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Social Competition in Low-Information Cournot Markets

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JEL classification codes
C9, L13.

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1. Introduction

Behavior in strategic environments crucially depends on the amount of information players have about the environment. In low-information environments, defined as those where players do not know the process by which payoffs are generated, players may base their decisions on their own experience. In addition, players may integrate information about others' behavior following an imitative heuristics. In the context of Cournot competition, Vega-Redondo (1997) shows that the imitation of the most successful firm leads to the most competitive outcome, rather than to Nash or even more profitable collusive actions. Despite the negative prospect of converging to the null profits outcome, this theoretical result has been extensively confirmed in the lab (Huck et al, 1999, 2000, Apesteguia et al, 2007).[2]

Information about the performance of others is many times disclosed in an aggregated manner, rather than individually. That is, players only get to know a measure of average success. In industrial organization firms may get information about average market profits without necessarily being able to ascribe individual profits to rivals. In these scenarios, aggregation prevents individuals from using the "imitate the best" heuristics. In this paper we theoretically and experimentally test the effects of alternative heuristics fed by aggregated information about the success of others. We are specifically interested in investigating the competitive effects of a simple reference point in Cournot competition: average market profits.

Relative performance assessment based on average market profits may allow firms to easily compare themselves with the market, and compete more with rivals. Why do we expect this social competition to alter firms' behavior in Cournot markets? Psychologists and management scholars have long recognized that individuals (say, workers) are not exclusively motivated by absolute monetary rewards (Etzioni, 1971 and Deci, 1975). The evidence about the interaction between relative performance and and intrinsic motivation in other domains is overwhelming. A taste for higher rank may be a powerful behavioral force even when agents are paid according to absolute rather than relative performance. Individuals may exhibit loss aversion in social comparisons: negative deviations from a reference point count more than positive deviations.[3] We formalize this idea using a *win-stay, lose-shift* heuristics (Thorndike, 1911) where the average profits in the market plays the role of an "endogenous" aspiration level. Under this rule, when a firm makes profits below the average profits in the market, it switches and experiments with another quantity; the firm sticks to the current choice otherwise.[4]

[2] The usual experimental length in the Cournot market experiments is about 50-60 periods. Recently, Friedman et al (2015) develops a methodology that allows them to extend competition to 1200 periods. They also observe convergence to the competitive outcome over a horizon of 50-60 periods. Later though, firms escape from this "negative" situation and learn to play more collusive actions. Kopányi and Kopányi-Peuker (2015) reach collusive results by allowing firms in Cournot markets endogenously choose to strategically disclose information.

[3] Loss aversion is one of the foundations of Prospect Theory and it has been documented as a powerful driver in many economic/psychological situations (see the seminal contribution by Kahneman and Tversky, 1979). Buunk and Gibbons (2007) surveys the extensive research on the relevance of social comparison. It also lies at the heart of Inequity Aversion in Fehr and Schmidt (1999).

[4] There is evidence that in situations where subjects compare to inferior performers they are more satisfied with performance as when they compare to superior performers, see Blanton et al. (1999) and

What kind of dynamics is expected under a social comparison rule in Cournot competition? In this paper we prove that the long run outcome will be the Walrasian one, the same as under the imitative heuristics, because the Walrasian quantity has one striking property that went unnoticed until quite recently. Regardless of the choices of the other participants, a firm choosing the Walrasian quantity will never get profits below the average profits in the market (Morales and Fernandez-de-Cordoba, 2012). Hence, under the social comparison rule, once a firm chooses the Walrasian quantity, it will never switch away.[5]

Note that both heuristics (social comparison and imitation) make use of information about others. We test the effectiveness of social comparison in a Cournot competition experiment in which the same long-run outcome is predicted for both heuristics. The evidence on alternative heuristics in these settings is to the best of our knowledge very limited. Apesteguia et al (2010) offers indirect experimental evidence when reporting convergence to the Walrasian outcome in asymmetric Cournot competition (because no imitative heuristic predicts such competitive drift). They conclude that the experimental data were better explained by a suitable mixed process of imitation, best reply, fictitious play and relative payoff maximization.

In an attempt to discriminate between these two heuristics, in this paper we present the results of a series of experiments using the same setting as in Apesteguia et al (2007). Unlike them, participants do not receive individualized information about the profits of others, making the imitation of the most successful competitor impossible. The experimental setting is a simple 3-player symmetric Cournot game with five actions repeated for 60 rounds. In the baseline treatment (*No information*), at the end of each round, participants receive information about their own payoffs and the profile of actions chosen in the market. In the main treatment (*Information*), participants receive one additional piece of information: the average market profits.

Our results suggest that this information substantially changes the behavior of our participants. Moreover, it does change their behavior in the direction predicted by our theoretical model and with a similar magnitude to the effect observed in Apesteguia et al (2007), when imitation of the most successful rival was possible. Without information about market profits (as in *No information*), profits quickly stabilize around the Nash-Cournot payoffs and the modal action is the Cournot quantity. With information on the average market profits (as in *Information*), profits converge to the competitive levels and the modal action is the Walrasian quantity.

To assess if our results are consistent with the social comparison heuristic described above, we compare switching behavior across treatments, and find significant differences. In the *No information* condition, firms switch away from Cournot-Nash significantly less than from the Walrasian quantity (47% vs. 64%). In the *Information*

Buunk and Gibbons (2007). The social comparison heuristic implies that subjects are more satisfied with their performance when they earn more than the average (and stay), and less satisfied and more eager to improve when they are below the average (and switch).

[5] This theoretical result contrasts with findings by Dixon (2000) and Oechssler (2002), which proved that this type of rule yields cooperation (collusion) when interaction takes place in *many* markets simultaneously and the aspiration level equals the average profit in the *population*. In this paper the focus is on a single oligopoly market and the aspiration level equals the average profits in the market.

condition, the opposite phenomenon is observed (56% vs. 43%). We back up these differences with probit models with random effects.

We also run an additional treatment with a *natural selection* mechanism. In the *Selection* condition, the worst performer is kicked out of the market and remains inactive the next period (earning zero profits and without receiving any informational feedback). By making the consequences of competition more dramatic we increase the competitive effect of social comparison, and the pre-eminence of the Walrasian outcome. Interestingly, it does not generate significantly different switching patterns.

The final issue we investigate in this paper is the existence of a particular type of *imitation* in our setting. In all our experimental conditions, participants always received information about the distribution of actions in their market. Hence, it is not impossible for an unsuccessful firm, when deciding to switch away from her current action, to pick one of the actions played by her rivals. In other words, our subjects could use the "win-stay, lose-shift" heuristics, experimenting with new actions, and still imitate one of the rivals' actions observed in the previous period, even without knowing which firm was the most successful one. This particular type of imitation would push low performing firms to chose more often one of the actions already played in the market. However, our data strongly rejects this add-on imitation. When experimenting with other actions, low performers choose actions at random in the strategy space, without making any distinction between those played by better performers and the rest, and still driving the market towards Walrasian quantities.

In this paper we contribute to the more general experimental literature on social comparisons. A large branch of this literature shows that the revelation of information about the behavior of other players may trigger non-trivial dynamics; the selection of one particular dynamic is sensitive to the task type and to the social information disclosed.[6] In portfolio decisions, Dijk et al (2014) find that information about relative performance makes over-performers prefer less risky portfolios and underperformers to be more prone to choosing riskier ones. In public good settings, the availability of information on individual contributions reinforces conditional cooperation, a well-documented behavioral pattern. Among others, Andreoni and Petri (2004), Croson et al (2005) and Fischbacher and Gätcher (2010) show that this type of social information promotes imperfect convergence in cooperation levels. [7]

Experimental research on the impact of social comparisons in market settings is surprisingly scarce. Schoenberg and Haruvy (2012) show that relative performance information had a significant impact on the outcome of a double auction asset market: prices were higher in markets in which traders observed the best performer as compared to those in which traders received information about the performance of the worst. Our paper adds to this literature by showing that providing information of relative

[6] There are also field studies. For example, Tran and Zeckhauser (2012) and Azmat and Iriberri (2010) reported field experiments using high school students as subjects, whereas Blanes and Nossol (2011) focused on workers performance in firms.

