast, in the Pacman equilibrium, the monopolist cuts the price to 18 only after one unit is sold. This is why hypotheses 2 and 5 for the Certain and Uncertain Demand treatments differ. For comparison to the results summarized below hypothesis 2, we note that in the inexperienced Uncertain Demand treatment, the median offer prices immediately after one unit has been sold are 18, 17, and 17 for $\delta = .6$, .75, and .9 when all rounds are pooled. These median offer prices are 16, 9, and 15 for the final inexperienced round.

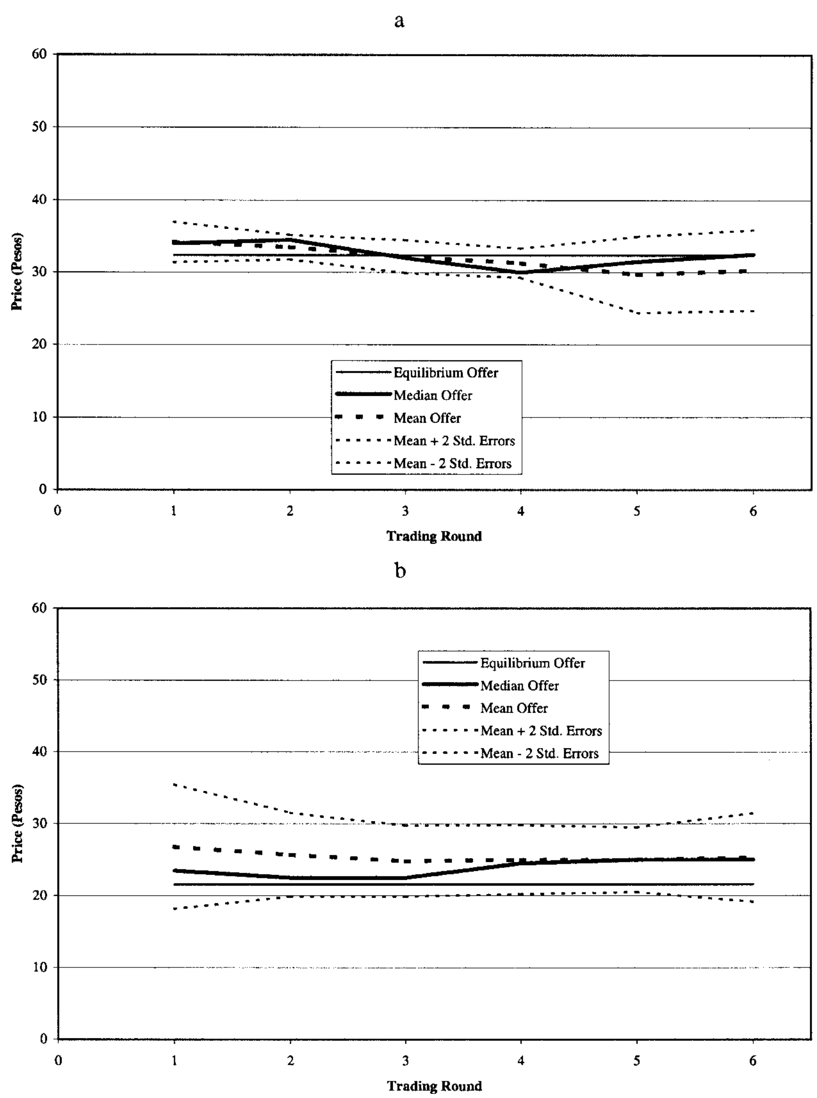


FIG. 4.—Opening offer prices, by trading round, for experienced uncertain demand. *a,* Continuation probability $\delta = .6$; six observations per round. *b,* Continuation probability $\delta = .9$; six observations per round.

TABLE 7
Opening Price Offers and Acceptance Rate for Uncertain Demand Sessions

| | Price Range (Pesos) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | <19 | 19–21 | 22–24 | 25–27 | 28–30 | 31–32 | 33–35 | 36–38 | 39–41 | >41 |
| | Inexperienced Sessions | | | | | | | | | |
| $\delta = .6$: | | | | | | | | | | |
| Opening price frequency | 13 | 9 | 2 | 18 | 13 | 7 | 6 | 10 | 11 | 15 |
| Number accepted | 12 | 8 | 2 | 14 | 7 | 3 | 4 | 5 | 6 | 1 |
| Acceptance rate | **.92** | **.89** | **1.00** | **.78** | **.54** | **.43** | .67 | .50 | .55 | .07 |
| $\delta = .75$: | | | | | | | | | | |
| Opening price frequency | 15 | 10 | 6 | 22 | 16 | 2 | 12 | 3 | 8 | 13 |
| Number accepted | 15 | 7 | 4 | 9 | 6 | 2 | 2 | 1 | 1 | 0 |
| Acceptance rate | **1.00** | **.70** | **.67** | **.41** | .38 | 1.00 | .17 | .33 | .13 | .00 |
| $\delta = .9$: | | | | | | | | | | |
| Opening price frequency | 13 | 16 | 10 | 14 | 14 | 0 | 14 | 3 | 5 | 25 |
| Number accepted | 7 | 9 | 3 | 1 | 2 | 0 | 1 | 0 | 0 | 2 |
| Acceptance rate | **.54** | **.56** | .30 | .07 | .14 | … | .07 | .00 | .00 | .08 |
| | Experienced Sessions | | | | | | | | | |
| $\delta = .6$: | | | | | | | | | | |
| Opening price frequency | 2 | 0 | 0 | 0 | 12 | 3 | 18 | 0 | 1 | 0 |
| Number accepted | 2 | 0 | 0 | 0 | 9 | 1 | 5 | 0 | 0 | 0 |
| Acceptance rate | **1.00** | … | … | … | **.75** | **.33** | .28 | … | .00 | … |
| $\delta = .9$: | | | | | | | | | | |
| Opening price frequency | 2 | 12 | 2 | 11 | 1 | 0 | 5 | 1 | 1 | 1 |
| Number accepted | 1 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Acceptance rate | **.50** | **.33** | .00 | .09 | .00 | … | .00 | .00 | .00 | .00 |

