Cournot Competition between Teams: An Experimental Study*

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Abstract

In the literature on market competition, firms are often modelled as individual decision makers and the internal organization of the firm is neglected (unitary player assumption). However, as the literature on strategic delegation suggests, one can not generally expect that the behavior of teams is equivalent to the behavior of individuals in Cournot competition. Nevertheless, there are models of team-organizations such that team-firms and individual firms are behaviorally equivalent. This provides a theoretical foundation for the unitary player assumption in Cournot competition. We show that this assumption is robust in experiments, which is in contrast to experimental results on price competition.

Keywords: Unitary player assumption, Group behavior, Experiments, Theory of the firm.

JEL-Classifications: C72, C91, C92, D21, D23, D43, L13, L22, M52.

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1 Introduction

In the literature on market competition such as Bertrand or Cournot competition, firms are modeled as individual decision makers and the internal organization of the firm is neglected. This is known as the *unitary player assumption.* In contrast, studies of the theory of the firm (e.g. Hart, 1995) and personnel economics (e.g. Lazear, 1995, Prendergast, 1999) focus extensively on the internal organization of the firm but the market environment is considered just in a very stylized form. In quantity competition à la Cournot, teams may not display the same behavior as individuals. This is illustrated by the literature on strategic delegation in Cournot oligopoly, where the delegation of a principal to a manager leads to revenue maximization of the firm rather than to profit maximization (see Vickers, 1985, Fershtman and Judd, 1987). This example shows that the behavior of the firm may depend crucially on the interaction within the team/firm. Thus from a theoretical point of view, the unitary player assumption does not hold in general in Cournot competition.

In this paper we ask whether there exists some organizational forms of the firm in a Cournot oligopoly generating behavior that is equivalent to the behavior of an individual decision maker. We show in Section 2.1 that with respect to theoretical predictions of behavior this question can be answered in the affirmative. There do exist simple models of firm organizations in Cournot oligopoly with equilibrium behavior that is equivalent to equilibrium behavior of individual decision makers. This provides a theoretical foundation of the unitary player assumption in the Cournot oligopoly. For example, we consider a Cournot oligopoly where members of each firm choose efforts. For simplicity, the efforts of the members in each firm are aggregated additively to the quantity of the firm. We consider two different regimes of distributing the firm's profits among its members. First, profits may be distributed equally per head (treatment SH), an arrangement that may loosely correspond to a co-operative like an Israeli Kibbutz or a German Genossenschaft. In a second regime, profits may be distributed proportionally according to each member's costly effort (treatment SP). We observe that in both cases there are Nash equilibrium quantities of the team-firms that are equivalent to the Nash equilibrium in an analogous Cournot oligopoly in which each firm is an individual decision maker. We call this the *behavioral equivalence* of teams and individual decision makers.

The behavioral equivalence is taken as a hypothesis for the subsequent experimental study, the main focus of our paper. We conduct experiments for all profit distribution arrangements mentioned above as well as a standard Cournot oligopoly with individual decision makers as control (treatment C). We find that team-firms do not behave significantly different from individual firms. Moreover, in all treatments average market quantities are not significantly different from the Cournot Nash equilibrium. Thus we can not reject the hypothesis of behavioral equivalence for Cournot competition.

One fundamental conceptual difference between individual decision makers and team players is that latter have eventually to resolve an intra-team coordination problem that is trivially absent when the firm consist of one individual only. This intra-team coordination problem is especially severe in treatment SH where there exists a multiplicity of Nash equilibria besides the symmetric Nash equilibrium (see Section 2.1 for details). Consequently, a player with teams as opponents may face a larger degree of strategic uncertainty about the opponents' quantities than when she would have individual decision makers as opponents. Pure strategy Nash equilibrium would not predict any differences because irrespective of whether the opponents are teams or individual decision makers, it resolves probabilistically the strategic uncertainty. I.e., in equilibrium every player plays a pure strategy best response to her conjecture that the opponents' play independently their pure strategy best response. Yet, it seems plausible that because of the intra-team coordination problem, a player who faces team-opponents is "less confident" in her equilibrium conjecture about opponents' play than when she faces individual decision makers as opponents. Lack of confidence in probability judgements is modeled formally in the literature on ambiguity or Knightian uncertainty (see Schmeidler, 1989, Gilboa and Schmeidler, 1989). Recently, such approaches have been applied to strategic games and to Cournot oligopoly in particular (see Eichberger, Kelsey and Schipper, 2008a, 2008b for theory and experiments respectively). It has been shown that if players are averse to ambiguity, then their best response decreases in the amount of strategic uncertainty. Based on these results, we hypothesize that subjects facing team-opponents play on average lower quantities than subjects facing individual decision makers as opponents. To test this hypothesis, we design treatment AH that is analogous to treatment SH except that one of the firms in each market consists of just one subject. We find that average quantities of individual firms in treatment AH do not differ significantly from those in treatment C. Thus we do not find support for our hypothesis that the intra-team coordination problem may lead to strategic ambiguity.

The article is organized as follows: Section 2 introduces the experimental design and procedures. The experimental results are described in Section 3. We conclude with a discussion in Section 4, in which we also discuss the related literature. A translation of the instructions to the subjects is included in the Appendix.

2 Design

2.1 Treatments and Theoretical Predictions

Our model of market competition is a symmetric 3-firm Cournot oligopoly in which every firm faces the linear inverse demand function

$$p(Q) = \max\{500 - \frac{1}{6}Q; 0\}, \tag{1}$$

where $Q = \sum_{j=1}^{3} q_j$ is the sum of all firms' quantities $q_j \in \mathbb{R}$, $j = 1, ..., 3$. Each firm has unit marginal costs, i.e. $c(q_j) = q_j$ for all $q_j \in \mathbb{R}$. The profit function of firm $j = 1, 2, 3$ is given by

$$\pi_j(q_j, q_{-j}) = (p(Q) - 1)q_j, \tag{2}$$

where $q_{-j} = \sum_{h \neq j} q_h$ denotes the sum of quantities of firm j's opponents.

Let F_j be the set of members of firm j. Each firm $j = 1, 2, 3$ is viewed as a team of members $i_j \in F_j$. Member i_j of firm j chooses the effort level $e_{i_j} \in \mathbb{R}$. For all treatments, $q_j = \sum_{i_j \in F_j} e_{i_j}$. That is, the quantity of each firm is the sum of its members' efforts.

We chose a 3-firm oligopoly rather than a duopoly because collusion occurs sometimes in duopolies but rarely in oligopolies with more than two firms (see Huck, Normann and Oechssler, 2004, and the discussion in Section 4). On the other hand, an oligopoly with more than 3 firms would require a larger number of subjects.

