

# Collusion in Growing and Shrinking Markets: Empirical Evidence from Experimental Duopolies

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## Abstract

We study collusive behaviour in experimental duopolies that compete in prices under dynamic demand conditions. In one treatment the demand grows at a constant rate. In the other treatment the demand declines at another constant rate. The rates are chosen so that the evolution of the demand in one case is just the reverse in time than the one for the other case. We use a box-design demand function so that there are no issues of finding and co-ordinating on the collusive price. Contrary to game-theoretic reasoning, our results show that collusion is significantly larger when the demand shrinks than when it grows. We conjecture that the prospect of rapidly declining profit opportunities exerts a disciplining effect on firms that facilitates collusion and discourages deviation.

## Keywords

Laboratory experiments, industrial organisation, oligopoly, price competition, collusion

## JEL Classification Codes

C90, C72, D43, D83, L13

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## 1. Introduction

Game-theoretic analysis of price competition suggests that collusion will arise more easily in growing than in declining markets. Tacitly collusive agreements involve that deviations from the collusive path trigger retaliations by other firms, such that, from that point on, the deviating firm's profits will be lower than if it had stuck to the agreed behaviour. When the demand grows steadily the gains from deviating from the collusive agreement are, at any point in time, small in comparison to the future losses from retaliation. Analogously, when the demand keeps shrinking these losses will be relatively small compared to the short-term gains from deviations. Indeed, when the market is on the verge of collapsing, it will be virtually impossible to motivate firms to maintain the collusive agreement.

This prediction is somewhat at odds with some of the views of the European Commission where demand growth is often interpreted to be a factor that makes collusion more difficult. This discrepancy can be explained by the fact that the above reasoning assumes a constant number of market participants despite market growth, while in markets with growing demand the pro-competitive effect of entry may have to be taken into account. Nevertheless, there do exist markets with high entry barriers in which the intrinsic impact of demand growth is not moderated by entry. In addition, the study of the pure effect of market growth and decline is interesting in its own right given economists' general interest in understanding collusion.

Here it is important to point out that the game-theoretic rationale presented above seems rather intuitive and may, hence, be expected to have some predictive value. However, other possibilities are also reasonable a priori and need to be considered. For instance, one can argue that in an industry with brilliant future demand conditions firms might not punish deviations very severely, since the short-term losses of firms that have been cheated on are small in comparison to the possibilities of earning, in one way or another, good profits in the future. In contrast, in industries with declining demand firms may have the tendency to stick together out of a sense of desperation.

We believe that the relation between demand growth and collusion is a relevant policy issue. In their analysis of the economics of tacit collusion for the European Commission, Ivaldi et al. (2003) discuss demand growth as one of the potentially relevant factors for collusion, together with, among others, the number of competitors, the symmetry of market shares and market transparency. In his comprehensive analysis of competition policy, Motta (2004) also refers to the relation between demand evolution and collusion.

To shed some light on this issue we present an experimental comparison of collusion under price competition in duopoly markets with growing and shrinking demand. In designing the experiment we took advantage of the possibility yielded by experiments of studying the two cases completely in parallel. The evolution of demand in our growing markets is just the reverse in time than the one for the shrinking markets. Our design choices also make it

possible to completely eliminate issues related to the complexity of identifying what (perfectly) collusive behaviour consists in. As a result of these choices we have what we believe is a very clean comparison of behaviour under the two conditions.

Collusion has been one of the subjects of several experimental studies on price competition, albeit in a static demand framework. Dufwenberg and Gneezy (2000) study the effects of market concentration in a one-shot price competition framework with constant marginal cost and inelastic demand. In equilibrium prices are at the marginal costs and profits are zero, but if firms manage to establish collusion substantial profits are possible. In their experiments, price is above marginal cost for the case of two firms but equal to that cost for three and four firms.<sup>1</sup> Thus collusion is a relevant phenomenon in duopolies, but for markets with three firms or more the competitive equilibrium retains its predictive power. Apesteguía, Dufwenberg, and Selten (2003) study theoretically and experimentally how leniency programs in anti-trust influence pricing as well as the formation and detection of cartels in a simple Bertrand competition environment. The experimental results show that leniency conditions which grant whistle-blowers immunity from fines lead to lower prices than the standard anti-cartel conditions under which all firms in a detected cartel will be punished.

Selten and Apesteguía (2002) experimentally study price competition in a model of spatial competition. The authors can identify collusive behaviour in individual markets, and average prices slightly above those chosen in equilibrium. Abbink and Brandts (2003) examine an experimental design in which price competition can lead to positive equilibrium price-cost margins. Their design is based on the theoretical model by Dastidar (1995) in which there are multiple equilibria in pure strategies. Firms operate under decreasing returns to scale and have to serve the whole market. In the experimental results the collusive outcome is, though not an equilibrium, one of the most frequently observed. The result that average prices tend to decrease with the number of firms is mainly due to less collusion in larger oligopolies.

Numerous studies report results on related issues from quantity competition environments. Huck, Normann and Oechssler (1999, 2004) provide results and a recent survey of work on collusion and competition under repeated quantity competition. Their conclusion is that duopolists sometimes manage to collude, but that in markets with more than three firms collusion is difficult. With exactly three firms, Offerman, Potters, and Sonnemans (2002) observe that market outcomes depend on the information environment: Firms collude when they are provided with information on individual quantities, but not individual profits. In many instances, however, total average output even exceeds the Nash prediction.

Holt (1995) discusses some experimental research on so-called plus factors for collusion, but does not refer to any work with demand changing over time. The closest work to ours is by Davis, Harrison and Williams (1993), who compare behaviour in posted price and double

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<sup>1</sup> With duopolies, Dufwenberg, Gneezy, Goeree, and Nagel (2002) find that the introduction of price floors (the minimum feasible price is above marginal costs) lead to *lower* average prices compared to the standard Bertrand game. Thus, collusion is weakened when price floors are introduced.

auction settings with a demand that first grows and then shrinks. The demand is played by human subjects and, in the tradition of the older market experiment literature, participants only know their own parameter values. This means that sellers are not informed about demand shifts. In the analysis observed prices are compared to the Walrasian one. It turns out that double auction prices tend to be close to the Walrasian one. In contrast, the posted offer prices tend to start, when the demand grows, below the Walrasian price and drift slowly upward; when the demand then declines prices exhibit some inertia and remain high with respect to the Walrasian.

