Does Auctioning of Entry Licenses Induce Collusion?

An Experimental Study*

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

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1. Introduction

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

Auctions have a number of advantages over alternative allocation mechanisms. Unlike, for example, lotteries or queuing (first-come-first-served), they tend to select the more cost-efficient entrants. Furthermore, auctions are more transparent and less prone to rent-seeking than administrative processes (beauty contests). Finally, the license fees paid by the auction winners are often seen as welcome revenue to governments, diminishing their need to rely on distorting taxes.[1]

This latter benefit is not uncontested though. In particular, it is often argued that auctioning will increase the prices that consumers ultimately pay. Many companies claim that they will charge higher prices in order to recuperate part of the entry fee. For example, in response to plans by the Dutch government to auction the locations for petrol stations along the highways oil company Shell argues that "auctioning the selling points drives up costs. After all, just like the auctioning of locations at fun fairs by local governments, ultimately these costs will have to be included in the product price. The extra revenue to the government will ultimately be paid by the motorists" (Shell, 1999). The criticism from these companies is perhaps not so

[1] The auctioning of spectrum licenses in the US raised over 20 billion dollars. Revenues for the third generation mobile spectrum (umts) licences have been more than 25 billion dollars in both the UK and Germany. For an interesting overview of different 3G auctions in Europe, see Klemperer (2002).

surprising. They have to pay substantial fees for licenses which often they used to get for free. Interestingly though, also consumers[2], regulators and policymakers are sometimes concerned about the use of auctions. For example, the European Commission states that "reliance on auctions should not lead to an excessive transfer to the public budget or for other purposes to the detriment of low tariffs for the users" (European Commission, 1994, proposed position I.11). Hence, there is a rather widespread concern that auctioning of licenses may lead to higher consumer prices.

Economists easily find the flaw in this line of reasoning (see, e.g., McMillan, 1995, Van Damme, 1997). Once the right to operate on a market has been obtained, the entry fee constitutes a sunk cost. Entrants interested in expected profits will base their decisions on an evaluation of marginal revenues and marginal costs, and these are unaffected by sunk costs. Bygones are bygones, as the saying goes. From the standard theoretical perspective the argument for increased (cost-based) prices does not seem to make much sense.

There is a potential caveat to the sunk cost argument, however. Some experimental studies have found that entry fees may affect the equilibrium that is being selected in coordination games (Cooper, DeJong, Forsythe and Ross, 1993, Van Huyck, Battalio and Beil, 1993, Cachon and Camerer, 1996).[3] It is possible that a related effect will influence prices when entry licenses are auctioned by inducing the entrants to become more collusive. This is not obvious though. Coordination games have multiple perfect equilibria, whereas oligopoly games (also the repeated one that we will study) often have a unique perfect equilibrium.

There exists another potential effect of license auctioning on prices. An auction will select the entrants with the highest profit expectations. Profit expectations will partly depend on the players' beliefs about the possibilities to collude. Bidders who are optimistic about the prospects for collusion will expect to make higher profits than those that expect to enter a very

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

[3] Another noteworthy study is Güth and Schwarze (1983), who auctioned off player positions in ultimatum game experiments (see also Güth and Tietz, 1985). They found the auction winners for the proposer position to be more 'greedy' than is typically the case in ultimatum games without an entry auction.

competitive market. An auction may then have the effect of selecting the more optimistic bidders, and, to the extent that these are also the more collusive entrants, this may have an upward effect on prices. Notice that this argument for increased prices relies on self-selection, whereas the previous one does not.

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

In the present paper we employ the experimental method to investigate the arguments outlined above. Does auctioning of entry licenses lead to an increase of market prices? And, if so, is this because the entry fee induces the players to *behave* more collusively, or because the auction tends to *select* the more collusive players? To examine these questions we set up an experimental market, corresponding to a symmetric price-setting duopoly with product differentiation.[5] We implemented three stylized allocation treatments. In the *Auction* treatment,

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

[5] A symmetric setup allows for the cleanest test possible of the two arguments put forward for a potential upward price effect of auctioning entry licenses. It is not our purpose to give an overall assessment of the costs and benefits of license auctions. Such an assessment should, for example, include the potential of

we had four subjects bidding for the right to enter the market, and paying their bids in case they were among the two highest bidders. In the *Fixed Cost* treatment, the entry rights were randomly assigned, and the two selected entrants had to pay an exogenous entry fee, comparable in size to the winning bids in the Auction treatment. In our *Baseline* treatment, finally, the entry rights were also assigned randomly, but now the two entrants did not have to pay any entry fee at all.

We find that in the short and medium term market prices are higher in the Auction treatment than in the Baseline treatment. Moreover, the design allows us to attribute the price-enhancing effect to the fact that an entry fee is paid rather than selection, since the Fixed Cost treatment leads to the same high prices as the Auction treatment. Given these results, an interesting question is whether the price effect of auctions is due to the use of cost-based pricing, as industry representatives argue, or whether it is the result of a collusion-facilitating role of entry fees. If the cost-based pricing argument is correct, one would even expect an effect of auctioning licenses in a monopoly market. To further investigate this possibility, we ran two additional monopoly treatments, *Mon Baseline* and *Mon Auction*.[6] In the *Mon Auction* treatment, subjects competed for the right to operate in monopoly markets, while in the Mon Baseline treatments licenses were randomly assigned without entry fee. We do not observe different price levels in the Mon Baseline and Mon Auction treatments, which allows us to reject the cost-based pricing argument put forward by the industry representatives.

The remainder of this paper is organized as follows. Section 2 presents the duopoly model and gives a more detailed outline of the hypotheses to be tested. Section 3 provides details of the experimental design and procedure of the duopoly treatments. Section 4 presents the experimental result of the duopoly treatments. Section 5 introduces the monopoly setting and presents the experimental results of the monopoly treatments. Section 6 contains a concluding discussion.

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auctions to select the most (productively) efficient firms. In this paper we are mainly interested in the force of the sunk cost argument.

[6] We thank the editor (Mark Armstrong) for suggesting these additional experiments.

