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STACKELBERG BEATS COURNOT: ON COLLUSION AND EFFICIENCY IN EXPERIMENTAL MARKETS*

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We report on an experiment designed to compare Stackelberg and Cournot duopoly markets with quantity competition. We implement both a random matching and a fixed-pairs version for each market. Stackelberg markets yield, regardless of the matching scheme, higher outputs than Cournot markets and, thus, higher efficiency. For Cournot markets, we replicate a pattern known from previous experiments. There is stable equilibrium play under random matching and partial collusion under fixed pairs. We also find, for Stackelberg markets, that competition becomes less intense when firms remain in pairs but we find considerable deviations from the subgame perfect equilibrium prediction which can be attributed to an aversion to disadvantageous inequality.

The von Stackelberg (1934) model is among the most frequently applied models of oligopolistic interaction. In duopoly, it refers to a situation in which one firm, the Stackelberg leader, can commit to its output first.[1] The second mover, the Stackelberg follower, produces its quantity knowing the output of the Stackelberg leader.[2] Actual markets may indeed exhibit such a sequential order of moves. Incumbency, sequential entry, R&D races – all these phenomena can, although in a simple fashion, be captured by the Stackelberg model.

An important implication of the Stackelberg model is that it improves market efficiency.[3] Daughety (1990) considers a parameterised class of Stackelberg markets and shows that all sequential-move structures are beneficial compared to the simultaneous-move Cournot markets. The intuition for this result is simple. Switching from a Cournot to a Stackelberg market and holding the number of firms constant[4] increases aggregate output. While there is a loss in total profits, the gain in customers' surplus more than compensates for this loss, so that total welfare increases. Concentration measures (like the

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[1] Note that a sequential order of moves is today's interpretation of Stackelberg's model. Stackelberg's original idea was a behavioural difference between the firms. The Stackelberg follower is a firm which reacts according to the Cournot best-reply logic. The Stackelberg leader realises this and takes advantage of the adaptive behaviour of the follower; see von Stackelberg (1934, pp. 16–24).

[2] In most models (and in our experiment), the order of moves is exogenously fixed. Recently, however, there has been some interest in the literature in investigating the conditions under which a sequential move Stackelberg game results *endogenously*. See Robson (1990) and Hamilton and Slutsky (1990). A recent paper by van Damme and Hurkens (1999) contains further references. For experimental evidence, see our companion paper (Huck *et al.*, 2001).

[3] To be technically precise, this claim requires that outputs are strategic substitutes.

[4] Daughety (1990) analyses a generalised n-firm Stackelberg oligopoly with $m \leq n$ Stackelberg leaders and $n - m$ Stackelberg followers.

Herfindahl index) increase in the Stackelberg case due to the asymmetry, but it is precisely the sequentiality of moves that leads to the increase in welfare.

The purpose of our paper is to explore the basic consequences of a Stackelberg structure in an experimental market. While there are many Cournot experiments, to our knowledge, a sequential move Stackelberg game has not yet been analysed. Our special interest is directed to the question of whether observed efficiency relations resemble the theoretically predicted ones. Therefore, we analyse both Stackelberg and Cournot duopolies, and we have two treatments: In the first, subjects are randomly matched in every period such that interaction is one-shot. In the second, pairs of subjects play together for the entire course of the experiment such that repeated-game effects can arise.

In Cournot duopolies, experimental results confirm the theory very well, though this depends on the matching scheme. Generally speaking, most papers with random matching – see, for example, Holt (1985) – report convergence to the Cournot–Nash equilibrium. Holt observes no successful collusion in a ten-period Cournot duopoly market with random matching. He observes, instead, that most choices coincide with the quantity predicted by the Nash equilibrium. This is in contrast to Holt's findings for repeated Cournot settings with fixed pairs of participants where play often converges to the collusive outcome.[5]

Our results fully confirm these experimental findings in Cournot markets. Concerning the Stackelberg markets, we find that the level of output increases. Stackelberg markets yield higher outputs, higher consumer rents and higher welfare levels than Cournot markets, regardless of whether subjects are randomly matched or play in fixed pairs. Under random matching, Stackelberg markets yield total quantities which are even higher than theoretically expected, while Cournot markets match the theoretical predictions very accurately. Under fixed pairs, aggregate output is lower than under random matching. This holds for both Cournot and Stackelberg markets, but there is much less collusion in Stackelberg markets and, hence, they again yield higher efficiency. Nevertheless, we find considerable deviations from the subgame perfect equilibrium predicion in Stackelberg markets. In the case of followers, these deviations are accurately predicted by Fehr and Schmidt's (1999) model of inequality aversion.

The remainder of the paper is organised as follows: Section 1 introduces the markets which are explored and presents both the basic experimental design and the theoretical predictions. Section 2 describes the experimental procedures, and Section 3 presents the experimental results. Section 4 focuses on Stackelberg markets and discusses the behaviour of followers in more detail. Section 5 concludes.

[5] There are many more papers on Cournot duopoly, but there are only few experiments with more than two firms. Fouraker and Siegel (1963) ran tripoly experiments. Recently, Rassenti *et al.* (2000), Huck *et al.* (1999) and Offerman *et al.* (1997) conducted Cournot oligopoly experiments with more than three firms.