Our work is different in several ways. First, we will have complete information about market conditions, including the time-evolution of demand. This is the case the game-theoretic analysis directly pertains to and it is also the natural one in many instances. Second, we will study the case of demand growth and the one of demand decline in separate treatments. Therefore, we will not have to deal with any possible sequence effects, which are not relevant in our context. Third, we are interested in the case of an indefinite temporal relation between firms and not in the case of a fixed and known number of market rounds. In the design section we will explain how we implemented such an environment. Finally, our demand and cost conditions are extremely simple so as to be able to focus on the issue at hand.<sup>2</sup>

Our results show that, contrary to the game-theoretic intuition, collusion is significantly higher in shrinking than in growing markets. Moreover, it is for all the rounds of the experiment that average market prices for the shrinking demand case are above those for the growing demand case. Overall, prices are more than twice as high under shrinking demand conditions. We conjecture that the prospect of rapidly decreasing profits exerts a disciplining effect on decision makers in the shrinking demand environment. High profits need to be made quickly. In growing markets, on the other hand, co-operation becomes more essential in the future, such that it seems little harmful to experiment with different strategies early on. This may be illusionary, however, as erratic and competitive pricing might be interpreted as aggressive and destroy trust between the firms. This makes it then very difficult to establish trust and co-operation later when it really matters.

Though our experiment was designed with antitrust applications in mind, our results are relevant to a broader range of issues. Competition and co-operation are vital issues in the huge literature on public good and dilemma games.<sup>3</sup> Like in our framework, the stage game equilibrium and the pareto-efficient co-operative outcome are at the opposite ends of the strategy space (an important difference, though, is that there is no dominant strategy in our price competition environment). We might expect that outcomes in public good games are also sensitive to dynamics in the stakes.

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<sup>2</sup> For other experimental work with dynamic market features see the work of Isaac and Reynolds (1992a and 1992b) on R&D competition.

<sup>3</sup> See Ledyard (1995) and Camerer (2003) for surveys of public goods experiments.

## 2. Design and Procedures

The background model for both our treatments in duopolistic price competition is a homogenous good market with exogenously given demand and no costs. In each round the demand is willing to buy any amount of the good at a constant price up to a certain maximum quantity. This kind of “box” demand schedule has previously been used for the study of double auctions by Smith (1982), Holt, Langan and Villamil (1986), and more recently by Dufwenberg and Gneezy (2000) for the study of Bertrand competition. Figure 1 illustrates the demand schedule we used. The diagram depicts the case of a growing market. The demand’s willingness-to-pay is normalised to 1. The variables  $q_t$ , etc. are the quantities demanded in period  $t$ .

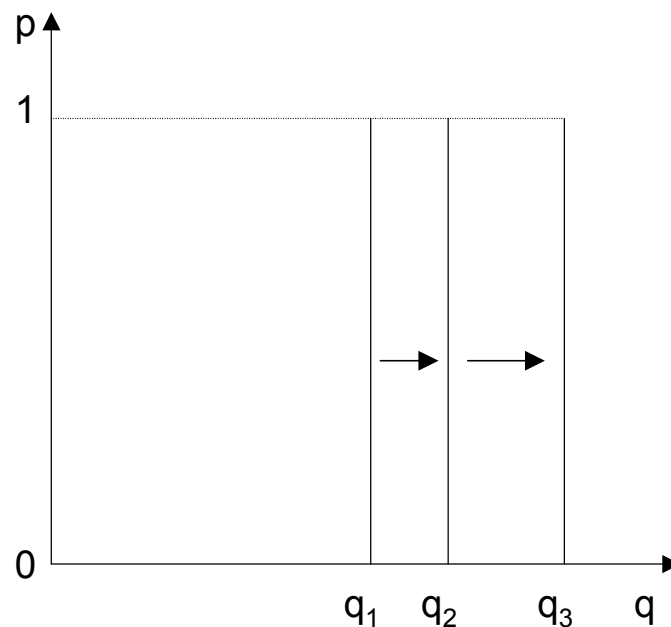


Figure 1: The Demand Schedule

### 2.1. The model and the experimental environment

In our design firms compete by simultaneously posting a price. The firm that has posted the lower price serves the entire market and realises a profit of its price times the market demand. If both firms set the same price, then it is assumed that each of the firms serves exactly half of the demand.<sup>4</sup> The strategic analysis of the stage game is straightforward and leads to the well-known Bertrand paradox (Bertrand (1883)). Whatever the price set by the competitor, each firm’s best response is to slightly undercut that price. It follows that if there is no smallest money unit, there can be no equilibrium with a positive price, and the unique equilibrium is one in which both firms set a price of zero and hence make zero profit. If a smallest money

<sup>4</sup> Alternatively, a random draw could decide which firm sells the good. This does not alter any of the theoretical arguments.

unit exists (as it typically does in both real life and experimental environments), then another equilibrium exists in which both firms set their price equal to the smallest money unit.

In the context of an infinitely repeated game the equilibrium analysis leaves us with an embarrassment of riches. If players value future payoffs sufficiently high, then virtually every distribution of profits is supported by an equilibrium of the repeated game. In this framework collusion is no longer incompatible with rational play. Firms could, for example, agree to first set always the maximum price, but punish deviations with playing the competitive equilibrium ever after. It is easy to see that such an agreement is self-enforcing. The short-term gain from undercutting the competitor once is far outweighed by the loss from being stuck in the unprofitable equilibrium forever after the cheat.

This is just one example of a retaliation strategy that triggers a collusive equilibrium. Countless others exist, many may involve less harsh retaliation. Notice that the collusive “agreements” we are talking about are only figurative. When collusion is illegal and explicit agreements subject to prosecution, such agreements need to be tacit. The question then arises as to which factors of the economic environment facilitate the emergence of collusive behaviour without explicit negotiation. A market that is characterised by strong growth, as depicted in figure 1, looks much more susceptible to the emergence of tacit agreements than a market in which demand is contracting. The reason is that in a growing market future payoffs, as compared to the current payoff, are higher than in a shrinking market. Thus, the gains from undercutting the competitor now are relatively low compared with the foregone profit that future co-operation would yield. This increases the incentives to sustain collusion, making it more likely to emerge. The experimental environment we create here allows us to put this conjecture to a test.

This environment was presented to participants in a very stylised manner. In each round there was a “prize” which, depending on the treatment, either grew or shrank over time. Subjects knew from the start the way in which the prize would change over time. In each round the two players in a match had to separately choose a percentage consisting in an integer between 0 and 100 inclusive; matches were held constant throughout the experiment. If both players chose the same percentage then each player obtained half the prize multiplied by the (common) percentage. If the chosen percentages were not the same then the player who had chosen the lower percentage obtained the prize multiplied by that percentage, while the player who had chosen the higher percentage obtained nothing. Each round took place in exactly the same way, with a new different prize per round. This way of presenting the situation to participants is simple and facilitates focusing on the evolution of demand. Note that it reflects both the case where the demanded quantity changes over time and the one where the (constant) reservation price changes. In the latter case, which is strategically equivalent, the quantity would be normalised to 1 and the demand’s willingness-to-pay would grow or shrink. We could have implemented this by asking subjects for the absolute payoff they demand, where we would have allowed a growing or shrinking upper bound. However, we

preferred the framing we used because the competitive and the collusive strategies do not change their appearance throughout the experiment. In this study, we do not focus on the question whether individuals are able to identify collusive strategies.

