Bonn Econ Discussion Papers

Discussion Paper 13/2004

Cournot Competition between Teams: An Experimental Study

by

Philippe Raab, Burkhard C. Schipper

July 2004

Bonn Graduate School of Economics
Department of Economics
University of Bonn
Adenauerallee 24 - 42
D-53113 Bonn

The Bonn Graduate School of Economics is
sponsored by the

Deutsche Post World Net

MAIL EXPRESS LOGISTICS FINANCE

Cournot Competition between Teams: An Experimental Study*

Philippe Raab† and Burkhard C. Schipper‡
Department of Economics
University of Bonn

July 2004

Abstract

In the economic literature on market competition, firms are often modeled as single 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-organization such that teams and individuals are behaviorally equivalent providing a theoretical foundation for the unitary player assumption in Cournot competition. We show that this assumption is robust in experiments in contrast to analog experimental results on price-competition in the literature.

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

Keywords: unitary player assumption, experiments, group behavior, theory of the firm.

---

*We thank Rosemarie Nagel, Axel Ockenfels, Jörg Oechssler, and participants at ESA Meetings in Erfurt and Tucson for helpful comments. Financial support by the Bonn Graduate School of Economics and the DFG (SFB/TR 15 C4) is gratefully acknowledged.

†Email: praab@uni-bonn.de, web: www.bgse.uni-bonn.de/∼philippe

‡corresponding author: Department of Economics, University of Bonn, Adenauerallee 24-42, 53113 Bonn, Germany, phone: +49-228-73 6148, fax: +49-228-73 1785, email: schipper@uni-bonn.de, web: www.bgse.uni-bonn.de/∼burkhard

1 Introduction

In the economic literature on market competition such as Bertrand or Cournot competition, firms are modeled as single 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 often neglected. In quantity competition a là Cournot, teams do not generally display the same behavior as individuals. Strategic delegation of a principal to a manager in Cournot oligopoly leads to revenue maximization of the firm rather than profit maximization (see Vickers, 1985, Fershtman and Judd, 1987). This example shows that the behavior of the firm depends crucially on the model of interaction within the team/firm. Thus from a theoretical point of view, the unitary player assumption in Cournot competition must be questioned. However, there exist models of firm organization generating behavior equivalent to a single decision maker providing 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 (see also Nabantian and Schotter, 1997). We consider two different regimes of distributing the firm's profits among its members. First, profits may be distributed equally per head, an arrangement that may correspond loosely to a co-operative like a Kibbutz. Second, profits may be distributed proportionally according to the member's effort and each member's effort is costly. In both cases the Nash equilibrium quantities of the firms are equivalent to the Nash equilibrium in an analog Cournot oligopoly in which each firm is a single decision maker. The question is whether there is also empirical evidence for such behavioral equivalence. We study experimentally this behavioral equivalence and find support for the unitary player assumption in Cournot competition.

Our work is in direct contrast to recent experimental results on price competition between teams. Bornstein and Gneezy (2002) and Bornstein, Budescu, and Kugler (2002) test the unitary player assumption in Bertrand duopoly. In these studies, the organizations of the firms are analog to ours. However, instead the aggregation of efforts to quantities, individual prices are aggregated additively to the firm's price. They reject the unitary player assumption in price competition between teams.

An early experimental study investigating quantity competition between firms consisting each of a group of subjects is Sauermann and Selten (1959). In this study, the internal structure of the firm is rather complex aiming at replicating a "realistic" decision environment. In contrast, we want to have more control over the internal organization of the firm, i.e., the aggregation of decisions and the the distribution of profits. The design of our experiment is related to experiments on Cournot competition, in particular with regard to the number of firms, the time horizon, the feedback information between rounds, the fixed matching scheme, and the computational support available to subjects (see for example Dolbear et al., 1968, Huck, Normann, and Oechssler, 1999, 2000, 2004, Huck et al., 2002, Huck, Müller, and Normann, 2001, and Siegel and Castellan, 1963; for a recent survey see Huck, 2002).

Our study relates to the growing literature studying the difference between decisions taken by teams and individuals. Nabantian and Schotter (1997) examine the influence of different incentive schemes on team production, among them also the distribution of profits per head as well as proportional distribution. As in our design, they aggregate decisions of subjects inside the firm additively. However, their study is restricted to a monopoly.

Bornstein and Erev (1994), Bornstein, Erev, and Rosen (1990), Erev, Bornstein, and Galili (1993), Bornstein, Gneezy, and Nagel (2003) as well as Rapoport and Bornstein (1989) all investigate the effect of intragroup competition with regard to two famous problems of social interaction, namely the co-ordination problem and the free-riding problem. One finding is that competition between teams may ease some of the well known social dilemmas like contributions to a public good. Work by Insko et al. (1994), Bornstein, Budescu, and Zamir (1997), Bornstein and Ben-Yossef (1994), and Schopler and Insko (1992) focuses on testing the unitary player assumption in other games than Cournot oligopoly.

The article is organized as follows: Section 2 introduces in detail the experimental design. The hypotheses are presented in Section 3. All results are described in Section 4. We conclude with a discussion in Section 5. The instructions to the subjects are given in the Appendix.

2 Design

Our model of market competition is a symmetric 3-firm Cournot oligopoly[1] with linear demand and costs. Every firm faces the inverse demand function

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

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

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

whereby $q_{-j} = \sum_{k \neq j} q_k$ is 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 $i_j \in F_j$ choosing effort levels e_{i_j}. 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. The four treatments differ in their model of the internal organization of the firm. In particular the incentive structure varies across treatments. However, parameters were chosen such that there is

[1] Three firms are chosen rather than two in order to avoid collusion which is observable in some two-firm Cournot games (Huck, Normann, and Oechssler, 2004).

a behavioral equivalence between firms and single decision makers (see Table 1).

