# A Rational Explanation for Price Endings in 99: Experimental Evidence

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Comments Welcome

**Abstract**

There exist numerous theories that attempt to explain the ubiquitous 99-cent price ending. Most of these theories either do not hold up to inspection or posit irrational consumers who serve as a money pump for firms. We offer an experimental test of Basu's (1997) rational expectations equilibrium model, an economic model of the phenomenon in which consumers are fully rational. We find ample support for Basu's model. Convergence to the 99-cent equilibrium is faster and more widespread when firms are able to observe the previous pricing decisions of others. By imitating the optimal 99-cent price endings of rational firms, less rational firms display an "as if" rationality.

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# 1 Introduction

The ubiquity of price endings in 99 around the world is well documented. Brick-and-mortar stores and commercial internet sites alike employ price endings in 99 for almost every conceivable item. In the marketing literature, theories offering explanations for this pricing phenomenon abound. However, many of these theories don't hold up to inspection. The remainder posit irrational consumers. One such form of irrationality involves consistently ignoring or truncating the last two digits of the price, treating them as "00". This type of behavior results in consumers purchasing more units than they otherwise would.

For these reasons economists have recently developed alternative explanations for prices ending in 99. These explanations are coherent and do not rely on irrational consumers. One such explanation is a rational expectations model developed by Basu (1997). In Basu's model, consumers do not bother to examine or take into account the last two digits of the price when contemplating how many units of a good to buy. Rather, through either experience or the unwitting collection of this information, consumers know the distribution of the last two digits of all prices of goods they might possibly purchase. For every good, consumers simply assume that the last two digits of the price are equal to the average of this distribution. Thus, the consumer decides how many units of a good to buy based on the actual dollar component of the good's price and the average cent component of all relevant goods in the market. Notice that this consumer is, on average, correct about the cent component of the price.

Given this type of consumer behavior and a large number of goods on the market, each supplied by a monopolist, any individual monopolist may change the cent component it charges without affecting the overall average. Thus, each monopolist has an individual incentive to charge the maximum number of cents, 99, since doing so doesn't change the quantity demanded of its product. In the unique Nash equilibrium, all monopolists choose 99 cents. The consumer in this model is not duped: his assumption that the cent component of the price on each good he purchases is not only correct on average, it is precisely accurate for all goods he purchases since all goods are priced exactly at 99 cents. And herein lies the

appeal of Basu's model.

In this paper, we offer an experimental test of Basu's model. Subjects in our experiments represent price-setting monopolists. Each monopolist faces a demand function and a constant marginal cost. Subjects are monopolists in the sense that there is no substitution between their goods and no price competition between them. Nonetheless, just as in Basu's model, each monopolist's demand depends on the cent choices of other monopolists. Specifically, the quantity demanded of each monopolist's product is a function of the actual dollar amount it charges and the average of all cent components charged by all monopolists in the market. To minimize the impact of any individual monopolist's cent choice on the overall average and to give the 99-cent Nash equilibrium its best chance for success, we created relatively large markets, consisting of 26 monopolists on average. Essentially, we ask whether firms are able to reach the 99-cent equilibrium, given the assumed form of consumer behavior.

Rendering Basu's static model amenable to laboratory testing raises several interesting issues. Since we cannot reasonably expect all subjects to arrive immediately at the 99-cent equilibrium, we repeat the experiment for 10 periods. The question arises as to the feedback with which to provide subjects between periods. We design two treatments: in the no-price-revelation treatment, each monopolist observes its own profit from the period. This allows subjects to compare their price and profit choices from the previous two periods and to adjust their cent choices in the direction that appears profitable. In the price-revelation treatment, in addition to observing their own period profit, subjects observe the prices of all other subjects. This allows for imitation.

Our experiment resembles a public goods game. Each subject has a dominant cent choice of 99 cents. However, by choosing 99 cents, a subject increases the average cent choice thereby reducing the quantity sold by other monopolists. Choosing a lower cent component can be likened to investing in the public good. Under certain parameterizations of this game, the social optimum occurs when each subject sets his monopoly price.

The 99-price-ending phenomenon is economically important for two reasons. First, during our lifetimes, we, as consumers, purchase hundreds of thousands of goods whose prices end

in 99. If we are oblivious to the last two digits of the price, treating them as "00", for instance, as some of the marketing explanations claim, then we are overconsuming; more precisely, we are purchasing (weakly) more units of these goods than we desire according to our demand curves. Moreover, firms have tapped into one of the most persistently profitable pricing strategies. Firms' ability to extract such rents from willing consumers surely deserves our attention as economists whose cornerstone is rational economic behavior.

Second, models of strategic firm behavior focus on market structure, the relative timing of competing firms' decisions, and whether firms choose prices or quantities. Monopoly, Bertrand, Cournot and Stackelberg solutions are among the possible outcomes that emerge as a function of the realizations of these variables. Given firms' profit functions, all of these models make precise price and quantity predictions. Yet the ubiquity of price endings in 99 imply that all of these models are inaccurate to at least the last two digits of the price prediction.

In the next section, we examine explanations from the marketing and economics literatures for the 99-pricing phenomenon. We also lay out Basu's model more fully. In section 3, we show how we adapted Basu's model to the laboratory. Section 4 details the experimental procedures. The experimental results follow in section 5. Section 6 examines individual subjects' pricing behavior. The observation that not all subjects reached the 99-cent equilibrium suggests directions for future research, which we discuss in section 7. Section 8 concludes with some broader implications of these experiments for pricing behavior and the design of economic institutions.

# 2 Possible Explanations for Pricing in the 9's

## 2.1 Explanations involving Consumer Irrationality

The marketing literature offers numerous explanations for the phenomenon it refers to as the "odd-pricing strategy" (see e.g., Evans and Berman, 1994, or Wilkie, 1990).[1] Let us examine several of these explanations in turn.[2]

*1. Store Owners Like to Give Change: If the cashier is required to make change, then the cash register must be opened. The transaction thus gets recorded and the money is put in a safe place.*

This explanation may indeed be part of the historical reason for the introduction of 99-cent price endings. At the beginning of the century, as store owners began to allow their employees to run their stores, they needed a means to ensure that the employees would place the money from purchases in the cash register (rather than in their pockets). The 99-cent price ending was an ingenious way to solve this principal-agent problem between store owner and employee.

This motivation to charge 99 cents seems less relevant today. The vast majority of purchases are necessarily recorded because either the failure do so would trigger the electronic theft alarm upon exiting the store or they are paid for by credit or debit cards.

Interestingly, this explanation leads to the testable hypothesis that 99-cent endings should be less prevalent in owner-operated stores, as well in e-commerce, mail-order catalogues and other businesses in which purchases are not paid for by cash.

*2. Consumers like to Receive Change: Consumers like to receive change from their purchases. When pricing, if stores take this into account, then they maximize their profits by returning the minimum possible change with each purchase, namely, one cent.*

[1] Odd prices are prices set below even dollar amounts and include 95 cents, \$6.49, \$19.98 and \$199. We and others focus on the most common form of odd pricing, namely, prices with 99 as the last two digits.

[2] We present here a few of the most highly cited and more plausible explanations. There are many others related to product image (see Schindler, 1991) and the attractiveness of the double nines (see Wilkie, 1990) that seem much less plausible. Shtudiner (2001) provides a very thorough survey.

This theory does not hold up well to inspection. Firstly, in countries such as Israel, for instance, in which the smallest unit of currency is a 5-agarot coin, it is impossible to return 1 agara. Notwithstanding, prices ending in 99 agarot are widely observed in Israel. The cashier always rounds up the customer's payment to the nearest shekel so that no change is received at all, contradicting the hypothesized motive for pricing with 99.

Secondly, in 45 out of 50 U.S. states, plus the District of Columbia, a state sales tax ranging from three percent (Colorado) to seven percent (Mississippi and Rhode Island) is added on to the sticker price. In Canada, a federal sales tax is applied to the sticker price in all 10 provinces and three territories in addition to varying provincial sales in six of the provinces. Thus, setting a pre-tax price that ends in 99 does not minimize the amount of post-tax change returned to the customer. Thirdly, an ever increasing number of purchases are made via credit or debit so that no money is exchanged and no change is given.

*3. Impression of a Discount: Price endings in 99 convey the impression that the firm contemplates carefully its prices and makes every effort to set them as low as possible (see e.g., Evans and Berman, 1994, p. 718).*

This explanation may be challenged on two fronts. First, offering a one-penny discount hardly constitutes a meaningful discount, particularly in those countries in which the penny cannot be returned due to the absence of such a coin. Second, why the consensus on 99? Why do we not see more prices ending in 67, 84 or 92?

*4. Rounding Illusion: Consumers focus on the larger digits and truncate the price, ignoring the smaller digits. Thus, a price of $28.99 will be recalled as $28 (see e.g., Gabor and Granger, 1964; Wilkie, 1990, p. 274).*

We would argue that this last argument has the most intuitive appeal. It likely provides a partial explanation for price endings in 99. Nonetheless, for an economist, this explanation is unsavory. It implies irrational consumers who are continually fooled. A possible retort is that whether the price ends in 99, 49, 15 or 0 is immaterial to the consumer. The mental cost of concerning oneself with the number of cents after the decimal place exceeds any benefit gained in adjusting one's demand more optimally in accordance with the precise number of

cents.

However, just as rounding up to 99 can make a substantial difference in the price-setting firm's revenue from its aggregate sales, so the volume of purchases the typical consumer makes during a lifetime would seem to portray him as a money pump for the firm. What makes this story particularly unappealing is the consumer's ability to overcome easily his susceptibility to deceit. For instance, by reading the price of an item from right to left, the consumer increases the saliency of the cent component of the price.

## 2.2 Economic Explanations

The pricing in the nines phenomenon has recently drawn the attention of economists. In a differentiated products model, Shy (2000) shows that if the transportation costs are at least \$1, then firms will choose a 99-cent price ending in the Bertrand-Nash equilibrium. Anderson and Simester (2000) develop a model in which price endings in \$9 serve an informational role, signaling to uninformed consumers which prices are low compared to others. They show both theoretically and through the results of a mail-order experiment that \$9 price endings actually increase the demand for products compared to price endings in smaller numbers.[3] This effect however is moderated by the number of products with \$9 endings. Basu (1997) arrives at an equilibrium price ending of 99 in which both consumers and firms hold rational expectations of the price. It is Basu's model upon which we focus. We detail the model in the next section.