In the instructions (reproduced in appendix A)<sup>5</sup> participants were told that the experiment consisted of a number of rounds, but it was not specified how many.<sup>6</sup> At the time of recruitment subjects had been told that the experiment would last for about two hours so that they probably expected a good number of rounds. In both treatments we ended the experiment after 27 rounds. In this way the data from both treatments were obtained in the same ex-ante and ex-post length conditions. In the case of increasing demand the growth rate of the prize was 25% from round to round. To generate the exact reverse sequence in prizes for the 27 rounds, in the decreasing demand case prizes shrank at 20% from round to round. We chose these high rates to ensure the saliency of the variation in demand.

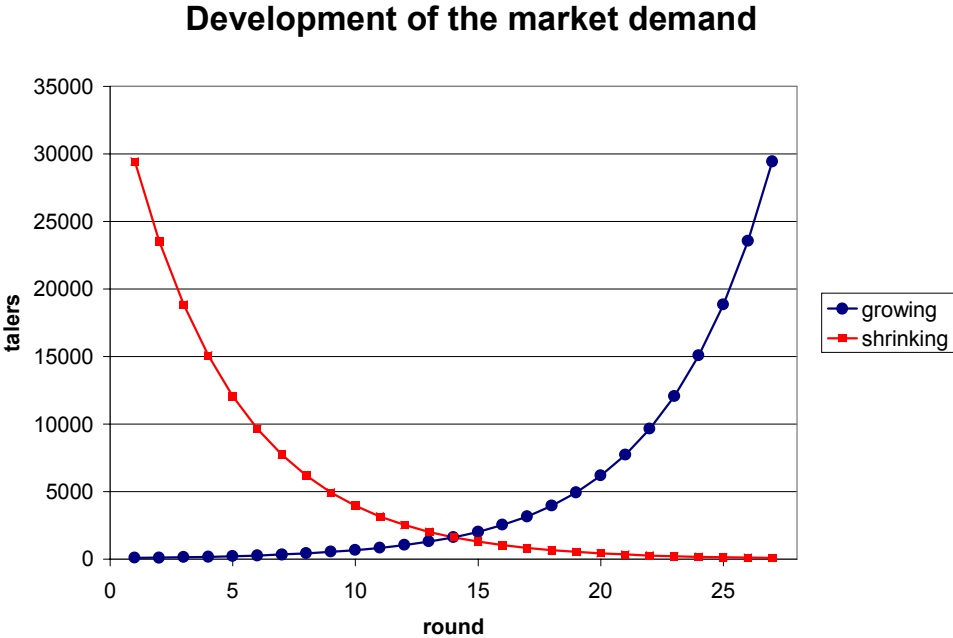


Figure 2

Figure 2 illustrates the development of the market demand (prize), denominated in the fictitious experimental currency. It can be seen that the growth rates we have chosen indeed lead to a rather extreme range of values. The instructions explained the way in which the prize would evolve over time. In addition, at the beginning of each round the prize for the next round was highlighted on the computer screen. At the end of each round participants received

<sup>5</sup> The Spanish original is available upon request.

<sup>6</sup> The data analysis does not reveal any indication of an end-game effect. Thus we are confident that subjects did not anticipate the actual number of rounds.

information about the percentage chosen by the other player in the match and about the resulting payoffs for both participants.

The number of rounds was chosen as a trade-off between two conflicting goals. On the one hand we aimed at having a large number of rounds to study collusion in a long-term relationship between two firms. On the other hand, the exponentially increasing or decreasing prizes meant that the difference between low-payoff and high-payoff rounds would quickly become very large, so large indeed that low-payoff rounds would be worth less than a cent. The choice of twenty-seven rounds balanced these two goals in a reasonable way.

## **2.2. The conduct of the experiment**

The experiment was conducted at the *Universitat Autònoma de Barcelona* (UAB), Spain. The experiment was computerised, with software developed using the *RatImage* programming package (Abbink and Sadrieh (1995)).<sup>7</sup> Subjects were recruited by posters placed all over the university campus. Each subject was allowed to participate in only one session, and no subject had participated in experiments similar to the present one. The subjects were undergraduate students from a wide range of disciplines, with slightly more women than men. Almost all participants were Catalan or Spanish.

At the beginning of a session the written instructions were read aloud. The instructions used a “neutral” language, i.e. we did not refer to “markets” or “prices” and did not explain the underlying market model. We chose this wording solely because the rules of the game seemed easier to understand this way.

After all questions were answered, the computer programme started play. At the outset of each round, participants were informed about the prize in the current round in *talers* (the fictitious experimental currency). The smallest prize was 89, exponentially increasing to (decreasing from, resp.) 29448 talers. Table 1 shows the development of the prize in the two treatments. All prizes, percentages and profits were rounded to integers for convenience.

The same subjects played in the same market throughout the session. To ensure anonymity subjects were not told with whom of the other participants they were in the same pair. The subjects were seated distantly from one another in order to ensure that they could not influence each other’s behaviour.

The total earnings of a subject from participating in this experiment were equal to the sum of all the profits he made during the experiment. A session lasted for about 45 minutes (this includes the time spent to read the instructions). At the end of the experiment, subjects were paid their total earnings anonymously in cash, at a conversion rate of one euro for 1500 talers. Subjects earned between €3.49 and €56.42 with an average of €23.44, which is considerably

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<sup>7</sup> The software was a modified version of the programme presented in Abbink and Sadrieh (1996).



more than students' regular wage in Barcelona. At the time of the experiment, the exchange rate to other major currencies was approximately US-\$1.30 and £0.70 for one euro.