1. Markets, Treatments and Predictions

In a series of experiments, we study two homogeneous duopoly markets with quantity competition, the Stackelberg and the Cournot duopolies. In both markets, the two firms, firm 1 and firm 2, face linear inverse demand

$$p(Q) = \max\{30 - Q, 0\} \qquad Q = q_1 + q_2 \tag{1}$$

while linear costs are given by

$$C_i(q_i) = 6q_i \qquad i = 1, 2. \tag{2}$$

The two markets differ in the timing of decisions. In the Cournot market, firms decide simultaneously. Nash equilibrium play imples $q_i^C = 8$, $i = 1, 2$. In the Stackelberg market firms choose their quantities sequentially. First, the Stackelberg leader (L) decides on its quantity q^L, then – knowing q^L – the Stackelberg follower (F) decides on its quantity q^F. The subgame perfect equilibrium (SPE) solution is given by $q^L = 12$ and the follower's best-reply function $q^F(q^L) = 12 - (q^L/2)$ yielding $q^F = 6$ in equilibrium.[6]

Joint-profit maximisation implies, regardless of the timing, an aggregate output of $Q^J = 12$. On a symmetric Cournot market, one would expect – if collusion is observed at all – to observe the symmetric joint profit maximising outputs $q_i^J = 6$, $i = 1, 2$. An overview over all relevant predictions concerning quantities, consumers' surplus and total welfare is given in Table 1.

As mentioned, we study random matching as well as fixed pairs. This creates a 2 × 2-design as shown in Table 2. We explore Stackelberg and Cournot markets – each under both matching schemes. As the number of participating subjects shown in Table 2 indicates, the Cournot markets serve mainly as a control treatment while our main focus is on the Stackelberg markets.

The above Nash equilibrium solution for the Cournot market and the subgame perfect solution for the Stackelberg market apply – from a game-theoretic point of view – to a situation where these games are played only once. Hence, these are the predictions for sessions in which we matched

Table 1

Theoretical Predictions

	Cournot	Stackelberg	Collusion
Individual quantities	$q_i^C = 8$	$q^L = 12$; $q^F = 6$	$(q_i^J = 6)_{sym}$
Total quantities	$Q^C = 16$	$Q^S = 18$	$Q^J = 12$
Profits	$\Pi_i^C = 64$	$\Pi^L = 72$; $\Pi^F = 36$	$(\Pi_i^J = 72)_{sym}$
Consumers' surplus	$CS^C = 128$	$CS^S = 162$	$CS^J = 72$
Total welfare	$TW^C = 256$	$TW^S = 270$	$TW^J = 216$

[6] As pointed out by Bagwell (1995), the theoretical prediction of the Stackelberg outcome crucially depends on the perfect observability of the Stackelberg leader's action. For experimental evidence on this point, see Huck and Müller (2000).

Table 2

The 2 by 2 Factorial Design of Markets and Matching Procedures and the Numbers of Subjects Participating in the Four Treatments

	Random matching	Fixed matching
Stackelberg	*STACKRAND* (44 = 24 + 20)	*STACKFIX* (48 = 18 + 14 + 16)
Cournot	*COURRAND* (20)	*COURFIX* (22)

subjects randomly. Our matching scheme ensured that no subject would meet any other subject twice. The participants were informed about this in the instructions. They were also informed about the exact number of repetitions. With random matching, no rational punishments, nor any other form of repeated interaction, was possible.

When fixed pairs of subjects interact over several rounds, collusion may arise. Theory requires an indefinite horizon to make collusion possible. In experiments, this theoretical requirement is often met by using a random stopping rule for the termination of the experiment. However, as, for example, Selten *et al.* (1997) point out, this can be problematic since an indefinite horizon cannot credibly be implemented in the lab. Moreover, in experimental markets with fixed pairs, collusive play is quite frequently observed even with a fixed horizon and is typically maintained until the second last period; see, for example, Selten and Stoecker (1983). Accordingly, we preferred a commonly known finite horizon for both matching schemes.

2. Methods and Procedures

The experiments reported here were conducted at Humboldt University in June and July 1998. One hundred and thirty-four subjects participated in seven sessions altogether. They were students from various fields, mainly students of economics, business administration and law. Subjects were either randomly recruited from a pool of potential participants or invited to participate by leaflets distributed around the university campus.

The experiments were run in large lecture rooms with pen and paper. Subjects were seated with enough space between them to prevent communication. After having read the instructions, participants were allowed to ask the experimenters questions privately. In the Stackelberg treatments, player roles were randomly assigned to subjects and were kept constant during the whole session. All sessions consisted of ten rounds with individual feedback between rounds. Sessions lasted between 60 and 75 minutes. Subjects' average earnings were DM 15.67 (including a flat payment of DM 5) which was about $9 at the time of the experiment.

In the instructions (see Appendix A) subjects were told that they were to act as a firm which, together with another firm, produces one and the same product and that, in each round, both have to decide which quantity to produce. Depending on whether subjects were in a *FIX* treatment or in a *RAND* treatment, they were informed about the kind of matching as explained above.

Participants were given a payoff table (see Appendix B) in which all possible combinations of quantity choices and the corresponding profits were shown. The numbers given in the pay-off table were measured in a fictitious currency unit called a 'Taler'. Each firm could choose a quantity from the set $\{3, 4, \ldots, 15\}$. The pay-off table was generated according to the demand and cost functions given in (1) and (2). Notice that, especially around the Cournot equilibrium, the pay-off function is rather flat. Although this is a common feature of Cournot oligopoly experiments – see, for example, Fouraker and Siegel (1963) or Holt (1985) – this is a potential pitfall of the design. However, in the baseline treatment, subjects converged to playing Cournot almost instantaneously – relieving us from such worries.

