Imitation of Successful Behavior in Cournot Markets *

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Abstract:
In an experimental standard Cournot oligopoly we test the importance of models of behavior characterized by imitation of successful behavior. We find that the players appear to be rather reluctant to imitate.

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1. Introduction

Imitation has played an important role in the recent literature on learning in economics.[1] This is not surprising since imitation seems easy and straightforward. It does not use particularly many cognitive skills and it does not require much information. Social imitation certainly qualifies as a *'fast and frugal heuristics for making decisions'* (Gigerenzer & Goldstein [1996]). Conventional wisdom seems to assert that in situations with little information or understanding, imitation of the successful behavior of others is likely.[2] Yet imitation, although deemed easy, is not necessarily a *realistic* mode of behavior in some environments. To assess the extent of imitative behavior, we set up an experimental symmetric Cournot market under different information treatments, some of them very conducive to imitation. The choice of a symmetric Cournot market is not accidental. First, recent theoretical results (see Vega-Redondo [1997]) show that under general evolutionary dynamics, a Cournot market in which firms (loosely) imitate the more successful firms converges to the Walrasian competitive equilibrium. This implies that we can use the market outcomes as a proxy for the possible presence of imitation. Second, any symmetric game facilitates imitation of successful behavior. Absence of imitation in such games would be damaging evidence against the prevalence of imitation.

Our experimental results show that even in situations in which imitation seems straightforward, subjects are reluctant to resort to it. Two complementary hypotheses may explain this result. First, subjects need not be naive learners. They realize that their environment is not stationary. Second, even in a difficult Cournot environment, subjects learn soon enough to recognize that imitation of successful behavior may reduce their profits. To infer from our results that imitation is not a good description of market behavior may be stretching our observations in excess. After all, in real markets, forces may be at play that are kept out of our experiments. Nevertheless, our results certainly question any uncritical acceptance of imitation as an obvious mode of behavior in markets.

The remainder of this paper is organized as follows. In section 2 we discuss Cournot oligopoly models. In section 3 we present our experimental design. Section 4 contains the analysis of the data, and section 5 concludes.

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[1] For example, in evolutionary economics or industrial organization in the Schumpeter tradition (Nelson & Winter [1982]), in evolutionary game theory with replicator dynamics and related processes (Weibull [1995]), and in computational economics with, e.g., Genetic Algorithms (Sargent [1993]).

[2] To quote Bikhchandani et al. [1998]: "*Social observers have long recognized imitation as important in human society. Machiavelli (1514) wrote: "Men nearly always follow the tracks made by others and proceed in their affairs by imitation." The philosopher Eric Hoffer (1955) asserted: "When people are free to do as they please, they usually imitate each other"*" (p. 152).

2. Competitive Output in Cournot Markets

As is well-known, output levels in Cournot markets may approach competitive output levels as the number of firms increases, because the Cournot-Nash equilibrium converges to the Walrasian competitive output. But there are two forms of behavior that can sustain the competitive (Walrasian) equilibrium, even in Cournot markets with few players.

First, agents may have a preference for beating their opponents. This can be identified with what has been called *spiteful behavior*, i.e., choosing an action that hurts oneself, but others even more (see Hamilton [1970]). As explained in appendix A, in a Cournot market, a firm that stays closer to its equal share of the Walrasian output tends to realize higher profits than its competitors. The classic reference in the experimental economics literature is Fouraker & Siegel [1963], which is a detailed study of (rivalistic) behavior in oligopolies. In later experimental work (e.g., Holt [1995], or Davis [1995]), spiteful behavior has been observed occasionally. It is claimed, then, that some players simply like to beat their opponents, even at the cost of spoiling the party (see also Levine [1998]).

The second way to reach the Walrasian equilibrium in a Cournot market with few players is through the adaptive behavior of boundedly rational firms. The central message following from Schaffer [1989], Rhode & Stegeman [1995], and Vega-Redondo [1997] is that any adaptive mechanism in which the probability of choosing a certain action is a positive monotonic function of the payoffs generated will eventually lead to the Walrasian equilibrium, provided there is enough noise. As Vega-Redondo [1997] shows, the convergence is not due to the specifics of a particular example, but it is true with great generality in symmetric Cournot oligopoly games.

Both forms of behavior bring about a spite effect, i.e., a generalized reduction of profits, that affects to a larger degree the previously most successful firm. But, of course, these forms of behavior do not exhaust the possibilities for a spite effect. This effect will appear as well in evolutionary selection processes if the likelihood to survive selection pressure is a positive monotonic function of a species' biological fitness. Similarly, we may find it as a form of strategic behavior in dynamic games. For example, in the context of a struggle for survival, when some agents deliberately trade short term gains for long term ones, in an effort to get rid of rivals.[3]

More interestingly, in our context, a spite effect may also be observed if subjects follow consciously a dynamic strategy that implies reciprocating behavior.[4] A Cournot game can be interpreted as a game

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[3] See, for example, the confrontation between easyJet and BA, in which easyJet publicly accuses BA of being copycats.

[4] Fouraker & Siegel [1963], although they stress the subjects' preferences in their explanation of behavior, also notice that rivalistic actions might be related to the dynamics of the game. A player might be motivated solely by his own profits but employ the rivalistic signal as a means of increasing those profits. Notice that this departs from the pure psychological disposition point of view, but it is still far from considering adaptive behavior and bounded rationality as such. Notice also that there are two aspects of learning in an oligopoly game. First, learning about the (continued...)

in which firms choose degrees of cooperation, full cooperation meaning that the subjects produce the joint-monopoly (Pareto) output level. A reciprocating strategy of the type *'give as good as you get'*, or GGG, could bring about the spite effect if cooperation fails to be achieved. Notice that when looking at individual decisions, it may be impossible to distinguish between blind imitation of successful behavior and a deliberate reciprocating strategy. Yet the distinction appears to be crucial. Not only are these two types of behavior fundamentally different mental processes, but they may also lead to sharply different outcomes. In a Cournot market, imitation of the most successful firm (with noise) can only lead to a competitive equilibrium, while a deliberate GGG strategy, if successful, may take the market into the opposite direction, towards full cooperation.

Therefore, if firms rely on some form of imitation of the output decisions of the more successful firms,[5] then the spite effect will manifest itself in the Cournot market as competitive output levels with low profits. But output levels around the Walrasian equilibrium, may or may not be due to imitation. However, if output levels turn out to be low, they do not show a trend towards the competitive output, and there is enough noise or experimenting, then we know, without having to look into the individual decisions, that imitation of the most profitable decision is *not prevalent* enough to affect significantly the output levels in the Cournot market.[6]

3. Experimental Design

We conducted seven experimental sessions in the computerized experimental laboratory LeeX at the Universitat Pompeu Fabra in Barcelona in Winter/Spring 1997. The experiment was based on the classic Cournot duopoly and triopoly experiments designed by Fouraker & Siegel [1963], and subsequently modified (see Holt [1985]). For both the duopolies and triopolies we used three treatments based on different information setups.[7] For each treatment there were 18 players simultaneously in the laboratory. Players sat in front of personal computers, and could not observe the screens of other players nor communicate with them. As will be explained below, the time that a session lasted depended on the

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[4](...continued)
environment. Second, learning about the behavior of one's opponent. This second form seems loosely related to what Fouraker & Siegel call 'the dynamics of the interaction between the players', but is not recognized by them as a learning issue.

[5] This includes strict imitation of the most successful firm, $q_i^t = q_j^{t-1}$ if $\pi_j^{t-1} \geq \pi_k^{t-1}$ $\forall i, j, k$, and less strict forms of imitation, $\text{prob}(q_i^t = q_j^{t-1}) \geq \text{prob}(q_i^t = q_k^{t-1})$ if $\pi_j^{t-1} \geq \pi_k^{t-1}$ $\forall i, j, k$.

[6] An alternative way of detecting imitation might be to ask the players. This should be done with great care since players need not be aware of fact that they are imitating each other. For example, a study based on a Fourier analysis of the voices in the Larry King Live talk show revealed interesting convergence patterns in the frequencies used by the host and his interviewed guests, but it seems unlikely that they were doing this consciously (Mirsky [1996]).

[7] In addition to these six treatments we ran one control treatment, in which we rewarded the players for their relative performance (see below).

treatment. It ranged from about one to about two hours. The average payment over the 126 players was 2200 pesetas (≈ US$ 15). Examples of the instructions given to the players can be found in appendix B.

3.1 The Standard Cournot Model

We consider a standard symmetric Cournot oligopoly. There is a number n of firms producing the same homogeneous commodity. The only decision variable for firm i is the quantity q_i to be produced. We assume that the inverse demand function is $P(Q) = a + bQ$, where $Q = \Sigma q_i$, $a > 0$, and $b < 0$, with the exact values of a and b differing from treatment to treatment (see below). The n players are firms competing in the same market for 22 consecutive periods. The total costs for a firm are given by $C(q) = k \cdot q + K$, with $k > 0$, and $K < 0$, ensuring positive profits at Walrasian output levels. Given the market price P, the profit V for an individual player is computed as follows: $V = P \cdot q - C$.

