

Does Auctioning of Entry Licences Induce Collusion? An Experimental Study

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We use experiments to examine whether the auctioning of entry rights affects the behaviour of market entrants. Standard economic arguments suggest that the licence 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 licences has a significant positive effect on average prices in oligopoly but not in monopoly. These results are consistent with the conjecture that entry fees induce players to take more risk in pursuit of higher expected profits. In oligopoly, entry fees increase the probability that the market entrants coordinate on a collusive price path. In monopoly, taking more risk does not make sense since average prices are already close to the profit-maximizing price.

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 16th to the 18th century. The practice of selling offices was most pronounced in 17th-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 ability 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 entry licences for markets, which have limited entry 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 entry fees paid by the auction winners are often seen as welcome revenue to governments, diminishing their need to rely on distorting taxes.¹

1. The auctioning of spectrum licences in the U.S. raised over 20 billion dollars. Revenues for the third-generation (3G) mobile spectrum Universal Mobile Telecommunications System (UMTS) licences have been more

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 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 surprising. They have to pay substantial fees for licences, which often they used to get for free. Interestingly though, also consumers,² regulators, and policy-makers 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 licences may lead to higher consumer prices.

Economists easily find the flaw in this line of reasoning (see, for example, 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 licences 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 licence auctioning on prices. An auction will select the entrants with the highest profit expectations. Profit expectations partly depend on the players' beliefs about the possibilities to collude. Bidders who are optimistic about the prospects for collusion will expect to make higher profits than those that expect to enter a very competitive market. An auction may then have the effect of selecting the more optimistic bidders, and, to the extent that these are also the more collusive entrants, this may have an upward effect on prices. Notice that this argument for increased prices relies on self-selection, whereas the previous one does not.

Unfortunately, it is almost impossible to rely on empirical data to test for a positive relation between licence 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 telecommu-

than 25 billion dollars in both the U.K. and Germany. For an interesting overview of different 3G auctions in Europe, see Klemperer (2002).

2. The International Telecommunications Users Group (INTUG) 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 licence 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. Likewise, Güth, Ockenfels and Wendel (1997) find that auctioning positions in a one-shot trust game reduces trust.

nication and the licence fees paid by the operator (see European Commission, 1999*a,b*).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 licence (Global Systems for Mobile Communication (GSM), Digital Communication Services (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 licences lead to an increase of market prices? And, if so, is this because the entry fee induces the players to *behave* more collusively or because the auction tends to *select* the more collusive players? To examine these questions we set up an experimental market, corresponding to a symmetric price-setting duopoly with product differentiation.⁵ We implemented three stylized allocation treatments. In the *Auction* treatment, we had four subjects bidding for the right to enter the market and paying their bids in case they were among the two highest bidders. In the *Fixed Cost* treatment, the entry rights were randomly assigned, and the two selected entrants had to pay an exogenous entry fee that was 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 were correct, one would even expect an effect of auctioning licences 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 licences 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 our conjectures. Section 3 provides details of the experimental design and procedure of the duopoly treatments. Section 4 presents the experimental results 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.

4. Within the European Union the highest licence fees (more than 200 million Euro for the most valuable licences) 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 (European Commission, 1999*a*). 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 (European Commission, 1999*b*). For example, Ireland and Luxembourg are the two countries with only two mobile operators. The most expensive licence in Ireland was 216 million Euro and average annual tariffs are about 1300 Euro. Luxembourg had licence fees less than 4 million Euro and annual tariffs of about 700 Euro.

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

6. We thank Mark Armstrong for suggesting these additional experiments.

2. DUOPOLY MODEL AND CONJECTURES

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, competitive—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 0) and the collusive profits.

Specifically, demand, costs, and profits, respectively, are given by

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

$$c(q_i) = 10q_i \quad i = 1, 2 \quad (2)$$

$$\pi_i(p_i, p_j) = (p_i - 10)q_i \quad i \neq j = 1, 2. \quad (3)$$

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

$$r_i(p_j) = 36 + 0.4p_j. \quad (4)$$

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 $(p_1^{\text{Col}}, p_2^{\text{Col}}) = (160, 160)$ with corresponding profits of $(\pi_1^{\text{Col}}, \pi_2^{\text{Col}}) = (9000, 9000)$. The competitive outcome, with prices equal to marginal cost and maximal social welfare, is characterized by $(p_1^{\text{Com}}, p_2^{\text{Com}}) = (10, 10)$ and $(\pi_1^{\text{Com}}, \pi_2^{\text{Com}}) = (0, 0)$. 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 $\pi_2 = 16,200$. 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 10th period, each subject is randomly allocated to a group of four (among which is his or her opponent from the first 10 periods). These groups remain fixed until the end of the experiment (period 30). Before the start of the 11th, 16th, 21th, and 26th period, two of the four subjects are selected to play the market game for another five periods against each other. 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 periods 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 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 examine three main conjectures regarding the assignment of entry licences. To spell out these conjectures, 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 Conjecture: $P_{BL} = P_{FC}$.

This conjecture 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 Conjecture: $P_{BL} < P_{FC}$.

