University of Heidelberg

Department of Economics

Discussion Paper Series | No. 588

From Imitation to Collusion – A Comment

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March 2015

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March 18, 2015

Abstract

In oligopoly, imitating the most successful competitor yields very competitive outcomes. This theoretical prediction has been confirmed experimentally by a number of studies. A recent paper by Friedman et al. (2015) qualifies those results in an interesting way: while they replicate the very competitive results for the first 25 to 50 periods, they show that when using a much longer time horizon of 1200 periods, results slowly turn to more and more collusive outcomes. We replicate their result for duopolies. However, with 4 firms none of our oligopolies becomes permanently collusive. Instead, the average quantity always stays above the Cournot-Nash equilibrium quantity. Thus, it seems that "four remain many" even with 1200 periods.

JEL codes: C91, C72, D74.
Keywords: imitation, experiment.

*We would like to thank Steffen Huck for comments. The University of Heidelberg provided financial support for the experiments.

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1 Introduction

Imitation, in some strategic settings, has been shown to have negative side effects for the players involved. Specifically, in oligopoly, imitating the most successful competitor yields very competitive outcomes and correspondingly low profits. This has been predicted theoretically by Vega-Redondo (1997) and confirmed experimentally by a number of studies (Huck, Normann, and Oechssler 1999; Offerman, Potters, and Sonnemans, 2002; Apesteguia, Huck, and Oechssler 2007; Apesteguia, Huck, Oechssler, and Weidenholzer, 2010; Bigoni and Fort, 2013). A recent paper by Friedman, Huck, Oprea, and Weidenholzer (2015) qualifies those results in an interesting way: while they replicate the very competitive results for the first 25 to 50 periods, they show that when using a much longer time horizon of 1200 periods, results slowly turn to more and more collusive outcomes.

Friedman et al. (2015) show this result for long-horizon duopolies and triopolies. Huck, Normann, and Oechssler (2004) review results from a large number of short-horizon experiments and conclude that 4 firms are usually sufficient to prevent tacit collusion. An interesting question, then, is whether collusive outcomes come about in long-horizon markets with more than 3 firms. Furthermore, given the novelty of the long-horizon result, it is important to test its robustness.

This paper seeks to address these issues by looking at long-horizon markets with 2 and 4 firms, using linear demand curves. We succeed in replicating Friedman et al.'s (2015) result that duopolies eventually became fairly collusive. However, while we also replicate a downward trend in quantities for 4 firms, none of our 4 firm oligopolies becomes permanently collusive. The average quantity always stays above the Cournot-Nash equilibrium quantity. Thus, it seems that "four remain many," even with 1200 periods, in the sense that collusion is very difficult to achieve.

2 Experimental design

Our experimental design was based on the one by Friedman et al. (2015). In order to allow for a replication, several key elements of their environment were maintained. Like in their experiment, the total number of periods was 1200, the length of each period was 4 seconds, the computer interface very closely resembled theirs, and subjects received the same feedback information. However, we used a Cournot market with linear demand and cost functions, in contrast to Friedman et al. (2015) who used a unit elastic demand function. We did this for two reasons. First, we wanted to make our experiment comparable to the bulk of the literature, which uses linear demand and cost functions (see e.g. Huck et al. 1999, Apesteguia, Huck, and Oechssler 2007; and Apesteguia, Huck, Oechssler, and Weidenholzer, 2010). Second, due to the profit functions used in Friedman et al. (2015), two of their benchmark cases (the joint profit maximizing output and the perfectly competitive Walrasian outcome) are on the boundary of the strategy space, which could have an effect. Replicating their duopoly treatment with a more standard profit function can thus be valuable.

A further difference between their design and ours is that we do not rematch firms after 400 periods. However, letting subjects interact in fixed groups for 1200 periods should make collusion more likely.

Finally, we extend their experiment by studying a market with 4 firms. Depending on the treatment, we had either 2 or 4 symmetric firms in each market. Quantities could be chosen with a slider almost continuously between 0 and 100.[1] 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 $Q^t = \sum_{i \in I} q_i^t$ denoting total quantity in period t and I the set of firms. The cost function for each seller was simply $C(q_i^t) = q_i^t$. Hence, profits were $\pi_i^t = (p^t - 1)q_i^t$.

In the stage game, the following benchmarks can be derived (see Table 1). In the 4-firm treatment with $I = \{1, 2, 3, 4\}$, the unique Cournot Nash equilibrium (CNE) is given by $q_i^{CNE} = 19.8, i \in I$. The corresponding price is $p^{CNE} = 20.8$. The symmetric joint profit maximizing (JPM) output is given by $q^{JPM} = 12.375, i \in I$ resulting in a price of $p^{JPM} = 50.5$. Finally, the perfect competitive *Walrasian* outcome, in the following PCW, is signified by $q_i^N = 24.75, i \in I$ and a price of $p^N = 1$.