3.2 Treatments: Duopolies and Triopolies

Since there were always 18 players simultaneously in the laboratory, 9 duopoly or 6 triopoly markets were going on at the same time. The players were matched randomly, and anonymously, to form markets, and they played for consecutive 22 periods in the same market. In our experiment, unlike in Fouraker & Siegel [1963], subjects knew the length of the experimental sessions. Players also knew whether it was a duopoly or triopoly they were in, but they did not know who was in their market. In the duopolies, the inverse demand curve was $P = 414 - 4Q$, and the cost function $C = 174q - 146$. In the triopoly these were: $P = 530 - 4Q$, and $C = 174q - 266$.

We can distinguish the following three symmetric pure strategy equilibria for the static Cournot game: the joint-monopoly Pareto (P), the Cournot-Nash (N), and the competitive Walrasian output (W). Given the specifications of the demand and cost functions, these three equilibria in the duopoly are $Q^P = 30$ (with $q^P = 15$), $Q^N = 40$ (with $q^N = 20$), and $Q^W = 60$ (with $q^W = 30$). And in the triopoly they are $Q^P = 45$ (with $q^P = 15$), $Q^N = 66$ (with $q^N = 22$), and $Q^W = 90$ (with $q^W = 30$).[8]

Players can choose a quantity from 8 to 32 and are allowed to enter only integer values for their output

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[8] See appendix A for the formal analysis of the Cournot oligopoly. Due to the integer restriction, there are some asymmetric equilibria as well. In the duopoly, one firm producing 19, and the other 21 would be an asymmetric Cournot-Nash equilibrium. In the triopoly $Q^P = 45$ gives the only symmetric Pareto equilibrium, but it is not strict since $Q = 44$ would give the same total profits. Also the Cournot-Nash equilibrium leading to $Q^N = 66$ is not strict since one player could deviate to $q^N = 23$ and be equally well-off. In fact, $Q^N = 67$ is an asymmetric Cournot-Nash equilibrium. The Walrasian equilibrium occurs at $Q^W = 89$. Hence, when all firms produce 29, two want to deviate to 30, and when all produce 30, one wants to deviate to 29. Nevertheless, $q^W = 30$ is an equilibrium in the sense that it is the only symmetric output where no player can realize a higher profit than the other two by deviating unilaterally.

levels. Notice that the Walrasian individual output level of 30 is near the upper bound of the output range. Had we allowed for a higher range of output, random output choice or choice in the middle of the output range might have resulted in market output levels close to Walras, confounding the effect of imitation of successful firms.

3.3 Treatments: 'Bounded Rationality'

We consider three different treatments that differ in the way the information is provided, and the time pressure put on the players. Yet, the underlying market is exactly the same in the three treatments, and in fact, the objectively 'available' information is exactly the same in each treatment. Consequently, the theoretical benchmarks provided by the equilibria computed above are appropriate for all treatments. If some pieces of information were objectively missing in one treatment, even fully rational agents might converge to different output levels.

The difference among treatments lies in how *difficult it is to construct* this information from the data provided and the market behavior. We call these three treatments *'easy'*, *'hard'*, and *'hardest'*, and we claim that subjects are more boundedly rational as we move from easy to hard to hardest treatments, in the sense that they have *less time* and the information is provided in a more *confusing* format. In the *'easy'* treatment there is no time pressure on the players. They can spend as much time as they want. In the *'hard'* and *'hardest'* treatments, players have just one minute to decide on their output level.

The differences in information setup between the three versions are more involved. In neither of them did the players get the demand and cost functions as such. In the *'easy'* version, the players were given a profit table that *conveniently* summarized all the information concerning the inverse demand curve and the cost function (see appendix B). This profit table contains for each combination of outputs, the profits for the firms. The column entry shows the output of firm X, and the row entry the output of the other firm (duopoly) or the average output level of the other firms (triopoly). The cells show the profits of firm X, and the profits the other firm (duopoly) or the average of the profits of the other firms (triopoly). Hence, in the *'easy'* treatment, there was no need for additional learning about the environment, or about the exact demand and cost functions used. In this treatment, after each period, each player gets information about the actions of each of the other players in the same market, but not about their profits. Notice, however, that if they wanted, they could look up the profits of the other players in the profit table. In addition, in the *'easy'* version a player always gets a complete history of his own past actions and profits. The way this information appears on the screen can be seen in figure B1 in appendix B.

In the *'hard'* version, the players did not get the convenient profit table. Instead, they got an *inconveniently* arranged enumeration of the market prices associated with all possible aggregate output levels. They got a similarly arranged enumeration of all possible cost levels. Since the players knew that their profits were simply their revenues minus their costs, and they knew that all firms were identical, they had exactly the same information as in the *'easy'* version, although less discernible. The history provided to the subjects was also different from the previous treatment. After each period, both the actions of all players in the same market in that period, and the *profits* obtained by each player were given on the screen (see figure B2 in appendix B). In addition, to make sure that subjects did not miss what output decision had led to the highest profit, it appeared on the screen with a *border of *s*.

Finally, the *'hardest'* version differed from the *'hard'* treatment in that the information about the demand side of the market was limited to the statement that *'the price level depends on aggregate output'*.

The differences between the *'easy'*, and the *'hard'* and *'hardest'* versions can be summarized as follows. In the *'easy'* version, by providing subjects with a convenient profit table, we minimize the need for further learning about the environment and we facilitate best replies. As we move into the *'hard'* and *'hardest'* versions, we scramble the information about the market, increasing the subjects' need to learn about the environment. This, combined with the one-minute time pressure, become obstacles to 'doing the best one can'.[9] In addition, we provide flashing information about the most successful decision in each period, facilitating imitation of it.

Conventional wisdom claims that imitation should be more prevalent the more complex the subjects' decision task is. Therefore, showing that imitation does not frequently occur when subjects can easily compute best replies or when they are little aware of what other subjects are doing would not be surprising. But this scenario, which corresponds to the *'easy'* treatment, can be used as a benchmark. The question, then, is whether imitation would be more frequent in more difficult environments, when the players are more boundedly rational in the sense that their time and information constraints are tighter. The purpose of the second and third treatments is to explore this question.

3.4 Monetary Incentives

In all treatments, each player gets a show-up fee of 250 pesetas (≈ US$ 1.65). If a player realized losses, these would be subtracted from the *'show-up'* fee. This was known to the players. No player realized cumulative losses. In addition, players were paid depending on their performance, the details of the payoff scheme applied being known by the players. In the duopolies, the monetary payoff was 0.035 pesetas per profit point realized during periods 1 to 20, and 0.35 pesetas in the last two periods 21 and

[9] To readers not fully convinced about the relevance of the difference between the *'easy'*, and the *'hard'* and *'hardest'* versions, we suggest the following two exercises, which will take exactly one minute each. Look at the instructions for the *'hard'* duopoly with absolute performance payoff in table B2 in appendix B. What is your output choice? 30 seconds, 50 seconds, 1 minute. Now, suppose that you chose 21 (with profits 1322), whereas your competitor chose 25 (profits 1546). What is your next choice? 30 seconds, ... You can check the quality of your choices with the profit table supplied for the *'easy'* version in appendix B.

22. In the triopolies the coefficients were 0.025 and 0.25. These coefficients varied between duopoly and triopoly in order to compensate for the fact that profit opportunities are different in these markets. The result was identical monetary incentives across the different information treatments.

The decision to make the payoffs of periods 21 and 22 ten times higher reflects our interest, as will be explained in section 4, in these last two periods. The higher payoffs were incentives for the players to stay concentrated till the very end. In addition, they were meant to reinforce the so-called '*end effect*', making collusive and strategic behavior more unlikely during the last periods,[10] thereby encouraging higher output levels. In these circumstances, levels of output below Walras give *additional* credibility to a conclusion of little imitation.

In addition to the treatments mentioned above, we also ran a session with an '*easy*' duopoly treatment in which players were rewarded by their relative, instead of their absolute, performance. After each period, only the player who made the largest profit received a fixed positive payoff (100 pesetas during each of the periods 1 to 20, and 1000 pesetas in periods 21 and 22), while the other player(s) got nothing. When two players have the same profit, they share the monetary reward of the winner. The main purpose of this treatment was to verify that the '*easy*' treatment was very easy indeed, and that our experimental set-up did not contain any insurmountable obstacle to the attainment of the Walrasian output expected in such a treatment, given the induced preference to beat their opponents. Indeed, a Walrasian output level of 30 was chosen by 100% of the players in the last two periods in this control treatment.

4. Analysis

As explained in section 3, the '*hard*' and '*hardest*' treatments should be particularly conducive to imitation. The intuition being that when the subjects are more intensely confronted with their bounded rationality, imitation of the successful firm becomes a prevalent mode of behavior. We therefore formulate the hypothesis to be tested in the following terms:

> ***Hypothesis***: In the '*hard*' and '*hardest*' treatments, the occurrence of imitation will make the Walrasian equilibrium the best description of the Cournot market in the last two periods.

The hypothesis was rejected by the experiment. It appears that the bounded rationality factor did not induce players to imitate much. We now explain in detail how we derive this conclusion. Our analysis of the experimental data begins focussing on the last two periods, the standard approach when it comes to testing an equilibrium hypothesis (see Crawford [1998]).