[7] However, not all the experimental evidence reports a substantial and positive effect. Erikson et al (2009) found that relative performance feedback on employee effort has no effect. Charness et al. (2013) documented the dark side of competition for status in an experiment where workers could sabotage others, or artificially inflate their own output.

performance has a significant impact on the outcome of the Cournot market: competition is fiercer and consequently prices are lower, without imitation of the most successful rival, or rivals.

The rest of the paper is as follows. In Section 2 we present the theoretical model and the experimental design and procedures, together with some qualitative hypothesis. Experimental results are presented in Section 3, as well as the estimation of individual learning rules. Section 4 analyses the existence of imitation in our experiment and finally Section 5 concludes.

2. Experimental design and procedures

This paper consists of one game and three treatments. Table 1 below summarizes the experimental design.

[Table 1 around here]

2.1 The game

The game is a standard symmetric Cournot game in which n firms with cost function $c(q)$ face a downward-sloping demand function $p(Q)$. There is a unique symmetric Walrasian quantity q^w, defined as the quantity at which price equals marginal costs when all firms produce the same quantity $p(nq^w) = c'(q^w)$.

Dynamics under a social comparison rule

Firms repeatedly play the Cournot game in discrete time. After each period $t = 1, 2, ...$ each firm observes his own payoff and the average profits in the market. We hypothesize that firms use a "win-stay, lose-shift" learning rule: if the current payoff to a firm is equal or larger than the market average profit, the firm chooses the same quantity next period; otherwise the firm experiments randomly with an alternative action. With small probability $\varepsilon > 0$ each firm forgets the action prescribed by the learning rule and chooses an action at random. Proposition 1 states that the long-run outcome of the dynamics under the social comparison rule is the Walrasian outcome.

Proposition 1. *The Walrasian state is the unique stochastically stable state under the social comparison rule*

Proof. The proof makes use of a property of the Walrasian quantity proved by Morales and Fernandez-de-Cordoba (2012). This property states that the profits accrued to a firm choosing the Walrasian quantity are never below the market average profits. Consider an absorbing state in which all firms are choosing the same quantity different from the Walrasian quantity q^w. It is easy to see that a unique mutation is necessary to destabilize it and put it in its way to the Walrasian state. The reason is that once a firm mutates and chooses (with positive probability) the Walrasian quantity q^w, all other firms in the market will gain below the average profits and, with positive probability, will switch to the Walrasian quantity q^w.[8] Consider next the Walrasian state. Note that if there is a unique mutation, the system returns to the Walrasian state, as the mutant firm will get below the average profit in the market. This ends the proof.

The proof is immediate using the property of the Walrasian quantity described in Morales and Fernandez-de-Cordoba (2012): the Walrasian quantity never yields payoffs below the average payoff in the market.

2.2 Experimental design

We follow the same design as in Apesteguia et al (2007). Subjects repeatedly play (during 60 periods) a simple 3-player game with five actions derived from a symmetric Cournot game. Subjects are not informed about the underlying payoff structure, which corresponds to a linear demand function $p(Q) = 120 - Q$ and zero marginal cost, even when they are aware that the payoff process remains constant along the duration of the experiment. The five actions are $a = 20$ (Collusive quantity), $b = 23$, $c = 30$ (Cournot-Nash quantity), $d = 36$ and $e = 40$ (Walrasian quantity).

Interaction in the experiment takes place within groups of 9 participants each (12 participants in the *Selection* treatment). At the beginning of the experiment subjects were randomly assigned into 5 groups. Each period, participants within a group are randomly matched into three-firm markets to minimize repeated game effects. We consider three experimental treatments:

- *No information*: 45 participants are allocated into 5 independent groups of 9 participants each. At the end of each period *t*, participants are informed about their own individual payoffs and the market actions profile (the three letters/actions chosen in the market in that period).
- *Information*: 45 participants are allocated into 5 independent groups of 9 participants each. At the end of each period *t*, players are informed about their own individual payoff, the market actions profile (as in the *No information* condition), plus the average profit in their market.
- *Selection*: 60 participants are divided into 5 groups of 12 players each. Each period *t*, there are 9 active players (which are randomly matched into three-firm markets) and 3 passive players. At the end of each period t, active players are informed about the market actions profile, their own individual payoffs, plus the average profit in the market (as in the *Information* condition). Passive players receive no information at all. The firm with the lowest profits in each market in period *t* becomes a passive player in period *t+1*[9] and passive players at period *t* become active in period *t+1*.

2.3 Experimental procedures

[8] Note that there exists also the non-generic case that firm j and firms $i \neq j$ make the same profits but offer different quantities. In this case, a unique mutation of a firm choosing the Walrasian quantity is enough to make the system go to the Walrasian state.

[9] Ties are randomly broken.

We collected 5 independent observations per treatment, each one consisting of 2,700 actions (45 participants x 60 rounds), for a total of 40,500 non-independent observations. Experiments were run in the laboratory for research in experimental economics at the University of Valencia (LINEEX) using the z-tree software (Fischbacher, 2007). One hundred and fifty business and economics students were recruited using a standard electronic recruitment procedure and they were allocated randomly to any of the three treatments. Participants got an average pay of $24.50 for an experiment that lasted 63 minutes on average.

2.4 Hypothesis and simulations

We state a set of hypothesis regarding behaviour in the three treatments. In the treatment *No information*, subjects were only informed about one's own payoff and the profile of actions in the market. The theoretical literature on learning in repeated games when players know only their own payoff (*uncoupledness*) and the common history of play (*perfect monitoring*) shows positive results on convergence to Nash equilibrium (see for example, Kalai and Lehrer, 1993 or Hart and Mas Colell, 2006). Convergence to the Cournot-Nash outcome is expected to prevail. [10]

Hypothesis 1. Behavior will converge to the Cournot-Nash prediction in treatment No information.

In the Treatment *Information*, subjects received information about the average profits in the market. Based on Proposition 1, we expect subjects will follow a social comparison dynamic that drives them away from the Cournot-Nash prediction into more competitive outcomes. Furthermore, we expect the attraction to the Walrasian quantity to be more prominent if an additional selection mechanism is introduced. The intuition is that, according to Morales and Fernandez-de-Cordoba (2012), the Walrasian quantity is the only choice that eliminates the probability of being excluded.

Hypothesis 2. In treatment Information, behavior will be more competitive than in treatment No information but less than in treatment Selection.

Hypothesis 1 and 2 motivate the following joint hypothesis about the ordering of profits in the three treatments.

Hypothesis 3. $No\ information \geq Information \geq Selection$

[10] Boyce and Oxoby (2005) found convergence to Nash-equilibria with minimal information in Cournot-Nash experiments in which participants were provided with no information about the structure of payoffs.

Hypothesis 3 highlights the role played by treatments *No information* and *Selection* as lower and upper bounds for the impact of providing information on relative performance in competitive markets.

We close this section by presenting some simulations of the social comparison rule with non-vanishing noise. This seems important because Proposition 1 contains a long run prediction; e.g. it shows that under the social comparison rule, the dynamics will converge to the competitive outcome with vanishing noise. Figure 1 displays results from 100 simulations of a market with three firms over 60 periods under the social comparison rule, with a noise parameter equal to 0.2, the same noise level used for the simulations in Apesteguia et al (2007). This noise level implies that with probability 80%, a firm will play the quantity prescribed by the social comparison rule, and that with the complementary probability, 20%, the firm will play a random quantity.