Due to the discreteness of the strategy space, such a pay-off table typically induces multiple equilibria (Holt, 1985). To avoid this, the bi-matrix representing the pay-off table was slighty manipulated. By subtracting one Taler in 14 of the 169 entries, we could ensure uniqueness of both the Cournot–Nash equilibrium and the subgame perfect Stackelberg equilibrium as given in Table 1.

Subjects were informed that, at the end of the experiment, two of the ten rounds would be randomly selected to determine the actual monetary profit in German marks. The latter was computed by using an exchange rate from 10:1. Further, we added a flat payment of DM 5 since subjects could have made losses in the game. Before the first round started, subjects were asked to answer a control question (which was checked) to make sure that everybody fully understood the pay-off table.

For the Stackelberg treatments, the firms were labelled A (Stackelberg leader) and B (Stackelberg follower). In each of the ten rounds, the Stackelberg leaders received a decision sheet on which they had to note their code number and their decision by entering one of the possible quantities in a box. These sheets were then passed on to the subjects acting as followers. Subjects were not able to observe how the Stackelberg leaders' decision sheets were allocated to the followers. After collecting the sheets from the Stackelberg leaders, one experimenter left the room to bring the sheets in the final order.

Followers had to enter their code number, too, and then made their decision on the same sheet. In doing so, they immediately had complete information about what happened in the course of the actual round. Afterwards, the sheets were collected and passed back to the Stackelberg leaders who now were also informed about this round's play. Again, one of the experimenters left the room with the decision sheets. After collecting the sheets again, the next round started.

No labels were assigned to firms for the Cournot markets. The instructions simply used the words 'you' and the 'other firm'. In each of the ten rounds, all subjects received a perforated two-part decision sheet on which they twice had to enter their code number and their decision. Afterwards the two parts of the sheet were separated: one part was collected by the experimenters; the other part was kept by the subjects. The parts of the decision sheets collected by the experimenter were then (according to the matching scheme of the session) passed on to the respective subjects. Thus, all subjects immediately had full information about what happened in this round. The next round started after all sheets were collected.

3. Experimental Results

We focus on four key questions:

1 Do we replicate earlier results on experimental Cournot duopolies, i.e., static Nash equilibrium play for random matching and partial collusion for fixed pairs?
2 Will there be a similar pattern in Stackelberg games, i.e., static subgame perfect equilibrium play with random matching and partial collusion with fixed pairs?
3 Will Stackelberg markets yield higher outputs at smaller prices than Cournot markets, thus increasing total welfare?
4 How will behaviour change over time?

Table 3 provides essential summary statistics at an aggregate level for all treatments. More detailed information is given in Tables 4 and 5. Table 4 shows, for each round, mean individual quantities and mean industry outputs while Table 5 shows the distribution of individual quantities aggregated over all ten rounds and, in parentheses, the distribution for round 9 only.

Table 3
Aggregate Data (Averages). Standard deviations in parentheses.

	STACKRAND	*STACKFIX*	*COURRAND*	*COURFIX*
Individual quantity	10.19/8.32	9.13/7.92	8.07	7.64
	(2.45/2.07)	(2.67/2.00)	(1.60)	(2.04)
Total quantity	18.51	17.05	16.14	15.27
	(2.86)	(3.67)	(3.21)	(4.08)
Total profits	93.48	105.01	116.60	116.73
	(45.59)	(45.99)	(36.02)	(42.87)
Consumers' surplus	175.37	152.14	135.38	124.91
	(56.70)	(66.12)	(55.04)	(68.74)
Total welfare	268.85	257.16	251.98	241.64
	(13.51)	(23.96)	(24.28)	(31.39)

(Note that, for the Cournot markets under random matching, average profit and surplus depend on the actual matching.)

Table 4

Summary of Experimental Results: Means of Individual and Total Quantities per Round (Standard deviations in parentheses)

