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An experimental study*

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Abstract

On an increasing scale auctions are used to allocate the licenses to operate on markets which are thought not suited for free entry. According to standard economic arguments, the license fees paid at the auction will not affect consumer prices since they constitute a sunk cost. This standard view is not uncontested though. In the present paper we experimentally investigate two arguments for a potential upward effect of auctioning on prices: the incorporation of entry fees in prices due to the use of mark-up pricing rules, and the tendency of auctions to select the more collusive firms. Our results indicate that auctioning increases the probability of high prices, and that this is mainly due to the use of mark-up pricing rules.

1. Introduction

At several markets entry is limited for natural reasons such as geographical bounds or technological restrictions. Examples are mobile telecommunication, broadcasting, petrol stations, oil drilling, airport slots, and vendor locations at fairs. Governments can use different procedures to allocate the licenses to operate on such markets. Lotteries, queuing (first-come-first-served) and rotation are being used, but most common is some kind of administrative process (beauty contest).

The last decade, however, has witnessed an increased use of auctions as a means to allocate entry licenses. A prime example is the global trend to auction the rights to use the spectrum. The advantages of auctions are well-known. Compared to administrative processes in particular, auctions are quicker, involve lower transaction costs, and are less prone to rentseeking activity. More importantly, auctions tend to assign licenses to the firms that value them most, and, to a first approximation, these are also the firms that will put the licenses to their most efficient use from a social welfare point of view. Finally, the license fees paid by the auctions winners are seen as welcome revenue to governments, diminishing their need to rely on distortive taxes. Auctions prove that these revenues can be considerable indeed. The auctioning of spectrum licenses in the US has already raised over 20 billion dollars. Revenues for the auctioning of the third generation mobile spectrum licences promise to be spectacular. The recent UK auction of 5 such licences yielded a staggering revenue of 22.5 billion UK pounds.

Yet, the acclaimed benefits of auctions are not uncontested. In particular, it is often argued that auctioning will increase the prices that consumers ultimately pay. Many companies claim that they will have to charge higher prices in order to recuperate the entry fee. For example, in reponse to plans by the Dutch government to auction the locations for petrol stations along the highways, oil company 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 too surprizing. After all, they have to pay substantial fees for licenses which often they used to get for free.[1] Interestingly though, even some policy-makers and regulators seem reluctant to

[1] Often also the firms' customers adhere to this line of reasoning. For example, 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-

use auctions. 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.

Auctioning the rights for privileged positions is not a new phenomemon. 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.[2] Even at the time, the selling of offices was criticized for multiple reasons, one of them being that the buyers of offices would recoup their losses by charging high prices for their services.

Theorists easily find the flaw in this line of reasoning (see, e.g., McMillan, 1995, Van Damme, 1997). Once the right to operate in a market has been obtained, the fee paid in the auction constitutes a sunk cost. Firms interested in expected profit will base their decisions on an evaluation of marginal revenues and marginal costs, and these are unaffected by sunk costs (or fixed costs, for that matter).[3] Bygones are bygones, as the saying goes. Hence, from the standard theoretical perspective the argument for increased prices does not seem to make much sense.

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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, 1999).

[2] 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).

[3] Notice furthermore that in an auction firms are never forced to bid more than their expected value of obtaining the license. In other words, the bids to enter the market will be based on (expected) market prices and not the other way around. Hence, when firms bid rationally, they will be able to earn at least a normal return on their investments, whatever the funding source of these investments. There is a caveat to the sunk cost argument though (see, e.g., McMillan, 1995). With an imperfect capital market, the interest rate may be increasing in the amount borrowed, and an increased marginal cost of capital may reduce a firm's efficiency enhancing investments, leading to a higher marginal cost.

This does not guarantee though, that the argument is empirically incorrect. A longstanding debate, initiated by a survey study by Hall and Hitch (1939), is whether the pricing decisions by firms do in fact adhere to the marginalist principles (see Mongin, 1992, for an exposition of the controversy). Also more recent empirical studies suggest that firms often employ some kind of mark-up or full-cost pricing rule. This evidence is usually based on interviews and questionnaires (e.g., Blinder, 1992, Hall et al., 1997). Hence, it cannot be excluded that managers say, or even think, that they apply mark-up pricing rules, whereas in fact their decisions adhere to the principles of marginalism. In any case, if it is true that firms employ mark-up pricing rules, then an entry fee may indeed increase prices.

Furthermore, there exists another potential upward pressure on prices as a result of auctioning (which to our knowledge has not been put forward before). Empirical studies suggest that a wide variety of outcomes can be observed in oligopolistic markets. Some industries seem to be more competitive than the static Nash equilibrium, others are more cooperative than Nash (Martin, 1993; Slade, 1994). This observation is corroborated by the experimental literature. There, also outcomes on either side of Nash are observed in oligopoly games (Holt, 1995). If firms with more cooperative or collusive strategies on average earn higher profits than firms with competitive strategies, then it seems reasonable to predict that firms with a more cooperative orientation expect to earn higher profits than firms with a more competitive orientation. An auction may then have the effect of selecting the more optimistic firms, and, to the extent that these are also the more collusive types, this may have an upward effect on prices.