The four treatments outlined below differ in their models of the internal organization of the firm. In particular the incentive structure varies across treatments. However, the parameters are chosen such that there is a behavioral equivalence between firms and individual decision makers in equilibrium (see Table 1).

Treatment C

Treatment C is a (C)ontrol-treatment with a standard 3-firm symmetric Cournot oligopoly. Each firm corresponds to an individual member (i.e., a unitary player) such that each individual's effort corresponds to a firm's quantity. The payoff function of each individual is simply the profit function of her firm (Equation (2)).

Treatment SP

Treatment SP is a treatment with (S)ymmetric firm-size and (P)roportional incentives. Each firm has three members, i.e., $F_j = \{1_j, 2_j, 3_j\}$, for all firms $j = 1, 2, 3$. Every member faces identical linear costs of efforts $k(e_{i_j}) = 83\frac{1}{6}e_{i_j}$, that are chosen such as to yield a behavioral equivalence between individuals in treatment C and teams in this treatment in equilibrium (see Table 1). Moreover, every member is entitled to a share of her firm's profit that is proportional to her effort level. That is, the payoff function of each member $i_j = 1_j, 2_j, 3_j$ is

$$\pi_{i_j}(e_{i_j}, e_{-i_j}, q_{-j}) = \frac{e_{i_j}}{q_j}\pi_j(q_j, q_{-j}) - 83\frac{1}{6}e_{i_j}, \tag{3}$$

where $e_{-i_j} = \sum_{h \neq i} e_{h_j}$ is the sum of the other members' efforts in the same firm j.

Note that treatment SP is equivalent to a standard nine-firm Cournot oligopoly with marginal cost $k + c$. Thus, the treatment allows us also to check whether the framing of three firms lead to deviations from the Cournot Nash equilibrium.

At the first glance, the treatment appears to be contrived by the additional effort costs k for each member of a firm. Does it not add extraneous structure to the original Cournot oligopoly? Yes, it does add structure, which is usually neglected in the standard models. The effect of such internal structure of the firm is what we want to study here. If such effort cost would not be added in this treatment, then a difference between observed behavior in treatments SP and C would not be surprising and predicted by Nash equilibrium. The next two treatments do not require extra effort costs of the members but the profits of each firm are not allocated proportionally across members.

Treatment SH

Treatment SH is a treatment with (S)ymmetric firm-size and an equal allocation of a firm's profits per (H)ead. The treatment is analogous to treatment SP except for the distribution of the profits of a firm and the effort costs. Effort costs $k(e_{i_j}) = 0$ are nil so as to obtain a theoretical behavioral equivalence between individual firms and team firms (see Table 1). For each firm $j = 1, 2, 3$, the payoff function of each member $i_j = 1_j, 2_j, 3_j$ is

$$\pi_{i_j}(q_j, q_{-j}) = \frac{1}{\sharp F_j}\pi_j(q_j, q_{-j}) = \frac{1}{3}\pi_j(q_j, q_{-j}). \tag{4}$$

That is, profits of the firm are allocated equally across members of the firm and this allocation is independent of any member's effort.

Note that in this treatment any distribution of efforts among members adding up to the Cournot Nash equilibrium quantity of the firm is a Nash equilibrium. Thus in comparison with treatments C and SP, this treatment allows us to investigate the impact of an *intra-firm coordination problem* on the quantities of the firms and the market outcome, and whether such a coordination problem is a source of different behavior between teams and individual decision makers. Note, however, that there exists a symmetric profile of Nash equilibrium efforts that aggregated to firm quantities is equivalent the Cournot Nash equilibrium quantities in treatment C (see Table 1).

Treatment AH

Treatment AH is a treatment with (A)symmetric firm-size and an equal allocation of profits per (H)ead. The treatment is analogous to treatment SH except for the different sizes of the firms. Firm 1 consists just of a individual member, whose effort corresponds to the quantity of firm 1. Firm 2 and 3 have three members each as in treatment SH before. Consequently, the payoff functions of each member differ depending on whether the member is in firm 1 or in the two other firms.

$$\pi_{1_1}(q_1, q_{-1}) = \frac{1}{1}\pi_1(q_1, q_{-1}) = \pi_1(q_1, q_{-1}), \tag{5}$$

$$\pi_{i_j}(q_j, q_{-j}) = \frac{1}{3}\pi_j(q_j, q_{-j}), j = 2, 3. \tag{6}$$

Note again, that as in treatment SH, there is a continuum of Nash equilibrium efforts in the team-firms since every distribution of efforts over members of a firm that sums up to the Nash equilibrium quantity of the firm is a Nash equilibrium effort level. Thus players face a co-ordination problem within each firm of more than one player. Together with the treatments C and SH, treatment AH enables us to analyze first, whether individuals behave differently towards team-firms with an intra-firm coordination problem than towards other individual firms that do not have such a coordination problem. Second, we are able to analyze whether team-firms behave differently in markets with individual firms from markets with other team-firms only.

Individual firms may face a higher degree of strategic uncertainty in treatment AH than in treatment C because of the intra-team coordination problem of team-firms in treatment AH. To see how this may strategically impact the behavior of such individual firms, we assume that individual firms face ambiguity about quantities of team-opponents and are ambiguity averse.[1] Ambiguity averse players lack confidence in their probability judgements of uncertain outcomes and react to it by overweighting "bad" outcomes.

[1]We know from previous experiments on ambiguity in single person decision problems (see Camerer and Weber, 1992) that the majority of subjects behave in an ambiguity-averse manner. Moreover, in

A theory of strategic interaction under ambiguity has been developed and applied to Cournot oligopoly in Eichberger, Kelsey and Schipper (2008a). Here we just sketch the simplified main intuition. Instead maximizing the payoff function given in Equation (2), the individual team firm may behave as if they maximize a weighted average of the payoff function (Equation (2)) and the "worst" payoff from the largest quantity available to team-opponents, where the weight on the worst payoff depends on the amount of ambiguity (i.e. severity of the intra-firm coordination problem) and the degree of ambiguity aversion. Consequently, the best response of an individual firm facing ambiguity is lower than without ambiguity.[2] If quantities of individual firms in treatment AH are lower than in treatment C, then this would be consistent with the hypothesis of strategic ambiguity due to the intra-firm coordination problem in treatment AH and ambiguity aversion among subjects.

Note that in treatment SP, no intra-firm coordination problem arises because the Nash equilibrium efforts in treatment SP are unique. Thus we refrained from introducing an asymmetric treatment analogous to treatment SP.

Table 1 provides an overview of prominent outcomes such as the unique symmetric Nash equilibrium, the collusive outcome and the competitive outcome[3], revealing the theoretical behavioral equivalence between those treatments. The calculations are standard and thus omitted. Note that due to the individual effort costs in treatment SP, the collusive and the competitive level from the individual's view differs from those corresponding levels from the firm's view. Thus the theoretical behavioral equivalence between treatments SP and C is restricted to the unique Cournot Nash equilibrium. For treatments SH and AH, the table reports the symmetric Nash equilibrium effort level only.