## 2.3 Rational Expectations Explanation

Basu (1997) arrives at a rational expectations Nash equilibrium in which all firms (monopolists in Basu's model) choose a price ending in 99 cents. Assume that there are thousands of goods, each produced by a monopolist. Each monopolist faces a demand

[3]Ginzberg (1936) reports mixed results from a similar mail-order catalogue experiment in which numerous items were priced with odd price endings (e.g. 49, 79 and 98 cents) in one edition of the catalogue and with round prices in another edition.

curve $x_i = x_i((D_i, C_i))$ for the good it supplies, where $(D_i, C_i)$ represents the monopolist's price decomposed into $D_i$ dollars and $C_i$ cents. Hence $D_i$ is a non-negative integer and $C_i \in \{0, 1, \ldots, 99\}$. Since our interest is in the cent component of the price, let $\phi(\cdot)$ be the frequency distribution of the chosen $C_i$s. That is, for each possible value $C$ belonging to the interval $\{0, 1, \ldots, 99\}$, $\phi(C)$ is the number of goods for which the price ends in $C$ cents. More formally,

$$\phi(C) = \#\{i | C_i = C\}.$$

The key assumption in Basu's model is that consumers know the mean of the distribution $\phi(C)$. The consumer may have actively sought this price information, collected it more casually through browsing or window shopping or he may have unwittingly acquired it through experience. In contemplating how many units of good $i$ to purchase, it is assumed that a consumer looks at $D_i$ but does not waste effort looking at $C_i$; instead he simply assumes that $C_i$ equals the mean value of $C$. In making such an assumption, the consumer is, by definition, on average correct. Given that there may be some cost to paying attention to, processing and remembering, the precise $C_i$ attached to each good, this could be a perfectly rational way of thinking.

If all consumers behave in this manner, then the demand for good $i$ priced at $(D_i, C_i)$ becomes $x_i(D_i, \bar{C})$, where $\bar{C}$ is the mean of the distribution $\phi(\cdot)$. The assumption that there are thousands of firms means that the impact of any one firm on $\bar{C}$ is negligible.[4] It follows that for each firm the optimal choice of $C_i$ is 99. Hence, each firm $i$ chooses a price equal to $(\hat{D}_i, 99)$ where $\Pi_i(\hat{D}_i, 99) \geq \Pi_i(D_i, 99)$ for all non-negative integers $D_i$. As a result, the unique Nash equilibrium price profile that prevails in the market is given by $\{(\hat{D}_i, 99)\}_{i=1,2,\ldots}$.

All firms choose the 99-cent price ending. Thus, the average cent component is 99. Consumers know this and decide upon their number of purchases for each good $i$ according to $x_i((D_i, 99))$. The consumer still only looks at $D_i$ and simply assumes that $C_i$ takes its

[4]In actual fact, the assumption of "thousands of goods" is more restrictive than it needs to be. Basu really only needs enough goods such that pricing at 99 cents is firm $i$'s dominant cent choice, for all $i$. In our experimental setup, two goods are sufficient for 99 cents to be firm $i$'s dominant choice, $i = 1, 2$.

expected value. Indeed, in equilibrium, the consumer's expectation is not merely correct on average, it accurately describes the prices for all goods, since no monopolist will charge a price different from 99. The consumer in Basu's model is not fooled or deceived and herein lies the model's appeal.

It is worth noting that 99 cents is also the dominant cent choice if the consumers observe the median or modal cent component of the price distribution, rather than the average, the logic being that as the number of monopolists grows large, the probability that any one monopolist will affect the median or the mode decreases to zero. Thus, each individual monopolist should set his cent component equal to 99 to maximize the price obtained per unit sold.

In this paper, we test whether, given the consumer behavior described in this model, producers are able to reach the unique 99-cent equilibrium. In the next section we present our experimental design and some of the interesting issues that arise in making this static model amenable to a laboratory test.

# 3 Experimental Design

One obvious question regarding this model is whether consumers actually behave according to the assumption that they observe the mean of the cent-component distribution of all of the goods they intend to purchase. In section 7 we discuss a class of goods for which consumers base their purchases on the average choice of firms in the market, rather than an individual firm's choice. Moreover, we've already noted the model's robustness to other order statistics. Finally, the assumption of consumer behavior needn't be taken literally: it may be a simplification of some form of consumer behavior to reduce processing or storage costs. Beyond these partial justifications, we leave the issue of consumer price perceptions to marketing researchers. Instead, we focus on seller pricing behavior, given the assumed consumer behavior.

Subjects played the role of monopolists. Each subject received the identical set of instruc-

tions (see Appendix A) with the sole difference being each subject's linear demand curve and constant marginal cost. Subjects were explained that the quantity they sold would be determined by their demand curve where the price that consumers saw was the dollar component they chose and the average of all of the cent components chosen by all monopolists.

If $(D_i^m, C_i^m)$ is the ordinary monopoly price (where all monopolists' decisions are independent), it is easy to show that if $C_i^m < 0.50$, then $\hat{D}_i = D_i^m - 1$; otherwise, for $C_i^m \geq 0.50$, $\hat{D}_i = D_i^m$.[5] In words, if the monopoly price is such that the optimal cent component is less than 50, then the monopolist in this model should subtract one dollar from the dollar component of the monopoly price. Say, for example, the monopoly price is \$8.34, then \$7.99 is the strictly dominant price for the monopolist in this model; whereas a monopoly price of \$8.56 yields a strictly dominant price of \$8.99.

The demand and cost conditions were varied so that the ordinary monopoly price differed across subjects. Choosing different demand and cost parameters in order that the monopoly solution varies across subjects increases the robustness of our test of Basu's model. For this purpose, the monopoly solution for different subjects consisted of five different dollar components (6, 9, 12, 15, and 18) and two different cent components (0.20 and 0.80). Combining these in all possible ways yields the ten different sets of parameters (also to be referred to as "subtreatments") used in these experiments and displayed in Table 1. Each subtreatment is associated with a different dominant strategy, to be discussed below.

Subjects were randomly assigned to one of the ten parameter subtreatments. We calibrated the parameters and the experimental exchange rate such that if all subjects choose their dominant-strategy price, they all earn similar per period profits. In the unique Nash equilibrium, all subjects assigned to the odd subtreatments (rows 1, 3, 5, 7 and 9 in Table 1) earn 14.56 units of profit in each period; whereas, all subjects assigned to the even subtreatments (rows 2, 4, 6, 8 and 10) earn 31.96 units. To more or less equalize the equilibrium profits of all subjects, we set the exchange rate at two (four) units of experimental currency

[5]The proof is straightforward and therefore omitted. But it can be found in Shtudiner (2001) or is available from the authors upon request.

| Subtreatment | Demand Curve | Marginal Cost | Monopoly Price | Equilibrium Price | Equilibrium Profit (in NIS) |
|---|---|---|---|---|---|
| 1 | $P = 20.6 - 0.22Q$ | 17 | 18.80 | 18.99 | 7.28 |
| 2 | $P = 20 - 0.1Q$ | 16.4 | 18.20 | 17.99 | 7.99 |
| 3 | $P = 17.6 - 0.22Q$ | 14 | 15.80 | 15.99 | 7.28 |
| 4 | $P = 17 - 0.1Q$ | 13.4 | 15.20 | 14.99 | 7.99 |
| 5 | $P = 14.6 - 0.22Q$ | 11 | 12.80 | 12.99 | 7.28 |
| 6 | $P = 14 - 0.1Q$ | 10.4 | 12.20 | 11.99 | 7.99 |
| 7 | $P = 11.6 - 0.22Q$ | 8 | 9.80 | 9.99 | 7.28 |
| 8 | $P = 11 - 0.1Q$ | 7.4 | 9.20 | 8.99 | 7.99 |
| 9 | $P = 8.6 - 0.22Q$ | 5 | 6.80 | 6.99 | 7.28 |
| 10 | $P = 8 - 0.1Q$ | 4.4 | 6.20 | 5.99 | 7.99 |

Table 1: Experimental parameters and outcomes for the ten different combinations of the linear demand curves (column 2) and constant marginal cost (column 3). The ordinary monopoly price is shown in column 4 along with the monopolist's Nash equilibrium price in column 5. The parameters were calibrated such that if all subjects choose their strictly dominant price of $(\hat{D}_i, 99)$, all subjects in the odd (even) subtreatments earn the identical equilibrium profit of 7.28 (7.99) shekels (column 6).

equals one NIS for odd (even) subtreatments.

In selecting the parameters, it is also important to provide subjects a significant incentive to choose both 99 cents and the optimal dollar component. With this in mind, we set the parameters such that if subject $i$ chooses his monopoly price (see column 4 in Table 1) and all other subjects choose their dominant-strategy prices, then by switching to his dominant-strategy price, subject $i$ increases his profit from 13.22 to 14.56 units in the odd subtreatments, and from 18.65 to 31.96 in the even subtreatments. Moreover, the dominant strategy of subjects in the even subtreatments requires them to subtract one dollar from their monopoly dollar component. If, for example, all subjects choose 99 for their cent component, by switching from the monopoly dollar component to the dominant one, all even subjects increase their per period profit from 26.16 units to 31.96.[6]

Notice that the possible cent components of the monopoly prices of 0.20 and 0.80 mean that (in expectation) if subjects choose their cent components randomly or according to the monopoly price, the average cent component ($\bar{C}$) will be 0.50. Therefore, the extent to which cent choices exceed 0.50 reflects the degree of subjects' understanding and the number of subjects who have reached the equilibrium solution.

This game resembles a public goods game. Each player's dominant strategy is to choose 99; however, this decision hurts other monopolists by raising the average cent component and thus the price observed by consumers on all goods, thereby decreasing the quantity demanded of each good. A parameterization in which all monopolists are *ex ante* identical would render this game strategically equivalent to a public goods game with an interior Pareto optimum and a boundary dominant strategy, as in Isaac et al. (1985). The framing of this game is nonetheless notably different from usual public goods experiments in which subjects decide how to divide their token endowment between a private account (from which they alone profit) and a public account (from which everyone profits equally). The frames

[6]The reason that the Nash equilibrium per period profits of the even subjects were set slightly higher than those of the odd subjects (7.99 NIS versus 7.28 NIS) is to compensate them for the non-trivial task of arriving at the equilibrium dollar component.

can be made more similar by thinking of each monopolist's endowment as 99 tokens. Each cent the monopolist charges represents a token invested in the private account. Equivalently, each cent less than 99 represents a token invested in the public account. Monopolists collectively maximize the sum of their profits if each chooses his monopoly price. However, each monopolist has an individual incentive to deviate from the monopoly price and charge 99 cents along with the equilibrium number of dollars, $\hat{D}_i$.

Because our goal is to test Basu's model and its robustness to different parameterizations, we employ different demand and cost parameters for different subjects. With the particular parameters that we have chosen, it turns out that the collective profits from the 99-cent Nash equilibrium are nearly identical to those earned if each subject sets his monopoly price.