Round	*STACKRAND* q^L	*STACKRAND* q^F	*STACKRAND* Q	*STACKFIX* q^L	*STACKFIX* q^F	*STACKFIX* Q	*COURRAND* q	*COURRAND* Q	*COURFIX* q	*COURFIX* Q
1st	10.09	8.27	18.36	8.83	8.04	16.88	8.25	16.5	7.91	15.81
	(2.69)	(2.37)	(2.82)	(2.73)	(2.05)	(3.43)	(1.83)	(2.88)	(2.14)	(3.25)
2nd	9.36	8.27	17.64	10.12	8.29	18.42	7.65	15.3	8.27	16.54
	(2.79)	(1.78)	(2.68)	(2.29)	(1.97)	(3.06)	(2.23)	(2.79)	(2.05)	(3.62)
3rd	10.68	8.05	18.73	9.88	8.42	18.29	8.35	16.7	7.27	14.54
	(2.59)	(2.01)	(2.98)	(2.66)	(2.26)	(4.10)	(1.69)	(2.50)	(2.29)	(4.44)
4th	10.23	8.32	18.54	9.17	7.88	17.04	7.85	15.7	8.14	16.27
	(2.84)	(2.23)	(2.99)	(2.48)	(1.70)	(3.33)	(1.79)	(2.26)	(2.51)	(4.13)
5th	11.36	8.41	19.77	9.38	7.83	17.21	8.3	16.6	7.41	14.82
	(1.79)	(2.24)	(2.49)	(3.09)	(2.43)	(4.24)	(1.56)	(1.78)	(2.22)	(2.79)
6th	9.86	8.27	18.14	9.79	8.00	17.79	8.1	16.2	7.86	15.72
	(2.61)	(2.21)	(3.24)	(2.65)	(2.41)	(3.90)	(1.29)	(1.87)	(2.19)	(3.93)
7th	10.36	7.64	18.00	8.67	8.08	16.75	8.25	16.5	7.14	14.27
	(2.04)	(1.65)	(2.18)	(2.60)	(2.06)	(3.66)	(1.68)	(2.72)	(1.83)	(2.83)
8th	10.09	8.77	18.86	8.38	7.62	16.00	8.05	16.1	7.09	14.18
	(2.54)	(2.47)	(3.33)	(2.48)	(2.04)	(3.80)	(1.54)	(2.33)	(1.66)	(2.52)
9th	10.09	8.89	18.91	8.50	7.38	15.88	7.85	15.7	7.55	15.09
	(1.93)	(2.32)	(3.22)	(2.84)	(1.58)	(3.81)	(1.18)	(1.42)	(1.92)	(3.05)
10th	9.77	8.36	18.14	8.62	7.67	16.29	8.05	16.1	7.73	15.45
	(2.39)	(1.29)	(2.47)	(2.63)	(1.4)	(2.85)	(1.19)	(1.29)	(1.39)	(2.07)
Mean	10.19	8.32	18.51	9.13	7.92	17.06	8.07	16.14	7.64	15.27

Table 5

Distributions of Quantities (results of the ninth round in parentheses)

Quantity	*STACKRAND* Leader	*STACKRAND* Follower	*STACKFIX* Leader	*STACKFIX* Follower	*COURRAND*	*COURFIX*
3	1.8 (0.0)	0.0 (0.0)	1.3 (0.0)	0.8 (0.0)	1.0 (0.0)	1.4 (0.0)
4	1.4 (0.0)	0.5 (0.0)	0.4 (0.0)	0.8 (0.0)	0.0 (0.0)	0.5 (0.0)
5	0.5 (0.0)	5.5 (4.5)	0.0 (0.0)	2.5 (4.2)	0.5 (0.0)	0.9 (0.0)
6	2.3 (0.0)	13.2 (9.1)	20.8 (33.3)	23.8 (33.3)	12.0 (5.0)	41.8 (50.0)
7	4.1 (4.5)	16.8 (9.1)	7.9 (16.7)	17.1 (20.8)	21.5 (30.0)	8.6 (4.5)
8	17.3 (22.7)	27.7 (36.4)	18.8 (12.5)	24.2 (25.0)	35.5 (55.0)	19.5 (18.2)
9	10.5 (9.1)	5.5 (4.5)	7.1 (8.3)	11.7 (0.0)	14.5 (5.0)	6.8 (13.6)
10	14.5 (27.3)	17.7 (18.2)	12.5 (8.3)	7.9 (12.5)	5.5 (0.0)	6.8 (0.0)
11	8.6 (13.6)	7.7 (9.1)	3.3 (0.0)	5.4 (4.2)	5.0 (0.0)	9.1 (9.1)
12	27.3 (13.6)	2.3 (0.0)	19.6 (12.5)	2.9 (0.0)	4.0 (5.0)	3.6 (4.5)
13	4.1 (0.0)	0.9 (4.5)	2.1 (0.0)	1.7 (0.0)	0.5 (0.0)	0.5 (0.0)
14	5.5 (9.1)	0.5 (0.0)	3.8 (0.0)	0.8 (0.0)	0.0 (0.0)	0.5 (0.0)
15	2.3 (0.0)	1.8 (4.5)	2.5 (8.3)	0.4 (0.0)	0.0 (0.0)	0.0 (0.0)

In the following, we will typically either work with average data (taking into account that many observations are not independent of one another) or with data from round 9 when subjects have gathered a lot of experience. Like Fouraker and Siegel (1963) and Holt (1985), we prefer the second last round to the last one due to possible (and actual) end-game effects. From Table 3, it can be seen that the following relation between the four treatments holds:

$$Q^{STACK\ RAND} > Q^{STACK\ FIX} > Q^{COUR\ RAND} > Q^{COUR\ FIX} \tag{3}$$

This implies that the same relation holds for welfare levels. While this already provides a partial answer to one of our research questions, let us proceed step by step.

Question 1. Do we replicate the basic results on Cournot duopolies in our experiment? The answer is yes, we do. Under random matching, quantites are, right from the start and up to the end, very close to 8 (see Tables 4 and 5). In contrast, average quantities under the fixed-pairs treatment are usually below 8 and the modal choice is the collusive quantity 6. Over all rounds, the collusive action is chosen in more than 40% of all instances and, in round 9, half the decisions are collusive. Comparing collusion rates (defined by the number of successfully colluding pairs) shows that there is a highly significant difference between the two matching schemes ($p = 0.015$ in round 9, one-sided Mann–Whitney-U test). Overall the results are virtually the same as given by Holt (1985).