The duopoly with $I = \{1, 2\}$ yields following predictions. The price in the case of the CNE is $p^{CNE} = 34$ resulting from $q_i^{CNE} = 33, i \in I$. JPM is given by $q_i^{JPM} = 24.75, i \in I$ and a price of $p^{JPM} = 50.5$. Finally the PCW is signified by $q_i^{PCW} = 49.5, i \in I$ and $p^{PCW} = 1$.

Like in Friedman et al. (2015) subjects were not told the profit function in order to generate a low information environment. Subjects were only told that they represented

[1] The step size of the slider was 0.016.

Table 1: **Theoretical benchmarks**

	2-firms				4-firms			
	q_i	Q	p	π_i	q_i	Q	p	π_i
PCW	49.5	99	1	0	24.75	99	1	0
CNE	33	66	34	1089	19.8	79.2	20.8	392.04
JPM	24.75	49.5	50.5	1225.13	12.375	49.5	50.5	612.56

firms and that the market price was decreasing in total quantity. Furthermore they were told that the profit depended only on the current period's quantity decisions of the subjects in their group and that the profit function did not change across time.[2]

After making his or her decision in each period, each subjects had access to information about his or her total earnings, the current period, the number of periods remaining, the amount of time left in the current period (in the form of a progress bar), and information related to the quantities chosen and the profits earned by all subjects in his or her group in the previous period. The information about the previous period was presented on a 2-dimensional plot (see the appendix), which again closely resembled the clever display used by Friedman et al. (2015). Quantity and profit pairs were plotted with quantity on the x axis and profit on the y axis. This allowed subjects to quickly identify the quantities and profits of other players and themselves (players were color coded to help with differentiation). Subjects could choose a quantity for the current period by clicking anywhere on the plot. When clicking, the x value of the cursor location would be updated as the current quantity choice. An empty box along the x axis was used to show this current choice. This choice could be updated as often as desired until the end of the period.

The experiment was computerized using z-Tree (Fischbacher, 2007).[3] In order to squeeze so many periods into a short time, periods only lasted 4 seconds each. In order to implement such short periods, a pseudo-real-time experiment was used.[4] The specific functionality allowed subjects to select a quantity using a slider at any time. Every 4 sec-

[2] The Instructions subjects received are shown in the Appendix.

[3] The fact that z-Tree can be used to run experiments in almost continuous time has also be used by Bigoni et al. (2015).

[4] The z-Tree program utilizes the "later(t) repeat { } " command with t being a fraction of a second. Each iteration counts down the time left in the period. When the countdown finishes, current quantities and profits for each firm are recorded and reported to the group. Individual quantities can be updated at any time during the countdown or can be left at the previous period's level. Other firms' changes are only reported at the end of each period.

onds, the current quantities for each subject were recorded to determine a 1-period payoff, and this information (quantities and payoffs for each subject) was communicated to each player. Quantity changes within the 4-second window did not take effect and were not communicated to other subjects until the beginning of the next 4-second window. To allow subjects to familiarize themselves with the software, the first period lasted 10 seconds.

The experiments were conducted in the experimental lab of the economics department of the University of Heidelberg. Subjects were recruited via ORSEE (Greiner, 2004). Subjects were randomly allocated to computer terminals in the lab such that they could not infer with whom they would interact in a fixed group. In the 2-firm treatment there was 1 session of 12 subjects, for a total of 6 observations (1 pair = 1 statistically independent observation). In the 4-firm treatment there were 2 sessions of 8 and 16 subjects, for a total of 24 subjects and 6 observations (1 group of 4 subjects = 1 observation). Subjects participated in a single, 1200-period, Cournot oligopoly market in a session. Profits where denominated in 'Taler', the exchange rate for euro (€) (70000:1 in the 2-firm treatment, 20000:1 in the 4-firm treatment) was known. The average payoff was about 17.70 €.[5] Experiments lasted less than 120 minutes including instruction time. Instructions (see Appendix A) were written on paper and distributed at the beginning of each session.

3 Results

Like Friedman et al. (2015) we first consider the initial 25 periods (see Figure 1).[6] As in their experiment, and in most of the existing literature, median total quantities are very competitive and clearly above the Nash equilibrium quantity (CNE). This holds for both the 2-firm and the 4-firm treatment, although the quantities in the 4-firm treatment are even more competitive.

