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Two are Few and Four are Many: Number Effects in Experimental Oligopolies*

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Abstract

In this paper we investigate how the competitiveness of Cournot markets varies with the number of firms in an industry. We review previous Cournot experiments in the literature. Additionally, we conduct a new series of experiments studying oligopolies with two, three, four, and five firms in a unified frame. With two firms we find some collusion. Three-firm oligopolies tend to produce outputs at the Nash level. Markets with four or five firms are never collusive and typically settle at or above the Cournot outcome. Some of those markets are actually quite competitive with outputs close to the Walrasian outcome.

JEL–classification numbers: L13, C92, C72.

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1 Introduction

In a classical paper, Selten (1973) argues that "four are few and six are many", referring to the number of firms that separates a small group of firms from a large one. This distinction between small and large groups expresses the general belief (see, e.g., Chamberlain, 1933) that cooperative behavior should be expected in small groups, while large groups are characterized by the prevalence of non–cooperative (Nash equilibrium) behavior.[1] While Selten's prediction depends on specific institutional assumptions regarding commitment possibilities in a quota cartel, we want to test the general notion that a "large" group need not be very large indeed.

We focus on standard homogenous Cournot oligopolies (as did Selten, 1973). Cournot oligopoly is certainly among the most frequently employed models in the theory of industrial organization and other applied fields. Moreover, the Cournot model plays an important role in antitrust policy. It is therefore of interest how the predictive value of the Cournot–Nash equilibrium depends on the number of firms in the market.

We review the scattered evidence of previous Cournot experiments that we could find in the literature and present a meta–analysis. A problem with this approach is, however, that the reviewed experiments differ with respect to numerous design features. Therefore, we supplement the meta–analysis by a new set of experiments that for the first time compares experimental Cournot oligopolies in a unified frame for two, three, four, and five firms. For both, the meta–analysis and our own data, we introduce a measure that relates actual total output to total output in equilibrium and find that it is increasing in the number of firms. More specifically, we conclude that "many" may be even less than Selten suggested, namely about four firms.

There are several papers pertaining to market structure and the competitiveness of outcomes in posted–offer markets (see Holt, 1995, for a survey). In posted–offer experiments, a key question is for which number of firms the market price tends to be above marginal cost. For example, Isaac

[1] The notion that cooperation is harder to sustain the larger the number of firms, is also supported by repeated game arguments without, however, giving a specific critical number of firms.

and Reynolds (1989) analyze posted–offer markets with two and with four firms and conclude that four firms may be sufficient for competitive performance. In the Cournot model, the price–cost margin depends directly on the number of firms.[2] It is presumably this feature of the Cournot model which explain its prominence in strictly structure–based merger policy. We therefore think that a systematic analysis of number effects in experimental Cournot oligopoly is of substantial interest.[3]

A disclaimer seems warranted right at the beginning. We do not claim that there exists a unique number of firms which determines a definite borderline between non–cooperative and collusive[4] markets irrespective of all institutional and structural details of markets. In fact, extensive experimental research has explored the impact of such institutional and structural factors (e.g., announcements or information provision) on market outcomes (see, e.g., Holt, 1995). Nevertheless, the evidence from the various different experiments we survey suggests that collusive tendencies can rarely be found in markets with more than two firms.

The remainder of the paper is organized as follows. Section 2 surveys previous Cournot experiments. Section 3 introduces our own experimental design and Section 4 presents our data. We briefly conclude in Section 5.

2 Previous experimental studies

For this survey we have selected suitable treatments from all experiments we are aware of that study standard Cournot oligopolies with quantity setting

[2] In posted–offer markets, the market price may also directly depend on the number of competitiors as the number of firms affects the range of prices which are part of the support of the mixed strategy Nash equilibrium. However, the experimental evidence does not support the hypothesis that subject mix over prices (see Brown-Kruse *et al.*, 1994).

[3] A related study with differentiated Bertrand competition is by Dolbear *et al.* (1968), and one with homogenous Bertrand competition is by Dufwenberg and Gneezy (2000).

[4] We refer to markets with prices higher than those in Nash equilibrium as "collusive". This is not to suggest that there are explicit coordination devices in such markets. This notion departs somewhat from the distinction between competitive and supra–competitive prices in the posted–offer markets literature where the former refers to marginal cost pricing and the latter refers to prices above marginal cost.

firms and homogeneous products.[5] While the experiments vary in their design with respect to numerous dimensions, we try to select treatments from each experiment that are somewhat comparable.[6] In particular, we select treatments without communication and without discounting. Further, we require that subjects are matched with the same opponents for the entire course of the experiment and receive only aggregate information about the behavior of other firms.[7] With one exception, we selected experiments with symmetric firms.[8]

There are a number of remaining differences in designs, e.g., the number of periods, random end versus fixed end, the action space, the functional form of the cost and the demand functions, etc. Despite such remaining differences in designs, we compare the results of all those studies with respect to one single number, the ratio of average total quantity in the market to the total quantity predicted by the Cournot–Nash equilibrium, $r := \bar{Q}/Q^N$.[9] Table 1 lists all experimental studies we are aware of.