[Figure 1 around here]

Figure 1 displays the relative frequencies of the different quantities for rounds 31-60 for the *social comparison* and the *imitate-the-best* rule. Even though firms in the experiment reported in this paper could not use the latter because detailed individual information were not provided to subjects, the simulated dynamics under the imitation rule sets a natural benchmark on which to compare firms' behavior when information is offered in an aggregated manner. In line with the simulations presented in Apesteguia et al (2007), the modal action in rounds 31-60 under the imitation dynamics is the Walrasian quantity, chosen in 80% of the occasions; also, simulated profits are 231.86 (note that for the parameters chosen in the experiment Nash equilibrium profits are 900). When participants receive information about the average profits in the market, simulations under the social comparison rule show that the modal action is the Walrasian quantity, with a proportion of 50%, well above the other quantities (the second in importance is quantity *d*, with a frequency of 19%); and average profits are 491.02. [11]

These simulations show that the long-run result found in Proposition 1 using stochastic stability tools also applies to non-vanishing noise simulations, and that the absence of detailed individual information on rivals does not prevent the market to display extremely competitive outcomes if an aggregate measure of the performance of others is available.

3. Experimental results

This section presents the experimental analysis of the results. It is organized as follows. First, data are evaluated at the aggregate level. Second, an analysis of the individual

[11] We include in the appendix a more detailed analysis of different simulations using three noise levels. As we briefly discuss in the appendix, the results are robust to different parameter choices.

behavior is performed in order to assess the importance of the proposed reinforcement-learning rule with endogenous aspiration level in explaining the results. Finally, estimations of individual learning rules are presented.

3.1 Aggregate behaviour

Table 2 shows average profits for all treatments, separately for first round, all rounds and first half and second half of the experiment.

[Table 2 around here]

Differences across treatments are not significant in the first round, but they are significant over all 60 periods and in both 30 period blocks, with the unique exception of treatments *Information* and *Selection* in the first half of the experiment. The three treatments are ordered according to Hypothesis 3, and Hypothesis 1 is remarkably confirmed, as average profits in the *No information* treatment are 899.60, extremely close to the Cournot-Nash equilibrium profits (900).

Result 1. Without information about average profits in the market (as in No information), profits converge to the Cournot-Nash

Result 2. With information about average profits in the market (as in Information), we observe more competitive (and significantly lower) profits. The introduction of a selection mechanism (as in Selection), exacerbates this competitive drift

Figure 2 presents the relative frequencies of actions by treatment, for the whole experiment and the second half of the experiment (bottom of Figure 2).

[Figure 2 around here]

In *No information*, the modal action is the Cournot-Nash quantity, which is selected 27.59% of the times, and the less chosen action is the Walrasian quantity (14.96% of the times). In sharp contrast, in *Information* the modal choice is the Walrasian quantity, chosen 32.74% of the times, while the proportion of times the Walrasian quantity is chosen goes up to 40.63% in *Selection*.[12] The Walrasian quantity is chosen significantly more often in *Information* and *Selection* than in *No information* (MW p-values<0.0086 and 0.0088, respectively). The difference between the frequency of the Walrasian quantity in treatments *Information* and *Selection* is also significant (p-value<0.0278),

[12] The differences are more prominent in the second half of the experiment.

but differences in the frequencies of Cournot-Nash quantities are significant to a lesser extent (p-values are never greater than 0.0758 for the comparison *No information - Information*, 0.0160 for *No information - Selection* and 0.0749 for *Information - Selection*).

Table 3 complements Figure 2 by focusing on the Cournotian and Walrasian quantities, and it provides useful information to understand the behavior of our participants across the different treatments. The first two columns in Table 3 provide information about average payoffs obtained in the experiment when playing Cournot Nash (action *c*) and the Walrasian quantity (action *e*). Note that the average payoff associated to the Cournot-Nash quantity always exceeds that of the Walrasian quantity in all treatments. If decisions were driven by absolute payoffs, one would expect the switching ratios from the Cournot-Nash quantity to be smaller than those from the Walrasian quantity in all the three treatments, particularly when the difference is more prominent (as in *Information* or *Selection*). However, this is only observed in *No information*, when participants only received information about their own payoff, but it does not hold for the two remaining treatments, where a reversal of the switching ratios is observed.

[Table 3 around here]

How does the information about average profits in the market make subjects switch from Cournot to Walras? Our intuitive answer is that this information leads them to make social comparisons. The last two columns in Table 3 display the percentage of times that the Cournot-Nash and the Walrasian quantities yielded profits below the average profits in the market. In the *Information* treatment, those subjects who played the Nash Cournot received a profit below the average profit in the market in almost half of the times (48.66%). In the *Selection* treatment, this percentage goes up to more than 60%. As described in our Proposition 1, the Walrasian quantity never yielded lower-than-average profits.

Result 3. If subjects receive information about average profits in the market (as in Information), they learn to avoid the Cournotian quantity and play the Walrasian quantity more often, despite the superiority of the Cournotian quantity in absolute payoffs. This phenomenon is exacerbated with exclusion (as in Selection).

We observe very different prevalent actions across our experimental condition at the aggregate level. While our treatment *No information* is relatively more Cournotian, whenever participants receive information about average market profits the Walrasian quantity is the norm. We explore in the next subsection whether this phenomenon occurs also at the individual level, and whether it is related to the type of individual behavior associated with the social comparison rule outlined in section 2.

3.2 Individual behavior

In this subsection, we define types in a straightforward way: subjects are classified using to their preferred (and most frequently chosen) action. Table 4 displays the resulting taxonomy for all rounds and for the second half of the experiment. A player is of type *t* if her modal action in the 60 rounds of the experiment is action *t*. The fraction of rounds that a type t plays her preferred (modal) quantity (averaged by all type-t subjects) is a measure of the intensity of the type, and it is also included in Table 4.[13]

In *No information*, the most popular type is the Cournotian one: one third of the subjects are Cournotian, and its intensity is 50% (rising to two thirds of the periods in the second half of the experiment). This finding fits well with the aggregate picture that emerged in the previous section: markets in the treatment *No information* are populated by Cournotian players that give raise to the Nash outcome.

[Table 4 around here]

In *Information* and *Selection*, the most popular type is the Walrasian type: 40% and 55% of subjects are Walrasian players respectively, with an average intensity between 51% and 66%. Differences get more pronounced in the second half of the experiment.

Result 5. Individuals are mostly Walrasian in the Information and Selection treatments

Is the preponderance of Walrasian types in the *Information* and *Selection* treatments the result of players performing social comparisons using the "win-stay, lose-shift" learning rule? We answer this question by analysing individual compliance rates. For each subject, we compute (i) the proportion of times he *switched* when receiving a payoff below the average payoff in the market, and (ii) the proportion of times he *stayed* when receiving a payoff above the market average profit. Table 5 displays these figures averaged by subjects for treatments *Information* and *Selection* (the median value is also included).

[Table 5 around here]

Consider first switching rates when being beaten by the market. Following our interpretation of social comparison, a subject would be dissatisfied with her performance and more prone to switching. In *Information*, the average subject switched 69% of the times that he was below the average profit in the market (and the median subject switched 78% of the times). This percentage rises up to 83% in *Selection* (and this difference is significant: MW test, $p<0.0472$), consistent with the idea that a higher

[13] Multimodal subjects are arbitrarily divided equally between the two quantities. This does not affect the conclusions.

pressure for not being excluded makes subjects to experiment more when below the market profit.[14]

Result 6. Social comparisons play a significant role in the experiment: Earning less than the average spurs on experimentation with new actions. The introduction of the selection mechanism exacerbates this effect.