Next, we turn to the evolution of median total quantities over all 1200 periods (see Figure 2; see also Table 2 for mean quantities, prices, and profits). The left panel of Figure 2 shows the median quantities in the 2-firm treatment. Median quantities decrease over time, just as those observed in Friedman et al. (2015). After 400 periods, median quantities are persistently between the CNE and the collusive JPM output. This indicates that the results of Friedman et al. (2015) are robust to the specific functional form of the demand and cost functions, since we can replicate their results with more standard functional forms.

[5] We added a show-up fee of €10 after the earnings in the first session were unexpectedly low.

[6] We use median quantities in the figures because Friedman et al. (2015) do so as well. The appendix contains the corresponding figures with mean quantities.

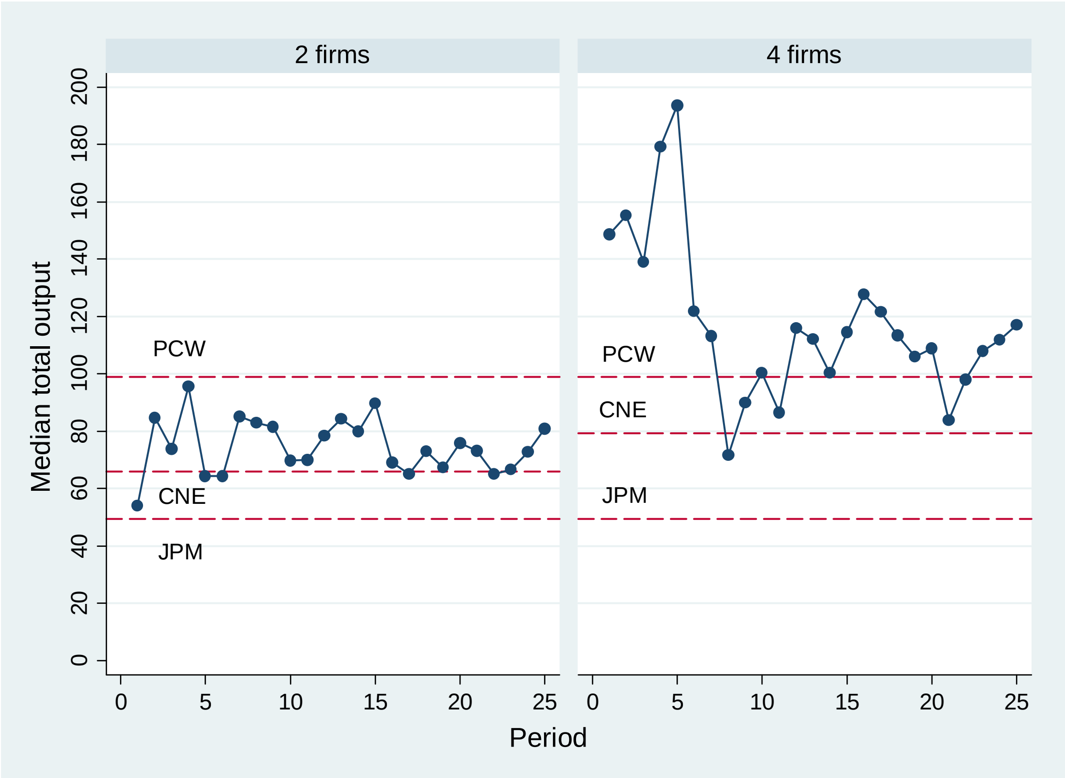

Figure 1: Median quantities over the first 25 periods
Note: Medians are calculated for each period over all 6 markets.

The right panel of Figure 2 shows the median quantities in the 4-firm treatment. As in Friedman et al. (2015, Figure 3) we observe a clear downward trend in quantities. However, in contrast to their study, the downward trend in our experiment comes to a halt after around 600 periods.[7] More importantly, median quantities stay above the CNE. On the aggregate, there are no collusive tendencies in markets with 4 firms.

Indeed, looking at individual 4-firm market medians (see Figure 3) we see that not one of the median quantities reaches the JPM permanently. Only one market (market 3) comes close at around period 800 but returns later to the CNE. While the JPM was not attained in any of the 4-firm markets, there seem to be cases of both the CNE and PCW. Markets

[7] Simple OLS regressions of total quantity on period show no significant time trend for $t > 600$ while there is a highly significant ($p < 0.01$) time trend for $t \leq 600$.

