

## MARKETS UNDER BOUNDED RATIONALITY: FROM THEORY TO FACTS

FERNANDO VEGA-REDONDO

*Universidad de Alicante*

*In this paper, I survey the issue of how bounded rationality impinges on market performance. This is done at two complementary levels. First, I address matters theoretically, discussing a variety of different models which suggest that firms' behavior under bounded rationality should be imitative and, furthermore, lead to competitive outcomes. Second, I assess the empirical basis for this conclusion, discussing both experimental and field evidence supporting. (JEL C32, E32)*

### 1. Introduction

Markets, in the real world, are indeed very complex environments. Two of their essential features underlie such large complexity. On the one hand, market outcomes are simultaneously affected by a rich plethora of alternative factors: heterogenous consumer preferences, intricate technological and organizational details impinging on production, a wealth of exogenous facts (social, historical) shaping agents' perceptions, etc. But, on the other hand, a crucial reason why these reinforcing sources of complexity must be taken seriously (both by market participants and researchers alike) is that they typically display a very rapid and mostly unpredictable variability. Thus, in particular, one cannot resort here to the easy line that agents will *eventually* learn. In these contexts, the "Red Queen curse" uncompromisingly applies:<sup>1</sup> agents have to continue learning just to keep knowing essentially as much as they knew.

Naturally, the huge and ever-changing complexity of market environments forces agents to behave in a less-than-omniscient manner; or,

<sup>1</sup>This is a reference to Lewis Carroll's book *Alice Through the Looking Glass*, where the Red Queen says at one point: ". we have to run as hard as we can just to stay in one place"

using a more standard phrase, it leads them to exhibit boundedly rational behavior. But, once it is agreed that bounded rationality is a consideration that should play an important role in the analysis of markets, the problem arises as to what is to be the right (precise) way of modelling it. Admittedly, the received full-rationality paradigm has a convenient modelling advantage in this respect. For, within this paradigm, it is not only implicitly supposed that agents are accurately informed of the world (i.e. model) in which they live in but, furthermore, that they are subject to *no* bounds in analyzing it exhaustively. Naturally, this leads to a precise and coherent way of formulating their behavior: given their own preferences (merely one of the components of the “known model”), agents’ decisions are modelled as the result of some suitably induced optimization problem.<sup>2</sup>

In contrast, when our attention turns towards agents who can only be boundedly rational, no behavioral rule on their part seems to arise in any obvious fashion. Is there, however, any hope of enriching the model so that this ambiguity might be settled endogenously? Evolutionary Theory has explored one such possibility. Specifically, it has proposed studying the endogenous rise of behavioral rules within a population context, any pre-existing range of alternative candidate rules undergoing a selection process which sieves them out in the long run. Here, of course, “selection among rules” is to be conceived as channelled through the agents themselves, those that rely on successful ones coming to dominate the population through a higher “survival” potential. As we shall explain, even when this question is addressed in a basic (non-strategic) context, a sharp conclusion arises: imitation-based rules uniquely fare best on average, at least when one considers long time horizons and the possibility of variable environments.

To clarify this question will be our first task in what follows. Then, with the motivation it avails in hand, our next objective will be to put the corresponding “imitation paradigm” to work in the context of simple market environments. Naturally, we shall start with one of the simplest such setups that can be possibly considered: a Cournot market for an homogeneous good, where a pre-specified number of

<sup>2</sup>Of course, in strategic scenarios, the optimization problem faced by each player is not independent of those confronted by others. This raises difficult theoretical questions that cannot be minimized. However, the important question remains that, in the traditional approach, behavior must always be conceived as the outcome of some suitably defined optimization problem, coherent with the underlying (commonly known) features of the model.

identical firms compete “in quantities” and the production technology exhibits non-increasing returns. In this context, with firms’ behavior simply modelled through a dynamic process that reflects both imitation and occasional (“experimental”) noise, the following clear-cut prediction obtains: in the long run, the market will be, almost always, at a competitive (i.e. Walrasian) state.