Treatment C

Treatment C is a (C)ontrol-treatment with a standard 3-firm symmetric Cournot oligopoly. Each firm corresponds to a single member (i.e., a unitary player) such that each member's effort corresponds to a firm's quantity. The payoff function of each subject is simply the profit function of his 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 $k(e_{i_j}) = 83\frac{1}{6}e_{j_i}$, that are chosen such to yield a behavioral equivalence between individuals in treatment C and teams in this treatment (see below). Moreover, every member is entitled to a share of his firm's profit that is proportional to his effort level. That is, the payoff function of each member $i_j = 1_j, 2_j, 3_j$ is

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

Note that treatment SP is equivalent to a standard nine-firm Cournot Oligopoly with marginal cost $k+c$. In this sense, the treatment allows us also to test whether the framing of three players each as a firm influences behavior.

Treatment SH

Treatment SH is a treatment with (S)ymmetric firm-size and an allocation of profits per (H)ead. The treatment is analog to treatment SP except for the distribution of firm-profits and effort costs. Effort costs $k(e_{i_j}) = 0$ are nil, such that we obtain a behavioral equivalence between individuals in treatment C and teams in this treatment (see below).

For each firm $j = 1, 2, 3$, the payoff function of each member $i_j = 1_j, 2_j, 3_j$ is

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

That is, profits of the firm are allocated per head and independent of the member's effort.

Note that in this treatment (as well as in treatment AH below) any distribution of efforts among members adding up to the Cournot Nash equilibrium quantity of the firm is a Nash equilibrium. Thus this treatment allows us to investigate the impact of an intra-firm coordination problem on the quantity of the firm and the market outcome. In comparison with treatment SP, we can evaluate the effect of two different rules of profit distribution among members of a firm. Again, we have a behavioral equivalence between single-player firms and team-firms.

Treatment AH

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

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

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

This treatment with asymmetric team size allows us to study the effect of team-size on competition. Together with treatment SH, treatment AH enables us to analyze first, whether individuals behave differently towards team-firms than towards other individual firms, second, whether team-firms behave differently in markets with individual firms than in markets with other team firms only, and third, whether the number of members per firm has any influence on results.

Table 1 provides an overview of prominent outcomes such as the Nash equilibrium, the collusive outcome and the competitive outcome, revealing the theoretical behavioral equivalence between those treatments. The calculation is standard and thus omitted. Note again, that in treatment SH and AH there is a continuum of Nash equilibrium efforts 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 in each firm with more than one player. The table reports just the symmetric Nash equilibrium effort level. Note further, 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 behavioral equivalence between treatment SP and C is restricted to the Cournot Nash equilibrium.

Based on previous Cournot experiments in the literature, the game in each of our treatments was played repeatedly for 40 rounds with fixed matching in order to enable subjects to learn. Each subject had to choose his 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 single-member firms). The grid was chosen such to make all prominent outcomes feasible and allow also for the monopoly outcome. Between the rounds, each subject received feedback information on his own effort and profit, the total effort of all other members in his firm (only treatment SP, SH, and for team-firms in treatment AH) and the total quantity of all other firms in the previous period. Note that this information is sufficient for myopic best-reply learning.

Each session consisted of three stages: the briefing stage, the interaction-stage, and the debriefing stage. Stages 2 and 3 were programmed in the 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

Table 1: Behavioral equivalence across treatments

	treatments			
outcomes	SP	SH	AH	C
Nash equilibrium				
ind. effort	249.5	249.5^{a}	$249.5^{a,b}$ / 748.5^{c}	748.5
firm quantity	748.5	748.5	748.5	748.5
market quantity	2245.5	2245.5	2245.5	2245.5
collusive outcome				
ind. effort	$166\frac{1}{3}$ / 138.61^{d}	${166\frac{1}{3}}^{a}$	${166\frac{1}{3}}^{a,b}$ / 499^{c}	499
firm quantity	499 / 415.83^{d}	499	499	499
market quantity	1497 / 1247.5^{d}	1497	1497	1497
competitive outcome				
ind. effort	$332\frac{2}{3}$ / 277.22^{d}	${332\frac{2}{3}}^{a}$	${332\frac{2}{3}}^{a,b}$ / 998^{c}	998
firm 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

of the 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, costs functions, effort costs, profit-distribution and team-sizes were public knowledge. Moreover, all subjects knew what feedback they would receive after each round. The appendix provides an example of a screen-shoot. 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.[2] Subjects had a standard calculator available. Only after all subjects successfully completed the test, the interaction-stage was started. The exchange rate from the experimental currency Taler to EURO was announced in the instructions. It varied between 2500 to 400 Taler per Euro-cent depending on treatment and type of firm. Moreover, since losses are possible, each subject received a lumpsum payment upfront, which was also announced in the instructions.

In the interaction stage, subjects had to play the game repeatedly for 40 rounds. To support their decision, they had three different "trial"-calculators available (see screen-shoot in the appendix). It was understood from the instructions that the inputs in those calculations have no influence on their payoff from the experiment. First, there was a calculator (2a) that automatically computed the member's payoff if he inserted a number each for his own effort, the total effort by other members of the team and the total quantity of opponent-firms (the "trial calculator").[3] Second, there was a calculator (2b) that automatically computed the member's best response and profit if he 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 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. After each round subjects received feedback information (see above), which was displayed at the top of the next period's screen.

The debriefing stage consisted of a computerized questionnaire that asked for the

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

[3]The input fields of the calculator was adjusted to the different treatments.

following information: major, term, gender, whether the subject participated in a lecture on game theory, and how the participant would summarize his behavior. At the end of the questionnaire the final payoff converted in EURO was announced to the subject. The exchange rates were announced previously in the instructions. Final payoffs were paid immediately after the session concluded.

Beside the obvious treatment variables discussed above, there are other variables that could influence the experimental outcome, but which we fixed throughout the experiment. For instance, we do not study the influence of information on the behavior of firms. We are aware that different information may lead to different learning behavior and outcomes (see for example Huck, Normann and Oechssler, 1999, 2000). Since we do not want to study how subjects master the degree of computational complexity involved in playing optimally, we provided them with the three different calculators discussed above. We also decided to use the framing as "firms", "market" etc. since it is standard in the literature on Cournot experiments (see Huck, 2002).