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a simple game with strategic substitutes, Eichberger, Kelsey and Schipper (2008b) find experimental support for ambiguity aversion.

[2]This comparative statics is reversed if we assume ambiguity loving players. See Eichberger, Kelsey and Schipper (2008a) for details.

[3]In the competitive outcome, the firm does not perceive any influence on the price.

Table 1: Behavioral equivalence across treatments

	Treatments			
Outcomes	**SP**	**SH**	**AH**	**C**
Nash equilibrium				
Individual effort	249.5	249.5^a	$249.5^{a,b}$ / 748.5^c	748.5
Firm's quantity	748.5	748.5	748.5	748.5
Market quantity	2245.5	2245.5	2245.5	2245.5
Collusive outcome				
Individual effort	$166\frac{1}{3}$ / 138.61^d	$166\frac{1}{3}^a$	$166\frac{1}{3}^{a,b}$ / 499^c	499
Firm's quantity	499 / 415.83^d	499	499	499
Market quantity	1497 / 1247.5^d	1497	1497	1497
Competitive outcome				
Individual effort	$332\frac{2}{3}$ / 277.22^d	$332\frac{2}{3}^a$	$332\frac{2}{3}^{a,b}$ / 998^c	998
Firm's quantity	998 / 831.67^d	998	998	998
Market quantity	2994 / 2495^d	2994	2994	2994

[a] symmetric outcome

[b] effort of a member in three-member firm

[c] effort of a member in the single member firm

[d] from the individual's point of view

2.2 Experimental Procedure

Motivated by previous Cournot experiments in the literature (e.g. Huck, Normann and Oechssler, 1999), the game in each of our treatments was played repeatedly for *40 rounds* with *fixed matching*. We chose fixed matching over random matching because first, we wanted to enable subjects to learn, and second, the lab had just 18 computer terminals available so that effect of "reshuffling" each of the 9 subjects in a market is limited. It is also known that collusion occurs rarely in Cournot tripolies even with fixed matching (see Huck, Normann and Oechssler, 2004). We chose 40 rounds mainly because on one hand, experiments on Cournot oligopoly in the literature (e.g. Huck, Normann and Oechssler, 1999) find 40 rounds sufficient for learning. On the other hand, we did not want to extent the duration of the experiment to more than $2\frac{1}{2}$ hours.

Each subject had to choose her effort level from the grid $\{0, 0.1, 0.2, ..., x\}$, whereby x was fixed at 1500 in treatment SP, SH and AH (for subjects in three-member firms) and at 4500 in treatment C and AH (for subjects in individual firms). The grid was chosen such as to make all prominent outcomes feasible and allow also for the monopoly outcome in every treatment.

Each session consisted of three stages: the briefing stage, the interaction stage, and the questionnaire stage. Stages 2 and 3 were computerized with the experimental software z-Tree (Fischbacher, 1999).

In the *briefing stage*, subjects received written instructions that were read aloud by the experimenter. In the appendix, we include as an example an English translation of the German instructions for treatment SP, which we consider the most complex instruction among all treatments. The instructions describe the game as well as the details of the session. The game was indeed framed as competition among firms as presented in this article. The demand function, cost functions, effort costs, the profit-distribution and team-sizes were public knowledge.

The appendix provides an example of a screen-shot. Such an example was also presented and explained to subjects in the instructions. Subjects were encouraged to ask questions about the instructions, which some did. Answers were given publicly. After the instructions, an example was computed in front of the subjects by the experimenter to enhance the subjects' understanding of the incentives. After that, each subject had to take a simple test that required the calculation of firm-profits and member-payoffs.[4] Subjects had a standard calculator available. Only after all subjects successfully completed the test, the interaction stage was started.

In the *interaction stage*, subjects had to play the game repeatedly for 40 rounds. Since the aim of our experiment was not to analyze the impact of limited computational

[4]The values in the examples did not correspond to any prominent values in the game. There was also no evidence that in the experiment subjects started out with the values of the examples.

capabilities on outcomes, we provided the subjects with three different "trial"-calculators (see the screen-shot in the appendix). Similar calculators have been employed in previous experiments on Cournot oligopoly (see for instance Huck, Normann and Oechssler, 1999). It was understood from the instructions that the inputs in those calculators have no influence on payoffs. First, there was a calculator (2a) that automatically computed the member's payoff if she inserted a number each for her own effort, the total effort by other members of the team and the total quantity of opponent-firms (the "trial calculator").[5] Second, there was a calculator (2b) that automatically computed the member's best response and profit if she inserted a number each for the total effort by other members of the team and the total quantity of opponent firms (the "best-reply calculator"). Subjects could try out as much as they wanted and the computed payoffs were listed below the calculators respectively. Those lists were automatically deleted from the subjects' screens after each round. However, all entries to the calculators have been recorded by the experimenter automatically. Third, there was a standard calculator on the computer available. After all subjects in the session had chosen and confirmed their effort levels, payoffs were computed automatically and the next round was started.

All subjects knew what *feedback* they would receive after each round. Between the rounds, each subject received feedback information on her own effort, the total effort of all other members in her firm (only in treatment SP, SH, and for team-firms in treatment AH), and the total quantity of all other firms in the previous period. Each subject also received feedback information about her own profit but not about profits of other team-members or other firms.

The *questionnaire stage* consisted of a computerized questionnaire that asked for the following information: the major of studies, the term of studies, the gender, whether the subject participated previously in a lecture on game theory or not, and how the participant would summarize her/his behavior. At the end of the questionnaire the final payoff converted in EURO was announced to the subject. The exchange rate from the

[5]The input fields of the calculator were adjusted to the different treatments.

experimental currency Taler to EURO was announced in the instructions. It varied between 2500 to 400 Taler per Euro-cent depending on the treatment and the type of firm such as to equalize the levels of incentives between subjects in individual firms and subjects in team-firms.[6] If all treatments were conducted with the same exchange rate for every subject, then any differences could be due to the different levels of incentives rather than to "team" effects. The final payoffs were paid out to the subjects immediately after the session concluded.

Finally, we need to mention that losses were possible. Thus subjects could possibly become bankrupt even with the initial lump sum payment that subjects received upfront. Indeed, this occurred in a few cases in the early rounds of the experiment in the treatment SP. In such cases we bilaterally agreed with those subjects on a loan such that they could continue with the experiment.