Note.—The incomplete information model predicts acceptance rates of 1.00 in the bold highlighted regions and acceptance rates of .00 elsewhere.

As in the Certain Demand treatment, price offers are frequently rejected and the game typically continues for more than two periods. Because of the random termination rule, again we include only those rounds that continued for at least two periods to test hypothesis 6. Table 4 shows that in the inexperienced Uncertain Demand treatment, both units were purchased by the end of the second period in only 5–31 percent of the rounds that could continue through two periods. In the experienced Uncertain Demand treatment, both units were purchased by the end of the second period in only 3–39 percent of the rounds. As in the Certain Demand treatment, as $\delta$ rises, it is more rare to observe both units sold within two periods.

In the same format as table 5, table 7 presents the distribution of opening prices pooled across rounds for the Uncertain Demand treatment, along with the number of offers in each price range accepted by at least one buyer. The acceptance rates highlighted in bold indicate the price ranges for which opening price offers are accepted with probability one in the incomplete information game. For example, all prices below 33 pesos should be accepted when $\delta = .6$, and we observe 46 of the 62 prices (74 percent) below 33 accepted in the inexperienced sessions and 12 of the 17 prices (71 percent) below 33 accepted in the experienced sessions. No price above 32 should be accepted in this $\delta = .6$ treatment, and we observe 16 of the 42 prices (38 percent) and five of the 19 prices (26 percent) in this range accepted in the inexperienced and experienced sessions, respectively. For the other $\delta > .6$ treatments, the acceptance rate in the equilibrium acceptance region tends to be lower, and buyers usually reject most offers in the rejection region. The frequent rejections for prices in the equilibrium acceptance region (especially for $\delta > .6$) are a major reason that rounds often last more than two periods.

### C. *Comparison of the Certain and Uncertain Demand Treatments*

Hypothesis 7. Median opening offer prices are higher in the Certain Demand treatment than in the Uncertain Demand treatment.

Tables 3 and 6 and figures 1–4 indicate that the median opening offers are very similar in the Certain and Uncertain Demand treatments. We have data for six trading rounds in each of the three inexperienced $\delta$ treatments, for a total of 18 inexperienced data sets for testing hypothesis 7. On the basis of a one-tailed Wilcoxon test, the median offers are significantly different at the 5 percent significance level in only three of the 18 data sets: rounds 5 and 6 of $\delta = .6$ and round 3 of $\delta = .75$. Median prices in the experienced data are never significantly different in the Certain and Uncertain Demand treatments for $\delta = .6$ and are significantly different only in period 2 at the 10 percent level (one-tailed) for $\delta = .9$. The data therefore provide little support for hypothesis 7.

To formally test the conjecture that the endogenous incomplete information in the Certain Demand treatment leads to offers more consistent with the imperfect information model of Section II, consider the following alternative hypothesis to hypothesis 1.

Hypothesis 1′. In the Certain Demand treatment, median opening offer prices equal 32.4, 27, and 21.6, respectively, when $\delta = .6$, .75, and .9.

Recall figures 1 and 2 and table 3, which display median and mean offer prices for the Certain Demand treatment. Especially in the later rounds, median prices correspond somewhat closely to the imperfect information model predictions. According to a two-tailed Wilcoxon test, at the 5 percent significance level the median opening offer price for the inexperienced data is significantly above the model prediction in rounds 1 and 2 for $\delta = .6$, rounds 2–4 for $\delta = .75$, and rounds 1–3 for $\delta = .9$. In 10 of the 18 rounds the data fail to reject hypothesis 1′, and this hypothesis is never rejected in the later rounds. It is also not rejected in any experienced session round. This provides some support for hypothesis 1′.

The preceding results can be summarized as follows. Opening offer prices are similar in the Certain Demand and the Uncertain Demand treatments, and for both treatments the results are more consistent with the imperfect information model equilibrium than with the perfect price discrimination (Pacman) equilibrium. The next hypothesis therefore compares second-period prices *irrespective of whether a unit was sold* in the first period. This comparison is based on the conclusion that subjects do not play the Pacman equilibrium in the Certain Demand treatment.[19]

HYPOTHESIS 8. Median offer prices in the second period are equal in the Certain Demand and Uncertain Demand treatments.