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

3 Hypotheses

The aim of this article is to test the unitary player assumption in the Cournot oligopoly. Our design allows us to test the following hypotheses. Note that each market is an independent observation.

Hypothesis 1 *Total outputs of markets do not differ significantly across treatments.*

Hypothesis 2 *Total outputs of markets do not differ significantly from total Cournot Nash equilibrium output.*

Hypothesis 3 *Team-firms do not behave significantly different in markets with individual firms than in markets with other team firms only. I.e., outputs of team-firms in treatment SH are not significantly different from outputs of team-firms in treatment AH.*

Hypothesis 4 *Individual firms do not behave significantly different in markets with team-firms than in markets with other individual firms only. I.e., outputs of individual firms in treatment AH are not significantly different to outputs of individual firms in treatment C.*

Above hypotheses summarize what one associates with the unitary player assumptions in our framework. That is, one may be confident with the unitary player assumption in the Cournot oligopoly if above hypotheses are not rejected.

Above hypotheses concern the average behavior in the experiment. We do not expect that subjects choose exact equilibrium efforts over all 40 periods. Rather, our design allows subjects to learn using a (sequential) best-reply process. Indeed, since the game in each treatment has a potential function[4], one can show that sequential myopic best-reply converges to the Nash equilibrium in finite time (see Monderer and Shapley, 1996).

Hypothesis 5 *Individual efforts, firms' quantities and market quantities converge to Nash equilibrium levels.*

Apart from the above hypotheses we would like to analyze the following issues. First, how is the co-ordination problem in treatments SH and AH reflected in the data? Do

[4]To see this, note that according to Monderer and Shapley (1996) a Cournot oligopoly with linear demand and costs has a potential function. Notice that treatment SP is equivalent to a 9-firm Cournot oligopoly with linear costs $c + k$. Finally, note that treatment SH and AH is equivalent to a 3-person Cournot games except for the a fixed factor $\sharp F_j^{-1}$ in firm j's profit function. This factor, however, causes no problem for the existence of an ordinal potential.

subjects manage to select an equilibrium or are they unable to co-ordinate on one of them? Second, our design allows subjects to follow a (sequential) best-reply process converging to the Cournot Nash equilibrium. We would like to check whether this is indeed the case. Third, we would like to relate the calculator inputs to the individual quantities. Do subjects choose an effort that they calculated beforehand? Are subjects' "beliefs" about opponents correct in the sense that opponents behave as assumed in their previous calculations? Do subjects search for best or better replies?

4 Results

The experiment was conducted in the Bonn Laboratory of Experimental Economics in May 2003. For each treatment we generated 6 independent observations. In total 168 subjects participated in our experiments. According to answers to the questionnaire at the end of the experiment, 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. We could not find any focal correlation between the results and the subjects' characteristics

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

4.1 Market Quantities

Figure 1 presents the average market quantities per treatment across the 40 periods. A first glance suggests that average market quantities are very similar across treatments. Average market quantities are slightly larger in treatments SH and AH. Figure 1 also reveals that market quantities are distributed closely around the Cournot Nash equilibrium market quantity.

Figure 1: Average market quantities

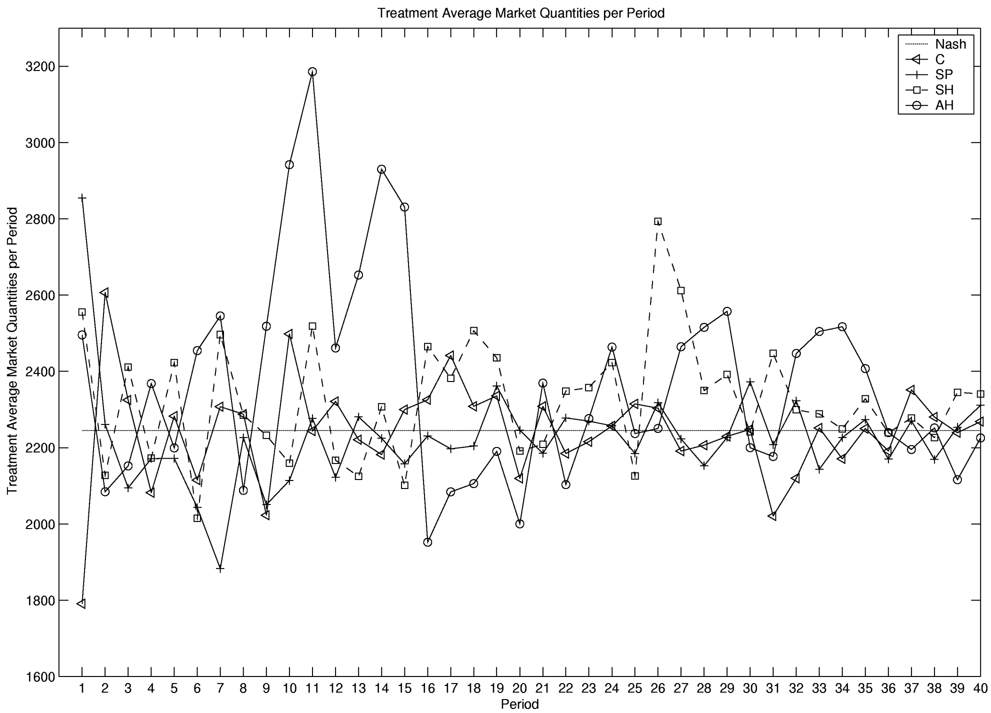


Table 2 provides the summary statistic for market quantities per treatment. Treatments SH and AH have slightly higher average market quantities than treatments SP and C. The latter two have also smaller standard errors. The Cournot Nash equilibrium is in all treatments the best predictor compared with the competitive outcome and the collusive outcome. However, treatments SP and C deviate less from the Cournot Nash equilibrium prediction than treatments SH and AH.