Dealing with the Cournot data, also provides a first answer to Question 4 concerning behaviour over time. As we have already pointed out, this is very stable under random matching. On the other hand, we find with fixed pairs a slow and slight downward trend in quantities and also a clear end effect with average quantities rising and collusion rates dropping.

We summarise these observations in Result 1:

RESULT 1. *Behaviour in Cournot markets depends crucially on the matching scheme. As in earlier studies, we find stable equilibrium play under random matching and partial collusion with fixed pairs. However, collusion often breaks down in the last round.*

Question 2. Can we find a similar pattern in the Stackelberg data? The answer to this question is both yes and no. It is no for the SPE prediction for random matching. Tables 3 and 4 show that average quantities chosen by the Stackelberg leaders are clearly different from the SPE prediction. Over all rounds, they produce on average nearly two units less than predicted and there is no trend towards the subgame perfect equilibrium. We will provide an explanation for this behaviour in section 4.

Before comparing the random matching data with the fixed-pairs data, it is wouthwhile having a look at Table 5 which shows three important things. First, behaviour is quite dispersed and a closer analysis easily shows that it varies considerably among Stackelberg leaders and among followers. Second, although Stackelberg leaders' average quantity is smaller than predicted by the subgame perfect equilibrium ($q^L = 12$), the mode of the Stackelberg leaders' choices over all rounds is given by it. However, this no longer holds for more experienced Stackelberg leaders, a fact which will also be addressed in section 4. Third, there were hardly any attempts to collude.

The last two observations are crucial for the comparison with the fixed-pairs treatment where the pattern is roughly the reverse. There are many attempts to collude[7] and choices in line with the SPE are not the mode. These are two reasons why one part of the answer to Question 2 is yes. Another reason is that average total quantities are 1.5 units smaller when pairs are fixed (see again Table 3). Looking at separate rounds, this difference is also highly significant (e.g., round 9, $p = 0.004$). As in Cournot markets, competition becomes significantly less intense when subjects interact in pairs.

We summarise by

RESULT 2. *In Stackelberg markets under random matching, in contrast to Cournot markets, behaviour does not settle down at the theoretical prediction. Instead, behaviour of Stackelberg leaders appears as a compromise between the SPE and the symmetric Cournot equilibrium predicition while Stackelberg followers produce, on average, about one unit more than predicted by the best-reply function. However, as in Cournot markets, behaviour in Stackelberg markets becomes considerably less competitive when pairs are fixed.*

Question 3. We asked whether Stackelberg markets in an experiment exhibit the same welfare advantage over Cournot markets they exhibit in theory. The answer is, yes, they do. The difference in average total output is nearly 2.5 units under random matching and roughly 1.5 units under fixed pairs. Total welfare increases from 254.74 to 268.85 under random matching and from 244.55 to 257.16 when pairs are fixed. This can also be statistically validated. For the fixed-pairs treatment we can compare average welfare levels by taking each pair as one observation. Here, the significance level is $p = 0.053$ (one-sided MWU test). This procedure cannot be applied for the random-matching data as the average observations based on pairs are not independent. However, we can do comparisons between *STACKRAND* and *COURRAND* by analysing each round separately and, in fact, in nearly all rounds, the significance levels are below 5%.[8] Moreover, Stackelberg markets, even under a fixed-pair matching scheme, yield higher total outputs than Cournot markets do in theory (and in the lab).

Thus, we have

RESULT 3. *Stackelberg markets yield higher welfare than Cournot markets. This is independent of the matching scheme.*

Question 4. To conclude this section, we answer the last question concerning the behaviour over time in our experiment. First of all, inspection of Table 4 reveals that first round behaviour is already rather sophisticated and that the relations given in (3) hold. Besides that, virtually all decisions in all rounds of all treatments are rationalisable: In *COURRAND*, for example, only 5.5% of all choices are a never-best reply. This indicates that subjects must have understood the rules of the game pretty well from the very beginning.

[7] Again, a comparison of the collusion rates in the two Stackelberg treatments shows that there is a significant difference ($p = 0.045$ in round 9).

[8] The p-values are: 0.059; 0.026; 0.032; 0.006; 0.000; 0.055; 0.102; 0.006; 0.000; 0.005 (all with one-sided MWU).

Moreover, the data show that there is not much learning going on in markets with random matching; behaviour in these markets is fairly stable over the rounds. In markets with fixed matching, however, we observe that quantities decrease slightly over time, especially in *COURFIX*. This is due to the increasing number of successfully colluding pairs. However, in this treatment, where collusion works best, there is a noticable end-game effect.

RESULT 4. *Whereas behaviour in random matching markets is quite constant over time, with fixed matching, we observe decreasing total quantities over rounds in markets.*

4. A Closer Look at What Drives Behaviour

Regardless of the matching scheme, behaviour in Stackelberg markets does not settle down at the theoretical prediction. So, while the theory does well in predicting overall differences between the two market forms, it fails in predicting the individual quantity choices of firms in Stackelberg markets. How can this be explained?

