Imitation in Cournot Markets *

Antoni Bosch-Domènech, Universitat Pompeu Fabra, Barcelona, Spain
Nicolaas J. Vriend, Queen Mary and Westfield College, London, UK

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Abstract:

In an experimental standard Cournot oligopoly we test the importance of models of behavior characterized by imitation. We find that the players appear to be rather reluctant to imitate, and we explain why they have good reasons for this.

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Corresponding author: N.J. Vriend, Queen Mary and Westfield College, University of London, Dept. of Economics, Mile End Road, London, E1 4NS, UK, <n.vriend@qmw.ac.uk>, http://www.qmw.ac.uk/~ugte173/.

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1. Introduction

Imitation has played an important role in the theoretical literature on learning. This is not surprising since imitation seems easy: It does not use particular cognitive skills, and does not require much information[1]. Conventional wisdom asserts that, when in doubt, imitation of the successful behavior of others is likely. After all, "if you don't know what's going on, what else can you do but imitate?" Yet imitation, although deemed easy, may not be a realistic mode of behavior in many environments. To see to what extent imitating behavior is prevalent, 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 F. Vega-Redondo (1997)) show that under general evolutionary dynamics, a Cournot market in which firms (loosely) imitate the most successful firm converges to the Walrasian (competitive) equilibrium. Second, a symmetric game facilitates imitation. But third, in a Cournot market, imitation of the successful firms may lead to a profit loss, hindering imitation.

The experiment shows that even in situations that would seem conducive to imitation, subjects appear rather reluctant to resort to it. To infer from this that imitation does not appear to be a good descriptive model of behavior in general, or at least in the case firms facing oligopolistic situations may be stretching our observations in excess. After all, in real markets, forces may be at play that have been kept out of our experiments. Nevertheless, our results certainly question any uncritical acceptance of imitation as an obvious mode of behavior in markets.

Two complementary hypothesis may account for the observed reluctance to imitate. First, subjects appear not to be naïve learners: they realize that the world is not stationary, which is not surprising since their own behavior clearly suggests it. Second, even when subjects are given confusing information about the environment, they learn soon enough to recognize the high cost of imitation in terms of profit loss[2].

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[1] Sushil Bikhchandani, David Hirshleifer and Ivo Welch (1998) write: "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 mitate each other…"."

[2] More technically, one can say that strict imitation of a higher payoff strategy is not "strictly improving" in the sense that, when used by everyone, it does not enable to learn which action maximizes expected payoff. It can be shown, for some contests, that a rule which is not strictly improving is not evolutionary robust (see Jonas Bjornerstedt and Karl H. Schlag

2. Competitive Output in Cournot Markets

Two forms of behavior can lead a Cournot market with few players towards the competitive (Walrasian) equilibrium. First, agents may have a preference for beating the opponent. In the Cournot game this can be identified with what has been called a spiteful behavior, i. e., choosing an action that hurts oneself, but others even more (see Hamilton [1970] and Appendix A). This aspect is stressed in the experimental economics literature. The classic reference is Fouraker & Siegel [1963], which is a detailed study of rivalistic and other behavior, and the factors influencing it in oligopolies[3]. In later experimental work (e.g., Holt [1995], or Davis [1995]), spiteful behavior has been observed occasionally. The typical analysis, then, is that some players simply like to beat their opponents, even at the cost of spoiling the party (but see Levine [1996]).

The second way to reach the Walrasian equilibrium is through an 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 positively monotonic function of the payoffs generated in the population will eventually lead to the Walrasian equilibrium. This includes strict imitation of the most succesful firm (NICK, USE SYMBOLS HERE: for all i, j belonging to N, qi,t = qj, t-1, such that for all k belonging to N , Pi(qj, t-1, q-j, t-1) greater or equal than Pi (qk, t-1, q-k, t-1))[4] and less strict forms of imitation. As Vega-Redondo

(1996) "On the Evolution of Imitative Behavior"). The intuition being that it is much more difficult for a behavior to survive when it does not teach which action is best. "Imitate if better" is not strictly improving in the Cournot game that we are exploring. In a Cournot game, imitating (within bounds) the lowest output provides a strictly improving rule. Perhaps this is why Dixon et al (1995) find with simulations that the joint profit maximizing behavior is the unique rule that survives in the long run.