In evaluating hypothesis 5 above, we noted that in the inexperienced Uncertain Demand treatment, with rounds pooled, the median offer price in the second period is 20 pesos when $\delta = .6$, 20 pesos when $\delta = .75$, and 25 pesos when $\delta = .9$. In the inexperienced Certain Demand treatment, with rounds pooled, the median offer price in the second period is 25 pesos when $\delta = .6$, 20.5 pesos when $\delta = .75$, and 25 pesos when $\delta = .9$. To test hypothesis 8, we compare second-period offer prices in the Certain and Uncertain Demand treatments separately by round for each $\delta$ treatment. According to a two-tailed Wilcoxon test, second-period offer prices are significantly different at the 5 percent level in only three of the 18 data sets: rounds 3 and 6 of $\delta = .75$ and round 5 of $\delta = .6$. The second-period offer prices are never significantly different in the Certain and Uncertain Demand treatments in the experienced sessions. The data therefore support hypothesis 8, as well as our broad conclusion that pricing behavior is very similar in the Certain and Uncertain Demand treatments.[20]

Another way to evaluate the pricing behavior in the Certain and Uncertain Demand treatments is to compare first-period prices with second-period prices, taking into account the number of units the seller has remaining for sale in the second period. Table 8 presents this comparison. Column 1 reproduces the data from the lowest rows of tables 3

[19] Recall that in the Pacman equilibrium, the second-period price is 54 if no unit was sold in the first period, and it is 18 if a unit was sold in the first period. In the imperfect information model equilibrium, the second-period price is 18 regardless of whether a unit was sold in the first period.

[20] Note also from a comparison of tables 5 and 7 that buyer behavior is similar in the Certain and Uncertain Demand treatments. In both treatments the rejection rate increases in the offer price and as $\delta$ increases. Although sample size limitations for individual periods and individual price ranges do not permit a statistical test, in most cases the rejection rates (within a $\delta$ treatment) appear rather similar in the Certain and Uncertain Demand treatments.

TABLE 8
POOLED PRICES IN THE FIRST AND SECOND PERIODS FOR INEXPERIENCED SUBJECTS, BY THE NUMBER OF UNITS REMAINING

| | First-Period Price, Two Units Remain (1) | Second-Period Price, Two Units Remain (2) | Second-Period Price, One Unit Remains (3) |
|---|---|---|---|
| | Certain Demand | | |
| $\delta = .6$: | | | |
| Median offer | 35 | 30 | 24.5 |
| Mean offer | 46.2 | 35.3 | 24.1 |
| Standard error | 7.04 | 5.88 | 1.38 |
| $\delta = .75$: | | | |
| Median offer | 30 | 25 | 16 |
| Mean offer | 31.2 | 26.1 | 17.8 |
| Standard error | .78 | 1.13 | 1.15 |
| $\delta = .9$: | | | |
| Median offer | 26 | 25 | 17 |
| Mean offer | 35.6 | 33.9 | 18.6 |
| Standard error | 6.80 | 6.61 | 1.60 |
| | Uncertain Demand | | |
| $\delta = .6$: | | | |
| Median offer | 30 | 25 | 18 |
| Mean offer | 33.9 | 28.4 | 19.2 |
| Standard error | 1.96 | 3.49 | 1.40 |
| $\delta = .75$: | | | |
| Median offer | 28 | 24 | 15 |
| Mean offer | 33.9 | 24.0 | 16.8 |
| Standard error | 4.15 | 1.12 | 1.28 |
| $\delta = .9$: | | | |
| Median offer | 28 | 25 | 19 |
| Mean offer | 32.1 | 29.3 | 20.4 |
| Standard error | 1.92 | 2.13 | 1.62 |

and 6. Recall that when no units are sold in the first period, in the Pacman equilibrium the seller should not lower price. Table 8 shows, however, that except for $\delta = .9$, column 2 prices are lower than column 1 prices in both Certain and Uncertain Demand treatments.[21] That is, sellers appear to update their beliefs following zero sales in period 1, inconsistent with the Pacman equilibrium but consistent (in a qualitative sense) with the equilibrium in the imperfect information model. The incomplete information model also predicts that second-period prices are the same regardless of whether one or two units were sold in the first period, but this is not supported: column 3 prices are lower than column 2 prices in all cases shown in table 8.[22] It therefore appears that

[21] Statistical tests indicate that prices are significantly different at the 5 percent level in about one-third (seven out of 24) of the individual periods with $\delta = .6$ and $\delta = .75$.

[22] Statistical tests indicate that prices are significantly different at the 5 percent level in 40 percent (15 out of 36) of the individual periods.

sellers do not update beliefs as strongly as the incomplete information model predicts, which is reasonable given the (disequilibrium) buyer rejection pattern shown above in tables 5 and 7.

### D. *Comparison of Opening Offer Prices across the Continuation Probability ($\delta$) Treatments*

Hypothesis 9. Median opening offer prices are lower in treatments with a higher continuation probability ($\delta$) in the Certain Demand treatment.

This hypothesis, like hypothesis 8, is based on the imperfect information model rather than on the Pacman equilibrium. Figure 5*a* presents the median prices in the three $\delta$ treatments for the inexperienced Certain Demand treatment. As predicted, the median price is highest in the $\delta = .6$ treatment for all rounds, and after round 2 the three median prices are ordered according to hypothesis 9 in every round. According to a one-tailed, two-sample Wilcoxon test, at the 5 percent significance level, the median price is greater for $\delta = .6$ than for $\delta = .75$ in rounds 1 and 2 (and in round 6 at the 10 percent significance level). This same test indicates that the median price is greater for $\delta = .75$ than for $\delta = .9$ in rounds 4 and 6 (and in rounds 3 and 5 at the 10 percent significance level). The predicted difference in price is of course substantially higher for the $\delta = .6$ versus $\delta = .9$ comparison, and for this comparison the Wilcoxon test rejects the hypothesis that the two median prices are equal in every round. Moreover, a Kruskal-Wallis test rejects the null hypothesis that median prices in the three $\delta$ treatments are equal in rounds 1, 2, 5, and 6. In sum, the inexperienced data provide support for hypothesis 9.