2. Duopoly 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

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

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

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

The unique stage game Nash equilibrium is equal to $(p_1^N,p_2^N) = (60,60)$ with corresponding profits of $(\pi_1^N,\pi_2^N) = (5000,5000)$. 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 player 1 prices at $p_1 = 160$, player 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 who are playing the game.[7] After the five periods are over, there is a new selection of two players from the group of four subjects for the next block of five periods, or, after period 30, the experiment is over.

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

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

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

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

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

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

Entry Fee Hypothesis: $P_{BL} < P_{FC}$

Two arguments can be made to support the entry fee hypothesis. Mark-up (cost-based) pricing provides the simplest reason why an entry fee may lead to an increase of market prices. This is the argument that most industry representatives and policymakers refer to.

A second argument is that entry fees will encourage collusion. In other settings it has been shown that entry fees may affect equilibrium selection. Van Huyck, Battalio, and Beil (1993) examine a coordination game with multiple Pareto-ranked equilibria. They find that auctioning the entry rights to the game helps players to coordinate on the Pareto efficient equilibrium. Forward induction can be the active principle here. Cachon and Camerer (1996) find that the impact of entry fees does not necessarily rely on self-selection through the auction mechanism. Coordination on the Pareto-efficient equilibrium may be improved even if an *exogenous* entry fee is imposed on the players (like in our Fixed Cost treatment). This effect has been attributed to loss avoidance. Players do not pick strategies that result in certain losses, if other equilibrium strategies are available that result in a positive payoff.

Our pricing game, unlike a coordination game, has a unique perfect equilibrium. From this perspective we should not expect to find an effect of entry fees. Furthermore, rational players will not enter bids above the payoffs in this equilibrium (and in fact, in the experiments on average subjects do not bid above the subgame perfect equilibrium payoffs). So, there is no need for them to change to another strategy in order to avoid losses. Hence, neither forward induction nor loss avoidance should be expected to have force in our pricing game.[8]

Still we believe a case can be made for the hypothesis that entry fees encourage collusion, if it is assumed that an entry fee encourages players to take more risk. Our finitely repeated pricing game has a unique subgame perfect equilibrium, but it also has multiple non-perfect equilibria. Though collusion is not a subgame perfect equilibrium, it is a Nash equilibrium.[9] If both players coordinate on a collusive equilibrium, payoffs will be higher than in the subgame perfect equilibrium. There is of course a possibility that the players will fail to coordinate on collusion. If one player opts for collusion while the other player opts for the subgame perfect equilibrium, payoffs to the former player will be lower than those in the subgame perfect equilibrium. In this sense an attempt to coordinate on a collusive price path is risky, and riskier than opting for subgame perfect play. If entrants have just paid a (large) entry fee this may stimulate them to pursue a more risky strategy (cf. prospect theory).

[8] Forward induction and loss avoidance also require that entry fees are common knowledge. In our experiment entry fees are private information, so also for this reason the two concepts should have no bite. We cannot control beliefs though. As one referee has pointed out, in the Auction treatment entrants know that entry fees are based on bids so entrants may have some idea about the level of their opponent's entry fee and more so than in the Fixed Cost treatment.

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

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

The selection hypothesis is based on the assumption that an auction will select the players with the highest profit expectations. Since the cost and demand conditions of the players are identical in our market game, players' profit expectations will largely depend on the subjective beliefs about their own and the other player's pricing behavior. To the extent that players who expect to earn relatively high profits are also the players who tend to be relatively collusive, the entry auction may result in an upward effect on prices.[10] Since selection of the more collusive players can only take place in the Auction treatment, the Selection Hypothesis postulates that prices will be higher in the Auction treatment than in the Baseline and Fixed Cost treatment, where the assignment of entry rights is exogenous.

3. Experimental Design

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

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

Upon entering the room subjects were randomly seated in the laboratory behind tables with partitions. Instructions were distributed and read aloud. We will send a translation of the

[10] For example, in the duopoly price-setting experiments with complete information of Fouraker and Siegel (1963, experiment 16), there is a positive correlation between a firm's average price and his average profit. Within each duopoly the firm with the lower average price typically earns the higher profit. Across all duopolies, however, the higher price firms earn more money than their more competitive counterparts. See Offerman et al. (2002) for a similar result in a quantity-setting oligopoly.

Dutch instructions upon request. All interaction took place by means of networked computers.[11] Each experimental session consisted of two parts, with the instructions for part 2 being distributed only after the completion of part 1. In part 1, subjects first went through a practice round. Then they played the price-setting game outlined above for 10 periods with a fixed, randomly assigned opponent, and subjects were informed about this. We kept pairs of players fixed in the first part in an attempt to approximate the world outside the laboratory where firms interact in the same industry for some time before the composition of the industry changes. 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 done 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, because we felt that by not doing so we approximated the situation outside the lab better. Another undesirable aspect of profit tables is that it encourages subjects to provide best responses, while such a force is absent in the world outside of the laboratory.

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

Part 2 consisted of another 20 periods of the same game, divided in 4 blocks of 5 periods. Subjects were informed that they were assigned to a group of four subjects, that these groups would remain fixed throughout part 2, and that in each block of 5 periods two of them would be

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

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

selected to enter the market together. The two inactive subjects received a fixed payment of 1000 points per period, that is, 5000 for a block of five periods, and were informed about the prices and profits of the two active subjects.[13]

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.[14]

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.

[13] Without an outside option subjects may become desperate to play the game. We chose a rather small outside option compared to the Nash profits of a supergame (25,000 points), because otherwise the incentives to play the game would become too diluted.

[14] 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. Results

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

4.1 Overview of the results

Figure 1 gives a general impression of the development of prices in the three treatments. It can be seen that in part 1 (period 1-10) the development of prices is by and large the same for the three treatments. Average prices start out somewhat above the stage game Nash equilibrium of 60, and then decrease to about 60 in period 3. From period 3, average prices remain approximately stable. There is a small drop in prices in period 10.[15] 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).[16] 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.

[15] In periods 1-10 we find average prices slightly above the equilibrium price. This is in line with the few other experiments on price competition with product differentiation (Dolbear et al., 1968, Huck et al., 2000).

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

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 show a reversed U-shape in the other treatments, with the downward trend being sharper in the Auction than in the Fixed Cost treatment. As a result, the average price difference between the treatments has almost disappeared in the final period.

