Does information about competitors' actions increase or decrease competition in experimental oligopoly markets?*

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Abstract

This paper investigates the impact of information about rivals' actions on the competitiveness of experimental oligopoly markets. We compare two treatments: in one, firms are informed about their rivals' actions and profits. In the other, firms are only given some aggregate information about their rivals' actions (aggregate quantities, average price). We find that in markets where goods are strategic substitutes (Cournot) the first, full information treatment leads to a significantly higher degree of competition. This is in contrast to conventional wisdom in IO. However, in markets with strategic complements (Bertrand), we find no significant difference between the two treatments.

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1 Introduction

At least since Stigler's (1964) seminal paper, economists have recognized that the publication of private firm–specific data may have an adverse effect on the competitiveness of markets. Stigler argued that the greatest obstacle to collusion is, what he called, "secret price cutting". When competitors cannot observe secret price cuts by rivals, cartels will inevitably break down. However, when firms are well informed about the moves of their rivals, firms may successfully cartellize a market since deviations are immediately detected.

Green and Porter (1984) and Green (1980) came to similar conclusions employing a framework of non–cooperative repeated games. In Green and Porter (1984) there is uncertainty about demand. Firms set their quantities in every period, but they do not know the quantities of their rivals. When the market price is low, firms do not know whether this is because of unusually low demand or because someone deviated from the implicit cartel agreement. As a result, Green and Porter show that, in equilibrium, firms are able to maintain some collusion, but they have to engage in episodic price wars to prevent cheating. However, if firms were informed about their rivals' actions, they would be able to infer the full–information cartel outcome. Green (1980) provides a model in which there is a large number of firms. Each firm is so small that a deviation from the collusive price would not be detected—given that firms' prices cannot be observed. Then the outcome is competitive. However, when firms can observe the decision of the other firms in the market, the fully collusive outcome can be sustained as an equilibrium of the repeated game.

Recently, the contrary argument was made by Vega–Redondo (1997) in a game theoretic learning model based on imitation. He assumes that firms set quantities and that they are informed about their competitors' quantity decisions and profits in every period. The novel approach of Vega-Redondo's paper is to leave the framework of non–cooperative game theory with its best–reply logic and to check what happens if firms *imitate* successful behavior. Interestingly, if firms myopically imitate the most successful strategy of the previous period and if there is a small probability that firms mistakenly choose an arbitrary quantity, the market evolves to the competitive equilibrium. The intuition of the result is easy to get: if the price is above marginal cost, the firm with the largest quantity has the highest profit. Then the quantity is imitated by the other firms. This explains why quantities increase and why the price is pushed downwards, even below its Cournot–Nash level. But, if the price is below marginal cost, the firm with the lowest quantity has the highest profit. Vega–Redondo (1997) shows that the only long–run stable state is where all firms produce at the competitive outcome, that is, where price equals marginal cost. In the theory section of this paper we extend Vega–Redondo's result to the case of price competition.

We conclude that the theoretical evidence to our problem is mixed. On the one hand, along the line of Stigler's point, the provision of information about firms' actions would make markets less competitive and would reduce welfare. From that point of view, the publication of individual firms' actions is a powerful instrument to enforce collusion. On the other hand, Vega-Redondo's theory suggests that such information makes markets more competitive and increases welfare. From that point of view the publication of firms' actions makes imitation and related phenomena like rivalistic behavior or the maximization of relative profits possible, which leads to (more) competitive markets. Note that both theories lead to outcomes that depart distinctly from the non–cooperative Nash equilibrium.

Also competition policy regarding the provision of information about firm specific actions seems to follow different routes. The Commision of the European Union considers the publication of detailed information as anti–competitive. In various decisions, the Commission argued that such firm–specific information would create an "artificial transparency" of the market, leading to less competition. While the Commission allows for the publication of aggregate industry data, the information must not be suited to identify individual actions.[1] By contrast, U.S. authorities do not consider such information arrangements as a violation of the Sherman Act *per se*. The publication of firm–specific industry data by trade associations is generally tolerated (see Kühn and Vives, 1994, and Scherer and Ross, 1990). Albæk, Møllgaard and Overgaard (1997) report that, until only recently, Danish competition policy went even further as the Danish Competition Council was very much in favor of the publication of firm–specific price data. Regarding the concrete industry, the Council decided to publish transaction prices of individual firms in order to promote market transparency. Albæk, Møllgaard and Overgaard show, however, that prices increased by 15-20% after publication. The Council stopped the publication of the data and, moreover, changed the design of its competition policy.[2]

Given those diverging views in theory and policy we attempt to test them

[1] See Kühn and Vives (1994) for a detailed discussion of the policy of the Commission.