When subjects receive a payoff above the average payoff in the market, things are quite different: median and mean individual compliance rates are around 50% in both treatments (without any significant difference, p=0.7540), consistent with the idea that when above the market average profit, subjects focus less on their relative performance when choosing an action. The fact that experimental subjects switch away from the current action half of the times when they earn more than the market explains well why experimental markets do not fully converge to the Walrasian quantity. By choosing this Walrasian quantity, a player may be extremely satisfied in relative terms –because it will never earn less than the average profit in the market, and quite dissatisfied with her small absolute payoff, especially if other players are also choosing a Walrasian quantity. In a market in which all three firms choose to produce the Walrasian quantity, individual earnings and market earnings are zero; a situation that is payoff equivalent to being excluded from the market.

Hence, there exists a powerful trade-off between relative concerns, and absolute payoffs. The opportunity cost of caring exclusively about your relative performance is extreme in our experimental setting (as in Apesteguia et al, 2007), and this deserved further investigation. In the next section we estimate individual learning rules to assess the hazardous balance between relative and absolute payoffs.

3.3 Estimating learning rules

We estimate probit models with random effects to analyze switching behavior (that is, subjects' decision to change their action, presented in Table 6). Models 1, 2, 3 and 4 in table 6.a closely follow the reinforcement learning literature and consider as independent variables the individual payoffs, *Own profit*, and the relative propensity of the chosen action, *Relative propensity*, defined as the sum of all past payoffs yielded by the action, divided by the sum of all past payoffs, and the dummy *Lagged exclusion*, to control for exclusion in the previous period in *Selection*. The coefficients for both variables are significantly negative in all four models (and in all three treatments), in line with the theoretical intuition: the larger the individual payoff (or its relative propensity), the larger the probability that a subject will play the same action in the next period.

Table 6.b explicitly incorporates social comparison as an explanatory variable by including a new explanatory variable: *Relative performance*, as the distance between the

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[14] The results are identical if only the last 30 rounds are considered.

average market profit and the individual profit in each period t. The results of models 5 to 7 are consistent with the idea that relative performance has a strong and significant effect across both *Information* and *Selection* treatments, being the effect stronger in the latter. The positive and significant effect of *Lagged exclusion* in model 7 is in line with the intuition that those excluded from the market in the previous round experiment more, and change their decisions more often.

Models 8 and 9 in Table 6.c distinguish between two interesting cases: when the decision maker is below (with the dummy *Below*) and above (with the dummy *Above*) the average market profits. It is not difficult to see that social comparison has a strong asymmetric effect. In treatment *Information* it significantly increases the probability of switching away from the current action when the individual is below the market (as noted by the dummy *Below*), being the magnitude of the marginal effect quite substantial (14% more often). However, as the insignificant coefficient *Above* suggests, successful individuals no not switch more often than individuals in the benchmark condition (markets in which all three individuals choose the same action). In the *Selection* treatment, the asymmetric effect of social comparison is even stronger, as *Below* is larger and *Above* becomes marginally significant, suggesting that individuals above the market are marginally more eager to stick to their current action than in the benchmark condition.

[Table 6 around here]

Figure 3 visually represents the effect of social comparisons and the probability of switching by plotting the estimated probabilities of switching in models 5 and 6, as a function of the distance between the individual profits and the market profits (showing a non linear fit of the predicted data, with the standard confidence intervals). As discussed above, the probability of switching is very small in both treatments when individuals are beating the market by a large margin (far left part of the graph). When individuals do worse than the market, the probability of switching increases, reaching 40% in the *Information* treatment and almost 60% in the *Selection* condition when individuals do substantially worse than the market.

[Figure 3 around here]

Result 7. Reinforcement terms are negatively correlated with the switching probability in all treatments. Social comparison plays a significant role when market info is provided, but the effect is stronger for those individuals below the market. Selection reinforces the effect of social comparison, and those excluded from the market switch away with higher probabilities.

4. Imitation in type-2 and type-3 environments

The experimental results show convergence to the Cournotian quantity in the treatment *No information* and to the Walrasian quantity in the treatment *Information*, when subjects are exposed to information about the average profits in the market but are not aware of the individual performance of other firms in the market. Throughout the paper this treatment effect has been rationalized using a social comparison heuristic: Given that subjects are provided with information about average payoffs in the market, it seems natural to assume that subjects adapt their behavior upon focusing on whether they are above or below the market.

This section however departs from this assumption and takes the opposing view: what if subjects use imitation rules in the treatment *Information*, specifically the rule "imitate the best", as much as they can, *whenever imitation is at least partially possible*?[15] In all the experimental treatments and rounds, subjects were informed about the action profile in their market. At least in some cases, the profile was informative about the relative profitability of some actions. In these specific cases, they could opt to switch to a more profitable action based on imitative purposes because the rule "imitate the best" only requires uncovering the ordering of the actions. It is relative and not absolute values what is needed.[16]

In what follows, it is said that a market action profile in a given round is of type-n if the number of different actions in the action profile is n. Given that there were three firms per market, there will be action profiles of type 1, 2 and 3. Just to give you an idea of how frequent these action profiles are, in the treatment *Information* alone we find 54 profiles of type 1 (6%), 466 profiles of type 2 (51.78%) and 380 profiles of type 3 (42.22%).

In type-1 action profiles, all three participants choose the same action and therefore it is trivial for a player to infer that her action is the most (and least) profitable. Naturally enough, this type of environment doesn't help us to discriminate between the social comparison rule and the rule imitate-the-best, because both rules prescribe sticking to one's own action.

The situation is quite different in the other two action profiles. Consider now a type-2 action profile, where the number of different actions and the number of different profit levels in the market is two. After being informed about the average profits in the market, a participant may easily infer which of the two different actions in the profile yielded the highest payoff. The reason is simple: being above (below) the market and earning the largest (smallest) profits in the market are identical events. When individual profit is above the average market profit, both the imitative and the social comparison rule prescribe sticking to one's own action. When an individual earns less than the average market profits, the prescriptions of the two heuristics are very different: while imitation would require switching to the only other action observed with probability

[15] We thank Bob Sugden for her insistence on this issue during a seminar.

[16] The literature considers other imitative rules in which information in absolute terms is needed, as for example the proportional imitation rule of Schlag (1998) and Morales (2002). But these rules cannot be applied in our context, as the individual information about the rivals' payoffs wasn't revealed to the subjects.

one, the “win-stay, lose-shift” rule would prescribe it with a much smaller probability: one out of four.[17]

Tracking the evolution of the transition ratio between the currently played action and the observed action in environments of type-2 for those players earning less than the average profits in the market does help us to easily discriminate between the two behavioral rules. Figure 4 displays the evolution of this transition ratio by blocks of ten rounds, together with two horizontal lines set at the levels predicted by the rule imitate-the-best (100%) and the social comparison rule (25%). The evolution of the ratio oscillates around its average value, 21.33%, close to the prediction of the social comparison rule and strikingly away from the imitative prediction.

[Figure 4 around here]

In type-3 environments, all three participants choose different actions. For this type of profiles, being informed of the average market profit is not enough for inferring which action yields the largest profits in the market. However, by earning less than the average market profit, participants get an informative signal: one of the two actions observed is the most successful in that round, even without knowing exactly which one is.[18] Note that when a participant earns less than the average market profits, switching to any of the two actions observed is compatible with both the social comparison and the imitative rules, although again with different probabilities: the predicted ratio is 50% under the social comparison rule and 100% under the imitative rule.[19] Figure 5 displays the evolution of this ratio in blocks of ten rounds for those players with below the market profits in profiles of type-3, together with two horizontal lines set at the 50% and 100% level. The picture that we get is actually similar to the one observed for type-2 profiles: the transition ratio oscillates around its average value, 47.24%, which is in fact extraordinarily close, again, to the value predicted by the model of social comparison.