Unfortunately, no empirical data are available for a reliable statistical analysis of the relation between entry fees and consumer prices. Yet, the following stylized facts for mobile voice telecommunication are noteworthy. 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. These figures hint at a positive relation between entry fees and consumer tariffs.

Reliable conclusions cannot be based on these data though. The number and relative size of the firms vary considerably across the different markets. Also, the quality of the services varies across firms and countries, making average tariffs difficult to compare. Furthermore, the entry fees do not relate to identical licenses (GSM, DCS, local/nation-wide), and the time path and the method of selection (auction, beauty contest, fixed fee) are not uniform accross countries. Therefore, is it very difficult to analyze the relation between entry fees and consumer tariffs on the basis of industry data. If data are available at all, a comparison of entry fees and consumer prices across markets is confounded by differences in market structure, product characteristics, timing, and selection procedures.

Therefore, in the present paper we rely on the experimental method to investigate the strength of the two arguments outlined above. Does auctioning of entry licenses lead to an increase of market prices? And, if so, is this increase due to the use of mark-up pricing rules, to a selection of the more collusive players, or perhaps to both? To examine these questions we set up an experimental market, corresponding to a symmetric price-setting duopoly with product differentiation.[4] We employed 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 highest 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 attribute such a price effect to mark-up pricing (by comparing the Baseline treatment and the Fixed Cost treatment), or to selection of the more collusive players (by comparing the Fixed Cost treatment and the Auction treatment).

The results show that the critics' concerns for higher prices are not completely unfounded. Auctioning the entry licenses leads to significantly higher prices. The results suggest that the effect of auctioning should be mainly attributed to mark-up pricing. In particular, we find a significant price difference between the Baseline treatment, on the one hand, and the Auction treatment and Fixed Cost

[4] The symmetric setup implies that our experiments do not incorporate the potential of auctions to select the most (productively) efficient firms. This allows for the cleanest test possible of the two arguments put forward for an upward price effect of auctioning entry licenses. Of course, an overall assessment of auctioning should include these (and other) beneficial effects of auctions. We will come back to this in our concluding discussion.

treatment, on the other hand, but average prices in the latter two treatments are almost identical. The price effects of the three different assignment mechanisms are to some extent time-dependent. They are stronger after the entry rights are assigned for the first and second time, than after they are assigned for the third and fourth time. Even in the latter instances though, we find a significantly positive correlation between the entry fees and the prices charged.

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

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

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

and

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

Profits are thus equal to

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

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

$$p_i^*(p_j) = 36 + 0.4p_j \tag{4}$$

The unique stage game Nash equilibrium is equal to $(p_1^N,p_2^N) = (60,60)$ with corresponding profits of $(\pi_1^N,\pi_2^N) = (5000,5000)$. 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 $(\pi_1^C,\pi_2^C) = (9000,9000)$. The competitive Walrasian outcome, with prices equal to marginal cost and maximal social welfare, is characterized by $(p_1^W,p_2^W) = (10,10)$ and $(\pi_1^W,\pi_2^W) = (0,0)$. 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 firm 1 prices at $p_1 = 160$, firm 2 will be tempted to set its price at $p_2 = 100$. Corresponding profits are $\pi_1 = 0$ and $\pi_2 = 16200$. 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 that are playing the game.[5] 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. The first allocation mechanism that we consider is the Auction treatment. Here each of the four subjects submits a bid for the

[5] 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 firms with substantial experience, either at the very same market, at related product markets, or at similar markets in other geographical areas.

right to service the market for the next five periods, and 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. The second mechanism is called the Fixed Cost treatment. The two subjects who are randomly selected to enter the market pay exogenous sunk entry costs, S_1 and S_2, respectively. Like the bids in the auction, these costs are private information. To allow for the cleanest possible comparison between this treatment and the previous treatment, we have chosen to match these sunk 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 subjects who enter the market for free are randomly selected from the group of four. 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 and their predictions, 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 which is irrelevant for the pricing decisions of the firms once they have entered the market. Profit maximizing firms 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 firms (subjects) to the government (experimenter).

Under the assumptions that firms will repeatedly play the stage game Nash equilibrium when they are at the market, that they will forecast this when they are at the bidding stage, and that they will engage in non-cooperative bidding, we can also predict what their bids will be in the auction. In the repeated play of the stage game Nash equilibrium of the market game each firm will make a profit of 5000 per period, and it will receive an opportunity payment of 1000 per period when it is not active in the market. Winning the auction gives the right to enter the market for five periods. Since all four firms are in identical positions, in equilibrium they will each enter a bid of 20000 ((5000-1000) times 5). Hence, all supra-normal profits will be skimmed by the auction. But even if these game-theoretic assumptions fail for some reason, still the standard neoclassical hypothesis would be that the assignment of entry right does not affect the pricing decisions. Therefore, we should observe the same prices in the Baseline, Fixed Cost, and Auction treatment.