[3] Fouraker & Siegel [1963] stress the subjects' preferences in their explanation of behavior, but they 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 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.

[4] Which, by the way, means that when most successful firm in a period t-1 sticks to the same decision in period t, this behavior will be considered imitation.

[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 generalize reduction of profits, that affects in 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 relative to other species. Similarly, we will find it 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. But we are not concerned with these situations now. More interestingly, it can also be observed if subjects follow a concious reciprocating strategy: A revealing way of interpreting a Cournot game is as a game of more or less cooperation. Subjects cooperate fully when they produce the joint-monopoly (Pareto) output level. Subjects compete fully when they produce the competitive (Walrasian) output. In between we observe different degrees of cooperation/competition on the scale that goes from Pareto to Walras. A reciprocating strategy of the type "give as good as you get" or GGG, could bring about the spite effect. Notice that when looking at individual decisions it may be impossible to distinguish between blind imitation and a deliberate reciprocating strategy. Yet the distinction appears to be crucial in the context of a Cournot market, since imitation of the most succesful firm (with noise) can only lead to a competitive equilibrium, while a deliberate GGG strategy may take the market to the opposite direction, towards the collusive solution.

In our experimental design we will test for the presence of the spite effect. We will do this by analyzing the output levels of firms. With noise, if output levels are high, then a spite effect is present. This could or could not be due to imitation of the most successful firm, and we would have to look into the individual decisions to claim that imitation was in fact driving the results. But this would not be an easy task. First, there may be more imitation that meets the eye since imitation does not have to be strict to drive the market to the Walrasian equilibrium; it can be messy. But, second, what may appear as blind imitation could be in fact a *deliberate* GGG ("give as good as you get" or "tit for at") strategy with ambiguous equilibrium implications. In general, some forms of behavior may agree with the definition of imitation while representing a different decision process that, in particular, does not share the same dynamics.[5]

Now, if output levels turn out to be low, and do not show a trend towards the competitive output, then we know, without looking into the individual decisions, that imitation of the most profitable decision is not *prevalent*, provided that there is enough noise or experimenting. Of course, we might still want to know if there is *some* imitation taking place. But even if some imitation were occurring, this would not modify the conclusion that imitation was insufficient to significantly affect the output levels in the Cournot market.

3. Experimental Design

We conducted 7 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 same classic Cournot duopoly and triopoly experiment designed by Fouraker & Siegel [1963], and subsequently modified (see Holt [1985]). But in the sessions we used three treatments based on different information setups. 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. As will be explained below, the time that a session lasted depended on the treatment. This ranged from about one to about two hours. Each player got a fixed `show-up' fee of Pts. 250 (≈ U$ 1.65). In addition, each player was paid according to his performance, the details of the payoff scheme applied being known by the players. The average payment over the 126 players was Pts. 2200 (≈ U$ 15.00). Examples of the instructions given to the players can be found in appendix B.

[5] A 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 Larry King Live showed interesting convergence patterns in the frequencies used by the host and his interviewed guests which seem unlikely to be intentional (Scientific American [1997]).

In our experiment, unlike in Fouraker & Siegel [1963], the subjects would know the length of the experimental sessions and, also unlike them, we decided that the payoffs of periods 21 and 22 would be ten times higher than in the previous periods, so that in these two periods subjects could obtain as many profits as in the rest of the experiment. This is a controversial decisions that requires some explanation. Two periods of high returns at the end of each experimental session foster concentration, and give a special relevance to the decisions taken in these two periods, in which the subjects also reach the end of their learning process. In addition it reinforces the so-called `end effect', making collusive and strategic behavior more unlikely during the last periods and, therefore, encouraging higher output levels.

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 $P(Q) = a + b \cdot Q$, where $Q = Óq_i$, a>0, and b<0, with the exact values of a and b differing from treatment to treatment (see below). The n players are competitors who stay 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 competitive output levels. Given the market price P, the profit V for an individual player is computed as follows: $V = P \cdot q - C$. The boundaries of the players' action space are 8 and 32, while the players are allowed to enter only integer values for their output levels.

Treatments: Duopolies and Triopolies

Since there were always 18 players simultaneously in the laboratory, there were 9 duopoly or 6 triopoly markets going on simultaneously. The players were matched randomly, and anonymously, to form markets, and they played for consecutive 22 periods in the same market. Hence, the players did know 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 $P = 414.0 - 4.0 \cdot Q$, and the cost function $C = 174.0 \cdot q - 146.0$. In the triopoly these were: $P = 530.0 - 4.0 \cdot Q$, and $C = 174.0 \cdot q - 266.0$.