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

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

We now make these findings statistically more precise. The upper part of Table 1 presents prices by treatment, averaged over blocks of periods. The lower part of the table gives two-tailed significance levels of Mann-Whitney tests of the differences between treatments.[17]

[17] The test results reported in Table 1 are robust with respect to the method of testing. We also compared the treatments with the Robust Rank Order test and obtained similar results as in Table 1.

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. 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 Entry Fee hypothesis ($P_{BL}<P_{FC}$) must be accepted at the expense of the Sunk Cost hypothesis ($P_{BL}=P_{FC}$) and the Selection hypothesis ($P_{FC}<P_{AU}$), and (b) when entry rights are being assigned for the third and the fourth time, the Sunk Cost hypothesis cannot be rejected in favor of either the Entry Fee hypothesis or the Selection hypothesis.[18]

[18] 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 $P_{FC}=P_{AU}$. Hence, we believe a rejection of the Sunk Cost hypothesis ($P_{BL}=P_{FC}$) would still be warranted, especially since the alternative Entry Fee hypothesis ($P_{BL}<P_{FC}$) posits a clear direction for the price difference and a one-tailed test might thus be more appropriate.

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.[19]

[19] The differences between winning bids of successive blocks of periods and between excess profits of successive blocks of periods all miss the significance level of $p=0.05$.

4.3 Entry Fee hypothesis

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

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

Table 3. Correlation between entry fees and prices

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

There was not much reason to give up collusive pricing, since on average it proved quite a profitable strategy. Figure 2 shows the relationship between starting prices in a block of five periods and realized average profits in the corresponding block of five periods. The figure displays both the average profit and the average profit plus and minus the standard deviation of profits. The figure is based on all blocks and all treatments (the picture is similar for all three treatments, although in the Baseline treatment it is based on a relatively high number of lower starting prices). It can be seen that up until a price of 100 average profits are increasing in the starting price, while the variance of profits increases at the same time. An increase of prices above 100 does not translate into higher mean profits. Hence, subjects who start a block of five market periods with a collusive price of 100 earn the highest payoffs on average (i.e., not controlling for other features of their pricing strategy).[20]

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

Next we investigate the dynamic pricing strategies of the players. In section 2 we suggested that collusive pricing might be sustainable if players employ trigger-like strategies. Table 4 displays, for all treatments combined as well as for each treatment separately, how subjects change their price from one period to the next, conditional on whether their own price in the previous period is higher than or lower than their rival's price. Overall, these dynamics are reminiscent of the “measure-for-measure” strategy found by Selten, Mitzkewitz and Uhlich (1997).

Table 4. Dynamics of pricing behavior

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

[20] We compared the profits for subjects who choose a "low starting price" defined as 50 < starting price < 70 and the profits for subjects who choose a "high starting price" defined as 90 < starting price < 110. The average (per period) profits for low starting prices equal 4,883 points, while the average profits for high starting prices equal 7,152 points. The difference in profits is significant according to a Mann-Whitney rank test (m=71, n=31, p=0.00).

punishments more often and more severely than they use rewards (which may explain the downward trend of average prices within each block of periods that was observed in Figure 1).

Further evidence for strategic play can be found in the presence of a clear end-effect. As noted before, on average there is a decline of prices within each block of 5 periods. However, in the Auction and Fixed Cost treatments the average price decline from the 4th to the 5th period in a block (-11.5 in absolute terms for FC and -7.0 for AU) is much stronger than the average decline across the earlier periods within a block (+0.6 for FC and -1.3 for AU). This end-effect from the 4th to the 5th period is stronger in the Auction and Fixed Cost treatments than in the Baseline (-3.2). Moreover, the end-effect is about twice as large in the last two blocks as in the first two blocks of part 2, indicating that it becomes stronger with learning (cf. Selten and Stoecker, 1986).[21]

Another noteworthy result is that not all players seem to be influenced by an entry fee to the same degree. It appears that some players are induced to price more collusively, while others adhere to the sunk cost hypothesis. To illustrate this, Figure 3 displays, for each treatment, the distribution of starting prices immediately after the rights to play have been newly assigned, that is, the distribution of prices in periods 11, 16, 21 and 26. As can be seen, the frequency distribution of starting prices in the Baseline treatment is concentrated around the stage game Nash equilibrium price of 60 with the mode being somewhat below it. The Fixed Cost and Auction treatments also have a mode around the Nash price of 60 but they also display a concentration of prices at a higher level: around 85 in the Auction treatment and around 100 in the Fixed Cost treatment. Hence, players' strategies are heterogeneous in how they deal with an entry fee.[22]

Figure 3. Frequencies of starting prices per treatment

[21] The end effect is significant for the Fixed Cost (Wilcoxon Rank test: n=10; p=0.02) and Auction treatments (Wilcoxon Rank test: n=9; p=0.03), but not for the Baseline treatment (Wilcoxon Rank test: n=10; p=0.24).

[22] 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.

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

In sum, the data reveal the following regularities. An entry fee stimulates some of the players to charge a collusive starting price, though not as high as the maximum collusive price of 160. Rewards and punishments are employed to sustain collusive prices and avoid exploitation by defecting players. Higher starting prices lead to higher profits on average, but only up to some point (Figure 3). At the same time the variance of profits is increasing in prices, indicating that collusive pricing is risky.

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

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

4.4 Selection hypothesis

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

A selection effect would provide an upward pressure on prices if the auction would tend to select players that set high prices. Before we investigate whether selected players charge high prices, we address the question whether the auction selects the players that made the highest profit in the past.

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

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

Table 5. Effects of selection on prices in Auction treatment

In our design inactive players can 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. Spectators may learn to bid and to set prices like the successful others after the first block of periods. Imitation may thus haved helped to generate common beliefs about the profitability of a license and about how the game should be played. Therefore, after the first block of periods it did perhaps not matter who was selected by the auction.

In view of this, an interesting question is whether the selection effect will be stronger in later rounds if imitation (common belief formation) is excluded by design. To examine this we ran two new treatments, called "Fixed Cost─" and "Auction─", in which inactive players could *not* observe the prices and profits of the active players.[23] In all other respects, the two treatments are identical to the Fixed Cost and Auction treatment, respectively. For both Fixed Cost─ and Auction─ we ran two sessions with 36 subjects per treatments (i.e., 9 independent observations per treatment).