[2] We should mention here that neither the Danish, nor the U.S. authorities made use of arguments comparable to that of Vega-Redondo (1997). Rather, the idea is that the publication of firm–specific data increases market transparency. When potential buyers' are better informed about the conditions in the market, this reduces their search costs.

experimentally. We study two kinds of multi–period oligopoly markets—homogenous Cournot markets where actions are strategic substitutes and heterogenous Bertrand markets where actions are strategic complements. In both cases we compare two different settings varying in the information that is available. In one treatment subjects have all basic information about the market structure that is needed to play the equilibrium. Here we expect the Nash outcome and find on both, the Cournot and the Bertrand market, behavior converging to it. In the second treatment firms have additional information about rivals' actions and profits.[3] It turns out that the effect of this additional information crucially depends on the strategic situation: In the case of strategic complements it has no significant effect on market outcomes. But in the case of strategic substitutes it renders market outcomes significantly more competitive. In neither cases we find evidence for the hypothesis that additional information or a higher degree of market transparency facilitates collusive behavior.

2 Experimental design and theoretical predictions

In a series of computerized[4] experiments we studied multi–period oligopoly markets with four symmetric firms. To check for robustness we compared two strategic settings, one in which actions are strategic substitutes (a homogenous Cournot market) and one in which actions are strategic complements (a Bertrand markets with product differentiation).

Actions could be chosen from finite but sufficiently fine grids such that continuous action spaces were approximated. For both strategic settings we have conducted two treatments which varied only with regard to the information given to subjects. The number of periods was 40 in all sessions and this was commonly known.[5]

In treatments labeled "BASIC" subjects had sufficient information about demand and cost conditions to calculate best replies to the actions of the other firms. This information was provided verbally and in the form of a 'profit calculator'. The profit calculator served two functions. When fed

[3] To make imitation work subjects must be able to assess the success of different actions. Of course, in a symmetric market, subjects could infer profits from observing actions only.

[4] We thank Abbink and Sadrieh (1995) for letting us use their software toolbox "RatImage".

[5] We consider the time horizon of 40 periods long enough to make repeated game arguments possible. Selten and Stoecker (1986) show that, apart from an end game effect, there is no behavioral difference between an experiment with a long finite horizon and one which approximates an infinite horizon by the device of a stopping probability.

Table 1: **Design**

	Strategic	
Information	Substitutes	Complements
Basic	BASIC COURNOT	BASIC BERTRAND
Extra	EXTRA COURNOT	EXTRA BERTRAND

with data regarding the other firms (total quantities of the firms in the Cournot case, average price of active other firms in the Bertrand case), the calculator allowed to try out the consequences of own actions. Furthermore, it allowed to calculate a best reply against the (hypothetical) actions of the other firms.[6] Thus, these treatments were conducive towards best reply behavior and the setup was chosen such that best reply dynamics would converge to the unique Nash outcome.

Treatments labeled "EXTRA" provided the same information as BASIC plus additional information about the other firms' individual actions of the previous period. This 2–by–2 design is summarized in Table 1. In the following we will describe the Cournot and Bertrand markets in more detail.

2.1 Strategic substitutes: The Cournot market

On the homogenous Cournot market four symmetric firms chose quantities from a finite grid between 0 and 100 with .01 as the smallest step. The demand side of the market was modelled with the computer buying all supplied units according to the inverse demand function

$$p^t = \max\{100 - Q^t, 0\} \tag{1}$$

with $Q^t = \sum_{i=1}^{4} q_i^t$ denoting total quantity in period t. The cost function for each seller was simply

$$C(q_i^t) = q_i^t.$$

Since we expected the Walrasian output (in which profits are zero) as a possible outcome in one treatment, we wanted to make sure—besides avoiding the usual bankruptcy problems—that subjects would not be frustrated by low or negative payoffs.[7] Thus subjects received a fixed payoff of 150 each

[6] The profit calculator provides essentially the same information as the usually used payoff tables. Furthermore, it helps to avoid a bias due to limited computational abilities of subjects.

[7] See Holt (1985, p. 317) for the argument that the usual promises in the instructions that one can earn a "considerable amount of money" might bias subjects against zero–profit outcomes.

round. This ensured that no losses could be made. Hence, profits were

$$\pi_i^t = (p^t - 1)q_i^t + 150. \tag{2}$$

It is well known that the best reply dynamics, in which firms simultaneously choose best replies to other firms' last period's total output, do not converge in markets with 4 firms and with linear demand and cost (Theocharis, 1960). Therefore, we introduced inertia by letting chance moves decide whether subjects were allowed to revise their quantity or not.[8] It is then straightforward to show the following

Result Q1 Myopic best reply dynamics with inertia converge globally to the Cournot–Nash equilibrium (Huck, Normann, and Oechssler, 1997, Prop. 1).

Note the informational requirements to play myopic best replies. (1) One needs to know the demand and cost functions. (2) One needs to know last period's total quantity price of other players. And (3) one needs to know how to calculate a best reply. All three requirements are met in both experimental treatments BASIC and EXTRA.