Mark-up Pricing Hypothesis: $P_{BL} < P_{FC} = P_{AU}$

This hypothesis relates to the argument that firms will try to recoup (at least part of) the entry fee by means of higher prices. As we noted in the introduction, this is the hypothesis put forward by many industry representatives, from the companies involved, their costumers, as well as some of their regulators. The hypothesis is in line with survey evidence on the pricing rules employed by firms. On the basis of a survey among 654 UK companies, Hall et al. (1997) find that, although market conditions are of primary importance, many companies set prices on the basis of cost plus a mark-up. In particular, 47% of the firms recognize this as an important pricing principle. In a similar study among 72 US firms, Blinder (1991) finds that 57% of the firms regard cost-based pricing to be an important behavioral principle. For wholesale and retail firms there is also some econometric evidence that pricing strategies often deviate from marginalist principles and are more in line with cost mark-up pricing rules (e.g., Nooteboom, 1985, van Dalen and Thurik, 1998).[6]

The mark-up hypothesis can be made a bit more precise. Remember that in our experiment the players first play the market game for 10 periods. Suppose that they arrive at the stage game Nash equilibrium during or at the end of these 10 periods. They will then be pricing at $p_i = 60$, with a cost mark-up of p_i-c = 50, produce at $q_i = 100$, and make profits of $\pi_i = 5000$. In the Fixed Cost and Auction treatment they will have to pay an entry fee in order to be in the market for another 5 rounds. Let this entry fee be equal to K, which corresponds to an entry cost of k = K/5 per round. Now, if players would be tempted to keep the mark-up over average costs constant, they would have to charge a price such that p_i -

[6] The hypothesis is also in line with experiments in which people are observed to fall prey to a sunk cost fallacy (see, e.g., De Bondt and Makhija, 1988, Kogut, 1990, Kogut and Phillips, 1994). People tend to overcommit resources to a particular investment project, even after evidence has become available indicating that the project should be stopped. Hence, it seems that people often find it difficult to disregard sunk costs. Relatedly, in the empirical finance literature it is sometimes found that investors are reluctant to accept losses and hang on to assets for too long. Loss aversion has been pointed at as potential explanation for this phenomenon.

$c - k/q_i = 50$. Inserting $c = 10$, $k = 20000/5 = 4000$ (Nash bidding), and $q_i = 100$ would yield a price of $p_i = 100$. Of course, this kind of mark-up pricing would be myopic. First of all, with a price of $p_i = 100$ (and $p_j = 100$), q_i will not be equal to 100 but drop to 84.[7] Second, at prices of $p_1 = p_2 = 100$ (or any price above the stage game Nash equilibrium), both players will have an incentive to reduce their prices. After all, the unique stage game equilibrium is $p_1 = p_2 = 60$.

Clearly, mark-up pricing cannot be an equilibrium strategy when all players are rational profit maximizers. Yet, when the population of players consists of a mixture of profit maximizers and mark-up pricing players, then it may be possible to sustain mark-up pricing by *all* players as an equilibrium in the repeated game. In particular, suppose a rational player believes that there is some (small) probability that his opponent is irrational and applies mark-up pricing upon entering the game followed by a tit-for-tat pricing strategy. Then it may be optimal for the rational player to start off with mark-up pricing as well and to deviate from this price only in the final period(s). This argument is in line with the support for cooperative outcomes in finitely repeated games with incomplete information (Kreps et al., 1982, Fudenberg and Maskin, 1986). The point is that players need to be "real" mark-up players only with some (small) probability in order to induce other players to behave in a likewise manner. We will come back to this below.

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

The selection hypothesis is based on the assumption that an auction will tend to select the firms with the highest profit expectations. Since the cost and demand conditions of the firms are identical in our market game, each firm's profit expectations will largely depend on its subjective beliefs about its own and the other firm's pricing behavior. A firm's subjective beliefs could be based on introspection but are more likely to be based on prior experience. Whatever the source of the beliefs, the selection hypothesis is based on the supposition that firms which expect to earn relatively high profits are also the firms which will tend to be relatively collusive, charging relatively high prices.[8]

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[7] It is easily verified that a price of 110 by both firms would consistently allow them to maintain a mark-up of 50.

[8] 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

Since self-selection of the more collusive type of players can only take place in the Auction treatment, the selection hypothesis implies that prices will be higher in the latter treatment than in the Baseline or Fixed Cost treatment, where the assignment of entry rights is fully exogenous.

Summarizing, the Selection Hypothesis argues that auctioning the licenses has an impact on prices because the auction will tend to select those firms that will charge the highest prices. The Mark-up Hypothesis, on the other hand, postulates that the pricing behavior of each individual firm that enters the market will be affected by the entry fee resulting from the auction. These two possible 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.

The present experimental study is not the first to examine the effect of entry fees on game playing behavior. The first study, as far as we know, is Güth and Schwarze (1983), who auctioned proposer and responder positions in an ultimatum game and found this to make proposer demands somewhat more 'greedy' (see also Güth and Tietz, 1985). More recently, it has been found that auctioning the right to play may serve as a selection principle that helps players to coordinate on the Pareto superior equilibrium in coordination games (Van Huyck, Battalio and Beil, 1993). Exogenously fixed entry fees may also affect the equilibria that are selected in coordination games (Cooper at al, 1993, Camerer and Cachon, 1996). One important difference between these experiments and the present one though, is that the stage game in our experiment has a unique Nash equilibrium. We will come back to this below.

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

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 a similar result in a quantity-setting oligopoly.