Treatments: The Boundedly Rational Dimension

We have three different treatments that differ only in the way the information is provided, and the time pressure put on the players. The underlying market situation is exactly the same in the three treatments. In addition, the objectively `available' information is exactly the same in each treatment. The reason to stick to this identical information is to make sure that the theoretical benchmarks provided by the equilibria computed above are valid 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 will call these treatments `easy', `hard', and `hardest'.

To begin, in the `easy' treatment there was no time pressure on the players. They could use as much time as they wanted. In the `hard' and `hardest' treatment, in each period players got just one minute to decide on their production level. In the easy treatment, calculators were allowed but not so in the other two treatments.

The differences in information set-up between the three versions are more involved. In neither of them the players got a functional specification of the demand and cost conditions. In the "easy" version, the players would get a profit table that *conveniently* summarized all the information concerning the inverse demand curve, and the cost function (see appendix D). 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 average of) the output(s) of the other firm(s). The cells, then, give the profits of firm X, and (the average of) the profits the other firm(s).[6] Hence, in the `easy' treatment, there is no need for additional learning about the environment, or about the exact functions used. 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 compute the profits of the other players with help of the profit table. In addition, in the `easy' version a player always gets a complete history of his own past actions and profits.

In the `hard' version, the players did not get the convenient profit table. Instead, they got

[6] We made sure that subjects knew how to use the profit table by doing some exercises during the practice period previous to the session. The information provided to the players on the screen can be seen in figure D.1 in appendix D.

an *inconveniently* arranged enumeration of all possible market prices, ordered on the possible aggregate output levels. They got a similarly arranged enumeration of all possible cost levels, ordered on the possible individual output levels. Since the players knew that their profits were simply their revenues minus their costs, and they knew that all firms were identical, this provided them with exactly the same information as the profit table in the `easy' version, although less discernible. The history provided to the subjects was also different from the previous treatment: After each period, the actions of all players in the same market in that period, plus the profits generated by each single player were given on the screen (see figure D.2 in appendix D). In particular, since we wanted to make sure that subjects did not miss the highest profit and what output decision had led to it, the highest profit appeared on the screen with a border of *s.

Finally, the "hardest" version differed from the "hard" in that the information about the demand side of the market was limited to state that aggregate output and prices "were related". Nevertheless, subjects had 22 periods to try to infer the demand function. Hence, the objectively available information was common to all versions, and could eventually be retrieved, but was the hardest to be obtained in this treatment.

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 history of their own profits, we reduce 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 and we provide flashing information about the most profitable decision in each period. Moreover, in the hard and hardest treatments, the one minute time pressure, and the lack of a convenient history of own profits, should be obstacles to `doing the best one can'.[7]

The justification of the three treatments is the following. Conventional wisdom claims that imitation should be more prevalent the more confused subjects are about the environment.

[7] 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 B.2 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 C.

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 whatever subjects do in this situation could be useful as a benchmark. And this is the purpose of the easy treatment. Would imitation be more frequent in more difficult environments? Would it be so frequent as to bring about competitive outcomes in a Cournot oligopoly? The purpose of the second and third treatments is to explore this claim.

In addition to the treatments mentioned above, we also run a session with a treatment in which players were rewarded by their relative performance: At each period, only the player who made the largest profit received a positive payoff. The purpose of this treatment was to verify that our experimental set-up did not contain any insurmountable obstacle to the attainment of the Walrasian output. Indeed a Walrasian output level of 30 is chosen by 100% of the players in the last two periods. A different result would have seriously questioned our experimental design.

4. Analysis

The three symmetric pure strategy equilibria for the static Cournot game are: the joint-monopoly Pareto, the Cournot-Nash, and the competitive Walrasian output. 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]

Starting from the baseline, "easy", treatment, subjects are submitted to situations in which learning about the market becomes more difficult ("hard" and "hardest" treatments), thus increasing subjects' bounded rationality, while information about the decision of the most

[8] See appendix A for the formal analysis of a 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

successful firm is displayed prominently on the screens. We believe these situations should be particularly conducive to imitation and formulate the hypothesis to be tested in the following terms:

Hypothesis: In the `hard' and `hardest' treatments, the Walrasian equilibrium is the equilibrium that best describes the Cournot market. The inference being that when subjects are "boundedly rational", imitation of the successful firm is a prevalent mode of behavior.