**Table 1. Development of the prizes**

Round	Prize in talers (growing)	Prize in talers (shrinking)	Prize in € (growing)	Prize in € (shrinking)
1	89	29448	0.06	19.63
2	111	23558	0.07	15.71
3	139	18846	0.09	12.56
4	174	15077	0.12	10.05
5	217	12062	0.14	8.04
6	272	9649	0.18	6.43
7	340	7720	0.23	5.15
8	424	6176	0.28	4.12
9	530	4940	0.35	3.29
10	663	3952	0.44	2.63
11	829	3162	0.55	2.11
12	1036	2530	0.69	1.69
13	1295	2024	0.86	1.35
14	1619	1619	1.08	1.08
15	2024	1295	1.35	0.86
16	2530	1036	1.69	0.69
17	3162	829	2.11	0.55
18	3952	663	2.63	0.44
19	4940	530	3.29	0.35
20	6176	424	4.12	0.28
21	7720	340	5.15	0.23
22	9649	272	6.43	0.18
23	12062	217	8.04	0.14
24	15077	174	10.05	0.12
25	18846	139	12.56	0.09
26	23558	111	15.71	0.07
27	29448	89	19.63	0.06

We conducted one session with each treatment. Subjects interacted with each other within pairs but not across pairs so that each pair can be considered as a statistically independent observation. We gathered 7 independent observations with growing markets and 9 independent observations with shrinking markets. The difference in the number of observations stems from a different show-up rate in the sessions.

Our analysis consists of nonparametric tests performed on these data points. Most analyses comprise of comparisons across treatments. For these we use Fisher's two-sample randomisation test, applied to test statistics (e.g. average prices) from the independent observations.<sup>8</sup> In some occasions we also apply tests to statistics within one sample, e.g. to identify effects in the treatments separately. In this case, we use the nonparametric binomial test.

<sup>8</sup> This test can be seen as a non-parametric variant of the t-test, with which differences in the mean of two samples can be detected. For a discussion of the power of this test see Moir (1998).

**Table 2. Asking prices in the treatment with growing markets**

rd.	Market 1		Market 2		Market 3		Market 4		Market 5		Market 6		Market 7	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
1	30	50	50	5	40	20	30	50	50	80	78	45	100	10
2	25	30	1	1	19	30	15	35	30	50	11	35	100	20
3	15	10	1	4	25	10	20	75	25	20	30	25	29	100
4	20	10	1	90	15	15	45	20	5	20	10	15	100	100
5	5	20	45	1	20	15	40	15	10	50	1	12	100	100
6	5	20	1	0	20	20	5	20	30	50	13	1	100	100
7	10	20	90	1	30	25	25	1	45	30	6	5	100	100
8	10	20	1	1	30	30	50	10	30	50	2	3	100	100
9	15	10	1	1	35	35	11	15	25	70	1	1	100	100
10	5	15	1	5	40	40	5	12	50	40	4	5	100	100
11	10	15	1	5	45	45	50	6	50	50	3	2	100	100
12	15	10	4	5	50	50	15	7	50	50	1	2	100	100
13	10	15	1	5	55	55	5	8	50	60	0	2	100	100
14	10	10	1	5	60	60	15	100	40	60	3	1	100	100
15	10	10	1	1	65	65	25	50	40	60	41	2	100	100
16	5	10	10	1	70	70	10	100	35	50	29	15	100	100
17	10	5	1	10	75	75	30	45	40	50	60	20	100	100
18	5	5	1	10	80	80	15	30	50	50	100	30	100	100
19	10	4	2	10	85	85	40	90	45	50	1	30	100	100
20	5	10	8	2	90	90	45	35	45	30	1	15	100	100
21	5	50	1	8	95	95	19	70	50	40	2	1	100	100
22	20	4	1	8	99	100	35	18	50	50	1	1	100	100
23	15	20	2	1	100	100	12	17	45	50	1	1	100	100
24	10	15	1	1	99	100	20	9	45	45	1	1	100	100
25	10	4	1	1	100	99	35	10	30	50	1	1	100	100
26	5	5	1	1	99	99	35	9	50	50	1	1	100	100
27	10	5	1	1	100	99	29	19	45	50	1	1	100	100

Note: “F1” and “F2” stand for Firm 1 and Firm 2, respectively

### 3. Results

Tables 2 and 3 show the raw data of our experiment. These consist of an asking price for each subject and each of the 27 rounds of the experiment. Two adjacent columns, separated from the others by a vertical line, represent two players that were matched to the same market. The ordering of the markets as “market 1” through “market 9” is arbitrary, as well as the labelling of the firms as “firm 1” and “firm 2”. In our symmetric set-up the two firms play exactly the same role.

In this study we focus on the incidence of collusion. A natural measure of collusion is the degree to which the firms in a market are able to sustain high market prices. Thus we look at this measure first to identify which of the treatments leads to more collusion. Later, we will also look explicitly at the occurrence of perfect collusion, i.e. the co-ordinated posting of an asking price of 100.

**Table 3. Asking prices in the treatment with shrinking markets**

rd.	Market 1		Market 2		Market 3		Market 4		Market 5		Market 6		Market 7		Market 8		Market 9	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
1	30	75	80	50	100	25	50	10	50	55	100	80	30	100	80	50	50	25
2	45	20	40	50	25	80	10	26	49	50	20	100	50	50	50	50	20	25
3	20	40	40	40	50	50	10	6	45	30	100	100	50	50	50	80	25	10
4	40	60	40	40	75	50	0	5	80	29	100	100	50	50	75	70	10	25
5	45	70	50	40	50	70	30	0	80	80	100	100	50	50	70	70	100	15
6	50	50	40	50	50	45	100	20	80	80	100	100	50	50	70	75	15	15
7	60	60	50	50	40	39	30	30	80	80	100	10	50	50	75	70	20	10
8	58	70	60	80	20	70	40	35	80	80	1	100	50	50	69	75	15	50
9	70	60	80	80	15	70	20	30	80	80	100	100	50	50	70	75	20	50
10	40	65	100	80	50	64	0	30	80	80	100	100	50	50	74	70	50	50
11	50	70	100	100	55	55	30	20	80	80	100	100	50	50	69	73	50	50
12	30	60	100	100	50	60	10	15	80	80	100	100	50	50	65	69	100	100
13	60	75	100	100	48	50	10	15	80	80	100	100	50	50	65	60	100	100
14	70	75	100	100	39	47	10	5	80	80	100	100	50	50	90	64	100	100
15	75	70	100	100	34	25	5	5	80	80	100	100	50	50	90	90	100	100
16	65	70	100	100	25	23	10	20	80	80	100	100	50	50	89	95	100	100
17	70	70	100	100	100	100	20	15	80	80	100	100	50	50	90	90	100	100
18	65	70	100	100	100	100	20	10	80	80	100	100	50	50	89	95	100	100
19	65	80	100	100	100	100	5	30	80	80	100	100	50	50	95	88	100	100
20	80	80	100	100	100	100	20	25	80	80	100	100	100	50	85	95	100	100
21	90	80	100	100	100	100	20	15	80	80	100	100	100	50	90	90	100	100
22	80	90	100	100	100	100	10	15	80	80	100	100	50	100	89	95	100	100
23	90	90	100	100	100	100	10	5	80	80	100	100	100	50	90	95	100	100
24	100	100	100	100	100	100	10	5	80	80	100	100	100	100	90	89	100	100
25	100	100	100	100	100	100	5	5	80	80	100	100	100	100	85	90	100	100
26	100	100	100	100	100	100	5	5	80	80	100	100	100	100	84	90	100	100
27	90	100	100	100	100	100	5	80	80	80	100	100	100	100	90	84	100	100