Figure 2 displays the market quantities for each of the six markets per treatment across the 40 periods of the experiments. Again, there are no visible differences across treatments. The market quantities are distributed around the Cournot Nash equilibrium market quantities.

Figure 2: Market quantities per treatment

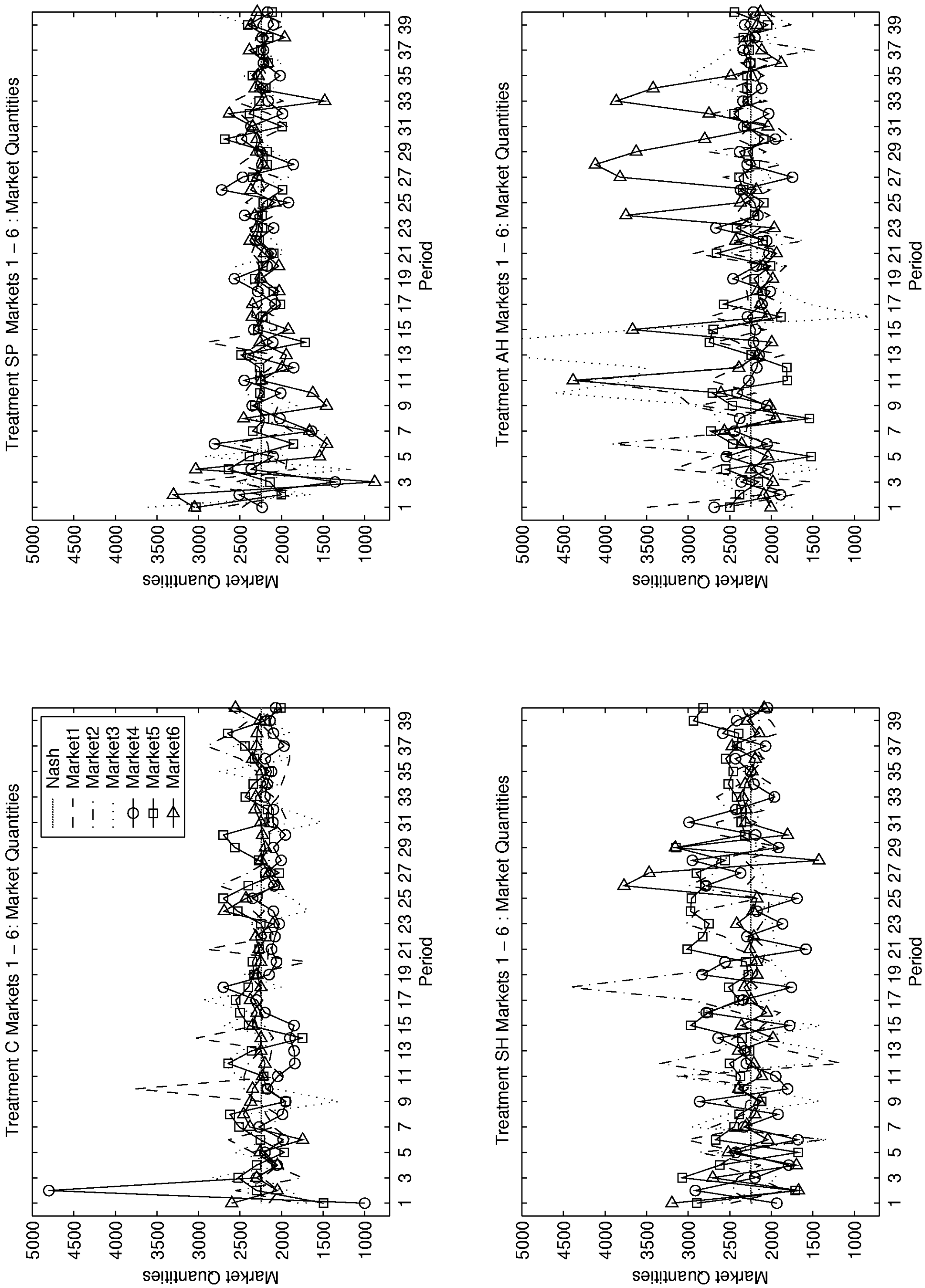


Table 2: Summary statistic of market quantities across treatments

	treatments			
	SP	SH	AH	C
average	2224.74	2324.37	2369.05	2243.06
standard error	292.24	396.80	510.10	306.34
st. err. to Nash equ.	290.94	427.96	522.80	306.46
st. err. to competitive out.	825.50 / 397.94[a]	782.11	843.19	813.40
st. err. to collusion	789.62 / 1024.20[a]	918.57	1020.00	813.29

[a] from the individual's view

The behavioral equivalence is indeed confirmed for treatment SP and SH by the two-sided Wilcoxon-Mann-Whitney Test and the Robust Rank Order Test (see Siegel and Castellan, 1988)[5], in which we compared the average market quantities of SP and SH with the ones of treatment C. For the two-sided Wilcoxon-Mann-Whitney Test we can not reject Hypothesis 1 even at the 0.29 level for treatment SP and SH, and at the 0.045 level for treatment AH (always compared to treatment C). For the Robust Rank-Order Test, we can not reject Hypothesis 1 for treatment SP and SH at the 0.1 level and for treatment AH at the 0.05 level. The lower significance levels for treatment AH are probably due to a few periods of extreme outliers in two observations of AH. If we omit these two observations and compare the 4 remaining average market quantities of AH with the ones of C we cannot reject a behavioral equivalence even at the 0.1 significance levels.

The Nash equilibrium prediction is confirmed by a two-sided Kolmogorov-Smirnov

[5]The two-sided Wilcoxon-Mann-Whtiney Test indicates whether samples from two populations have the same distribution without presupposing the direction of eventual differences. In contrast, the Robust Rank-Order Test is concerned with the medians of those two samples without assuming that they are sampled from the same distribution. Note that 0.1 is the highest significance level in Siegel and Castellan (1988) for this test.

