Does Auctioning of Entry Licenses Induce Collusion?
An Experimental Study[*]

Theo Offerman

Department of Economics / CREED, University of Amsterdam
Roeterstraat 11, 1018 WB Amsterdam, the Netherlands
phone: 31-20-5254294, fax: 31-20-5255283, e-mail: theoo@fee.uva.nl

Jan Potters

Department of Economics / CentER, Tilburg University
Warandelaan 2, 5000 LE Tilburg, the Netherlands
phone: 31-13-466.8204, fax: 31-13-466.3042, e-mail: j.j.m.potters@kub.nl

March 2001

Does Auctioning of Entry Licenses Induce Collusion?

An Experimental Study

Abstract

We use experiments to examine whether the auctioning of entry rights affects the behavior of market entrants. Standard economic arguments suggest that the license fee paid at the auction will not affect prices since it constitutes a sunk cost. This argument is not uncontested though and this paper puts it to an experimental test. Our results indicate that an auction of entry licenses may affect prices. The payment of an entry fee increases the probability that the market entrants tacitly coordinate on a collusive price path.

1. Introduction

The last decade has witnessed a return to the practice of auctioning the rights for privileged positions. From the late Roman times, rulers all around the world have to a greater or lesser extent relied on the sale of offices to highest bidders in order to generate income (Swart, 1980). For example, in the Dutch republic much sought offices like postmaster, clerk, broker, porter and carrier were often publicly sold to the highest bidder from the 16-th to the 18-th century. The practice of selling offices was most pronounced in 17-th century France, where the kings needed large amounts of money to fulfil their costly appetites for waging wars and building luxurious palaces. The French sold virtually all public offices.[1] Gradually the possibility to levy taxes reduced the necessity to generate income by selling offices. Recently, however, governments again make increased use of auctions, in particluar to allocate the licenses to operate at markets where entry is limited for geographical or technical reasons. Examples are mobile telecommunication, broadcasting, oil drilling, airport slots, and vendor locations at fairs.

Auctions have a number of advantages over alternative allocation mechanisms. Unlike, for example, lotteries or queuing (first-come-first-served), they tend to select the more cost-efficient entrants. Furthermore, auctions are more transparent and less prone to rent-seeking than administrative processes (beauty contests). Finally, the license fees paid by the auction winners are often seen as welcome revenue to governments, diminishing their need to rely on distorting taxes.[2]

This latter benefit is not uncontested though. In particular, it is often argued that auctioning will increase the prices that consumers ultimately pay. Many companies claim that they will charge higher prices in order to recuperate part of the entry fee. For example, in response to plans by the Dutch government to auction the locations for petrol stations along the highways oil company

---

[1] The French were noteworthy for being creative in finding new offices to be sold. There existed, for example, inspectors of hogs' tongues and controllers of perukes. When Louis XIV asked his Controller-General Pontchartrain how he always succeeded in finding new people interested in buying new offices, Pontchartrain answered: "Your majesty forgets one of his most beautiful privileges, i.e., as soon as the king institutes an office, God creates a fool who will buy it" (Swart, 1980, p.15).

[2] The auctioning of spectrum licenses in the US raised over 20 billion dollars. Revenues for the third generation mobile spectrum (umts) licences have been more than 25 billion dollars in both the UK and Germany.

Shell argues that "auctioning the selling points drives up costs. After all, just like the auctioning of locations at fun fairs by local governments, ultimately these costs will have to be included in the product price. The extra revenue to the government will ultimately be paid by the motorists" (Shell, 1999). The criticism from these companies is perhaps not so surprising. They have to pay substantial fees for licenses which often they used to get for free. Interestingly though, also consumers[3], regulators and policymakers are sometimes concerned about the use of auctions. For example, the European Commission states that "reliance on auctions should not lead to an excessive transfer to the public budget or for other purposes to the detriment of low tariffs for the users" (European Commission, 1994, proposed position I.11). Hence, there is a rather widespread concern that auctioning of licenses may lead to higher consumer prices.

Economists easily find the flaw in this line of reasoning (see, e.g., McMillan, 1995, Van Damme, 1997). Once the right to operate on a market has been obtained, the entry fee constitutes a sunk cost. Entrants interested in expected profits will base their decisions on an evaluation of marginal revenues and marginal costs, and these are unaffected by sunk costs. Bygones are bygones, as the saying goes. In addition, entrants are never forced to bid more than their expected value of obtaining the license. When bidders bid rationally, they will be able to earn a normal return on their investments, even profits will be lower than the profits they were used to when licenses were obtained for free. From the standard theoretical perspective the argument for increased prices does not seem to make much sense.

There is one caveat to the sunk cost argument, however. If the game for which the positions are allocated has multiple equilibria, an entry fee may affect the equilibrium that is being selected. Several experimental studies have demonstrated the force of this principle. For example, Cooper, DeJong, Forsythe and Ross (1993), Van Huyck, Battalio and Beil (1993), and Cachon and Camerer, (1996) study coordination games with multiple equilibria and find that an entry fee

---

[3] The International Telecommunications Users Group is strongly opposed to auctioning of scarce telecom resources like radio frequencies, numbering space and orbital slots on the ground that "funding of auction bids creates a debt-financing burden for the succesful bidder. This must then be serviced by income during the operating period of the license won by the bid. The cost of financing the debt is therefore borne by the end customer of the licensed service" (INTUG, 1996).

may induce players to coordinate on a different (Pareto superior) equilibrium. We will discuss details of these studies and their differences with the present study below. What is important for now is that entrants typically play a repeated game after they have obtained an entry license. Repeated games often have multiple Nash equilibria and in selecting among these equilibria an entry fee may make a difference. In particular, the entry fee may stimulate the entrants to choose for a more collusive pricing strategy.

Furthermore, there exists another potential upward pressure on prices as a result of auctioning. An auction will select the entrants with the highest profit expectations. Profit expectations will partly depend on the players' beliefs about the possibilities to collude. Bidders who are optimistic about the prospects for collusion will expect to make higher profits than those that expect to enter a very competitive market. An auction may then have the effect of selecting the more optimistic bidders, and, to the extent that these are also the more collusive entrants, this may have an upward effect on prices. Notice that this argument for increased prices relies on self-selection, whereas the previous one does not.

Unfortunately, it is almost impossible to rely on empirical data to test for a positive relation between license auctions and market prices. For some markets there are indications that higher entry fees are associated with higher consumer prices. For example, within the European Union there seems to be a positive relation between the tariffs for mobile voice telecommunication and the license fees paid by the operator (see EU, 1999a, 1999b).[4] The problem with such data, however, is that the number and relative size of the operators also varies considerably across countries, and so does the quality of the service, the size of the market, the type of license (GSM, DCS, regional, national), and the selection method (auction, beauty contest). As a consequence, a positive association between entry fees and tariffs tells us little about the causality of the

---

[4] Within the European Union the highest license fees (more than 200 million Euros for the most valuable licenses) have been paid in Austria, Belgium, the Netherlands and Ireland, and the lowest fees (less than 5 million Euro) in Denmark, Finland, Luxembourg and Portugal (EU, 1999a). Annual tariffs for a representative basket of services average about 750 Euro in the former four countries, but only 550 Euro in the latter four countries (EU, 1999b). For example, Ireland and Luxembourg are the two countries with only two mobile operators. The most expensive license in Ireland was 216 million Euro and average annual tariffs are about 1300 Euro. Luxembourg had license fees less than 4 million Euro and annual tariffs of about 700 Euro.

relationship. It may be that entrants charge higher prices when they have paid an entry fee, but it may also be that they have entered higher bids *because* they anticipate higher prices and profits.

In the present paper we employ the experimental method to investigate the arguments outlined above. Does auctioning of entry licenses lead to an increase of market prices? And, if so, is this because the entry fee induces the players to behave more collusively, or because the auction tends to select the more collusive players? To examine these questions we set up an experimental market, corresponding to a symmetric price-setting duopoly with product differentiation.[5] We implemented three stylized allocation treatments. In the *Auction* treatment, we had four subjects bidding for the right to enter the market, and paying their bids in case they were among the two highest bidders. In the *Fixed Cost* treatment, the entry rights were randomly assigned, and the two selected entrants had to pay an exogenous entry fee, comparable in size to the winning bids in the Auction treatment. In our *Baseline* treatment, finally, the entry rights were also assigned randomly, but now the two entrants did not have to pay any entry fee at all.

With this design, a potential price effect of auctioning shows up by comparing the market prices in the Baseline treatment with those in the Auction treatment. Moreover, the design allows us to distinguish whether a price effect is due to entry fees facilitating collusion (by comparing the Baseline treatment and the Fixed Cost treatment), or due to the auction selecting the more collusive players (by comparing the Fixed Cost treatment and the Auction treatment).

The remainder of this paper is organized as follows. Section 2 presents the model and gives a more detailed outline of the hypotheses to be tested. Section 3 provides details of the experimental design and procedure. Section 4 presents the experimental result and section 5 contains a concluding discussion.

2. Model and hypotheses

---

[5] A symmetric setup allows for the cleanest test possible of the two arguments put forward for a potential upward price effect of auctioning entry licenses. It is not our purpose to give an overall assessment of the costs and benefits of license auctions. Such an assessment should, for example, include the potential of auctions to select the most (productively) efficient firms. In this paper we are mainly interested in the force of the sunk cost argument.