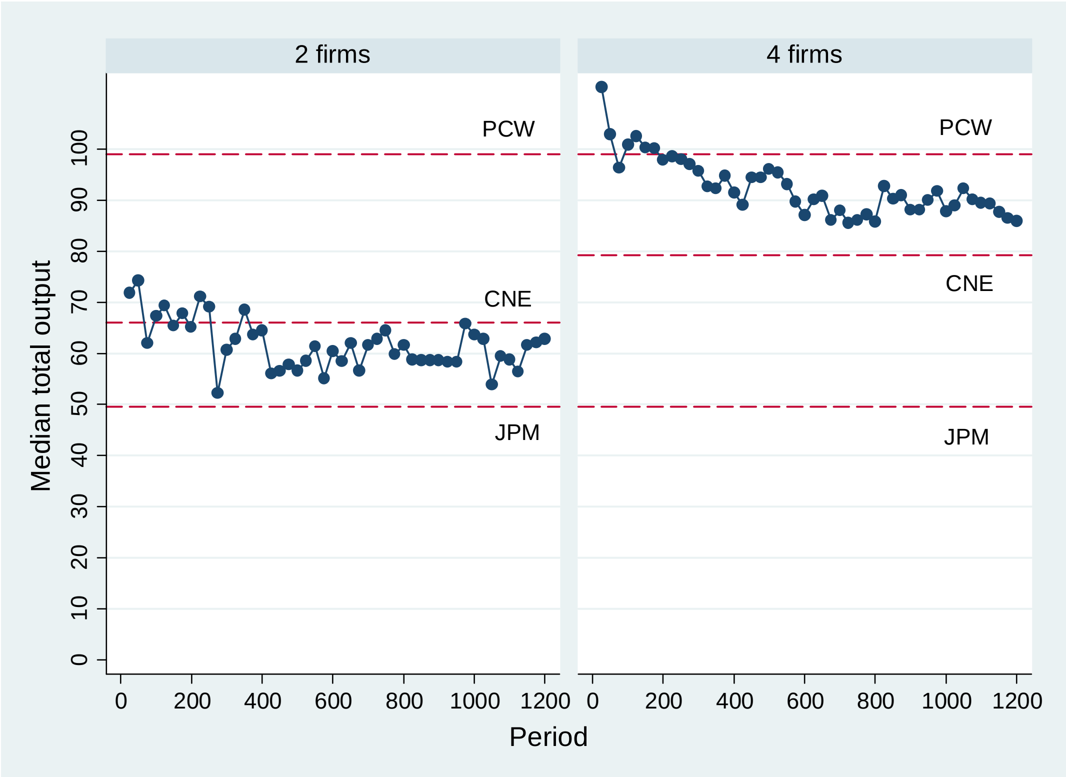

Figure 2: Median quantities over all periods, plotted in bins of 25 periods
Note: Medians are calculated for each bin over all 6 markets and periods in the bin.

Table 2: **Mean quantities, prices, and profits**

	2-firms			4-firms		
periods	q_i	p	π_i	q_i	p	π_i
1-50	37.24	28.20	728.51	29.05	8.82	112.06
1-400	34.76	31.61	884.76	25.56	7.72	123.16
401-800	29.52	41.25	1098.26	22.75	11.86	204.67
801-1200	29.29	41.45	1134.60	22.24	12.35	221.79
1151-1200	30.88	38.40	1098.99	21.69	13.76	258.02
1-1200	31.19	38.11	1039.21	23.51	10.64	183.00