Note: “F1” and “F2” stand for Firm 1 and Firm 2, respectively

### 3.1. Market prices and the occurrence of collusion

The two treatments of our experiment allow us to study the effect of the market development on collusive behaviour. In particular, we can analyse whether market prices in growing markets are, as game-theoretic reasoning would suggest, higher than in shrinking markets. Table 4 indicates that, on average, this is not the case. The table shows average market prices, i.e. the lower of chosen percentages, for the different groups over the 27 rounds of the experiment. In all following tables, the ordering of observations is as in tables 2 and 3. Indeed, the average market price is more than twice as high in shrinking as in growing markets. Fisher’s two-sample randomisation test rejects the null hypothesis of equal average prices at a one sided p-value of  $p=0.018$ .

This result appears counterintuitive, as it is the opposite of what the theoretical argument would lead us to expect. It seems that the prospect of great future profits in growing markets does not encourage collusion; on the contrary, high prices are much more common in shrinking markets, where we would expect greater incentives to realise a short-term gain by deviating from a collusive agreement. It seems that it is not the promise of growing profit

opportunities, but rather the pressure from rapidly declining profits that exerts a disciplining effect on firms. If the prize shrinks at a dramatic rate, high profits need to be made early.

**Table 4. Average market prices**

No.	growing markets	shrinking markets
1	8.96	62.52
2	1.30	82.22
3	59.04	63.30
4	15.41	10.78
5	37.22	74.00
6	6.85	89.30
7	91.07	56.67
8		75.52
9		68.15
Average	31.41	64.72

The reverse effect holds for growing markets. Since prizes are relatively small in early rounds, firms feel less pressure to co-ordinate quickly and can experiment with different strategies. We conjecture that these early deviations from collusion make it difficult to establish co-operation in later rounds, when prizes become very substantial. As a result, firms in these markets fail to co-operate and realise low prices over the entire experiment.

### 3.2. Evolution of market prices over time

We now turn our attention to the dynamic aspects of behaviour in our setting. Figure 3 shows the evolution of average prices, for each round averaged over all markets within a treatment. In both treatments the figure suggests rising prices over time, with this effect being much stronger in shrinking than in growing markets. Further, over the entire duration of play average prices are higher under shrinking than under growing demand conditions. The difference is relatively small in early rounds, but the gap widens with time.

To test for trends statistically, we use the following method. We compute, for each session separately, non-parametric Pearson correlation coefficients between the market price and the round number. Using these as summary statistics, we apply the binomial test to detect a systematic tendency to rising or falling prices. The binomial test rejects the null hypothesis at a one-sided 5% level if at least 6 out of 7 observations for growing markets and 8 out of 9 observations with shrinking markets point in the same direction. Table 5 shows the outcome of this analysis. The null hypothesis of no trend can be rejected in favour of the alternative hypothesis of increasing prices for shrinking markets, but not for growing markets.

### Average market price

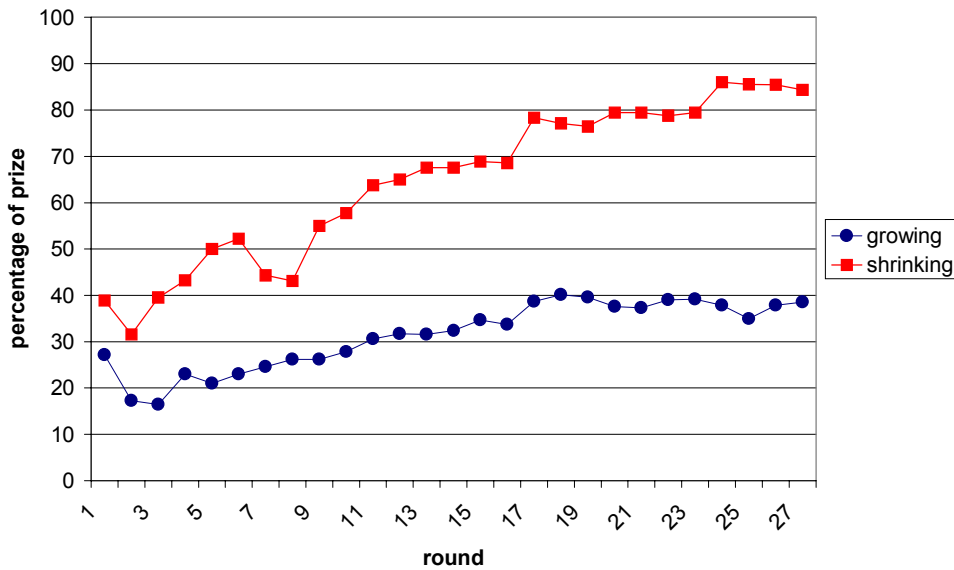


Figure 3

Table 5. Pearson correlation coefficients for market prices over time

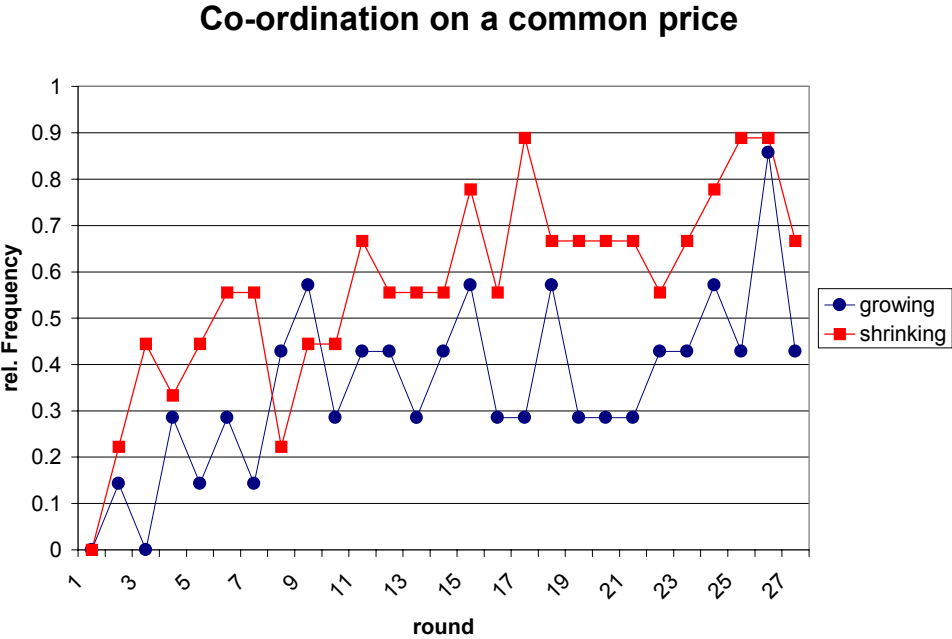
No.	growing markets	shrinking markets
1	-0.53	+0.91
2	-0.19	+0.84
3	+0.98	+0.80
4	+0.10	-0.21
5	+0.51	+0.58
6	-0.39	+0.41
7	+0.55	+0.66
8		+0.82
9		+0.86
Average	+0.15	+0.63