The market that we induced in our experiments is a textbook example of a symmetric linear price-setting duopoly with product differentiation (e.g., Martin, 1993, p.38). One reason to opt for price-setting is that the argument against the use of auctions usually refers to firms increasing their prices rather than decreasing their quantities. Furthermore, most of the markets of interest seem to be characterized by at least some degree of product differentiation. The parameters of the model are chosen such that three benchmark outcomes - Nash, collusion, Walras - are well within the set of feasible prices. Furthermore, we wanted these three outcomes to lead to substantially different profit levels, with the Nash profits about midway between the competitive profits (of zero) and the collusive profits.

Specifically, demand and costs, respectively, are given by

$$q_i = \max[0, 124 - 2p_i + 1.6p_j] \quad i \neq j = 1,2 \tag{1}$$

and

$$c(q_i) = 10q_i \qquad i = 1,2 \tag{2}$$

Profits are thus equal to

$$\eth_i(p_i,p_j) = (p_i-10)q_i \qquad i \neq j = 1,2 \tag{3}$$

Players simultaneously choose prices, with p_i å [0,200]. It is straightforward to verify that the best reply functions are given by

$$r_i(p_j) = 36 + 0.4p_j \tag{4}$$

The unique stage game Nash equilibrium is equal to $(p_1^N,p_2^N) = (60,60)$ with corresponding profits of $(\eth_1^N,\eth_2^N) = (5000,5000)$. It is easy to check that joint profit maximization leads to the collusive outcome $(p_1^C,p_2^C) = (160,160)$ with corresponding profits of $(\eth_1^C,\eth_2^C) = (9000,9000)$. The competitive Walrasian outcome, with prices equal to marginal cost and maximal social welfare,

5

is characterized by $(p_1^W, p_2^W) = (10,10)$ and $(\eth_1^W, \eth_2^W) = (0,0)$. These outcomes summarize the main features of the model.

The best reply functions are quite flat. As a consequence, (full) collusion is a risky enterprise. For example, when player 1 prices at $p_1 = 160$, player 2 will be tempted to set its price at $p_2 = 100$. Corresponding profits are $\eth_1 = 0$ and $\eth_2 = 16200$. Hence, relative to the collusive profits of 9000, both the loss (-9000) and the temptation (+7200) of cheating are substantial.

In all three treatments of the experiment, subjects first play this market game for 10 periods against the same opponent. After the tenth period, each subject is randomly allocated to a group of four (among which is his or her opponent from the first ten periods). These groups remain fixed until the end of the experiment (period 30). Before the start of the 11-th, 16-th, 21-th and 26-th period, two of the four subjects are selected to play the market game for another five periods against each other. The two subjects that are not selected to play receive an opportunity payment of 1000 per period. Furthermore, they are informed about the prices and profits of the two subjects in their group who are playing the game.[6] After the five periods are over, there is a new selection of two players from the group of four subjects for the next block of five periods, or, after period 30, the experiment is over.

The three treatments of our experiment differ in the manner in which the two players are selected from the group of four subjects at the beginning of periods 11, 16, 21, and 26. In the Auction treatment, each of the four subjects submits a bid for the right to service the market for the next five periods. The two highest bidders are allowed to enter the market. We use a discriminative sealed-bid auction in which the two highest bidders pay their respective bids, B_1 and B_2, as entry fees (and random assignment in case of ties). For each of the four blocks of five rounds there is a separate auction. In the Fixed Cost treatment, two subjects who are randomly selected enter the market. They pay exogenous sunk entry costs, S_1 and S_2, respectively. Like the

---

[6] To have the outsiders observe prices and profits of insiders seems closer to real world settings than giving them no information. Also, the decision to have subjects gain some familiarity with the market before any entry auctions take place, is partly motivated by the empirical observation that potential entrants (e.g., in telecom) are often players with substantial experience, either at the very same market, at related product markets, or at similar markets in other geographical areas.

bids in the auction, these costs are private information. To allow for the cleanest possible comparison between this treatment and the previous treatment, we matched the entry costs exactly with the fees paid by the subjects in the Auction treatment. For each group of four subjects in the Auction treatment we observe a sequence of four winning bid-pairs and we induce the very same sequence of entry fees for a group of four subjects in the Fixed Cost treatment. Hence, for each observation of entry fees (B_1, B_2) in the Auction treatment, we also have an observation with $S_1 = B_1$ and $S_2 = B_2$ in the Fixed Cost treatment. Also the sequence of fees is exactly matched. Finally, in our Baseline treatment, the two entrants do not pay an entry fee and are randomly selected from the group of four subjects. An independent lottery is performed for each of the four blocks of five periods.

These three treatments allow us to test three main hypotheses regarding the assignment of entry licenses. To spell out these hypotheses, P_{BL}, P_{FC} and P_{AU} will be used to refer to average prices in the Baseline, Fixed Cost, and Auction treatment, respectively.

Sunk Cost Hypothesis: $P_{BL} = P_{FC} = P_{AU}$

This hypothesis is based on the standard argument that an entry fee is a sunk cost that is irrelevant for the pricing decisions. Profit maximizing players will base their prices on marginal cost and revenue calculations and these are not affected by the cost of entry. The entry fees are simply a lump sum transfer from the entrants (subjects) to the government (experimenter). Therefore, we should observe the same prices in the Baseline, Fixed Cost, and Auction treatment.

Collusion Facilitation Hypothesis: $P_{BL} < P_{FC} = P_{AU}$

The stage game of the market has a unique Nash equilibrium. Therefore, a finite repetition of the game has a unique subgame perfect equilibrium, one in which the stage game equilibrium is played in each repetition. From this perspective we should not expect an entry fee to have an effect on play in the repeated game. At the same time, the repeated game has multiple non-perfect

7

Nash equilibria. If a player believes that the other player may revert to a price below the stage game equilibrium in the final period(s), then prices above the stage game equilibrium can be supported in the early periods of the game.[7] Reverting to prices below the stage game equilibrium is an incredible threat (that is why the equilibrium is not subgame perfect), but the threat does not need to be carried out if both players manage to coordinate on a collusive price path. In the final period they can then choose the stage game equilibrium price. Hence, even though tacit collusion is not a subgame perfect equilibrium, it is a Nash equilibrium.[8]

If both players coordinate on a collusive equilibrium, payoffs will be higher than in the subgame perfect equilibrium. However, in situations with multiple equilibria there is a possibility that the players fail to coordinate on the same equilibrium. If one player opts for collusion while the other player opts for the subgame perfect equilibrium, payoffs to the former player will be lower than those in the subgame perfect equilibrium. In this sense an attempt to coordinate on a collusive price path is risky, and riskier than opting for the subgame perfect equilibrium. If entrants have just paid a (large) entry cost this may stimulate them to pursue the risky strategy in an attempt to recover the loss as much and as quickly as possible.

In other settings it has already been shown that entry fees may affect equilibrium selection. Van Huyck, Battalio, and Beil (1993) examine a coordination game with multiple Pareto-ranked equilibria. They find that auctioning the entry rights to the game helps players to coordinate on the Pareto efficient equilibrium. Forward induction can be the active selection principle here. Cachon and Camerer (1996) find that the selection effect of an entry fee does not necessarily rely on self-

---

[7] It is easily checked that (160, 160, 160, 131, 60) is the most collusive sequence of prices that can be supported as a Nash equilibrium if the market game is repeated five times. To derive that 131 is the maximum price that can be supported in round 4, consider an optimal deviation in round 4 if the proposed equilibrium price for round 4 is z. The optimal deviation is $r(z) = 36 + 0.4z$ and corresponding profits are $\eth(r(z),z)$. In round 5 the deviator will face maximal punishment when the opponent prices at 0. The best reponse to this punishment is a price of $r(0) = 36$. Deviation in round 4 thus gives a payoff of at least $\eth(r(z),z) + \eth(36,0)$ for the remainder of the game. For a price z to be an equilibrium price in round 4, following the equilibrium must give a payoff at least as large as the payoff from deviating. Hence, z can be supported as an equilibrium in round 4 if $\eth(z,z) + \eth(60,60) \geq \eth(r(z),z) + \eth(36,0)$, which is equivalent to $z \leq 131$.

[8] Moreover, experimental studies have found that players often manage to cooperate (collude) in finitely repeated games with a unique stage game equilibrium (see, e.g., Engle-Warnick and Slonim, 2000, Selten and Stoecker, 1986). In other words, even in settings in which cooperation is not a theoretical equilibrium it may still be a *behavioral* equilibrium.

selection through the auction mechanism. Coordination on the Pareto-efficient equilibrium may be improved even if an *exogenous* entry fee is imposed on the players. This effect has been attributed to loss avoidance. Players do not pick strategies that result in certain losses, if other (equilibrium) strategies are available that might result in a positive payoff.

A result by Cachon and Camerer that is particularly relevant for our present hypothesis is that play may be affected even if the entry fee is below the payoffs in the 'bad' equilibrium. That is, even if the players would not behave differently as a result of the entry fee, they would still earn a positive payoff. Cachon and Camerer observe that play is nevertheless affected by the entry fee in about 40% of the cases. Cooper at al. (1993) find a similar result in a battle-of-the-sexes game. Play is affected when one player pays an entry fee, even though the entry fee is below the lowest payoff in any equilibrium.[9] In our market game these results provide ammunition for the hypothesis that play may be affected by an entry fee, even if the fee is below the payoffs of the unique subgame perfect equilibrium.