One-Sample Test (see Siegel and Castellan, 1988).[6] Rejection of the null-hypothesis was not possible even at the 0.2 significance level.

So far, the observations of market quantities are summarized as follows:

Observation 1 *Total output of markets do not differ significantly across treatments C, SP, and SH. I.e., for these treatments we can not reject Hypothesis 1. For treatment AH significance levels are lower than in treatment SH and SH.*

Observation 2 *Total output of markets do not differ significantly from the total Cournot Nash equilibrium output. I.e., we can not reject Hypothesis 2.*

From Table 2 we know that standard errors in treatment SH and AH are higher than in treatment SP and C. Indeed, judging by the Figures 1 and 2, the volatility seems to be higher in treatment SH and AH than in SP and C. This is probably due to the co-ordination problem subjects faced within each firm in those treatments. Recall that there are many individual Nash equilibrium efforts all adding to the firm's Nash equilibrium quantity. Figure 2 may also suggest that the volatility does not decrease and perhaps even increases in treatment SH and AH. However, in treatments SH, AH, and C there is only one market each where the standard error is higher in the last 20 periods than in the first 20 periods. In treatment SP there is no market with increased standard error in the last 20 periods.

Observation 3 *Standard errors are higher in treatments SH and AH, which is probably due to the co-ordination problem faced by the individuals in each firm. There is no substantial evidence that standard errors increase over the 40 periods.*

[6] The two-sided Kolmogorov-Smirnov One-Sample Test is concerned with the goodness-of-fit between the distribution of a set of sample values and some theoretical distribution. It evaluates whether the sample values could have come from the same theoretical distribution.

4.2 Individuals and Firms

We want to test whether team-firms behave significantly different in markets with individual firms than in markets with other team-firms only. Notice that treatment AH is more similar to treatment SH than treatment SP or C. Hence we compare data from team-firms in treatment AH to team-firms in treatment SH instead SP or C. Since we have three (two) team-firms per market in treatment SH (AH), we randomly select one from each market in order to get six independent observations from each treatment. The significance level is 0.47 for the two-sided Wilcoxon-Mann-Whitney Test and rejection is not possible at the 0.1 level for the Robust Rank-Order Test. Clearly, we can not find any significant difference.

We also want to test whether individual firms behave significantly different towards team-firms than towards other individual firms. To test this, we consider data from individual firms in treatment AH and compare these to quantities of individual firms in treatment C. Whereas in each market of treatment AH we have a single individual firm (playing with two other team firms), in treatment C we have three individual firms in each market. Thus in treatment C we randomly select for the test one of the three individual firms in each market. Thus, for treatment AH and C, we have six independent observation each, which we test for whether they differ significantly or not. The significance level is 0.35 for the two-sided Wilcoxon-Mann-Whitney Test and rejection is not possible at 0.1 level for the Robust Rank Order Test. Again, there is no significant difference.

Observation 4 *Team-firms do not behave significantly different in markets with individual firms than in markets with other team firms only. I.e., we can not reject Hypothesis 3.*

Observation 5 *Individual firms do not behave significantly different in markets with team-firms than in markets with other individual firms only. I.e., we can not reject Hypothesis 4.*

In treatments SH and AH the standard errors of the firm quantities and individual

Table 3: Standard error of firm quantities and individual efforts

treatment	ind. effort	firm's quantity
SP	79.44	149.35
SH	121.67	201.27
AH	191.08[b]	204.13[a] / 264.72[b]
C	-	162.37

[a] only 1-player firms

[b] only 3-player firms

efforts are higher than in treatments SP and C (Table 3). Interestingly, in treatment AH the standard deviation of subjects in three-player firms (191.08) is almost as high as the standard deviation of subjects in one-player firms (204.13). Again, this is probably due to the co-ordination problem that subjects faced in treatment SH and AH. Moreover, standard errors for team-firms in treatment AH are higher than standard errors for team-firms in treatment SH. The latter are at about the same magnitude as standard errors of individual firms in treatment AH. It appears that the heterogeneity of firm size in treatment AH increases the standard error of quantities of team-firms.

Standard errors do not decrease during the 40 rounds for a substantial portion of subjects and firms. I.e., standard errors for the last 20 rounds are higher for a sizeable portion of individual firms and team-firms across treatments, especially in treatments SH and AH (about 30% of individual firms and about 20% of team firms).

Observation 6 *The standard errors of firms' quantities and individuals' efforts are higher in treatments SH and AH than in treatments SP and C, which is probably due to the co-ordination problem. The standard errors in those treatments do not decrease in the last 20 periods of the experiment for a substantial proportion of individuals and firms.*

Our data on individual efforts/quantities suggest some behavioral heterogeniety among subjects. A way of capturing this heterogeniety is by constructing different types of sub-

Table 4: Types of players

	SP	SH	AH	C
aggr. ind.	16.7%	25.9%	25.0%	-
def. ind.	11.1%	35.2%	27.8%	-
aggr. firms	5.6%	11.1%	2.8%[a] / 0.0%[b]	5.6%
def. firms	5.6%	16.7%	2.8%[a] / 0.0%[b]	5.6%

[a] only in 3-player firms

[b] only in 1-player firms

jects. We distinguish between aggressive and defensive subjects and firms. We say a subject (firm) is aggressive if 60% of the periods he plays at least 50 (100) grid-points above the Nash equilibrium level. Similarly, a subject (firm) is defensive if 60% of the periods he plays at last 50 (100) grid-points below the Nash equilibrium level. Table 4 reveals the distribution of types across treatments. For individual efforts, treatment SH and AH have a higher percentage of extreme types compared to SP. Note that in those treatments there were also asymmetric equilibria involving asymmetric levels of efforts across individuals within the same firm. Similarly, treatment SH has more extreme firms compared to SP, AH, and C. There is not much difference among the latter three treatments in terms of the distribution of types of firms. Remarkably, the percentage of defensive and aggressive types of firms is almost equal in each treatment.