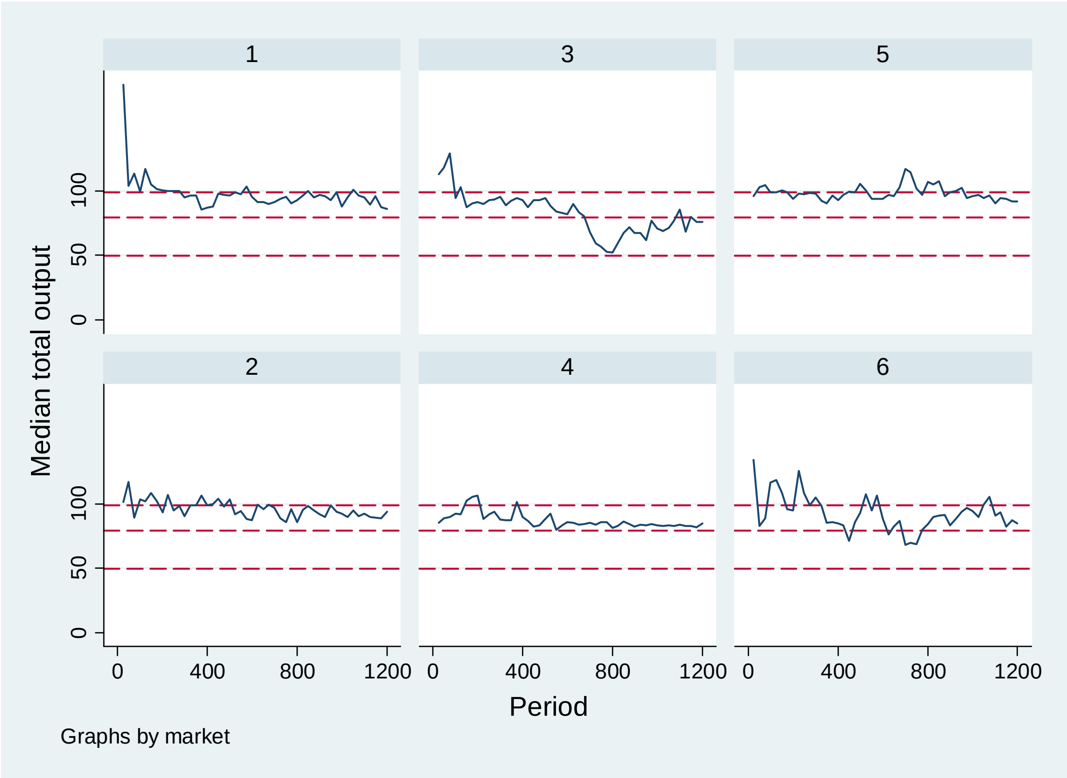

Figure 3: Median total output for the 6 individual markets in treatment 4-firms: Only market 3 ever comes close to the JPM

1, 2, and 5 never actually reach the CNE, and instead hover near the PCW, while firms in markets 3, 4, and 6 reach total output near the CNE for at least some periods. That said, of the markets that reached CNE levels of output, only market 4 seems to have spent much time there. Markets 3 and 6 were much more volatile.

This bimodality seen in the 4-firm markets can also be seen in the individual 2-firm medians (see Figure 4). While in the 4-firm markets we saw either the PCW or CNE, 2-firm markets tend toward either the CNE or the JPM. Markets 1, 2, and 6 were able to sustain the JPM, while markets 3, 4, and 5 settled near the CNE.

In both treatments, then, it seems that the individual market medians are distributed bimodally and, further, the 6-market median total output (from Figure 2) is rarely observed in any particular market. It seems instead that the PCW, CNE, and JPM are somewhat

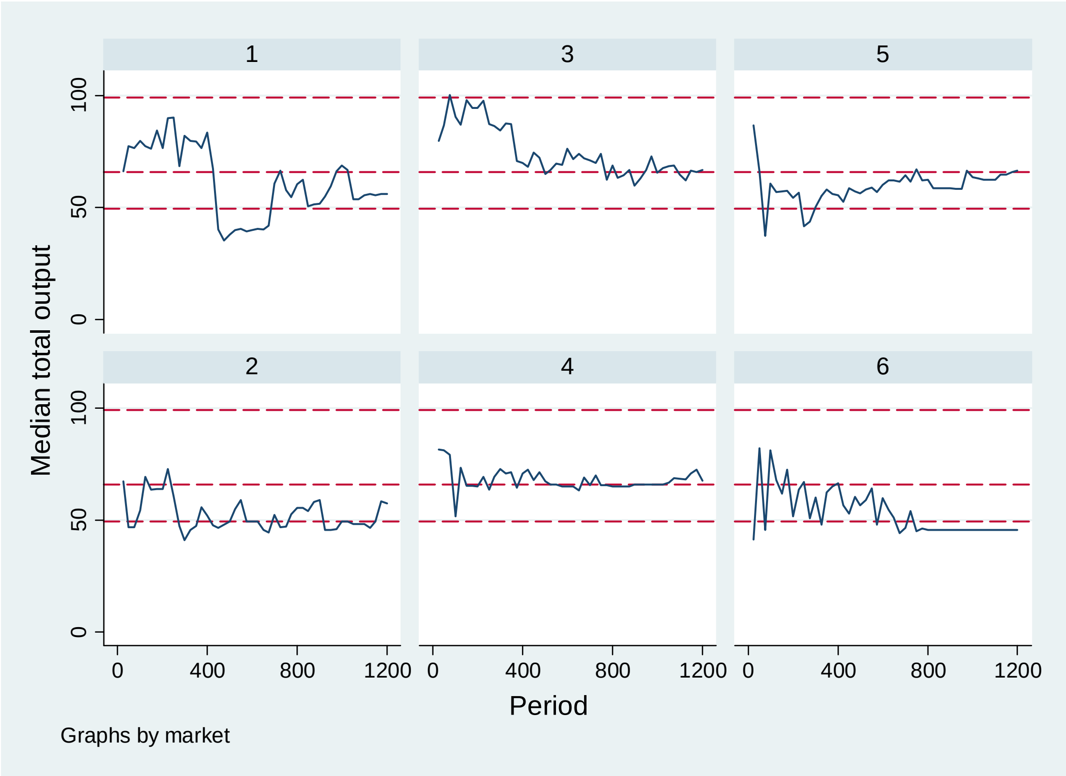

Figure 4: Median total output for the 6 individual markets in treatment 2-firms

focal, and that the difference in treatments can largely be attributed to the number of markets drawn to each focal quantity. Mean figures in the appendix give further evidence of this bimodality.