Selection Hypothesis: $P_{BL} = P_{FC} < P_{AU}$

The selection hypothesis is based on the assumption that an auction will select the players with the highest profit expectations. Since the cost and demand conditions of the players are identical in our market game, players' profit expectations will largely depend on the subjective beliefs about their own and the other player's pricing behavior. To the extent that players who expect to earn relatively high profits are also the players who tend to be relatively collusive, the entry auction may result in an upward effect on prices.[10] Since selection of the more collusive

---

[9] Another noteworthy study is Güth and Schwarze (1983), who auctioned off player positions in ultimatum game experiments (see also Güth and Tietz, 1985). They found the auction winners for the proposer position to be more 'greedy' than is typically the case in ultimatum games without an entry auction. Although this result is sometimes interpreted in terms of entitlement rights, others have stressed the fact that the ultimatum game has multiple Nash equilibria (even though only one is subgame perfect).

[10] For example, in the duopoly price-setting experiments with complete information of Fouraker and Siegel (1963, experiment 16), there is a positive correlation between a firm's average price and his average profit. Within each duopoly the firm with the lower average price typically earns the higher profit. Across all duopolies, however, the higher price firms earn more money than their more competitive counterparts. See Offerman et al. (1998) for

players can only take place in the Auction treatment, the Selection Hypothesis postulates that prices will be higher in the Auction treatment than in the Baseline and Fixed Cost treatment, where the assignment of entry rights is exogenous.

Summarizing, according to the Sunk Cost Hypothesis an entry fee is a pure sunk cost and therefore an entry auction should not affect market prices. The Selection Hypothesis argues that auctioning the licenses has an impact on prices because the auction will tend to select those entrants that expect to embark on a relatively collusive price path. The Collusion Facilitation Hypothesis, on the other hand, postulates that an entry fee will stimulate the entrants to coordinate on a more collusive price path. These two possible collusive effects of auctioning are not mutually exclusive. Our main reason to include the Fixed Cost treatment, is precisely to be able to separate these two effects and assess their relative force.

3. Experimental Design

We had six experimental sessions, two for each of the three treatments. Each session hosted 20 subjects, except one session in the Auction treatment in which we had only 16 students due to no-shows. In a session all interaction took place within groups of four subjects, yielding 5 independent observation per session in the five sessions with 20 subjects and 4 observations in the session with 16 subjects. Hence, in total we have 10 independent observations for both the Baseline and Fixed Cost treatments, and 9 for the Auction treatment.

Undergraduate students of Tilburg University were recruited as subjects. In total we had 116 subjects. Sessions lasted for about 1½ hours, and earnings averaged 43.55 Dutch guilders, which is about 21.75 US$.

Upon entering the room subjects were randomly seated in the laboratory behind tables with partitions. Instructions were distributed and read aloud. All interaction took place by means of

---

a similar result in a quantity-setting oligopoly.

networked computers.[11] Each experimental session consisted of two parts, with the instructions for part 2 being distributed only after the completion of part 1. In part 1 subjects first went through a practice round. Then they played the price-setting game outlined above for 10 periods with a fixed, randomly assigned opponent, and subjects were informed about this. Profits were denoted in points, which at the end of the experiment were converted into cash at a rate of 2000 points = 1 Dutch guilder.

The market structure was common information. It was explained how a subject's own price and the other subject's price would affect the demand for their product. This was explained both with a formula and in words. Subjects also had access to a pocket calculator, and to a table reporting quantity as a function of own price and other's price. Demand was simulated in the experiment: no subject had the role of consumer. Profit functions were also explained, in words and with a formula. Subjects were also told how the other subject's production and profits were determined. They were not given a profit table though.

After all subjects in the session had entered their prices, they received feedback information about their own and their opponent's price, quantity, revenue, cost and profit.[12] Information from earlier periods was not available on screen, but they could keep track of this themselves by means of a results table (and most of them did). No information about other pairs was revealed.

Part 2 consisted of another 20 periods of the same game, divided in 4 blocks of 5 periods. Subjects were informed that they were assigned to a group of four subjects, that these groups would remain fixed throughout part 2, and that in each block of 5 periods two of them would be selected to enter the market together. The two inactive subjects received a fixed payment of 1000 points per period, that is, 5000 for a block of five periods, and were informed about the prices and profits of the two active subjects.

As explained in the previous section, the procedure to select the two subjects entering the

---

[11] The program is written in Turbo Pascal using the RatImage library. Abbink and Sadrieh (1995) provide documentation of this library.

[12] Subjects could only choose integer prices. This does not affect the benchmarks discussed in section 2, except for the fact that besides the stage game Nash equilibrium of $(p_1^N, p_2^N) = (60, 60)$ there is an additional stage game Nash equilibrium at $(p_1^N, p_2^N) = (59, 59)$.

market distinguished the three treatments. In the Baseline treatment the subjects entering the market were randomly selected, with an independent lottery being used for each of the four blocks of five periods and for each group of four subjects. In the Auction treatment, subjects entered bids for the right to be in the market for a block of five periods. Within each group of four subjects, the two with the highest bids were selected to enter the market, and their bids were subtracted from their earnings. Bids were restricted to integer values between 0 and 50000 points. Subjects received no information about the bids of other subjects from their own groups or from other groups. In the Fixed Cost treatment, the subjects selected to enter the market had to pay an exogenous entry fee. They were given no information about how this fee was determined or about the fees of other subjects. In fact, the entry fees were exact copies of the entry fees generated in the Auction treatment. An Auction session was run first, and the sequence of highest bids generated by a group of four subjects in this session was also imposed upon a group of four subjects in the Fixed Cost treatment.[13]

At the end of period 30, subjects' profits (net of entry fees) were added up. The subjects filled in a questionnaire before they were privately paid their earnings in cash.

4. Results

This section provides tests of the Sunk Cost hypothesis, the Collusion Facilitation hypothesis, and the Selection hypothesis. The section will be broken into four parts. In the first part we focus on a simple comparison of the average price levels in the three treatments. This part provides a first crude overview of the results. In the second part we present the bidding data of the Auction treatment. In the last two parts we delve deeper into the data and look for more

---

[13] Since we had 9 groups in the Auction treatment and 10 in the Fixed Cost treatment, the sequence of entry fees from one group in the Auction treatment was used twice in the Fixed Cost treatment. Furthermore, one subject in the Auction treatment entered a bid of 41270 in his first auction. After the experiment, he indicated that this had been a mistake since he had based his profit expectations on 10 periods of part 1 (instead of 5 periods). Therefore, we decided to divide this fee by two for the Fixed Cost treatment.

refined evidence for the three hypotheses.

4.1 Overview of the results

Figure 1 gives a general impression of the development of prices in the three treatments. It can be seen that in part 1 (period 1-10) the development of prices is by and large the same for the three treatments. Average prices start out somewhat above the stage game Nash equilibrium of 60, and then decrease to about 60 in period 3. From period 3, average prices remain approximately stable. There is a small drop in prices in period 10. Between periods 6 and 10 the average price level is somewhat higher in the Fixed Cost treatment than in the Auction and the Baseline treatment. The difference is far from significant, however (Mann-Whitney test result for Fixed Cost versus Baseline treatment: m=10, n=10, p=0.88; for Fixed Cost versus Auction treatment: m=10, n=9, p=1.00).[14] Since the design of part 1 is identical for the three treatments, we would not expect to see any significant differences between them.

Figure 1. Average price levels in the three treatments

In period 11, when entry rights have been assigned for the first time, prices increase sharply in both the Fixed Cost and the Auction treatment, but to a much lesser extent in the Baseline treatment. Prices then show a downward trend in all treatments up until period 15.

In period 16, when entry rights have been newly assigned, again prices increase in the Fixed Cost and Auction treatment. Now, however, the increase in the Baseline treatment is of about the same magnitude. In the remaining periods of this block prices decrease in the Baseline treatment, but stay at about the same level in the Fixed Cost and Auction treatment. As a consequence, the distance between the former and the latter two treatments even widens somewhat.

In period 21 there is a sharp increase in prices in the Baseline treatment. There is no similar

---

[14] Unless explicitly indicated otherwise, we carry out prudent statistical tests throughout the paper using average variables per independent observation as data points.

13

increase in the other two treatments. The decline of prices within the block of 5 periods is also less pronounced in the Baseline treatment than in the other two treatments. As a consequence, the gap between the treatments becomes much smaller.

In the final block of five periods, prices stay at about the same level in the Baseline treatment and show a reversed U-shape in the other treatments, with the downward trend being sharper in the Auction than in the Fixed Cost treatment. As a result, the average price difference between the treatments has almost disappeared in the final period.

The pattern in the Baseline treatment is similar to the one observed already by Murphy (1966). In a duopoly setting he found that an initial downward trend in prices was followed by an upward trend. Notice that in the Baseline treatment subjects start pricing higher than the stage-game equilibrium price of 60. Then follows a phase where they 'undershoot' the equilibrium price. Finally, they learn to price slightly above the stage-game equilibrium.

In summary, eyeballing the data leads to four main findings. (1) In the first part of the experiments (periods 1-10), average price levels are by and large the same in all treatments. (2) In the first two blocks of part 2 (periods 11-20), average prices are higher in the Auction and Fixed Cost treatments than in the Baseline treatment. (3) In the final two blocks of part 2 (periods 21-30), the differences between the treatments are much less pronounced. (4) The average price level in the Auction is never higher and usually very close to the average price level in the Fixed Cost treatment.