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.

The last two periods

Figure 1 summarizes the average output levels in the last two periods for the various treatments (with the standard deviations in parentheses).

treatment	`easy'	`hard'	`hardest'
duopoly	18.2 (2.7)	23.4 (6.1)	22.4 (5.9)
triopoly	23.7 (3.8)	24.3 (5.8)	26.4 (4.9)

Figure 1 Average output levels (st. dev.), last two periods

profit than the other two by deviating unilaterally.

As mentioned, the experiment focusses on the last two periods where earnings are multiplied by 10. The higher payoffs reinforce the end effects, approaching a one-shot game situation. Consequently this will play against colluding strategies and in favor of higher output decisions. In these circumstances, levels of output below Walras give *added* credibility to the conclusion that imitation does not pull the Cournot market towards the competitive equilibrium.

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Figure 2 Frequency distribution of output in the `easy' duopoly, last two periods

Figure 2 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). Since no output larger than 22 was chosen, no subject got close to the Walrasian output of 30. These results are in agreement with Fouraker & Siegel [1963], and other previous experiments, if only giving more evidence in favor of the focality of these two among the three equilibria for the stage game.

Will the Walras output become more prevalent as the task of learning about the market becomes more and more difficult, while the decision of the most succesful firm is displayed more prominently?

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a `Hard' treatment

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b `Hardest' treatment

Figure 3 Frequency distributions of output in the duopoly hard and hardest treatments, last two periods

Figures 3.a and 3.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[9]. Although we are not concerned in this paper with providing an explanation of 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 more useless to punish the other player, since punishment makes sense only if a player 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

[9] 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 2, 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.

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 there a spite effect, driving the players to the Walrasian output level through imitation?[10] First, a Wilcoxon test shows that the players produce significantly more in the `hard' version than in the `easy' version (0.0% significance; 1-sided), but we saw above that the distribution of output levels in the corresponding `easy' duopoly was pulled down by the presence of a lot of collusion. In period 21 there were ten colluding players, and four of them even persisted in the last period, each producing the Pareto output of 15. Two of these four were stabbed in their back by their up-to-then fellow colluders, and would seem more than likely to convert to Cournot-Nash output in a subsequent period. 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, away from the Walrasian equilibrium, and 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' (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 must be rejected for the duopolies.

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Figure 4 Frequency distribution of output in the `easy' triopoly, last two periods

[10] The tests reported are based on the individual output levels in each period. This has the advantage of providing 3[illegible] observations for each treatment. But the fact that the output levels in period 22 might depend on those in period 21, and the fact that the output levels of the firms in a given market might be interdependent are neglected in this way. (Had imitation been a frequent behavior, then undoubtedly the assumption of independence would have been unsustainable).Therefore, we also carried out all tests for the market data, taking the average output of all firms in a given market over the periods 21 and 22. Hence, we have 9 observations for each duopoly treatment, and 6 for each triopoly treatment. These tests do not change the qualitative conclusions reported in the paper, with one exception, noticed below, in the hardest triopoly.

Figure 4 presents the frequency distribution for the triopolies in the `easy' treatment, the baseline treatment for triopolies. We observe that there is a wider spread of output levels that in the baseline duopoly session, and that practically no collusion occurs. The latter is related, according to the usual explanation, to the fact that not only it is more complicated with three than with two subjects to learn what other players are up to, but rewarding and punishing individual players is also difficult because the only available instruments work through the market without the possibility to 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. Outputs between 21 and 25 represent 67% of all outputs, while outputs around Walras, from 28 to 32, represent 14% of the outputs chosen. This, again, confirms previous experimental observations. The Wilcoxon test shows that the output levels chosen in the `easy' triopoly are significantly lower than the Walrasian output levels (significant at 0.0%; 1-sided). 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 imitating easier.