How robust is this result to the consideration of less stylized market environments? Much needs to be done in this respect, but a few reassuring answers can already be put forward. Specifically, similar (competitive-like) predictions are found to prevail as well in the long run even when the production technology displays increasing returns, firms are not identical, or the number of firms may change over time as the result of entry and exit.

Of course, the conclusions just outlined lie in stark contrast with the customary analysis of oligopolistic competition derived from classical (full-rationality) strategic models of market interaction. In this literature, Nash equilibrium reigns supreme, inducing predictions that display substantial deviations from competitive behavior when the number of agents involved is relatively low. In aiming to shed some light on this conflict between classical and evolutionary models, we need to resort to the empirical evidence available on these matters and “let the facts speak”. Unfortunately, facts rarely provide fully non-controversial answers. However, in the present case, I shall explain that there is a variety of evidence suggesting that, by and large, the conclusions derived from the evolutionary approach outlined above are in better accordance with the facts than the classical paradigm.

In this respect, my discussion will be organized at two levels. First, I shall focus on recent experimental evidence concerning Cournot-like markets, arguing that it represents a suitable basis for understanding the (much more complex) market environments encountered in the real world. Then, I shall turn to the large number of empirical (field) studies that have explored the relationship between market structure (e.g. concentration) and performance (profitability) across different industries. This issue represents a natural “test case” for comparing the classical and evolutionary approaches since their corresponding predictions differ so drastically.

As advanced, in both setups (experiments and field studies), we shall find good reasons to support the market predictions derived from

evolutionary analysis. This will lead me to conclude the paper with a rather positive outlook on the potential of Evolutionary Theory as a promising complement, if not alternative, to the traditional full-rationality paradigm that pervades most of present economic analysis.

## 2. The imitation paradigm

First of all, I address the preliminary but important issue of what should be conceived as reasonable behavior on the part of boundedly rational agents. Of course, this must depend on the particular scenario they face as well as on how this scenario is matched by their “information-processing abilities”.

Adopting a rather stringent view on these matters, we shall focus on a context where:

- 1) Agents possess *no* global information on the environment.
- 2) The “local” information enjoyed by each of them consists of the following two items:
  - (a) his own action and payoff;
  - (b) the payoff and action of some other agent, randomly sampled among the rest of the population.

- 3) Agents display short memory.

The three rather extreme postulates reflected by (1)-(3) above should be conceived as a *metaphorical* description of an environment whose complexity vastly overwhelms the capabilities of agents. As argued above, markets in the real world are clear instances of such kind of environments. Of course, this is not to say that the simple market contexts that we (“boundedly-rational researchers”) are forced to contemplate in our models can be reasonably qualified as “overwhelming”. For, naturally, the main purpose of any theoretical model is just to provide a scaled-down version of reality that reflects its essential features. And for our present purposes (i.e. modelling bounded rationality in markets), the crucial aspect we certainly do not want to miss is the sharp *asymmetry* between the complexity of the environment and agents’ capabilities (*not* ours) in processing it.

Under the conditions specified in (1)-(3) above, agents could follow a variety of alternative behavioral rules. By way of illustration, let me heuristically describe three of them:

- “*Imitate if better*”, i.e. adopt the action of the sampled individual if, and only if, his payoff is higher than one’s own.
- “*Never switch*”, i.e. always stay with the former action.
- Switch to the action of the sampled individual with probability  $1/2$  (independently of payoffs); otherwise, choose any other possible action with uniform probability.

As advanced, in order to select among the wide range of possible rules consistent with (1)-(3), we shall rely on evolutionary arguments. Specifically, we shall require from any prevailing rule that it should perform well in a sufficiently wide range of different environments. The idea here is that, even though the agents will typically face a variety of different environments over time, behavioral rules cannot be tailored to the particular one at hand (i.e. they cannot be meta-rules). Therefore, any chosen rule should be sufficiently versatile (or robust) to work well under a rather diverse set of alternative circumstances.

As it turns out, such a robustness criterion already provides quite significant cutting power when circumscribed to operate on a relatively narrow subset of decision environments. Specifically, it is enough to consider those basic (i.e. non-strategic) decision contexts where a population confronts a repeated sequence of two-armed bandit problems against nature. This is the setup studied by Björnerstedt & Schlag (1996) (henceforth BS) that is now summarized.