There are a number of other interesting issues involved in rendering Basu's static one-shot rational expectations model amenable to laboratory testing. It is not reasonable to expect all subjects to appreciate immediately that their dominant cent component is 99. A repeated game is thus required to allow for convergence to the 99-cent equilibrium. This raises questions regarding the feedback to provide subjects after each repetition. At the very least, each subject needs to learn his own profits from the round. Having changed the cent component from one round to the next, a subject may infer by comparing his earnings in each round whether such a change was profitable. This type of inference can however be misleading since a subject may increase the cent component of his price and earn less due to the offsetting effect of a more substantial increase in the overall average of cent choices. In other words, by increasing his cent choice, the monopolist increases his price received on each unit sold without affecting significantly his quantity sold; however, if other increase their cent choices by even more, then his quantity sold will decrease by more than his price increase and his earnings will fall.

We conducted a second treatment in which the sole addition was that subjects' pricing decisions were displayed at the end of the round to all subjects. This allows subjects who have not yet arrived at the solution of 99 cents to observe the pricing decisions of others who have, thus enabling them to ponder whether the same price ending might be also appropriate

for them. To avoid possible demand effects, both the dollar and cent components of subjects' decisions were displayed in order not to draw attention exclusively to the cent component.

# 4 Experimental Procedures

The subject matter of this experiment limits our subject pool to those who are able to compute the monopoly price, since failure to do so in our experiments can lead to zero profits (if the dollar component is set above the demand curve's vertical axis intercept) or negative profits (if the price is set below marginal cost). Thus, we recruited subjects from classes with introductory microeconomics as a prerequisite. That students learned to solve for the monopoly outcome in introductory micro does not necessarily mean they remember it. For this reason, potential subjects were told that the experiment dealt with the subject of monopoly. Those who signed up were telephoned a day or two before the experiment to confirm their participation. During the phone conversation, they were told to bring a calculator and that they would be tested on their ability to compute the monopoly solution that they learned in introductory microeconomics; if they did not recall how to compute the monopoly solution, they were advised to review their lecture notes.

We made good on our promise to test subjects' understanding of the monopoly solution. Upon arrival, students were seated and briefly instructed how to solve for the monopolist's price and quantity choices. More precisely, one of the authors derived in the most general terms the monopolist's first-order condition, showed them that the monopolist equates marginal revenue to marginal cost and showed the proof that the marginal revenue curve has twice the slope of the demand curve, for linear demand curves. Subjects were then given a preliminary exercise to solve (see Appendix A, Preliminary Exercise). They were presented with one of two versions of a monopoly problem containing a linear demand curve and constant marginal cost. They were asked to solve for the monopolist's profit-maximizing price, quantity and profit. Once a subject had completed the monopoly exercise, he raised his hand. One of the experimenters checked his answer. If he had answered correctly, he

was told that the experiment would begin shortly. If there was a mistake in any part of his solution, he was told that all or part of his answer was incorrect and he was given additional time to correct his answer. Subjects unable to compute the full monopoly solution within a reasonable amount of time were excused from the experiment and paid a 15 NIS showup fee. Only three out of the total 264 subjects who showed up were in this category.

All those subjects who, having solved the preliminary exercise, remained in the experiment, received a copy of the experimental instructions (see Appendix A, Instructions). After having read the instructions on their own, one of the experimenters read aloud the instructions. Questions were answered and a random example designed to illustrate the payoff structure of the game was performed. The random example consisted of four imaginary monopolists numbered 31, 32, 33 and 34. Monopolists 31 and 33 (32 and 34) faced the same set of parameters as those in version 1 (version 2) of the preliminary exercise. The dollar and cent decisions of these four imaginary subjects were randomly drawn, displayed to all participants and written on the board. One number representing the dollar-component decision was randomly drawn from a plastic bag for each of the imaginary subjects. Next, a number between 0 and 99 representing the cent-component decision was randomly drawn from another plastic bag for each of the four imaginary subjects. An experimenter computed aloud the average of the four cent decisions and showed subjects how the average was used to compute each imaginary subject's quantity sold and profit. Thus, the logic of consumer behavior and the monopolist profit calculation in the random example was just like that in the experiment. Unlike the experiment, the prices in the example were purposefully randomly determined to avoid providing unintended cues to subjects. Along these same lines, the demand and cost parameters and the monopoly and equilibrium price and quantity solutions bear no resemblance to any of the 10 subtreatments (as can be seen by comparing Versions 1 and 2 of the Preliminary Exercise in the Appendix with the experimental parameters and solutions displayed in Table 1).

The dominant cent choice is the same for all monopolists in these experiments, namely, choose 99 cents in all periods. This poses the risk that subjects in a given session may

reveal details of the experimental design or, for those who understood it, the solution itself to students participating in a subsequent experiment. Although Ben-Gurion University has a relatively large student body with more than 15,000 undergraduate students, more than 90% of whom live off campus, there is still the risk that classmates participating in different sessions may discuss the experiment. We adopted several measures to prevent this form of subject pool contamination. For example, whenever more than one session was conducted on a particular class (as in the case of the first-year and second-year economics majors), we scheduled the sessions so that they overlapped. The first of the two sessions began at, say, 15:00. The second session we scheduled for 17:00 in a different computer classroom, on a different floor of the building or a different building altogether. Thus, the students in the second session began the experiment before those in the first session had completed their session. This prevented the two groups from communicating. Along these same lines, we requested all students to turn off their mobile phones. This way one friend, just having completed the experiment, could not call another friend in the second experiment to report on the experiment – an admittedly paranoid, but effective precaution.

We conducted a total of 10 experiments, five in each treatment. The subjects were students in economics (labeled "*econ*" in all subsequent tables), accounting ("*accg*") , industrial management ("*ind*") and business management ("*bus*"). Between 16 and 31 monopolists participated in each experiment. In total, 261 subjects participated, each in one experiment only. An entire experiment required between two and two and a half hours. The average earnings were 84.7 NIS including a 10 NIS participation payment.[7]

[7]This is well above the student wage in Israel of 18 NIS per hour. At the time these experiments were conducted 4 NIS equaled approximately $1 U.S.

# 5 Results

## 5.1 No-Price-Revelation Treatment

We begin by focusing on the five experiments in which the only feedback subjects received between rounds was their private profits. Figure 1 displays the average cent component by round for each of these five experiments. Figure 2 shows the fraction of subjects who chose 99 cents by round for each experiment.

[insert Figure 1 here]

[insert Figure 2 here]

Notice, first of all, from Figure 1 that the average cents in period 1 in all sessions is greater than 50, the average cent component of monopoly prices (20 and 80 cents) over all subjects. This observation suggests that in every session several subjects understood from the outset that 99 is the optimal cent choice. Figure 2 reveals that initially between 20% and 32% of subjects in a session selected 99 cents.

Both figures also reveal a learning process in all five sessions. The average cent component and the fraction of subjects who chose 99 steadily increased over the ten periods in each experiment. A notable exception to these increasing trends is period 5 in experiment *n29ind*. In period 4, the average cent component jumped from 66 to 81. This sudden increase meant that the profits of numerous subjects fell, even though they had increased their cent choice. Many such subjects reasoned that their cent increase was unprofitable; they therefore decreased their cent choice in period 5, precipitating the sharp drop in the average cent choice.[8] Similarly, the drop in the average cent component in period 6 of experiment *n30econ* follows a sharp increase in period 5.

Overall, these five experiments show movement in the direction of convergence to 99 cents. By period 10, between 33% and 77% arrived at 99 cents, depending on the session.

[8]This type of directional learning is explored further in section 6 where we examine the behavior of individual subjects.

And while the average cent component in period 1 from 52.6 to 63 cents across sessions, the period 10 range was between 80.9 and 96 cents.

To make more precise the convergence process in each session, we employ the Ashenfelter-El-Gamal dynamic regression model (Noussair et al., 1995, 1997). We model each subject's cent choice in each period, $C_{it}$, as a function of $1/t$ and $\frac{t-1}{t}$. The model takes the following functional form:

$$C_{it} = B_{11}D_1(1/t) + \ldots + B_{1k}D_k(1/t) + B_{21}D_1(\frac{t-1}{t}) + \ldots + B_{2k}D_k(\frac{t-1}{t}) + u_{it}. \qquad (1)$$

The term $D_j$ is a dummy variable that assumes a value of 1 for experiment $j$, and 0 otherwise. According to the specification, in period 1 ($t = 1$), the price in experiment $j$ equals $B_{1j}$. This leads to the interpretation of $B_{1j}$ as the initial price in experiment $j$. Its impact decays over time, as indicated by the term $1/t$. By contrast, the impact of $B_{2j}$ increases over time, as indicated by the expression $\frac{t-1}{t}$. The term $B_{2j}$ can thus be thought of as the price asymptote for experiment $j$. The random error term $u_{it}$ is distributed normally with mean zero.

Column 2 of Table 2 summarizes the regression results for the five no-price-revelation sessions. The first column indicates the name of the relevant $B_{1j}$ and $B_{2j}$ coefficients, where $j$ refers to the experiment. The experiment name consists of three components: a letter ("n" or "p") referring to either the no-price or price-revelation treatment; the number of subjects in the experiment; and their field of study. The second column displays the coefficient estimates (standard errors in parentheses) for the five "n" sessions.

To explore the convergence properties of the different experiments, we compare the $B_{2j}$ estimates with the corresponding $B_{1j}$ estimates and the equilibrium cent component of 99. If the estimate $B_{2j}$ is not statistically different from the prediction of the model, Noussair et al. (1995) define this as strong convergence. The third column of Table 2 gives the results of an F-test of the null hypothesis that $B_{2j}$ equals 99. In all but one experiment (*n27ind*), we can reject this hypothesis at the 5% level. For the experiment *n27ind* we can reject it at the 10% level.