Two arguments can support the entry fee conjecture. 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 most industry representatives and policy-makers 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 *et al.* (1993) examine a coordination game with multiple Pareto-ranked equilibria. They find that auctioning the rights to enter the game helps players to coordinate on the Pareto-efficient equilibrium. Forward induction can be the active principle here. Cacho 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 pay-off.

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 pay-offs in this equilibrium (and in fact, in the experiments on average subjects do not bid above the subgame-perfect equilibrium pay-offs). 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.⁷

Still we believe a case can be made for the conjecture that entry fees encourage collusion, by assuming 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.

7. 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 did not 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. Therefore, another interesting possibility is to run two treatments where the bids and the entry fees are made public, respectively. A comparison of these treatments will reveal the potential effect of forward induction in a direct way. Janssen (2005) provides a theoretical model in which forward induction allows bidders to coordinate on the cooperative equilibrium of the subsequent game.

Though collusion is not a subgame-perfect equilibrium, it is a Nash equilibrium.⁸ If both players coordinate on a collusive equilibrium, pay-offs 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, pay-offs 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. We will come back to this argument below.

Selection Conjecture: $P_{FC} < P_{AU}$.

The selection conjecture 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 behaviour. 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.⁹ Since selection of the more collusive players can only take place in the Auction treatment, the Selection Conjecture 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.¹⁰

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 five independent observations per session in the five sessions with 20 subjects and four observations in the session with 16 subjects. Hence, in total we have 10 independent observations for both the Baseline and Fixed Cost treatments, and nine for the Auction treatment.

Undergraduate students of Tilburg University were recruited as subjects. In total we had 116 subjects. Sessions lasted for about $1\frac{1}{2}$ hours, and earnings averaged 43.55 Dutch guilders, which is about 19.80 Euro.

Upon entering the room subjects were randomly seated in the laboratory. Instructions were distributed and read aloud. We will send a translation of the Dutch instructions upon request. All interaction took place by means of networked computers (using a program written with RatImage, Abbink and Sadrieh, 1995). 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 period. Then they played the price-setting game outlined above for 10 periods with a fixed, randomly assigned opponent, and subjects were informed about this.

8. Moreover, experimental studies have found that players often manage to cooperate (collude) in finitely repeated games with a unique stage-game equilibrium (see, for example, Selten and Stoecker, 1986; Engle-Warnick and Slonim, 2006). In other words, even in settings in which cooperation is not a theoretical equilibrium it may still be a *behavioural* equilibrium.

9. 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 its 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, Potters and Sonnemans (2002) for a similar result in a quantity-setting oligopoly.

10. A recent theoretical paper by Janssen and Karamychev (2005) identifies an alternative selection effect in licence auctions. Their argument is that in differentiated Bertrand games, auctions will select the more risk-seeking players who set higher prices in the subsequent oligopoly game.

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 (= 0.45 Euro).

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. 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 20 periods of the same game, divided in four blocks of five 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 five periods two of them would be selected to enter the market. 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.¹¹

As explained in the previous section, the procedure to select the two market entrants 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 50,000 points. Subjects received no information about the bids of other subjects from their own group 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.¹²

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.

11. 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.

12. 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 41,270 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.

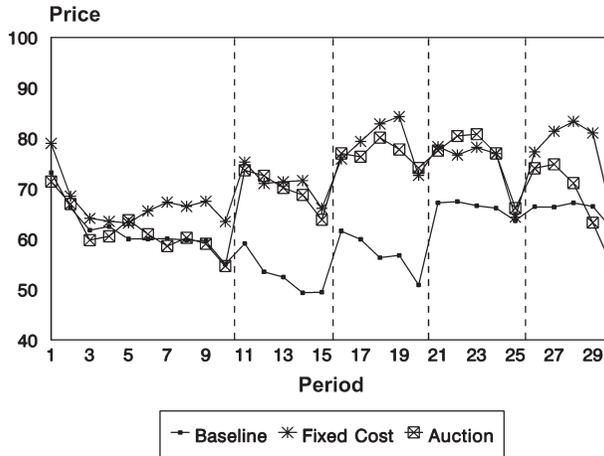


FIGURE 1
Average price levels in the three treatments

4. RESULTS

We present the results in two parts. The first part provides an overview of the price levels in the three treatments and an examination of the conjectures. The second part provides an explanation of the findings.

4.1. Overview of the results and examination of the conjectures

Figure 1 presents the development of average prices in the three treatments. It can be seen that in part 1 (periods 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 10.¹³ 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, but as will be shown below the difference is far from significant. Since the design of part 1 is identical for the three treatments, we would not expect to see significant differences between them.

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 five periods is also less pronounced in the Baseline treatment than in the other two treatments and the gap between the treatments becomes much smaller.

13. 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, Lave, Bowman, Lieberman, Prescott, Rueter and Sherman, 1968; Huck, Normann and Oechssler, 2000).