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[10] Notice that since the game is a finitely repeated one with complete information, the unique subgame perfect equilibrium is playing the equilibrium of the stage game anyway.

market	duopolies 'easy'	'hard'	'hardest'	triopolies 'easy'	'hard'	'hardest'
1	20.00	15.75	25.00	24.50	26.00	28.67
2	19.75	22.00	16.75	21.83	21.67	23.83
3	18.00	26.25	22.50	25.50	24.83	29.33
4	16.75	23.00	20.25	23.33	29.83	20.83
5	20.00	26.00	20.00	24.17	18.83	27.83
6	18.50	31.00	22.50	22.83	24.50	27.67
7	15.75	16.50	25.75			
8	15.00	27.75	23.75			
9	20.00	22.00	24.75			
average	18.19	23.36	22.36	23.69	24.28	26.36

Table 1 Average output in last two periods for each market

4.1 The last two periods

Table 1 presents the *average* output level in the last two periods for each market in the various treatments. These output levels are the independent observations (9 for each duopoly treatment, and 6 for each triopoly) for our statistical tests on which our conclusions rely. In the following we present graphs of the *individual* output levels in the last two periods, and for presentational reasons we report some statistical tests corresponding to these 36 individual observations. Although this obviously neglects the possible interdependence between the individual output levels in a given market, these tests invariably lead to the same qualitative conclusions as the tests based on the independent market observations (not reported here), with only one exception, noticed below, in the *'hardest'* triopolies.

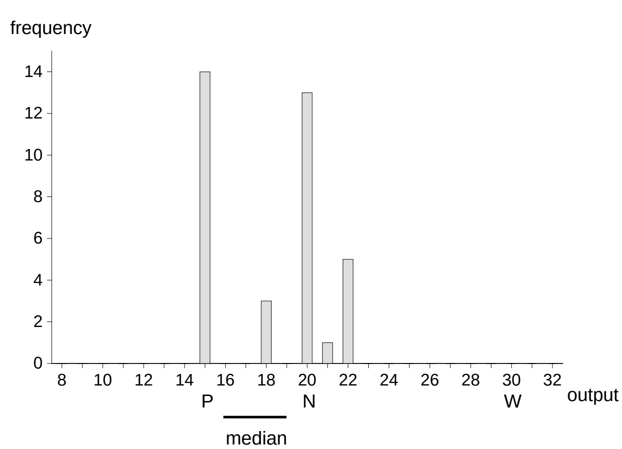
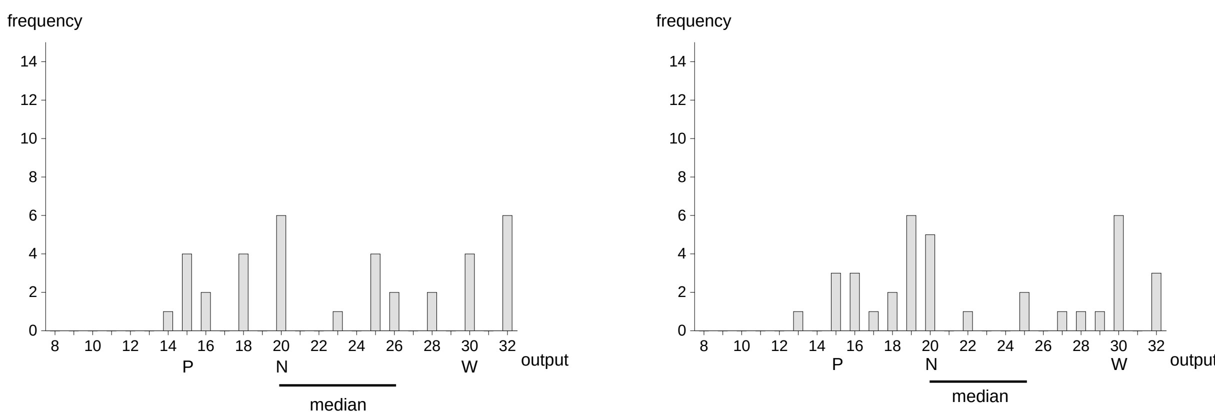


Figure 1 Frequency distribution of individual output levels in the *'easy'* duopoly, last two periods

Figure 1 shows the frequency distribution of actions in the last two periods for the *'easy'* duopolies. Notice that a Pareto output of 15 is the most frequently chosen (14 out of 36 times), followed by a Cournot-Nash output (13 times). In period 21 there were ten colluding players, and four of them persisted in colluding in the last period. Since no output larger than 22 was chosen, no subject got close to the Walrasian output of 30. A sign test shows that the 90% confidence interval for the median output ranges from 16 to 19. These results are in agreement with Fouraker & Siegel [1963], and other previous experiments. But whereas most of those experiments focused on possible explanations for the persistence or unraveling of collusion (see Holt [1995] for a survey), we will merely use the *'easy'* markets as the benchmark treatment.

The data do not suggest a preference for beating the opponents. Assuming that preferences remain constant across the treatments, any differences in the output levels in the other treatments can be attributed to a bounded rationality effect. Will the Walrasian output become more prevalent as the task of learning about the market becomes more and more difficult, while the decision of the most successful firm is displayed more prominently?



a *'hard'* treatment ***b*** *'hardest'* treatment

Figure 2 Frequency distributions of individual output levels in the *'hard'* and *'hardest'* duopoly, last two periods

Figures 2.a and 2.b give the frequency distributions of the output levels in the last two periods of the *'hard'* and *'hardest'* duopoly treatments. In the *'hard'* case, output is spread along the whole range, and has two peaks corresponding to Cournot and the highest possible output, 32, above Walras.[11] Although

[11] Six times, out of thirty-six, an output level of 32 is chosen, resulting in large falls in profits. This might be an indication that some subjects were confused, desperate or bored. For those interested in the analysis of individual behavior we should add that only one of the six cases could be called imitation, in period 21, of the previous most successful decision. But even the firm that appeared to imitate in period 21 did not do so again in period 22.

we are not concerned in this paper with providing an explanation for observed behavior, this spreading out, and the decrease of collusion with respect to the *'easy'* version, may be the result of the added difficulty in learning about the environment, making it more difficult to discover the Pareto output, and making it less useful to punish the other player, since punishment makes sense only if one believes the other understands what is expected from him when punished. The spreading out is equally notorious in the *'hardest'* case, but while the average output increased from *'easy'* to *'hard'*, it slightly fell from *'hard'* to *'hardest'*. As can be seen from the graphs, this is not due to a fall in the relative frequency of outputs around the Walrasian equilibrium, but to a fall in the frequency of outputs in between Cournot-Nash and Walras, and to a frequency increase for outputs between Pareto and Cournot-Nash.

Is imitation driving the players to the Walrasian output level? First, a Wilcoxon-Mann-Whitney test (Wilcoxon test from here on) shows that the players produce significantly more in the *'hard'* version than in the *'easy'* version (0.0% significance; 1-sided). Second, using the same test we find that firms produce significantly less than the Walrasian output level (significant at 0.0%, 1-sided). Third, we apply the sign test to determine the 90% confidence interval for the median output level. Thanks to the spread in output levels this ranges from 20 to 26, still away from the Walrasian equilibrium, but including the Cournot-Nash equilibrium of 20.

Applying the same tests to the *'hardest'* duopolies, we find that they produce significantly more than in the *'easy'* duopoly (0.7%; 1-sided Wilcoxon), but less than the Walrasian output of 30 (0.0%; 1-sided Wilcoxon), while there is no significant difference with the *'hard'* duopolies. The 90% confidence interval for the median output (20 to 25; sign test) is even farther away from the Walrasian output than in the *'hard'* version, including again the Cournot-Nash equilibrium. Hence, the hypothesis that in the *'hard'* and *'hardest'* treatments the Walrasian equilibrium would be a good description of the market must be rejected for the duopolies. The inference is that imitation was not prevalent.