We define the notion of partial convergence as the case in which the convergence asymptote, $B_{2j}$, is closer to the model's prediction than to the corresponding initial price estimate,

| Coefficient | Estimate (Std.Error) | $H_0 : B_{2j} = 99$ | Estimate (Std.Error) |
|---|---|---|---|
| $B_{1,n24econ}$ | 44.97** (5.43) | — | 46.91** (4.80) |
| $B_{1,n27ind}$ | 53.89** (5.12) | — | 59.94** (4.54) |
| $B_{1,n29ind}$ | 56.47** (4.94) | — | 52.01** (4.39) |
| $B_{1,n30econ2}$ | 59.98** (4.86) | — | 63.55** (4.32) |
| $B_{1,n30econ1}$ | 54.43** (4.86) | — | 47.39** (4.26) |
| $B_{1,p22aacg}$ | — | — | 54.68** (4.98) |
| $B_{1,p31econ}$ | — | — | 63.85** (4.23) |
| $B_{1,p16econ}$ | — | — | 53.53** (5.81) |
| $B_{1,p25bus}$ | — | — | 50.78** (4.70) |
| $B_{1,p27bus}$ | — | — | 59.23** (4.91) |
| $B_{2,n24econ}$ | 89.79** (2.83) | F=10.57 (p=.001) | — |
| $B_{2,n27ind}$ | 94.41** (2.67) | 2.96 (.086) | — |
| $B_{2,n29ind}$ | 82.60** (2.58) | 40.49 (.000) | — |
| $B_{2,n30econ2}$ | 91.62** (2.53) | 8.48 (.004) | — |
| $B_{2,n30econ1}$ | 80.93** (2.53) | 50.84 (.000) | — |
| $B_n$ | — | — | 87.61** (1.18) |
| $B_p$ | — | — | 4.89** (1.59) |

Table 2: Regression results from the Ashenfelter-El-Gamal dynamic linear regression model. The first column indicates the name of the estimated coefficient, $B_{1j}$ and $B_{2j}$, where $j$ is the experiment name with ("$n$") "$p$" indicating (no) price revelation, followed by the number of subjects in the session and the subjects' field of study. The coefficient estimates for the "n" sessions are reported in the second column (standard errors in parentheses). The third column reports the results of F-tests on the estimates of the convergence term, $B_{2j}$. The fourth column reports the regression results from all ten sessions combined, where $B_n$ is the convergence term for the "$n$" sessions and $B_p$ is the additional measure of convergence of the "p" sessions.
** significant at the 1% level.
* significant at the 5% level.

$B_{1j}$.[9] By this definition, all five experiments exhibit partial convergence.

In short, all five sessions show considerable progress the 99-cent equilibrium over the 10 periods; however, none of them converged unambiguously. The absence of unequivocal convergence on both the session and individual subject levels led us to design a second treatment. This second treatment is identical to the first one, with the addition that at the end of each period all subjects observe the full price decision (dollar and cent component) of all other subjects.

## 5.2 Price-Revelation Treatment

We conducted five experiments on economics (*econ*), accounting (*accg*) and business (*bus*) majors. Figure 3 shows the average cent component by period for each of the five price-revelation sessions. The figure reveals that for this treatment the period 10 average cent choice ranged from 88.6 to 97.7 cents, with four of the five sessions above 94 cents. Figure 4 displays the fraction of subjects who chose 99 cents in each period according to session. By period 10, between 59% and 87% priced at 99 cents. A comparison of Figure 4 with Figure 2 reveals that a higher fraction of subjects learned to price at 99 cents in the price-revelation treatment.

[insert Figure 3 here]

[insert Figure 4 here]

One casual observation that arises from comparing Figures 3 and 1 is the absence of sharp drops in the average cent choice in the price-revelation treatment. Recall from the no-price-revelation treatment that steep declines in the average cent choice often followed sudden rises. The logic underlying these steep declines is that, in seeing their profits fall following a higher cent choice, many subjects incorrectly inferred that higher cent choices

[9] Noussair et al. (1995) define weak convergence as $B_{2j}$ being closer to the model prediction than $B_{1j}$ is. In all of our experiments, this holds trivially. We thus use partial convergence as an intermediate measure between weak convergence and strong convergence.

are unprofitable. While this same opportunity for mistaken inference exists in the price-revelation treatment, the display of all subjects' prices has an offsetting effect: the subject who is confused at his decline in earnings following an increase in his cent choice can resort to imitating the cent choices of others in the experiment.

The absence of sharp declines and the steady climb in cent choices may partially account for the finding that period 10 prices in this treatment are higher than those in the first treatment. To compare the period 10 cent choices across treatments, we treat the period 10 average cent choice of a session as one observation (since subjects' cent choices are inter-dependent, particularly in the price-revelation treatment). Despite limited statistical power (10 observations), results from the Wilcoxon-Mann-Whitney nonparametric test allow us to reject at the 5% level the null hypothesis that the period 10 cent choice averages from the two treatments come from the same population distribution (exact p=.047, one-tailed).[10]

Another simple way to see the effect of displaying prices to subjects' is to compare their period 1 and period 10 cent choices. We may compare the proportions of monopolists in the two treatments who chose higher, lower and the same cent choices in period 10 as in period 1. We are able to reject the null hypothesis that the fractions of subjects who raised, lowered and did not change their prices across the two treatments are the same at the 2% level, $\chi^2(3) = 9.73,\ p = .02$, test of proportions. The most striking difference between the treatments is the negligible proportion of monopolists who lowered their cent choice in the "p" treatment (3/121) compared to more than 10% (15/140) in the "n" treatment.

[10]Part of the difference in the period 10 price endings in these treatments appears to stem from higher period 1 prices in the price-revelation treatment (compare Figures 1 and 3), although the difference is not statistically significant (exact p=.420). Nonetheless, if we control for the period 1 cent choice in each session and compare the amount by which the cent choice rose in the remaining 9 periods, the difference between the two distributions is no longer significant (exact p=.210). To the extent that period 1 cent choices are higher in the price-revelation sessions, the knowledge that their price choices will be displayed publicly may encourage subjects to contemplate more carefully their pricing decisions. Subject pool differences is another possible explanation even though recruited groups of subjects were arbitrarily assigned to a treatment.

To obtain a quantitative estimate of the additional impact of price revelation on subjects' cent choices, we conduct the Ashenfelter-El-Gamal regression on all observations from all 10 sessions. We assume that all sessions converge to the same period 10 price, $B_n$, and add a dummy variable, $D_p$, equal to one for price-revelation sessions, and zero otherwise. The coefficient $B_p$ therefore measures the additional degree of convergence in the price-revelation sessions. Equation (2) displays the regression specification:

$$C_{i,t} = B_{1,1}D_1(1/t) + \ldots + B_{1,10}D_k(1/t) + B_n(\frac{t-1}{t}) + B_pD_p(\frac{t-1}{t}) + u_{it}. \qquad (2)$$

The results from column 4 in Table 2 establish that overall the five sessions from the no-price-revelation treatment converge to 87.6 cents after 10 rounds. The convergence term for the price-revelation treatment, $B_p$, is about five cents higher (p=.002).

In sum, we have seen in both treatments that through repetition and feedback many subjects arrive at the 99-cent equilibrium. Moreover, additional feedback in the form of observing the distribution of prices of all subjects increases the trend toward convergence to this equilibrium.

## 5.3 More Rounds, More Complete Convergence?

A look at the price trends in both treatments might lead one to surmise that had we allowed the experiments to continue for a few more rounds perhaps the cent choices would have converged more fully to 99. Certainly prices rise through period 7. Beginning in period 8 Figures 1 and 3 show a flattening out of cent choices.

Recall that these sessions lasted up to two hours and thirty minutes.[11] Concerned that we would not be able to recruit subjects for a three-hour experiment and that their concentration would wane, we decided that ten periods were adequate. Nonetheless, we allowed two of the ten sessions (one in each treatment) to run for 15 periods. Figure 5 displays the average cent trend for each of these sessions.

[11]The brief review of monopoly, the test, the instructions and the random example required just over an hour, while the experiment took the remainder of the time.

[insert Figure 5 here]

The two price trends reveal mixed evidence. Both sessions start at an average of roughly 58.5 cents. By period 10, session *p25bus* has climbed to 96.4 cents, while session *n30econ2* has reached 80.9 cents, down from the period 9 average of 88.2 cents. The additional five periods lead to a decrease to 92.8 cents for session *n30econ2* and an increase to 91.2 for session *p25bus*. The number of subjects who reached 99 cents tells an opposite story. In session *n30econ2* (the session in which the average cent choice fell during the extra five periods), the number of subjects who chose 99 cents actually increased from 10 in period 10 to 14 in period 15; whereas, the number of subjects who chose 99 cents fell in session *p25bus* from 19 in period 10 to 17 in period 15, despite the increase in the average cent choice. Based on this very mixed evidence, it remains inconclusive whether more rounds actually contribute to more complete convergence.

# 6 Analysis of Individual Behavior

Up to this point, we have examined the *degree* of convergence of the different experimental sessions and treatments. We now turn to the *means* by which these sessions converge. To do so, we explore more closely the behavior of individual subjects and their responses to the between-period feedback. Tables 3 and 4 display individual subjects' prices and profits from one "n" session (*n30econ2*) and a similar "p" session (*p31econ*), respectively, for all ten periods. These experiments are of similar size (30 vs. 31 subjects) and both consist of second-year undergraduate economics students. What is more, the first-period cent average is approximately 63 cents in both sessions. However, the price-revelation session converges toward the 99-cent equilibrium more quickly and more fully.

[insert Table 3 here]

[insert Table 4 here]

In all but one experiment (*p22accg*), there were one or more subjects who grasped from the outset that the dominant cent choice is 99 and stuck with this choice for the entire experiment. A higher fraction of this type of subject cannot account for the quicker and more complete convergence of session (*p31econ*) compared to session *n30econ2* since four (five) subjects chose 99 throughout in session *n30econ2* (*p31econ*), $\chi^2(1) = 0.09,\ p = .76$, test of proportions. Overall, the fractions of subjects who selected 99 in every period are also very similar in the two treatments, 12/140 in treatment "n" compared to 16/121 in treatment "p", $\chi^2(1) = 1.47,\ p = .22$.

For those subjects who did not immediately recognize that their dominant cent decision is 99, an examination of their prices and their responsiveness to profit feedback (and others' prices in treatment "p") allows us to discern between at least two types of subjects.

The most common type of behavior is directional learning (Selten and Stoecker, 1996). Directional learners compare their price choices and resultant profits from previous periods and adjust their current period price in the direction that appears profitable. In experiment *n30econ2*, subjects 5, 12, 16, 17, and 29 are all clear examples of directional learners, as are subjects 1, 4, 5, 7 and 13 in *p31econ*. Subject 7 in *p31econ*, for instance, set her monopoly price of 15.80 in period 1. She increased the cent component to 95 in period 2, which yielded more profit encouraging a further increase to 99 cents in period 3. In period 3, however, the average cent choice soared to 84.8 (an increase of 14.5 units from the previous period) thereby reducing subject 7's profits. This subject incorrectly inferred that a decrease in the cent choice was in order. Two consecutive decreases in her cent choice in periods 4 and 5 led to her lowest profits. She returned to 95 cents and then to 99 cents. The latter increase was accompanied by a decline in profits, again the result of a dramatic 10-cent climb in the average choice. One final unprofitable attempt to lower her cent choice in period 8 convinced this subject to return to 99 cents for the remaining two periods.