We now make these findings statistically more precise. The upper part of Table 1 presents prices by treatment, averaged over blocks of periods. The lower part of the table gives two-tailed significance levels of Mann-Whitney tests of the differences between treatments. The table shows that average prices in the first part of the experiment (periods 1-10) are slightly higher in the Fixed Cost treatment than in the Baseline and Auction treatment, but that these differences are not significant. In the first block of the second part (periods 11-16), average prices in the Baseline treatment (52.8) are lower than in the Fixed Cost treatment (71.1) and in the Auction treatment (69.8). The former difference is significant at $p=0.06$ and the latter at $p=0.01$. Moreover, there is no significant difference between the Auction and Fixed Cost treatment. The price differences

between the Baseline treatment on the one hand and the Fixed Cost and Auction treatment on the other hand, remain significant in the second block (periods 16-20). In the third and fourth blocks (periods 21-25 and 26-30, respectively) the picture changes considerably. In both of these blocks, prices are still lower in the Baseline treatment, but the differences are less pronounced and fail to reach statistical significance (at $p<0.10$). An increase in the average price level in the Baseline treatment - where prices move from levels below Nash (60) in periods 11-20 to above Nash in periods 21-30 - diminishes the difference between the treatments.

Table 1. Treatment effects

Turning back to our three main hypotheses, we draw the following 'time-contingent' conclusion: (a) when entry rights are being assigned for the first or second time (periods 11-20), the Collusion Facilitation hypothesis ($P_{BL}<P_{FC}=P_{AU}$) must be accepted at the expense of the Sunk Cost hypothesis ($P_{BL}=P_{FC}=P_{AU}$) and the Selection hypothesis ($P_{BL}=P_{FC}<P_{AU}$), and (b) when entry rights are being assigned for the third and the fourth time, the Sunk Cost hypothesis ($P_{BL}=P_{FC}=P_{AU}$) cannot be rejected in favor of either the Collusion Facilitation hypothesis or the Selection hypothesis.[15]

4.2 Bidding

From a theoretical perspective the bidding stage is probably best characterized as a common value auction because of the symmetry between the players' positions. It could be argued that strategic uncertainty exists about the common value, because one is not certain about the actual strategy of the other player. The experience gained in the first part of the experiment

---

[15] If we base our test on a comparison of average prices over *all* blocks of part 2 (periods 11-30), then the significance levels of the two-tailed Mann-Whitney tests are $p=0.06$ for $P_{BL}=P_{FC}$, $p=0.12$ for $P_{BL}=P_{AU}$, and $p=1.00$ for $P_{SC}=P_{AU}$. Hence, we believe a rejection of the Sunk Cost hypothesis ($P_{BL}=P_{FC}=P_{AU}$) would still be warranted, especially since the alternative Collusion Facilitation hypothesis ($P_{BL}<P_{FC}=P_{AU}$) posits a clear direction for the price difference and a one-tailed test might thus be more appropriate.

provides subjects with a private signal of the common value. The player with the highest signal is likely to win the auction, but if (s)he neglects the fact that in case of winning the auction the signal was probably too optimistic, (s)he may easily overestimate the value of the right to play and bid too much. Thus, an interesting question is whether subjects were able to anticipate the value of the right to play in the Auction treatment.

Table 2. Winning bids and excess profits

Table 2 shows that average winning bids are close to 20,000, the net expected value of the right to play under the assumption that in all periods the Nash equilibrium of (60,60) will materialize. The table also shows that subjects do not fall prey to a winner's curse. On average there is an excess profit of entering the market that may reflect a return for the risk taken. In the course of the experiment there is a decrease in the excess profit of entering the market. The table suggests that subjects quickly become aware of the value of the right to play and that they bid competitively to obtain a license.

4.3 Collusion Facilitation

The Collusion Facilitation Hypothesis posits a positive relation between entry fees and prices. Section 4.1 has shown that a comparison of average price levels across the three treatments supports this hypothesis. The present section examines the Collusion Facilitation hypothesis on the basis of less aggregated data.

On the basis of the Collusion Facilitation hypothesis one would expect that differences in entry fees will be reflected in the prices. To test for this we use the variation of entry fees within the Auction and Fixed Cost treatments. Entry fees average 19,749, with a standard deviation of 5,088, a low of 10,000 and a high of 30,000. Table 3 presents Spearman rank correlation coefficients between the entry fees that subjects paid and the average prices they charged for

16

several groups of periods. For each group of periods (1-30, 11-20, and 21-30) we find a positive correlation between entry fees and prices. In line with Collusion Facilitation, we find that higher entry fees lead to higher prices.

Table 3. Correlation between entry fees and prices

Remarkably, in both treatments the correlation between entry fees and prices is more pronounced in periods 21-30 than in periods 11-20. Hence, there is no evidence that over time subjects learned to ignore the entry fees and dismiss collusive pricing.

There was not much reason to give up collusive pricing, since on average it proved quite a profitable strategy. Figure 2 shows the relationship between starting prices in a block of five periods and realized average profits in the corresponding block of five periods. The figure displays both the average profit and the average profit plus and minus the standard deviation of profits. The figure is based on all blocks and all treatments (the picture is similar for all three treatments, although in the Baseline treatment it is based on a relatively high number of lower starting prices). It can be seen that up until a price of 100 average profits are increasing in the starting price, while the variance of profits increases at the same time. An increase of prices above 100 does not translate into higher mean profits. Hence, subjects who start a block of five market periods with a collusive price of 100 earn the highest payoffs on average (i.e., not controlling for other features of their pricing strategy).

Figure 2. Average profits per period as a function of starting prices

Next we investigate the dynamic pricing strategies of the players. In section 2 we suggested that collusive pricing might be sustainable if players employ trigger-like strategies. Table 4 displays, for all treatments combined as well as for each treatment separately, how subjects change their price from one period to the next, conditional on whether their own price in the previous period is higher than or lower than their rival's price. Overall, these dynamics are

17

reminiscent of the "measure-for-measure" strategy found by Selten, Mitzkewitz and Uhlich (1997).

Table 4. Dynamics of pricing behavior

For all treatments combined, we find that players decrease their price in 67% of the cases in which their own price in the previous period was higher than their competitor's (high ↓ + high ↓↓), whereas they increase their price in only 13.3% of these cases (high ↑). Hence, they punish competitive pricing by their opponent. At the same time they reward cooperative pricing, though here the reactions are more moderate. Players increase their price in 49.2% of the cases in which their own price was lower than their opponent's (low ↑↑ + low ↑) but in as much as 32.3% of these cases they decrease their price even further (low ↓). Also the size of the price change is more moderate in case of rewards than in case of punishments. This can be seen by comparing the ratio of high ↓↓ (34.6%) to high ↓ (32.6%) with the ratio of low↑↑ (9.4%) to low ↑ (39.4%). In case of punishments subjects often go below the previous lower price of their rival but in case of rewards they seldom go above the previous higher price of their rival. Hence, subjects use punishments more often and more severely than they use rewards (which may explain the downward trend of average prices within each block of periods that was observed in Figure 1).

Further evidence for strategic play can be found in the presence of a clear end-effect. As noted before, on average there is a decline of prices within each block of 5 periods. However, in the Auction and Fixed Cost treatments the average price decline from the 4th to the 5th period in a block (-11.5 in absolute terms for FC and -7.0 for AU) is much stronger than the average decline across the earlier periods within a block (-0.4 for FC and – 1.0 for AU). This end-effect from the 4th to the 5th period is stronger in the Auction and Fixed Cost treatments than in the Baseline (-3.2). Moreover, the end-effect is about twice as large in the last two blocks as in the first two blocks of part 2, indicating that it becomes stronger with learning (cf. Selten and Stoecker, 1986).

Another noteworthy result is that not all players seem to be influenced by an entry fee to the same degree. It appears that some players are induced to price more collusively, while others adhere to the sunk cost hypothesis. To illustrate this, Figure 3 displays, for each treatment, the

distribution of starting prices immediately after the rights to play have been newly assigned, that is, the distribution of prices in periods 11, 16, 21 and 26. As can be seen, the frequency distribution of starting prices in the Baseline treatment is concentrated around the stage game Nash equilibrium price of 60 with the mode being somewhat below it. The Fixed Cost and Auction treatments also have a mode around the Nash price of 60 but they also display a concentration of prices at a higher level: around 85 in the Auction treatment and around 100 in the Fixed Cost treatment.[16] Hence, players' strategies are heterogeneous in how they deal with an entry fee.[17]

Figure 3. Frequencies of starting prices per treatment

The data also reveal that collusion is clustered. The degree of collusive pricing is not uniform across group, but highly concentrated. Some groups have prices close to the stage game Nash equilibrium (60) while others set prices at higher levels (80-100). This does not only hold for prices in the first period (Figure 3) but also for later periods. Hence, it is more accurate to say that entry fees increase the *probability* of collusion than that they increase the *degree* of collusion.

In sum, the data reveal the following regularities. An entry fee stimulates some of the players to charge a collusive starting price, though not as high as the maximum collusive price of 160. Rewards and punishments are employed to sustain collusive prices and avoid exploitation by defecting players. Higher starting prices lead to higher profits on average, but only up to some

---

[16] A price of 100 is remarkably close to the price that a naive mark-up pricing rule would predict. In the stage-game equilibrium the players obtain a mark-up of p-c = 60-10 = 50 and produce at q = 100. In the Auction and Fixed Cost treatments the entrants pay an entry fee of about 20000 which amounts to a fixed cost of 4000 per period. Keeping the mark-up over average cost equal to 50 would require a price p such that p-c-4000/q = 50. If the players would expect to produce at q=100 again, this mark-up rule gives a price of p=100. However, apart from the fact that such a mark-up rule is quite naive, a recent experimental study by Bucheit and Feltovich (2000) casts doubt on a mark-up interpretation of our data. They systematically vary the exogenous sunk costs in a duopoly pricing game and find that subjects' pricing decisions vary non-monotonically with the level of the sunk cost.