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 $P_{BL} = P_{FC}$	$p = 0.60$	$p = 0.06$	$p = 0.02$	$p = 0.10$	$p = 0.11$
$P_{BL} = P_{AU}$	$p = 1.00$	$p = 0.01$	$p = 0.03$	$p = 0.17$	$p = 0.46$
$P_{FC} = P_{AU}$	$p = 0.74$	$p = 0.84$	$p = 0.68$	$p = 0.87$	$p = 0.24$

Note: $P_{BL}(P_{FC}; P_{AU})$ 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: $n_{BL} = 10$; $n_{FC} = 10$; $n_{AU} = 9$.

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.

We summarize the main features as follows.

Finding 1. (a) In the first part (periods 1–10), average price levels are, by and large, the same in all treatments. (b) 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. (c) In the final two blocks of part 2 (periods 21–30), the differences between the treatments are much less pronounced. (d) 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.¹⁴ 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.¹⁵ 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), 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.¹⁶

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

15. 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 results similar to those in Table 1.

16. 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

TABLE 2
Correlation between entry fees and prices

Treatment	Correlation	Periods		
		1–30	11–20	21–30
Fixed Cost	Fixed Cost:	$\rho = 0.29$	$\rho = 0.17$	$\rho = 0.27$
	average price	$p = 0.00; n = 120$	$p = 0.14; n = 40$	$p = 0.05; n = 40$
Auction	Winning bid:	$\rho = 0.38$	$\rho = 0.22$	$\rho = 0.42$
	average price	$p = 0.00; n = 108$	$p = 0.10; n = 36$	$p = 0.00; n = 36$

Note: For periods 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.

On the basis of the Entry Fee conjecture 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. Recall that the entry fees are based on the bids that subjects entered in the Auction treatment. Overall, we can say that subjects bid in a very reasonable way. Entry fees average 19,749, with a S.D. of 5088, a low of 10,000, and a high of 30,000. The average winning bids are very close to 20,000, the net expected value of the right to play if in all periods the Nash equilibrium of (60, 60) would materialize. Since average prices are above the Nash equilibrium, the auction winners make an excess profit of 3737 points on average. Table 2 presents Spearman rank correlation coefficients between the entry fees and the average prices 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 conjecture, we find that higher entry fees lead to higher prices. Remarkably, in both treatments the correlation between entry fees and prices is more pronounced in periods 21–30 than in periods 11–20. In the next section we will provide an explanation for this finding.

Finding 2. In line with the Entry Fee conjecture, higher entry fees lead to higher prices.

The preceding analysis suggests that entry fees *per se* are responsible for increased prices after an auctioning of entry licences 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.

$p = 1.00$ for $P_{FC} = P_{AU}$. Hence, we believe a rejection of the Sunk Cost conjecture ($P_{BL} = P_{FC}$) would still be warranted, especially since the alternative Entry Fee conjecture ($P_{BL} < P_{FC}$) posits a clear direction for the price difference and a one-tailed test might thus be more appropriate.

TABLE 3
Effects of selection on prices in Auction treatment

Average own price	Periods							
	11–15		16–20		21–25		26–30	
	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

Note: 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.

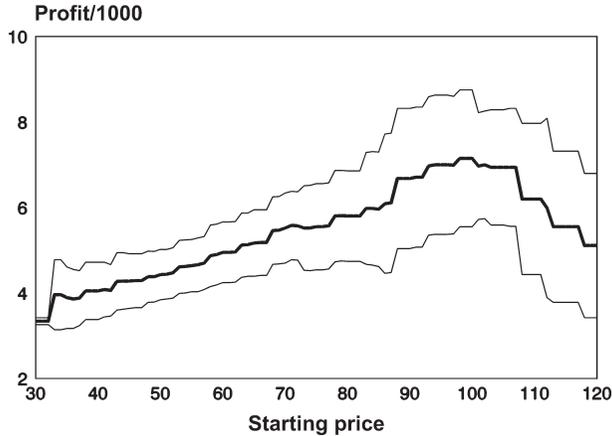
Given that the auction only selects successful players in the first block of periods, one might expect that an upward pressure of selection on prices is only observed after the first assignment of the rights to play. Table 3 displays average prices in the present block, as well as the average prices 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.

In our design inactive players can observe how successful players perform 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 licence 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 have helped to generate common beliefs about the profitability of a licence 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 periods 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.¹⁷ 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 treatment (*i.e.* nine 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 charge higher prices in the previous periods than the auction losers (compare Table 3). 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 charge an

17. We thank one of the referees for suggesting these additional experiments.



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

FIGURE 2

Average profits per period as a function of starting prices

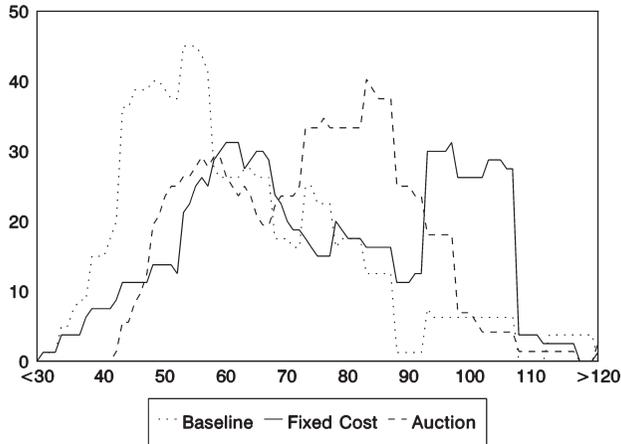
average price in periods 1–10 (68.5) which is only slightly (and insignificantly) higher than the one of the auction losers (66.1). Moreover, average price levels as well as the pattern of prices over time, are almost identical for the Auction– and the Fixed Cost– treatment.¹⁸ So, we reject the conjecture that the selection effect is an important cause for an upward effect of auctioning on prices.