The main result of treatment Auction─ is that we do not find evidence for a selection effect in later auctions. For each of the auctions, we examined whether the auction winners on average charged higher prices in the previous periods than the auction losers (compare Table 5). In none of the last three later auctions we find any evidence for this. Previous prices of the auction winners are even somewhat lower on average than those of the auction losers. In fact, even in the first auction the evidence for a selection effect is very weak. The winners of the auction charged an average price in periods 1-10 (68.5) which is only slightly (and insignificantly) higher than those of the auction losers (66.1). Moreover, average price levels as well as the pattern of prices over time, are almost identical for the Auction─ and the Fixed Cost─

[23] We thank one of the referees for suggesting these additional experiments.

treatment.[24] So, we reject the hypothesis that the selection effect is an important cause for an upward effect of auctioning on prices.

4.5 Quantitative analysis

In this section, we zoom in on the dynamics underlying the prices chosen by the subjects in part 2 of the experiment (periods 11-30). The foregoing qualitative analysis of the dynamics is roughly in line with both a model that assumes that players best respond to their competitor's behavior in the previous period and a model that assumes that players reward favorable behavior but punish unfavorable behavior of the other player. Here, we will compare the performance of simple best-response models with the performance of simple punish-and-reward models using maximum likelihood.

According to the "basic best-response model", subjects choose a starting price in the first period of a block and best-respond to the previous price chosen by the competitor in the subsequent periods of a block. The starting price, denoted by *sp*, is a free parameter that will be estimated from the data. The basic model assumes that there is no difference between the treatments. In the following, $p_{k,t,b}$ refers to the price chosen by subject *k* (*k*=*i* refers to the player's own price, *k*=*j* to the competitor's price) in period *t* ($1 \le t \le 5$) of block *b* ($1 \le b \le 4$).

$$p_{i,1,b} = sp + \epsilon_{i,1,b}$$
$$p_{i,t,b} = 36 + 0.4\, p_{j,t-1,b} + \epsilon_{i,t,b} \qquad \text{for } 2 \le t \le 5$$

The "basic reward-and-punish model" makes the same assumption about subjects' behavior in the first period of a block. Its predictions differ for the subsequent periods. In particular, for $2 \le t \le 5$,

$$p_{i,t,b} = 0.5\, p_{i,t-1,b} + 0.5\, p_{j,t-1,b} + \epsilon_{i,t,b} \qquad \text{if } p_{i,t-1,b} \le p_{j,t-1,b}$$

[24] Furthermore, at the level of the individual players, the correlation between the entry fee for a block of periods and the average price in that block of periods is significantly positive for both Auction– (ρ=0.25, p=0.00, n=108) and Fixed Cost– (ρ=0.17, p=0.04, n=108).

$p_{i,t,b} = p_{j,t-1,b} + \epsilon_{i,t,b}$ if $p_{i,t-1,b} > p_{j,t-1,b}$

In agreement with results reported in the literature (Fehr and Schmidt, 1999; Offerman, 2002), this model assumes that players reward favorable behavior of the other player to a lesser extent than they punish unfavorable behavior. For both models we assume that the error terms $\epsilon_{i,t,b}$ are drawn from a truncated normal distribution with mean 0 and variance σ^2, where errors are independently distributed across subjects, blocks and periods.

These basic models do not predict a difference between the treatments. The previous qualitative analysis suggests that the entry fees paid for the licenses cause differences in the price paths. In particular, the analysis highlighted the possibility that an entry fee leads to an increase of the probability that a subject opts for a collusive price path. We allow for this effect in the "general best-response model" and the "general reward-and-punish model".

The difference between the basic models and the general models lies solely in the assumption about the behavior of the first period in a block. In the general models, players of the Baseline treatment select a competitive starting price (sp_{comp}) with independent probability $prob_{no\text{-}fee}$ and a collusive starting price (sp_{coll}) with probability ($1\text{-}prob_{no\text{-}fee}$). Players of the Auction and Fixed Cost treatments select a competitive starting price (sp_{comp}) with $prob_{fee}$ and a collusive starting price (sp_{coll}) with probability ($1\text{-}prob_{fee}$). Notice that the general model attempts to describe possible differences between the treatments in a parsimonious way: the probability that a player chooses a collusive price path is the only parameter that is allowed to differ between the treatments. The parameters sp_{comp}, sp_{coll}, $prob_{no\text{-}fee}$ and $prob_{fee}$ will be estimated from the data. The basic models are nested in the general models. By setting $prob_{no\text{-}fee} = 1$ and $prob_{fee} = 1$ in the general models, the general models collapse into the basic models.

With this model structure, the unconditional likelihood $L_i(p_{i,t,b})$ of all choices made by a player *i* in the Baseline treatment becomes:

$$L_i(p_{i,t,b}) = prob_{no-fee} L_i(p_{i,t,b} \mid sp_{comp}) + (1 - prob_{no-fee}) L_i(p_{i,t,b} \mid sp_{coll})$$

where $L_i(p_{i,t,b} \mid sp_{comp})$ [$L_i(p_{i,t,b} \mid sp_{coll})$] represents the conditional likehood of all choices made by player *i* given the competitive [collusive] starting price. Likewise, the unconditional likelihood $L_i(p_{i,t,b})$ of all choices made by a player *i* in the Fixed Cost or Auction treatments becomes:

$$L_i(p_{i,t,b}) = prob_{fee} L_i(p_{i,t,b} \mid sp_{comp}) + (1 - prob_{fee}) L_i(p_{i,t,b} \mid sp_{coll})$$

Table 6 presents the maximum likelihood results for these models together with the results for the random model, that says that each of the 201 feasible integer prices between 0 and 200 is chosen with equal probability. The random model provides a (weak) lower bound on the expected performance of the models. All basic and general models significantly outperform the random model.[25] Both within the class of basic models and within the class of general models, the reward-and-punish model provides a substantially better fit of the data than the best-response model. In both cases the likelihood of the reward-and-punish model is greater than the likelihood of the best-response model. In addition, the estimates for the error parameter σ are smaller in the reward-and-punish models. In fact, the general best-response model is even outperformed by the basic reward-and-punish model with three less parameters.