[17] This result is corroborated by subjects' bi-modal response to a question in the post-experimental questionnaire in the Fixed Cost and Auction treatments. We asked subjects' agreement (on a 7-point scale) with the statement: "Because in part 2 you had to pay for the right to enter the market, you asked a higher price than in part 1 of the experiment". 44.6% of the answers were in category 1 or 2, implying that they (strongly) disagreed with the statement. At the same time, a proportion of 23.0% of the subjects filled out category 6 or 7, stating their (strong) agreement with the statement.

point (Figure 3). At the same time the variance of profits is increasing in prices, indicating that collusive pricing is risky.

The fact that the entrants do not try to coordinate on the maximum collusion equilibrium is not surprizing in view of the potential for coordination failure. The collusive equilibrium that maximizes joint profits involves prices of 160 in the early periods of a block of five (see footnote 7). Starting with a price of 160, however, will lead to very low profits if the other player tries to coordinate on a less collusive equilibrium such as the subgame perfect equilibrium. The higher the starting price, the higher the cost of coordination failure. Therefore, the collusive price that maximizes expected profits will be below the maximum collusive price as long as there is a positive probability for coordination failure (see Appendix A for a stylized model that illustrates this point).

Prospect theory may help to explain why an entry fee induces entrants to become more collusive. Entrants who have just paid a (large) entry fee may regard themselves to be in a loss frame. This is especially true if entrants compare their situation to one in which entry is free. Being in the domain of losses stimulates risk seeking behavior. As we have seen in Figure 3, opting for collusion is a more risky strategy than opting for the subgame perfect equilibrium price of 60 (see also the model in Appendix A). The payment of an entry cost may stimulate entrants to opt for a risky collusive strategy in an attempt to recover the losses as much or as quickly as possible.

4.4 Selection hypothesis

The preceding analysis suggests that entry fees *per se* are responsible for increased prices after an auctioning of entry licenses and not the tendency of auctions to select the more optimistic (i.e., collusive) bidders. Nevertheless, Figure 1 shows that the jump in prices after period 10 is somewhat higher for the Auction treatment than for the Fixed Cost treatment. Perhaps there is a slight selection effect at the first auction.

A selection effect would provide an upward pressure on prices if the auction would tend to select players that set high prices. Before we investigate whether selected players charge high

prices, we address the question whether the auction selects the players that made the highest profit in the past.

For each of the two winners in an auction, we determine whether her or his assignment as a player is in accordance with the ranking of her or his average previous profits. In the very first auction (after period 10) successful players tend to be selected. In 14 out of 18 cases, the winner of the auction either had made the highest profit or the second highest profit in previous periods. A binomial test rejects the hypothesis that this is due to mere chance (p=0.03, given the null hypothesis that the probability of being selected equals 0.5). For the auctions for the next three blocks of periods, however, there is no indication that the auction selects the players with the highest previous earnings.

Given that the auction only selects successful players in the first block of periods, one might expect that an upward pressure of selection on prices is only observed after the first assignment of the rights to play. Table 5 displays average prices in the present block, as well as the average prices in the previous block(s) for both the presently active and presently inactive players. For periods 11-15 (block 1), there are clear signs of a selection effect. Average prices are 69.8 in block 1. The players who are active in this block, charged an average price of 70.0 in the previous block (periods 1-10), whereas the players who are inactive in block 1 charged an average price of 53.2 in the previous block (this difference is significant according to a Wilcoxon rank test: n=9, p=0.04). The price history of auction winners and losers is clearly different here, and average current prices are remarkably close to the average historic prices of the winners. In later auctions these effects are much weaker. For the second and third auction, the prices in the previous block are still higher for auction winners than auction losers, but the differences are small.

Table 5. Effects of selection on prices in Auction treatment

Hence, we do find clear signs for selection of the more collusive (optimistic) players in the first auction. Nevertheless, this did not result in a substantial effect on the average price level compared with the Fixed Cost treatment. There are hardly any signs for selection in the later

auctions.

Inactive players observe how successful players operate in the market. They observe prices and profits of the active players of their group. This gives them an idea about the potential profitability of a license and of the appropriate price level. As a consequence, spectators may learn to bid and to set prices like the successful others after the first block of periods. In all the treatments spectators change their behavior much more often in the direction of the more successful players than in the opposite direction. This process of imitation usually leads to a substantial increase in price levels, because players with higher prices tend to generate higher profits in all the treatments (see the bottom half of Table 4). For example, in the 18 relevant cases of the Fixed Cost treatment spectators observe more successful players choosing a price level of on average 79.3, and increase their own price levels from on average 61.0 to 81.3. Thus, imitation helped to generate common beliefs about the profitability of a license and about how the game should be played. As a consequence, after the first block of periods it does not really matter who is selected by the auction. Selection only matters at the first assignment, when players have not yet formed common beliefs.

5. Conclusion

This paper examined the empirical strength of the argument that the auctioning of entry licenses will increase market prices. Two potential causes for such an increase were identified. The first one is that the entry fee will induce entrants to behave more collusively. We found clear support for this hypothesis in the short term. Both in the Fixed Cost and the Auction treatment players charged significantly higher prices than in the Baseline treatment. On the long term, when the entry licenses had been re-allocated a couple of times, the difference in average price levels between the treatments tended to become much smaller. Nevertheless, even in the longer term, we found a significant positive correlation between entry fees and prices.

The other possible reason for increased prices due to auctioning is that an auction will tend

22

to select the more collusive players. We found evidence for such a selection effect only in the first auction. At later auctions, however, there were no signs for such a selection effect. Over time, players' beliefs about the value of an entry licence seemed to converge.

Our results should not be interpreted as an argument against the use of auctions to allocate entry-licenses. In our experimental market all players face identical cost and demand functions, whereas in most naturally occurring markets the potential entrants are asymmetric. Efficiency then requires the licenses to be allocated to the most (cost) efficient players. Thus an important efficiency-enhancing selection effect of auctions exists, which is absent from our experiments. Therefore, our experiments do not provide an argument against the auctioning of entry licenses *per se*. Our results do suggest though, that the license fee may not just be a lump sump transfer from the entrants' profits to the government budget. Some efficiency loss due to increased prices may be involved.

The result that sunk costs affect play in repeated games potentially has a wide range of applications. After all, many games involve repeated interaction and may thus have multiple equilibria. Examples include team production, common pool resources, public goods, and clubs. Hence, an interesting hypothesis is that the players in these games are more likely to take the risk of trying to coordinate on a cooperative equilibrium if they have paid a large entry cost. In future work we hope to put this hypothesis to a test.

Appendix A

Any collusive price $z \in [60, 160]$ can be supported as a Nash equilibrium (though not a subgame perfect one) in the early periods of the repeated market game. These collusive outcomes rely on a threat to set a price below the stage game equilibrium of 60 in case the opponent deviates from the collusive price z. However, even though prices up to the full collusive price of 160 can be a Nash equilibrium, an attempt to coordinate on very high prices may not be a good option if there is a possibility that coordination on this outcome will fail. A simple model may serve to illustrate this point.

Suppose the players consider only two outcomes on which to coordinate. One is the subgame-perfect equilibrium in which players use the non-cooperative strategy N which prescribes to always price at 60. The other outcome is a collusive outcome in which prices are z ($60 \leq z \leq$ 160) in the first four rounds and 60 in the fifth and final round. Assume that the players try to support the collusive outcome with a strategy C_z that prescibe to play z if all previous prices were z, to play 60 if a previous price was not equal to z, and to always play 60 in the final round. Strictly speaking this is not an equilibrium strategy but it keeps matters simple and suffices to illustate the point.

Now suppose that a player does not know on which outcome the other player will try to coordinate. In particular, assume that a player believes that the opponent will opt for strategy N with probability p and opt for strategy C_z with probability $1-p$. The expected payoff of choosing strategy C_z is then equal to:

$$E\eth[C_z] = p[(z-10)(124-2z+1.6*60)+20000] + (1-p)[4(z-10)(124-0.4z)+5000] \; .$$

This expected payoff is a parabola in z with an optimum at $z^*(p)$:

$$z^*(p) = \frac{512-272p}{0.8p+3.2} \; .$$

So, if a player believes that the opponent will certainly opt for the collusive strategy C_z ($p=0$) then the expected payoff of playing C_z reaches a maximum at $z^*(0) = 160$. If a player believes that the opponent will surely play the non-cooperative strategy N ($p=1$), then the expected payoff of playing C_z reaches a maximum at $z^*(1) = 60$. For each p with $0 < p < 1$, there is a corresponding $z^*(p)$ with $60 < z^*(p) < 160$. For example, when p equals 0.55, z^* equals 100. This illustrates that if there is a positive probability that coordination on a collusive outcome fails, then it will not be

in the players' interest to try and coordinate on the full collusive outcome. The more likely it is that the opponent will play a non-cooperative strategy, the better it is for the collusive players to opt for a more moderate collusive strategy.

It is easy to show that strategy C_z (ith $60 < z < 160$) will give a higher expected payoff than strategy N if the probability p is small enough. At the same time, it is straightforward to show that the payoff *variance* is larger for strategy C_z than for strategy N. In this sense we can say that players are more likely to opt for the collusive strategy if they become more risk seeking or less risk averse. The Collusion Facilitation hypothesis is based on the supposition that an entry fee may have that effect.

Appendix B. Experimental instructions

Instructions (distributed and read aloud)

Welcome to this experiment on decisionmaking. During the experiment you wil be asked to make a number of decisions. Your decisions and the decisions of other participants will determine how much money you earn. We will first go through the instructions of the experiment together. Then you will get the opportunity to ask questions.