The experienced data do not support hypothesis 9, however. As shown in figure 2, mean and median opening prices in the experienced sessions are not lower than 30 pesos except for round 5 with $\delta = .9$. According to the Wilcoxon test, experienced session prices are not significantly different in the two $\delta$ treatments.

Hypothesis 10. Median opening offer prices are lower in treatments with a higher continuation probability ($\delta$) in the Uncertain Demand treatment.

Figure 5*b* presents the median prices in the three $\delta$ treatments for the inexperienced Uncertain Demand treatment. In rounds 1, 3, and 4 the medians are ordered according to hypothesis 10, but in rounds 5 and 6 the median prices are virtually identical in the three $\delta$ treatments. A Wilcoxon test never rejects the null hypothesis that the median prices are equal in different $\delta$ treatments. A Kruskal-Wallis test also fails to reject, in any round, the null that median prices in the three $\delta$ treatments

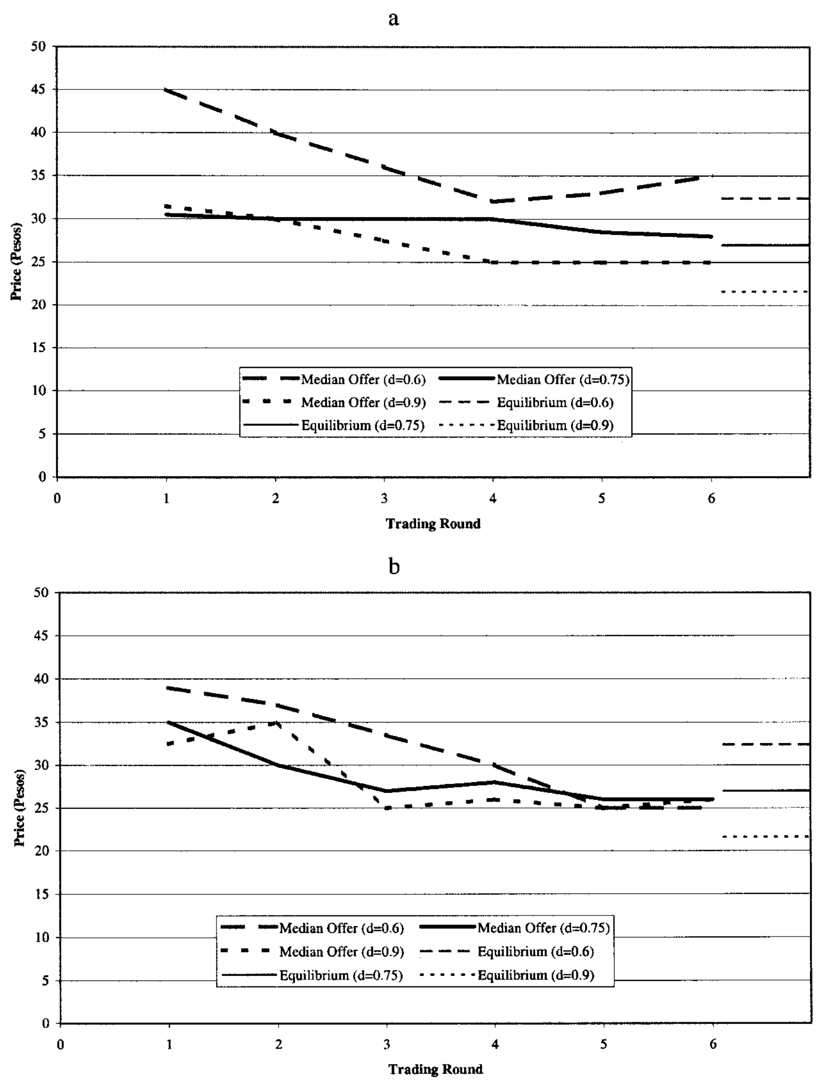


FIG. 5.—Comparison of median opening offer prices, by trading round, for different continuation probabilities. *a,* Certain Demand treatment. *b,* Uncertain Demand treatment.

are equal. The inexperienced data therefore fail to support hypothesis 10.

The experienced data, however, do provide support for hypothesis 10. Figure 4 shows that mean and median opening prices range between 30 and 35 pesos when $\delta = .6$ and that they remain well below 30 pesos when $\delta = .9$. These experienced Uncertain Demand treatment prices are significantly lower when $\delta = .9$ than when $\delta = .6$ according to the Wilcoxon test in periods 2, 3, and 4 at the 5 percent level and in period 1 at the 10 percent level.

### *E. Comparison with Previous Laboratory Studies*

We are aware of three previous laboratory studies that are related to this research, and all three provide substantially less support for theory than the present experiment. Reynolds (2000) reports an experiment with both single-buyer and five-buyer durable good monopoly environments. His durable good setting differs in many respects from ours, including a finite horizon (usually six periods) and a proportional (20 percent) discount of payoffs across periods. Contrary to the Coase conjecture, observed initial period prices were *higher* in the multiperiod durable goods sessions than in the nondurable good control sessions. That is, the durability of the good enhanced rather than constrained monopoly power.