[Figure 5 around here]

This aggregate analysis offers little evidence in favor of imitation. We run an additional individual analysis to check whether imitative behavior at the individual level is not

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[17] Note that this is because the social comparison rule prescribes random experimentation of new actions, and there are four actions to experiment with.

[18] It could be that both actions yield higher profits than the action chosen by the individual in that round. From the point of view of imitating-the-best, knowing whether one or two of the actions observed yield higher profits is irrelevant in this discussion.

[19] The predicted ratio is 50% under the social comparison rule because the participant will play one of the two observed actions, out of the four possible actions to experiment with. The probability goes up to 100% under the imitative rule because by choosing one of the two observed actions, the participant is doing better in expected terms.

captured well by the aggregate analysis. As our participants played the Cournot game for sixty periods, they experienced several instances of earning less than the average profits in the market in type-2 and type-3 environments. On average, a participant was below the market in type-2 (type-3) environments in 15 (11) rounds out of 60.

For every subject, we compute the individual transition ratio (from played to an observed action) in on of these two environments. This individual ratio may be easily interpreted as an *imitation index* for each player. [20] Figure 6 displays the distribution of the individual *imitation index* in the population for both types of environments. We also include two vertical lines at the levels predicted by the *social comparison* rule (0.25 and 0.50, respectively), keeping in mind that the predicted value from the *imitation rule* is 1 (not included in the figure).

[Figure 6 around here]

Figure 6 presents very clear results, closely in line with Figures 4 and 5. The average *imitation index* in type-2 environment is 0.1983, and a substantial fraction of values are below the 0.25 reference point. Even when individuals in type-2 environments observe a single action that is the most successful action, rather than their own, they still exhibit weak imitative patterns. Only 10% of the population has a ratio larger than 0.4 and there is no single individual in the population with an individual imitation index larger than 0.6. Results in type-3 environments are not very different. The average *imitation index* is 0.3698 and the distribution of values is remarkably symmetric around the level predicted by *social comparison*. Again, the fraction of imitators is quite small, as only 20% of subjects have an imitation index larger than 0.6.

Following the analysis of individual imitation patterns, we conclude that even when the information available gives subjects an opportunity for imitation, subjects did not put much emphasis on imitating the best, and rather experimented with a random action, as suggested by the social comparison heuristic.

Result 8. Imitation plays a negligible role in explaining our experimental results

5. Conclusions

Whenever information about the payoff generating process is limited or non-existent, economic agents face a behavioral challenge in strategic environments. It is natural for players to think of different heuristics to update their behavior. In the context of Cournot competition, a standard mechanism incorporating information about the choices and success of others is imitation of the most successful player. The market is

[20] Using the index, we could even classify individuals by types: from ratios close to one for *perfect imitators*, to ratios close to zero for *no-imitators*. The clean results shown in Figure 6 made us drop this taxonomy of players.

predicted to converge to the Walrasian outcome under this rule, and this prediction has been extensively confirmed by many experiments.

In this paper we study an alternative heuristics available to players with aggregate information about market performance: *social comparison*. Under this rule, players do not follow the most successful choice because this information is not available. The rule simply reinforces current choices when players perform relatively better than the market, and prescribe a change when they do not. We test this idea in a stylized experiment run under identical conditions to previous studies on imitation. The only remarkable change is that participants do not receive information about individual profits, and do get information about the average performance in the market. Two main conclusions can be drawn from our research.

First, although the *imitative* and the *social comparison* heuristics are quite different, they share the same *curse* in Cournot markets. Under both heuristics, players converge to the worst outcome for players: the Walrasian solution. Players in the short run (less than 60 periods) seem to be unable to efficiently handle the information conveyed in the choices of others. By adopting the *social comparison* heuristic, players do try to beat the market, and experiment with a different action when their profits are below the average market profits. The Walrasian quantity has an interesting property: by choosing it, they never get profits below the average market profits. In this sense, our results confirm our hypotheses 2 and 3.

Second, players consider both heuristics to be orthogonal in the following sense: once players use the *social comparison* rule, players do no further exploit the available information. As described in section 4, at least in some cases players might infer the most successful choice, and use the imitative heuristic to switch to in the next round. Our results strongly suggest that individuals did not use this heuristics in our experiment, but rather show an experimenting pattern consistent with social comparison.

Interestingly, a small amount of information generates a major behavioral change. We do confirm our hypothesis 1 in a control treatment with no information about the average profit in the market, as our participants converge to the Cournot Nash equilibrium. The average market profit clearly leads subjects to the most competitive, and collectively pernicious, action. By competing with others using the social comparison heuristics, individuals beat the market, but they cannot *beat* Walras. Once trapped, social comparison retains them in the inefficient, low-profit, solution.

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Table 1. Experimental design

	Treatment		
	No information	*Information*	*Selection*
Subjects	45	45	60
Sessions	1	1	1
Markets	15	15	15
Groups	5	5	5
Matching	Strangers	Strangers	Strangers
Feedback	Action profile and own payoff	+ Market average profit	

Figure 1. Simulations with noise parameter equal to 0.2

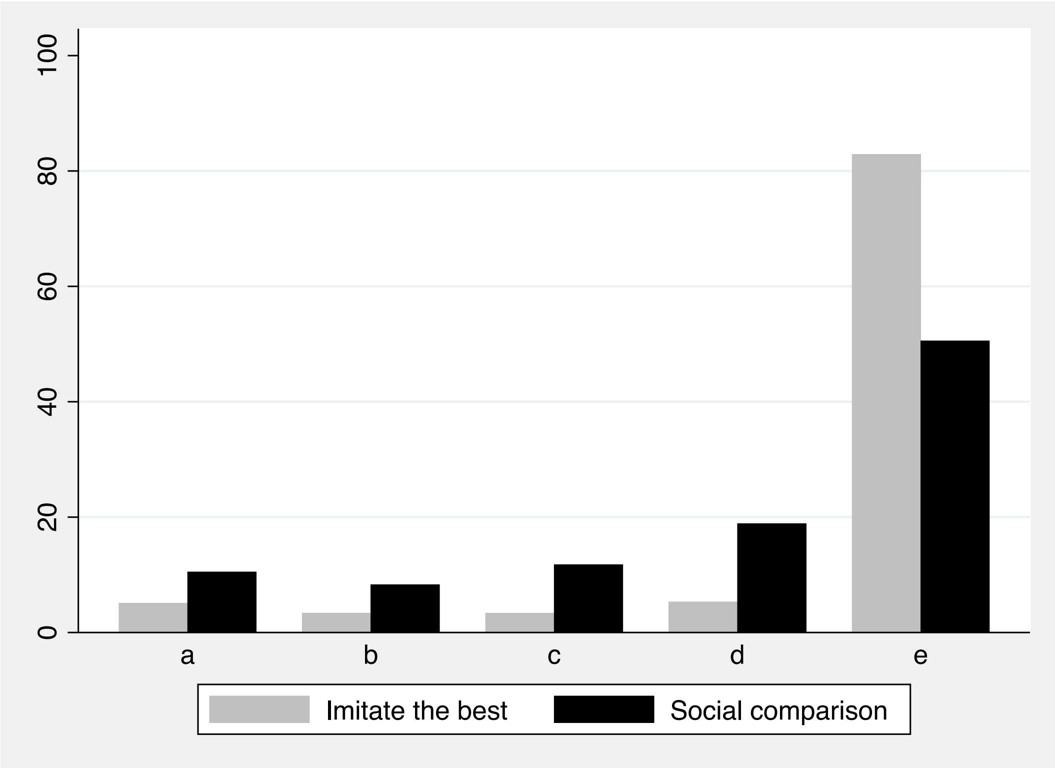
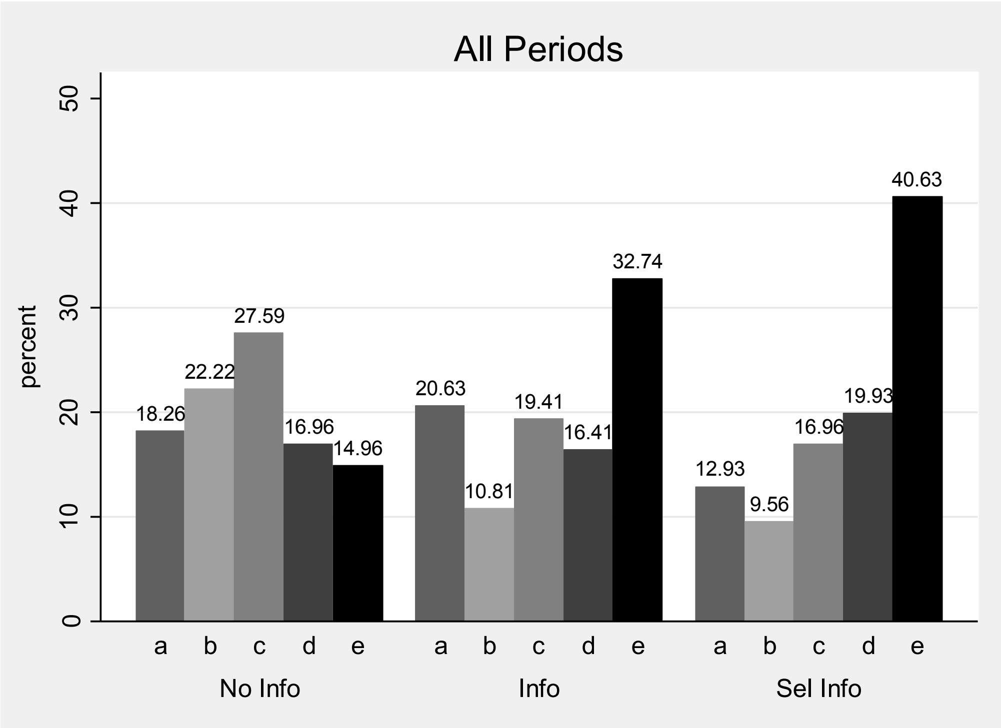