4 Conclusion

Our experiment explores the robustness of the main result of Friedman et al. (2015). In Cournot duopoly markets, we confirm the presence of high levels of collusion after 1200 periods. However, when moving to markets with 4 firms, we find little difference from the existing literature. As predicted by theories of imitation, markets with 4 firms remain more competitive than the Cournot-Nash equilibrium even with 1200 periods. Our results, when added to those for 3-firm oligopolies in Friedman et al. (2015), suggest that the effect of increasing the number of periods quickly diminishes for markets with more firms.

In both our treatments we further find evidence of focality for certain market quantities. The majority of our individual markets stabilized at quantities associated with the PCW, CNE, or JPM. Since subjects were not made aware of the profit function, this result is that much more striking.

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Appendix (for online publication only)

A Instructions

[English translation of the German instructions, 4-firm treatment. 2-firm treatment was modified in the obvious way.]

Welcome to our experiment. Please read these instructions carefully.

Turn off your mobile phone, don't talk to your neighbors, and remain quiet throughout the experiment. If you have any questions, please raise your hand, and someone will come over.

You will receive your payoff individually and privately right at the end of the experiment.

The experiment's payoffs will be calculated in Taler (T). At the end of the experiment your payoffs will be converted into euros, with 20,000 T = 1 euro.

The first experiment comprises 1200 periods, each of them lasting 4 seconds. Only the first period is different, as it lasts 10 seconds.

During the whole experiment you will be interacting with three participants in this room. These three participants will remain the same over all 1200 periods. No one will learn as to who interacted with whom.

Each of you represents a firm that produces and sells a product. So there are, in addition to you, three competitors who produce and sell the same product.

During each of the 1200 periods you can decide what quantity of your product you want to produce. The higher the total quantity of the product offered on the market, the lower the market price.

Although you have no precise information on the profits' structure, the following important rules apply:

- Your profit in each period exclusively depends on your decision and on the competitors‘ decisions in the current period.
- The profit function will not change over time. If your and your competitors' decision in a given period is the same as in the previous period, all companies will make the same profit as in the previous period.

At the end all profits realized during the periods will be added up and paid out.

Starting from the second period you will receive the following information in each period:

Your own quantity and the resulting profit of the previous period as well as the competitors' quantities and profits will be shown in following figure.

[here a figure like Figure 5 was displayed]

In the upper left corner you will be shown the number of remaining periods, the quantity you selected in the previous period, and the resulting profit.

Below this information you have a time indicator. The green bar indicates your time remaining in the current period for selecting a quantity. The more time has passed, the shorter the bar.

Your quantity/profit combination will be indicated by a red dot. Your competitors' combinations will be displayed in different colors as shown in the upper right corner.

To select a quantity, click on the screen. The slider on the x-axis shows the decision you have made. You are free to change your decision during a period.

Unless you choose a different quantity for a period, the same quantity as in the previous period will be produced.

To be sure, everything described above applies to the three other firms as well. All four of you are reading exactly the same instruction.

Have fun!