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 networked computers.[9] 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.[10] 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

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

[10] 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 $(p_1^N,p_2^N)=(59,59)$.

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 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.[11]

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 Mark-up Pricing hypothesis, and the Selection hypothesis. This section will be broken into four parts. In the first part we will 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 will present the bidding data of the Auction treatment. In the last two parts we will delve deeper in the data and look for more refined evidence for the three hypotheses.

[11] 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.

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).[12] 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 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

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

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 by Murphy (1966): in a duopoly setting he found the result 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 Nash price of 60. Then follows a phase where they 'undershoot' compared to the Nash price. Finally they learn to price slightly higher than Nash.

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 Mark-up Pricing 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 Mark-up Pricing hypothesis or the Selection hypothesis.[13]

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 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.

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[13] 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 Mark-up Pricing 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.

4.3 Mark-up pricing

The Mark-up Pricing Hypothesis postulates that players charge higher prices when they have paid an entry fee. Section 4.1 has shown that a comparison of average price levels across the three treatments supports this hypothesis. The present section provides a closer investigation of the mark-up pricing hypothesis on the basis of less aggregated data. First, we examine the relationship between the level of entry fees and the level of prices. Second, we examine the relationship between prices and profits. Finally, we analyze in more detail the pricing strategies employed by the subjects.

The Mark-up Pricing hypothesis not only predicts different prices in the Baseline treatment on the one hand and the Fixed Cost and Auction treatments on the other hand, it also predicts that differences in entry fees will be reflected in the prices. Higher entry fees should lead to higher prices. To test for this we use the variation of entry fees within the Auction treatment and the Fixed Cost treatment. In particular, entry fees average 19,749 with a standard deviation of 5,088, a low of 10,000 to 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 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 mark-up pricing, 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 dismiss mark-up pricing. As will be shown below, there was not much reason for them to do so, since on average mark-up pricing proved quite profitable.

Figure 2. Frequencies of starting prices per treatment

Now we have a closer look at the pricing strategies that lay behind the difference in average prices between the Baseline treatment on the one hand, and the Fixed Cost and Auction treatment on the other hand. Roughly speaking, there are two possibilities. One is that all players are susceptible to mark-up pricing to some degree. The other is that mark-up pricing is a more heterogeneous phenomenon, with some players incorporating the entry fee in their prices while others adhere to the sunk cost hypothesis. The data strongly support this latter possibility. To illustrate this, Figure 2 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. Hence, players' strategies are heterogeneous in how they deal with an entry fee.[14]

Figure 3 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 profits 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, of course, 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 (mark-up) price of 100 earn the highest payoffs on average (i.e., not controlling for other features of their pricing strategy).

Figure 3. Prices and profits

Next we investigate the dynamic pricing strategies of the players. In section 2 we suggested that mark-up pricing may be sustainable as an equilibrium if players employ trigger-like strategies. Table 4

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[14] 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.

displays, for all treatments combinedly, 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 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 but 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 seldomly 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).[15]

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 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 than in

[15] Interestingly, these results, including the asymmetry between punishments and rewards, are in line with the results of an extensive questionnaire of managers of UK companies (Hall, Walsh and Yates, 1997). They find that price increases are mainly caused by increases in costs. Price decreases, on the other hand, are mainly caused by price decreases of competitors. This supports the mark-up pricing interpretation of the experimental results: firms charge higher prices as a result of the entry fee; subsequently they decrease their prices in case the other firm's pricing behavior forces them to do so.

the first two blocks of part 2, indicating that it becomes stronger with learning (cf. Selten and Stoecker, 1986).

The pricing dynamics illustrate that players employ rewards and punishments. This explains why an initial price increase due to mark-up pricing cannot be easily exploited by rational players who disregard the entry fee. As we know from the literature on repeated games (e.g., Fudenberg and Maskin, 1986), cooperative prices may even be supported as an equilibrium when there is incomplete information about the players' types, particularly when there is some probability that the other player uses trigger strategies. When rational players anticipate that there will be some proportion of players who (irrationally) employ mark-up pricing followed by tit-fot-tat dynamics, then it may well be in their own interest to follow a similar strategy.

Appendix A illustrates a model this by means of a simple five period model in which players' prices are restricted to the set {60,100} and in which there is some probability å that players (irrationally) employ mark-up pricing followed by a tit-fot-tat strategy. If the players using a trigger strategy start with a price of 100 it will be easier to sustain collusive prices (and more difficult to support non-collusive prices) than if they start with a price of 60. Hence, if some fraction of players employs mark-up pricing followed by trigger strategies, an entry fee increases their first period prices from 60 to 100 and this increases the incentive for other (rational) players to behave in a likewise manner. For some values of the proportion of mark-up pricing players collusive pricing (100) is the only possible equilibrium when there are entry fees, while non-collusive pricing (60) is the only possible equilibrium when there are no entry fees. For some other values of the proportion of mark-up pricing players both types of equilibria co-exist simultaneously. Then the entry fee may serve as a selection principle leading the players to coordinate on the collusive equilibrium. In both cases entry fees increase the probability of the collusive equilibrium and decrease the probability of the non-collusive equilibrium of the repeated game.