Following the lead of previous work by Schlag (1998), Björnerstedt and Schlag study the following scenario. There is an infinite population repeatedly facing a particular two-armed bandit problem (cf. Rotschild (1974)) in a certain family  $\mathcal{G}$ . Bandit problems in  $\mathcal{G}$  involve the choice of one of two possible decisions (“arms”), 1 and 2, each of them producing stochastic real payoffs with respective densities  $P_1$  and  $P_2$ , support on some bounded interval  $[a, b]$ , and expected values  $\zeta_1$  and  $\zeta_2$ .

Every individual is to choose one of the two arms without knowing the particular problem in  $\mathcal{G}$  actually confronted. Initially, suppose that the population adopts each of the two actions, 1 and 2, with respective frequencies  $y^o$  and  $1 - y^o$ . Before having to choose an action afresh, every player is taken to receive an independent sample draw of the action formerly adopted (together with the payoff received) by some other individual randomly selected within the population. On

the basis of this information and the recollection of what was his own former action and payoff, the player is postulated to choose the new action through some *revision rule*<sup>3</sup>

$$X : (\{1, 2\} \times [a, b])^2 \rightarrow \Delta(\{1, 2\}).$$

Here, the interpretation is that  $X_k(i, r, j, s) \in [0, 1]$  stands for the probability that the agent will choose action  $k$  when his prior choice was  $i$ , his prior payoff  $r$ , the sampled action  $j$ , and the sampled payoff  $s$ .

The first question addressed by BS may be posed as follows. Suppose that the whole population were to adopt a *common* revision rule  $X \equiv (X_1, X_2)$ : Will this rule guarantee that, given *any* decision problem  $G \in \mathcal{G}$  (with  $\zeta_1 \neq \zeta_2$ ) and any arbitrary initial conditions  $y^o$  (with  $0 < y^o < 1$ ), the average payoff of the population increases over time? If the answer is in the affirmative,  $X$  is said to belong to the class of *strictly improving rules*, a set that BS characterize as follows.

**THEOREM 1** *A revision rule is strictly improving if, and only if, it satisfies:*

- a) *It is imitating, i.e.  $\forall i, j \in \{1, 2\}, X_k(i, \cdot, j, \cdot) = 0$  if  $k \notin \{i, j\}$ .*
- b) *There exists some  $\sigma > 0$  such that, for all  $r, s \in [a, b]$ ,  $X_2(1, r, 2, s) - X_1(2, s, 1, r) = \sigma(s - r)$ .*

The above two features characterizing strictly improving revision rules reflect quite intuitive ideas. First, (a) indicates that any given action may be chosen only if it is the original status quo *or* the action adopted by the sampled agent. It is in this sense that we speak of the corresponding rule as being based on imitation. On the other hand, (b) specifies a very specific form for the revision rule: *net* switching probabilities must be *linear* in the payoff gap between the observed and status-quo payoffs. Note, for example, that this formulation is incompatible with ultra-sensitive revision rules such as “imitate if better”, described above. The intuition here is that this latter rule is strictly ordinal, i.e. it only depends on the ranking between actions

<sup>3</sup>This formulation implicitly assumes that every agent has always some prior experience that acts as his status quo and could possibly introduce some bias (positive or negative) in his decision. However, no such status quo would exist if, for example, one allowed for the existence of some newcomers (called “mutants” below) lacking any previous experience. To address this case, one simply needs to enlarge the notion of revision rule by contemplating the possibility of an “empty” status quo (cf BS).

associated to whether a higher or lower payoff is attained. Thus, since it cannot be responsive to the cardinal considerations that underlie *expected* payoff maximization (a “cardinal” optimization problem), it will fail to be strictly improving in some cases.

The above clear-cut characterization of strictly improving rules is certainly interesting. However, our chief aim here is not the normative one of identifying what behavioral rules might be beneficial (on average) for the population as a whole. Instead, we are interested in the positive objective of singling out those rules that may be judged as evolutionary robust over the *whole class* of problems in  $\mathcal{G}$ .