Guth, Ockenfels, and Ritzberger (1995) report finite horizon durable goods monopolists matched with 10 buyers, either two or three trading periods, and different discount factors. Prices were inconsistent with the comparative statics predictions of theory and were much higher than predicted. Again, the durability of the product failed to constrain monopoly power, and standard theory failed to organize the results.

The study by Rapoport, Erev, and Zwick (1995) is more closely related to the present study. The authors report a one-buyer, one-seller bargaining experiment with the seller making all the offers. However, payoffs are discounted from period to period rather than discounted using a random termination rule. They use three discount rate treatments of $\delta$, where $\delta$ has values .33, .67, and .9. They implement uncertainty with buyer values drawn from a known distribution with a (nearly) continuous support rather than the two-point distribution employed in the present study. In contrast to our findings, Rapoport et al. find that opening prices are higher for higher discount rates.

Without a controlled experiment, one can only conjecture about the substantial differences in the success of theory organizing the results of our experiment and those of the previous studies. Surely the sensitivity of the theoretical predictions to the underlying assumptions of the models is important. This is one reason that the finite horizon experiments of Reynolds (2000) and Guth et al. (1995) are difficult to compare to the infinite horizon experiments of Rapoport et al. (1995) and the present study. As for the difference between the results in our study and those in Rapoport et al., there is an important difference between our two-buyer model and the one-buyer model of Rapoport et al. As the model of Section II highlights, we need at least two buyers to bring into play the externality that buttresses the Coase conjecture. We believe that multibuyer conditions are particularly important in understanding durable goods markets in the field, and future experiments can determine whether the use of two buyers instead of one is a primary reason that theory fares better in our study.

## V. Conclusion

Though discrete demand curves may be a fact of real life, complete information environments could be very rare. For the purpose of generating predictions, we suggest that it may be important to model imperfect information. In this paper we introduce a specific, tractable kind of uncertainty to the durable goods monopoly problem in an environment that could contradict the Coase conjecture, namely, one in which there is perfect information, a finite number of buyers, and a patient seller. Uncertainty is introduced in the form of private information for the buyers. To analyze situations close to one in which the monopolist is perfectly informed about a downward-sloping demand curve, we assume that all buyers have “high” valuations only with a small probability. In this environment, the Coase conjecture emerges as an outcome of a (generically) unique perfect Bayesian equilibrium.

In our two-type, two-buyer model, we show that along the equilibrium path, the game always ends in at most two periods. This is true for all parameters of imperfect information in a “small” range close to a situation of perfect information. This result is independent of the discount factor. Consequently, our robustness result is independent of the speeds of convergence. Thus we are able to transport hypotheses from our theory to our experiments with a fair degree of confidence.

The experimental results provide some support for the theory. Opening offer prices in the Certain and Uncertain Demand treatments are very similar. Furthermore, opening offer prices in both treatments clearly reject the Pacman strategy (perfect price discrimination) and are often not significantly different from the price predicted by the imperfect information model. This model, in spite of its strong assumptions, generates predictions consistent with observed outcomes with certain demand. Furthermore, as in Coasian dynamics, we observe lower opening offer prices for treatments with a higher continuation probability ($\delta$) in the inexperienced Certain Demand treatment and the experienced Uncertain Demand treatment. This strategic response of opening prices to changes in the continuation probability provides evidence against the hypothesis that low offer prices are due only to considerations of fairness, unlike typical results in the ultimatum game. The high offers (near the second-buyer valuation of 18) after one unit has been sold also suggest that fairness concerns are muted in this market environment.

Buyers nevertheless frequently withhold demand, however, so that the game usually extends beyond the prediction of two periods. We observe this same violation of the theoretical prediction in all treatments, although it is most pronounced for high continuation probability ($\delta$) sessions. The simple model presented here does not allow for bounded rationality, decision error, or learning and experimentation. Recent research (see, e.g., McKelvey and Palfrey [1998] for finite horizon games) has emphasized the role of these "noise" factors in explaining behavior, and such extensions may provide insight into the nature of the deviations from theory that we observe.

## Appendix A

*Proof of Lemma 5*

It is standard to show that the monopolist never charges a price below $v_2$. If the monopolist could charge different prices to the two different buyers, then the monopolist could make a profit at least as large as that when she has to charge the same price to the two different buyers. So suppose that the monopolist could charge different prices to the two different buyers. In such a situation she could make larger profits if she could commit to two different prices, one for each buyer. If so, then she would charge either $v_1$ or $v_2$ in period $t$ to the two different buyers. Her expected payoffs from charging $v_1$ to buyers 1 and 2 are $\mu^t_{11}v_1$ and $\mu^t_{21}v_1$. Similarly, her expected payoff from charging $v_2$ to each buyer 1 and 2 is $v_2$. So when $\mu^t_{11} \leq v_2/v_1$ $(= \alpha_1)$ and $\mu^t_{21} \leq v_2/v_1$ $(= \alpha_1)$, then it is optimal for the monopolist to charge the same price of $v_2$ to both the buyers. Now $v_2$ is a price that she can indeed commit to since she will never sell below $v_2$. Also, as a result, it is optimal for both the buyers to buy at this price. Q.E.D.

*Proof of Lemma 6*

Since $\epsilon^t < \alpha^* < \alpha_1$, we have $2\alpha_1 - \epsilon^t > 0$. So $(1 - \delta) + (\delta/\mu^t_{11})(2\alpha_1 - \epsilon^t) > 0$.