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a `Hard' version

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b `Hardest' version

Figure 5 Frequency distributions of output in the “hard” and “hardest” triopolies, last two periods

The frequency distributions of output levels for the `hard' and `hardest' triopoly are given in figures 5.a and 5.b. One observation again stands out, which is the wider spreading of choices with respect to the `easy' version. In the `hard' version, the frequency of the Walrasian output actually decreases, while Cournot-Nash looses 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 a frequent decision. Let’s apply the same statistical tests as before. First, a Wilcoxon test rejects the nil hypothesis that the output levels are higher in the `hard' triopoly than in the corresponding `easy' treatment (significant at 48.0%; 1-sided), while 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. This being an ambiguous result we turn to the the average output in each market in the last two periods as our observations. We find now 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[11].

[11] In the market involving firms 4, 10 an 16, firm 2 imitates twice, and firms 10 and 16 do not imitate at all. In the market made up by firms 5, 11 and 17, 5 imitates twice, while 11 never imitates and firm 17 only once. Finally, in the market of firms 6, 12 and 18, 6 never imitates, 18 imitates three times and firm 12 imitates

To verify what these tests seem to indicate we turn now to the individual behavior of the players in one market in the hardest triopoly session. We choose the market for firms 1, 7 and 13 because its output is among the highest for most of the periods (including the finishing ones). This corresponds to the ideal set-up for finding imitative behavior. Table A1 in the appendix shows decisions and profits in this market, and Table A2 helps to identify when "imitation" is taking place. If by "imitation" we mean, as before, taking the same decision as was taken by the most successful firm in the previous period, then firm 1 does not imitate *at all* for the 21 periods. What firm 1 seems to be doing is to keep output low (with an occasional "punishing" jump to higher output), in spite of confronting two firms that never showed any sign of cooperating.

Firm 7 imitated in 7 out of 21 possibilities, but we doubt that most of these were "do as the best does". For one thing, this subject tends to repeat her decisions twice in consecutive periods. This repetitive behavior by itself results in "imitating" herself five times, the five times that her decision turns out to be the most profitable in the period. Only twice this subject imitated the successful behavior of another subject. But if one insisted in interpreting this repetitive behaviour as imitation, then it turns out that as the experiment proceeds, the subjects learns *not* to imitate. The first four occasions in which the subject imitates occurs in his first six opportunities. After that he lets 10 periods pass by without imitating.

Finally, firm 13 seems to have imitated a lot, 11 out of 21 times. But when we look more carefully at what the subject does, this turns out to be something different. The subject stays put at one output (28) five periods in a row. While he stayed at this output, this output turned out to be the most successful in two periods, and consequently it seemed as if he was "imitating" himself. But this was probably not imitation, it was immobility. And immobility recurred again for another eight consecutive periods during which he decides to stay put at the output level of 31. This output being so high it is not surprising that it was the most successful in seven out of these eight periods, therefore apparently "imitating" himself during these seven rounds[12]. In these rounds he did not make much profit; in fact, he even got *losses*, but he unflinchingly continued to repeat the same output. It is hard to believe

itself (stays put, basically) 6 times.

[12] Other subjects also behave similarly. In another market of the same treatment, firm 9 stays put at output 32 from period 6 onwards. This being the most successful output (although profits can be very low, in fact, even negative), a superficial analysis of imitation by means of counting the number of cases or by relying on regression techniques would yield the false impression of a high frequency of imitative behavior when, most likely, we are encountering a subject that has dropped out.

that we are dealing with a person pursuing a systematic strategy of imitating the best.

Looking at all 18 firms, it turns out that five firms (1, 6, 10, 11 and 16) never imitate, not even once in the 22 periods. If we limit "imitation" to the imitation of another firm (not of oneself) then 11 out of 18 firms (the previous ones plus firms 4, 5, 9, 12, 15 and 17) never imitate in the whole experiment. Of the remaining firms, 2 imitates 4 times, 3 imitates 5 times, 7 imitates 3 times, 8 imitates twice, 13 imitates twice, 14 imitates once, and 18 imitates twice, in his first two opportunities.

Hardly a record on which to justify imitation as an empirically frequent behavior in oligopolistic markets. Hence, we have to conclude that in the triopoly sessions, a possible 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 players' output in the last two periods, two general conclusions can be drawn. First, as the learning-about-the-environment task becomes more complex, output choices become more spread. 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. The second conclusion is that although we can observe an increase in output as the complexity of understanding the environment increases, the competitive output level is not a good summary of what is observed in the experiment. This conclusion is reached in spite of the special display, each period, of the most profitable decision, and in spite of focusing on the last two periods, when end-effects favoring high outputs are likely.[13] From this, plus the support given by the analysis of the individual decisions, we conclude that imitation is not a prevalent mode of behavior, and clearly not prevalent enough to bring about competitive outcomes in Cournot markets.