The data reveal that collusion is clustered. That is, the degree of collusive pricing is not uniform across group, but highly concentrated, with some groups pricing close to the stage game Nash equilibrium (60) and others setting prices at higher levels (80-100). This does not only hold for prices in the first period (see Figure 2) 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.

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 queston whether the auction selects the firms 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 is 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 (bottom half 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 may have helped to generate common beliefs about the profitability of a licence 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. Concluding discussion

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 mark-up pricing, which hypothesizes that firms will increase market prices in an attempt to recover the entry costs incurred at the auction. 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. Interestingly, a moderate mark-up pricing strategy turns out to be quite profitable. Realized average profits where higher at mark-up prices than at stage game equilibrium prices.

The other possible reason that prices will increase due to auctioning is that an auction will tend to select the more collusive players. We found evidence for such a selection effect in the first auction. Typically, the players winning the first auction tended to be the ones with the highest profits and the highest prices in the first part of the experiment. At later auctions, however, there were no signs for such a selection effect. Probably, the information provided in the second part of the experiment helped to form common beliefs about the profitability of a license to play. Moreover, even the selection effect of the first auction was found not to have a significant impact on the average price level. Throughout the experiment, the price level in the Auction treatment was very close to the price level in the Fixed Cost treatment.

When there is uncertainty about the proportion of mark-up pricing players in the population, both repeated play of stage game Nash prices as well as more collusive (mark-up) prices can be supported as an equilibrium of the repeated game. The entry fee may serve as a selection principle guiding the players toward the equilibrium of collusive pricing. Players that start with mark-up pricing followed by a trigger strategy increase their starting price when they are faced with an entry fee. This increases the incentive for other (rational) players to behave in a likewise manner. Entry fees thus increase the support for a more collusive price path.

As discussed earlier, other experimental studies have also found that entry fees affect how subjects play a game. In particular, entry fees may help players to select the Pareto-dominant equilibrium in (median or minimum effort) coordination games with multiple Pareto-ranked equilibria (Van Huyck et al., 1993, Cachon and Camerer, 1996, Crawford and Broseta, 1998). The effect of entry fees in the present study is in one sense weaker but in another sense stronger. Whereas almost all play is affected by auctioning the entry rights in coordination games, in our market game only a proportion of play is affected. At the same time, in another sense our results are stronger. In the coordination experiments, the entry fees induce subjects to coordinate on a different equilibrium of the stage game, whereas in our experiment the entry fees induce players to arrive at an outcome which is *not* an equilibrium of the stage game.

The fact that the effect of the entry fees on our experiment is weaker than in the coordination game experiments is not surprizing in view of the results of Cachon and Camerer (1996). They find a strong selection effect of the exogenous entry fee only if the level of the fee is above the payoffs that players tend to achieve in the baseline periods without an entry fee. If the entry fee is below these baseline payoffs - as on average they are in our experiment - Cachon and Camerer find a much smaller effect of the entry fee, because forward induction and loss avoidance have no force in this case. They still find some effect of the entry fee in this case though, just as Cooper et al. (1993) do for the battle-of-the-sexes-game and just as we do for the duopoly market game.

Another difference between the coordination games and our market game is the welfare effect of auctioning the right to play. In coordination games, the effect of the entry fee is sometimes welcomed as a Pareto improvement. “The efficiency-enhancing effect of auctioning the right to play [in coordination games] suggests a new and potentially important way in which competition may promote efficiency”, as Crawford and Broseta (1998, p. 221) note. However, in our market game auctioning leads to higher prices and consequently to welfare losses. The consumers - though not present as active players in the experiment - are hurt by the increase in prices.

Of course, one should be very cautious in trying to translate our experimental results into policy conclusions. Apart from the fact that we used students as decisionmakers instead of businessmen or managers[16], the stylized market setting in our experiment cannot capture the many intricacies of "real world" market environments. Arguably, the most important omission in our experimental design is firm heterogeneity. In our experimental design all firms have identical cost functions, whereas in real markets firms differ, for example, in terms of their technological, organizational, and financial strategies. Efficiency then requires the licenses to be allocated to the most efficient firms, in particular to those that produce at lowest cost. These firms probably expect to make more profit than productively inefficient firms. As a consequence, they would make higher bids in an auction and win the auction. Thus, in the real world 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 experimental results can be interpreted though as challenging the revenue raising aspect of auctions. Often the entry fees collected at an auction are seen as welcome by-products to governments that come at no welfare costs and may be used to reduce distortive taxes. However, our experimental results show that entry fees increase the probability of collusive pricing and that higher fees may lead to higher prices. Hence, the entry fees come at the expense of some efficiency loss. This suggests that for efficiency purposes it may be more prudent to choose an allocation mechanism which retains the positive selection

[16] Without an explicit test, it is hard to speculate whether, to what extent, and in what sense, professionals from the field would make different decisions than the students from our subject pool. Several experimental studies, in a variety of settings, though, have found remarkably little difference between the experimental conduct of students and that of professionals from the relevant field (e.g., Dyer, Kagel and Levin, 1989, DeJong, Forsythe and Uecker, 1988, Potters and van Winden, 1999).

properties of an auction, but leaves the surplus as much as possible with the bidders.