B Additional figures

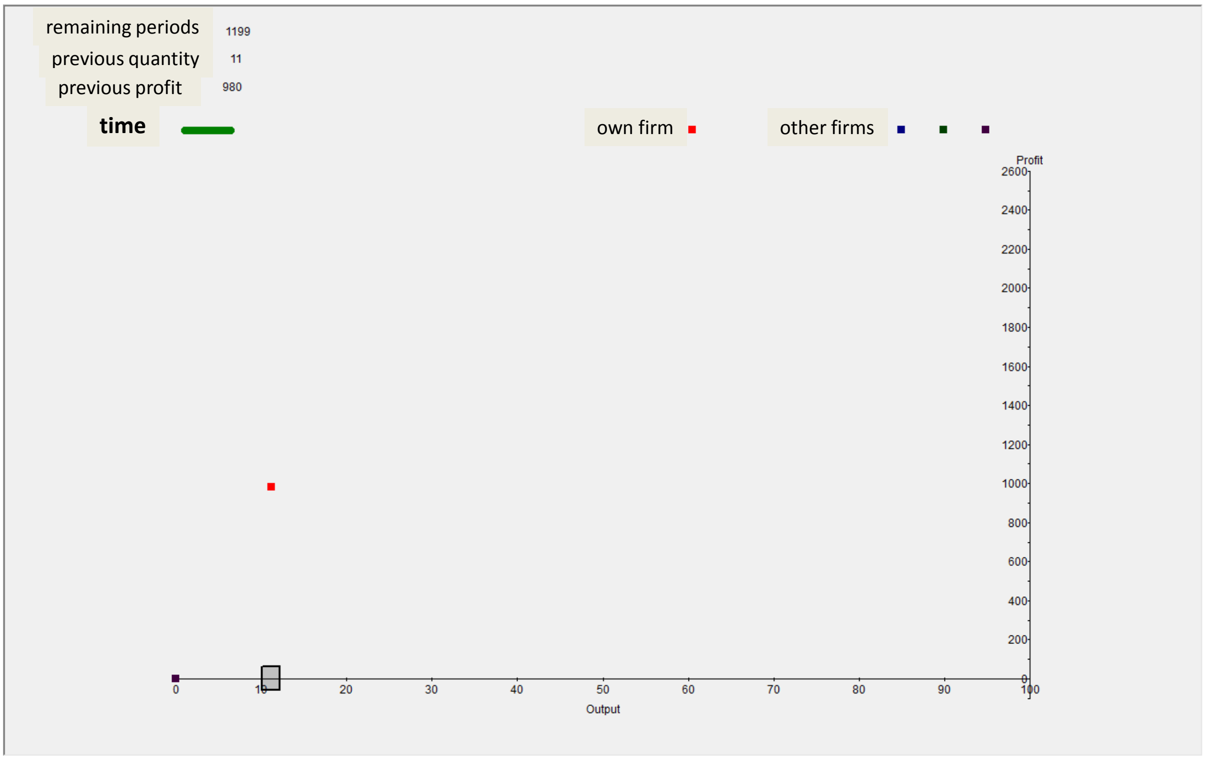

Figure 5: z-tree Interface. By clicking anywhere on the plot, subjects could choose a quantity for the current period. When clicking, the x value of the cursor location was updated as the current quantity choice. The y-axis displayed profits for all firms