Table 2: Summary statistics by treatment

Average Profit	*No information*		*Information*		*Selection*
Period 1	1057.76		969.67		993.04
	(81.36)		(140.22)		(75.73)
Periods 1-60	899.60	***	742.58	**	610.56
	(33.16)		(77.54)		(29.07)
Periods 1-30	912.18	***	767.05		708.84
	(37.14)		(64.61)		(34.11)
Periods 31-60	887.01	***	718.10	***	512.27
	(46.44)		(107.42)		(33.99)

*Standard errors for the five independent observations per treatment are given in parenthesis. The outcome of Mann Whitney non-parametric tests are shown only when significant: ** at the 5% level, *** at the 1% level.*

Figure 2. Relative frequencies of actions



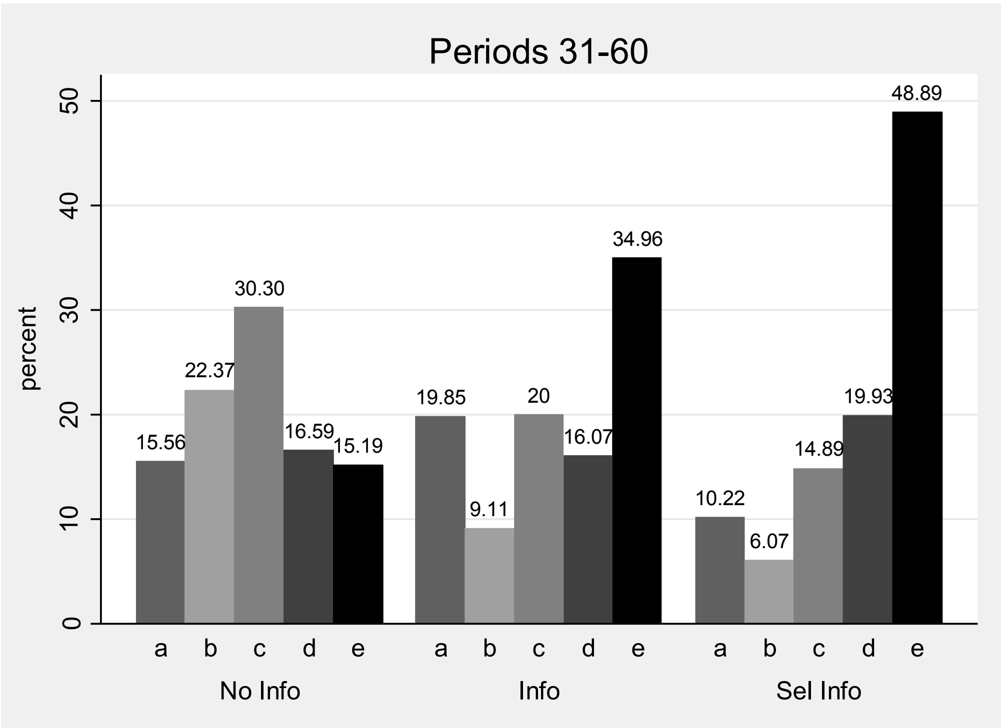


Table 3. Cournot-Nash and the Walrasian quantities

Treatment	Average profits		Switching probability		% below market profit	
	Cournot-Nash	Walrasian	Cournot-Nash	Walrasian	Cournot-Nash	Walrasian
No information	951.30	875.45	47.54	64.39	-	-
Information	828.38	674.93	56.03	43.93	48.66	0
Selection	726.68	525.54	58.37	35.29	61.35	0

Table 4: Taxonomy of subjects by modal actions

All periods	No information		Information		Selection	
Subject type	# Subjects	Intensity	# Subjects	Intensity	# Subjects	Intensity
a	9	34.81	9^m	45.50	7	38.01
b	10	51.00	2	32.50	2	34.62
c	15	56.89	10	46.33	8	39.26
d	6	56.67	6	46.11	8.5^m	41.33
e	5	47	18^m	51.67	34.5^m	54.56
Total	45		45		60	

Periods 31-60	No information		Information		Selection	
Subject type	# Subjects	Intensity	# Subjects	Intensity	# Subjects	Intensity
a	7.5^m	36.67	11	49.70	7^m	35.93
b	12	54.72	2.5^m	33.33	1	44.44
c	14	67.14	8.5^m	54.07	5.5^m	39.62
d	6.5^m	54.29	6	58.33	12.5^m	44.59
e	5	58	17	62.55	34	66.51
Total	45		45		60	

^{m} denotes a multimodal subject

Table 5. Individual compliance rates with "win-stay, lose-shift" learning rule

	Treatment			
	Information		*Selection*	
	Switch if below	Stay when above	Switch if below	Stay when above
Mean	69%	50%	83%	53%
Median	78%	47%	85%	59%

Using a Mann Whitney non-parametric test, compliance is significantly higher in Selection only for the "lose-shift" rule (p-value<0.0472), and no differences are found for the "win-stay" rule across the two treatments (p-value<0.7540).