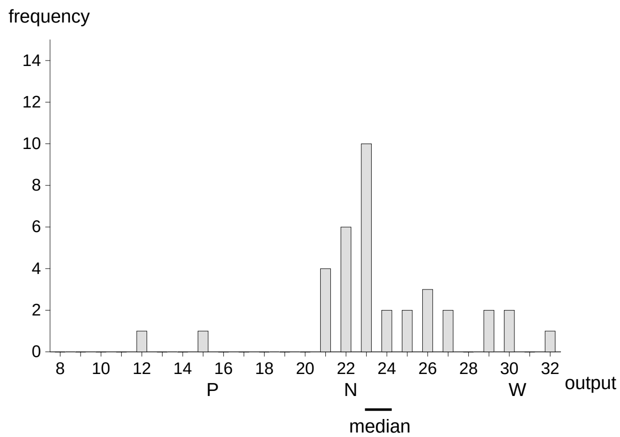
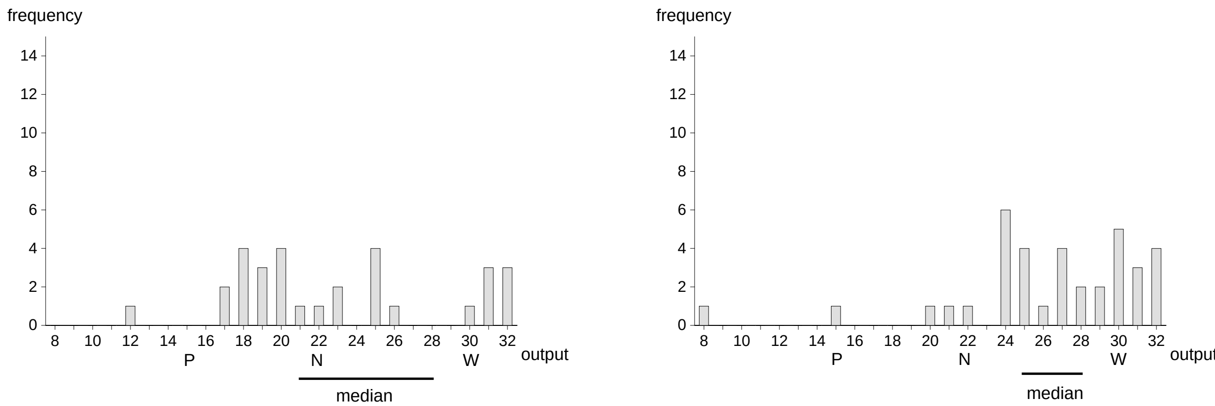


Figure 3 Frequency distribution of individual output levels in the '*easy*' triopoly, last two periods

Figure 3 presents the frequency distribution for the triopolies in the '*easy*' treatment, the baseline treatment. We observe that there is a wider spread of output levels than in the baseline duopoly session, and that practically no collusion occurs. The latter is related, according to the usual explanation, to the increased difficulty, with three rather than two subjects, to learn what other players are up to, and to reward and punish individual players since the only available instruments work through the market and do not discriminate between players. The most frequent output levels in the last two periods are 23 (10 times), 22 (6 times), and 21 (4 times). Remember that Cournot-Nash is at 22. The 90% confidence interval for the median output goes from 23 to 24 (sign test). This, again, confirms previous experimental observations. As in the '*easy*' duopoly, spite effects are not prevalent in this baseline treatment. We want again to verify whether they come to the fore as we make the players' learning-about-the-environment task more complicated and imitation easier.



a *'hard'* treatment ***b*** *'hardest'* treatment

Figure 4 Frequency distributions of individual output levels in the *'hard'* and *'hardest'* triopoly, last two periods

The frequency distributions of output levels for the *'hard'* and *'hardest'* triopoly are given in figures 4.a and 4.b. One observation again stands out, which is the wider spreading of choices compared to the *'easy'* version. In the *'hard'* version, the frequency of the Walrasian output actually decreases, while Cournot-Nash loses in frequency in favor of lower values. The highest frequency in periods 21 and 22 corresponds to outputs of 18, 20, and 25 (4 times each), and the average output in the last two periods is 24.3. The odd outputs of 31 and 32, possibly mere end effects, help pull up this average. The spread is not surprising due to the added difficulty in learning about the environment. But it is also an indication that imitation of the successful firms was not frequent. Let us apply the same statistical tests as before. First, a Wilcoxon test rejects the null hypothesis that the output levels are higher in the *'hard'* triopoly than in the corresponding *'easy'* treatment (significant at 48.0%; 1-sided), confirming that they are lower than the Walrasian output levels (significant at 0.1%; 1-sided). Second, a sign test provides us with a 90% confidence interval for the median output level ranging from 21 to 28, including the Cournot-Nash output of 22 but not the Walrasian output of 30.

In the *'hardest'* triopolies, the modal output in the last two periods is 24 (6 times), followed by 30 (5 times), with an average of 26.4. Although the spread is again considerable, it is concentrated most of all in the range from 24 to 32. This output is significantly higher than in the *'easy'* version (0.0% significance; 1-sided Wilcoxon), but not higher than in the *'hard'* triopolies (6.2%; 1-sided Wilcoxon). Moreover, output in the *'hardest'* triopolies *is* significantly lower than the Walrasian level of 30 (0.0%; 1-sided Wilcoxon). The sign test gives a 90% confidence interval for the median output from 25 to 28, in the middle between Cournot-Nash, and Walras. As mentioned above, this treatment was the only one for which the tests based on the individual data did not lead to the same conclusion as those based on the independent market observations. Using as observations the average output over the last two periods in each market, we find that the output in the *'hardest'* triopolies is *not* significantly higher than in the *'easy'* triopolies (8.7%; 1-sided Wilcoxon), whereas the 90% confidence interval for the median output ranges from 21 to 29 (sign test), including only the Cournot-Nash equilibrium.

Hence, we have to conclude that in the triopoly sessions, a case in favor of the hypothesis seems rather weak at best. Combining the evidence for the duopolies and triopolies, on the basis of our analysis of the output levels in the last two periods, two general conclusions can be drawn.

> ***Fact 1***: As the learning-about-the-environment task becomes more complex, output choices become more spread out.

Whether this is due to errors, misunderstandings, chance or deliberate decisions, it is not for us to clarify. In any case, the equation between environmental complexity and uncertainty of results seems to be confirmed in all cases.

> ***Fact 2***: As the learning-about-the-environment task becomes more complex, output increases, but the Walrasian output is not a good description of the output levels observed in the experiment.[12]

Therefore, one can safely reject the hypothesis that imitation related to bounded rationality drives the players to the Walrasian output level.

4.2 The trend

Since the hypothesis to be tested concerns an equilibrium prediction, our analysis thus far was based on the output levels in the last two periods. Nevertheless, data from previous periods can help decide whether there is anything in the dynamics which suggests that running the experiment *longer* would lead to output levels closer to the Walrasian output. As we will see, there is no such evidence.

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[12] While the absence of Walrasian outputs implies little or no imitation, it is not necessarily true, as we argued above, that a high frequency of Walrasian or near-Walrasian outputs would be a sign of imitation. These outputs could be reached through decisions not based on the imitation of success. See Offerman et al. [1997] for an opposite point of view.

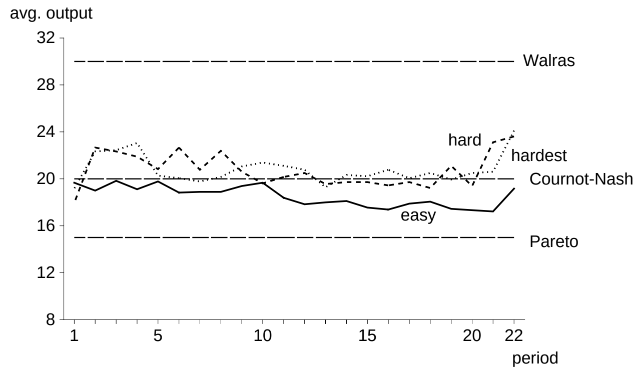

Figure 5 Time series of the average output in duopolies

Figure 5 gives the time series of the average outputs in the duopolies. In the *'easy'* duopolies, output starts just below 20, and slowly decreases as collusion builds up. With the collapse of collusion in the last two periods, output shoots up towards Cournot-Nash. In the *'hard'* duopoly, output starts slightly below 20 as well, increases to 22.7 in period 2, and then very slowly goes down to 19.4 in period 20, followed by an end effect leading to 23.6 in period 22. Hence, it stays close to Cournot-Nash, and if a trend exists during the first 20 periods, it is downward sloping. We see a very similar pattern in the *'hardest'* duopoly treatment. Average output starts at 19.3, reaches a peak in period 4 at 23.1, followed by fluctuations around Cournot-Nash until the last period, where we see a jump to 24.1. The conclusion is that in the *'hard'* and *'hardest'* duopolies nothing suggests a trend towards Walrasian output levels.

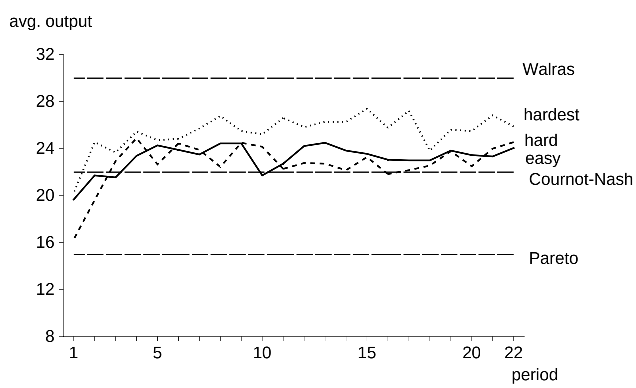

Figure 6 Time series of the average output in triopolies

Figure 6 shows the average output levels for the triopolies. In the *'easy'* triopolies, output starts slightly below 20, increases a little bit until period 5, and then stays relatively constant till the end. There is no end effect, as collusion was never established. In the *'hard'* triopolies, output starts at 16.3, increases to 24.9 in period 4, and then slowly decreases to 21.8 in period 16, followed by a slight increase to 22.5 in period 20 (remember Cournot-Nash is at 22), and 24.6 in period 22. Notice that the average output level from period 11 to 20 is always *lower* than in the *'easy'* baseline treatment. The *'hardest'* triopolies, are somewhat different, but not too much. The average output level in period 1 is 20.2, followed by a quick jump to 24.5 in the second period, and reaches a first peak at 26.8 in period 8. After this, the average output level fluctuates somewhat, with a dip of 23.8 in period 18, and a value in the final period of 25.9. As we see, the series is consistently above the *'easy'* and *'hard'* series, but apart from the increase in the first periods, there is no upward trend.