As Pingle and Day (1996, p. 193) note, this type of trial and error search can be extremely effective if the environment is stable and there exists a sufficiently regular connection between actions and payoffs. The constantly changing average cent component and the regularity of

misleading feedback make our environment unstable and the connection between actions and profits imperfect. The result is that directional learners often do not reach 99 cents. Subject 5 in this same experiment is a case in point. This subject began with his monopoly price. A decline in profit resulting from a lower price in period 2 informed his successive price increases in periods 3 and 4. Despite the price hike in period 4, his profit eroded causing the subject to drop his period 5 price. Further profit erosion in period 7 despite a price increase again led this subject to lower his price. By period 10, it is by no means clear whether this subject would have ever reached 99 cents.

The revelation of the pricing decisions of all subjects permits imitation in the second treatment only. Pingle and Day (1986, p. 200) write that, "Imitation may have its niche in relatively unfamiliar situations." Subjects who behaved according to directional learning and whose feedback in different rounds was contradictory with respect to the profitable direction in which to adjust the cent component usually found themselves confused. Some resorted to imitation. Monopolist 12 in experiment *p31econ* provides an example. A profitable price increase in period 2 guided two back-to-back price hikes in periods 3 and 4, both of which were accompanied by successive declines in earnings. The subject responded in period 5 by selecting 52 cents, his lowest cent choice. Further unprofitable prices changes in periods 6 and 7 undoubtedly left the subject at a loss. At his wit's end, the subject allowed the modal pricing decision of other monopolists of 99 cents to inform his period 8 choice and stuck with this choice through the duration.[12]

More generally speaking, we observed three broad patterns of behavior in these experiments: subjects who immediately understood their optimal cent choice, those who learned to and those who never did. Within this last group, there are those who never will and those who might be helped by increased feedback.

[12]That this subject copied the modal choice of other subjects is supported by the subject's own words. In response to the question, "Did the display of cent choices at the end of each round affect your choice of cent component? If so, explain how," on the post-experiment questionnaire, the subject wrote, "yes, I chose according to the majority choice of other participants."

# 7 Discussion of Future Research

To augment the feedback in the price-revelation treatment we propose two extensions. Although subjects in the "p" treatment observe other monopolists' prices, they don't observe others' profits. Thus, while a subject at a loss at what to do may wish to imitate another, it may not be obvious to the subject who he should imitate. By displaying publicly each subject's profit along with his chosen price, subjects would be able to identify those pricing strategies that are most profitable and imitate them.

Alternatively, Pingle and Day (1996) suggest that the "follow authority" mode of behavior may be effective when decision makers make poor decisions and the authority is, for example, an expert. This suggests a treatment in which the identity numbers of all subjects are known to all monopolists and a few of the subjects are "experts" (e.g., outstanding peer students, graduate students or economics professors). As in the price-revelation treatment, all prices are revealed at the end of each round according to identity number, thereby allowing imitation of these authorities.

There are other scenarios in which consumers may not observe the decisions of specific firms, but may have some idea about the average firm decision. When booking a holiday vacation package to a distant location, for instance, one may be well aware that hotels in the region are known to be of a certain quality. However, one may have no idea about the quality of any particular hotel. In other words, one may be familiar with the average quality, but not the quality choice of any individual hotel. One could easily reformulate our experimental game in terms of monopoly hotel owners who decide on the level of quality they choose each round. The consumer demand for an individual hotel is determined by the average quality choice. If quality choice is costly, then it should converge toward the unique Nash equilibrium in which each hotel offers the lowest possible quality.

# 8 Conclusions

Economic theory predicts that firms will arrive at the competitive, Bertrand-Nash, Cournot-Nash, Stackelberg-Nash or monopoly price, depending on the market structure and strategy space available to firms. The ubiquitous 99 cents price ending testifies to the fact that in selecting the final price some tinkering or "rounding" occurs. This paper shows that under particular assumptions about consumer behavior, firms are capable of responding optimally and adjusting their prices to maximize profits given the constraints that consumer price perceptions place upon them.

Still, we observed numerous subjects unable to arrive at the optimal 99-cent price ending. In some cases, their round-profit was a source of misleading feedback, which obstructed them from reaching the 99-cent price ending. However, with additional feedback in the form of displaying all subjects' prices, imitation was possible and a larger fraction of subjects reached the optimal price ending. More generally, the right kind of feedback and institutional design can overcome irrationality so that individuals' decisions reflect an "as if" rationality.

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# Appendix: Forms

## Preliminary Exercise

Version 1

The demand curve faced by the monopolist is given by, P=132.7-13.7Q

and the marginal cost is constant and given by, MC=119.

Compute the price and quantity that maximize the monopolist's profit.

Monopoly Price _____ Monopoly Quantity _____ Monopoly Profit _____.

Version 2

The demand curve faced by the monopolist is given by, P=92.7-7.4Q

and the marginal cost is constant and given by, MC=72.

Compute the price and quantity that maximize the monopolist's profit.

Monopoly Price _____ Monopoly Quantity _____ Monopoly Profit _____.

Solution to Version 1: $P^m = 125.85$, $Q^m = 0.5$, $\Pi^m = 3.425$.

Solution to Version 2: $P^m = 82.35$, $Q^m = 1.39$, $\Pi^m = 14.38$.

## Instructions

This is an exercise in individual decision-making. Read the following instructions carefully until you fully understand the exercise. A full understanding is important in this exercise to avoid unintended financial losses. Because your are meant to make your decisions individually, it is important that you refrain from talking aloud during the entire exercise. If at any stage you have any questions, please raise your hand and one of the experimenters will come to assist you.

In this exercise, you will act as a monopolist in a market for a particular product. The demand curve for your product is given by: $P = 20.60 - 0.22Q$. Your marginal cost for producing this product is constant and given by: $MC = 17$. As a monopolist, your task is to choose a price for your product. In the room with you, there are 29 additional participants in this exercise. Each one of them acts as monopolist in a different market. (In total, there are 30 monopoly firms in this economy where a different student participant represents each monopolist.) It is important to note that not every monopolist possesses the same demand curve and the same marginal cost.

The price that you are to choose consists of two components: a dollar component and a cent component. The consumers are simulated and behave according to the following logic: due to

limited time and limited storage space in their memories, consumers do not exert effort observing the cent component of the price that you chose. When they look at the price of your product, they see the dollar component that you chose. However, the cent component that they see is the average of the 30 cent components chosen by the monopolists in this economy. (Somehow, the consumers anticipate correctly the average cent component and observe this instead of your specific cent-component choice.)

The quantity of your product that consumers purchase is determined by this price (they substitute this price into their demand curve for your product, given above). However, the price that you will be paid for each unit sold is the true price that you selected (the dollar component that you chose and the cent component that you chose).

After reading the instructions, you must decide upon a dollar and cent component you wish to charge, and enter your choices in the appropriate place on your screen. (Please type all cent components as two-digit numbers.) Also, after deciding, write your chosen dollar and cent components on your personal record sheet. After all participants have entered their decisions, your profit will appear on the screen. Your profit is calculated according to the above demand curve and marginal cost. Also write your profit on your personal Record Sheet. ["p" treatment: In addition to observing your own profit after all participants have entered their decisions, a table displaying the decisions of all participants (including your own) will be displayed on your screen.]

This exercise will repeat itself 10 times. In each of the 10 repetitions (rounds), you will face the same demand curve and marginal cost. At the end of the exercise, you will be paid 50% of your accumulated profits from the 10 rounds (i.e., 2 units of profit in the exercise = 1 NIS) plus a 10 NIS show-up fee in cash.

["p" treatment: The table displaying the decisions of all participants is updated at the end of each round.] You may return to the decisions from previous rounds by pressing the labeled button below the table.

Before beginning the exercise, an experimenter will read aloud the instructions to all participants. Then, an experimenter will solve with you a random example based on 4 imaginary monopolists in order that everyone will fully understand the exercise.

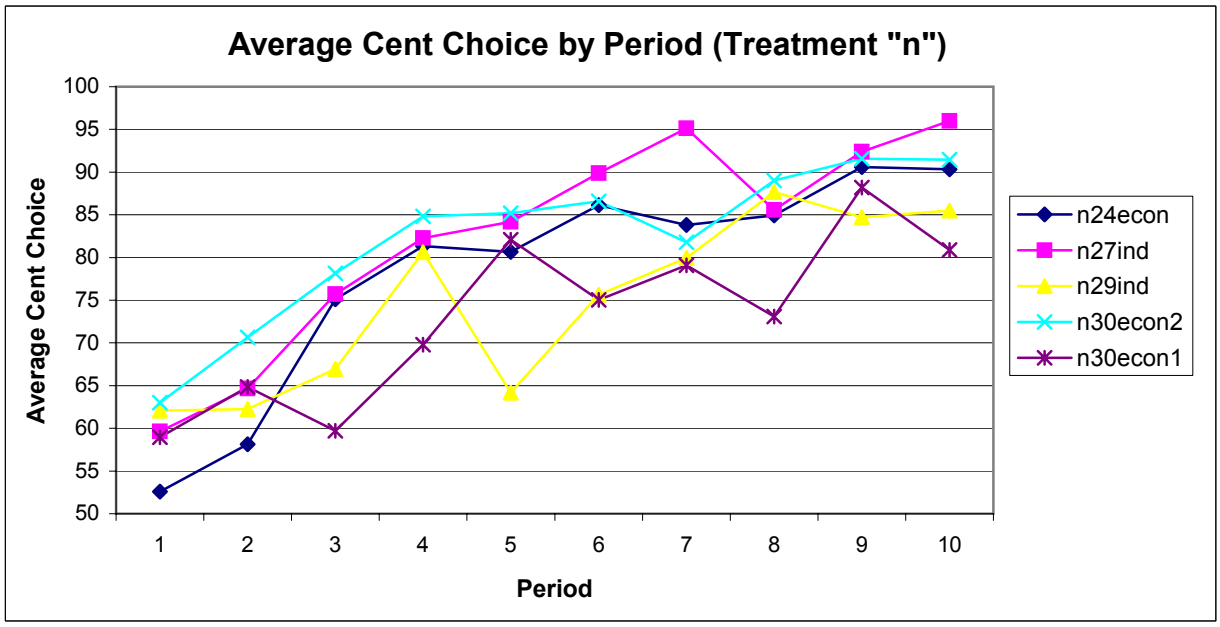


Figure 1: Average cent choice by period for each of the five experiments in the no-price-revelation treatment.