Table 6. Maximum likelihood results best-response versus reward-and-punish

We now turn to a comparison of the basic and general reward-and-punish models. This comparison will clarify the treatment effect. The general reward-and-punish model organizes the data better than the basic reward-and-punish model. The improvement of the fit of the data compensates the loss of parsimony in a statistically significant way. The performance of the general model deteriorates significantly when the restriction $prob_{no\text{-}fee}=prob_{fee}$ is inserted. These maximum likelihood results confirm the existence of a treatment-effect between on the one hand the Baseline treatment and on the other hand the Fixed Cost and Auction treatments. Allowing the parameter $prob_{fee}$ to differ for the Fixed Cost and the Auction treatment does not lead to a significant improvement of the fit of the data. In fact, in this case the estimates for $prob_{fee}$ are

[25] In this section, all tests are Likelihood Ratio tests and significance is measured at the 5% level.

equal to 0.56 in the Fixed Cost treatment and 0.57 in the Auction treatment. Thus, according to these results there is no difference between the Fixed Cost and Auction treatments.

In the reward-and-punish model we made specific assumptions about the levels of rewards and punishments. We did this to make the structure of the reward-and-punish model similar to the best-response model, which made a comparison between the models possible. Now we relax these specific assumptions, and let the data decide about the levels of rewards and punishment. To do so, we estimate the general model with the following dynamic rules.

$$p_{i,t,b} = (1-\alpha)\, p_{i,t-1,b} + \alpha\, p_{j,t-1,b} + \epsilon_{i,t,b} \qquad \text{if } p_{i,t-1,b} \leq p_{j,t-1,b}$$

$$p_{i,t,b} = (1-\beta)\, p_{i,t-1,b} + \beta\, p_{j,t-1,b} + \epsilon_{i,t,b} \qquad \text{if } p_{i,t-1,b} > p_{j,t-1,b}$$

By inserting α=0.5 and β=1, the original general model is obtained. Table 7 presents the maximum likelihood results for this case. Allowing the extra freedom in reward and punishment levels leads to a significantly better fit of the data (compared with the general model reported in Table 6).[26] Our subjects reward favorable pricing more moderately and they punish unfavorable pricing more mildly than we assumed in the original models.[27]

Table 7. Maximum likelihood results with free reward and punishment parameters

We draw the following conclusions from this exercise. According to our estimations, 83% of the subjects who receive a license for free choose a competitive starting price of 60, while the remaining 17% choose a collusive starting price of 94. When an entry fee is introduced for a

[26] We also estimated the model of Table 7 separately for periods 11-20 and periods 21-30 to check for the robustness of the results. There is only a little variation in the maximum likelihood estimates of the parameters of periods 11-20 and periods 21-30. The improvement of the loglikelihood is marginal when the model is estimated for these two blocks of periods separately: the total loglikelihood of the data for periods 11-20 (21-30) is improved with 2.43 (1.39) when the estimates of Table 7 are replaced by the optimal estimates for periods 11-20 (21-30). This means that per choice the loglikelihood is improved by 0.004 (0.002) in periods 11-20 (21-30). According to these estimations, actual strategies roughly remain constant across time.

[27] Since the estimated punishment parameter is larger than the estimated reward parameter, average prices should tend to fall within blocks of periods, like they often do (see Figure 1). The difference between the punishment and reward parameters is of a moderate size, however, which means that every now and then random noise will counterbalance the downward force of the model. This may explain the occasional upward trend in price levels observed in Figure 1.

license (in either the Fixed Cost or the Auction treatment), only 56% of the subjects choose the competitive starting price of 60. Here, a substantial proportion of 44% opts for the collusive price path. After the first period, the pricing dynamics are better described by a reward-and-punish model than by a best-response model.

5. Auctioning of a Monopoly License

An interesting question is whether the auctioning of a *monopoly* license will also increase prices. This question is important for two reasons. (i) One would like to know whether the price-enhancing effect of auctions are limited to the oligopoly case or whether they can be extrapolated to the monopoly case. (ii) It sheds light on the question why exactly auctions provide an upward pressure on prices in the oligopoly case.[28] In this section we report the results of a second series of experiments that addresses the issue of auctioning a monopoly license. First we will introduce the monopoly setting.

A player with a license to produce faces the following market circumstances. The costs of production are given by

$$c(q) = 10q \tag{5}$$

Demand is either low (q_L) or high (q_H), and both events occur with equal probability 1/2.

$$q_L = \max[0,220-2p] \tag{6}$$
$$q_H = \max[0,380-2p] \tag{7}$$

Notice that this monopoly set-up is very similar to the duopoly set-up of the previous sections. The intercept of the demand functions in the monopoly setting is obtained by inserting either a Nash price (p_j=60) or a collusive price (p_j=160) for the opponent in the demand function (1) of the

[28] Recall that in the Auction treatment we observe many prices close to 100. In fact, a price of 100 is remarkably close to the price that a naive mark-up pricing rule would predict. In the stage-game equilibrium the players obtain a mark-up of p-c = 60-10 = 50 and produce at q = 100. In the Auction and Fixed Cost treatments the entrants pay an entry fee of about 20000 which amounts to a fixed cost of 4000 per period. Keeping the mark-up over average cost equal to 50 would require a price p such that p-c-4000/q = 50. If the players would expect to produce at q=100 again, this mark-up rule gives a price of p=100.

duopoly case. As a consequence, the strategic uncertainty in duopoly is replaced by state uncertainty in monopoly.

A comparison of the auctioning of monopoly licenses and duopoly licenses will further illuminate the reason why players charge higher product prices in the duopoly set-up. If the argument put forward by industry representatives is correct, one would expect a similar effect in the monopoly case. According to their argument, the costs of buying a license will ultimately be included in the product price. Mark-up pricing will thus increase prices in both the monopoly and the oligopoly setting.

Alternatively, entry fees may encourage players to take more risks in an attempt to recover lost income. As we observed in the duopoly case, a collusive strategy is more profitable but also more risky. An entry fee may induce (some) players to accept a higher variance in profits to achieve a higher mean. A similar effect may result in the monopoly case, but only for a limited range of prices. Figure 4 shows the expected profit and the variance of profit as a function of the product price. A price of 80 maximizes expected profits. If without an entry fee players choose risk averse prices below 80, the entry fee may encourage them to take higher risk and move into the direction of 80 thereby insuring higher expected profits. In this sense a change in risk attitude may even sustain an effect of auctions in the monopoly case.