What notion of evolutionary robustness should we consider in addressing this issue? Certainly, a minimal one is that reflected by the concept of *neutral (evolutionary) stability*. Heuristically, a certain rule  $X$  is said to be neutrally stable if, once adopted by the whole population, there is *no* small fraction of “mutants” (adopting an alternative rule  $X'$ ) that, for some  $G \in \mathcal{G}$  and initial conditions  $y^0$ , may *significantly* affect the original dominance held by  $X$  (much less, of course, that could bring it to “extinction”).<sup>4</sup>

Naturally, the possible extinction (i.e. non-survival) of any given rule must be linked to whether it is able to earn an average payoff at least as large as that of some invading mutant rule. But, in order for this issue to be rigorously addressed, one must formulate an explicitly dynamic framework that permits a clear evaluation of long-run behavior and performance. This is the approach undertaken by BS, where a dynamic system is postulated that advances, in parallel, along the following two dimensions. On the one hand, it produces adjustments on the frequencies of both agent types (mutant and not), as induced by relative payoffs. On the other hand, the agents of each type revise their actions, as determined by their respective rules. Within such a dynamical framework, the following result is established:

**THEOREM 2** *A revision rule  $X(\cdot)$  is neutrally stable in  $\mathcal{G}$  if, and only if, it is strictly improving, i.e. satisfies (a)-(b) above.*

The intuition underlying this result is easy to apprehend. On the one

<sup>4</sup>Neutral stability is to be contrasted with the more demanding notion of (strict) evolutionary stability. This alternative concept requires that any mutant rule  $X'$  adopted by a small fraction of individuals be forced to extinction by  $X$ , thus leading to a restoration of the full dominance originally held by  $X$  over the whole population (see e.g. Vega-Redondo (1996)).

hand, if any given rule  $X$  is strictly improving, it will eventually be able to learn the best action (i.e. the arm yielding the highest expected payoff) and become absorbed by it in the long run. Thus, no matter what the initial action frequencies are among the  $X$ -population, if any threatening mutant rule invades in small frequency, it will not be able to drive the rule  $X$  to extinction before it has essentially completed its learning process. When this happens, almost all agents with the  $X$  rule are choosing the right action and will be able to resist the invasion.

The foregoing discussion provides some intuition for the sufficiency part of Theorem 2. Concerning its necessity statement, a similar line of argument suggests that if a certain rule  $X$  is not strictly improving (and therefore cannot be *ensured* to learn the right action in every case), there must be some problem  $G$  and initial conditions  $y^o$  which make it possible for some mutant rule (e.g. the stubborn one which always plays the best arm in  $G$ ) to gain a significant foothold in the population.

Theorem 2 has the following implication. Consider a population of boundedly rational agents whose revision rules satisfy (1)-(3). Furthermore, suppose that these rules are applied in a *sufficiently rich* set of environments that include, among possibly many others, *all* bilateral two-armed bandit problems. Then, the only rules that may be neutrally stable are the “linear” and “imitative” ones that verify (a) and (b).

The preceding conclusion suggests that, among boundedly-rational agents who are subject to (1)-(3) and face a wide enough universe of decision contexts, we should expect to find revision rules that are both imitative and strictly improving. In turn, this provides an “endogenous” rationale for studying models of bounded rationality that are built on the imitation paradigm. As advanced, models of market behavior with these characteristics will be our chief concern in the following section.

### 3. Market dynamics: theory

#### 3.1 Basic model

Consider a market for an homogenous good consisting of a set of firms,  $N = \{1, 2, \dots, n\}$ , that confront a given (inverse) demand function  $P : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ , assumed decreasing (i.e. the so-called Law of Demand

is satisfied). For each aggregate quantity  $Q$  sold in the market, this function specifies the corresponding market clearing price  $P(Q)$ .