The monopolist's expected payoff in $t$ is at least $(\mu^t_{11} + \epsilon^t)v' + \delta(2 - \mu^t_{11} - \epsilon^t)v_2$, where $v' \equiv (1 - \delta)v_1 + \delta v_2$. The reason is that the monopolist can always charge $p^t = (1 - \delta)v_1 + \delta v_2$ and $p^{t+1} = v_2$, buyers with valuation $v_1$ find it optimal to buy in period $t$, and those with valuation $v_2$ buy in period $t + 1$.

Define $v'' = (1 - \delta^2)v_1 + \delta^2 v_2$. The maximum prices that the monopolist can charge from $t$ onward are $p^t = (1 - \delta^2)v_1 + \delta^2 v_2$, $p^{t+1} = (1 - \delta)v_1 + \delta v_2$, and $p^{t+2} = v_2$ (since the game lasts up to only $t + 2$ in $\Xi$). Therefore, the monopolist's expected payoff in $\Xi$ cannot be greater than $(\mu^t_{11}x + \epsilon^t)v'' + \delta[\mu^t_{11}(1 - x)]v' + \delta^2(2 - \mu^t_{11} - \epsilon^t)v_2$.

Since $\Xi \neq \emptyset$, it has to be the case that

$$(\mu_{11}^t x + \epsilon^t)v'' + \delta[\mu_{11}^t(1-x)]v' + \delta^2(2-\mu_{11}^t - \epsilon^t)v_2$$
$$\geq (\mu_{11}^t + \epsilon^t)v' + \delta(2-\mu_{11}^t-\epsilon^t)v_2,$$

or

$$(\mu_{11}^t x + \epsilon^t)(1-\delta)v_1 + \delta(\mu_{11}^t + \epsilon^t)v'$$
$$\geq (\mu_{11}^t + \epsilon^t)v' + \delta(1-\delta)(2-\mu_{11}^t-\epsilon^t)v_2,$$

or (since $\delta < 1$)

$$(\mu_{11}^t x + \epsilon^t)v_1 \geq (\mu_{11}^t + \epsilon^t)v' + \delta(2-\mu_{11}^t-\epsilon^t)v_2,$$

or

$$(\mu_{11}^t x + \epsilon^t)v_1 \geq (1-\delta)(\mu_{11}^t + \epsilon^t)v_1 + 2\delta v_2,$$

or

$$x \geq (1-\delta) + \frac{\delta}{\mu_{11}^t}(2\alpha_1 - \epsilon^t).$$

Q.E.D.

*Proof of Lemma 7*

It suffices to show that $\theta_1^{t+1}\mu_{11}^{t+1} < \alpha_1$. Suppose not. Then $\theta_1^{t+1}\mu_{11}^{t+1} \geq \alpha_1$ or, from equation (1),

$$\frac{\mu_{11}^t(1-x)\epsilon^t y}{\mu_{11}^t x(1-\epsilon^t y) + (1-\mu_{11}^t x)\epsilon^t y} \geq \alpha_1,$$

or (since $[1-\mu_{11}^t x]\epsilon^t y \geq 0$)

$$\frac{\mu_{11}^t(1-x)\epsilon^t y}{\mu_{11}^t x(1-\epsilon^t y)} \geq \alpha_1,$$

or (since $x > 0$ from lemma 6)

$$(1-x)\epsilon^t y \geq \alpha_1 x(1-\epsilon^t y),$$

or (since $\alpha_1 < 1$)

$$\epsilon^t y - x\epsilon^t y > \alpha_1 x - x\epsilon^t y,$$

or (since $x \geq [1-\delta] + [\delta/\mu_{11}^t][2\alpha_1 - \epsilon^t]$)

$$\epsilon^t y > \frac{\alpha_1}{\mu_{11}^t}[\mu_{11}^t + \delta(2\alpha_1 - \epsilon^t - \mu_{11}^t)].$$

If $2\alpha_1 - \epsilon^t - \mu_{11}^t \leq 0$, the right-hand side of the inequality above is minimized when $\delta = 1$. So

$$\epsilon^t y > \frac{\alpha_1}{\mu_{11}^t}(2\alpha_1 - \epsilon^t),$$

or, since $\mu_{11}^t < 1$,

$$\epsilon^t > \alpha_1(2\alpha_1 - \epsilon^t),$$

or

$$\epsilon^t > \frac{2}{1+\alpha_1}\alpha_1^2,$$

a contradiction. So $2\alpha_1 - \epsilon^t - \mu_{11}^t > 0$. But then $\epsilon^t y > \alpha_1$, or $[2/(1+\alpha_1)]\alpha_1^2 > \alpha_1$, or $\alpha_1^2 > \alpha_1$, which is again a contradiction. Q.E.D.

*Proof of Lemma 8*

If $\Xi \neq \emptyset$, then either case 1, case 2, or case 3 has to hold. When $\epsilon^t \in (0, \alpha^*)$, lemma 7 shows that cases 1 and 2 cannot hold. Therefore, it is sufficient to show that case 3 cannot hold when $\epsilon^t \in (0, \alpha^*)$. Suppose that case 3 holds. Since $\theta_1^{t+1}\mu_{11}^{t+1} \leq \alpha_1$, by lemma 5, the price charged by the monopolist is $v_2$ when exactly one good is sold in $t$. So, for the game to go for more than two periods, it has to be the case that $p^{t+1} > v_2$ when no good is sold in period $t$. Let us call this price $p$.