Figure 4. Monopoly profits as function of prices

5.1 Experimental design of monopoly treatments

We ran two treatments to investigate the effect of auctioning a monopoly-license. In Mon Auction licenses were auctioned while in Mon Baseline licenses were given away for free. The experiments were structured in the same way as the duopoly experiments. That means that the first part of the experiment was the same for both treatments. After one practice round, each subject chose a price in each of the ten periods. After a subject had decided, a draw from a wheel of fortune determined whether the subject faced high or low demand. The draws were independent across subjects and periods. At the end of a period, each subject received feedback about the own quantity produced, the revenue, cost and profit.

Part 2 consisted of 4 blocks of 5 periods. Subjects were assigned to fixed groups of 4 persons each. In Mon Auction each block started with an auction where 2 monopoly licenses were sold to the highest 2 of a group of 4 bidders. Each winning bidder paid the own bid. Bids were restricted to integer values between 0 and 75,000 points. Like in the duopoly experiments, subjects were only informed whether their bid was among the highest two bids, and they were not provided with information about the vector of bids. A buyer of a monopoly-license could produce and sell goods in the same way as in part 1. The two inactive subjects received a constant payoff of 1000 points for each of the 5 periods.

In Mon Baseline, at the start of each block an independent random lottery decided which 2 out of the group of 4 subjects entered the market. Subjects who entered the market received the license for free. In all other respects the Mon Baseline treatment was similar to the Mon Auction treatment.

We ran 2 sessions at Tilburg University for each of the 2 monopoly treatments with either 20 or 16 subjects per session. We have observations for 40 subjects in Mon Auction and 32 subjects in Mon Baseline. Subjects earned on average 159,979 points or 40.00 euro (4,000 points = 1 euro).

5.2 Monopoly results

We start with a comparison of the price levels in the two monopoly treatments. Figure 5 shows the development of average price levels in both treatments. Overall, the price levels stay remarkably close together. The minor exception might be the block of periods after the first auction, where prices in Mon Baseline fall slightly below the prices in Mon Auction. There do not seem to be noteworthy trends in the price levels.

Figure 5. Average price levels in the two monopoly treatments

Table 6 reports the average price levels per block of periods in both treatments together with test results comparing the price levels across treatments. Table 8 reinforces the first impression provided by Figure 5. The hypotheses that mean prices are equal in both treatments are not rejected at conventional significance levels. It might be argued that after the first time the licenses have been assigned to 2 of 4 players, the difference in product prices is marginally significant (periods 11-15, p=0.06). Even so, in this block of periods the prices after auctioning are only a little higher than without auctioning. This validates the most important conclusion: there is no meaningful price effect of auctioning a monopoly-license.[29]

[29] The expected profit at the profit maximizing price of 80 equals 9800 points. Therefore, the net expected value of winning a license to produce in 5 periods equals 5*9800 - 5*1000 = 44000 points. Subjects submitted "reasonable" bids with an average winning bid of 35497 points. On average winners realized excess profits of 5442 points.

Table 6. Monopoly treatment effects

This result refutes the reasoning of industry-representatives, who argue that the costs of a license will be included in the cost-price of the product.[30] If their reasoning were sound, an upward effect of the auction in both monopoly and oligopoly would be expected. What about the effect working through the risk attitude? For the oligopoly case, we argued that the entry fee paid at the auction stimulates players to take more risk. Why did a similar force not affect prices in the monopoly case?

Figure 4 explains why we should not expect a strong effect of auctioning monopoly licenses, even if it is true that entry fees stimulate players to take higher risks in the pursuit of higher expected profit. Without auctioning the monopoly-licenses the product prices are already quite high. Pooled across all 30 periods, product prices in Mon Baseline are equal to 78.0, barely below the expected profit maximizing price of 80. Taking higher risks does not make sense in the monopoly case where expected profits decrease for prices higher than 80.

This suggests that we should expect a price effect of auctioning for players who price substantially below 80 when they get the license for free in the first ten periods. To examine this we single out those players in rounds 11-15 who had an average price below 75 in the first 10 periods. In the Mon Baseline these players set an average price of 69.3 in periods 1-10, and an almost identical average price of 69.4 in periods 11-15. In the Mon Auction treatment these players set an average of 65.0 in periods 1-10, but they increased their average price to 77.0 in periods 11-15. Subjects who priced below the profit maximizing price in the early rounds continued to do so if they had costless re-entry, whereas those subjects increased their price substantially when they had to pay for re-entry. This accounts for the small price effect that we observe for periods 11-15 in Figure 5. The number of subjects with prices well below 80 in the early rounds, however, is too small to generate a big price effect.

6. Conclusion

This paper examined the empirical strength of the argument that the auctioning of entry licenses will increase market prices. Two potential causes for such an increase were identified. The first one is that the entry fee will induce entrants to charge higher market prices. We found

[30] The experiment of Bucheit and Feltovich (2000) also casts doubt on the empirical relevance of cost-based pricing.

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. In 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 smaller. Nevertheless, even in the longer term, we found a significant positive correlation between entry fees and prices. The other possible reason for increased prices due to auctioning is that an auction will tend to select the more collusive players. We did not find a difference between the prices set in the Auction treatment and the Fixed Cost treatment and we rejected the selection hypothesis.

Given these results, an interesting question is whether a price-enhancing effect can also be expected in an auction of a monopoly-license. We ran two extra treatments to investigate this question. Subjects who had won a monopoly-license after an auction in Mon Auction charged similar prices as subjects who received the monopoly license for free. Thus, the price-enhancing effect of auctioning oligopoly-licenses does not carry over to monopoly-licenses. This refutes the industry representatives' claim that the entry fee will be incorporated in the market price via mark-up pricing. Instead, a parsimonious explanation consistent with our oligopoly data is that the entry fee encourages players to embark on a collusive price path, which leads to higher expected profits at a higher risk. A simple reward-and-punish model describes the pricing dynamics in the data better than a best-response model. In the monopoly treatments, subjects price close to the risk neutral optimum price even when they pay no entry fees. Therefore, when subjects do pay entry fees, there is no scope left to increase prices in the pursuit of higher expected profits.