Table 6: Probability models

(a)

	No information (1)	*Information* (2)	*Selection* (3)	*Selection* (4)
Own profit	-0.290	-0.229	-0.286	-0.082
	(0.04)***	(0.03)***	(0.02)***	(0.03)***
Relative propensity	-706.018	-507.406	-376.329	-396.569
	(51.64)***	(52.74)***	(48.93)***	(49.53)***
Lagged exclusion (dummy)				288.044
				(28.43)***
Log likelihood	-1451.149	-1469.171	-1461.467	-1416.676
Observations	2655	2655	2640	2640

(b)

	Information (5)	*Selection* (6)	*Selection* (7)
Own profit	-0.080	-0.093	0.066
	(0.04)**	(0.03)***	(0.04)*
Relative propensity	-516.426	-389.572	-407.866
	(53.26)***	(49.36)***	(49.79)***
Relative performance	0.558	0.813	0.702
	(0.07)***	(0.11)***	(0.011)***
Lagged exclusion (dummy)			265.008
			(29.04)***
Log likelihood	-1440.077	-1430.021	-1393.120
Observations	2655	2640	2640

(c)

	Information (8)	*Selection* (9)
Own profit	-0.1658	-0.123
	(0.03)***	(0.03)***
Relative propensity	-508.2352	-407.8962
	(53.16)***	(49.78)***
Below (dummy)	136.2407	248.9168
	(39.64)***	(33.48)***
Above (dummy)	-42.0775	-68.2063
	(41.02)	(36.46)*
Log likelihood	-1443.029	-1393.120
Observations	2655	2640

All coefficients and standard errors are multiplied by 10^3
Standard errors are in parenthesis
Only cases with $s_i^{t+1} \neq s_i^t$ considered
Marginal effects after random-effects probit regressions
**** 1% level, ** 5% level and * 10% level.*