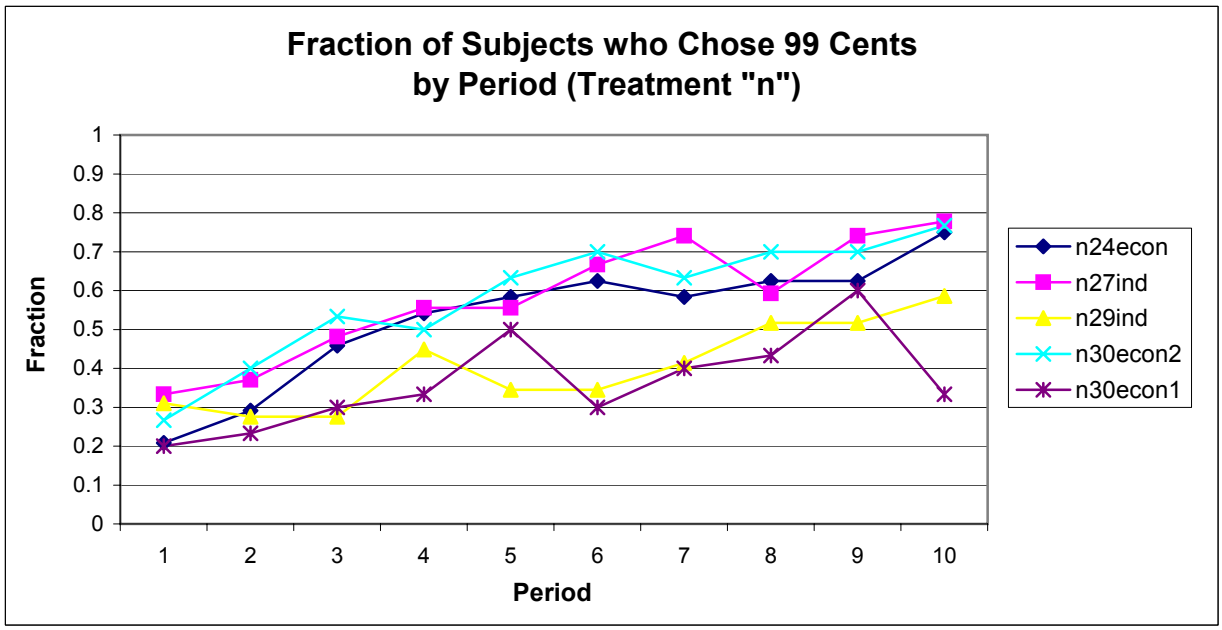


Figure 2: Fraction of subjects who chose 99 cents in each of the ten periods for the five no-price-revelation sessions.

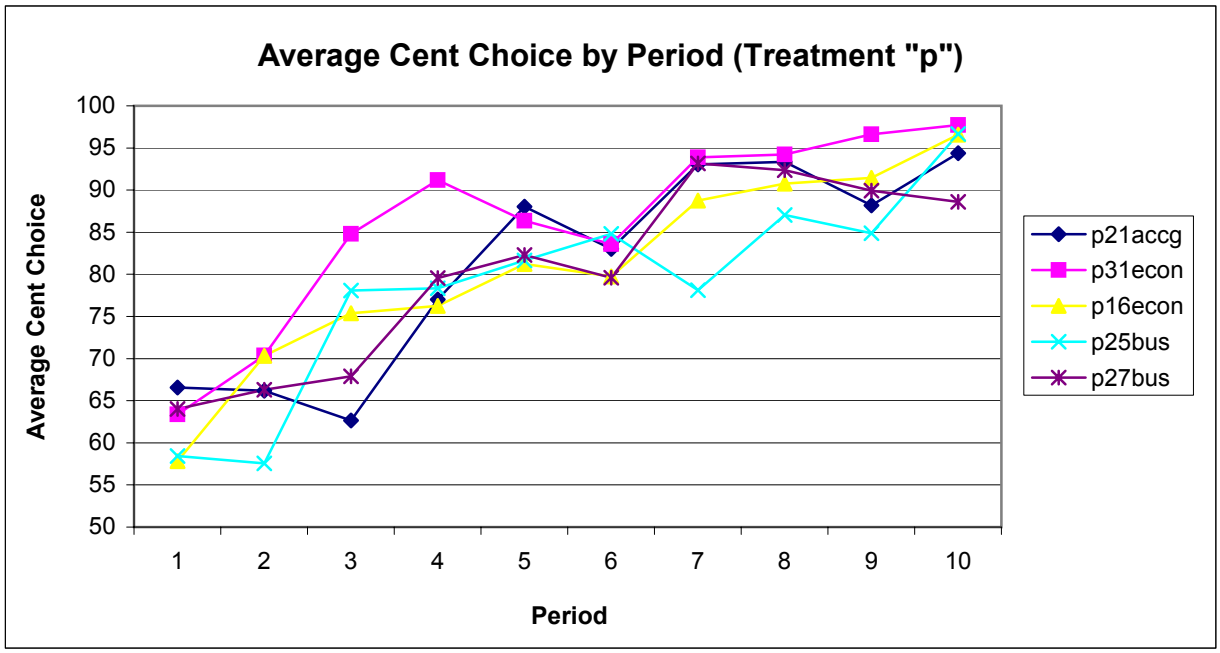


Figure 3: Average cent choice by period for each of the five experiments in the price-revelation treatment.

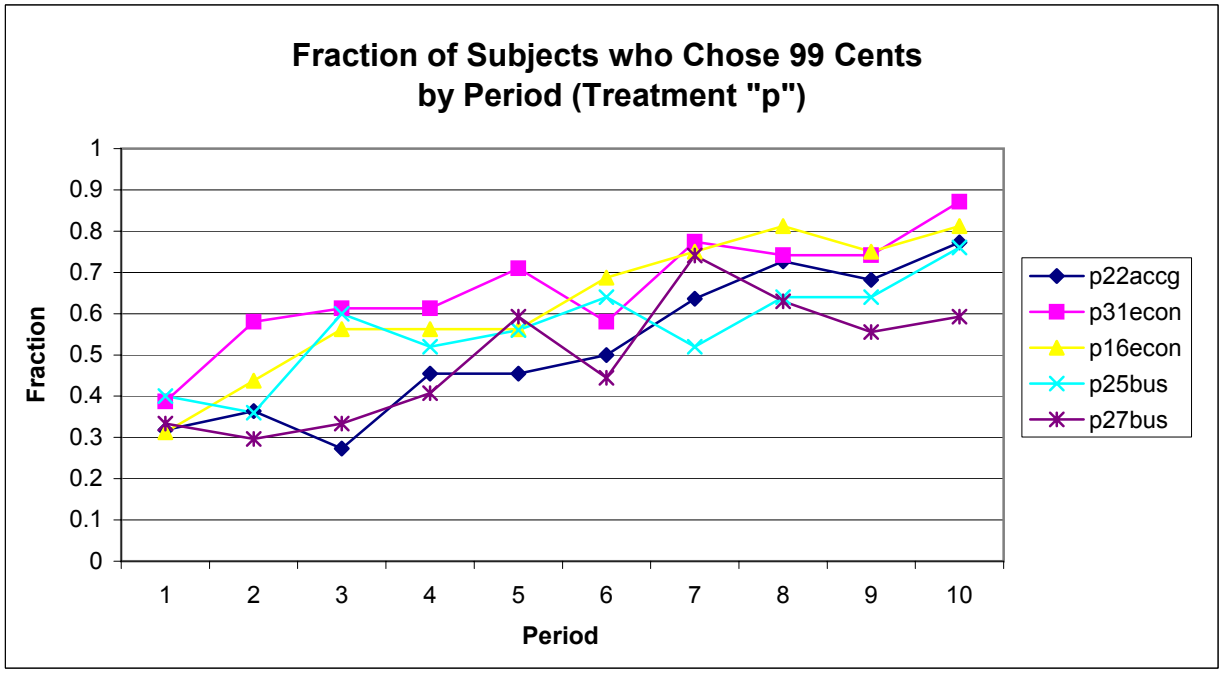


Figure 4: Fraction of subjects who chose 99 cents in each of the ten periods for the five price-revelation sessions.

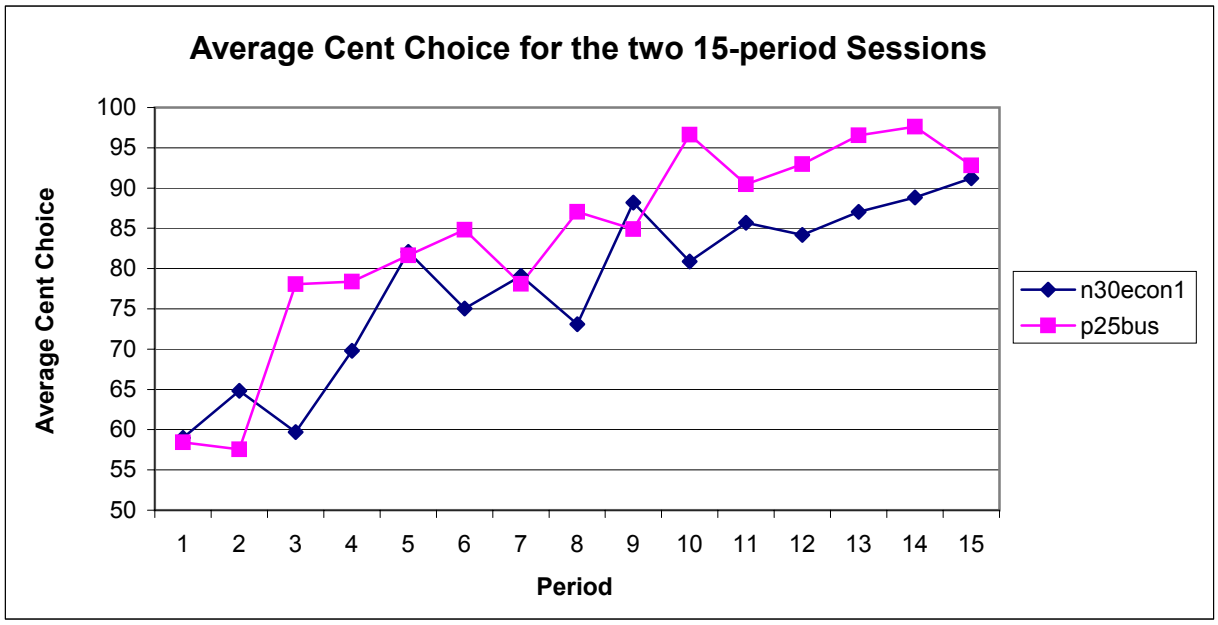


Figure 5: Average cent choice for the two sessions (one "n" session and one "p" session) that were allowed to run for 15 periods.