Like always one has to be careful when extrapolating experimental findings to field settings. In our experimental market all players face identical cost and demand functions, whereas in most naturally occurring markets the potential entrants are asymmetric. Efficiency then requires the licenses to be allocated to the most (cost) efficient players. Thus an important efficiency-enhancing selection effect of auctions exists, which is absent from our experiments.[31] Therefore, our experiments do not provide an argument against the auctioning of entry licenses *per se*. Our results do suggest though, that the license fee may not just be a lump sump transfer from the entrants' profits to the government budget. Some efficiency loss due to increased prices may be involved.

The result that sunk costs affect play in repeated games potentially has a wide range of applications. After all, many games involve repeated interaction. Examples include team

[31] Another difference is that in our experiment the entry fee is collected by the experimenters and also collusion is at the expense of the experimenters, whereas in the field collusion is at the consumers' expense.

production, common pool resources, public goods, and clubs. Hence, an interesting hypothesis is that the players in these games are more likely to take the risk of trying to cooperate if they have paid a large entry cost.

Appendix A

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

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

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

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

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

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

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

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

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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_{FC}	66.9	71.1	79.0	74.9	77.6
P_{AU}	61.6	69.8	77.1	76.4	67.6
hypothesis					
$P_{BL}=P_{FC}$	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
$P_{FC}=P_{AU}$	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

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

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

Table 6
Maximum likelihood results best-response versus reward-and-punish

basic models		general models		random
best-response	reward-and-punish	best-response	reward-and-punish	model
σ = 17.3 *0.36* sp = 71.8 *1.14*	σ = 13.9 *0.29* sp = 71.8 *0.91*	σ = 15.8 *0.34* sp_{comp} = 60.6 *1.67* sp_{coll} = 93.8 *2.73* $prob_{no\text{-}fee}$ = 0.86 *0.07* $prob_{fee}$ = 0.56 *0.08*	σ = 11.9 *0.24* sp_{comp} = 60.1 *1.29* sp_{coll} = 94.2 *2.13* $prob_{no\text{-}fee}$ = 0.84 *0.08* $prob_{fee}$ = 0.56 *0.07*	
logL = -4.27	logL = -4.05	logL = -4.22	logL = -3.94	logL = -5.30

Notes: Standard errors in italics; total number of choices is 1160; models are explained in the text. logL presents the average log likelihood per choice.

Table 7
Maximum likelihood results with free reward and punishment parameters

general reward-and-punish model with free reward and punish parameters	
$\sigma = 11.1$ *0.23*	$prob_{no\text{-}fee} = 0.83$ *0.08*
$sp_{comp} = 60.0$ *1.29*	$prob_{fee} = 0.56$ *0.06*
$sp_{coll} = 94.0$ *1.84*	$\alpha = 0.22$ *0.04*
	$\beta = 0.57$ *0.04*
LogL = -3.87	

Notes: Standard errors in italics; total number of choices is 1160; models are explained in the text. logL presents the average log likelihood per choice.

Table 8
Monopoly treatment effects

	periods				
	1-10	11-15	16-20	21-25	26-30
treatment					
P_{MonBL}	77.7	75.4	77.8	80.6	79.4
P_{MonAU}	77.3	79.3	75.6	78.3	77.9
hypothesis					
$P_{MonBL}=P_{MonAU}$	p=0.96	p=0.06	P=0.93	p=0.18	p=0.92

Notes: P_{MonBL} (P_{MonAU}) represents the average price level in Mon Baseline (Mon Auction). Mann-Whitney rank tests are used to compare the price levels in both treatments for each block of periods (n_{MonBL}=8; n_{MonAU}=10).

Figure 1
Average price levels in the three treatments

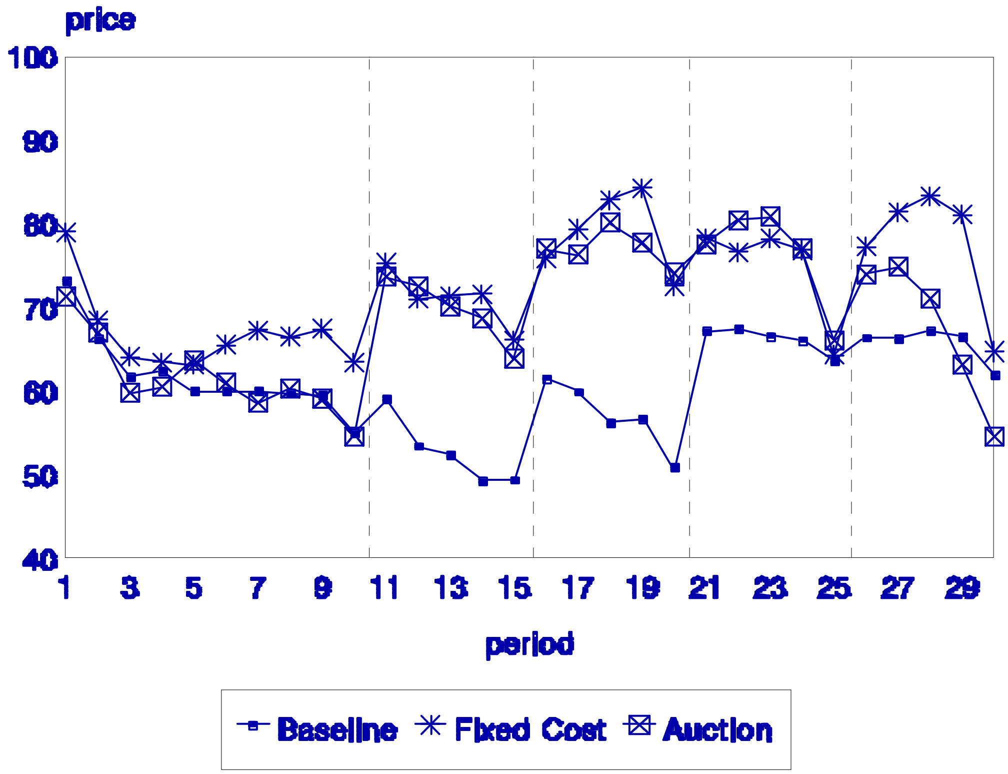
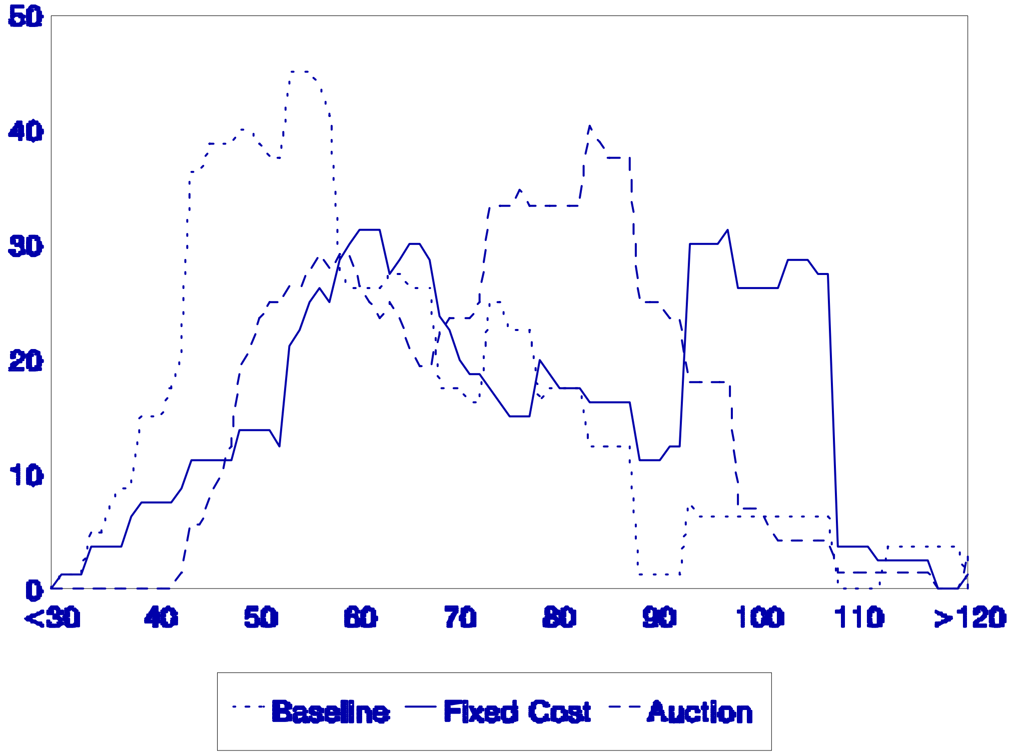