Let us first analyse the follower data more thoroughly. Followers who aim at profit maximisation (which is assumed in the derivation of the subgame perfect equilibrium prediction) are supposed to produce

$$q^{\mathrm{F}} = 12 - 0.5q^{\mathrm{L}}$$

the standard best reply.[9]

We estimate Stackelberg followers' actual response functions, $q^F = \gamma_0 + \gamma_1 q^L$, for the two different treatments by linear regressions, including intercept and slope dummy variables for subjects and rounds. We coded the

Table 6
Estimated Response Functions in the Stackelberg Markets. Standard deviation in parentheses.

Estimating equation: $q^F = \gamma_0 + \gamma_1 q^L$	γ_0	γ_1	R^2
STACKRAND	10.275	−0.178	0.636
	(0.533)	(0.051)	
STACKFIX	6.690	0.176	0.62
	(0.637)	(0.063)	

[9] A linear regression estimation of the best-reply function for the discretised game yields $q^{\mathrm{F}} = 12.1 - 0.49q^{\mathrm{L}}$.

dummy variables such that, both the estimated intercepts γ_0 and the estimated slopes γ_1 shown in Table 6 represent actual averages.[10]

Several observations are in order.

- Under *random matching*, the followers' empirical response function is much flatter than predicted. Intercept and slope are significantly different from zero and from the theoretical predictions. The function intersects with the rational resonse function at $q^L = 5.4$ implying that, from the collusive quantity of 6 upwards, followers produce, on average, more than theoretically predicted. The profit-maximising Stackelberg leader quantity against the estimated response function would be $q^L = 8.3$.
- Under *fixed pairs*, the followers' response function is *upward* sloping. Intercept and slope are both significantly different from zero and from the theoretical predictions. The function intersects with the rational response function at $q^L = 7.9$ implying that followers react to Cournot with Cournot, produce more above and less below. The profit-maxmising Stackelberg leader quantity would be $q^L = 7.4$.

Follower behaviour appears generally more 'aggressive' under random matching, and it resembles a reward-for-cooperation and punishment-for-exploitation scheme under fixed pairs. This suggest that followers might be averse to disadvantageous inequality. In a recent well-received study, Fehr and Schmidt (1999, henceforth F&S) have shown that a model incorporating inequality aversion predicts laboratory data across a wide range of games amazingly well; see Bolton and Ockenfels (2000) for a similar approach. For the case of two players, an agent's utility function is given by

$$U_i(\pi_i, \pi_j) = \pi_i - \alpha_i \max\{\pi_j - \pi_i, 0\} - \beta_i \max\{\pi_i - \pi_j, 0\}$$

where $i = 1, 2$; $i \neq j$ and π_i denotes agent i's material pay-off. Furthermore, F&S assume that the inequality-aversion parameters α_i, β_i satisfy $\beta_i \leqslant \alpha_i$ and $0 \leqslant \beta_i < 1$. Analysing ultimatum bargaining data across several studies, they estimate a stylised distribution of α-, β-types and then show that this distribution predicts behaviour well in a variety of other games.

Without specifying a distribution of α, β-types, F&S's model makes the following two equilibrium predictions for Stackelberg markets.

(*i*) A follower chooses a quantity in the interval ranging from the Stackelberg leader's quantity to the best response against the Stackelberg leader's quantity.[11]

[10] We restrict the sum of the dummy coefficients to equal zero. See Suits (1984) for the use of restricted least squares models in general and Königstein (2000) for their particular importance in experimental economics.

[11] Suppose, for example, the leader chooses 10. The profit-maximising quantity of the follower is 7. Choosing less would not only imply that his absolute pay-off decreases but also that the (disadvantageous) inequality increases. By choosing a quantity above 7, the follower can reduce the resulting inequality at the price of receiving a lower absolute pay-off, which might be rational if α is sufficiently large. By producing the same quatity as the Stackelberg leader, the follower can reduce inequality to zero. Going beyond this cannot be rational as now the loss in absolute pay-off is accompanied by advantageous inequality.

(*ii*) A Stackelberg leader chooses a quantity in the range from the Stackelberg-leader quantity to the collusive quantity.[12]

Notice that (*i*) implies that followers react to Cournot with Cournot and that it does not rule out (average) reaction functions being upward sloping.

To analyse more thoroughly whether our Stackelberg data is in line with F&S, we first compute for each follower decision a value of either α or β.[13] Table 7 compares F&S's stylised distributions of α- and β-types, which have only four and three mass points respectively,[14] with our empirical cumulative distributions observed at these mass points.[15] Inspecting Table 7, we make the following two observations. First, both our distributions of α-types match the F&S distribution remarkably well. Only at $\alpha = 1$ do we find lower values, i.e., in our sample, there are more subjects having a stronger aversion to disadvantageous inequality. Second, in the treatment with random matching, our distribution of β-types is similar to the F&S distribution. This is not the case in the treatment with fixed matching. Here we find distinctively lower values at $\beta = 0$ and $\beta = 0.25$, i.e., our distribution has more mass on higher values of β. Thus, in the treatment with fixed matching subjects, we have, on average, a stronger aversion to advantageous inequality than in the treatment with random matching and this is in line with the regression results presented above.

The question remains whether the Stackelberg leader data also fit into the F&S framework. It turns out they do not, and the reason is that, given the distribution of α-types in the follower population, raising the quantity above

Table 7

Cumulative distributions of α- and β-types of the Stackelberg followers.
Number of observations allowing the computation of either α or β in parentheses.