Visual examination of figure 3 and the distribution of Pearson correlation coefficients suggest that the upward trend in prices is much more pronounced in shrinking markets. We test this conjecture by checking whether the Pearson correlation coefficients listed in table 5 are significantly greater in the treatment with shrinking markets. If this is so, then we interpret this as evidence for a stronger tendency towards increasing prices in the shrinking market condition. Again using the coefficients as summary statistics, we apply Fisher’s two sample randomisation test to check for significance. Indeed, the test rejects the null hypothesis of equal coefficients with a one-sided p-value of  $p=0.028$ .

This result is consistent with the explanation we propose for the treatment difference in prices. Initial behaviour is relatively similar in both treatments. In fact, Fisher’s two-sample randomisation test applied to the market prices in the first round does not reject the null hypothesis of equal prices (one sided  $p=0.132$ ). Thus, the difference between the two treatments is not due to initial conditions, but to faster co-ordination in shrinking markets. This supports our conjecture that the expectation of rapidly diminishing profit opportunities disciplines firms to establish collusion quickly.

**3.3. Co-ordination on a common price**

The analysis of co-ordination provides some additional support for the above reasoning. Figure 4 shows the number of markets in which both firms submit the same price, over the 27 rounds of the experiment. Co-ordination on the same price, as typical in collusive agreements, is higher in shrinking markets than in growing ones. For most of the 27 rounds of the experiment, the frequency of co-ordinated prices in shrinking markets is above the corresponding figure for growing markets. The difference is weakly significant at  $p=0.094$  (one-sided), according to Fisher’s two-sample randomisation test.



**Figure 4**

Both growing and shrinking markets exhibit a tendency towards better co-ordination over time. In a manner analogous to our analysis of market price dynamics, we compute Pearson correlation coefficients for the co-ordination in the independent markets. In both treatments the majority of coefficients is positive. All six observations with growing markets to which

this analysis can be applied<sup>9</sup> are positive, in the shrinking markets condition this holds for seven out of nine observations. The binomial test rejects the null hypothesis that positive and negative coefficients are equally likely at a  $p=0.016$  (one-sided) for growing and a weakly significant  $p=0.090$  (one-sided) for shrinking markets.

**Table 6. Number of rounds with a market price of 100**

No.	growing markets	shrinking markets
1	0	3
2	0	17
3	1	11
4	0	0
5	0	0
6	0	23
7	24	4
8		0
9		16
Average	1.92	8.22
% of rounds	13.22%	30.44%

The high degree of co-ordination implies that firms' individual asking prices and the resulting market prices are very similar. Figure 5 shows the evolution of the average asking price, which include those demands that have not been the lowest. Naturally the average asking prices are higher than the average market prices. Besides that we can observe a picture that is very similar to that of the average market prices, as depicted in figure 3.

### 3.3. Perfect collusion

The purest form of collusion is a price set to 100 by both firms, in which case the whole prize is shared equally without deduction. Both firms then make a profit of half of the prize. This is the only way to collude in which firms extract the entire surplus from the market.<sup>10</sup> We rarely observe this type of collusion in growing markets. In only one of the seven markets firms established co-ordination on the maximum price. This is the most collusive of our experimental markets: Both firms set the maximum demand from round 4 on without any deviation. However, this market is an exception in the treatment with growing markets, as

<sup>9</sup> In one market no co-ordination was ever achieved, so a Pearson correlation coefficient cannot be computed.

<sup>10</sup> In a repeated setting, other forms of collusion are also possible. For instance, firms could agree to take turns in setting the lower price and extracting the surplus. However, the maximum feasible price is 100, thus the firm with the lower price needs to submit a price lower than 100 and thereby leave some money on the table. Apart from being inefficient, such forms of collusion are also less natural and focal than perfect collusion. So it may not be surprising that we do not observe them in the data.

table 6 shows. The table lists in how many of the 27 rounds the market price was 100, i.e. both firms had set this price.

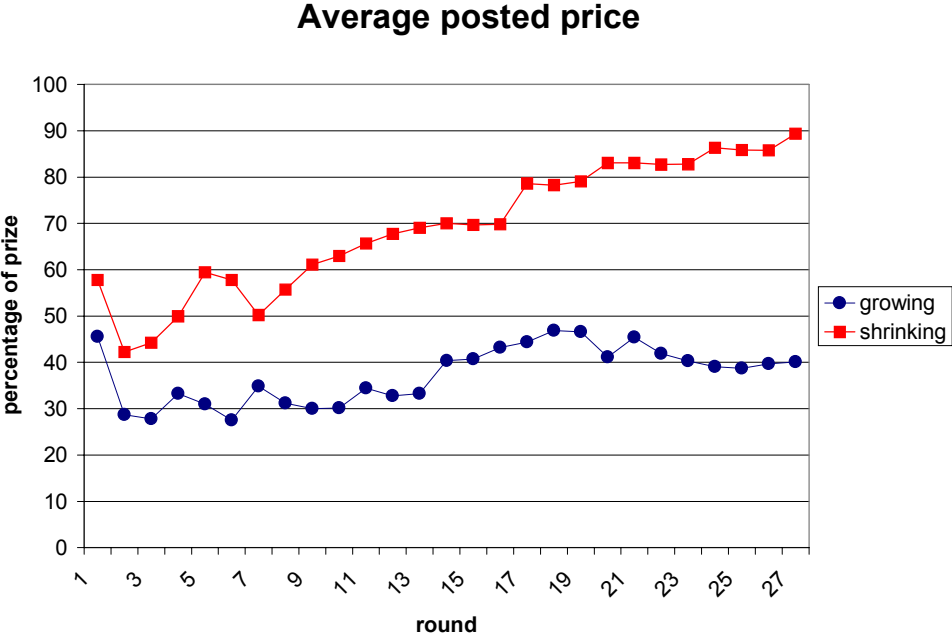


Figure 5

Figure 6 shows the evolution of perfect collusion over the 27 rounds of the experiment. In the shrinking markets condition collusion steadily increases after an initial period. Thus, the increased co-ordination observed earlier coincides with co-ordination on the maximum price. In the growing markets condition perfect collusion is almost constant over time, with one market perfectly colluding most of the time and all others virtually never.