If subjects have additional information about individual actions and profits (as in treatment EXTRA COURNOT), an alternative learning routine based on imitation becomes feasible. Suppose subjects imitate in each period, when they are allowed to change their quantities, the strategy which was most successful last period. Furthermore, with some small probability $\varepsilon > 0$ individuals choose some random strategy. Then we have the following

Result Q2 If individuals follow an "imitate–the–best" process with noise ε, then the symmetric Walrasian outcome, where price equals marginal cost, is the unique long run state as $\varepsilon \to 0$ (Vega-Redondo, 1997).

Note that the informational requirement needed for such imitation is only met in EXTRA.[9]

Following Stigler's (1964) argument the provision of firm specific data, as in treatment EXTRA, should make collusion easier to sustain. At the

[8] We have also run experiments without inertia but this did not alter the outcome in any significant way.

[9] Maximization of relative profits would also lead to the symmetric Walrasian outcome: Maximizing with respect to q_i the difference between firm i's profit and the average profits of its competitiors, $q_i(99 - Q) - \sum_{j \neq i} q_j(99 - Q)/(n - 1)$, yields $q_i = 99/n$ for all i, which is the competitive outcome.

Table 2: **Benchmarks for the Cournot market**

Outcomes	Indiv. quantities	Total quantities	Prices	Profits
Cournot–Nash	19.8	79.2	20.8	542.04
Walrasian	24.75	99	1	150
Collusion	12.375	49.5	50.5	762.56

(symmetric) collusive outcome, quantities are $q^C = 12.375$ and the price is $p^C = 50.5$.[10]

Thus we have three benchmark results for our experiment, the Cournot Nash equilibrium, the (symmetric) Walrasian outcome and the collusive outcome. Table 2 compares all three benchmarks for the parameters used in the experiment.

2.2 Strategic complementarity: The Bertrand market

On the Bertrand market prices had to be chosen from a finite grid between 0 and 1000 with .01 as the smallest step. We used a standard setup to model product differentiation (see e.g. Martin, 1993). For each firm i inverse demand was given by

$$p_i = \max\left\{ a - q_i - \theta \sum_{j \neq i} q_j, 0 \right\}, \tag{3}$$

where $\theta \in [0, 1)$ denotes the degree of product differentiation. The limiting cases are a homogeneous market for $\theta = 1$, and fully independent markets for $\theta = 0$. Solving the system of equations (3) for $i = 1, ..., 4$ and provided that $q_i \geq 0$ one obtains

$$\begin{aligned} q_i &= \frac{1}{1 + (n-1)\theta} \left(a - p_i + \frac{n\theta}{1-\theta} (\bar{p} - p_i) \right) \qquad (4) \\ &= \frac{1}{1 + (n-1)\theta} \left(a - \frac{1 + (n-2)\theta}{1-\theta} p_i + \frac{(n-1)\theta}{1-\theta} \bar{p}_{-i} \right), \end{aligned}$$

where n is the number of *active* firms (i.e. $q_i > 0$), $\bar{p} := \frac{1}{4} \sum_{\{i: q_i > 0\}} p_i$ their average price and

$$\bar{p}_{-i} := \frac{1}{3} \sum_{\{j \neq i: q_j > 0\}} p_j$$

[10] We should point out, that neither Green's (1980), nor Green and Porter's (1984) theory is directly applicable to our setting as we have only few firms and no demand fluctuations.

the average price of active firms other than i. We had to use this slightly complicated formulation because firms whose prices are so high that a negative quantity would result according to (4) do not enter into the calculation of the average prices $\bar{p}$ or $\bar{p}_{-i}$.

If all firms are active, we can simplify notation by setting $a = 100(1+3\theta)$, $\alpha := \frac{1+2\theta}{(1-\theta)(1+3\theta)}$ and $\beta := \frac{3\theta}{(1-\theta)(1+3\theta)}$. Thus (4) becomes

$$q_i = \max\{100 - \alpha p_i + \beta \bar{p}_{-i}, 0\}. \tag{5}$$

Note that $\alpha > \beta$ if $\theta < 1$.

In the experiment we used the following parameters

$$a = 300$$
$$\theta = 2/3$$

which implied for the case of 4 active firms that

$$\alpha = 7/3$$
$$\beta = 2.$$

The cost function for each seller was

$$C(q_i) = 2q_i.$$

Hence, profits were

$$\pi_i = (p_i - 2)q_i. \tag{6}$$

The unique Nash equilibrium of the stage game, in which all firms choose[11]

$$p_i^N = \frac{100 + \alpha c}{2\alpha - \beta} = 39.25, \; i \in I,$$

and a corresponding quantity of $q^N = 86.92$, is also the outcome of the unique subgame perfect equilibrium. As in the previous section we can derive benchmark results.

Result P1 Myopic best reply dynamics converge globally to the static Nash equilibrium.

[11]Note that given the demand function (4) and constant marginal cost of 2, it is never optimal for a firm to choose a price such that $q_i = 0$. Thus, when firms play best replies, they will always be active.