α	F&S	*RAND* ($N = 140$)	*FIX* ($N = 104$)	β	F&S	*RAND* ($N = 16$)	*FIX* ($N = 71$)
0	0.3	0.30	0.31	0	0.3	0.31	0.13
0.5	0.6	0.67	0.64	0.25	0.6	0.75	0.27
1	0.9	0.69	0.71	0.6	1	1	0.99
4	1	0.94	0.91				

[12] Taking (*i*) for granted, it is clear that producing more than the Stackelberg-leader quantity would reduce the Stackelberg leader's absolute payoff and increase the advantagous inequality. Producing less than the collusive quantity would lower the absolute payoff and increase the disadvantageous inequality.

[13] Equilibrium prediction (*i*) implies that we can compute a value of α whenever the Stackelberg leader produces more than the Cournot quantity of 8, and a value of β whenever he produces less. (Compare footnote 11). For example, if $x^L > 8$, we can take the follower's first-order condition $24(1 + \alpha) - x^L - 2(1 + \alpha)x^F = 0$ and solve for α which gives $\alpha = \frac{1}{2}[(24 - x^L - 2x^F)/(x^F - 12)](>0)$.

[14] Compare with Fehr and Schmidt (1999, p. 844, Table III) which shows that this distribution is in line with data from a broad range of experiments.

[15] Note that, in Table 5, we count only those cases which generate αs or βs satisfying the paramenter restrictions of the F&S model, see above.

Cournot causes smaller absolute pay-offs for the Stackelberg leader *and* greater inequality. (The same result can be derived by taking the estimated response functions instead of the αs.) Thus, Stackelberg leader quantities above Cournot can only be explained by *negative* values of β, i.e., by assuming that Stackelberg leaders gain some extra utility from earning more than followers.[16]

We summarise these findings by

RESULT 5. *Stackelberg followers' reaction functions are less steep than predicted. With fixed pairs, they are even upward sloping. This is in line with Fehr and Schmidt's (1999) model of inequality aversion. Stackelberg leader data, however, contradict the Fehr and Schmidt prediction as they suggest no aversion against advantageous inequality. In general, more balanced market shares result than predicted by standard theory.*

5. Conclusion

Many economists and especially competition practitioners are worried by concentration in general and dominant firms in particular. Daughety (1990) shows that such concerns about concentration are not warranted if concentration results from asymmetry. We find support for Daughety's point in our experiments. In Stackelberg duopolies, aggregate output is higher than in Cournot duopolies. Although Stackelberg leaders do not exploit their first-mover advantage as strongly as the theory predicts, Stackelberg markets exhibit higher welfare levels. Hence, not only theory, but also experimental markets, suggest that the Stackelberg leader–follower structure is beneficial for welfare.

Our results can be compared with two earlier experimental studies. Asymmetric Cournot oligopoly has been the subject of Rassenti *et al.* (2000) and Mason *et al.* (1992). Both studies concentrate on cost asymmetries while we focus on an asymmetric (sequential) order of moves. Rassenti *et al.* (2000) find no convergence to equilibrium quantities at the individual level, only at the aggregate level. Since they do not conduct a reference treatment with symmetric firms, it is difficult to assess the impact of the asymmetric costs in their experiment. Mason *et al.* (1992) compare a treatment with cost differences with a symmetric treatment. They find that, in asymmetric duopolies, there is a higher level of output than in symmetric duopolies. Note that, in contrast to our results, this increase in output is not predicted by the theory.

Further, we find that Stackelberg followers' behaviour is in line with Fehr and Schmidt's (1999) model of inequality aversion (and its calibration). Given this result, it is not surprising that, in our companion paper (Huck *et al.*, 2001), there is hardly any evidence for *endogenous* Stackelberg leadership. When both firms can freely decide whether to commit to a quantity in a first period or to wait, the only subgame perfect equilibria in undominated

[16] This is in line with recent evolutionary models that suggest that preferences incorporating aversion against disadvantagous inequality can be evolutionarily stable (Huck and Oechssler, 1999) but have difficulties in explaining aversion against advantageous inequality.

strategies have one firm moving first (playing the Stackelberg leader quantity) and the second firm waiting (playing a best reply) (Hamilton and Slutsky, 1990). However, in experimental markets, such endogenous leadership does not occur. Rather, the most frequently observed outcome has firms producing Cournot quantities.

There remain some open questions. The first is whether our findings are robust to a greater number of firms deciding on the two stages or deciding in a more complicated sequence. Our guess is that such structures would still be more efficient than a Cournot market with the same number of firms. The second is what would happen if there were different kinds of asymmetries, i.e., what would happen if we introduced additional cost asymmetries into our set up? Here it is much more difficult to formulate conjectures, especially when the cost advantage favours the second mover.

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Appendix A Translated Instructions

Welcome to our experiments! Please read these instruction carefully! Do not talk to your neighbours and be quiet during the entire experiment. Indicate if you have a question. We will answer them privately.

In our experiment, you can earn different amounts of money, depending on your behaviour and that of other participants who are matched with you.

You play the role of a firm which produces the same product as another firm in the market. Both firms always have to make a single decision, namely which quantities they want to produce. In the attached table, you can see the resulting profits of both firms for all possible quantity combinations.