Equilibrium pricing dictates that at least one high-valued buyer is indifferent between buying at periods $t$ and $t+1$. Otherwise the monopolist is better off charging a slightly higher or lower price. So either $p^t = (1-\delta)v_1 + \delta[\mu_{11}^t x v_2 + (1-\mu_{11}^t x)p]$ and the high-valued buyer 2 is indifferent or $p^t = (1-\delta)v_1 + \delta[\epsilon^t y v_2 + (1-\epsilon^t y)p]$ and the high-valued buyer 1 is indifferent. Since $p > v_2$ and $\mu_{11}^t x > \epsilon^t$ (which follows from the proof of lemma 7), we have

$$(1-\delta)v_1 + \delta[\mu_{11}^t x v_2 + (1-\mu_{11}^t x)p] < (1-\delta)v_1 + \delta[\epsilon^t y v_2 + (1-\epsilon^t y)p].$$

So if $p^t = (1-\delta)v_1 + \delta[\mu_{11}^t x v_2 + (1-\mu_{11}^t x)p]$, then the high-valued buyer 1 strictly prefers to buy in period $t$, that is, $x = 1$. But then $\theta_0^{t+1}\mu_{11}^{t+1} = 0$ and case 3 does not hold. So it must be the case that $p^t = (1-\delta)v_1 + \delta[\epsilon^t y v_2 + (1-\epsilon^t y)p]$ and the high-valued buyer 2 strictly prefers not to buy in period $t$ (i.e., $y = 0$). Therefore, $p^t = (1-\delta)v_1 + \delta p$.

Suppose that no good is sold in period $t$ and $p$ is charged in period $t+1$. Since the game goes on to period $t+2$ with positive probability and ends there with probability one, it has to be the case that $p = (1-\delta)v_1 + \delta v_2$. Given the analysis in the previous paragraph, the monopolist's expected profit in $t+1$ can be written as

$$\left[\frac{\mu_{11}^t(1-x)}{1-\mu_{11}^t x} + \epsilon^t\right][(1-\delta)v_1 + \delta v_2] + \delta\left[2 - \frac{\mu_{11}^t(1-x)}{1-\mu_{11}^t x} - \epsilon^t\right]v_2.$$

Further, this profit has to be at least as large as $2v_2$. Otherwise the monopolist would charge $v_2$ and the game would end in $t+1$ with probability one. This condition implies that

$$\frac{\mu_{11}^t(1-x)}{1-\mu_{11}^t x} + \epsilon^t \geq 2\alpha_1,$$

which in turn can be written as

$$\mu_{11}^t - \mu_{11}^t x + (\epsilon^t - 2\alpha_1)(1-\mu_{11}^t x) \geq 0$$

or

$$\frac{\mu_{11}^t + \epsilon^t - 2\alpha_1}{1 + \epsilon^t - 2\alpha_1} \geq \mu_{11}^t x.$$

Substituting for $x$ from lemma 6, we then get

$$\frac{\mu_{11}^t + \epsilon^t - 2\alpha_1}{1 + \epsilon^t - 2\alpha_1} \geq \mu_{11}^t + \delta(2\alpha_1 - \mu_{11}^t - \epsilon^t)$$

or

$$[(1 - \mu_{11}^t) + \delta(\mu_{11}^t + \epsilon^t - 2\alpha_1)](\epsilon^t - 2\alpha_1) \geq 0,$$

which is a contradiction since $(1 - \mu_{11}^t) + \delta(\mu_{11}^t + \epsilon^t - 2\alpha_1) > 0$ and $\epsilon^t - 2\alpha_1 < 0$. So case 3 cannot hold, and hence $\Xi = \emptyset$. Q.E.D.

*Proof of Proposition 2*

Let there exist some equilibrium path under which the game lasts for more than two periods. Then $\Xi' \neq \emptyset$. We shall prove the proposition by showing that $\Xi' \neq \emptyset$ is false.

From lemma 8, we know that $\Xi$ is empty. By the definition of $\Xi$, it therefore has to be the case either that the game does not go to period $t + 2$ with positive probability or that $\mu_{11}^t \notin (0, 1)$ or $\epsilon^t \notin (0, \alpha_1)$. Since $\Xi' \neq \emptyset$, it has to be the case that either $\mu_{11}^t \notin (0, 1)$ or $\epsilon^t \notin (0, \alpha_1^*)$. Therefore, by assumption and Bayes' rule, either $\mu_{11}^t = 0$ or $\epsilon^t = 0$. When $\mu_{11}^t = 0$, lemma 5 implies that the game stops in $t$ with probability one. So it has to be that $\epsilon^t = 0$.

Since $\epsilon^t = 0$, there exists $\tau < t$ such that buyer 2 of valuation $v_1$ buys with probability one in period $\tau$. Let $p_i^\tau$, $i = 0, 1$, be the period $\tau$ price charged by the monopolist when $i$ goods have been sold before period $\tau$. Let buyer 1, with valuation $v_1$, buy with probability $x^\tau$ in period $\tau$.