We are particularly interested in how r varies with the number of firms in a market. Despite all dissimilarities between the experiments, a trend emerges: r is increasing with the number of firms. While the average ratio for duopolies is 0.936 it becomes 1.0275 for three firms, 1.029 for four firms and 1.050 for five firms. Pearson's correlation coefficient between r and n, the number of firms, is 0.48 and is significant at the 5% level.

Summary 1. Previous studies indicate that collusion sometimes occurs in duopolies and is very rare in markets with more than two firms. On

[5] Experiments with differentiated Cournot competition include Huck, Normann, and Oechssler (2000) and Davis and Wilson (2000).

[6] We are grateful to several colleagues for providing unpublished data.

[7] When subjects can observe individual outputs and profits of their opponents, market outcomes may become significantly more competitive (see Huck, Normann, and Oechssler, 1999 and 2000).

[8] We include the experiment of Rassenti *et al.* (2000) with asymmetric costs because there is only one other experiment with five firms.

[9] The ratio r is computed using the periods listed under "rounds" in Table 1. In many cases, complete data was not available. Therefore we had to refer to the published averages which were based on the periods as listed under "rounds".

Table 1: **Previous Cournot experiments**

study	treatment	rounds	$\bar{Q}$	Q^n	r	n
Binger et al. (1990)	2 w/o comm.	43	40.61	40	1.02	2
Bosch/Vriend (1998)	easy	23	37	40	0.93	2
Holt (1985)	first market	13*	16.05	16	1.00	2
Holt (1985)	second market	9*	15.92	16	1.00	2
Feinberg/Husted (1993)	no discounting	5 – 11*	30.89	34	0.91	2
Mason et *al.* (1991)	all subjects	last of 25	21.56	32	0.67	2
Mason et *al.* (1992)	LL / HH	35	57.6/50.4	64/56	0.90	2
HMN (1999)	Fixed match	10	7.64	8	0.95	2
Fouraker/Siegel (1963)	incompl info	last of 21	41.8	40	1.05	2
Offermann et *al.* (1997)	Q	100	233.52	243	0.96	3
Bosch/Vriend (1998)	easy	23	69.6	66	1.05	3
Fouraker/Siegel (1963)	incompl info	last of 21	48.1	45	1.07	3
Davis et *al.* (1999)	UC and AC	45	12.33	12	1.03	3
Beil (1988)	NM	20	35.47	36	0.99	4
HNO (1998)	A	last 20 of 40	83.98	79.2	1.06	4
HNO(1999)	Best	last 20 of 40	82.56	79.2	1.04	4
Rassenti et *al.* (200)	75-No-Show**	last 25 of 75	454.6	425	1.07	5
Binger et *al.* (1990)	5 w/o comm.	43	51.53	50	1.03	5

Notes: *random end, ** asymmetric costs, HNO = Huck, Normann, Oechssler,

HMN = Huck, Müller Normann.

average, total outputs in markets with more than two firms slightly exceed the Cournot prediction. There is a weak trend suggesting that this effect may become stronger as the number of firms increases.

In the next section we introduce a new experiment that allows to test for number effects in oligopoly in a unified frame.

3 Experimental design and theoretical predictions

In a series of computerized[10] experiments, we studied linear symmetric n–firm Cournot oligopoly markets. We decided to design the experiment such that it is best compatible with the studies reviewed in Section 2. This implies that (*i*) firms are symmetric, (*ii*) there should be no means of communication and cheap talk, (*iii*) subjects are informed about the demand and cost parameters of the market and about the aggregate quantities of their opponents from the previous round.

Basis for all markets were the following demand and cost functions. The demand side of the market was modeled with the computer buying all supplied units according to the inverse demand function

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

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

$$C(q_i) = q_i,$$

that is, constant marginal cost was equal to one.

It is straightforward to derive the Nash equilibrium for this market. The individual equilibrium output is

$$q_i^n = \frac{99}{n+1}$$

and the equilibrium profit is $\pi_i^n = (q_i^n)^2$. The respective total quantities Q^n are shown in Table 2. Alternative benchmark outcomes are the symmetric

[10] We use the software toolbox "Z-Tree", developed by Fischbacher (1999).

collusive output, which is $q_i^c = 99/(2n)$ for an individual firm and $Q^c = 49.5$ in total, and the competitive (or rivalistic) outcome where price equals marginal cost at $q_i^r = 99/n$ and $Q^r = 99$, respectively.