One possibility would be to look for auctions that minimize rather than maximize expected revenue or to a mechanism that redistributes the auction revenue to the winning bidders. This involves interesting but intricate mechanism design problems, which obviously we do not intend to solve here. Another possibility to discard revenue collection while retaining efficient selection, is to change the determination of the auction winner. Rather than allocating entry rights to the bidders who are willing to pay the highest entry fee, the winners could be those that are willing to serve the market at the lowest prices. This is, of course, a well-known idea and not devoid of its own difficulties (e.g., Demsetz, 1968, Williamson, 1976). For markets in which services and technologies evolve relatively slowly (such as fairgrounds) this may be more relevant than for very dynamic markets (such as telecommunication). Perhaps though, the idea may receive some additional ammunition from our finding that entry fees, and not just market power, may be responsible for efficiency losses in oligopolistic markets.

However, a complicating factor is that political considerations are not necessarily aligned with welfare-economic ones. For example, one argument which is sometimes raised in favor of auctioning is that firms should not be allowed to receive "windfall profits" from employing a scarce public resource (like the radio spectrum). Hence, even if efficient selection mechanisms could be devised that leave the surplus with the firms, political arguments may be raised against such a mechanism. Probably though, the most important political argument in favor of auctioning is the revenue itself. In previous centuries rulers were clearly motivated by the money raised by selling offices to the highest bidder (see footnote 2). Also the political discussions about the recent spectrum auctions often seem to center around the amount of money that is generated and on how to spend it. Hence, mechanisms which reduce revenue collection, even if economically sound, may have a hard time to pass the test of political feasibility. But even if so, it is still important to realize that the auction revenues may not be completely innocuous from the viewpoint of economic efficiency.

Appendix A

We examine the conditions under which collusive (mark-up) prices and non-collusive (stage game Nash) prices can be sustained as an equilibrium of the repeated game when there is some probability that the rival player (irrationally) employs mark-up pricing followed by tit-for-tat. To make matters as simple as possible assume that there are only two possible prices: $p^N = 60$ and $p^C = 100$. That is, in each period t (t = 1,...5) the following normal form game is played:

	$p^C = 100$	$p^N = 60$
$p^C = 100$	7560 , 7560	1800 , 8200
$p^N = 60$	8200, 1800	5000, 5000

Assume that there is a commonly known probability ϵ that a player is irrational and plays a tit-for-tat pricing strategy. Hence, with $p_{j,t}$ denoting the other player's price in period t, such a player plays $p_{i,t} = p_{j,t-1}$ (t = 2,...5). We restrict attention to the following two extreme cases: (a) irrational players start with a price of $p_{i,1} = 100$ (because they employ mark-up pricing and there is an entry fee), and (b) irrational players start with a price of $p_{i,1} = 60$ (because there is no entry fee).

First, we examine for which values of ϵ it is an equilibrium strategy in the repeated game for a rational player to choose a price of 60 in each period: $p_{i,t} = 60$, t = 1,...,5. Table A refers to this equilibrium as "non-cooperation".

In case (a) the expected payoff of the proposed strategy is 25000+3200ϵ. The question is, given that all rational players follow this strategy, would it be profitable for a rational player to deviate? The best deviation would be to play cooperatively in the first period $p_{i,1} = 100$, see whether the other player is an irrational tit-for-tat type ($p_{i,t} = p_{j,t-1}$, t = 2, 3, 4), and then to defect in the last period ($p_{i,5} = 60$). The expected payoff of this deviation is 21800(1-ϵ)+38440ϵ, which is worse than the proposed equilibrium strategy if $\epsilon < 0.24$.

In case (b) the expected payoff of this strategy is 25000. The most profitable deviation would be to play cooperatively for the first two periods $p_{i,1} = p_{i,2} = 100$, see whether the other player is of the irrational tit-for-tat type ($p_{i,t} = p_{j,t-1}$, t = 3,4) and then to defect in the last period ($p_{i,5} = 60$). The expected payoff of this deviation is 18600(1-ϵ)+32680ϵ, which is worse than the proposed equilibrium strategy if $\epsilon < 0.45$.

Second, we examine when it is an equilibrium strategy for the rational players to start playing cooperatively ($p_{i,1} = 100$), followed by a tit-for-tat strategy ($p_{i,t} = p_{j,t-1}$, t = 2, 3, 4) and defection in the last period ($p_{i,5} = 60$).

In case (a) the expected payoff of this strategy is 35240(1-ϵ)+38440ϵ. The most profitable deviation would be to start defecting one period earlier: $p_{i,4} = 60$. The expected payoff of this deviation is: 35880, which is worse than the proposed equilibrium if $\epsilon > 0.20$. Table A refers to this equilibrium as "collusion".