The trend

Our analysis thus far was based on the output levels in the last two periods. Everything in our set-up was arranged such that the end effect was as strong as possible, favoring high output levels. Remember that the subjects knew when the sessions were ending. Remember, also, that payoffs in the last two periods were multiplied by ten. Nevertheless, data from previous periods can help us decide whether there is anything in the dynamics which

[13] While the absence of Walrasian outputs implies little or no imitation, it is not necessarily true 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

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. Let us look at the important cases.

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Figure 6 Time series of the average output in duopolies

Figure 6 gives the time series of the average outputs in the duopolies. In the `hard' duopoly, we start slightly below 20, increase to 22.7 in period 2, and then very slowly go down to 19.4 in period 20, followed by an end effect leading to 23.6 in period 22. Hence, all the time we are close to the Cournot-Nash output, and if there is any trend it is a downward sloping one. Looking at the individual markets we see that besides convergence to Cournot-Nash output, some collusion occurs, but less than in the `easy' version. The end effect is not only due to the collapse of collusion, but also to the fact that in some markets players attempt to take advantage of having fooled the other player during the periods 1 to 20. For example, in one market both subjects had played consistently around 10, and then simultaneously jump to 32 and 25 in period 21. In addition, as many as four subjects, either exasperated or ignorant, chose an output of 32 in the last period, by this hurting themselves more than anybody else. We see a very similar pattern for the `hardest' duopoly treatment. Average output starts at 19.3, reaches a peak in period 4 at 23.1, followed by fluctuations closely around the Cournot-Nash output until the last period, where we see a jump to 24.1, helped by the selection of 32 units of output on the part of three subjects. The conclusion is that in the `hard' and `hardest' duopolies nothing suggests a trend towards Walrasian output levels.

view.

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Figure 7 Time series of the average output in triopolies

Figure 7 shows the average output levels for the triopolies. In the `hard' triopolies, we start at 16.3, increase to 24.9 in period 4, and then slowly decrease 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. Taking a detailed look at the *individual* markets in the `hard' triopoly experiment, we find one market, out of six, showing convergence to Walrasian output levels, while in another market there are two players whose output converges on the Walrasian output level. Hence, we could have here some rare imitators, but they are uncommon enough to allow the time series of the average output level to show a downward trend, the average output level from period 11 to 20 being 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 an average 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 the 22 periods of the sessions does not reveal any trend towards the competitive equilibrium in neither of the six experiments. Nothing in the observed decisions seem to indicate that the sessions were too short for convergence. In addition, if the a priori case for imitation is based on the subjects’ confusion or their lack of information, then one should expect to encounter fewer and fewer cases of imitative behavior as the sessions proceed, and subjects learn.

Just in case there are some lingering doubts about the absence of convergence, let us report that once the 22 periods of each session were finished, we informed subjects that since the session had run so smoothly 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 10 times the payoffs of the previous periods.[14] To restart the experiment took between 3 and 5 minutes during which subjects could not communicate with each other; but they could think, which had been made difficult in the hard and hardest treatments due to the time pressure.

(NICK These are the data, please draw a figure like the previous. I'm trying to get the easy treatment results but so far I have not found them)

hardest	hard
21,278	21,5
23,389	23,8
23,667	24,8
23,722	23,8
24,667	23,5

[14] So far, we did not report these data since the procedure may be deemed controversial and the results spurious for the strict purpose of the experiment. Yet they can throw some light on whether a trend towards Walrasian results was lurking in our sessions of 22 periods.

23,5	21,5
23,611	22,2
24,667	21,5
22,944	21,3
24	21,8
25,056	22,3
25,611	26,9

Figure 8
Time series of the average output in the 12 extra periods for the triopoly sessions

In Figure 8, we draw the time series of the average output fro the extra 12 periods in the triopoly sessions, probably the most interesting for the present concern Again, there is no sign of a trend towards Walras. Average output are closer to the Cournot equilibrium, except for the end effect, which is sharp in the hard treatment. It is not unlikely that the pause of a few minutes helped subjects to collect their thoughts and prepare for the next rounds with a better grasp of the market situation. This agrees with the intuition that less knowledge means more imitation and that as subjects learn imitation dwindles, in accordance with the previous statement that if one does not observe much imitation in the first twenty periods of a session, it is unlikely that imitation should become prevalent in the following rounds.