The experiment was conducted in the Bonn Laboratory of Experimental Economics in May 2003. For each treatment, we generated 6 independent observations. (Each market is one independent observation.) In total 168 subjects participated in our experiment. According to answers to the questionnaires at the end of each session, about 58% of the subjects majored in economics, 23% in law, 5% in languages and the rest in history, communication, political science etc. About 62% of the subjects were undergraduates (3 years maximum). 16% of the subjects where above the 8th semester. The sex ratio was almost balanced with about 49% female subjects. About 19% of the subjects announced that they had previously discussed game theory in a course.

Each session took about 2 to $2\frac{1}{2}$ hours including briefing and questionnaire. The payoff to each student was about 18 Euros on average.

[6]The exchange rates were as follows: 2500 Talers per Euro-cent for individual decision makers in treatments C and AH, 800 Talers per Euro-cent for members of teams in treatments SH and AH, and 400 Talers per Euro-cent for members of teams in treatment SP. In treatment AH, all subjects received the instructions for both individual decision makers and members of teams. So all subjects knew both exchange rates.

3 Results

3.1 Market Quantities

For each treatment, Figure 1 presents market quantities averaged over blocks of five rounds and markets.[7] A first glance suggests that average market quantities are very similar across treatments. Figure 1 also reveals that market quantities are distributed closely around the Cournot Nash equilibrium (2245.5).

Table 2 provides the summary statistics for market quantities for each treatment. Treatments SH and AH have slightly higher average market quantities than treatments SP and C. The Cournot Nash equilibrium is in all treatments the best predictor compared to the competitive outcome or the collusive outcome. However, quantities in treatments SP and C deviate less from the Cournot Nash equilibrium prediction than treatments SH and AH.

Figure 1: Average market quantities

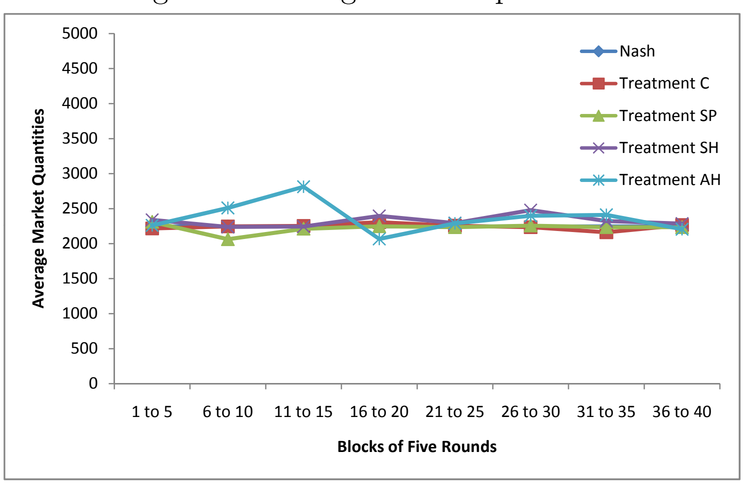


Figure 2 displays the market quantities for each of the six markets per treatment averaged over blocks of five rounds.[8] In terms of average market quantities there are no

[7]We follow a suggestion made by a referee to present the data in blocks of several rounds rather than per round.

[8]We follow a suggestion made by a referee to present the data in blocks of several rounds rather than

Table 2: Summary statistics of market quantities across treatments

	Treatments			
	SP	**SH**	**AH**	**C**
Average Market Quantities	2224.74	2324.37	2369.05	2243.06
Standard deviation	292.24	396.80	510.10	306.34
St. dev. to Nash equilibrium	290.94	427.96	522.80	306.46
St. dev. to competitive outp.	825.50 / 397.94[a]	782.11	843.19	813.40
St. dev. to collusion	789.62 / 1024.20[a]	918.57	1020.00	813.29

[a] from the individual's view

substantial differences between and within the treatments. The market quantities are distributed around the Cournot Nash equilibrium.

We can summarize our observations as follows:

Observation 1 *Average market outputs do not differ significantly between treatments C, SP, and SH (two-sided Wilcoxon-Mann-Whitney test:* $p = 0.29$*; Robust Rank Order test:* $p > 0.1$*).*[9] *For treatment AH, significance levels are lower than for treatments SP and SH.*

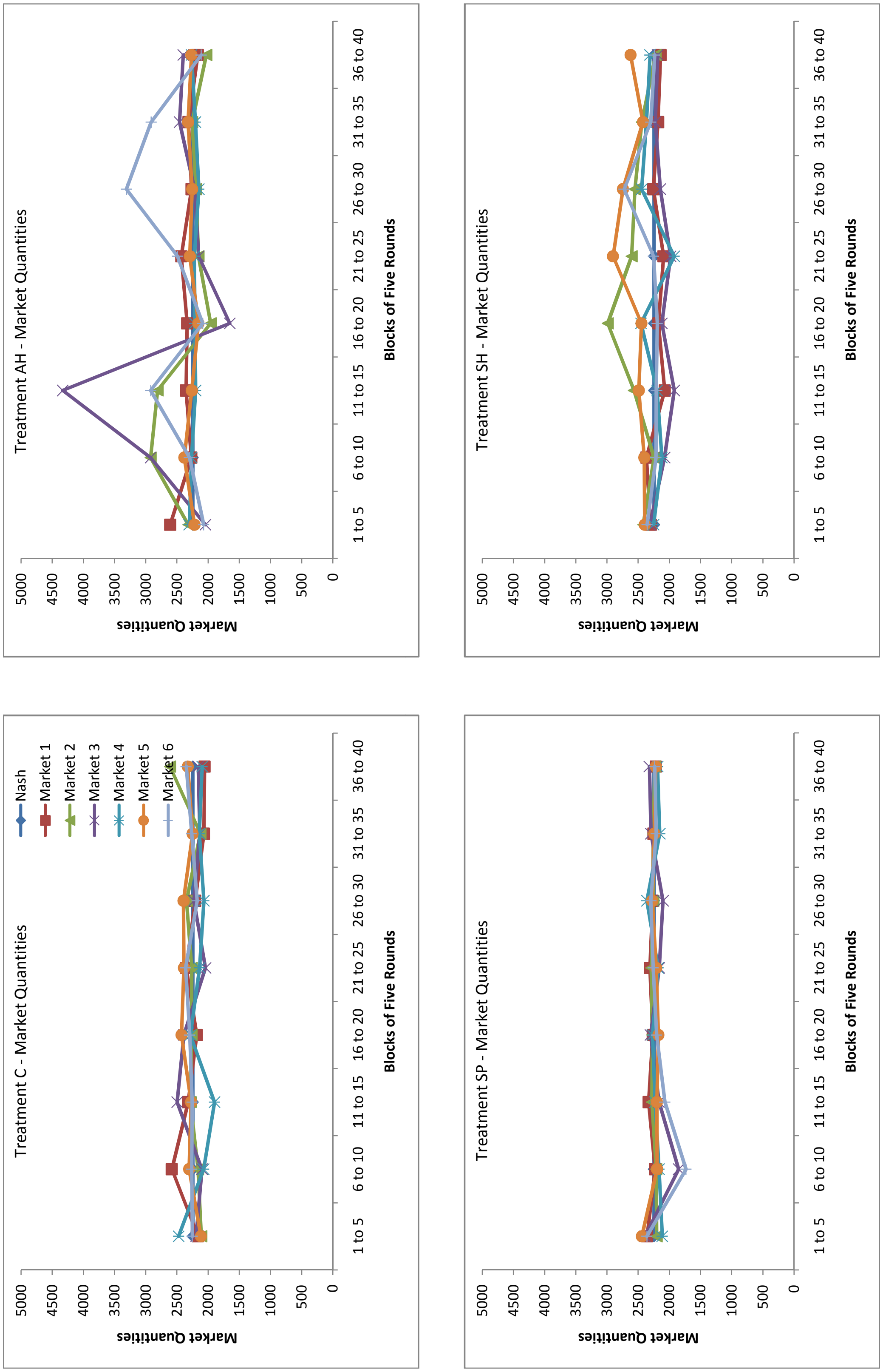
For average market quantities of treatment AH, significance levels are $p = 0.045$ for a two-sided Wilcoxon-Mann-Whitney test and $p = 0.05$ for the Robust Rank Order test when compared to average market quantities of treatment C. The lower significance levels for treatment AH are probably due to two extreme outliers[10] in treatment AH. If we omit these two observations and compare the four remaining average market quantities