| subject | subtr. | eqm price | price 1 | profit 1 | price 2 | profit 2 | price 3 | profit 3 | price 4 | profit 4 | price 5 | profit 5 | price 6 | profit 6 | price 7 | profit 7 | price 8 | profit 8 | price 9 | profit 9 | price 10 | profit 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 9.99 | 9.8 | 16.12 | 9.86 | 16.01 | 9.99 | 16.45 | 9.99 | 15.84 | 9.99 | 15.81 | 9.99 | 15.68 | 9.99 | 16.12 | 9.99 | 15.47 | 9.99 | 15.24 | 9.99 | 15.24 |
| 2 | 8 | 8.99 | 9.5 | 28.77 | 9.8 | 31.04 | 9.2 | 21.93 | 9.8 | 27.64 | 9.7 | 26.40 | 9.5 | 23.81 | 9.8 | 28.38 | 9.8 | 26.64 | 9.8 | 26.02 | 9.75 | 25.51 |
| 3 | 5 | 12.99 | 12.99 | 17.82 | 12.99 | 17.13 | 12.99 | 16.45 | 12.99 | 15.84 | 12.99 | 15.81 | 12.99 | 15.68 | 12.99 | 16.12 | 12.99 | 15.47 | 12.99 | 15.24 | 12.99 | 15.24 |
| 4 | 10 | 5.99 | 6.2 | 24.66 | 6.99 | 33.50 | 6.98 | 31.43 | 6.98 | 29.71 | 6.99 | 29.73 | 6.99 | 29.37 | 5.99 | 34.70 | 5.99 | 33.55 | 5.99 | 33.14 | 5.99 | 33.16 |
| 5 | 9 | 6.99 | 7.9 | 12.79 | 7.1 | 8.53 | 9.85 | 0.00 | 7.35 | 8.03 | 7.95 | 10.03 | 7.99 | 9.98 | 7.35 | 8.36 | 7.8 | 9.04 | 7.89 | 8.99 | 6.6 | 12.26 |
| 6 | 2 | 17.99 | 18.2 | 24.66 | 18.2 | 23.28 | 18.2 | 21.93 | 18.99 | 29.83 | 18.99 | 29.73 | 19.99 | 4.81 | 18.99 | 30.62 | 18.99 | 28.75 | 18.99 | 28.08 | 18.99 | 28.11 |
| 7 | 3 | 15.99 | 15.8 | 16.12 | 15.8 | 15.49 | 15.8 | 14.88 | 15.99 | 15.84 | 15.8 | 14.30 | 15.99 | 15.68 | 15.99 | 16.12 | 15.99 | 15.47 | 15.99 | 15.24 | 15.99 | 15.24 |
| 8 | 4 | 14.99 | 15.02 | 22.19 | 15.99 | 33.50 | 15.99 | 31.55 | 15.2 | 20.73 | 15.99 | 29.73 | 15.5 | 23.81 | 15.99 | 30.62 | 15.99 | 28.75 | 15.8 | 26.02 | 15.99 | 28.11 |
| 9 | 9 | 6.99 | 6.8 | 16.12 | 6.99 | 17.13 | 6.99 | 16.45 | 6.99 | 15.84 | 7.99 | 10.17 | 6.99 | 15.68 | 6.99 | 16.12 | 6.99 | 15.47 | 6.99 | 15.24 | 6.99 | 15.24 |
| 10 | 6 | 11.99 | 12 | 21.92 | 11.99 | 36.46 | 11.99 | 35.27 | 11.99 | 34.21 | 12.99 | 29.73 | 11.99 | 33.93 | 11.99 | 34.70 | 11.99 | 33.55 | 11.99 | 33.14 | 11.99 | 33.16 |
| 11 | 5 | 12.99 | 12.99 | 17.82 | 12.99 | 17.13 | 12.99 | 16.45 | 12.5 | 11.94 | 12.8 | 14.30 | 12.8 | 14.19 | 12.99 | 16.12 | 12.7 | 13.21 | 12.99 | 15.24 | 12.99 | 15.24 |
| 12 | 2 | 17.99 | 18.01 | 22.06 | 18.9 | 32.33 | 18.93 | 30.82 | 18.85 | 28.22 | 19 | 3.85 | 18.99 | 29.37 | 18.35 | 23.06 | 18.9 | 27.75 | 17.99 | 33.14 | 17.99 | 33.16 |
| 13 | 1 | 18.99 | 18.8 | 16.12 | 18.2 | 10.33 | 18.99 | 16.45 | 18.87 | 14.89 | 18.93 | 15.33 | 18.99 | 15.68 | 18.99 | 16.12 | 19.05 | 6.62 | 10.2 | -299.3 | 17.9 | 10.99 |
| 14 | 8 | 8.99 | 9.2 | 24.66 | 9 | 20.69 | 8.9 | 33.28 | 8.99 | 34.21 | 8.99 | 34.15 | 8.99 | 33.93 | 8.99 | 34.70 | 8.99 | 33.55 | 8.99 | 33.14 | 8.99 | 33.16 |
| 15 | 3 | 15.99 | 17.6 | 0.00 | 19.3 | 0.00 | 8.2 | -232.5 | 15.6 | 12.74 | 15.5 | 11.92 | 16.5 | 8.34 | 16 | 7.11 | 15.7 | 13.21 | 15.85 | 14.16 | 15.9 | 14.56 |
| 16 | 10 | 5.99 | 6.7 | 31.51 | 6.8 | 31.04 | 6.2 | 21.93 | 6.6 | 25.34 | 6.75 | 26.98 | 6.65 | 25.52 | 6.4 | 23.65 | 6.55 | 23.87 | 6.9 | 27.11 | 6.7 | 24.96 |
| 17 | 5 | 12.99 | 12.5 | 13.43 | 12.9 | 16.35 | 12.99 | 16.45 | 12.99 | 15.84 | 12.99 | 15.81 | 12.8 | 14.19 | 13.2 | 7.82 | 12.99 | 15.47 | 12.99 | 15.24 | 12.99 | 15.24 |
| 18 | 2 | 17.99 | 18.2 | 24.66 | 18.95 | 32.98 | 19.1 | 5.90 | 18.95 | 29.37 | 18.99 | 29.73 | 18.99 | 29.37 | 18.5 | 24.83 | 18.99 | 28.75 | 18.99 | 28.08 | 18.99 | 28.11 |
| 19 | 1 | 18.99 | 18.8 | 16.12 | 18.99 | 17.13 | 18.99 | 16.45 | 18.99 | 15.84 | 18.99 | 15.81 | 18.99 | 15.68 | 18.99 | 16.12 | 18.99 | 15.47 | 18.99 | 15.24 | 18.99 | 15.24 |
| 20 | 6 | 11.99 | 12.2 | 24.66 | 12.05 | 21.34 | 12.99 | 31.55 | 11.99 | 34.21 | 11.99 | 34.15 | 11.99 | 33.93 | 11.99 | 34.70 | 11.99 | 33.55 | 11.99 | 33.14 | 11.99 | 33.16 |
| 21 | 3 | 15.99 | 15.99 | 17.82 | 15.99 | 17.13 | 15.99 | 16.45 | 15.97 | 15.69 | 15.99 | 15.81 | 15.99 | 15.68 | 15.99 | 16.12 | 15.99 | 15.47 | 15.99 | 15.24 | 15.99 | 15.24 |
| 22 | 4 | 14.99 | 14.99 | 37.68 | 14.99 | 36.46 | 14.99 | 35.27 | 14.99 | 34.21 | 14.99 | 34.15 | 14.99 | 33.93 | 14.99 | 34.70 | 14.99 | 33.55 | 14.99 | 33.14 | 14.99 | 33.16 |
| 23 | 7 | 9.99 | 9.8 | 16.12 | 9.8 | 15.49 | 9.9 | 15.70 | 9.7 | 13.54 | 9.99 | 15.81 | 9.99 | 15.68 | 9.8 | 14.58 | 9.99 | 15.47 | 9.9 | 14.55 | 9.99 | 15.24 |
| 24 | 6 | 11.99 | 12.99 | 35.48 | 11.99 | 36.46 | 11.99 | 35.27 | 11.99 | 34.21 | 11.99 | 34.15 | 11.99 | 33.93 | 11.99 | 34.70 | 11.99 | 33.55 | 11.99 | 33.14 | 11.99 | 33.16 |
| 25 | 1 | 18.99 | 18.8 | 16.12 | 18.95 | 16.78 | 18.99 | 16.45 | 18.99 | 15.84 | 18.99 | 15.81 | 18.99 | 15.68 | 18.99 | 16.12 | 18.99 | 15.47 | 18.99 | 15.24 | 18.99 | 15.24 |
| 26 | 10 | 5.99 | 6.2 | 24.66 | 6.1 | 21.99 | 6.4 | 24.37 | 6.5 | 24.19 | 6.37 | 22.62 | 6.45 | 23.25 | 6.48 | 24.59 | 6.46 | 22.87 | 6.39 | 21.58 | 6.27 | 20.30 |
| 27 | 7 | 9.99 | 9.99 | 17.82 | 9.99 | 17.13 | 9.99 | 16.45 | 9.99 | 15.84 | 9.99 | 15.81 | 9.99 | 15.68 | 9.99 | 16.12 | 9.99 | 15.47 | 9.99 | 15.24 | 9.99 | 15.24 |
| 28 | 4 | 14.99 | 15.99 | 35.48 | 15.99 | 33.50 | 14.99 | 35.27 | 15.78 | 27.41 | 14.99 | 34.15 | 14.99 | 33.93 | 14.99 | 34.70 | 14.99 | 33.55 | 14.99 | 33.14 | 14.99 | 33.16 |
| 29 | 9 | 6.99 | 6.99 | 17.82 | 6.51 | 13.00 | 7 | 7.44 | 5.99 | 12.38 | 6 | 7.95 | 6.79 | 14.11 | 6.89 | 15.31 | 6.99 | 15.47 | 6.99 | 15.24 | 5.99 | 12.08 |
| 30 | 8 | 8.99 | 10.95 | 13.14 | 9.1 | 21.99 | 8.95 | 34.38 | 7.95 | 17.33 | 8.95 | 33.29 | 9.2 | 20.41 | 8.95 | 33.83 | 8.95 | 32.71 | 8.95 | 32.31 | 8.55 | 23.98 |
| average cent choice | | | **63.00** | | **70.67** | | **78.167** | | **84.83** | | **85.20** | | **86.60** | | **81.767** | | **89.00** | | **91.567** | | **91.47** | |

Table 3: Price choices and profits in all 10 periods for experiment *n 30 econ 2*. Each row indicates the subject's subtreatment, corresponding equilibrium price, and price choice and resultant profit labeled for each of the 10 periods. The average cent choice for each period appears in the bottom row. If the subject chose the full equilibrium price (dollar and cent components), the price is darkly shaded in. If the subject chose the equilibrium cent choice only, the price is lightly shaded in.