Subjects could choose quantities from a finite grid between 0 and 100 with .01 as the smallest step. The number of periods was 25 in all markets and this was commonly known.

Subjects had information about demand and cost conditions to calculate best replies to the quantities of the other firms. This information was provided verbally and in the form of a 'profit calculator'. When fed with data regarding the other firms (total quantities of the other firms), the calculator allowed to try out the consequences of own actions. After each period, subjects were informed about their own quantity and profit and the aggregate quantity their competitors produced.[11]

For each number of firms, we conducted six markets. The six duopolies were run in one session. For the three and four firm markets, we had two sessions, and for the five firm oligopolies, there were three sessions.[12] Subjects were randomly allocated to computer terminals in the lab such that they could not infer with whom they would interact. The 84 subjects for this experiment were recruited via telephone and email. No subject participated in more than one session nor had any subject previous experience with market experiments. Subjects were paid according to their total profit earned in the 25 periods. We varied the exchange rates such that, depending on the number of firms, subjects would have made identical earning at Nash equilibrium play. The average payoff was about DM 22. Sessions lasted about 45-60 minutes including instruction time.

Instructions (see Appendix) were written on paper and distributed in the beginning of each session. After the instructions were read, we explained the different windows of the computer screen. When subjects were familiar

[11] Note that a profit calculator essentially gives the same information as the profit tables normally used in Cournot experiments. With a profit table, a rather coarse discrete action space is required which often leads to multiple Nash equilibria (Holt, 1985). With a profit calculator, a continuous action space can be approximated such that additional Nash equilibria are arbitrary close to the prediction.

[12] Some of these sessions served as control treatments in an experiment on mergers (Huck, Konrad, Müller, and Normann, 2000).

Table 2: **average total quantities**

number of firms	Q^n	$\bar{Q}_{1-25}$	r_{1-25}	$\bar{Q}_{17-25}$	r_{17-25}
2	66.67	59.36 (6.45)	0.89	60.44 (4.71)	0.91
3	74.25	73.47 (7.71)	0.99	72.59 (5.67)	0.98
4	79.20	77.26 (8.01)	0.98	80.67 (5.47)	1.02
5	82.50	86.21 (6.68)	1.05	88.43 (6.56)	1.07

Note: Standard errors in parenthesis.

with both, the rules and the handling of the computer program, we started the first round.

4 Results

Table 2 and Figure 1 compare total quantities as implied by the theoretical Nash equilibrium prediction with total quantities in the experiment, averaged over all rounds and the final eight rounds, respectively.[13] In all cases average total quantity increases with the number of firms. The differences are all significant at the 1% level according to a MWU–test for rounds 17-25. For rounds 1-25, the differences between three and two firms are positive and significant at the 1% level and between five and four firms at the 5% level. The difference between 4 and 3 firms is positive but not significant.[14]

[13]There is no significant time trend in the data after the first 3 or 4 rounds. In a regressions of total quantities on time the trend variable is not significant for rounds 5-25 in any treatment (markets with 3 and 5 firms show no time trend even when the first 4 rounds are included).

[14]This seems to be caused by some very high quantities in rounds 15 and 16 (which appear to be punishment actions) of the 3–firms treatment.

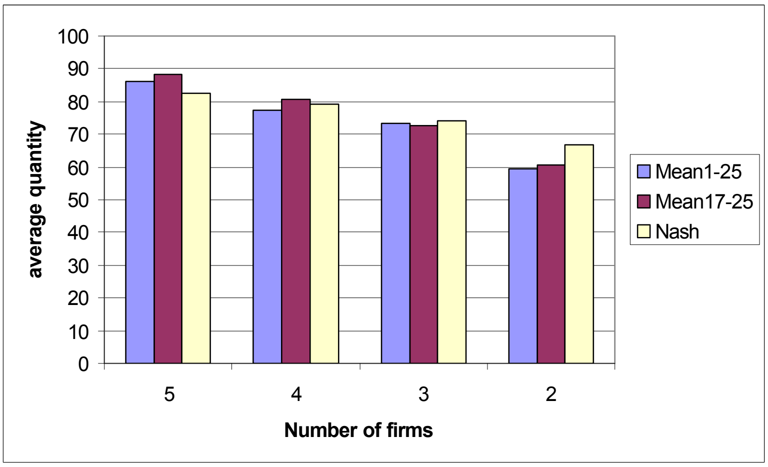

Figure 1: Theoretical predictions and average quantities in rounds 1-25 and 17-25.