per round.

[9] This holds for any pair of treatments C, SP, and SH. See Siegel and Castellan, 1988, for explanations of all tests used in this article. Note that 0.1 is the highest p-value printed in Siegel and Castellan (1988) for the Robust Rank Order test.

[10] An observation is here defined to be an outlier if the market quantity was above 4000 more than once in the last 35 periods of the play. Equivalently, an observation is an outlier if the market quantity was more than 4.6 standard deviations above the average market quantity (where here both the standard

Figure 2: Market quantities per treatment



of treatment AH with the ones of treatment C we cannot reject a behavioral equivalence at the 0.1 significance level.

Observation 2 *Average market outputs do not differ significantly from the Cournot Nash equilibrium market output in any of the treatments (two sided Kolmogorov-Smirnov one sample test:* $p = 0.2$*).*

3.2 Strategic Behavior towards Teams vs. Individual Players and the Intra-Firm Coordination Problem

According to Table 2, standard deviations are higher in treatments SH and AH than in treatments SP and C. Indeed, judging by the Figures 1 and 2, the volatility seems to be higher in treatments SH and AH than in SP and C. This is probably due to the intra-team co-ordination problem subjects faced within each team-firm in treatments SH and AH. Recall that any distribution of efforts among members of a firm that adds up to the Cournot Nash equilibrium quantity of the firm is a Nash equilibrium effort. This multiplicity of Nash equilibrium effort levels presents a coordination problem among members of each team. Further evidence for this intra-team coordination problem is provided in Table 3, which shows that the standard deviation of team-firms in treatment SH is larger than the standard deviation of individual firms in treatment C, and that the standard deviation of team-firms in treatment AH is larger than the standard deviations of individual firms in both treatments AH and C. It is therefore plausible that individual firms face a larger degree of strategic uncertainty about opponents' quantities in treatment AH compared to treatment C simply because their opponents suffer from an intra-team coordination problem.

In Section 2.1 we argued that the strategic ambiguity from the opponents' intra-team

deviation and the average market quantity are computed with respect to the remaining observations that are not outliers) more than once in the last 35 periods of the play. At such large output levels every player is certain to make large losses.

Table 3: Average quantities and standard deviation of team-firms and individual firms

	Treatments		
	SH	**AH**	**C**
Team firms			
Average quantities	774.79	813.13	n.a.
Standard deviation	244.01	331.35	n.a.
Individual firms			
Average quantities	n.a.	742.78	747.69
Standard deviation	n.a.	279.37	192.66

coordination problem should induce ambiguity averse individual firms in treatment AH to play lower quantities than individual firms in treatment C. Table 3 reveals that there is a small difference. In each market of the treatment AH we have an individual firm (playing with two other team-firms) while in treatment C we have three individual firms in each market. To test whether the difference is significant, we select randomly one of the three individual firms in each market in treatment C. In this way we obtain six independent observations each for treatments AH and C and use them for the test.

Observation 3 *Average quantities of individual firms in markets with team-firms (treatment AH) are not significantly different from average quantities of individual firms in markets with other individual firms only (treatment C) (two-sided Wilcoxon-Mann-Whitney Test: $p = 0.35$; Robust Rank Order test: $p > 0.1$).*

Our interpretation is that the strategic uncertainty from the intra-team coordination problem manifested in the higher standard deviations of team-firms in treatments SH and AH is not sufficient to alter significantly the behavior of individual decision makers as compared to treatment C. We do not find support for the joint hypothesis that individual decision makers face ambiguity about behavior of teams and that individual decision makers are ambiguity averse.

Despite the fact that individual firms do not behave significantly different in treatment AH from treatment C, members of team-firms in treatment AH may believe that individual firms in treatment AH face strategic ambiguity about the intra-team coordination problem of team-firms. Thus members of team-firms may believe that ambiguity averse individual firms play lower quantities in treatment AH as compared to treatment SH. This second order belief of members of team-firms should induce them to play a larger best response in treatment AH as compared to treatment SH. Table 3 shows that this is indeed the case, but the difference is not significant. Since we have three (resp. two) team-firms per market in treatment SH (resp. AH), we randomly select one from each market in order to get six independent observations from each treatment that are used in the test.

Observation 4 *Average quantities of team-firms in markets with an individual firm (treatment AH) are not significantly different from average quantities of team-firms in markets with other team-firms only (treatment SH) (two-sided Wilcoxon-Mann-Whitney test:* $p = 0.47$*; Robust Rank-Order test:* $p > 0.1$*).*

4 Discussion

Our experimental results on the unitary player assumption in quantity competition à la Cournot are in stark contrast to results by Bornstein, Kugler, Budescu and Selten (2008), who reject the unitary player assumption in price competition à la Bertrand. What could account for the differences? There are two focal differences between the experiments: the incentive structure and the number of firms in the market. Although Bertrand games have an incentive structure different from our Cournot games, in both types of games the theoretical predictions for teams and individual players coincide. Therefore, we actually believe it is mainly due to a number effect. Formally, the Bertrand duopoly with individual firms in Bornstein, Kugler, Budescu and Selten (2008) is a two-player game whereas their Bertrand duopoly with team-firms are four or six-player games. There is quite some experimental evidence (Fouraker and Siegel, 1963, Chapter

10, Dolbear et al., 1968, and Dufwenberg and Gneezy, 2000) that Bertrand duopolies tend to collusion whereas Bertrand oligopolies with a larger number of players are more competitive. This holds for fixed matching (Fouraker and Siegel, 1963, Dolbear et al., 1968) as well as random matching (Dufwenberg and Gneezy, 2000) between the rounds. Given the experimental evidence on the number effect in Bertrand oligopoly, it may be justified to ask whether the differences found by Bornstein, Kugler, Budescu and Selten (2008) between the individual setting and the team-player setting can be attributed to a number effect rather than a team effect. They find collusion in the individual Bertrand duopoly but more competitive prices in team-player Bertrand duopoly. Based on the findings in above mentioned experimental literature, we conjecture that in an experiment analogous to Bornstein, Kugler, Budescu, and Selten (2008) but with a sufficient large number of firms, one can not reject the unitary player assumption.