| subject | subtr. | eqm price | price 1 | profit 1 | price 2 | profit 2 | price 3 | profit 3 | price 4 | profit 4 | price 5 | profit 5 | price 6 | profit 6 | price 7 | profit 7 | price 8 | profit 8 | price 9 | profit 9 | price 10 | profit 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 9.99 | 9.8 | 16.09 | 9.99 | 17.15 | 10.2 | 7.52 | 9.99 | 15.27 | 9.75 | 13.81 | 9.95 | 15.64 | 9.99 | 15.03 | 9.99 | 14.99 | 9.89 | 14.04 | 9.99 | 14.68 |
| 2 | 8 | 8.99 | 9.2 | 24.59 | 9 | 20.74 | 9.5 | 24.19 | 9.65 | 24.48 | 10.2 | 3.82 | 9.5 | 24.45 | 8.95 | 31.95 | 8.95 | 31.89 | 8.95 | 31.53 | 8.95 | 31.35 |
| 3 | 5 | 12.99 | 12 | 8.94 | 12.99 | 17.15 | 12.99 | 15.85 | 12.8 | 13.81 | 12.99 | 15.71 | 12.99 | 15.96 | 12.99 | 15.03 | 11.99 | 11.96 | 12.99 | 14.78 | 12.99 | 14.68 |
| 4 | 10 | 5.99 | 6.2 | 24.59 | 6 | 20.74 | 6.2 | 20.73 | 5.99 | 33.20 | 5.99 | 33.97 | 5.8 | 30.30 | 5.95 | 31.95 | 5.99 | 32.72 | 5.99 | 32.34 | 5.99 | 32.16 |
| 5 | 9 | 6.99 | 6.8 | 16.09 | 6.4 | 12.07 | 6.8 | 14.33 | 6.85 | 14.20 | 6.75 | 13.81 | 6.9 | 15.24 | 6.93 | 14.57 | 6.91 | 14.39 | 5.9 | 10.78 | 6.89 | 13.94 |
| 6 | 2 | 17.99 | 18.99 | 35.38 | 18.99 | 33.58 | 18.9 | 28.80 | 18.99 | 28.18 | 18.99 | 29.44 | 18.99 | 30.15 | 18.99 | 27.49 | 18.99 | 27.39 | 18.99 | 26.78 | 18.99 | 26.49 |
| 7 | 3 | 15.99 | 15.8 | 16.09 | 15.95 | 16.81 | 15.99 | 15.85 | 15.75 | 13.43 | 15.5 | 11.84 | 15.95 | 15.64 | 15.99 | 15.03 | 15.94 | 14.62 | 15.99 | 14.78 | 15.99 | 14.68 |
| 8 | 4 | 14.99 | 18.99 | 0.00 | 14.99 | 36.51 | 14.99 | 34.22 | 14.99 | 33.20 | 14.99 | 33.97 | 14.99 | 34.41 | 14.99 | 32.77 | 14.99 | 32.72 | 14.99 | 32.34 | 14.99 | 32.16 |
| 9 | 9 | 6.99 | 6.99 | 17.78 | 6.99 | 17.15 | 6.99 | 15.85 | 6.8 | 13.81 | 6.99 | 15.71 | 6.99 | 15.96 | 6.99 | 15.03 | 6.99 | 14.99 | 6.99 | 14.78 | 6.99 | 14.68 |
| 10 | 6 | 11.99 | 12.99 | 35.38 | 12.99 | 33.58 | 12.99 | 29.83 | 11.99 | 33.20 | 11.99 | 33.97 | 11.99 | 34.41 | 11.99 | 32.77 | 11.99 | 32.72 | 11.99 | 32.34 | 11.99 | 32.16 |
| 11 | 5 | 12.99 | 12.99 | 17.78 | 12.99 | 17.15 | 12.99 | 15.85 | 12.99 | 15.27 | 12.99 | 15.71 | 12.99 | 15.96 | 12.99 | 15.03 | 12.99 | 14.99 | 12.99 | 14.78 | 12.99 | 14.68 |
| 12 | 2 | 17.99 | 18.55 | 29.37 | 18.75 | 30.47 | 18.81 | 27.76 | 18.9 | 27.20 | 18.52 | 24.09 | 19.32 | 4.79 | 18.6 | 23.35 | 18.99 | 27.39 | 18.99 | 26.78 | 18.99 | 26.49 |
| 13 | 1 | 18.99 | 18.8 | 16.09 | 19 | 8.15 | 18.9 | 15.13 | 18.8 | 13.81 | 16.9 | -1.70 | 17.9 | 11.31 | 18.3 | 9.82 | 18.6 | 12.06 | 18.99 | 14.78 | 18.99 | 14.68 |
| 14 | 8 | 8.99 | 9.01 | 21.99 | 9 | 20.74 | 9.99 | 29.83 | 9.99 | 28.18 | 10 | 3.55 | 8.99 | 34.41 | 8.99 | 32.77 | 8.99 | 32.72 | 8.99 | 32.34 | 8.99 | 32.16 |
| 15 | 3 | 15.99 | 15.99 | 17.78 | 15.99 | 17.15 | 15.99 | 15.85 | 15.8 | 13.81 | 15.99 | 15.71 | 15.99 | 15.96 | 15.99 | 15.03 | 15.99 | 14.99 | 15.99 | 14.78 | 15.99 | 14.68 |
| 16 | 10 | 5.99 | 6.2 | 24.59 | 5.99 | 36.51 | 5.99 | 34.22 | 4.99 | 18.22 | 5.99 | 33.97 | 6 | 18.63 | 5.99 | 32.77 | 5.99 | 32.72 | 5.97 | 31.93 | 5.99 | 32.16 |
| 17 | 5 | 12.99 | 12.99 | 17.78 | 12.99 | 17.15 | 12.99 | 15.85 | 12.99 | 15.27 | 12.99 | 15.71 | 12.99 | 15.96 | 12.99 | 15.03 | 12.99 | 14.99 | 12.99 | 14.78 | 12.99 | 14.68 |
| 18 | 2 | 17.99 | 12.99 | -251.2 | 18.01 | 20.87 | 18.99 | 29.83 | 18.99 | 28.18 | 17.99 | 33.97 | 17.99 | 34.41 | 17.99 | 32.77 | 17.99 | 32.72 | 17.99 | 32.34 | 17.99 | 32.16 |
| 19 | 1 | 18.99 | 18.99 | 17.78 | 17.99 | 13.03 | 18.89 | 15.05 | 18.79 | 13.73 | 18.99 | 15.71 | 19.09 | 7.26 | 18.99 | 15.03 | 18.89 | 14.24 | 18.99 | 14.78 | 18.99 | 14.68 |
| 20 | 6 | 11.99 | 12.99 | 35.38 | 12.99 | 33.58 | 12.99 | 29.83 | 11.99 | 33.20 | 11.99 | 33.97 | 12.2 | 20.96 | 11.99 | 32.77 | 11.99 | 32.72 | 11.99 | 32.34 | 11.99 | 32.16 |
| 21 | 3 | 15.99 | 15.49 | 13.32 | 16.32 | 9.45 | 15.33 | 10.59 | 15.68 | 12.89 | 17.78 | 0.00 | 14.84 | 10.55 | 15.85 | 13.97 | 16.74 | 8.19 | 15.97 | 14.63 | 15.97 | 14.53 |
| 22 | 4 | 14.99 | 15.99 | 35.38 | 15.02 | 21.00 | 15.99 | 29.83 | 15.99 | 28.18 | 14.99 | 33.97 | 15.89 | 28.99 | 14.99 | 32.77 | 14.99 | 32.72 | 14.99 | 32.34 | 14.99 | 32.16 |
| 23 | 7 | 9.99 | 9.8 | 16.09 | 9.99 | 17.15 | 9.99 | 15.85 | 9.99 | 15.27 | 9.99 | 15.71 | 9.99 | 15.96 | 9.99 | 15.03 | 9.99 | 14.99 | 9.99 | 14.78 | 9.99 | 14.68 |
| 24 | 6 | 11.99 | 12.02 | 22.13 | 11.99 | 36.51 | 11.99 | 34.22 | 11.99 | 33.20 | 11.99 | 33.97 | 12.99 | 30.15 | 11.99 | 32.77 | 11.99 | 32.72 | 11.99 | 32.34 | 11.99 | 32.16 |
| 25 | 1 | 18.99 | 18.3 | 11.62 | 18.99 | 17.15 | 18.99 | 15.85 | 18.99 | 15.27 | 18.99 | 15.71 | 18.99 | 15.96 | 18.99 | 15.03 | 18.99 | 14.99 | 18.99 | 14.78 | 18.99 | 14.68 |
| 26 | 10 | 5.99 | 6 | 21.86 | 5.99 | 36.51 | 5.99 | 34.22 | 5.99 | 33.20 | 5.99 | 33.97 | 5.99 | 34.41 | 5.99 | 32.77 | 5.99 | 32.72 | 5.99 | 32.34 | 5.99 | 32.16 |
| 27 | 7 | 9.99 | 9.6 | 14.30 | 8.6 | 7.90 | 9.5 | 11.94 | 9.79 | 13.73 | 9.59 | 12.55 | 9.75 | 14.03 | 9.76 | 13.29 | 9.61 | 12.13 | 9.6 | 11.88 | 9.75 | 12.91 |
| 28 | 4 | 14.99 | 14.99 | 37.62 | 15.99 | 33.58 | 14.99 | 34.22 | 14.99 | 33.20 | 14.99 | 33.97 | 14.99 | 34.41 | 14.99 | 32.77 | 14.99 | 32.72 | 14.99 | 32.34 | 14.99 | 32.16 |
| 29 | 9 | 6.99 | 6.8 | 16.09 | 6.85 | 15.95 | 6.8 | 14.33 | 6.99 | 15.27 | 6.99 | 15.71 | 6.99 | 15.96 | 6.99 | 15.03 | 6.99 | 14.99 | 6.99 | 14.78 | 6.99 | 14.68 |
| 30 | 8 | 8.99 | 9.2 | 24.59 | 9.99 | 33.58 | 9.99 | 29.83 | 9.85 | 26.66 | 9.99 | 29.44 | 9.99 | 30.15 | 9.99 | 27.49 | 9.99 | 27.39 | 9.95 | 26.36 | 9.99 | 26.49 |
| 31 | 5 | 12.99 | 13.2 | 9.66 | 5.09 | -238 | 13.65 | 9.06 | 12.99 | 15.27 | 12.99 | 15.71 | 12.99 | 15.96 | 12.99 | 15.03 | 12.8 | 13.56 | 12.95 | 14.48 | 12.99 | 14.68 |
| average cent choice | | | **63.39** | | **70.35** | | **84.81** | | **91.19** | | **86.35** | | **83.58** | | **93.87** | | **94.23** | | **96.613** | | **97.71** | |

Table 4: Price choices and profits in all 10 periods for experiment *p 31 econ.*