The ratio of actual to predicted total quantities, r, is also increasing with the number of firms. Most differences are not significant when n is increased by 1. However, the crucial difference in r between two and four firms (to which our title alludes) is significant at a 2% level of significance for r_{17-25} and at a 5% level for r_{1-25} (one–sided MWU tests). Furthermore, Pearson's correlation coefficient between r_{1-25} and n is 0.53 (significant at 1% level). Between r_{17-25} and n it is 0.61 (also significant at 1% level).

As in Fouraker and Siegel (1963) we want to classify each individual session according to the degree of competitiveness. Our measure for this is aggregate output. We check to which of the three predictions, (C)ollusive, (N)ash, or (R)ivalistic[15], the aggregate output is closest to and classify the outcomes accordingly. With five firms, two sessions qualify as Rivalistic and three as Nash. Also with four firms, we find that all sessions qualify either as Nash or as Rivalistic. With two firms, two out of six sessions are Collusive and the remaining are classified as Nash. Thus, there is clear evidence that there is a qualitative difference between two and four or more firms. Only with three firms, all sessions classify as Nash.

[15]The three predictions refer to Q^c, Q^n and Q^r as derived above.

Table 3: **classification of sessions**

	session					
n	1	2	3	4	5	6
2	61.28 (N)	60.40 (N)	58.44 (N)	64.86 (N)	57.36 (C)	53.80 (C)
3	74.64 (N)	72.48 (N)	83.56 (N)	63.24 (N)	69.84 (N)	77.04 (N)
4	73.00 (N)	76.00 (N)	92.82 (R)	72.12 (N)	74.24 (N)	75.36 (N)
5	89.00 (N)	93.36 (R)	80.04 (N)	76.80 (N)	93.96 (R)	83.52 (N)

Note: Classifications: (C)ollusive, (N)ash, (R)ivalistic.

Summary 2. In our experiments with a unified frame, we find that, with two firms, some collusion occurs. The evidence on three-firm is such that Nash equilibrium is a good predictor. Markets with four or more firms are never collusive and typically settle around the Cournot outcome while some of them are very competitive with outputs close to the Walrasian outcome. Overall, the ratio of actual and predicted total output is significantly increasing with the number of firms.

5 Conclusion

Number effects seem to play an important role in oligopolies. The review of the existing literature on Cournot experiments and our own new experiment suggest the following. While firms in duopolies sometimes manage to collude, this seems to be difficult to achieve in markets with more firms. In fact, total average output often exceeds the Nash prediction in those markets. Furthermore, the data suggest that these deviations are increasing in the number of firms. Both effects may be of relevance when evaluating the potential effects of proposed mergers.

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Translation of the instructions

Welcome to our experiment!

Please read these instructions carefully! Do not speak to your neighbors and keep quiet during the entire experiment! If you have a question, raise your hand. We will then come to your boot.

In this experiment you will repeatedly make decisions. Doing this you can earn real money. How much you earn depends on your decisions and on the decisions of other participants. All participants receive the same instructions.

You will stay anonymous for us and for the other randomly chosen participants you get in touch with during the experiment.

In this experiment you represent a firm that, like four [three, two, one] other firms, produces and sells on a market one and the same product. You will be constantly matched with the same other participants. Costs of production are 1 ECU per unit (this holds for all firms). All firms will always have to make one decision, namely which quantity they wish to produce.

The following important rule holds: The larger the total quantity of all firms, the smaller the price in the market. Moreover, the price will be zero from a certain amount of total output upwards.

Your profit per unit of output will be the difference between the market price and the unit cost of 1 ECU. Note that you will make a loss if the market price is below the unit costs. Your profit per round is, thus, equal to the profit per unit multiplied by the number of units you sell.

In each round the output decisions of all five [four, three, two] firms will be registered, the corresponding price will be determined and the profits will be computed.

From the second period on, in every period, you will learn about the total output produced by the other firms and your own profit of the previous period.

Furthermore you may simulate your decisions first. You can do this on the left side of the decision screen. You may simply enter an arbitrary value for your own output and for the total output of the other firms. After pressing the "compute" button, you will be shown which profit would result for you in the upper left corner of the screen.

Once you decided about your quantity, you enter it on the right hand side of the screen and press the "OK" button.

The experiment consists of 25 periods.

Your payment consists of the earnings made in all periods. At the end of the experiment, your earnings will be exchanged into DM. You will receive 1 DM for every 300 ECU. At the beginning of the experiment, you will receive a initial payment of 500 ECU.