In conclusion, the analysis of all the 22 periods of the sessions does not reveal any trend towards the competitive equilibrium in any of the six treatments. Nothing in the observed decisions seems to indicate that the sessions were too short for convergence to the Walrasian equilibrium. Of course, on the basis of our experimental evidence reported here we cannot exclude that such an upward trend itself might start later. But our hypothesis concerned imitation based on bounded rationality, and the longer the sessions go on, the less of an issue is bounded rationality, because players learn more and more about the environment. Hence, even if a trend were to start later on, it would be hard to explain it in terms of bounded rationality.

But, apart from this logical point, we actually did gather some evidence as to whether an upward trend might start later. In the *'hard'* and *'hardest'* duopolies and triopolies, once the 22 periods of each session were finished, we informed subjects that since the session had run so smoothly and fast, we still had some time left and that we would repeat the same experiment with the same matches for another 12 periods, the last two periods having again payoffs ten times the payoffs of the previous periods. In these 12 periods again, there is no sign of a trend towards Walras. Average output levels are close to the Cournot-Nash equilibrium, except for an end effect.[13] Therefore we can state the following.

Fact 3: Absence of a trend towards the Walrasian equilibrium.

One might argue that what happens in the periods 1 to 20 is in some sense cheap talk in preparation for the last two periods, which offer much higher payoffs. There is no denying that this could be the case. However, if it were so, then we would be dealing with some kind of strategic behavior, which implies a

[13] We do not fully report these data since the procedure may be deemed controversial and the results spurious for the strict purpose of the experiment. Yet they throw some light on whether a trend towards Walrasian results was lurking in our sessions of 22 periods. The corresponding graphs are available from the authors upon request.

reasoning process at a higher cognitive level than the learning-through-imitation hypothesis assumes. To the extent that some of this may be happening in the duopoly markets, it reinforces the conclusion that imitation is not a driving force in our experiments.[14] That end effects are hardly noticeable in the triopoly markets indicates that in these markets the first twenty periods are not mere foreplay and the absence of any convergence towards Walras should be taken at face value.

The conclusion of this section is that the absence of a trend towards Walrasian output indicates that imitation does not play a significant role in our experimental market.

4.3 Individual Behavior

We feel that a more systematic analysis of the individual period-to-period decisions is unnecessary. The essential reason being that imitation in these Cournot markets interests us to the extent that it has an effect on the output levels. And there is no amount of analysis of individual data that could change the conclusions reached above. There are additional reasons to be skeptical about the usefulness of the analysis of individual decisions. Even the observation that subjects choose the output level that was more profitable in the previous period is no sure indication of imitative behavior. Of course, if imitation is defined that way, then we have to call it imitation. But the analysis requires more subtlety. Consider, for example, that a subject follows a *deliberate* tit-for-tat strategy. This requires a deeper level of cognitive involvement than simple imitation of successful behavior. Therefore, it would be misleading to call a tit-for-tat strategy, or in general any reciprocating strategy of the type *'give-as-good-as-you-get'* (GGG), an imitative strategy, even though it amounts to the same decision when the firm responds tat to the non-cooperative, but successful, decision of another firm to increase its output. Notice that simple imitation of successful behavior and deliberate GGG strategies may lead to very different results. A GGG strategy in a Cournot market may lead to a competitive equilibrium, but it may also lead to the collusive solution. Hence, there exist strategies that resemble, in single periods, imitation of successful behavior, while in fact they represent a different behavior that, in particular, does not necessarily share the same dynamics.

In spite of our doubts about the procedure, but in order to illustrate the issues faced, we will analyze the individual behavior in the market for firms 4, 10 and 16 in the *'hard'* triopoly treatment. We choose this market because with its average output in the last 2 periods of 29.8 it was the one that converged most to the Walrasian output of 30. This seems the ideal set-up for finding imitative behavior. Table 2 shows the individual decisions and profits in this market, plus the most successful decisions with corresponding profits. If by imitation we mean taking the same decision as was taken by the most successful firm in the previous period, then firm 16 does not imitate *at all* for the 21 periods. Firm 10

[14] The same argument applies to any other form of dynamically strategic behavior.

imitated the successful behavior of another firm only twice out of 21 possibilities. The first time is in period 2, which might be genuine imitation. The second time is in period 21, but here we are dealing with a rather weak form of imitation since in the previous period all three firms, firm 10 included, had identical profits. Hence, one could argue that this subject, as the experiment proceeds, very quickly learns *not* to imitate. Finally, firm 4 seems to have imitated somewhat more, 6 out of 21 times. But when we look more carefully at what the subject does, it turns out that 4 out of these 6 times he imitates himself. That again is a rather weak form of imitation since it means staying put at some successful output level, which could simply indicate immobility.

If instead of strict imitation of the most successful firm, we look for a rather broad class of behavior, requiring only that a firm moves into the *direction* of the previously most successful firm, independently of by much,[15] we find that these three firms 'imitate' in 12, 10, and 10 periods respectively; an average frequency of 50.1%. Analysis of the individual behavior in other sessions shows similar patterns.

To sum it up, evidence on the individual period-to-period decisions bolsters our earlier conclusion based on the analysis of the output levels, and illustrates the difficulties to identify imitation proper.

[15] That is, all observations satisfying one of the following three rules count as a '*hit*': (i) if $q_i^t < q_*^t$ then $q_i^{t+1} > q_i^t$, (ii) if $q_i^t > q_*^t$ then $q_i^{t+1} < q_i^t$, and (iii) if $q_i^t = q_*^t$ then $q_i^{t+1} = q_i^t$, where q_*^t is the most successful output in period t.

	firm 4		firm 10		firm 16		most successful	
period	output	profits	output	profits	output	profits	output	profits
1	10	2306	8	1898	20	4346	20	4346
2	22	2818	20	2586	18	2354	22	2818
3	23	1830	28	2170	21	1694	28	2170
4	29	1310	26	1202	25	1166	29	1310
5	29	3282	20	2346	14	1722	29	3282
6	29	2006	15	1166	30	2066	30	2066
7	30	1946	20	1386	25	1666	30	1946
8	28	2618	20	1946	20	1946	28	2618
9	25	1766	20	1466	29	2006	29	2006
10	30	866	22	706	32	906	32	906
11	31	2994	16	1674	20	2026	31	2994
12	30	146	32	138	28	154	32	154
13	26	1618	25	1566	25	1566	26	1618
14	26	1930	19	1482	28	2058	28	2058
15	30	1826	20	1306	26	1618	30	1826
16	29	1310	23	1094	28	1274	29	1310
17	29	846	23	726	32	906	32	906
18	31	1134	24	938	27	1022	31	1134
19	30	146	30	146	30	146	30	146
20	32	266	29	266	28	266	28/29/32	266
21	30	506	32	522	25	466	32	522
22	32	-118	29	-82	31	-106	29	-82

Table 2 Individual actions and outcomes in one *'hard'* triopoly market

5. Conclusion

Theory has shown that 'imitating the best' leads to the competitive equilibrium in Cournot markets. Since imitation seems simple, it was natural to infer that the competitive output would be likely in such markets, provided that subjects were 'boundedly rational' enough and knew whom to imitate. We believe that our experiment has shown that this conclusion is unwarranted. In spite of our efforts at scrambling information and at flashing on the screen, each period, the most successful decision, we did not manage to induce imitation of the most successful players.

Why, then, do boundedly rational people not imitate in Cournot markets? Imitation in our setup was straightforward and simple but, boundedly rational as subjects can be, they still possess an arsenal of responses to somebody else's actions; among them the use of their imagination (see Selten [1978]).[16] In addition, in the Cournot game, a player, by systematically imitating more successful players, would worsen her own payoffs. Even in the treatments with scrambled information, it did not take long for subjects to discover this fact.

[16] A Cournot game allows for subtle behavior, and it would be surprising if subjects got stuck in a strategy of plain imitation. Consider, as an example in another context, the richness of reciprocal interactions among boundedly rational beings, in this case guillemots (*Uriae aalge*), as reported by Roberts and Sherratt [1998].

After we had run our experiments, we learned that some other people were pursuing a similar track (see Huck et al. [1999], and Offerman et al. [1997]). While our conclusion seems to be at odds with theirs, it does confirm preliminary experimental findings by Allsop & Hey [1997], who test for herd behavior in an experimental setup and find that players rely much more on their private signals than some theoretical work had suggested (see Banerjee [1992]), and by Holt [1998] and others on minimal effort games. With respect to Cournot games, Dixon et al. [1996] show that there are evolutionary processes that lead to Pareto outcomes, and Eichberger & Kelsey [1999] demonstrate how Knightian uncertainty leads to an equilibrium with output levels *below* Cournot-Nash (away from the Walrasian equilibrium) in a one-shot Cournot game.