A caveat applies to the suggestion that the team effect found in Bertrand by Bornstein, Kugler, Budescu and Selten (2008) may be due to a number effect. Dufwenberg and Gneezy (2000, p. 20) sketch a theoretical argument for the number effect in Bertrand oligopoly based on players' expectations of opponents' mistakes, where a mistake is interpreted as a large deviation from the Nash equilibrium price. Players can benefit from mistakes of opponents which allows them to demand higher prices as well, but the larger the number of opponents the lower is the probability that all opponents make a mistake. Such an argument does not extend to the team games studied by Bornstein, Kugler, Budescu and Selten (2008) like their "private profit" setting.[11] The reason is that the marginal expected profit from a price increase may actually (weakly) decrease in the joint probability of mistakes by members of a player's own team, while it (weakly) increases in the joint probability of mistakes by opponents in a Bertrand oligopoly. So adding ad-

[11]Bornstein, Kugler, Budescu and Selten (2008) study a game with two teams as follows: In each round of the game, each member in a team simultaneously demands a price. The demands are summed up over the members of each team to the demand of the team. A team wins if her demand is smaller than the other team's demand. In the "private profit" treatment each player is paid her own demand if her team wins and half of her demand in the case of a tie.

ditional team-members to a player's team may be beneficiary to the player, while adding additional team-members to an opponent's team or additional firms hurts the player. Yet, this line of arguments suggests that eventually experiments on Bertrand oligopoly with asymmetric team-sizes (analogous to our treatment AH) are required to disentangle fully the team effect from a number effect.

The arguments by Dufwenberg and Gneezy (2000) do not extend to Cournot oligopoly without further assumptions. While in Bertrand oligopoly studied by Dufwenberg and Gneezy (2000) or Bornstein, Kugler, Budescu and Selten (2008) mistakes can only involve higher prices than Nash equilibrium, mistakes in Cournot oligopoly can go in any direction. Since actions are aggregated within a team (and among opponents), mistakes may even offset each other. Nevertheless, a number effect has also been reported for experimental Cournot oligopolies. Huck, Normann and Oechssler (2004) conclude based on a meta-study of a number of experiments in the literature as well as additional own experiments that collusion occurs sometimes in duopolies. The stage game Nash equilibrium seems a good predictor for tripolies. Moreover, collusion appears rarely in oligopolies with more than two firms. In our experiment we avoid this number effect (on purpose) largely because we focus on a Cournot tripoly rather than a duopoly.

There is another reason for focusing on three-player games rather than two-player games. In terms of the complexity of strategic reasoning, two-player games differ slightly from n-player games, for $n \geq 3$. In a two-player game, each player can reason at most about one other opponent. This is in contrast to n-player games, where each player may have to reason also about what one opponent reasons about yet another opponent. In our design, we want to avoid that just such differences in the complexity of strategic reasoning between two-player games and team-players games drives any experimental results.

To our knowledge, our hypothesis on strategic ambiguity due to an intra-team coordination problem is new in the literature on testing the unitary player assumption. There could be two reasons for why we do not find support for this hypothesis: First, the strategic uncertainty from the intra-firm coordination problem may not be large enough, and second, subjects may not be sufficiently ambiguity averse. It could well be that in other strategic situations, intra-team coordination is even more difficult to achieve and subjects are more sensitive to the amount of ambiguity over opponents' actions.

4.1 Additional Related Literature

Huck, Konrad, Müller and Normann (2007) find that merged firms behave significantly more aggressive than their competitors in experimental Cournot competition. This could be contrasted with Observations 3 and 4 in Section 3.2. If a team-firm is viewed as a "merged" firm, then we find no differences in average behavior of merged and non-merged firms. Huck, Konrad, Müller and Normann (2007) explain their result with the merger history and aspiration levels based on pre-merger profits. In their experiment, subjects experienced the merger during the experiment. In contrast, our team-firms do not have any merger experience. We conclude that while we see no difference between team-firms and individual firms, such differences may arise if subjects experience a "merger" into a team-firm during the experiment.

An early experimental study investigating quantity competition between firms consisting each of a group of subjects is Sauermann and Selten (1959), who consider an asymmetric 3-firm Cournot oligopoly, in which each firm is represented by five subjects on average. Those subjects play different roles: some communicate with the "market central office", others keep the books of the firm, etc. It is a dynamic problem because firms can borrow money for production and have to pay interest. Subjects play it over 30 periods. During the play, firms can acquire information about other firm's market share, debt etc. Sauermann and Selten (1959) report results that are remarkably close to one of the asymmetric Cournot Nash equilibria of the stage game under complete information. The aim of their study was not so much on testing Cournot's theory but on replicating a "realistic" yet controlled decision environment in order discover how subjects make decisions. In contrast, we aim to conduct a less complex experiment with more experimental control over the internal organization of the firm, i.e., the aggregation of decisions and the distribution of profits.

Huck, Müller and Normann (2004) conduct an experiment to test strategic delegation à la Vickers (1985) and Fershtman and Judd (1987) in Cournot oligopoly. Theory predicts that firms set output levels well above the Cournot Nash equilibrium in order to maximize revenues instead profits. Yet, they find output levels similar to the Cournot Nash equilibrium. Together with our experimental findings we conclude that the Cournot outcome appears to be quite robust for firms that are represented by teams and engage in quantity competition no matter whether or not the Cournot outcome is the theoretical prediction for such a structure.

Nabantian and Schotter (1997) examine the influence of different incentive schemes on the production in teams. Among the incentive schemes they consider are also those analyzed in our study, namely the distribution of profits per head and the proportional distribution. They also aggregate decisions of subjects inside the firm additively, which is followed in our study as well. However, their work is restricted to an individual firm production problem. This leaves out completely strategic reasons for differences between behavior of teams and individuals. We believe that a firm's behavior is not just influenced by its internal organization but also by the opponents' reaction to the firm's internal organization. Our experiment allows to test for such strategic sources of potential violations of the unitary player assumption (see Observations 3 and 4).