**3.5. Average profits**

Naturally in our game, profits are directly linked to the prices set, thus we would expect firms to make higher profits in the treatment with shrinking markets. Table 9 shows that overall, this is the case. The table lists the average per firm profit in the individual markets, totalled over the 27 rounds of the experiment.

While we do observe higher profits in shrinking markets, the effect is not as pronounced as the difference in average prices would suggest. Indeed, Fisher’s two-sample randomisation test does not reject the null hypothesis of equal payoffs. The reason is that firms in shrinking markets do not benefit from the upward trend of market prices over time in the same way as firms in growing markets do. When they achieve the highest degree of co-operation, towards the end of the experiment, demand has already decreased so much that the gains from collusion do not add as much to the firms’ profits as they would do in earlier rounds.



### Markets with perfect collusion

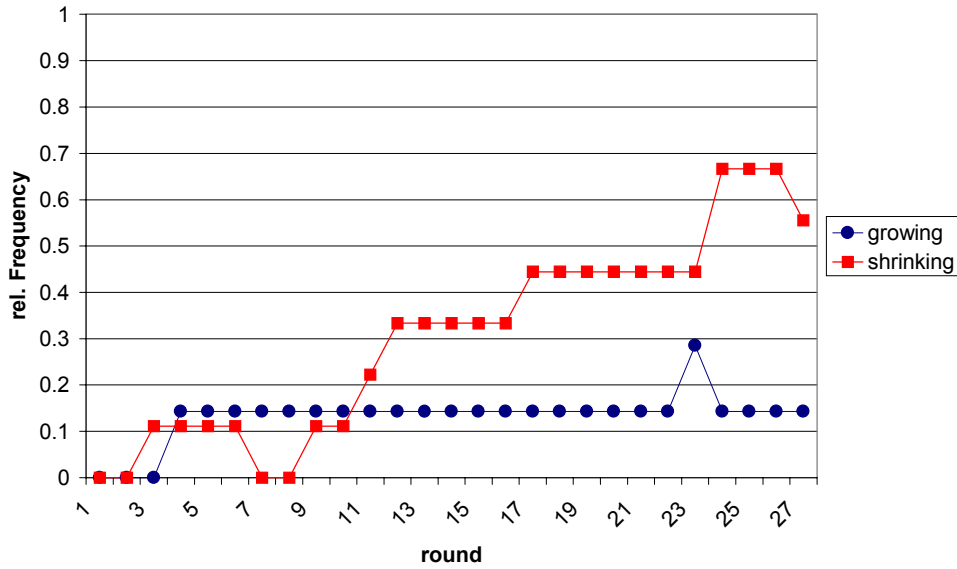


Figure 6

Table 7. Total profit per firm

No.	growing markets	shrinking markets
1	4717	27754
2	806	38267
3	68394	28253
4	11383	7790
5	31447	42128
6	1861	54542
7	73307	33904
8		44540
9		18629
Average	27416	32867

### 4. Summary and Conclusions

We report a simple experiment on collusion in duopolies. We analyse whether collusion is more likely to occur in markets with growing or in those with shrinking demand. Game-theoretic reasoning suggests that, if no entry or exit is possible, growing markets should be more prone to collusive behaviour. The intuition behind this argument is that short-term gains from deviation from the collusive agreement are small in comparison with long-term losses

from retaliation. In a shrinking market, on the other hand, future profits are relatively small, such that the short-term gains from deviating are much more attractive.

In our experiment we observe the exact opposite. Collusion is much more frequent in shrinking markets, leading to average prices that are more than twice as high as in growing markets. In shrinking markets co-ordination on the maximum price is almost three times as frequent as in growing markets. Further, we observe a strong and significant upward trend in shrinking markets that is much more pronounced than in growing ones.

We conjecture that this is due to a strong disciplining effect that is exerted by the prospect of shrinking profits. If co-operation is not achieved early, then profit opportunities melt away at a fast pace. In growing markets, however, early rounds are worth relatively little, which might tempt firms to “play around” and try out different strategies, rather than strive for the collusive outcome immediately. This behaviour can then easily be interpreted as aggressive by the competitor. This perceived aggressive behaviour may destroy trust between the firms in early rounds. Without trust co-operation is not possible. As a consequence, when the prize becomes precious in the later rounds of the experiment, collusion is difficult to establish.

The policy implications of our results are straightforward. Antitrust authorities should be advised to be particularly vigilant towards markets that are shrinking or stagnating. As our experimental results show, firms find it easier to establish collusive co-operation in those markets than in markets that are especially dynamic in their development. Our experiment exhibits a pure behavioural effect, but in real life other factors might even reinforce these tendencies. Shrinking markets are often long-established markets for product families that have passed the peak of the product cycle. Thus, firms know each other typically quite well and can anticipate each other’s behaviour better than competitors in growing markets that are newly emerging.

Of course, our experiment is not the last word in the matter. To focus on the behavioural effect we were examining, we used an extremely simplified market model, abstracting from much of the richness of real-life oligopolies. In our experiment firms sold a homogeneous good without product differentiation. Further, we abstracted from the effect that different costs structures might have on collusion. We also did not address the effect of possible entry and exit, taking the number of firms as exogenously given. In order to obtain a complete picture of collusion in dynamic markets, more research is needed that takes these issues into account. Nevertheless, we believe that our counterintuitive results are a good starting point for a comprehensive analysis.