[The following two paragraphs only in *STACK* treatments.] The table reads as follows: the head to the row represents one firm's quantity (A-firm) and the head of the column represents the quantity of the other firm (B-firm). Inside the little box where row and column intersect, the A-firm's profit matching this combination of quantities is up to the left and the B-firm's profit matching these quantities is down to the right. The profit is denoted in a fictitious unit of money which we call Taler.

So far, so simple. But how do you make your decision? Take a look at your code-number: if it begins with an A, you are an A-firm; if it begins with a B, you are a B-firm. The procedure is that the A-firm always starts. This means that the A-firm chooses its quantity (selects a line in the table) and the B-firm is informed about the A-firm's choice. Knowing the quantity produced by the A-firm, the B-firm decides on its quantity (selects a colomn in the table). The B-firm then of course already knows its own profit. The A-firm will be informed about it (or rather B's choice). The decisions are marked on a separate decision sheet, which we will hand out to all participants with role A soon.

[The following two paragraphs only in *COUR* treatments.] The table reads as follows: the head of the row represents your firm's quantity and the head of the column represents the quantity of the other firm. Inside the little box where row and column intersect, your profit matching this combination of quantities is up to the left and the other firm's profit matching these quantities is down to the right. The profit is denoted in a fictitious unit of money which we call Taler. You and the other firm decide simultaneously about the quantities.

After each round, you will be informed about the quantity of the other firm. The decisions are marked on a separate decision sheet which we will hand out soon.

[This paragraph only in *RAND* treatments.] This procedure is repeated over ten rounds. You do not know the participant with whom you serve the market. You will be matched with a different paticipant each round and we will ensure that you will be matched with ten different particpants during the ten rounds.

[This paragraph only in *FIX* treatments.] This procedure is repeated over ten rounds. You do not know the participant with whom you serve the market, but you will stay matched with the same participant during all rounds.

During the entire experiment, anonymity among participants and instructors will be kept since your decisions will only be identified with your code number. Therefore, you have to keep your code card carefully. Only when you show the code card will you later receive your payment.

Concerning the payment, note the following: at the end of the experiment two of the ten rounds will be randomly chosen to count for payment. The sum of your profits in Taler of (only) these two rounds determines your payment in DM. For each ten Taler you will be paid 1 DM. In addition to this, you will receive 5 DM independent of the course of the ten rounds.

Appendix B Pay-off Table

Quantity	3	4	5	6	7	8	9	10	11	12	13	14	15
3	54 / 54	51 / 68	48 / 80	45 / 90	42 / 98	39 / 104	36 / 108	33 / 109	30 / 110	27 / 108	24 / 104	21 / 98	18 / 90
4	68 / 51	64 / 64	60 / 75	56 / 84	52 / 91	48 / 96	44 / 99	40 / 100	36 / 99	32 / 96	28 / 91	24 / 84	19 / 75
5	80 / 48	75 / 60	70 / 70	65 / 78	60 / 84	55 / 88	50 / 89	45 / 90	40 / 88	35 / 84	29 / 78	25 / 70	20 / 60
6	90 / 45	84 / 56	78 / 65	72 / 72	66 / 77	60 / 80	54 / 81	48 / 80	41 / 77	36 / 72	30 / 65	24 / 56	18 / 45
7	98 / 42	91 / 52	84 / 60	77 / 66	70 / 70	63 / 72	55 / 71	49 / 70	42 / 66	35 / 60	28 / 52	21 / 42	14 / 30
8	104 / 39	96 / 48	88 / 55	80 / 60	72 / 63	64 / 64	56 / 63	48 / 60	40 / 55	32 / 48	24 / 39	16 / 28	8 / 15
9	108 / 36	99 / 44	89 / 50	81 / 54	71 / 55	63 / 56	54 / 54	45 / 50	36 / 44	27 / 36	18 / 26	9 / 14	0 / 0
10	109 / 33	100 / 40	90 / 45	80 / 48	70 / 49	60 / 48	50 / 45	40 / 40	30 / 33	20 / 24	10 / 13	0 / 0	−10 / −15
11	110 / 30	99 / 36	88 / 40	77 / 41	66 / 42	55 / 40	44 / 36	33 / 30	22 / 22	11 / 12	0 / 0	−11 / −14	−22 / −30
12	108 / 27	96 / 32	84 / 35	72 / 36	60 / 35	48 / 32	36 / 27	24 / 20	12 / 11	0 / 0	−12 / −13	−24 / −28	−36 / −45
13	104 / 24	91 / 28	78 / 29	65 / 30	52 / 28	39 / 24	26 / 18	13 / 10	0 / 0	−13 / −12	−26 / −26	−39 / −42	−52 / −60
14	98 / 21	84 / 24	70 / 25	56 / 24	42 / 21	28 / 16	14 / 9	0 / 0	−14 / −11	−28 / −24	−42 / −39	−56 / −56	−70 / −75
15	90 / 18	75 / 19	60 / 20	45 / 18	30 / 14	15 / 8	0 / 0	−15 / −10	−30 / −22	−45 / −36	−60 / −52	−75 / −70	−90 / −90

Note: The head of the row represents one firm's quantity and the head of the column represents the quantity of the other firm. Inside the box at which row and column intersect, one firm's profit matching this combination of quantities is up to the left and the other firm's profit down to the right. As mentioned in the text, 14 entries were manipulated to achieve unique best replies. For the quantity combination (7, 9), a mistake was made in that 56 rather than 55 appeared in the table.

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