The experiment consists of two parts, and each part consists of several periods. In each period your earnings will be denoted in *points*. Your earnings in the experiment will be equal to the sum of the earnings in each of the periods. At the end of the experiment your earnings in points will be transfered into money. For each 100 points that you earn, you will receive 5 cents. Hence, 2000 points is equal to 1 guilder. Your earnings will be privately paid to you in cash at the end of the experiment.

We will start with the first part of the experiment. After the first part has ended, you will receive the instructions for the second part.

Instructions part 1

Part 1 consists of 10 periods. The only decision you will have to make in each period, is to determine your price for the good that is produced by you. Your earnings in points are fully determined by your price and the price charged by one of the other participants. During the first part of the experiment you will only be dealing with this one other participant. You will not know with which other participant you will be dealing, nor will the other participant know with whom he or she is dealing.

Prices and production

In each period you determine the price of your product. Your price has to be larger than or equal to 0 points and smaller than or equal to 200 points. You can only choose integer values.

Your price, as well as the price chosen by the other participant affect the quantity that you will sell. The higher your price, the less you will sell. The higher the price of the other participant, the more you will sell. To be precise, the amount of production that you will sell is equal to:

$$\text{your production} = 124 - 2*(\text{your price}) + 1.6*(\text{other's price})$$

In words this formula amounts to the following. If your and the other's price are both equal to 0, you will produce and sell 124 goods. For each point that you increase your price, your production will decrease by 2 goods. For each point that the other increases her or his price, your production will increase by 1.6 goods. You will always produce an integer number of goods. If the above formula does not result in an integer number, the number will be rounded. Your production will never be negative. If you charge a very high price (200 for example) and the other a very low price

26

(0 for example), then your production will simply be zero goods.

In order to make things a little easier, we have constructed a production-table. This table is added to the instructions. Have a look at this table now. Prices of the other participant are indicated above the columns. Your own prices are indicated next to the rows. If you want to know how much you will produce if, for example, the other's price is 100 and your price is 70, then you first move to the right until you find the column with 100 above it, and then you move down until you reach the row which has 70 on the left of it. You can read that you will produce 144 goods in that case. The table is not exhaustive. The table does not list all possible combinations of prices. For example, the table does not indicate what your production will be if you choose a price of 71 and the other chooses a price of 103. If you want to know exactly how much your production will be in such a case, you can use the pocket calculator that is on your desk.

The production of the other firm is determined in the same way as your production. To be precise, the production of the other participant is equal to:

other's production = 124 - 2*(other's price) + 1.6*(your price)

It also holds for the other participant that he or she produces 124 if both you and the other choose a price of 0 points. For each piont that the other increases her or his price, the other's production decreases by 2 goods. For each point that you increase your price, the other's production increases by 1.6 goods.

Production and costs

Producing goods costs money. Each good that you produce will cost you 10 points. These are your only costs of production. Notice that you will make a loss if you choose a price below 10 points. The costs of production of the other participant are determined in the same way as your costs. The other participant also pays 10 points for each good that he or she produces.

Profits

In each period your revenue is equal to your price times your production. Your profit in points is then equal to your revenue minus the costs of your production. To be precise, your profit is equal to:

your profit = (your price)*(your production) - 10*(your production)

This can also be written as:

your profit = (your price - 10)*(your production)

Notice that your price has a two-fold effect on your profit. On the one hand, an increase in your

price will increase your profit, since each good that your produce will earn you more money. On the other hand, an increase in your price will decrease your profit, since you will be producing and selling less.

For the other participant profit is determined in an identical manner. The profit of the other participant is equal to her or his revenue, (other's price)*(other's production), minus the cost of production, 10*(other's production).

Information

When you decide about your price, you do not know which price the other participant chooses in that period. The other participant does not know your price either at the time he or she decides. You will be informed about the price of the other participant only after all participants of the experiment have entered their prices.

On your screen you will be able to see the prices and results of the preceding period. If you want to have the decisions of earlier periods at your disposal, you need to keep track of these yourself. For that purpose you can use the "Results Form part 1" that you can find on your desk. The rows on this form correspond to the period numbers. The first four columns are reserved for your price, the other's price, your profit, and the other's profit, respectively. If you want to keep track of additional information, for example, on production or costs, then you can use the remaining four columns on the form.

At the top left of your screen you will see the current period number, and the number of points you have earned up till then.

Summary

The first part of the experiment consists of 10 periods. During these 10 periods you are matched with one of the other participants. In each period, you decide about your price, and the other participant decides about her or his price. You profit in each period will be determined by your price and the price of the other participant. The circumstances are identical in each of the ten periods. Your earnings in points for the first part of the experiment are equal to the sum of your profits in these ten rounds.

At the end of period 10 you will receive the instructions for the second and final part of the experiment.

Now you will have the opportunity to study the instructions at your own pace and to ask questions. Then there will be a practice period before we start the experiment. It is not allowed to communicate with other participants. If you have a question please raise your hand. One of use will come to your table to answer your question.

Result form part 1

period	your price	other's price	your profit	other's profit				
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Production table

Your production

Price other participant

Your price	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
0	124	140	156	172	188	204	220	236	252	268	284	300	316	332	348	364	380	396	412	428	444
10	104	120	136	152	168	184	200	216	232	248	264	280	296	312	328	344	360	376	392	408	424
20	84	100	116	132	148	164	180	196	212	228	244	260	276	292	308	324	340	356	372	388	404
30	64	80	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
40	44	60	76	92	108	124	140	156	172	188	204	220	236	252	268	284	300	316	332	348	364
50	24	40	56	72	88	104	120	136	152	168	184	200	216	232	248	264	280	296	312	328	344
60	4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244	260	276	292	308	324
70	0	0	16	32	48	64	80	96	112	128	144	160	176	192	208	224	240	256	272	288	304
80	0	0	0	12	28	44	60	76	92	108	124	140	156	172	188	204	220	236	252	268	284
90	0	0	0	0	8	24	40	56	72	88	104	120	136	152	168	184	200	216	232	248	264
100	0	0	0	0	0	4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244
110	0	0	0	0	0	0	0	16	32	48	64	80	96	112	128	144	160	176	192	208	224
120	0	0	0	0	0	0	0	0	12	28	44	60	76	92	108	124	140	156	172	188	204
130	0	0	0	0	0	0	0	0	0	8	24	40	56	72	88	104	120	136	152	168	184
140	0	0	0	0	0	0	0	0	0	0	4	20	36	52	68	84	100	116	132	148	164
150	0	0	0	0	0	0	0	0	0	0	0	0	16	32	48	64	80	96	112	128	144
160	0	0	0	0	0	0	0	0	0	0	0	0	0	12	28	44	60	76	92	108	124
170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	24	40	56	72	88	104
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	20	36	52	68	84
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	32	48	64
200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	28	44

30

Instructions part 2 (distributed and read aloud after the completion of part 1)

Text for the Baseline treatment between parentheses (), for the Fixed Costs treatment between brackets [], and for the Auction treatment between accolades {}.

The second part of the experiment consists of period 11 up until period 30. Hence, there will be another 20 periods. For each participant the conditions will be identical to those in the first part of the experiment. This means that production, costs and profits are determined in in the exact same manner as in part 1.

In part 2, however, not all participants will be making a decision in all periods. Each participant will be assigned to a group of 4 participants. From this group of four, there will only be two who will receive the right to produce. Just like in the first part of the experiment they will determine the price of their good, and, depending on the prices chosen, make a certain profit. The two other participants will not have the right to produce; they do not make decisions. The right to produce is assigned for 5 periods at the time. Since there are 20 periods to go, the rights will be assigned 4 times in total. For periods 11-15 first, then for periods 16-20, 21-25, and, finally, for periods 26-30.

(For each block of 5 periods the computer will, in a completely random manner, select two of the four participants who receive the right to produce. Everyone has the same chance to be selected.)

[For each block of 5 periods the computer will, in a completely random manner, select two of the four participants who receive the right to produce. Everyone has the same chance to be selected. If you receive the right to produce, you will pay a certain one-off amount for this. You cannot affect the size of this amount, and the amount will be deduced from your total earnings automatically.]

{   For each block of 5 periods an auction will determine who receives the right to produce. Just like the three other participants you will enter a bid for the right to produce. A bid must be above or equal to 0 points and below or equal to 50,000 points. A bid has to be an integer amount. Out of the four bids, the two highest bids will be selected. The two participants who submitted these bids will receive the right to produce in the next 5 periods. If two or more participants enter identical bids, then the computer will order them in a random manner.

After the bids by all participants have been entered, for each group of four the two highest will be selected. If your bid is among the highest two, you receive the right to produce in the next 5 periods and make profits. In return for this right you will pay an amount that is equal to your bid. This amount will be automatically deduced from your total earnings. If your bid is not among the highest two, you will not receive the right to produce in the next five periods. In that case, you also do not need to pay your bid.}

If you receive the right to produce, then during the next 5 periods you will be dealing with the one participant who received the right to produce together with you. Your price and the price of this other participant will determine how much profit you will make in each period in the same

way as in part 1 of the experiment. Also you will receive the same information as in part 1.

If you do not receive the right to produce, you will not make any decisions in the next 5 periods. Yet, in each of the 5 periods, you will earn a fixed amount of 1000 points, that is, 5000 points over the 5 periods. You will also receive information about the prices, production, costs, and profits of the two participants that did receive the right to produce (for convenience these two participants will be referred to as 'firm A' and firm B').

The two participants that do make decisions, as well as, the two participants that do not make decisions, will see all prices and results of the preceding period on their screens. If you want to keep track of additional information, you can use the "Results form part 2" that is attached to these instructions.