Observation 7 *Treatments SH and AH lead to more asymmetry among individual effort levels as compared to treatment SP. This is in line with the existence of asymmetric Nash equilibria in treatments SH and AH.*

4.3 Convergence and Learning

We say that a time series of a variable converges to the Nash equilibrium level if in the last 20 rounds a higher percentage of cases is within a range of $+/-\delta$ around the Nash

Table 5: Percentage of cases within the interval around symmetric Nash equilibrium

treatment	ind. efforts	firms' quantities	market quantities
SP	29.8% / 36.8%	39.2% / 52.5%	31.7% / 54.2%
SH	13.9% / 15.0%	26.7% / 42.5%	23.3% / 27.5%
AH	12.9% / 11.7%[a]	31.9% / 45.6%	20.0% / 34.2%
C	-	45.8% / 57.8%	33.3% / 45.0%

[a] 3-player firm

first 20 rounds /last 20 rounds

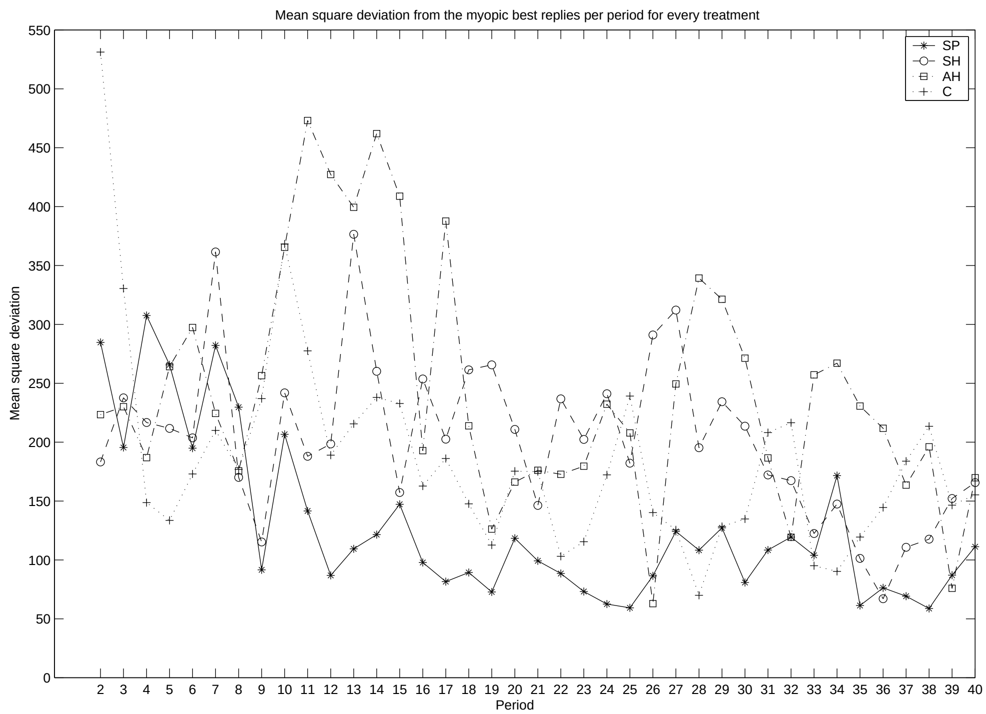
equilibrium level than in the first 20 rounds. We fix δ at 30, 80, and 100 grid-points for the individual efforts, the firm quantities and the market quantities respectively.

In Table 5 we report the percentage of cases which do belong to the interval in the first and second 20 periods of the experiment. In almost all treatments (except the individual efforts in treatment AH) a larger percentage of cases lies within the interval in the last 20 periods of the experiment compared to the first 20 periods. Whereas about 50% of firm quantities and market quantities lie in the interval for treatments SP and C, this is lower in treatments SH and AH. Percentages for individual values are lower than for firm and market quantities probably due to an averaging effect.

According to Hypothesis 5, individual efforts, firm quantities and market quantities should converge to the Nash equilibrium levels in all treatments. Indeed, our design allowed subjects to learn the respective equilibrium levels using a myopic sequential best-reply process. However, there is only weak evidence for myopic best-reply learning across treatment. Figure 3 shows the mean square deviation between each subject's best-reply and the actual effort choice per period per treatment. Although the mean square deviation declines over 40 periods, it is still substantial at the end of the 40 rounds.

Observation 8 *There is only weak evidence for myopic best-reply learning and convergence to Nash equilibrium levels.*