Table 3: **Benchmarks for the Betrand market**

Outcomes	Prices	Individual quantities	Profits
Nash	39.25	86.92	3237.6
Imitation	31.8	89.4	2664.1
Collusion	151	49.67	7400.3

Proof. See appendix. ■

The symmetric *collusive* or joint profit maximizing outcome is given by

$$p_i^C = \frac{100 + \alpha c - \beta c}{2(\alpha - \beta)} = 151,\ i \in I,$$

with a corresponding quantity of $q_i^C = 49.67$.

Finally, let

$$p^I = \frac{(n-1)(\alpha c + 100) + \beta c}{2\alpha(n-1) - \beta(n-2)} = 31.8.$$

We can now state the analogue of Vega-Redondo's (1997) result for Bertrand competition with product differentiation.

Result P2 If individuals follow an "imitate–the–best" process with noise ε, then p^I is the unique long–run stable state as $\varepsilon \to 0$.

Proof. See appendix. ■

We summarize the predictions in Table 3. Note that all predictions imply substantial positive profits. A fixed payment as in the Cournot case is therefore not required.

3 Experimental procedures

The 96 subjects for this experiment were recruited via posters at Humboldt University, Berlin. In each session eight subjects participated. Subjects were randomly allocated to computer terminals in the lab such that they could not infer with whom they would interact in a group of four. For each of our four treatment we had six groups of subjects.

Subjects were paid according to their total profits. Profits as in (2) or (6), respectively, were denominated in 'Taler', the exchange rates for German Marks (500:1 in the Cournot treatments and 4000:1 in the Bertrand treatments) were known.

The average payoff in the Cournot games was about DM 33, which is roughly \$19. The average payoff in the Bertrand treatments was DM 32. Thus, incentives were similar in both experiments. Sessions lasted about 90 minutes including instruction time.

Instructions (see Appendix C) were written on paper and distributed in the beginning of each session. After the instructions were read, we conducted one trial round in which the different windows of the computer screen were introduced and could be tested. When subjects were familiar with both, the rules and the handling of the computer program, we started the first round.

4 Hypotheses and results

We have argued in results Q1 and P1 that learning processes based on myopic best replies will yield convergence to the Nash equilibrium in both strategic settings. In the BASIC treatments the information available corresponds exactly to what is necessary to play best replies. Other behavioral rules based on imitation or relative performance are not available to subjects in the BASIC treatments. Thus, we have

Conjecture 1 In the BASIC treatments behavior converges to the Nash outcome.

In the EXTRA treatments subjects had additional information about individual actions of their competitors. Here, the theoretical predictions are contradictory. On the one hand, based on Stigler's (1964) point, we should expect that markets are less competitive since price cuts are detected more clearly.

Conjecture 2A In the EXTRA treatments behavior will be less competitive than in the BASIC treatments.

On the other hand, we have Results Q2 and P2 based on imitation which would suggest

Conjecture 2B In the EXTRA treatments behavior will be more competitive than in the BASIC treatments due to imitation.

Note that none of our conjectures makes a difference between strategic complements and substitutes.

Tables 4 and 5 present means and standard deviations of quantities and prices, respectively, over all groups and the last 20 and the last 5 rounds. We

Table 4: **Average total quantities in the Cournot games**

Cournot Rounds	Average total quantities Basic	Extra
Last 20	82.56 (2.48)	91.60 (6.48)
Last 5	81.28 (6.20)	89.89 (10.57)

Note: Standard deviations in parentheses

Table 5: **Average prices in the Betrand games**

Bertrand Rounds	Average prices Basic	Extra
Last 20	45.23 (6.44)	41.33 (4.64)
Last 5	41.91 (3.08)	39.49 (4.98)

Note: Standard deviations in parentheses

chose to report the later rounds to give any possible learning effects enough time to phase out.[12] Since each group counts as a single observation, all means and standard deviations are based on samples of six observations. These group averages are shown in Tables 6 and 7 in Appendix B.

With respect to Conjecture 1 we find that the experimental means are remarkably close to the theoretical predictions: In the Cournot Basic treatment the predicted total quantity was 79.2; the average total quantities given in Table 6 are 82.56 and 81.28 for the last 20 and the last 5 rounds, respectively. In the Bertrand Basic treatment the predicted average price was 39.25, and the average prices found in the experiment were 45.23 and 41.91, respectively. In all cases the experimental data are roughly within one standard deviation of the theoretical prediction.[13] Thus we have support for

[12] However, there was no noticeable time trend in the data. Neither the first 20 nor the last 5 rounds had significantly different averages from the last 20 rounds (according to MWU tests with 5% significance levels). In particular, while the last 5 rounds seem to be slightly more competitive than the last 20, there was no significant endgame effect.

[13] Due to the limited number of observations we did not make use of a t–test. However, we applied a non–parametric sign test to check whether the Nash outcome could be the median of the distributions. The according null hypothesis could only be rejected for the last 20 rounds of Cournot Basic. It could neither be rejected for the last 5 rounds nor for the Betrand Basic data.