Experiments on group versus individual behavior are an active and growing field of research. Bornstein (2007) provides a recent systematic survey and points out gaps in the literature. Most of the studies in the literature show that some relevant aspects of team behavior may be different from behavior of individuals. In contrast, we show with our study that there are situations where the average behavior of groups and the average behavior of individuals are not significantly different. It is a worthy task for this field of research to identify classes of decision making situations and aspects of behavior in which groups (do not) differ from individuals, and if possible explain why such differences (do not) occur. To this extend, it may be helpful to consider in more theoretical detail the internal structure of teams and its effect on the interaction between teams. A useful classification of different types of teams is provided by Bornstein (2007). He distinguishes between *unitary teams* on one hand - i.e. a team who can reach a binding agreement on a joint strategy - and *non-cooperative teams* - i.e. a team whose members act independently without binding agreements. In this article, we are only concerned with the latter kind of teams.

A Translation of Instructions: Treatment SP

Welcome to the experiment!

In this experiment you can earn money by making decisions. Your earnings will depend on your decisions as well as the decisions of the other participants. Please read the instructions carefully. All participants received the same instructions. From now on please do not talk to other participants anymore. For any questions please do not hesitate to contact us.

You will draw shortly a random number. With this number you will remain anonymous for us and other participants during the experiment. Please proceed to the cabin in the laboratory with the same number.

Firms

When arriving at your cabin, you will be matched automatically and randomly with other participants into a firm without knowing the other participants. In every firm there are 3 members (beside you there are two other members in your firm). Each market consists of 3 firms (beside your firm there are two other firms in your market). The experiment consists of 40 periods which are followed by a questionnaire. The matching of the participants into firms remains the same throughout the 40 periods. Moreover, there are always the same firms in a market. In each period each firm sells a quantity in the market. The cost to the firm is 1 Taler per quantity unit. The price per quantity depends on your firm's quantity as well as the quantities of the other two firms in your market. The higher the quantities in the market, the lower the price. The lowest possible price is nil. The price function is

$$\begin{matrix}\text{price per}\\\text{quantity}\end{matrix} = 500 - \left(\frac{1}{6} \times \begin{matrix}\text{total quantity of all}\\\text{firms in the market}\end{matrix}\right) \text{ or } 0$$

The profit per quantity is the profit of the firm per quantity. It is calculated as follows:

$$\text{profit per quantity} = \begin{matrix}\text{price per}\\\text{quantity}\end{matrix} - \begin{matrix}\text{firm's cost per}\\\text{quantity}\end{matrix}$$

The profit of the firm per period is simply the profit per quantity multiplied with the quantity of the firm:

$$\text{profit of the firm} = \text{profit per quantity} \times \text{quantity of the firm}$$

Your decision

In each period each participant has to take a decision about her effort spent in the firm. The effort can lie between 0 and 1500 (in steps of 0.1). The cost to each participant per effort is $83\frac{1}{6}$ Taler. The sum of all efforts over all participants within a firm is the quantity of the firm, which the firm sells in the market.

$$\text{quantity of the firm} = \text{sum of efforts of all members within the firm}$$

Each member of a firm receives a share of the profit of the firm. This share is calculated as follows:

$$\begin{array}{c}\text{share on}\\ \text{firm's profit}\end{array} = \frac{\text{own effort}}{\text{sum of efforts of all members}} \times \text{firm's profit}$$

The cost of effort is calculated from the cost per effort of $83\frac{1}{6}$ Taler multiplied with the own effort.

$$\begin{array}{c}\text{costs of}\\ \text{effort}\end{array} = \text{costs per effort} \times \text{own effort}$$

The payoff to a participant per period is calculated as follows:

$$\text{payoff} = \text{share on the firm's profit} - \text{cost of effort}$$

Computer

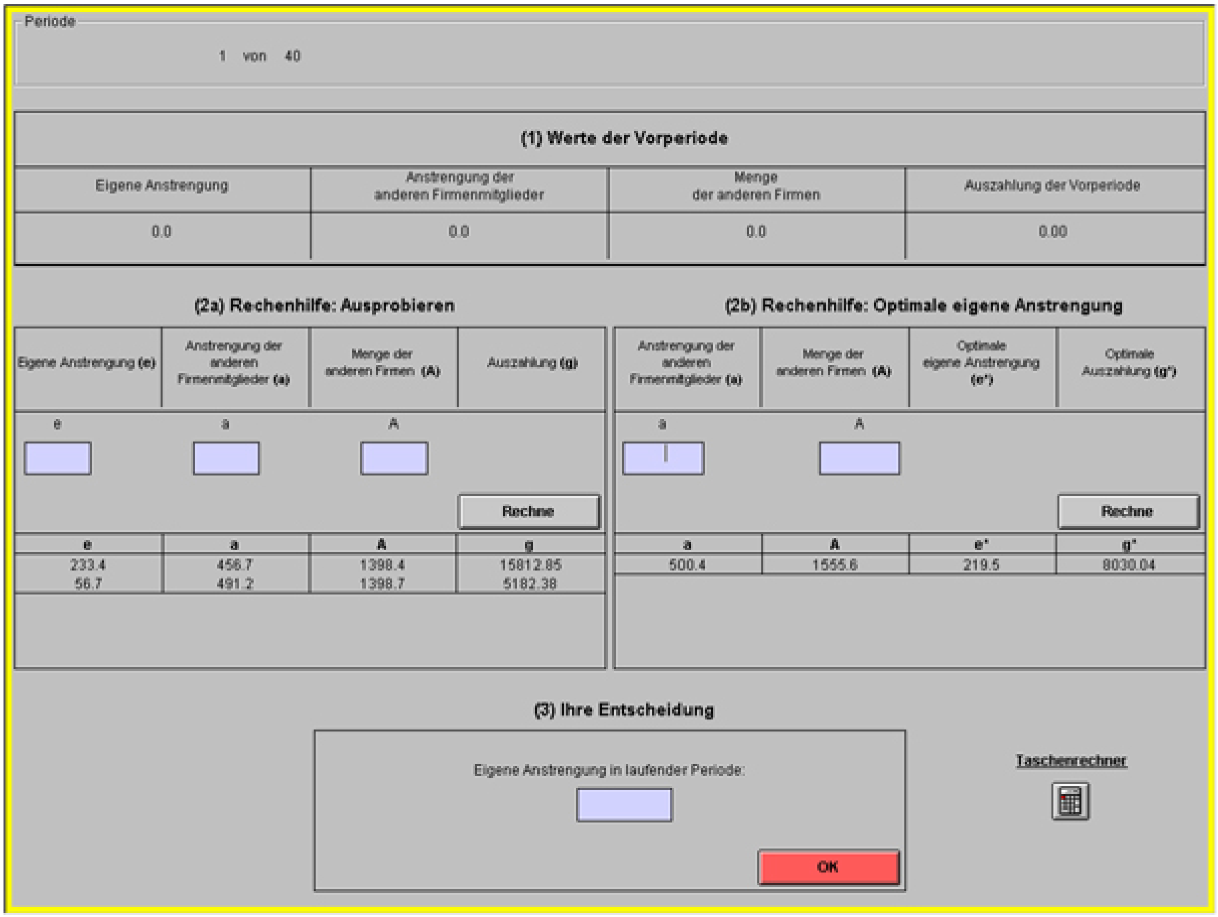
We use the computer for the input of the decisions, for trying out of decisions and for the calculation of payoffs. Latter is done automatically. At the beginning of each period you can see the following screen (in the top left corner you can find the number of the period):