What about firms 1, 7 and 13 in the hardest triopoly whose individual behavior for the first twenty periods we had analyzed? We had observed one firm trying to bring output down and two other firms staying at high output levels, with little overall imitation. Would imitation increase after allowing for some time to think? Would a trend towards Walras surge after the 5 minutes break? The fact is that in the second part of the session output started at 21-25-24, below the levels at the end of the first 22 periods. In the second period, the most successful output of 25 was not imitated (not even by the firm choosing it in the previous period), the outputs being 22-22-24. Again, the most successful output, 24, was not imitated and in the third period output was 21-22-23. And so on and so forth, up to period 12 when some end effect seems to have pushed output to 24-26-25. Again no imitation and no trend to Walras. Apparently, subjects had started the second part of the session having learned the high cost of high output. Give subjects some time to think and some experience, and Cournot outputs seem to become the best summary of the triopoly market.

Of course, one might argue that because all that happens in the periods 1 to 20 is in some sense cheap talk, all the fooling around observed in Figures 6 and 7 does not mean much. This is perfectly reasonable. However, if this was really the case, then we would be confronting some kind of strategic behavior by the players that implies a reasoning process at a higher cognitive level than the learning-through-imitation hypothesis assumes. Hence, the presence of end effects would favor the rejection of the imitation hypothesis as well. 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. But, then, end effects are not noticeable in the triopoly markets. Its absence, in this case, should be an indication that the first twenty periods are not unimportant foreplay and that the absence of any convergence towards Walras can be taken at face value. To sum it up, the presence of end effects, as in duopoly sessions, indicate a behavior more complex than simple imitation. The absence of end effects *together* with the absence of a trend towards the Walrasian output, as in the triopoly sessions, is also an indication that imitation does not play a significant role.

A more systematic analysis of individual decisions may be wanting. Yet, we feel that it is unnecessary. First, our goal is to verify whether imitation of successful behavior is so widespread that average output levels are affected by it. There is no amount of analysis of individual data that could supply any evidence to change the answer to that question. Second, observing that subjects move towards the successful output decision of the previous period, even observing the exact repetition of the successful output decision of the previous period, is no sure bet indication of imitating behavior. Of course, if imitation is defined that way, then the observation of that fact means that imitation is taking place. But we have to be more subtle here. By imitation we certainly must mean blind, unthinking imitation, because this is the behavior that leads, if followed, to the competitive equilibrium. "To-do-the-same as the most successful subject" is defined as imitation, but it may very well correspond to a different decision process; one which results in a completely different dynamics. A case in point is a *deliberate* tit-for-tat strategy. It requires a deeper level of cognitive involvement than imitation and does not necessarily converge towards the Walrasian equilibrium. Nobody calls a tit-for-tat strategy an imitative strategy, even though they look the same, because blind imitation and deliberate tit-for-tat may have *very different dynamic implications*. In general any reciprocating strategy of the type "give-as-good-as-you-get" (GGG) could blindly pass for blind imitation. But this would be a mistake, since a GGG strategy in a Cournot market may lead to a competitive equilibrium, but may also lead to the other extreme, to the collusive solution, provided that subjects understand that they are playing a repeated game of cooperation-defection.

5. **Conclusion**

Theory has shown that "imitating the best" leads to the competive equilibrium in Cournot markets. Since imitation seems simple, it was easy to infer that the competitive solution would be likely in such markets, provided that subjects were enough "bounded rational" and knew whom to imitate. We believe that our experiment has shown that this conclusion is unwarranted. Under very special circumstances that favor imitation, the Walrasian output level fails as a good description of these markets. I.e., in spite of our efforts at scrambling information and at flashing, each period, the most successful decision, we did not manage to induce the players to imitate the relatively more successful players.[15]

[15] After we had run our experiments, we learned that some other people were pursuing a similar track (see Huck et al. [1997], and Offerman et al. [1997]). While our conclusion seems to be at odds with those papers, it does confirm 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]).