That imitation has not been observed in our experiments, while an indication that imitation based on bounded rationality is not prevalent in this particular kind of games, does not belittle the hypothesis of imitation in other circumstances, for example, in survival-of-the-fittest type situations. Ultimately, what one could hope to achieve is a classification of situations and games according to the prevalence of imitation. Our contribution to such a project is to warn against simply assuming imitation in theoretical models, because the *boundary* between these two classes may be located at a place that is different from where some people seem to expect or assume.

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Appendix A. The Spite Effect and the Cournot Oligopoly

The essence of the spite effect is illustrated by the bimatrix game in figure A1 (see Palomino [1995]), where *T* and *B* are the two possible strategies, and the lowercase letters are the payoffs to the row and column player, with $a>b>c>d$. Clearly, (*T*, *T*) is the only Nash equilibrium since no player can improve by deviating from it, and this is the only combination for which this holds. Now, consider the strategy pair (*B*, *T*), leading to the payoffs (b, c). Remember that $a>b>c>d$. Hence, by deviating from the Nash equilibrium, the row player hurts her own payoff, but she hurts the column player's payoff even more.

	T	***B***
T	*a*, *a*	*c*, *b*
B	*b*, *c*	*d*, *d*

Figure A1 Bimatrix game, with payoffs $a>b>c>d$

Let us now focus on a standard symmetric Cournot oligopoly. There is a number of symmetrical firms producing the same homogeneous commodity. The only decision variable for firm *i* is the quantity q_i to be produced. Once production has taken place, for all firms simultaneously, the firms bring their output to the market, where the market price *P* is determined such that demand equals supply. In order to give the intuition behind the spite effect in this Cournot game, let us consider a simple symmetric Cournot market in which the inverse demand function is $P(Q) = a + bQ$, where $Q = \Sigma q_i$, and in which the cost function for the individual firm is $TC(q) = K + kq$. Making the appropriate assumptions on the parameters *a* and *b* ensures that the demand curve is downward-sloping. We can distinguish three symmetric equilibria of the static Cournot oligopoly game specified above for the case in which the players have complete information. First, suppose that the two firms collude, maximizing their joint-profits. This leads to an aggregate output level called Pareto $Q^P = (k\text{-}a)/(2b)$. Second, if the firms behave as price-takers in a competitive market, they simply produce up to the point where their marginal costs are equal to the market price *P*. Given the specification of the oligopoly model above, this implies an aggregate competitive, or Walrasian, output level of $Q^W = (k\text{-}a)/b$. If, instead, the firms realize that they influence the market price through their own output, they produce up to the point where their marginal costs are equal to their marginal revenue. Taking the output level of the other firm as given, this leads to an aggregate Cournot-Nash equilibrium output of $Q^N = (k\text{-}a)/[b((1/n)+1)]$. Which of these three equilibria occurs depends upon which behavioral assumption is the correct one. Do players collude?

Do they behave as price-takers? Or do they realize they influence the market price themselves?

To see how a spite effect might influence the outcomes of a Cournot market game, suppose, to simplify for illustrative convenience, that there are only two firms and that fixed and marginal costs are zero (see Schaffer [1989]), and let us concentrate on the Walrasian equilibrium. Observe that there are two alternative ways to look at it, based on different behavioral assumptions. In both cases it is the spite effect that makes it an equilibrium. First, suppose that the firms' preferences are such that they do not care about absolute payoffs, but only about relative payoffs. Any utility function assigning a higher value to an outcome in which the firm beats the other firm, and a lower value to an outcome in which it gets beaten will, after elimination of all weakly dominated strategies, leave only one strategy: producing its equal share of Q^W.

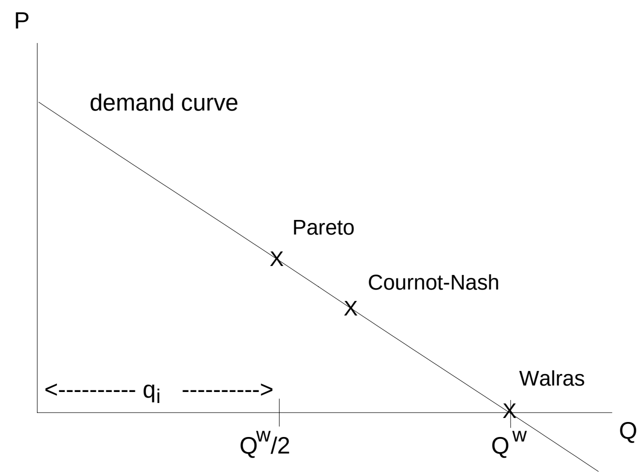

Figure A2 Example Cournot duopoly

To see why this is the only strategy where a firm is sure it can never be beaten, look at figure A2, and focus on the Walrasian output Q^W. Suppose firm i produces its equal share of the Walrasian output: $q_i = Q^W/2$. If firm j would do the same, aggregate output is Q^W, the market price P will be zero, and both make a zero profit. What happens when firm j produces more than $Q^W/2$? The price P will become negative, and both firms will make losses. But it is firm i that makes less losses, because it has a lower output level sold at the same market price P. What happens instead if firm j produces less than $Q^W/2$? The price P will be positive, and hence this will increase firm j's profits. But again it is firm i that makes a greater profit, because it has a higher output level sold at the same market price P. In some sense, firm i is free riding on firm j's production restraint. Hence, the firm that produces its equal share of Q^W will have the highest relative payoff in this Cournot duopoly. Note that this implies in particular the following. If firm i produces its share of the symmetric Walrasian output, while firm j naively chooses the symmetric output level to maximize its absolute payoffs (i.e., its equal share of the Cournot-Nash output), it is firm i that realizes the highest profits. Moreover, even if firm j is aware of the fact that firm i is producing at the Walrasian output level, and maximizes its profits taking this into account, it is firm i that realizes the highest payoffs. In case we consider more than two firms, matters become slightly more complicated, but the following holds. Whenever the aggregate output level is below Walras, i.e., on average an individual firm produces less than its share of the Walrasian output level, the price will be positive, and it is the firms with the higher output levels that generate the higher profits. Exactly the reverse holds when aggregate output exceeds the Walrasian output level: the lower a firm's output level, the higher its profits will be.

Now, suppose that the firms do not have a preference to beat their competitors, but that they are boundedly rational and tend to imitate successful behavior in the sense that the probability to choose any output level is a positive monotonic function of the profits realized in the past. Whenever the average output is below Walras, it is the highest output firm, realizing the highest profit, that is most likely to be imitated, and the other way round. As a result the market will converge to the Walrasian equilibrium.

Appendix B. Instructions to the Players

Table B1 gives the English translation of the Spanish instructions to the players in the *'easy'* duopoly.

Instructions

Introduction

- This is a decision experiment. The instructions are simple, and if you pay attention, you can gain a reasonable amount of money that will be paid to you at the end of the experiment. From now on till the end of the experiment you are not allowed to communicate with each other. If you have a question, please raise your hand.
- Each of you will play a firm that produces a fictitious good that is sold in a fictitious market.
- Within each market there will be only 2 firms that sell the same good. One is your firm, and the other is a firm that is identical to yours.
- Who will be this other firm will be decided randomly.
- The other people in the laboratory participate in other markets that have nothing to do with yours. In other words, various markets will operate simultaneously, but independently, in the laboratory.
- You will never know the identity of the person you are matched with, nor will he be aware of yours.
- The experiment will last 22 consecutive periods, and the other firm that participates in your market will be the same during all periods of the experiment.

Decisions and Outcomes

- Each period all firms simultaneously make only 1 decision: the quantity to be produced and supplied to the market. Only integer values from 8 to 32 can be chosen.
- You will get a table showing the various levels of profit or loss you and the other firms can attain depending upon the quantities chosen by you and the other firm. The quantities one firm (firm X) may produce are listed across the top of the table, while the quantities produced by the other firm are listed down the left-hand margin. The profits for firm X and for the other firm are given within the body of the table by the intersection of the quantities produced. The top number in **bold** gives the profit for firm X, whereas the bottom number in *italic* gives the profit of the other firm. Since the two firms are identical, at any moment you can identify either yourself or the other firm with firm X. We will do some exercises with the table in a moment.
- After each period, you will get some information on your screen. At the top part of the screen, you will see your output level, and that of the other firm in the previous period. At the bottom part, you will see the history of your own output levels and profits realized.
- There is no time limit for your period to period decisions. Decisions will ordinarily be made every few minutes or so.

Payment

- Each player gets a fixed fee of 250 Pesetas just for participating in the experiment.
- In addition, each player will be paid according to the total profits realized by his firm.
- During the periods 1 to 20, the monetary reward will be 0.035 Pesetas for every profit point realized.
- During the periods 21 and 22 (the last 2 periods), the monetary reward will be 0.35 Pesetas for each profit point realized. You will receive a reminder of this higher payoff (10 times as high) at the start of period 21.
- Note that losses realized will be subtracted from the 250 Pesetas.
- At the end of the experiment, we will add up your profits, and calculate your monetary rewards. This will be done such that you will not see what other players earned.

Keyboard

- To make your choice of output level, please enter a number. Remember that only integer values from 8 to 32 can be chosen.
- To confirm (or not) your choices, enter Y (or N) with your keyboard.
- Please, before confirming your choices, always make sure that you did not make a typing-error.