In case (b) the proposed equilibrium strategy of the rational players should be made slightly more patient ($p_{i,1} = p_{i,2} = 100$, $p_{i,t} = p_{j,t-1}$, t = 3, 4, $p_{i,5} = 60$), otherwise an irrational type will already trigger retaliation after period 1. However, this strategy can never be an equilibrium. After the first period, a rational player will know whether the opponent is rational ($p_{j,1}$ = 100) or irrational ($p_{j,1}$ = 60). In the former case, it is better to start defection one period earlier: $p_{i,4}$ = 60 rather than $p_{i,4} = p_{j,3}$. But defecting just one period earlier cannot be an equilibrium strategy for a rational player either, since defection yet again a period earlier would be a profitable deviation if the opponent player is known to be a rational type ($p_{j,1}$ = 100). As a consequence, the only possible equilibrium strategy with 'some' cooperation is for a rational player to play $p_{i,1}$ = 100 and $p_{i,2} = p_{i,3} = p_{i,4} = p_{i,5}$ = 60 if $p_{j,1}$ = 100 and $p_{i,2} = p_{i,3} = p_{i,4}$ = 100, $p_{i,5}$ = 60 if $p_{j,1}$ = 60. The expected payoffs of this strategy exceed those of a devation towards always defecting ($p_{i,t}$ = 60, t = 1,..,5) as long as $\epsilon > 0.33$. Note, however, that in this equilibrium cooperation is only partly realized: two rational types only cooperate in the first period, a rational and an irrational type only cooperate in periods 2-4 and two irrational types do not cooperate at all. Table A refers to this equilibrium as "partial collusion".

The results of this stylized model are summarized in Table A. It appears that in the Fixed Cost and the Auction treatment collusion is supported as an equilibrium for a larger set of values for ϵ, and that at the same time always playing the stage game equilibrium is supported as an equilibrium for a smaller set for ϵ than in the Baseline treatment.

Table A
Equilibria of incomplete information model

	proportion of "irrational" firms (å)	
equilibria	Baseline	Fixed Cost/Auction
non-cooperation	$0 \leq \epsilon \leq 0.45$	$0 \leq \epsilon \leq 0.24$
collusion (FC/AU) - partial collusion (BL)	$0.33 \leq \epsilon \leq 1$	$0.20 \leq \epsilon \leq 1$

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:

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

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.}

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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↔ average price	ρ=0.29 p=0.00; n=120	ρ=0.17 p=0.14; n=40	ρ=0.27 p=0.05; n=40
Auction	winning bid↔ average price	ρ=0.38 p=0.00; n=108	ρ=0.22 p=0.10; n=36	ρ=0.42 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

	period 11-15		period 16-20		period 21-25		period 26-30	
average own price	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