Experimental Result 1 If subjects have only aggregate information about their rivals' behavior (which is sufficient to play according to the Nash equilibrium) and in the absence of additional information about rivals' actions and profits, behavior converges to the Nash outcome.

Conjectures 2A and 2B are examined by testing the appropriate null hypotheses[14] with the one–tailed Mann–Whitney–U test. As is immediate from the inspection of Tables 4 and 5, we do not find any evidence for Conjecture 2A — regardless of whether actions are strategic substitutes or complements. The appropriate null hypothesis can never be rejected. This is different with Conjecture 2B. There, we can reject the null hypotheses (that behavior is either the same or less competitive in EXTRA) in the case of strategic substitutes, i.e. in the case of homogenous Cournot markets, for both, the last 5 ($p = 3.9\%$) and the last 20 rounds ($p = 0.8\%$). Thus, we can state the following result concerning the central question whether more information increases or decreases competitiveness on oligopoly markets:

Experimental Result 2 (a) The effect additional information exerts on the level of competition depends on whether actions are strategic substitutes or complements.

(b) In case of strategic substitutes additional information about rivals' actions and profits significantly increases competitiveness.

(c) In case of strategic complements additional information does not change the degree of competition.

(d) In neither case additional information facilitates collusion.

The difference between strategic substitutes and complements is somewhat puzzling. While there are many documented differences in the IO literature between those two strategic settings, we are not aware of any theoretical result that explains differences with respect to Conjecture 2B.

A closer look at the data might reveal what is going on. Figure 1 presents histograms of the frequencies of actions in the last 20 rounds on the level of groups. For the Cournot markets the histograms show neatly how behavior shifts towards more competition resulting in the observed increase in mean quantities.

For the Bertrand markets a different picture emerges. As shown above mean prices are not significantly different in BASIC and EXTRA. While in

[14] The null hypotheses are for Conjecture 1: mean price (EXTRA) $\geq$ mean price (BASIC), and for Conjecture 2: mean price (EXTRA) $\leq$ mean price (BASIC).

BASIC a clear peak emerges around the Nash price, the histogram reveals that actions are much more dispersed in EXTRA. In fact, it can be seen that although the Nash prediction is very close to the *average* price, specific actions coincide only rarely with Nash. It seems that some groups play more competitive than Nash resulting in the peak at the 35-38 bracket. But there also seems to exist other groups who play less competitive.[15] What accounts for this diverse behavior is an interesting question which should be explored in further work.

Finally, we compare our results with those of other studies. To our knowledge there are only a few experiments about Bertrand markets with product differentiation. Dolbear *et al.* (1968) investigate collusive behavior in an experimental market similar to ours. Their complete information treatment is similar to our BASIC treatment. But in their incomplete information treatment, firms were not informed about the impact their competitors' price had on their profit. Average prices did not differ in a significant way between treatments. Harstad, Martin and Normann (1998) also study Bertrand markets with product differentiation but they analyze mainly the effect of non–binding preannoucements of prices.

With respect to the Cournot setting there is ample evidence that supports our finding that more information about other players' actions yields more competitive behavior. In the early study by Fouraker and Siegel (1963) there are two treatments on homogenous Cournot triopoly with incomplete and complete information, which roughly resemble our BASIC and EXTRA treatments, respectively. Fouraker and Siegel found that total quantities were close to Nash with incomplete information but more competitive with complete information, which corresponds nicely to our results.

More recently, and independently of our study, Offerman, Potters and Sonnemans (1997) and Bosch-Domènech and Vriend (1998) have conducted similar experiments. Focus of those papers, like that of our companion paper (Huck, Normann, and Oechssler, 1997), is on individual learning in Cournot oligopoly. Offerman *et al.* (1997) analyze triopoly markets. Two of their three treatments are similar to our treatments. In their experiment, when information about rivals' quantities and profits is provided, average quantities are higher (if however not significantly) than in the treatment where only the rivals' aggregate quantity is available. This coincides with our BEST and EXTRA Cournot treatments where we found significant differences. Offerman *et al.* (1997), however, observe this effect on a generally lower level

[15] We do not provide a formal test for the difference between those frequency distributions as the observations are not independent.