Table B1 Instructions *'easy'* duopoly

Table B2 shows the instructions given to the players in the *'hard'* duopoly. We only list the subsection *'Decisions and Outcomes'*, which replaces the corresponding subsection in the *'easy'* duopoly. The remainder of the instructions was identical to the *'easy'* version.

Instructions

Decisions and Outcomes

- Each period all firms simultaneously make only 1 decision: the quantity to be produced and supplied to the market. Only integer values from 8 to 32 can be chosen.

(•) Given the TOTAL quantity supplied to the market by you and the other firm in a given period, the price is determined by the market. For total output levels from 16 to 64, taking steps of 1, the market prices will be 350 (with total output equal to 16), 346, 342, 338, 334, 330, 326, 322, 318, 314, 310, 306, 302, 298, 294, 290, 286, 282, 278, 274, 270, 266, 262, 258, 254, 250, 246, 242, 238, 234, 230, 226, 222, 218, 214, 210, 206, 202, 198, 194, 190, 186, 182, 178, 174, 170, 166, 162, 158 (64). This market price implies the revenue a firm gets for EACH UNIT it supplied to the market. Assume that all units produced are actually sold.

- For a given period, the costs to a firm producing a certain quantity in that period are as follows, starting with the minimum output of 8, and going in unit steps to the maximum output of 32: 1246 (with output equal to 8), 1420, 1594, 1768, 1942, 2116, 2290, 2464, 2638, 2812, 2986, 3160, 3334, 3508, 3682, 3856, 4030, 4204, 4378, 4552, 4726, 4900, 5074, 5248, 5422 (32).
- The profits to a firm for a given period are simply its revenues minus its costs.
- After each period, you will get some information on your screen. You will see your output level, and that of each of the other firms in the previous period, plus the profits realized by you and by the other firms in the that period. We also indicate (with *****) which firm realized the highest profit in the previous period.
- There is a 1 minute time limit for your period to period decisions. The experimenter will give a warning after 30 seconds, after 50 seconds, and after 60 seconds.

Table B2 Instructions *'hard'* duopoly

The only change made in the instructions of the *'hardest'* duopoly with respect to the *'hard'* version was that the information concerning the market demand was removed, that is, the item marked (•) in table B2.

The following table was given to the players in the *'easy'* duopolies, with the **bold** faced numbers indicating the profits for firm X, and the numbers in *italic* the profits for the other firm.