Figure 3: Mean square deviation between best-reply and individual efforts

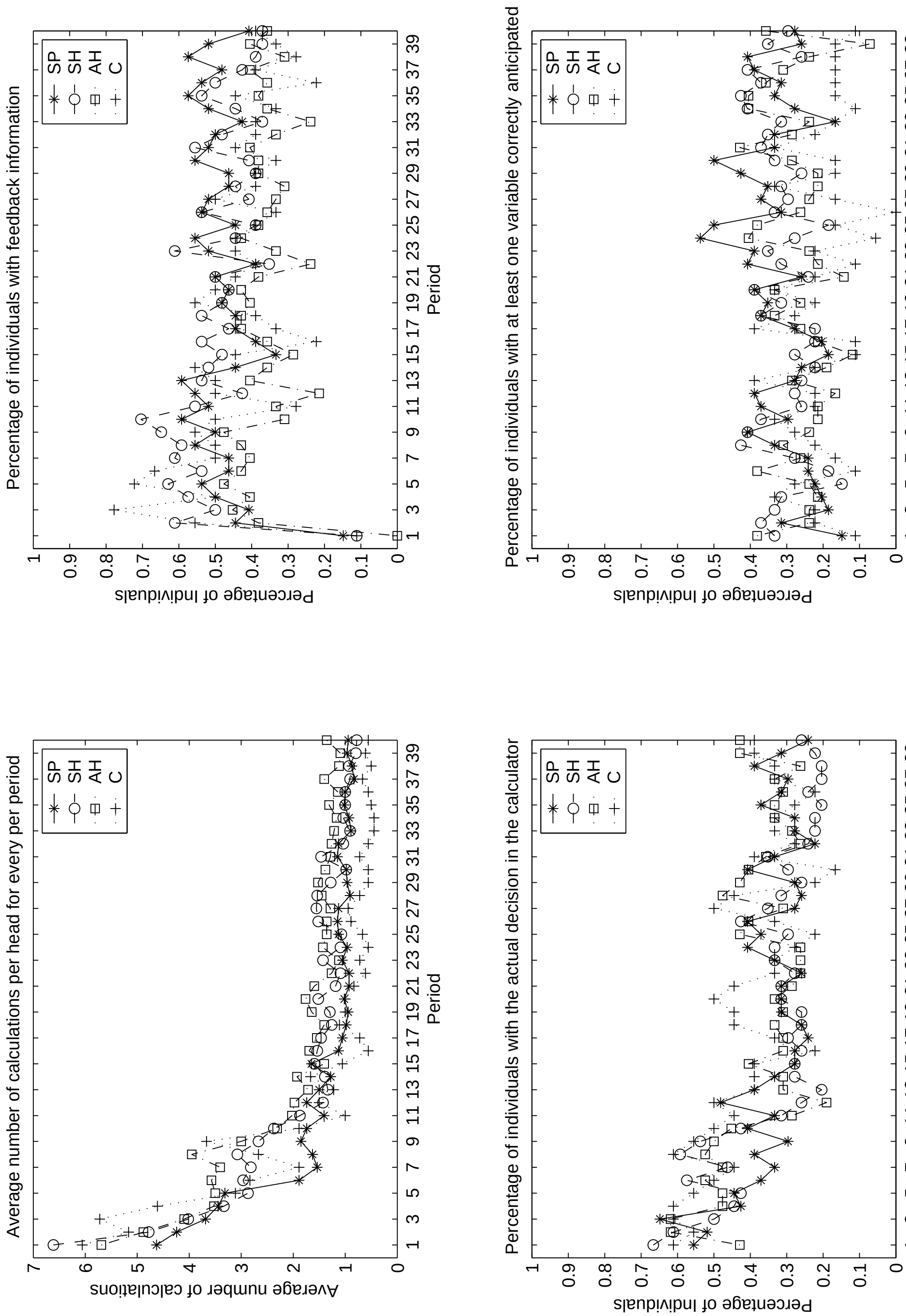


4.4 Calculator Data

One feature of our experimental design is the collection of data calculated by subjects. On average each individual made about 70 calculations with any of the two calculators during the experiment. This is about 1.75 calculations per head and per period. Thus subjects spent efforts to solve the interactive decision problem. In about 38.3% of all calculations, subjects used the trail calculator, whereas 61.7% of the time the best-reply calculator was used. These proportions did not vary much across treatments. The best-reply calculator was used more often than the trial calculator in all treatments.

The four charts in Figure 4 provide information about the use of calculators. The upper left chart shows the average number of calculations per head over all 40 periods. It starts with 5 to 7 calculations per period and falls to 1 to 2 calculators per period

Figure 4: Calculator



after the tenth period. It appears that treatment C required less calculations than the other treatments. The chart in the lower left corner answers the question about the percentage of individuals that played a decision previously calculated. It starts with 50% to 70% and seems to fall below 50% (in treatment SH even to about 20%). We do not know the subject's motivation for their calculations. However, the upper right chart indicates that only about half of the subjects used their calculations for checking the result of the previous period. Thus it is unlikely that they consciously used some myopic best-response adjustment process. Finally, the lower right graph shows that only a small fraction of individuals used at least one variable that also appeared in the subsequent period. This fraction does not increase over the 40 periods. If we assume that subjects try out what they believe opponents will do, then the graph indicates that subjects were unable to correctly anticipate the decisions of others and did not learn to anticipate other's decisions.

The time taken for decisions per period decreased from about 200 seconds at the beginning to about 50 seconds after the 10th period, and to about 30 seconds at the end. Almost across all periods these decision times were slightly higher in treatment SH and AH compared to treatments SP and C.

5 Conclusions

In Cournot competition, the decision making by firms is modeled as if the decision of the firm is done by a single decision maker (treatment C). This entails the unitary player assumptions. To provide a theoretical justification, we introduce simple team structures for each firm (treatments SP, SH, and AH) that lead to the same results as if the decisions of a firm are done by single decision maker. We test the unitary player assumption experimentally and find support for it on the level of market quantities even if members of a firm face a co-ordination problem within the firm (treatments SH and AH). That is, average market quantities does not differ significantly across treatments. The size of the team has no influence on the output of the firm and opponents.

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 (except you there are two other members in your firm). Each market consist of 3 firms (except 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 in 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 costs to the firm are 1 Taler per quantity. The price per quantity depends on your firm 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

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

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

$$\text{profit per quantity} = \begin{array}{c}\text{price per}\\\text{quantity}\end{array} - \begin{array}{c}\text{firm costs per}\\\text{quantity}\end{array}$$

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 his effort spent in the firm. The effort can lie between 0 and 1250 (in steps to 0.1). The costs to each participant per effort is

$83\frac{1}{3}$ 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 on the profit of the firm. This share is calculated as follows:

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

The costs of effort is calculated from the costs per effort of $83\frac{1}{3}$ 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 participants per period is calculated as follows:

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

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 (top left in the corner you can find the number of the period):