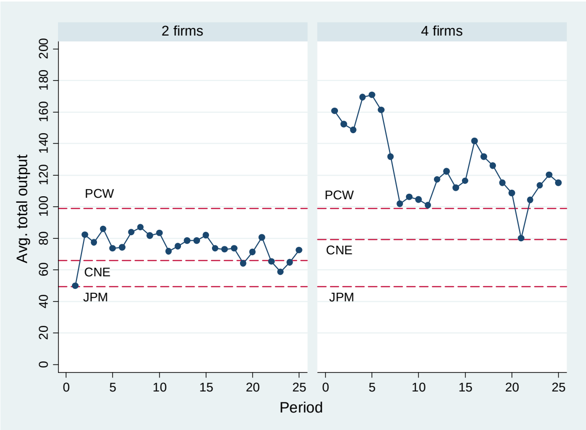

Figure 6: Mean quantities over the first 25 periods

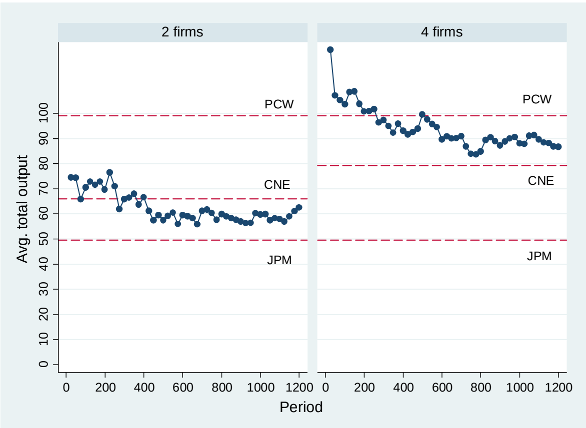

Figure 7: Mean quantities over all periods, plotted in bins of 25 periods

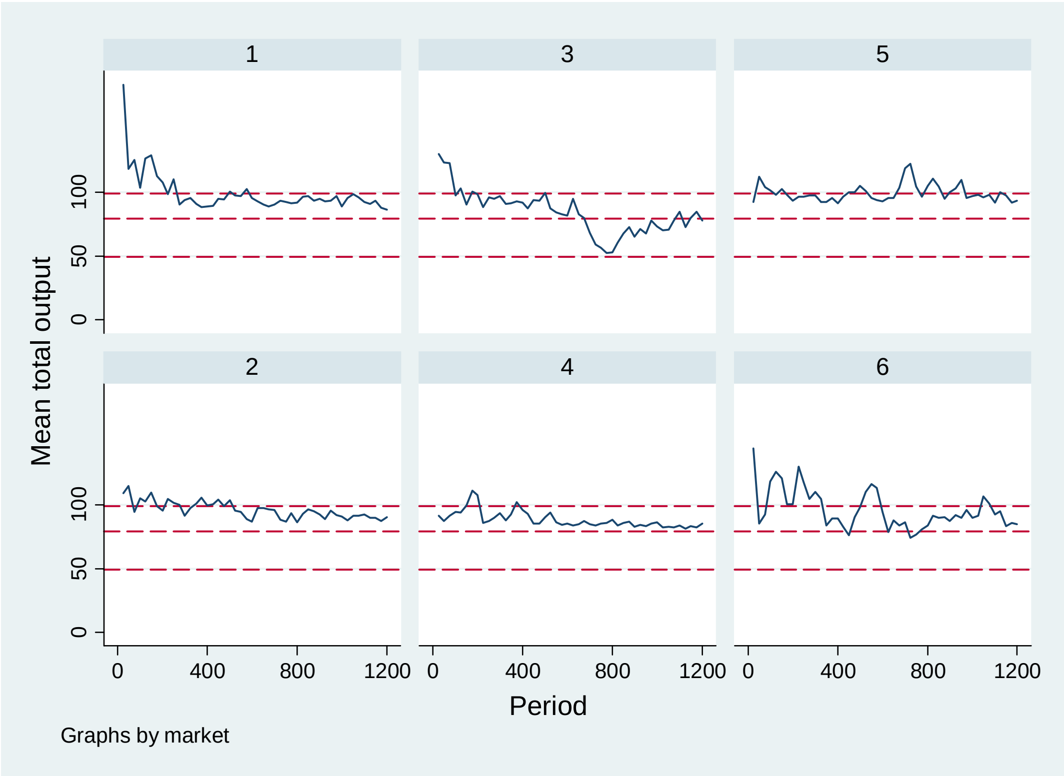

Figure 8: Mean total output for the 6 individual markets in treatment 4-firms: Only market 3 ever comes close to the JPM

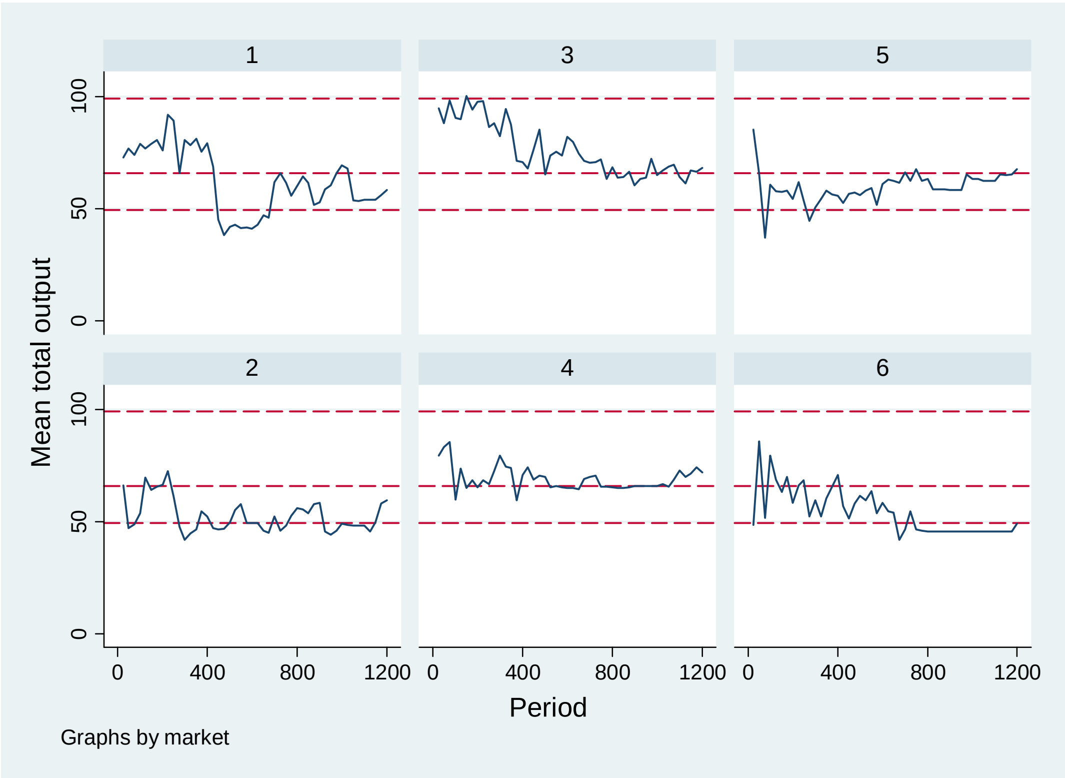

Figure 9: Mean total output for the 6 individual markets in treatment 2-firms