Figure 3: Predicted probability of switching

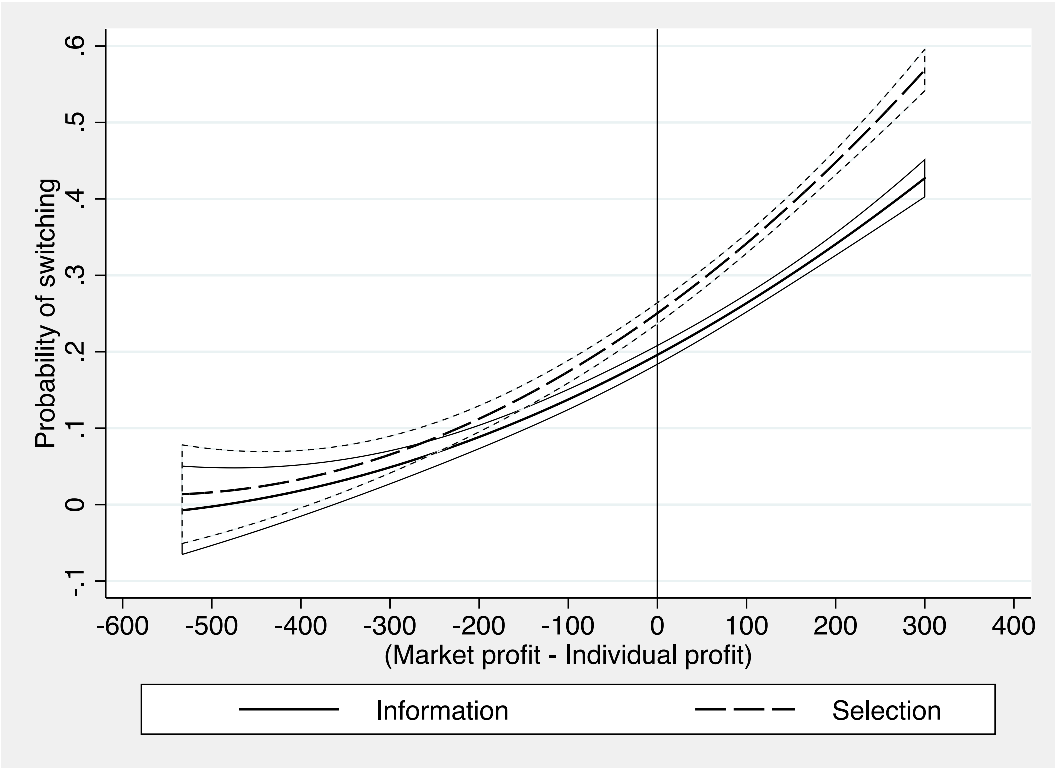


Figure 4. Transition ratio in type-2 environments

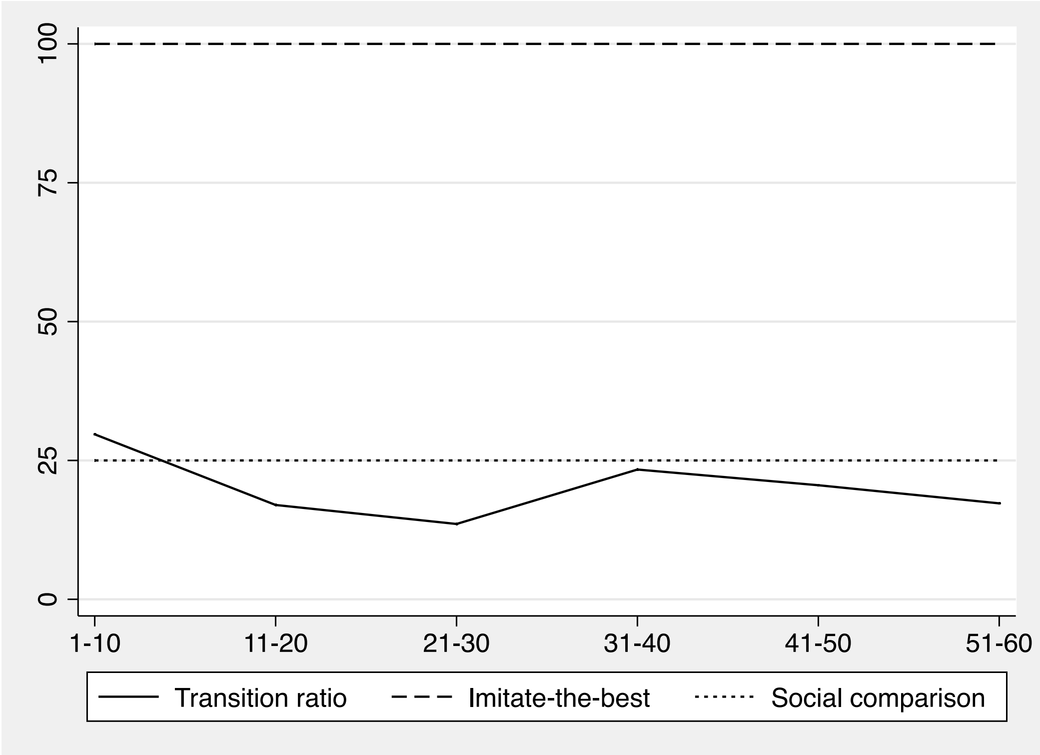


Figure 5. Transition ratio in type-3 environments

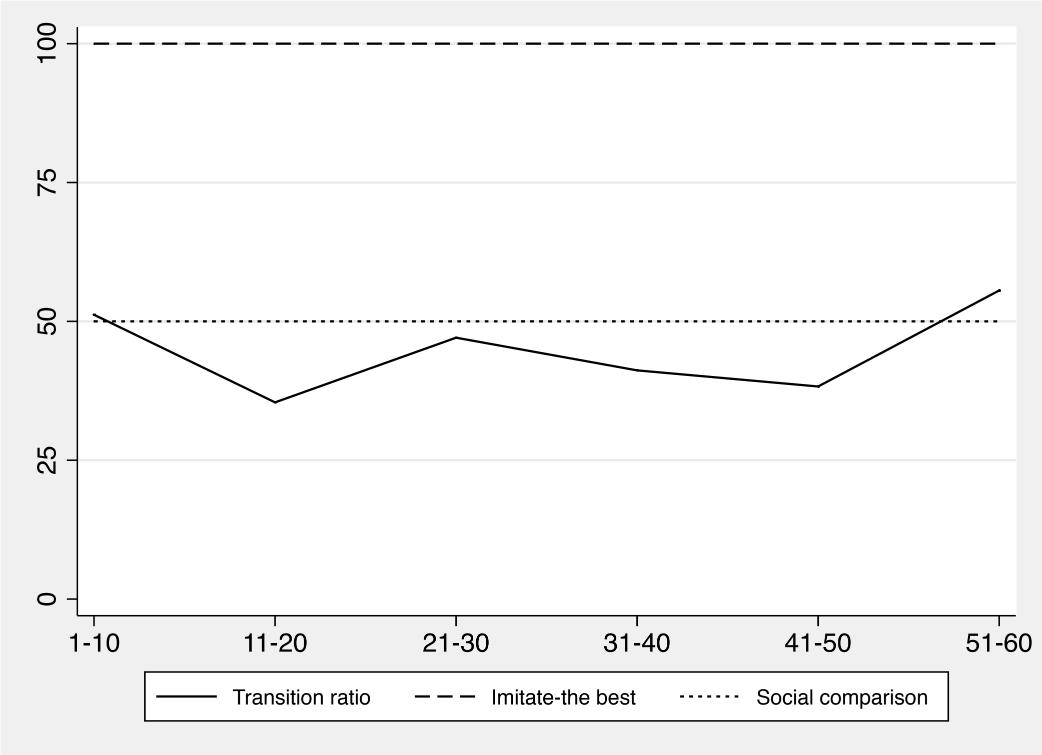
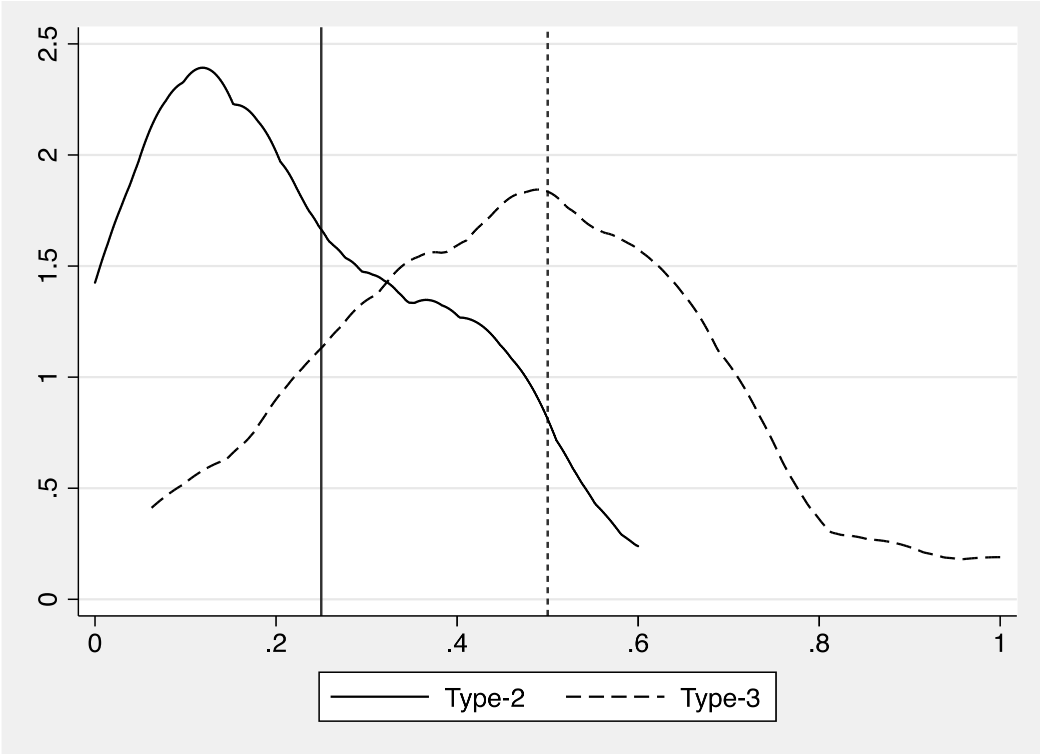
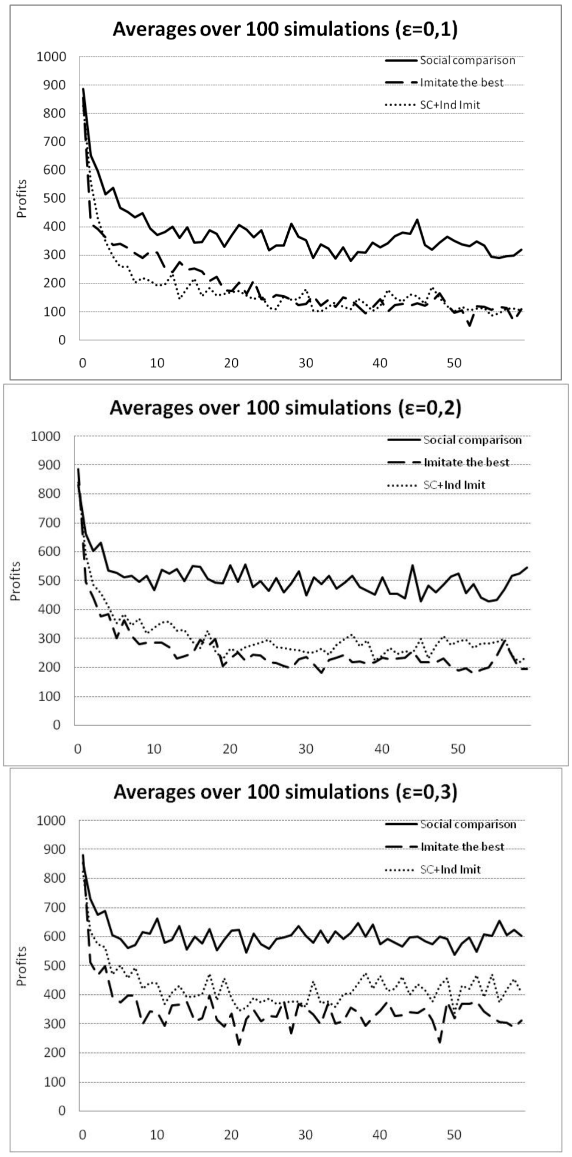


Figure 6. Imitation index



Appendix

Figure A1: A comparison of heuristics for different levels of noise



This figure displays the time evolution of the average profits in a market over 60 periods, averaged over 100 simulated markets, under three different heuristics (social comparison, imitate the best and social comparison plus add-on imitation), for different values of the noise parameter. In the main text, we report simulations using the same noise parameter as Apesteguia et al (2007), ε=0.2. Here, we perform a robustness analysis to the noise level, using three noise levels: ε=0.1, 0.2 and 0.3. We find that (i) average profits under the social comparison rule are roughly speaking twice/thrice as large as those under the imitative rule (both imitative heuristics achieve quite similar profits) and (ii) the convergence to null profits is achieved by the imitative rules for large values of the noise parameter. The reason why the imitative rule deals worse –compared to the social comparison dynamics- with the cursed competitive drift in Cournot markets for positive (but small) noise level is that in a given round, if one player has chosen the Walrasian quantity, there are high chances that all players choose the Walrasian choices in the next period by imitation. This means that once the Walrasian quantity appears in the market, it quickly spread throughout the whole market and is very persistent (it only disappears with the help of three simultaneous mutations). In contrast, under the social comparison rule, the presence of one firm in the market playing the Walrasian quantity does not mean than the remaining firms will pick the competitive quantity for two motives: first, in some states not all firms will switch at all (for example, if the action profile is “ade”, only the firm playing a will get profits below the average profits in the market); and second, conditional on switching, there is only a probability of 25% of switching to the Walrasian quantity. As a consequence, for fixed noise of level, there will typically be more variety of quantities in the market and the associated average profits will be larger than the competitive profits typical of the imitative dynamics.