(At the completion of a block of 5 periods, the rights will be assigned anew. Again all participants will have an equal chance to be selected. At the completion of the fourth block of 5 periods (periods 26-30), the experiment ends.)

[At the completion of a block of 5 periods, the rights will be assigned anew. Again all participants will have an equal chance to be selected. The amount you will have to pay for the right to produce may be different though. At the completion of the fourth block of 5 periods (periods 26-30), the experiment ends.]

{ At the completion of a block of 5 periods, the rights will be auctioned anew. Again all participants will have to enter a bid for the right to produce for the next 5 periods. The rights will again be assigned in the manner described above. At the completion of the fourth block of 5 periods (periods 26-30), the experiment ends.}

(Summarizing, there are two possibilities for each block of 5 periods. Either you receive the right to produce. In that case you have 5 periods in which you have the possibility to make a profit. Or you do not receive the right to produce. In that case you will earn a fixed amount of 1000 points in each periods, that is 5000 points in total.)

[Summarizing, there are two possibilities for each block of 5 periods. Either you receive the right to produce. In that case you pay a certain one-off amount for this right, and you will have 5 periods in which you have the possibility to make a profit. Or you do not receive the right to produce. In that case you do not need to pay anything, and you will earn a fixed amount of 1000 points in each periods, that is 5000 points in total.]

{Summarizing, there are two possibilities for each block of 5 periods. Either you receive the right to produce. In that case you pay a one-off amount that is equal to your bid, and you will have 5 periods in which you have the possibility to make a profit. Or you do not receive the right to produce. In that case you do not need to pay anything, and you will earn a fixed amount of 1000 points in each periods, that is 5000 points in total.

It is possible, though not likely, that you will make a loss. If you bid more than you have earned up to that point, and your profits in the 5 periods do not make up for this, then you make a loss. A loss can be easily prevented though, by never bidding more than your total earnings up to that point.}

References

Abbink, K., and A. Sadrieh (1995), "RatImage - Research Assistance Toolbox for Computer-Aided Human Behavior Experiments", *Discussion Paper* No. B-325, University of Bonn.

Bucheit, S., and Feltovich, N. (2000), "The Relationship Between Sunk Costs and Firms' Pricing Decisions: An Experimental Study", mimeo. University of Houston.

Cachon, G., and C. Camerer (1996), "Loss avoidance and Forward Induction in Experimental Coordination Games", *Quarterly Journal of Economics* 111, 165-194.

Cooper, R., D.V. DeJong, R. Forsythe, and T.W. Ross (1993), "Forward Induction in the Battle-of-the-Sexes Games", *American Economic Review* 83 (5), 1303-1316.

European Commission (1994), *Green Paper on a Common Approach in the Field of Mobile and Personal Communications in the European Union*, COM(93)145-final, Luxembourg: Office for Official Publications of the European Communities.

European Commission (1999a), *Fees for Licensing Telecommunications Services and Networks*, Second Interim Report prepared by ETO.

European Commission (1999b), *Fifth Report on the Implementation of the Telecommunications Regulatory Package*, COM(1999)537 final, Luxembourg: Office for Official Publications of the European Communities.

Engle-Warnick, K. and R. Slonim (2000), "A Method to Infer Repeated Game Strategies from Actions: Evidence from Trust Games", mimeo Case Western University.

Fouraker, L.E., and S. Siegel (1963), *Bargaining Behavior*, New York: McGraw-Hill.

Güth, W., and B. Schwarze (1983), "Auctioning Strategic Roles to Observe Aspiration Levels in Conflict Situations", in: R. Tietz (ed.), *Aspiration Levels in Bargaining and Economic Decision Making*, Berlin: Springer Verlag.

Güth, W., and R. Tietz (1985), "Strategic Power Versus Distributive Justice - An Experimental Analysis of Ultimatum Bargaining", in: H. Brandstätter and E. Kirchler (eds.), *Economic Psychology*, Linz: Trauner.

International Telecommunications Users Group (1996), "Users Object to Auctioning Scarce

Telecom Resources", (http://www.intug.net/views/auctions.html).

Martin, S. (1993), *Advanced Industrial Economics*. Oxford: Blackwell Publishers.

McMillan, J. (1995), "Why Auction the Spectrum?", *Telecommunications Policy* 19(3), 191-199.

Offerman, T., J. Potters and J. Sonnemans (1998), "Imitation and Belief Learning in an Oligopoly Experiment", working paper, University of Amsterdam.

Selten, R., M. Mitzkewitz and G.R. Uhlich (1997), "Duopoly Strategies Programmed by Experienced Players", *Econometrica* 65, 517-555.

Selten, R. and R. Stoecker (1986), "End Behaviour in Sequences of Finite Prisoner's Dilemma Supergames", *Journal of Economic Behaviour and Organization* 7, 47-70.

Shell (1999), "Only Fair Competition Helps the Motorist", press release (in dutch) by Shell, the Netherlands (http://www.shell.nl/client/documentatie).

Swart, K.W., (1980), *Sale of Offices in the 17th Century*, HES Publishers: Utrecht (unaltered reprint from the edition by Martinus Nijhoff: 's-Gravenhage (1949).

Van Damme, E.E.C. (1997), "Tien Misverstanden over Veilingen" (Ten Misunderstandings about Auctions), *Economisch Statistische Berichten,* 82 (nr. 4088), 24-28.

Van Huyck, J., R. Battalio and R. Beil (1993), "Asset Markets as an Equilibrium Selection Mechanism: Coordination Failure, Game Form Auctions and Tacit Communication", *Games and Economic Behavior* 5, 485-504.

Table 1

Treatment effects

	periods				
	1-10	11-15	16-20	21-25	26-30
treatment					
P_{BL}	61.8	52.8	57.1	66.2	65.7
P_{SC}	66.9	71.1	79.0	74.9	77.6
P_{AU}	61.6	69.8	77.1	76.4	67.6
hypothesis					
$P_{BL}=P_{SC}$	p=0.60	p=0.06	p=0.02	p=0.10	p=0.11
$P_{BL}=P_{AU}$	p=1.00	p=0.01	p=0.03	p=0.17	p=0.46
$P_{SC}=P_{AU}$	p=0.74	p=0.84	p=0.68	p=0.87	p=0.24

Notes: P_{BL} (P_{FC}; P_{AU}) displays the average price level in the Baseline (Fixed Cost; Auction) treatment. For the hypotheses, two-tailed significance levels of Mann-Whitney tests are presented with the following number of observations per treatment: $n_{BL}=10$; $n_{FC}=10$; $n_{AU}=9$.

Table 2

Winning bids and excess profits

treatment	periods	winning bids (std. dev.)	excess profit (std. dev.)
Auction (n=18)	11-15	17,829.9 (5,441.9)	5,002.4 (6,891.0)
	16-20	19,062.3 (3,628.0)	4,999.5 (10,019.2)
	21-25	20,070.3 (3,924.3)	3,865.5 (8,065.4)
	26-30	20,863.3 (3,828.6)	1,085.3 (4,018.8)

Notes: The column winning bids displays the average winning bids; the column excess profit displays the aggregate profits in a block of periods minus the own bid minus the opportunity costs (5000) averaged over players in the auction. In the first block the bid of the subject who wrongly assumed the right to last for 10 periods is divided by two.

Table 3

Correlation between entry fees and prices

treatment	correlation	period 1-30	11-20	21-30
Fixed Cost	fixed cost↔	ρ=0.29	ρ=0.17	ρ=0.27
	average price	p=0.00; n=120	p=0.14; n=40	p=0.05; n=40
Auction	winning bid↔	ρ=0.38	ρ=0.22	ρ=0.42
	average price	p=0.00; n=108	p=0.10; n=36	p=0.00; n=36

Notes: For period 1-10 the entry fees are equal to 0. The entries display Spearman rank correlation coefficients (ρ), significance level of the correlation (p), and the number of paired observations (n). Each block of periods for each player yields a paired data point.

Table 4

Dynamics of pricing behavior

treatment	position + direction of change	frequency *percentage*	position + direction of change	frequency *percentage*
all	high ↑	51 *13.3%*	low ↑↑	36 *9.4%*
	high =	75 *19.5%*	low ↑	153 *39.8%*
	high ↓	125 *32.6%*	low =	71 *18.5%*
	high ↓↓	133 *34.6%*	low ↓	124 *32.3%*
Baseline	high ↑	12 *11.7%*	low ↑↑	8 *7.8%*
	high =	23 *22.3%*	low ↑	37 *35.9%*
	high ↓	40 *38.8%*	low =	18 *17.5%*
	high ↓↓	28 *27.2%*	low ↓	40 *38.8%*
Fixed Cost	high ↑	24 *15.9%*	low ↑↑	17 *11.3%*
	high =	23 *15.2%*	low ↑	65 *43.0%*
	high ↓	50 *33.1%*	low =	29 *19.2%*
	high ↓↓	54 *35.8%*	low ↓	40 *26.5%*
Auction	high ↑	15 *11.5%*	low ↑↑	11 *8.5%*
	high =	29 *22.3%*	low ↑	51 *39.2%*
	high ↓	35 *26.9%*	low =	24 *18.5%*
	high ↓↓	51 *39.2%*	low ↓	44 *33.8%*

Notes: "high ↑" refers to cases in which a firm charged a higher price than its rival in the previous period and raises its price in the present period. "high =" refers to cases where a firm charged a higher price in the previous period and does not alter its price in the present period. "high ↓" ("high ↓↓") refers to cases where a firm charged a higher price in the previous period and decreases its price such that it is greater (smaller) than or equal to the price charged by the other firm in the previous period. "low --" is defined in a similar way, except that these entries refer to cases where the firm charged a lower price than its rival in the previous period. This table only uses cases where firms' prices were unequal in the previous period and both larger than or equal to 60. Starting prices in each block (periods 1, 11, 16, 21, 26) are excluded.