Figure 2
Average profits per period as a function of starting prices

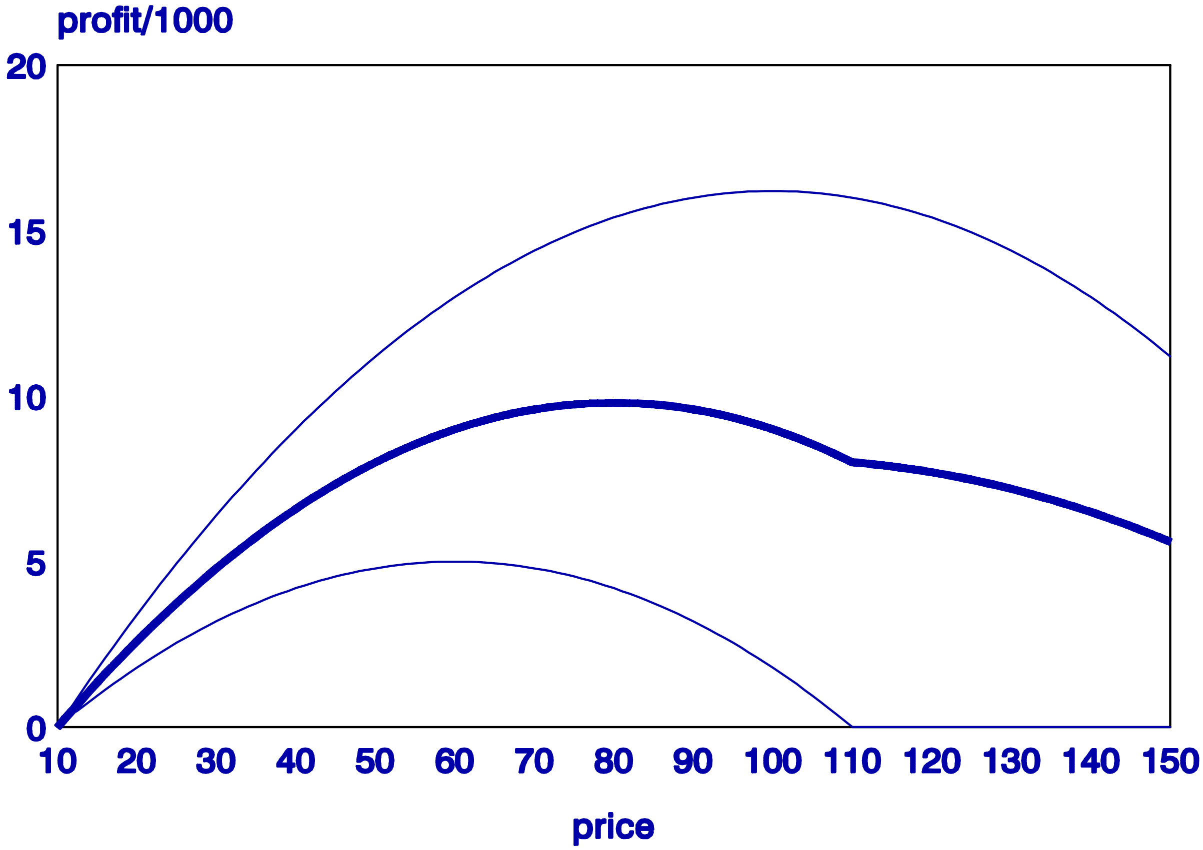
Notes: The thick line represents the running mean profits as function of starting price for all treatments. A firm's profits are averaged over the 5 periods in the block of the particular starting price. For each starting price P at the horizontal axis the vertical axis reports the mean profit of starting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

Figure 3
Frequencies of starting prices per treatment



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

Figure 4



Monopoly profits as function of prices

Notes: The thick line shows the expected profits as function of product prices. The upper (lower) line shows the expected profit plus (minus) the standard deviation.

Figure 5
Average price levels in the two monopoly treatments