Finding 3. In contrast to the prediction of the Selection Conjecture, oligopoly prices are not affected by the selection of players.

4.2. Explanation of behaviour

One striking finding of the previous section was that the correlation between entry fees and prices is stronger in the later periods than in the earlier periods of the experiment. Hence, there is no evidence that over time subjects learn to ignore the entry fees and dismiss collusive pricing. It turns out that 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 S.D. 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

18. 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– ($\rho = 0.25, p = 0.00, n = 108$) and Fixed Cost– ($\rho = 0.17, p = 0.04, n = 108$).



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

FIGURE 3

Frequencies of starting prices per treatment

collusive price of 100 earn the highest pay-offs on average (*i.e.* not controlling for other features of their pricing strategy).¹⁹

Finding 4. Up to a starting price of 100, higher starting prices led to higher expected profits at a cost of more risk.

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. It can be shown that the collusive price that maximizes expected profits will be below the maximum collusive price when a positive probability for coordination failure exists.²⁰

Not all players seem to be influenced by an entry fee to the same degree. Some players are induced to price more collusively, while others seem to ignore the sunk costs. 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

19. We compared the profits for subjects who choose a “low starting price” defined as $50 < \text{starting price} < 70$ and the profits for subjects who choose a “high starting price” defined as $90 < \text{starting price} < 110$. The average (per period) profits for low starting prices equal 4883 points, while the average profits for high starting prices equal 7152 points. The difference in profits is significant according to a Mann–Whitney rank test ($m = 71, n = 31, p = 0.00$).

20. Notice that the predicted price for the end period in a block is the same in a collusive equilibrium and the non-collusive equilibrium. In accordance with this prediction, Figure 1 shows that in the final two blocks the difference in end price between the Baseline treatment and the treatments with entry fees is smaller than the price differences in the periods before. From this perspective, it may be cleaner to exclude the end periods (15, 20, 25, and 30) when comparing price levels between the Baseline treatment and the other treatments. Doing so would make the result reported in Finding 1 more pronounced.

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.²¹

The data also reveal that collusion is clustered. Some groups have prices close to the stage-game Nash equilibrium (60) while others set prices at higher levels (80–100). This does not hold only 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.

Finding 5. Entry fees increase the probability of collusion.

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 behaviour. As we have seen in Figure 2, opting for collusion is a more risky strategy than opting for the subgame-perfect equilibrium price of 60. 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.

Collusive pricing may be sustainable if players employ trigger-like strategies. We examined 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. 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, whereas they increase their price in only 13.3% of these cases. 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, but in as much as 32.3% of these cases they decrease their price even further. Also the size of the price change is more moderate in case of rewards than in case of punishments. In case of punishments, subjects often go below the previous lower price of their rival, but in case of rewards they seldom go above the previous higher price of their rival. Hence, subjects use punishments more often and more severely than they use rewards (which may explain the downward trend of average prices within each block of periods that was observed in Figure 1). Overall, these dynamics are reminiscent of the "measure-for-measure" strategy found by Selten, Mitzkewitz and Uhlich (1997).

Notice, however, that in our differentiated Bertrand game best-response dynamics lead to roughly similar price paths as trigger-strategies do. Players who best respond also vary their price positively with the previous price of the other player (equation (4)). To discriminate between a best-response model and a reward-and-punish model, we present a quantitative analysis of the dynamics underlying the prices chosen by the subjects in periods 11–30. This analysis will also help to quantify some of the effects described above.

We use a flexible model that allows subjects to condition their choice on the previous price chosen by their competitor as well as on their own previous price level (and a constant). For subjects who want to reward or punish their competitor both their own previous choice and their competitor's previous choice matter. In contrast, subjects who best respond will let their choices completely be determined by the price level selected by the competitor (and a constant).

21. 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 seven-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", and 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.

In the model, we posit that subjects either start a cycle with a collusive starting price sp_{coll} or a competitive starting price sp_{comp} . These starting prices are free parameters to be estimated from the data. 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 ($1 \leq t \leq 5$) of block b ($1 \leq b \leq 4$). Thus, subjects with a competitive price path will choose the following initial price:

$$p_{i,1,b} = sp_{comp} + \varepsilon_{i,1,b},$$

whereas subjects who opt for a collusive price path will set

$$p_{i,1,b} = sp_{coll} + \varepsilon_{i,1,b}.$$

We assume that the error terms $\varepsilon_{i,t,b}$ are drawn from a truncated normal distribution with mean 0 and variance σ^2 , where errors are independently distributed across subjects, blocks, and periods. From periods 2–4 ($2 \leq t \leq 4$) in a block, both types of subjects proceed as follows:

$$\begin{aligned} p_{i,t,b} &= \text{const} + \alpha_1 * p_{i,t-1,b} + \alpha_2 * p_{j,t-1,b} + \varepsilon_{i,t,b} & \text{if } p_{i,t-1,b} < p_{j,t-1,b} \\ p_{i,t,b} &= \text{const} + \beta_1 * p_{i,t-1,b} + \beta_2 * p_{j,t-1,b} + \varepsilon_{i,t,b} & \text{if } p_{i,t-1,b} \geq p_{j,t-1,b}. \end{aligned}$$