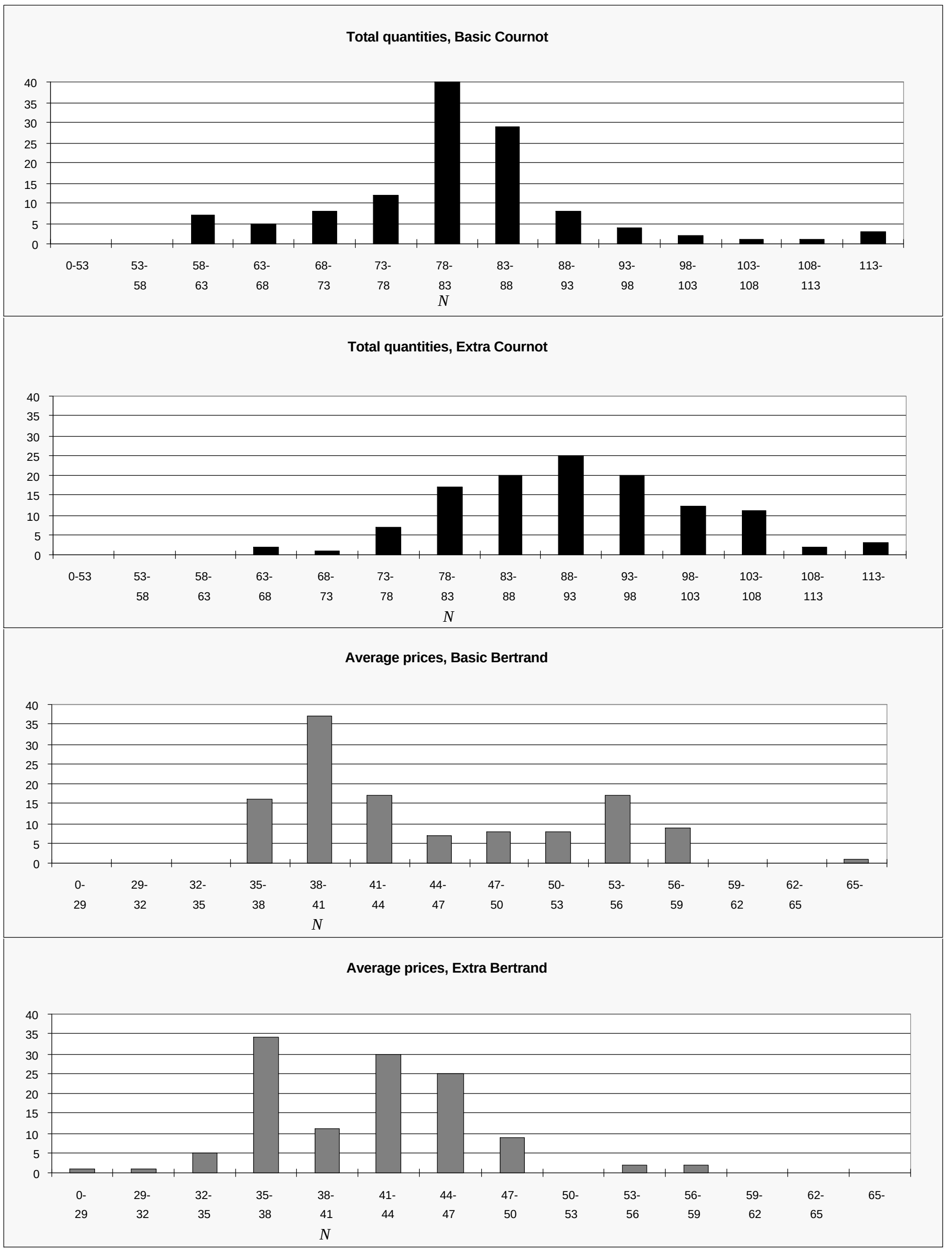

Figure 1: Frequencies of actions in the last 20 rounds
('N' indicates the bracket which includes the Nash outcome)

of competition as total quantities are always at or below the Cournot level, which does not match our experimental results.

Bosch-Domènech and Vriend (1998) study homogenous Cournot duopolies and triopolies. While in their experiments the objective amount of available information is always the same (and corresponds to our EXTRA treatment), they vary the presentation of the information and impose different time limits on decisions. Their evidence is slightly mixed. However, there is a noticeable trend towards more competition when the emphasis of the presentation is more on rivals' actions and profits and less on the market structure.

5 Conclusion

In a series of experiments we have investigated the influence of information about rivals' actions on the competitiveness of oligopolistic markets. Our results suggest that the effect of information on competitors' actions depends on the strategic situation: In the case of strategic complements (price competition) it has no significant effect on market outcomes. In the case of strategic substitutes (quantity competition) it renders market outcomes significantly more competitive. The dependence on the strategic situation remains somewhat a puzzle which merits attention in further work since we are unaware of any theoretical reason that would predict such results.

In neither strategic setting we find evidence for the hypothesis that additional information or a higher degree of market transparency facilitates collusive behavior. While we do not want to overemphasize the practical applicability of our results, this could tentatively be taken as evidence in favor of the publication of individual firm data to foster competition.