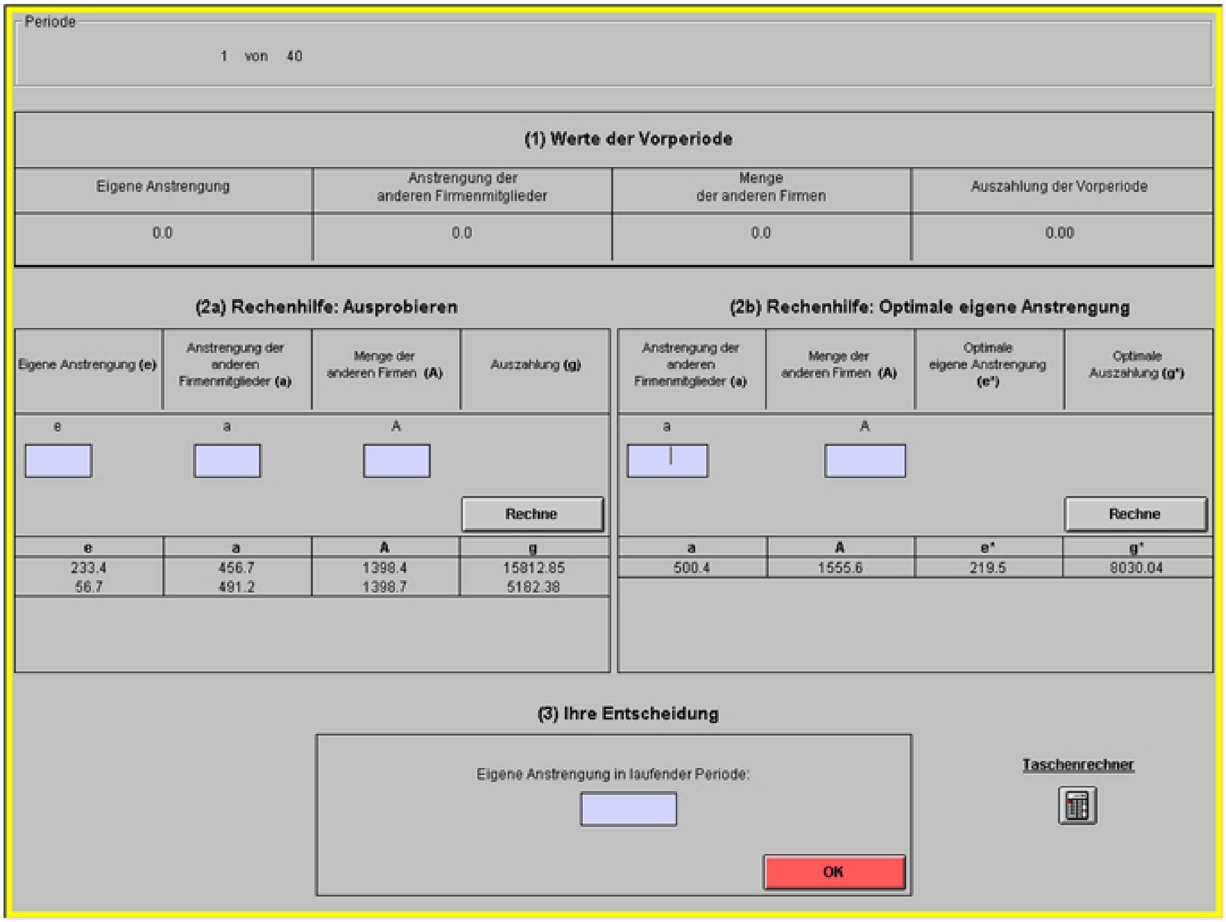
(1) Values of the previous period

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

Second, there are two calculators for trying out of decisions, which you can use. The input into the calculators do 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 efforts 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

quantity of other firms (A)	=	sum of quantities of the other two firms
	=	sum of efforts of all members of the other two firms

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 experiments proceeds with the next period. After 40 periods a questionnaire appears at the screen, which we ask you kindly 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. and I. Erev, 1994, The enhancing effect of intergroup competition on group performance, International Journal of Conflict Management 5, 271-284.

[2] Bornstein, G., Erev, I., and O. Rosen, 1990, Intergroup competition as a structural solution to social dilemmas, Social Behavior 5, 247-260.

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

[4] Bornstein, G., Gneezy, U., and R. Nagel, 2002, The effect of intergroup competition on group coordination: An experimental study, Games and Economic Behavior 41, 1-25.

[5] Bornstein, G. and M. Ben-Yossef, 1994, Cooperation in intergroup and single-group social dilemmas, Journal of Experimental Social Psychology 30, 52-67.

[6] Bornstein, G., Budescu, D., and T. Kugler, 2002, Repeated price competition between individuals and between teams, The Hebrew University of Jerusalem.

[7] Bornstein, G., Budescue, D., and S. Zamir, 1997, Cooperation in intergroup, two-person, and n-person games of Chicken, Journal of Conflict Resolution, 41, 384-406.

[8] 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.

[9] Erev, I., Bornstein, G., and R. Galili, 1993, Constructive intergroup competition as a solution to the free rider problem: A field experiment, Journal of Experimental Social Psychology 29, 463-478.

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

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

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

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

[14] Huck, S., 2002, Simple oligopoly experiments, mimeo, University College London.

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

[16] Huck, S., Normann, H., and J. Oechssler, 2000, Does information about competitors increase or decrease Competion in experimental Oligopoly markets?, International Journal of Industrial Organization 18, 39-58.

[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] Huck, S., Müller,W., and H.T. Normann, 2001, Stackelberg beats Cournot: On collusion and efficiency in experimental markets, Economic Journal 111, 749-765.

[19] Huck, S., Konrad, K.A., Müller, W., and H.T. Normann, 2002, Mergers and the perception of market power: An experimental study, Tilburg University.

[20] Insko, C., Schopler, J., Graetz, K., Drigotas, S., Currey, D., Smith, S., Brazil, D., and G. Bornstein, 1994, Interindividual-intergroup discontinuity in the Prisoner's Dilemma Game, Journal of Conflict Resolution 38, 87-116.

[21] Rapoport, A. and G. Bornstein, 1989, Solving public goods problems in competition between equal and unequal size groups, Journal of Conflict Resolution 33, 460-479.

[22] Schopler, J. and C. Insko, 1992, The discontinuity effect in interpersonal and intergroup relations: Generality and mediation, European Review of Social Psychology 3, 121-51.

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

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

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

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

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

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