Previous experimental work suggests that players reward favourable behaviour of the other player to a lesser extent than that they punish unfavourable behaviour (Fehr and Schmidt, 1999; Offerman, 2002). In agreement with this work, the model allows for asymmetries between the reward parameters (α_1 , α_2) and the punishment parameters (β_1 , β_2). The parameter *const* represents the constant.

At the end of a cycle we include a parameter *end* that captures a possible end effect (see Figure 1). Thus, in the final period of a block ($t = 5$), all subjects will choose according to:

$$\begin{aligned} p_{i,5,b} &= \text{const} + \alpha_1 * p_{i,4,b} + \alpha_2 * p_{j,4,b} + \text{end} + \varepsilon_{i,5,b} & \text{if } p_{i,4,b} < p_{j,4,b} \\ p_{i,5,b} &= \text{const} + \beta_1 * p_{i,4,b} + \beta_2 * p_{j,4,b} + \text{end} + \varepsilon_{i,5,b} & \text{if } p_{i,4,b} \geq p_{j,4,b}. \end{aligned}$$

The previous qualitative analysis revealed a salient role for the entry fees paid for the licences. In particular, the analysis highlighted the possibility that an entry fee increases the probability that a subject opts for a collusive price path. In addition, Figure 1 suggested that subjects' strategies might be time dependent. For the set of Baseline subjects who make choices in both the first part (periods 11–20) and the second part (periods 21–30) we estimate the probability that a subject uses a competitive starting price in both parts (denoted by $P_{BL,compcomp}$), the probability that a subject uses a competitive starting price in the first part and a collusive starting price in the second part (denoted by $P_{BL,compcoll}$) and the probability that a subject uses a collusive starting price in the first part and a competitive starting price in the second part (denoted by $P_{BL,collcomp}$). By definition, a subject then uses collusive starting prices in both parts with probability $1 - P_{BL,compcomp} - P_{BL,compcoll} - P_{BL,collcomp}$. For the subjects who participate in the treatments where subjects pay entry fees (Auction and Fixed Cost) we introduce the likewise defined parameters $P_{FEE,compcomp}$, $P_{FEE,compcoll}$, and $P_{FEE,collcomp}$.²²

22. One complication of our data-set is that, although the majority of subjects made choices in both parts, there were also subjects who only made choices in part 1 and some others who only made choices in part 2. We dealt with this complication in the following way. In the most general model that we considered, we estimated separate probability parameters $P_{BL,compno}$ ($P_{BL,nocomp}$) representing the probability that a subject of the Baseline treatment who only made choices in the first (second) part chose a competitive starting price. In addition, two similar parameters $P_{FEE,compno}$ and $P_{FEE,nocomp}$ were estimated for the subjects who only made choices in one part of the Auction and Fixed Cost treatments. When we imposed the four restrictions $P_{BL,nocomp} = P_{BL,compcomp}$, $P_{BL,compno} = P_{BL,compcomp}$, $P_{FEE,nocomp} = P_{FEE,compcomp}$, $P_{FEE,compno} = P_{FEE,compcomp}$, the likelihood did not deteriorate significantly according to a likelihood ratio test at the 5% level. Therefore, we proceed with this simpler model with the four restrictions. This model is presented as the 'general model' in Table 4.