A Proofs

Proof of Result P1. Let $\Pi(p_i^t, \bar{p}_{-i}^t)$ denote firm i's profit in period t given its price p_i^t and the average price of its *active* opponents $\bar{p}_{-i}^t$. According to the best reply dynamics players myopically choose every period a best reply to the other players' prices from *last* period,

$$r(\bar{p}_{-i}) := \arg\max_{p_i \in \mathbb{R}_+} \Pi(p_i^t, \bar{p}_{-i}^t).$$

Since best replies are such that $q_i^t > 0$, for all t and i, we can work with the demand function (5). Thus we have

$$p_i^t = r(\bar{p}_{-i}) = \frac{100 + \beta \bar{p}_{-i}^{t-1} + \alpha c}{2\alpha}.$$

Summing over all prices we get

$$\sum_{i=1}^{n} p_i^t = \frac{1}{2\alpha}\left(100n + n\beta \frac{n}{n-1}\bar{p}^{t-1} - \frac{\beta}{n-1}\sum p_i^{t-1} + n\alpha c\right)$$

and hence

$$\bar{p}^t = \frac{100 + \alpha c}{2\alpha} + \frac{\beta}{2\alpha}\bar{p}^{t-1}.$$

The solution to this difference equation is

$$\bar{p}^t = \frac{100 + \alpha c}{2\alpha - \beta} + \left(\frac{\beta}{2\alpha}\right)^t \left(p^0 - \frac{100 + \alpha c}{2\alpha - \beta}\right).$$

This difference equation is stable for $\beta < 2\alpha$ and converges to the Nash equilibrium price p^N. ■

Proof of Result P2. The imitation process is analyzed in a finite state space. Thus, in line with the experimental setup we require that prices must be chosen from a finite grid $\Gamma := \{0, \delta, 2\delta, ..., v\delta\}$, for arbitrary $\delta > 0$, and some $v \in \mathbb{N}$ large enough. Whenever a firm revises its strategy, it chooses one of those strategies which received the highest payoff last period according to some probability distribution with full support.

Furthermore, every period each firm "mutates" (makes a mistake) with independent probability $\varepsilon > 0$ and chooses an arbitrary $p \in \Gamma$ (all finite p are chosen with some strictly positive probability).

Let $\Delta(p, p')$ be the profit differential between a firm using price p when all other firms set price p' and a firm using p' against $n-2$ firms with p' and one firm with p:

$$\Delta(p, p') := \Pi(p, p') - \Pi\left(p', \frac{n-2}{n-1}p' + \frac{1}{n-1}p\right).$$

Note that $\max_p \Delta(p, p') \geq 0$ as one can always set $p = p'$. Simple calculations show that

$$p^* = \frac{1}{2\alpha}\left(100 + \beta p' + \alpha c - \frac{\beta}{n-1}\left(p' - c\right)\right)$$

is the unique p maximizing $\Delta(p, p')$. Next, define

$$p^I := \min_{p'} \Delta(p^*, p').$$

p^I is unique since $\Delta(p^*, p')$ is quadratic in p'. Since $\Delta(p^*, p') \geq 0$, p^I is given by setting $p' = p^*$. Thus

$$p^I = \frac{(n-1)(\alpha c + 100) + \beta c}{2\alpha(n-1) - \beta(n-2)}$$

is the unique price which when used by every firm is stable against invasion of other prices. In the following we assume that p^I, $p^N \in \Gamma$.

Consider first the Markov process defined by Assumption 2 for $\varepsilon = 0$. This process reaches an absorbing state if and only if prices of all firms are equal. Let Θ denote the set of absorbing states. By standard arguments (see e.g. Theorem 1 of Samuelson, 1994) only states in Θ can appear in the support of the limit distribution of the Markov process for $\varepsilon \to 0$.

To prove the result is suffices to show that it takes only one mutation to reach $\mathbf{p}^I = (p_1^I,\, p_2^I,\, p_3^I,\, p_4^I)$ from any state $\mathbf{p} \in \Theta, \mathbf{p} \neq \mathbf{p}^I$ whereas it takes more than one mutation in the opposite direction.

We will show first that

$$\Delta(p^I, p) > 0, \forall p \neq p^I.$$

$\Delta(p^I, p) > 0 \Leftrightarrow$

$$\left(p^I - c\right)\left(100 - \alpha p^I + \beta p\right) - (p - c)\left(100 - \alpha p + \beta\frac{(n-2)p + p^I}{n-1}\right) > 0.$$

Substituting for p^I yields after some calculations

$$(\alpha(n-1) - \beta(n-2))\left((n-1)(\alpha c + 100) + \beta c - 2(n-1)\alpha p + \beta(n-2)p\right)^2 > 0.$$

Note that the second term is zero if and only if $p = p^I$. For $p \neq p^I$, $\Delta(p^I, p) > 0$ since $\alpha > \beta\frac{n-2}{n-1}$ by assumption. Thus, one firm mutating from p to p^I will suffice to put the process in the basin of attraction of $\mathbf{p}^I$.

On the other hand one firm's mutation will not suffice to leave $\mathbf{p}^I$'s basin of attraction as $\Delta(p, p^I) < 0$ for all $p \neq p^I$ by definition of p^I. ■

B Group data

Table 6: Group averages over last 20 and last 5 rounds in the Cournot games

Cournot	Rounds	Gr.1	Gr.2	Gr.3	Gr.4	Gr.5	Gr.6
Basic	Last 20	85.01	81.90	84.75	83.43	82.02	78.25
	Last 5	71.33	83.30	89.80	82.05	84.19	78.00
Extra	Last 20	96.40	82.41	86.34	94.38	99.70	90.37
	Last 5	98.20	74.09	86.00	86.60	104.5	89.95

Note that the group number refers to different groups of subjects between treatments.