PROFITS

output other firm \ output firm X	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
8	**1554**	**1694**	**1826**	**1950**	**2066**	**2174**	**2274**	**2366**	**2450**	**2526**	**2594**	**2654**	**2706**	**2750**	**2786**	**2814**	**2834**	**2846**	**2850**	**2846**	**2834**	**2814**	**2786**	**2750**	**2706**
	1554	*1522*	*1490*	*1458*	*1426*	*1394*	*1362*	*1330*	*1298*	*1266*	*1234*	*1202*	*1170*	*1138*	*1106*	*1074*	*1042*	*1010*	*978*	*946*	*914*	*882*	*850*	*818*	*786*
9	**1522**	**1658**	**1786**	**1906**	**2018**	**2122**	**2218**	**2306**	**2386**	**2458**	**2522**	**2578**	**2626**	**2666**	**2698**	**2722**	**2738**	**2746**	**2746**	**2738**	**2722**	**2698**	**2666**	**2626**	**2578**
	1694	*1658*	*1622*	*1586*	*1550*	*1514*	*1478*	*1442*	*1406*	*1370*	*1334*	*1298*	*1262*	*1226*	*1190*	*1154*	*1118*	*1082*	*1046*	*1010*	*974*	*938*	*902*	*866*	*830*
10	**1490**	**1622**	**1746**	**1862**	**1970**	**2070**	**2162**	**2246**	**2322**	**2390**	**2450**	**2502**	**2546**	**2582**	**2610**	**2630**	**2642**	**2646**	**2642**	**2630**	**2610**	**2582**	**2546**	**2502**	**2450**
	1826	*1786*	*1746*	*1706*	*1666*	*1626*	*1586*	*1546*	*1506*	*1466*	*1426*	*1386*	*1346*	*1306*	*1266*	*1226*	*1186*	*1146*	*1106*	*1066*	*1026*	*986*	*946*	*906*	*866*
11	**1458**	**1586**	**1706**	**1818**	**1922**	**2018**	**2106**	**2186**	**2258**	**2322**	**2378**	**2426**	**2466**	**2498**	**2522**	**2538**	**2546**	**2546**	**2538**	**2522**	**2498**	**2466**	**2426**	**2378**	**2322**
	1950	*1906*	*1862*	*1818*	*1774*	*1730*	*1686*	*1642*	*1598*	*1554*	*1510*	*1466*	*1422*	*1378*	*1334*	*1290*	*1246*	*1202*	*1158*	*1114*	*1070*	*1026*	*982*	*938*	*894*
12	**1426**	**1550**	**1666**	**1774**	**1874**	**1966**	**2050**	**2126**	**2194**	**2254**	**2306**	**2350**	**2386**	**2414**	**2434**	**2446**	**2450**	**2446**	**2434**	**2414**	**2386**	**2350**	**2306**	**2254**	**2194**
	2066	*2018*	*1970*	*1922*	*1874*	*1826*	*1778*	*1730*	*1682*	*1634*	*1586*	*1538*	*1490*	*1442*	*1394*	*1346*	*1298*	*1250*	*1202*	*1154*	*1106*	*1058*	*1010*	*962*	*914*
13	**1394**	**1514**	**1626**	**1730**	**1826**	**1914**	**1994**	**2066**	**2130**	**2186**	**2234**	**2274**	**2306**	**2330**	**2346**	**2354**	**2354**	**2346**	**2330**	**2306**	**2274**	**2234**	**2186**	**2130**	**2066**
	2174	*2122*	*2070*	*2018*	*1966*	*1914*	*1862*	*1810*	*1758*	*1706*	*1654*	*1602*	*1550*	*1498*	*1446*	*1394*	*1342*	*1290*	*1238*	*1186*	*1134*	*1082*	*1030*	*978*	*926*
14	**1362**	**1478**	**1586**	**1686**	**1778**	**1862**	**1938**	**2006**	**2066**	**2118**	**2162**	**2198**	**2226**	**2246**	**2258**	**2262**	**2258**	**2246**	**2226**	**2198**	**2162**	**2118**	**2066**	**2006**	**1938**
	2274	*2218*	*2162*	*2106*	*2050*	*1994*	*1938*	*1882*	*1826*	*1770*	*1714*	*1658*	*1602*	*1546*	*1490*	*1434*	*1378*	*1322*	*1266*	*1210*	*1154*	*1098*	*1042*	*986*	*930*
15	**1330**	**1442**	**1546**	**1642**	**1730**	**1810**	**1882**	**1946**	**2002**	**2050**	**2090**	**2122**	**2146**	**2162**	**2170**	**2170**	**2162**	**2146**	**2122**	**2090**	**2050**	**2002**	**1946**	**1882**	**1810**
	2366	*2306*	*2246*	*2186*	*2126*	*2066*	*2006*	*1946*	*1886*	*1826*	*1766*	*1706*	*1646*	*1586*	*1526*	*1466*	*1406*	*1346*	*1286*	*1226*	*1166*	*1106*	*1046*	*986*	*926*
16	**1298**	**1406**	**1506**	**1598**	**1682**	**1758**	**1826**	**1886**	**1938**	**1982**	**2018**	**2046**	**2066**	**2078**	**2082**	**2078**	**2066**	**2046**	**2018**	**1982**	**1938**	**1886**	**1826**	**1758**	**1682**
	2450	*2386*	*2322*	*2258*	*2194*	*2130*	*2066*	*2002*	*1938*	*1874*	*1810*	*1746*	*1682*	*1618*	*1554*	*1490*	*1426*	*1362*	*1298*	*1234*	*1170*	*1106*	*1042*	*978*	*914*
17	**1266**	**1370**	**1466**	**1554**	**1634**	**1706**	**1770**	**1826**	**1874**	**1914**	**1946**	**1970**	**1986**	**1994**	**1994**	**1986**	**1970**	**1946**	**1914**	**1874**	**1826**	**1770**	**1706**	**1634**	**1554**
	2526	*2458*	*2390*	*2322*	*2254*	*2186*	*2118*	*2050*	*1982*	*1914*	*1846*	*1778*	*1710*	*1642*	*1574*	*1506*	*1438*	*1370*	*1302*	*1234*	*1166*	*1098*	*1030*	*962*	*894*
18	**1234**	**1334**	**1426**	**1510**	**1586**	**1654**	**1714**	**1766**	**1810**	**1846**	**1874**	**1894**	**1906**	**1910**	**1906**	**1894**	**1874**	**1846**	**1810**	**1766**	**1714**	**1654**	**1586**	**1510**	**1426**
	2594	*2522*	*2450*	*2378*	*2306*	*2234*	*2162*	*2090*	*2018*	*1946*	*1874*	*1802*	*1730*	*1658*	*1586*	*1514*	*1442*	*1370*	*1298*	*1226*	*1154*	*1082*	*1010*	*938*	*866*
19	**1202**	**1298**	**1386**	**1466**	**1538**	**1602**	**1658**	**1706**	**1746**	**1778**	**1802**	**1818**	**1826**	**1826**	**1818**	**1802**	**1778**	**1746**	**1706**	**1658**	**1602**	**1538**	**1466**	**1386**	**1298**
	2654	*2578*	*2502*	*2426*	*2350*	*2274*	*2198*	*2122*	*2046*	*1970*	*1894*	*1818*	*1742*	*1666*	*1590*	*1514*	*1438*	*1362*	*1286*	*1210*	*1134*	*1058*	*982*	*906*	*830*
20	**1170**	**1262**	**1346**	**1422**	**1490**	**1550**	**1602**	**1646**	**1682**	**1710**	**1730**	**1742**	**1746**	**1742**	**1730**	**1710**	**1682**	**1646**	**1602**	**1550**	**1490**	**1422**	**1346**	**1262**	**1170**
	2706	*2626*	*2546*	*2466*	*2386*	*2306*	*2226*	*2146*	*2066*	*1986*	*1906*	*1826*	*1746*	*1666*	*1586*	*1506*	*1426*	*1346*	*1266*	*1186*	*1106*	*1026*	*946*	*866*	*786*
21	**1138**	**1226**	**1306**	**1378**	**1442**	**1498**	**1546**	**1586**	**1618**	**1642**	**1658**	**1666**	**1666**	**1658**	**1642**	**1618**	**1586**	**1546**	**1498**	**1442**	**1378**	**1306**	**1226**	**1138**	**1042**
	2750	*2666*	*2582*	*2498*	*2414*	*2330*	*2246*	*2162*	*2078*	*1994*	*1910*	*1826*	*1742*	*1658*	*1574*	*1490*	*1406*	*1322*	*1238*	*1154*	*1070*	*986*	*902*	*818*	*734*
22	**1106**	**1190**	**1266**	**1334**	**1394**	**1446**	**1490**	**1526**	**1554**	**1574**	**1586**	**1590**	**1586**	**1574**	**1554**	**1526**	**1490**	**1446**	**1394**	**1334**	**1266**	**1190**	**1106**	**1014**	**914**
	2786	*2698*	*2610*	*2522*	*2434*	*2346*	*2258*	*2170*	*2082*	*1994*	*1906*	*1818*	*1730*	*1642*	*1554*	*1466*	*1378*	*1290*	*1202*	*1114*	*1026*	*938*	*850*	*762*	*674*
23	**1074**	**1154**	**1226**	**1290**	**1346**	**1394**	**1434**	**1466**	**1490**	**1506**	**1514**	**1514**	**1506**	**1490**	**1466**	**1434**	**1394**	**1346**	**1290**	**1226**	**1154**	**1074**	**986**	**890**	**786**
	2814	*2722*	*2630*	*2538*	*2446*	*2354*	*2262*	*2170*	*2078*	*1986*	*1894*	*1802*	*1710*	*1618*	*1526*	*1434*	*1342*	*1250*	*1158*	*1066*	*974*	*882*	*790*	*698*	*606*
24	**1042**	**1118**	**1186**	**1246**	**1298**	**1342**	**1378**	**1406**	**1426**	**1438**	**1442**	**1438**	**1426**	**1406**	**1378**	**1342**	**1298**	**1246**	**1186**	**1118**	**1042**	**958**	**866**	**766**	**658**
	2834	*2738*	*2642*	*2546*	*2450*	*2354*	*2258*	*2162*	*2066*	*1970*	*1874*	*1778*	*1682*	*1586*	*1490*	*1394*	*1298*	*1202*	*1106*	*1010*	*914*	*818*	*722*	*626*	*530*
25	**1010**	**1082**	**1146**	**1202**	**1250**	**1290**	**1322**	**1346**	**1362**	**1370**	**1370**	**1362**	**1346**	**1322**	**1290**	**1250**	**1202**	**1146**	**1082**	**1010**	**930**	**842**	**746**	**642**	**530**
	2846	*2746*	*2646*	*2546*	*2446*	*2346*	*2246*	*2146*	*2046*	*1946*	*1846*	*1746*	*1646*	*1546*	*1446*	*1346*	*1246*	*1146*	*1046*	*946*	*846*	*746*	*646*	*546*	*446*
26	**978**	**1046**	**1106**	**1158**	**1202**	**1238**	**1266**	**1286**	**1298**	**1302**	**1298**	**1286**	**1266**	**1238**	**1202**	**1158**	**1106**	**1046**	**978**	**902**	**818**	**726**	**626**	**518**	**402**
	2850	*2746*	*2642*	*2538*	*2434*	*2330*	*2226*	*2122*	*2018*	*1914*	*1810*	*1706*	*1602*	*1498*	*1394*	*1290*	*1186*	*1082*	*978*	*874*	*770*	*666*	*562*	*458*	*354*
27	**946**	**1010**	**1066**	**1114**	**1154**	**1186**	**1210**	**1226**	**1234**	**1234**	**1226**	**1210**	**1186**	**1154**	**1114**	**1066**	**1010**	**946**	**874**	**794**	**706**	**610**	**506**	**394**	**274**
	2846	*2738*	*2630*	*2522*	*2414*	*2306*	*2198*	*2090*	*1982*	*1874*	*1766*	*1658*	*1550*	*1442*	*1334*	*1226*	*1118*	*1010*	*902*	*794*	*686*	*578*	*470*	*362*	*254*
28	**914**	**974**	**1026**	**1070**	**1106**	**1134**	**1154**	**1166**	**1170**	**1166**	**1154**	**1134**	**1106**	**1070**	**1026**	**974**	**914**	**846**	**770**	**686**	**594**	**494**	**386**	**270**	**146**
	2834	*2722*	*2610*	*2498*	*2386*	*2274*	*2162*	*2050*	*1938*	*1826*	*1714*	*1602*	*1490*	*1378*	*1266*	*1154*	*1042*	*930*	*818*	*706*	*594*	*482*	*370*	*258*	*146*
29	**882**	**938**	**986**	**1026**	**1058**	**1082**	**1098**	**1106**	**1106**	**1098**	**1082**	**1058**	**1026**	**986**	**938**	**882**	**818**	**746**	**666**	**578**	**482**	**378**	**266**	**146**	**18**
	2814	*2698*	*2582*	*2466*	*2350*	*2234*	*2118*	*2002*	*1886*	*1770*	*1654*	*1538*	*1422*	*1306*	*1190*	*1074*	*958*	*842*	*726*	*610*	*494*	*378*	*262*	*146*	*30*
30	**850**	**902**	**946**	**982**	**1010**	**1030**	**1042**	**1046**	**1042**	**1030**	**1010**	**982**	**946**	**902**	**850**	**790**	**722**	**646**	**562**	**470**	**370**	**262**	**146**	**22**	**-110**
	2786	*2666*	*2546*	*2426*	*2306*	*2186*	*2066*	*1946*	*1826*	*1706*	*1586*	*1466*	*1346*	*1226*	*1106*	*986*	*866*	*746*	*626*	*506*	*386*	*266*	*146*	*26*	*-94*
31	**818**	**866**	**906**	**938**	**962**	**978**	**986**	**986**	**978**	**962**	**938**	**906**	**866**	**818**	**762**	**698**	**626**	**546**	**458**	**362**	**258**	**146**	**26**	**-102**	**-238**
	2750	*2626*	*2502*	*2378*	*2254*	*2130*	*2006*	*1882*	*1758*	*1634*	*1510*	*1386*	*1262*	*1138*	*1014*	*890*	*766*	*642*	*518*	*394*	*270*	*146*	*22*	*-102*	*-226*
32	**786**	**830**	**866**	**894**	**914**	**926**	**930**	**926**	**914**	**894**	**866**	**830**	**786**	**734**	**674**	**606**	**530**	**446**	**354**	**254**	**146**	**30**	**-94**	**-226**	**-366**
	2706	*2578*	*2450*	*2322*	*2194*	*2066*	*1938*	*1810*	*1682*	*1554*	*1426*	*1298*	*1170*	*1042*	*914*	*786*	*658*	*530*	*402*	*274*	*146*	*18*	*-110*	*-238*	*-366*

Figures B1 and B2 present two examples of the screens faced by the players. First, the *'easy'* version of the triopolies in figure B1.

previous period (period 2):	your production:	20	
	production firm X:	8	
	production firm Y:	17	
next period (period 3):	your production:	...	(please Enter)

history:

period	your production	your profit
1	23	2658
2	20	3786
3	...	...
4	...	...
5	...	...
6	...	...
7	...	...
8	...	...
9	...	...
10	...	...
11	...	...
12	...	...
13	...	...
14	...	...
15	...	...
16	...	...
17	...	...
18	...	...
19	...	...
20	...	...
21	...	...
22	...	...

Figure B1 Example screen *'easy'* version

The screen faced by the players in the *'hard'* and *'hardest'* triopolies is shown in figure B2.

previous period (period 2):

	production	profit	best
you	20	3786	*****
firm X	8	1674	
firm Y	17	3258	

next period (period 3):

your production: ... (please Enter)

Figure B2 Example screen *'hard'* and *'hardest'* version