TABLE 4
Maximum-likelihood results

	1. General model	2. Simple model	3. Strategy change	4. Treatment effect	5. Reward and punish	6. Best response
Restrictions	—	$P_{BL, collcomp} = 0$ $P_{FEE, compcoll} = 0$ $P_{FEE, collcomp} = 0$	$P_{BL, collcomp} = 0$ $P_{BL, compcoll} = 0$ $P_{FEE, compcoll} = 0$ $P_{FEE, collcomp} = 0$	$P_{BL, collcomp} =$ $P_{FEE, collcomp} =$ $P_{BL, compcomp} =$ $P_{FEE, compcomp} =$ $P_{BL, compcoll} =$ $P_{FEE, compcoll} =$	$\alpha_1 = 0$ $\beta_1 = 0$ $\alpha_2 = \beta_2$	$\alpha_1 = 0$ $\beta_1 = 0$ $\alpha_2 = 0.4$ $\beta_2 = 0.4$ End = 0 Const = 36
σ	10.5 (0.22)	10.5 (0.22)	10.5 (0.22)	10.5 (0.22)	12.4 (0.26)	15.8 (0.34)
$P_{FEE, compcomp}$	0.58 (0.06)	0.58 (0.06)	0.56 (0.07)	0.65 (0.05)	0.57 (0.07)	0.56 (0.08)
$P_{FEE, compcoll}$	0.00 (0.00)	—	—	0.02 (0.02)	0.00 (0.00)	0.00 (0.00)
$P_{FEE, collcomp}$	0.00 (0.00)	—	—	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
$P_{BL, compcomp}$	0.82 (0.07)	0.82 (0.07)	0.82 (0.08)	—	0.83 (0.07)	0.86 (0.07)
$P_{BL, compcoll}$	0.06 (0.06)	0.06 (0.06)	—	—	0.05 (0.06)	0.01 (0.07)
$P_{BL, collcomp}$	0.00 (0.00)	—	—	—	0.00 (0.00)	0.00 (0.00)
spcoll	95.0 (1.46)	95.0 (1.46)	—	—	—	—
spcomp	60.2 (0.96)	60.2 (0.96)	93.8 (2.06)	94.5 (1.57)	94.7 (1.95)	93.9 (2.04)
α_1	0.61 (0.06)	0.61 (0.06)	59.8 (1.31)	59.9 (1.02)	60.3 (1.10)	60.6 (1.42)
α_2	0.28 (0.05)	0.28 (0.05)	0.61 (0.06)	0.61 (0.06)	—	—
β_1	0.42 (0.04)	0.42 (0.04)	0.28 (0.05)	0.28 (0.05)	—	—
β_2	0.50 (0.05)	0.42 (0.04)	0.42 (0.04)	0.42 (0.04)	—	—
End	-7.01 (0.77)	0.50 (0.05)	0.50 (0.05)	0.50 (0.05)	0.82 (0.02)	—
Const	6.54 (1.15)	-7.01 (0.77)	-7.01 (0.80)	-7.01 (0.77)	-6.94 (0.90)	—
-log L	4431.3	6.54 (1.15)	6.54 (1.24)	6.54 (1.14)	12.58 (1.26)	—
	4433.8	4433.3	4433.8	4436.0	4616.4	4893.5

Note: S.E. in italics; total number of choices is 1160; models are explained in the text. log L presents the total log likelihood of all 1160 choices.

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:

$$\begin{aligned} L_i(p_{i,t,b}) = & P_{BL,compcomp}L_i(p_{i,t,b}|SP_{comp}, SP_{comp}) + P_{BL,compcoll}L_i(p_{i,t,b}|SP_{comp}, SP_{coll}) \\ & + P_{BL,collcomp}L_i(p_{i,t,b}|SP_{coll}, SP_{comp}) \\ & + (1 - P_{BL,compcomp} - P_{BL,compcoll} - P_{BL,collcomp})L_i(p_{i,t,b}|SP_{coll}, SP_{coll}) \end{aligned}$$

where $L_i(p_{i,t,b}|SP_{comp}, SP_{comp})$ represents the conditional likelihood of all choices made by player i given that she used the competitive starting price in both parts and $L_i(p_{i,t,b}|SP_{coll}, SP_{coll})$ represents the conditional likelihood of all choices given that the subject used the collusive starting price in both parts. $L_i(p_{i,t,b}|SP_{comp}, SP_{coll})$ [$L_i(p_{i,t,b}|SP_{coll}, SP_{comp})$] denotes the conditional likelihood of all choices when the subject switches from using the competitive (collusive) starting price to the collusive (competitive) starting price. The unconditional likelihoods of all choices made by a player in the Fixed Cost and Auction treatments are computed in the same way.

Table 4 presents the maximum-likelihood results for this general model in the left column. One striking result is that the estimated starting prices of the competitive price path and the collusive price path are remarkably close to the subgame-perfect Nash equilibrium of 60 and the empirically optimal starting price of 100 (Figure 2), respectively. In the treatments with entry fees, 58% of the subjects choose competitive price paths while 42% choose collusive price paths throughout the experiment. In the Baseline treatment, 82% of the subjects consistently opt for a competitive price path in both parts while 12% pursue a collusive price path in both parts. The remaining minority of 6% uses a competitive price path in the first part but switches to collusive price paths in the second part. Indeed, these results confirm that players face a stronger temptation to follow a collusive price path when they pay an entry fee. Notice further that subjects put relatively more weight on their own previous price when their own previous price was below the price set by the competitor (*i.e.* $\alpha_1/\alpha_2 > \beta_1/\beta_2$). This finding is consistent with the notion that players tend to be more conservative when rewarding favourable play of others than when they punish unfavourable play. Another noteworthy result is that the economically and statistically significant estimate of the end effect provides clear evidence for strategic play by the subjects.

We tested some hypotheses by introducing restrictions in the general model. Because all the models that we consider are nested in the general model, we can use standard likelihood ratio tests to determine whether the general model explains the data significantly better than the simpler models. All tests that we refer to in this section are likelihood ratio tests and significance is measured at the 5% level.

A comparison of columns 2 and 3 reveals the nature and significance of a time trend in our subjects' strategies. The simple model of column 2 is obtained by setting three of the four parameters that allow subjects to change strategies equal to 0. Unsurprisingly, this model results in the same likelihood as the general model because these parameters are estimated to be 0 in the general model. The model in the third column is obtained from the model in the second column by setting the fourth change parameter $P_{BL,compcoll}$ equal to 0. The latter restriction reduces the likelihood of the data significantly. Thus, there is a significant time trend in subjects' strategies that is identified by the switch of some subjects in the Baseline treatment from competitive to collusive price paths.