Since buyer 2 of valuation $v_1$ buys with probability one in period $\tau$, given that the monopolist optimizes, it has to be the case that buyer 2 is indifferent between buying in $\tau$ and $\tau + 1$. So

$$p_0^\tau = v_1 - \delta\{v_1 - [\mu_{11}^\tau x^\tau p_1^{\tau+1} + (1 - \mu_{11}^\tau x^\tau) p_0^{\tau+1}]\}.$$

Let us start by considering the case in which $p_1^{\tau+1} \geq p_0^{\tau+1}$. In equilibrium, if buyer 1 of valuation $v_1$ were to buy with probability zero, then

$$p_0^\tau \geq v_1 - \delta\{v_1 - [\epsilon^\tau p_1^{\tau+1} + (1 - \epsilon^\tau) p_0^{\tau+1}]\},$$

implying that $0 < \epsilon^\tau \leq \mu_{11}^\tau x^\tau$, which contradicts the fact that $x^\tau = 0$. So buyer 1 of valuation $v_1$ has to buy with probability greater than zero and less than one (otherwise the game would end with probability one in period $\tau + 1$). So when $p_1^{\tau+1} \geq p_0^{\tau+1}$, we have

$$p_0^\tau = v_1 - \delta\{v_1 - [\epsilon^\tau p_1^{\tau+1} + (1 - \epsilon^\tau) p_0^{\tau+1}]\}$$

and

$$\epsilon^\tau = \mu_{11}^\tau x^\tau.$$

We shall now show that $p_1^{\tau+1} \geq p_0^{\tau+1}$. Consider the case in which no good is bought in $\tau$; then in $\tau + 1$, to make the high-valued buyer 1 indifferent between buying in period $\tau + 1$ and $\tau + 2$, it has to be the case that

$$p_0^{\tau+1} = v_1 - \delta(v_1 - p_0^{\tau+2}).$$

Furthermore, if no good had been bought until $\tau + 1$ and one good is bought in $\tau + 1$, then, along equilibrium (since $\epsilon^{\tau+1} = 0$), the price in $\tau + 2$ is $v_2$ (by lemma 5) and the game ends in $\tau + 2$. So in period $\tau + 1$, buyer 2 (if he were still to be in the market) would correctly expect $p_1^{\tau+2} = v_2$ with probability $\mu_{11}^{\tau+1}x^{\tau+1}$. Recall that $x^{\tau+1} > 0$. So to restrict the high-valued buyer 2 from deviating in $\tau$, it has to be the case that

$$p_0^{\tau+1} \leq v_1 - \delta\{v_1 - [\mu_{11}^{\tau+1}x^{\tau+1}v_2 + (1 - \mu_{11}^{\tau+1}x^{\tau+1})p_0^{\tau+2}]\}.$$

The last two inequalities imply that $p_0^{\tau+2} \leq v_2$. Since $p_0^{\tau+2} \geq v_2$, it follows that $p_0^{\tau+2} = v_2$. Therefore, if no good is bought in period $\tau$, then the game ends with probability one in period $\tau + 2$. But for $\Xi' \neq \emptyset$, we need the game to go beyond period $\tau + 2$ with positive probability (as $\tau < t$). Otherwise, $\Xi' = \Xi = \emptyset$ (because of lemma 8). So the game has to go beyond $\tau + 2$ when one good is sold in period $\tau$. But then $p_1^{\tau+1} > p_0^{\tau+1}$.

Now, for the pricing sequence to be credible, it follows from lemma 4 that, contingent on no good being sold in period $\tau$, we have to have $\mu_{11}^{\tau+1} \leq \beta_2$ since the game has to end in $\tau + 2$. That is, $\mu_{11}^{\tau}(1 - x^{\tau})/[\mu_{11}^{\tau}(1 - x^{\tau}) + (1 - \mu_{11}^{\tau})] \leq \beta_2$. This in turn implies that $x^{\tau} \geq (\mu_{11}^{\tau} - \beta_2)/\mu_{11}^{t}(1 - \beta_2)$. Contingent on one good being sold in period $\tau$, we have, from lemma 2, $\mu_{11}^{\tau+1} \geq \alpha_2$ since the game has to go beyond $\tau + 2$. This along with $\epsilon^{\tau} = \mu_{11}^{\tau}x^{\tau}$ (since $p_1^{\tau+1} \geq p_0^{\tau+1}$) implies that

$$\frac{\mu_{11}^{\tau} - 2\alpha_2}{1 - 2\alpha_2} \geq x^{\tau}.$$

As $\beta_2 < 2\alpha_2$ (lemma 4), we have

$$\frac{\mu_{11}^{\tau} - \beta_2}{1 - \beta_2} > \frac{\mu_{11}^{\tau} - 2\alpha_2}{1 - 2\alpha_2}.$$

But then $x^{\tau} \geq (\mu_{11}^{\tau} - \beta_2)/(1 - \beta_2)$ and $(\mu_{11}^{\tau} - 2\alpha_2)/(1 - 2\alpha_2) \geq x^{\tau}$ cannot be true at the same time. Therefore, $\Xi' = \emptyset$ and there exists no equilibrium path under which the game lasts for more than two periods.

Constructing the equilibrium outcome is now easy. Since the game lasts for at most two periods, it is easy to see that, along the equilibrium path, $p^1 = (1 - \delta)v_1 + \delta v_2$ and $p^2 = v_2$ when $\mu_{11} + \mu_{21} > 2\alpha_1$ and $p^1 = v_2$ when $\mu_{11} + \mu_{21} \leq 2\alpha_1$. Furthermore, since we construct these equilibrium outcomes using backward induction, uniqueness of the outcome follows for all parameter values $\mu_{11} + \mu_{21} > 2\alpha_1$ and $\mu_{11} + \mu_{21} < 2\alpha_1$. When $\mu_{11} + \mu_{21} = 2\alpha_1$, either of the two equilibrium outcomes can hold. Q.E.D.

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