(1) Values of the previous period

To your information you find the values of the previous period at the screen. They are nil in the first period.

(2) Support for Calculations

There are two calculators for trying out possible decisions, which you can use. The input into the calculators does not influence your payoffs. The calculator left (2a) calculates the payoff (g) if you put in your possible effort (e), your belief about the efforts of the other members in your firm (a) as well as your belief about the quantities of the other firms (A). After the



input, the input data will be listed together with the calculated payoff under the calculator if you press the "calculate" button with the mouse. The effort of the other members in your firm (a) is calculated as follows:

$$\begin{array}{c}\text{effort of other}\\ \text{members of the firm (a)}\end{array} = \text{sum of efforts of all other members of the firm}$$

The quantity of the other firms (A) is

$$\begin{array}{c}\text{quantity of other}\\ \text{firms (A)}\end{array} \begin{array}{l} = \text{sum of quantities of the other two firms}\\ = \text{sum of efforts of all members of the other two firms}\end{array}$$

The calculator to the right side (2b) calculates your optimal own effort (e^*) and your optimal payoff (g^*) if you input your belief about the efforts of the other members of the your firm (a) as well as your belief about the quantities of the other firms (A). The optimal own effort (e^*) is the effort which maximizes your payoff in this period if the other members of your firm and the other firms behave as input by you. Your calculations are listed under the calculator after you press the "calculate" button with the mouse. At the right side below the calculator there is also a button. If you press this button a standard calculator appears on your screen.

(3) Your decision

In (3) you have to choose your effort level. In contrast to the calculators, this input will influence your payoff as outlined above. Only after you pressed "OK", your decision will be confirmed and the experiment proceeds with the next period. After 40 periods a questionnaire appears at the screen, which we kindly ask you to fill in.

Your final payoff

Since in this experiment there can be losses in a period, you will receive at the beginning an initial balance of 60 000 Taler. For your final payoff we calculate the sum of your initial balance plus the sum of payoffs of all periods. This payoff in Taler will be exchanged into EURO using an exchange rate of 400 Taler = 1 Cent. This will be paid to you immediately after the experiment.

References

[1] Bornstein, G. (2007). A classification of games by player type, mimeo., The Hebrew University of Jerusalem.

[2] Bornstein, G. and U. Gneezy, 2002, Price competition between teams, Experimental Economics, 5, 29-38.

[3] Bornstein, G., Kugler, T., Budescu, D., and R. Selten, 2008, Repeated price competition between individuals and between teams, Journal of Economic Behavior and Organization, 66, 808-821.

[4] Dolbear, F.T., Lave, L.B., Bowman, G., Lieberman, A., Prescott, E., Rueter, F., and R. Sherman, 1968, Collusion in oligopoly. An experiment on the effect of numbers and information, Quarterly Journal of Economics, 82, 240-259.

[5] Dufwenberg, M. and U. Gneezy, 2000, Price competition and market concentration: An experimental study, International Journal of Industrial Organization, 18, 7-22.

[6] Camerer, C. and M. Weber, 1992, Recent developments in modelling preferences: Uncertainty and ambiguity, Journal of Risk and Uncertainty, 5, 777-795.

[7] Eichberger, J., Kelsey, D., and B. C. Schipper, 2008a, Ambiguity and social interaction, Oxford Economic Papers, forthcoming.

[8] Eichberger, J., Kelsey, D., and B. C. Schipper, 2008b, Granny versus game theorist: Ambiguity in experimental games, Theory and Decision, 64, 333-362.

[9] Fershtman, C. and K. L. Judd, 1987, Equilibrium incentives in oligopoly, American Economic Review, 77, 927-940.

[10] Fischbacher, U., 1999, z-Tree. Toolbox for readymade economic experiments, IEW Working Paper 21, University of Zurich.

[11] Fouraker, L. and S. Siegel, 1963, Bargaining behavior (McGraw-Hill, New York).

[12] Gilboa, I. and D. Schmeidler, 1989, Maxmin expected utility with a non-unique prior, Journal of Mathematical Economics, 18, 141-153.

[13] Hart, O., 1995, Firms, contracts and financial structure (Claredon Press, Oxford).

[14] Huck, S., Konrad, K.A., Müller, W., and H.T. Normann, 2007, The merger paradox and why aspiration levels let it fail in the laboratory, Economic Journal, 117, 1073-1095.

[15] Huck, S., Müller,W., and H.T. Normann, 2004, Strategic delegation in experimental markets, International Journal of Industrial Organization, 22, 561-574.

[16] Huck, S., Normann, H.T., and J. Oechssler, 1999, Learning in Cournot oligopoly - An experiment, Economic Journal, 109, C80-C95.

[17] Huck, S., Normann, H.T., and J. Oechssler, 2004, Two are few and four are many: Number effects in experimental oligopolies, Journal of Economic Behavior and Organization, 53, 435-446.

[18] Lazear, E., 1995, Personnel economics (MIT Press, Cambridge, M.A.).

[19] Nabantian, H. R., and A. Schotter, 1997, Productivity under group incentives: An experimental study, American Economic Review, 87, 314-341.

[20] Prendergast, C., 1999, The provision of incentives in firms, Journal of Economic Literature, 37, 7-63.

[21] Sauermann, H. and R. Selten, 1959, Ein Oligopolexperiment, Zeitschrift für die gesamte Staatswissenschaft, 115, 427-471.

[22] Schmeidler, D., 1989, Subjective probability and expected utility with additivity, Econometrica, 57, 571-587.

[23] Siegel, S. and N. J. Castellan, 1988, Nonparametric statistics for the behavioral sciences (2nd edition, McGraw-Hill, New York).

[24] Vickers, J., 1985, Delegation and the theory of the firm, Economic Journal, 95, 138-147.