Table 5

Effects of selection on prices in Auction treatment

average own price	period 11-15		period 16-20		period 21-25		period 26-30	
	play= no	play= yes	play= no	play= yes	play= no	play= yes	play= no	play= yes
all previous blocks	53.2	70.0	63.4	65.5	67.4	68.1	72.4	67.0
previous block	53.2	70.0	66.7	73.6	76.0	77.9	78.0	74.8
this block	--	69.8	--	77.1	--	76.4	--	67.6

Notes: The table displays the average price charged by a player in the present block and her or his average prices in the previous block. It also displays the previous average price per block for present spectators.

Figure 1

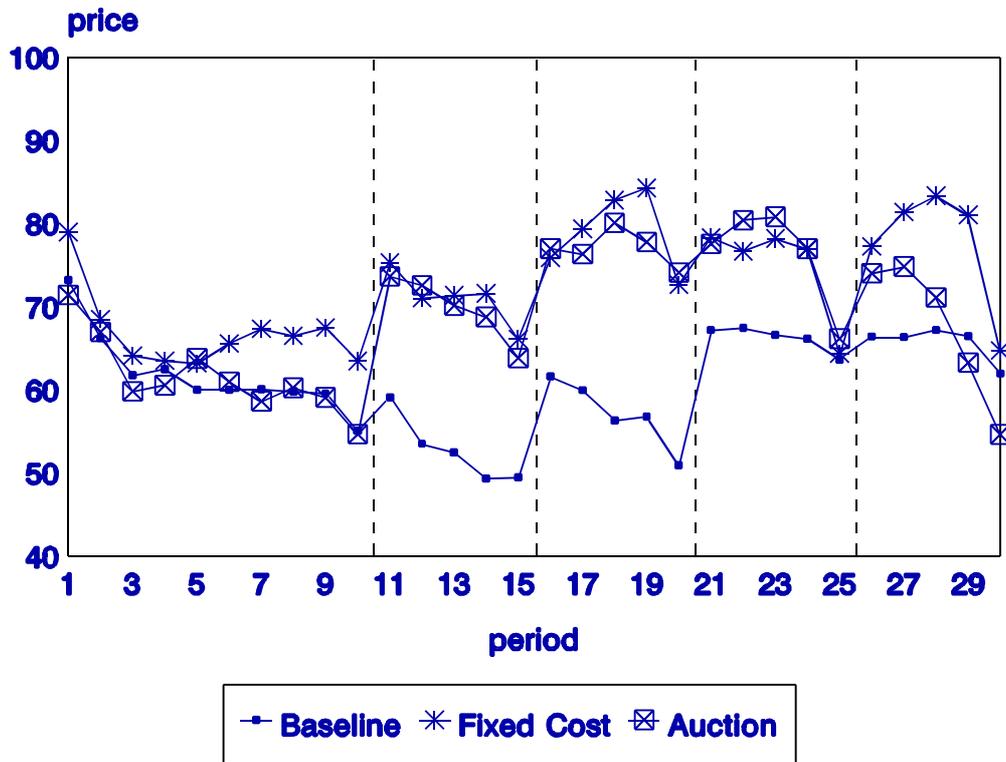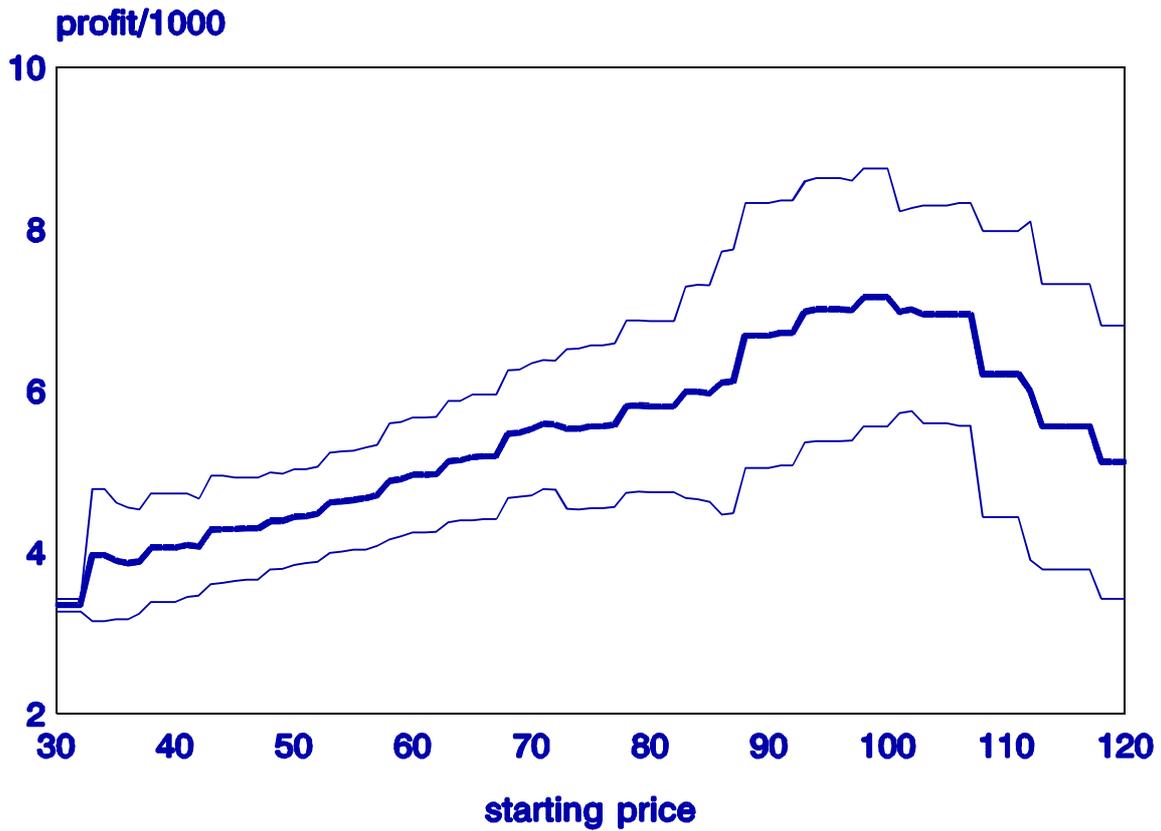**Average price levels in the three treatments**

Figure 2

Average profits per period as a function of starting prices

Notes: The thick line represents the running mean profits as function of starting price for all treatments. A firm's profits are averaged over the 5 periods in the block of the particular starting price. For each starting price P at the horizontal axis the vertical axis reports the mean profit of starting prices in the interval [P-7,P+7]. The upper (lower) line represents the running mean profit plus (minus) the standard deviation. There were only three starting prices higher than 120: these are discarded.

Figure 3

Frequencies of starting prices per treatment
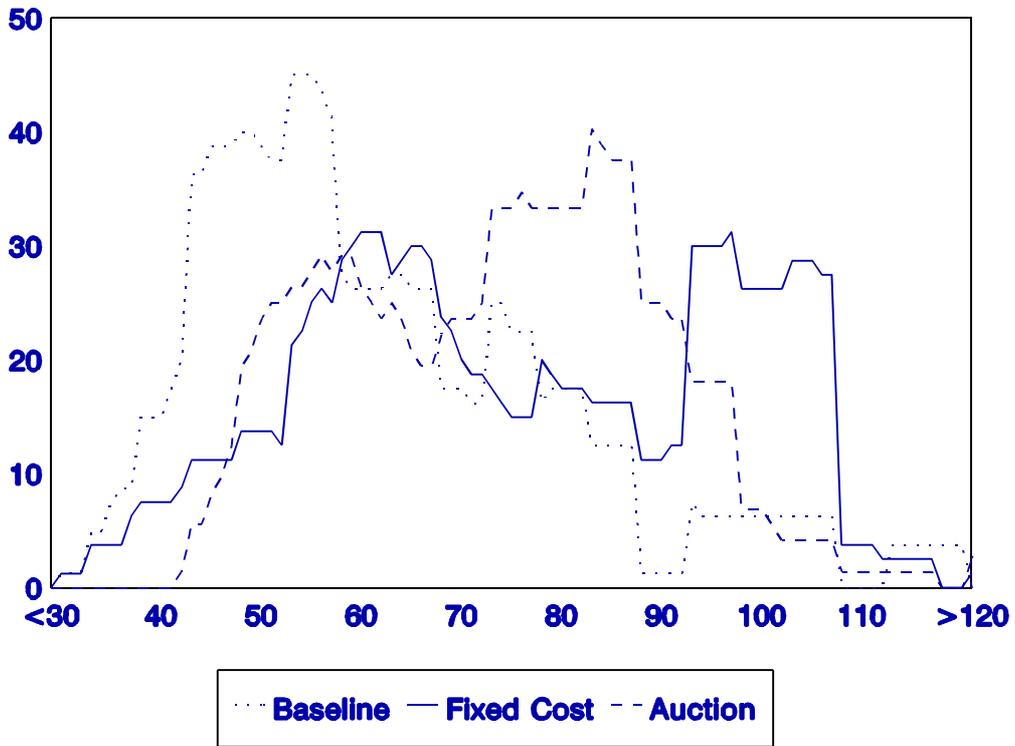
Notes: Running frequencies of starting prices after licenses have been newly assigned. For each starting price displayed at the horizontal axis the vertical axis reports the % of outcomes that fall in the interval [starting price-7, starting price+7].