## References

- Abbink, K., and J. Brandts (2003): "24". CeDEX Discussion Paper 2003-08, University of Nottingham.
- Abbink, K., and A. Sadrieh (1995): "RatImage – Research Assistance Toolbox for Computer-Aided Human Behaviour Experiments". SFB Discussion Paper B-354, University of Bonn.
- Abbink, K., and A. Sadrieh (1996): "RatDemo – A Ready-to-Run Experiment in 99 Program Lines". SFB Discussion Paper B-325, University of Bonn.
- Apesteuguía, J., M. Dufwenberg and R. Selten (2003): "Blowing the Whistle". BGSE Discussion Paper 9/2003, University of Bonn.
- Bertrand, J. (1883): "Théorie Mathématique de la Richesse Sociale". *Journal des Savants*, 67, 499-508.
- Camerer, C. (2003): Behavioral Game Theory: Experiments on Strategic Interaction, Princeton: Princeton University Press, 2003.
- Dastidar, K.G. (1995): "On the existence of pure strategy Bertrand equilibrium". *Economic Theory*, 5, 19-32.
- Davis, D., G. Harrison and A. Williams (1993): "The Effects of Nonstationarities on the Convergence to Competitive Equilibria". *Journal of Economic Behavior and Organization*, 22, 305-326.
- Dufwenberg, M., and U. Gneezy (2000): "Price competition and market concentration: an experimental study". *International Journal of Industrial Organization*, 18, 7-22.
- Dufwenberg, M., U. Gneezy, J. Goeree, and R. Nagel (2002): "Price Floors and Competition". Working paper, Stockholm University.
- Holt, C. (1995): "Industrial Organization: A Survey of Laboratory Research", in: J. Kagel and A. Roth (eds.), *The Handbook of Experimental Economics*, Princeton University Press, Princeton, N.J., 347-443.
- Holt, Charles A., L. Langan, and A.P. Villamil (1986): "Market Power in Oral Double Auctions". *Economic Inquiry*, 24, 107-123.
- Huck, S., H.T. Normann, and J. Oechssler (1999): "Learning in Cournot Oligopoly--An Experiment". *Economic Journal*, 109, C80-95.
- Huck, S., H.T. Normann, and J. Oechssler (2004): "Two are few and four are many: On number effects in experimental oligopolies". *Journal of Economic Behavior and Organization*, 53, 435-446.
- Isaac, R.M. and S. Reynolds (1992a): "Schumpeterian Competition in Experimental Markets". *Journal of Economic Behavior and Organization*, 17 (1992), 59-100.
- Isaac, R.M. and S. Reynolds (1992b): "Stochastic Innovation and Product Market Organization". *Economic Theory*, 2 (1992), 525-545.
- Ivaldi, M., B. Jullien, P. Seabright, and J. Tirole (2003): "The Economics of Tacit Collusion – Report for DG Competition, European Commission". IDEI Working Paper, University of Toulouse.
- Ledyard, J.H. (1995): Public Goods: A Survey of Experimental Research. In John Kagel and Alvin E. Roth (eds): *Handbook of Experimental Economics*. Princeton University Press. 111-194.
- Moir, R. (1998): "A Monte Carlo Analysis of the Fisher Randomization Technique: Reviving Randomization for Experimental Economists". *Experimental Economics*, 1, 87-100.
- Motta, M. (2004): Competition Policy. Cambridge University Press.
- Offerman, T., J. Potters and J. Sonnemans (2002): "Imitation and Belief Learning in an Oligopoly Experiment". *Review of Economic Studies* 69, 973-997.
- Selten, R., and J. Apesteuguía (2002): "Experimentally Observed Imitation and Cooperation in Price Competition on the Circle". BonnEcon Discussion Paper 19/2002, University of Bonn.
- Smith, Vernon L. (1982): "Markets as Economizers of Information: Experimental Examination of the "Hayek Hypothesis". *Economic Inquiry*, 20, 165-179.

## **Appendix A. Instructions**

### **General information**

We thank you for coming to the experiment. The purpose of this session is to study how people make decisions in a particular situation. During the session it is not permitted to talk or communicate with the other participants. If you have a question, please raise your hand and one of us will come to your desk to answer it. During the session you will earn money. At the end of the session a show-up fee of 3 euros plus the amount you will have earned during the experiment will be paid to you in cash. Payments are confidential, we will not inform any of the other participants of the amount you have earned. In the following, all amounts of money are denominated in talers, the experimental currency unit.

During the experiment you will be paired with another participant. You will be paired with the same participant throughout the experiment. You will not be informed of the identity of the person you are paired with.

The experiment consists of a number of separate rounds.

### **Prize per round**

In each round there will be a “prize”. This prize will increase (decrease) from round to round. The prize in round 1 will be 89 (29448) talers and increase (decrease) at a constant rate of 25% (20%). The prize in round 2 will be (111) 23558, in round 3 (139) 18846...At the beginning of each round you will be informed of what exactly the prize of the round is.

### **Decisions**

In each round you and the other participant that you are matched to will each separately make a decision. This decision will consist in choosing a percentage between 0 and 100. When you have decided on the percentage please enter it into the computer.

### **Earnings**

After each round, the earnings for each pair will be determined as follows. If the two percentages of the two participants in a pair are the same then each participant obtains half the prize of the round multiplied by the percentage. If the two percentages are not the same then the participant who chose the lowest percentage obtains the percentage multiplied by the prize of the round and the participant that chose the higher percentage obtains nothing in that round.

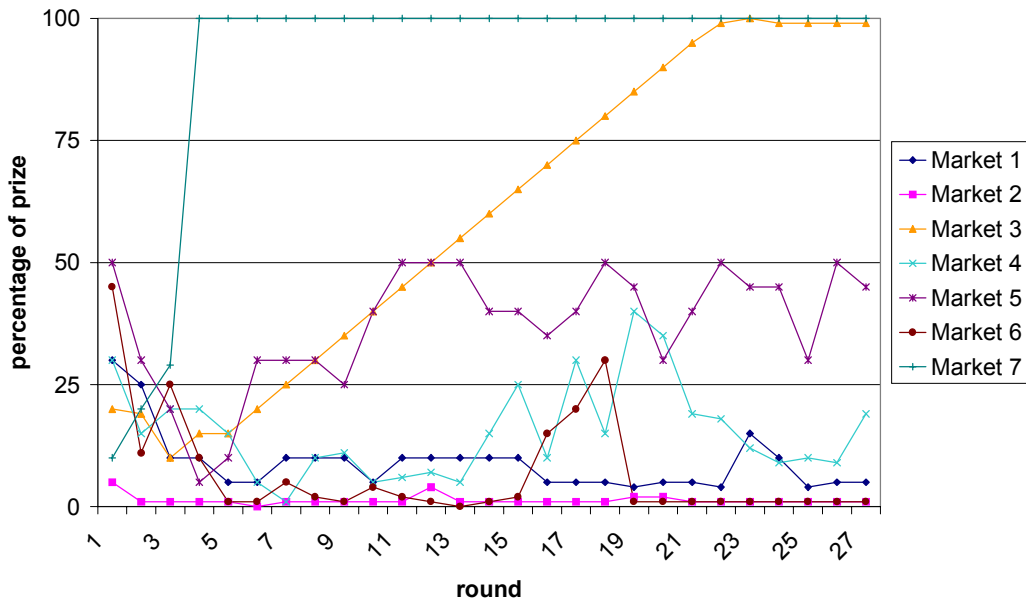
### **Information about Earnings**

After each round, your round earnings are credited to your talers account. At any moment during the experiment you will be able to check your talers account on the screen.

At the end of the experiment your total earnings in talers will be converted into Euros at the exchange rate of €1 for every 1500 talers.

## Appendix B. Prices in the individual markets

### Market prices (growing demand)



### Market prices (shrinking demand)