The treatment effect of the entry fees can be judged by comparing the results of the model in column 1 and the model in column 4. The model in column 4 assumes that there is no difference between the treatments by setting the three treatment specific probability parameters equal to each other. This leads to a significant deterioration of the likelihood. Thus, the estimations confirm the existence of a treatment effect between the Baseline treatment on the one hand and the Fixed Cost and Auction treatments on the other.

In column 5 restrictions are imposed on the general model that uncover the importance of reward-and-punishment strategies. For these strategies a crucial role exists for the position of the own previous price relative to the competitor's previous price. If the own previous price was lower than the competitor's price a reward is appropriate while in the opposite case a punishment is called for. In contrast, a best-response model assumes that a player's response depends on the competitor's previous price (and a constant). Best responses are independent of the relative position of the own previous price. Therefore, crucial parameters for rewards and punishments are the parameters α_1 and β_1 . If these parameters are set equal to 0, and if in addition $\alpha_2 = \beta_2$, a player's response does not depend on the relative position of the own previous price. In that case, it can safely be concluded that rewards and punishments do not play a role. However, when we impose these restrictions in column 5 it becomes clear that the likelihood deteriorates significantly and substantially compared to the likelihood of the general model of column 1. We interpret this finding as evidence that subjects actually do reward and punish.

In column 6 we impose the restrictions that correspond to the best-response model. This model leads to a clear and significant decrease of the likelihood of the general model. In retrospect, this is not so surprising. Best-response dynamics lead to a much faster fall of the price levels within a block of periods than we observe in the data. As can be seen in Figure 1, prices hardly fall in the first four periods of a block (after which a clear end effect follows). This is not the pattern that would be expected if subjects play best response.

The estimation results of the general model can be used to assess the long-term features of the model. If we insert the estimates for the parameters α_1 , α_2 , β_1 , β_2 and const in the model's dynamic equations for periods 2–4 and assume that players continue to use these equations forever, the price dynamics converge to a steady state price of 81.75, irrespective of the starting prices of the players. Of course, the path towards this steady state is different across the treatments as the probability that a competitive or collusive starting price is chosen differs.

We summarize the most important findings of the estimation exercise as follows.

Finding 6. (a) The introduction of an entry fee increases the probability that a collusive starting price (of 95) is chosen from 12% to 42% in the first part of the experiment and from 18% to 42% in the second part of the experiment. (b) After the first period, the pricing dynamics are better described by a reward-and-punish model than by a best-response model. (c) The clear end effect provides evidence for strategic play.

5. AUCTIONING OF A MONOPOLY LICENCE

An interesting question is whether the auctioning of a *monopoly* licence will also increase prices. This question is important for two reasons. (i) One would like to know whether the price-enhancing effect of auctions is limited to the oligopoly case or whether it 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.²³ In this section we report the results of a series of experiments that examine the effect of auctioning a monopoly licence. First we will introduce the monopoly setting.

A player with a monopoly licence faces the following market circumstances. The costs of production are given by

$$c(q) = 10q. \quad (5)$$

23. 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 20,000 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 $p = 100$.

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

$$q_L = \max[0, 220 - 2p] \quad (6)$$

$$q_H = \max[0, 380 - 2p]. \quad (7)$$

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 duopoly case. The strategic uncertainty in the duopoly market is replaced by state uncertainty in the monopoly market.

A comparison of the auctioning of monopoly licences and duopoly licences 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 licence will 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 on average 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 occur in the monopoly case, but only for a limited range of prices. 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 more risk and move into the direction of 80 thereby insuring higher expected profits. In this manner a change in risk attitude may even cause an effect of entry fees in the monopoly case.

5.1. *Experimental design of monopoly treatments*

We ran two treatments to investigate the effect of auctioning a monopoly licence. In Mon Auction licences were auctioned while in Mon Baseline licences were given away for free. The experiments were structured in the same way as the duopoly experiments. This means that the first part of the experiment was the same for both treatments. After one practice period, each subject chose a price in each of the 10 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, subjects received feedback about their own quantity, revenue, cost, and profit.

Part 2 consisted of four blocks of five periods. Subjects were assigned to fixed groups of four persons each. In Mon Auction each block started with an auction where two monopoly licences were sold to the highest two of a group of four bidders. The winning bidders paid their own bids. 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 licence could produce and sell goods in the same way as in part 1. The two inactive subjects received a constant pay-off of 1000 points for each of the five periods.