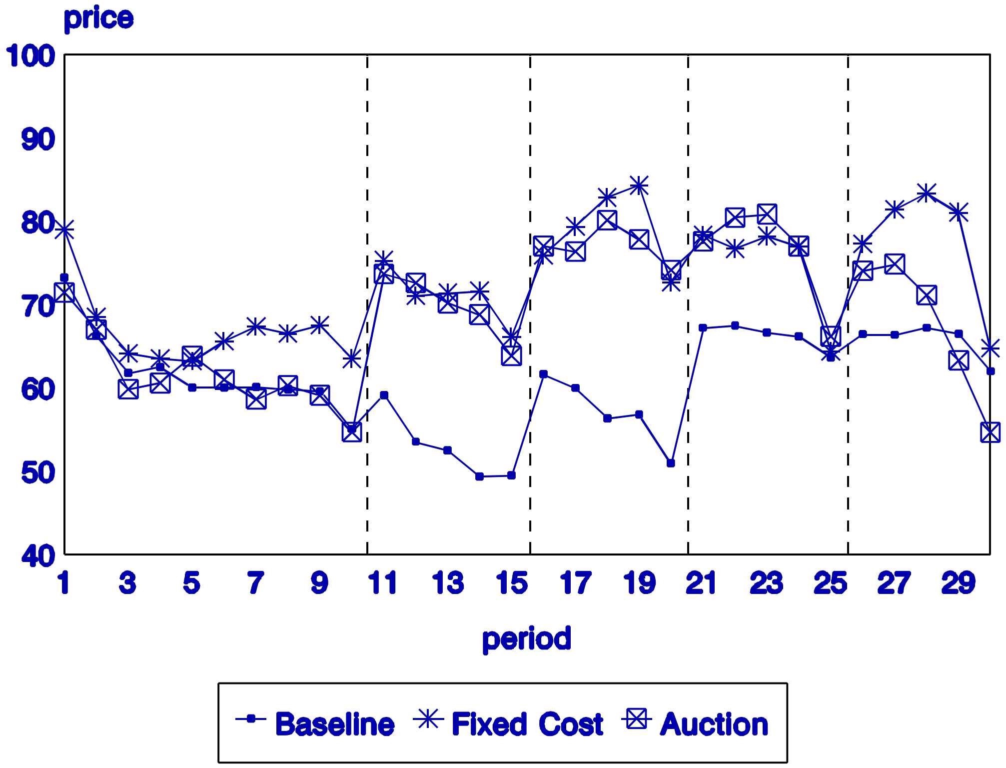
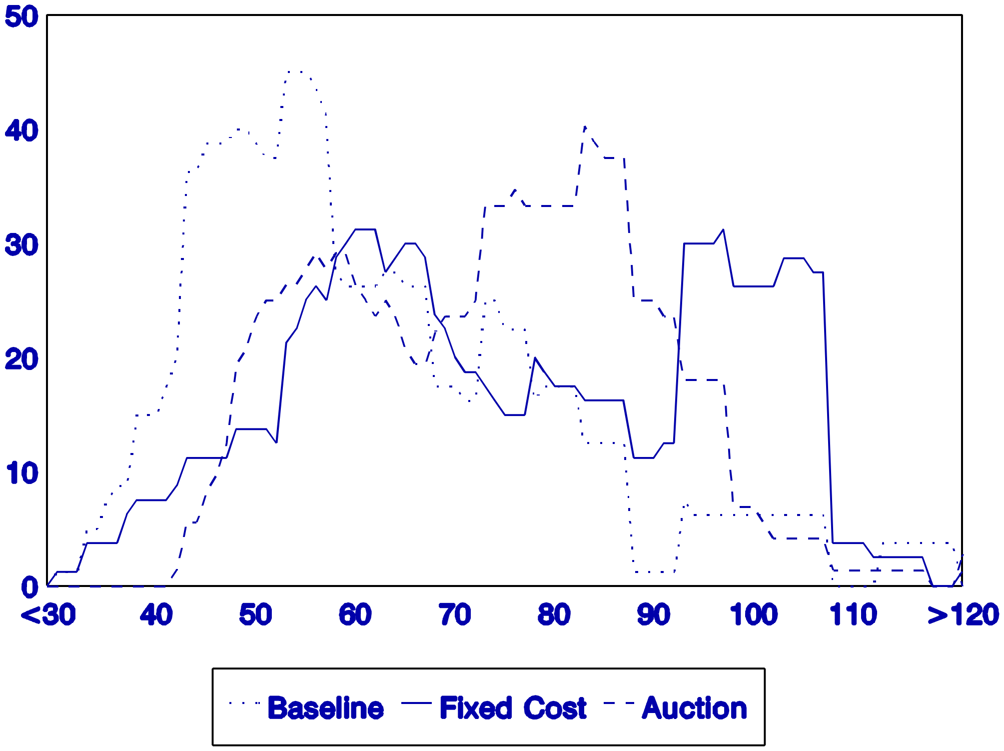
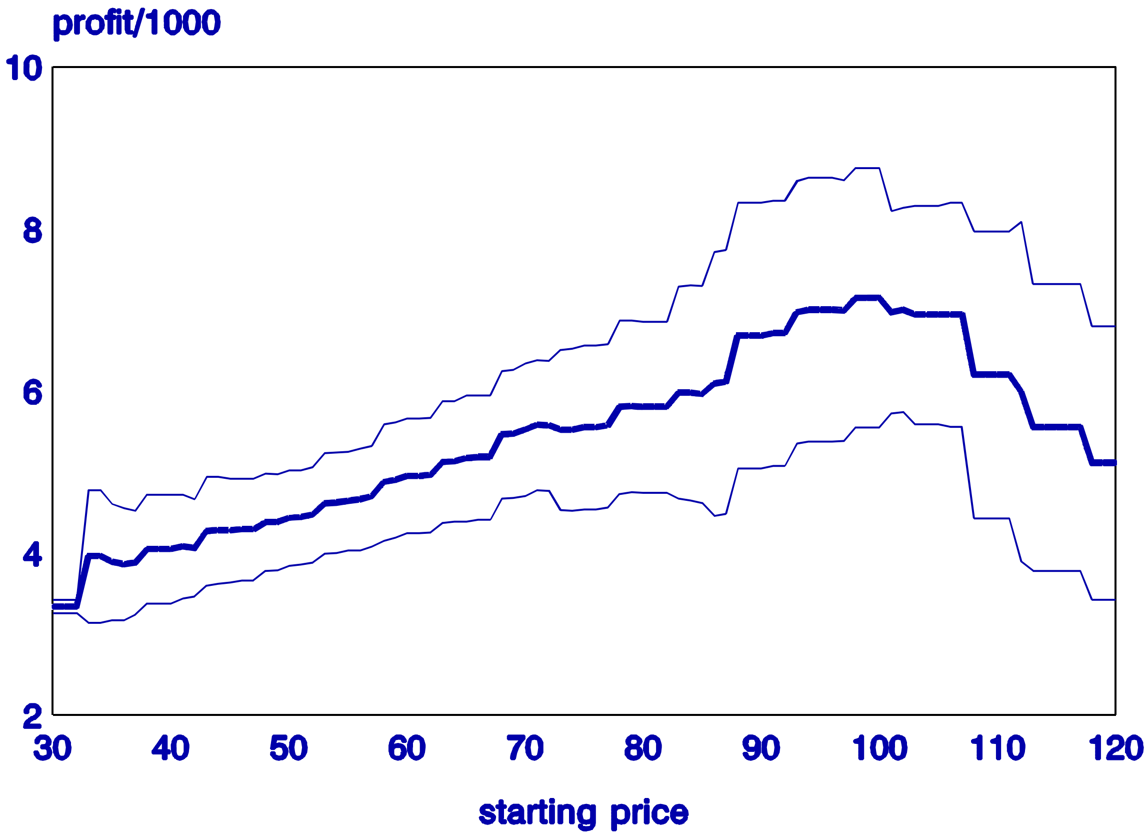


Figure 2
Frequencies of starting prices per treatment



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].

Figure 3
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.