Table 7: Group averages over last 20 and last 5 rounds in the Bertrand games

Bertrand	Rounds	Gr.1	Gr.2	Gr.3	Gr.4	Gr.5	Gr.6
Basic	Last 20	38.96	40.85	51.63	49.34	52.05	38.55
	Last 5	39.93	41.83	43.68	40.33	47.09	38.60
Extra	Last 20	44.61	40.40	35.32	36.84	43.83	47.06
	Last 5	44.21	34.69	34.58	36.15	45.72	41.60

Note that the group number refers to different groups of subjects between treatments.

C Translation of instructions

[These are the instructions for the Cournot games. The instructions for the Bertrand Games were similar except as mentioned below]

Welcome to our experiment. Please read these instructions carefully. In the next 1 or 2 hours you will have to make some decisions at the computer. You can earn some real money. But please be quite during the entire experiment and do not talk to your neighbors. Those who do not follow this rule will have to leave and will not get paid. If you have a question please raise your arm.

You will receive your payment discretely at the end of the experiment. We guarantee anonymity with respect to other participants and we do not record any information connecting your name with your performance.

You can operate the computer with the keyboard or the mouse. Before the experiment there is enough time to make yourself familiar with the computer in a trial round. Money in the experiment is denominated in "Taler". At the end we exchange your earnings into DM at a rate of 500 T = 1 DM. The experiment is divided into several rounds. As said, we start with a trial round. The real experiment starts with round 1.

You represent a firm which produces and sells a certain product. Besides you there are 3 other firms which produce and sell the same product. Your task is to decide how much to produce of your good. The capacity of your factory allows you to produce between 0 and 100 units each round. Production cost are 1T per unit. All units (also those of the other firms) are sold on a market (like on a stock exchange or in an auction).

For this the following important rule holds: The price can be between 100T and 0T. The more is sold on the market in total, the *lower* is the price one obtains per unit. To be precise the price falls by 1T for each additional unit supplied. If – this is only an example – the other firms supply together 10 units and your firm supplies 3 units, then total quantity is 13. The resulting price is $100 - 13 = 87$. If the total quantity were 90, the price would be $100 - 90 = 10$. *Profit per unit* is the difference between the price and the cost per unit of 1T. Note that you make a *loss* if the price is lower than the per unit cost. Your profit in a given round results from multiplying the profit per unit with your supplied quantity.

[For the Bertrand game demand was described as follows]

[For this the following important rule holds: The *higher your price*, the *fewer* units you sell. Above a certain price you don't sell anything anymore. On the other hand you sell the *more*, the *higher the average price* of the other *active* firms is (a firm is *active* when it sells a positive quantity; it is inactive when its price is so high that it doesn't sell anything. The price of an inactive firm does not enter into the calculation of the average prices).]

In each round the quantities of all firms are recorded and the resulting profits are calculated. In each round you will be told your profit. Profits from all periods are added and the sum is paid out to you in cash at the end. Additionally you receive a fixed payment of 150T each round. This will be added to your profit each round.

In the first round you decide on a quantity you want to produce and sell. In all further rounds *chance* decides whether you have the opportunity to revise your quantity. The computer has a mechanism which is comparable

This ¶ only for Cournot treatments.

to a "one–armed bandit": If you draw a "1" or a "2", you may change your quantity. If you draw a "0", you may not. That is, you may change your quantity in 2 out of 3 cases. With a "0" the quantity of last period is supplied automatically again. Note, that your quantity might be fixed for several rounds. Following a "1" or a "2" you may revise your quantity.

In this case you will receive the following information. You are told each firm's last period quantity, the total quantity of the other firms last period, last period's price, and the profit of each firm. This ¶ only for EXTRA.

In this case you will receive the following information. You are told the total quantity of the other firms last period, and last period's price. This ¶ only for BASIC.

Additionally, you have access to a profit calculator. The profit calculator is shown on the last page of the instructions. It has two functions: 1. It calculates your profit for arbitrary quantity combinations. That is, you can enter two values, a total quantity for the others (button "A") and a quantity for yourself (button "I"), and the machine tells you how much you would earn. 2. You can let it calculate for arbitrary quantities of others (button "A") the quantity at which you would make the highest profit (button "M"). You can use the machine as much as you want before each decision. Before we start you will have enough time to get to know the profit calculator directly at the computer.

Everything we have explained to you holds for the other firms as well. In fact, you are all reading exactly identical instructions.

The experiment lasts for 40 periods in total. Afterwards you will receive your payments in DM. We want to reassure you again that all data will be treated confidentially.

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