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

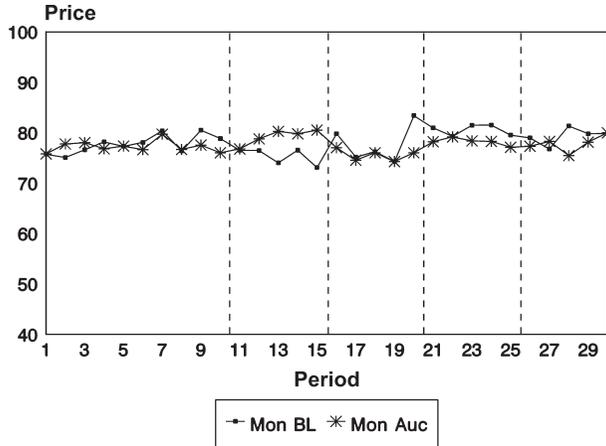


FIGURE 4
Average price levels in the two monopoly treatments

TABLE 5
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					
$P_{\text{MonBL}} = P_{\text{MonAU}}$	$p = 0.96$	$p = 0.06$	$p = 0.93$	$p = 0.18$	$p = 0.92$

Note: 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 ($n_{\text{MonBL}} = 8$; $n_{\text{MonAU}} = 10$).

We ran two sessions at Tilburg University for each of the two 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 (4000 points = 1 Euro).

5.2. Monopoly results

We start with a comparison of the price levels in the two monopoly treatments. Figure 4 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.

Table 5 reports the average price levels per block of periods in both treatments together with test results comparing the price levels across treatments. The table reinforces the first impression provided by Figure 4. The hypotheses that mean prices are equal in both treatments are not rejected at conventional significance levels. It might be argued that after the licences have been

assigned for the first time, the difference in 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. On the aggregate level there is no meaningful price effect of auctioning a monopoly licence.²⁴ This result refutes the reasoning of industry representatives, who argue that the costs of a licence will be included in the cost-price of the product.²⁵ 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 stimulates players to take more risk. Why did a similar force not affect prices in the monopoly case? Without auctioning the monopoly licences 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 only expect a price effect of auctioning for players who price substantially below 80 when they get the licence for free.

To examine this we single out those players who had an average price below 75 in the first 10 periods and compare this average price to their average price in the first block they re-entered. In the Mon Baseline these players (nine in total) decreased their price by 1.2 on average in the first block they re-entered. In the Mon Auction treatment these players (five in total) increased their price by 10.8 on average in the first block they re-entered.²⁶ This suggests that subjects who priced below the profit-maximizing price in the early periods 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. The number of subjects with prices well below 80 in the early periods, however, is quite small and there is considerable variance. As a result the difference between the treatments is not statistically significant (nor are the price changes significantly different from 0).

Another way to look at this issue is to compare within the Mon Auction treatment those subjects who priced below 75 in periods 1–10 with those who did not. Interestingly, the correlation between the entry fee and the price increase upon re-entry is very high for subjects who priced below 75 in periods 1–10 (Spearman $\rho = 0.90$, $p = 0.04$) whereas it is not significantly different from 0 for the subjects who already priced above 75 in periods 1–10 (Spearman $\rho = 0.02$, $p = 0.91$).

Finding 7. The few subjects who price low with costless entry on average increase their prices when entry is costly and the more so the higher the entry fee. Most subjects already price close to the profit-maximizing price without entry fees. Thus, in the aggregate, entry fees do not have a noticeable effect on monopoly prices.

6. CONCLUSION

This paper examined the empirical strength of the argument that the auctioning of entry licences 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 clear support for this conjecture in the short term. Both in the Fixed Cost and the Auction treatment

24. The expected profit at the profit-maximizing price of 80 equals 9800 points. Therefore, the net expected value of winning a licence to produce in five periods equals $5 \cdot 9800 - 5 \cdot 1000 = 44,000$ points. Subjects submitted “reasonable” bids with an average winning bid of 35,497 points. On average winners realized excess profits of 5442 points.

25. The experiment of Bucheit and Feltoich (2000) also casts doubt on the empirical relevance of cost-based pricing.

26. These numbers remain very similar if we vary the cut-off level of 75. For instance, with a cut-off level of 70 the average price-increase in the Mon Auction treatment equals 12.5, while average prices increase by 3.5 in the Mon Baseline treatment. With a cut-off level of 70 these numbers are based on only very few subjects (four in Mon Auction and three in Mon Baseline).

players charged significantly higher prices than in the Baseline treatment. In the long term, when the entry licences 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 conjecture.

Given these results, an interesting question is whether a price-enhancing effect can also be expected in an auction of a monopoly licence. We ran two extra treatments to investigate this question. Subjects who had won a monopoly licence after an auction in Mon Auction charged similar prices as subjects who received the monopoly licence for free. Thus, the price-enhancing effect of auctioning oligopoly licences did not carry over to monopoly licences. 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 encouraged players to embark on a collusive price path, which led to higher expected profits at a higher risk. In the monopoly treatments, subjects priced close to the profit-maximizing price even when they paid no entry fees. Therefore, when subjects did pay entry fees, there was no scope left to increase prices in the pursuit of higher expected profits. The (few) subjects who did price well below the profit-maximizing price with free entry on average increased their prices substantially with an entry fee, and the more so, the higher the entry fee. Overall then, the evidence is consistent with the conjecture that an entry fee encourages players to take more risk in the pursuit for 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 licences 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.²⁷ Therefore, our experiments do not provide an argument against the auctioning of entry licences *per se*. Our results do suggest though, that the licence fee may not just be a lump-sum 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 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.

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27. 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.

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