Why then boundedly rational people do not imitate? Imitation in our set-up was straightforward and simple but, then, bounded rational as subjects can be, they still possess an arsenal of responses to somebody else's actions (among them the use of the imagination, see R. Selten (1978))[16]. In addition, in our Cournot game, a player, by systematically imitating more successful players, would worsen her own payoffs. Even in the treatments with more complex information, it did not take long for subjects to discover this fact. The result, of course, does not mean that imitation cannot be a common, or even a prevalent, form of behavior in some other context, but we do not find its absence surprising when subjects can easily become aware that by imitating they hurt their payoff prospects.

Does this mean that the players are less boundedly rational, and more rational, than the imitation hypothesis would assume? Perhaps, but not necessarily, since even simpler forms of behavior, like not even bothering to look at what other people achieve, might avoid the spite effect, and keep the markets away from the Walrasian equilibrium. This would be the case, for example, with reinforcement learning, in which a player looks at her own experience only (see, e.g., Roth & Erev [1995]).

That imitation has not been observed in our experiments, while an indication that bounded rationality imitation may not be prevalent in this particular kind of games, does not belittle the hypothesis of *strategic* behavior leading to Walrasian equilibrium in other circumstances; in particular in survival-of-the-fittest type situations.[17]

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

[17] See, for example, the recent row between EasyJet and BA, in which EasyJet publicly accuses BA of being copycats.

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Appendix A

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

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

In order to illustrate the spite effect, consider the bimatrix game in figure A1 (see Palomino & Vega-Redondo [1996]), 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.

Suppose that players have a preference to beat their opponent. In that case, we could, for example, rewrite the payoff matrix as in figure 2, where we use the payoff differences as the relevant payoffs. Since (b-c)>0, and (c-b)<0, the only Nash equilibrium is (B, B). This is rivalistic behavior. It might spring from direct preferences to beat one's opponent in the given one-shot game, or from strategic considerations in a larger dynamic game, i.e., the repeated version of this game, if there was some positive payoff in bankrupting one's opponent and monopolizing the market.

	T	B
T	0, 0	c-b, b-c
B	b-c, c-b	0, 0

Figure A2 Bimatrix game, with payoff differences

Now, suppose instead that two boundedly rational players repeatedly play this bimatrix game, randomly choosing an action in the first period, and then imitating whichever of the two players achieved the highest payoff in the preceding period. As shown in figure A3, whenever a combination of actions different from (T, T) has been chosen, next period's action will be B for both players.

Figure A3 Imitation of most successful player in bimatrix game

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 duopoly in which the inverse demand function is $P(Q) = a + bQ$, where $Q =$ Óq_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?

Suppose, to simplify, that there are only two firms and that fixed and marginal costs are zero, 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 A4 Cournot duopoly

To see why this is the only strategy where a firm is sure it can never be beaten, look at figure 4, 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, and if a firm that wants to beat its opponent has no idea what the other firm might do, it should produce $Q^W/2$ because that is the weakly dominating strategy. 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.

Appendix B

Table A1. Decisions and profits of firms 1, 7 and 13

Table A2. Identical figures mean imitation for firms 1, 7 and 13.

Appendix C. Instructions to the Players

Table B.1 gives the English translation of the Spanish instructions to the players in the `easy' duopoly with absolute performance payoff

- -

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 B.1 Instructions `easy' duopoly.

Table B.2 shows the instructions given to the players in the `hard' duopoly with absolute performance payoff. 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 24 to 96, 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 B.2 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 with (•) in table B.2.

Appendix C. Profit Table `Easy' Duopoly

The following table was given to the players in the `easy' duopolies.

PROFITS	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	
output		1554	1694	1826	1950	2066	2174	2274	2366	2450	2526	2594	2654	2706	2750	2786	2814	2834	2846	2850	2846	2834	2814	2786	2750	2
other firm 8	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	
	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	
9	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	
	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	
10	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	
	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	
11	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	
	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	
12	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	
	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	
13	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	
	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	
14	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	
	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	
15	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	
	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	
16	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	

	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
17	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
	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
18	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
	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
19	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
	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
20	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
	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
21	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
	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
22	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
	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
23	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
	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
24	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
	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

25	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
	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
26	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
	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
27	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
	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
28	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
	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
29	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
	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
30	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
	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
31	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
	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
32	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

Appendix D. Examples Computer Screens

We give two examples of the screens faced by the players. First, the `easy' version of the triopolies in figure D.1.

[

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	...	...

The screen faced by the players in the `hard' and `hardest' triopolies is shown in figure D.2.

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)