Firms display identical cost conditions, with  $C(q_i)$  standing for the cost of producing the quantity  $q_i$  by firm  $i$ . For technical reasons, it is postulated that firms' outputs must belong to a finite grid  $\Gamma = \{0, \delta, 2\delta, \dots, v\delta\}$ , where both  $\delta \in \mathbb{R}_+$  and  $v \in \mathbb{N}$  are arbitrary. The Walrasian (symmetric) quantity  $q^*$  satisfying:

$$P(nq^*)q^* - C(q^*) \geq P(nq^*)q - C(q), \quad \forall q \geq 0 \quad [1]$$

is assumed both to exist (uniquely)<sup>5</sup> and to be part of the grid  $\Gamma$ .

In this context, we shall study the following imitation-based learning dynamics. Time is indexed discretely,  $t = 1, 2, \dots$ . The state of the system is identified with the output profile  $\omega(t) \equiv (q_1(t), q_2(t), \dots, q_n(t))$  specifying the production decision adopted at any  $t$  by each firm  $i = 1, 2, \dots, n$ . Such an output profile induces the corresponding profile of profits  $\pi(t) \equiv (\pi_1(t), \pi_2(t), \dots, \pi_n(t))$  where

$$\pi_i(t) \equiv \pi_i(\omega(t)) \equiv P\left(\sum_{j=1}^n q_j(t)\right) q_i(t) - C(q_i(t)).$$

In line with the framework outlined in Section 2, it is assumed that, at the end of every period, firms are randomly matched in pairs a certain number of times, every pair of matched firms observing the output and profit prevailing for both of them in that period. Let  $(q, \pi)$  and  $(q', \pi')$  denote the output-profit pairs associated to the two firms involved in one such encounter. It is postulated that, provided some other (irreversible) revision has not been already adopted in some prior matching, the firm originally choosing  $q$  will imitate  $q'$  with probabilities given by functions  $X_{q'}(q, \pi, q', \pi')$  satisfying a multi-action analogue of conditions (a)-(b) of Theorem 1.

Here, it is natural to specialize the previous formulation by postulating that, for each pair of matched firms, there is *no* positive probability that both of them may switch *simultaneously* (thus simply leading to a permuted output pair). This implies that the analogue of (b) above should be reformulated as follows:

( $\beta$ ) There exists some  $\sigma > 0$  such that, for all  $q, q', \pi, \pi' \in \mathbb{R}$ ,

$$(\beta.1) \quad \pi' \geq \pi \Rightarrow X_{q'}(q, \pi, q', \pi') = \sigma(\pi' - \pi);$$

<sup>5</sup>It is easy to check that if the symmetric Walrasian quantity exists, it is unique.

$$(\beta.2) \quad \pi' < \pi \Rightarrow X_{q'}(q, \pi, q', \pi') = 0.$$

Naturally, we need that

$$\sigma \leq \left( \max_{i,j \in N, \omega \in \Gamma^n} |\pi_i(\omega) - \pi_j(\omega)| \right)^{-1}$$

where it will be assumed that the above inequality is strict, i.e. the switching probability is always less than one.

Furthermore, as a counterpart of (a) in Theorem 1, we postulate that the revision rule is imitating, i.e.

$$(\alpha) \quad \forall q, q' \in \Gamma, X_{q''}(q, \cdot, q', \cdot) = 0 \text{ if } q'' \notin \{q, q'\}.$$

The first task is to characterize the long-run dynamics induced by  $(\alpha)$ - $(\beta)$ . To facilitate our discussion, it will be convenient to make the following two simplifications:<sup>6</sup>

1. There are no heterogenous profiles in  $\Gamma^n$  where firms producing different outputs obtain identical profits.
2. There are several (at least  $n - 1$ ) independent matching/revision rounds between consecutive times of play. At each of these rounds, a firm may irreversibly decide to revise the output to be produced in the following period

Under these simplifying conditions, it is clear that the limit sets of the imitation dynamics must consist of the singletons  $\{\omega_q\}$  with  $\omega_q = (q, q, \dots, q)$ , i.e. “monomorphic” profiles where every firm chooses a common output. Here, the basic idea is that, at any heterogenous state, there is positive probability that one of the firms that currently achieves the highest profit will be matched to every other firm with a lower profit, thus leading each of the latter to imitate the former’s output. Of course, this will eventually lead (with probability one) to a monomorphic profile, which is stationary under any revision rule that qualifies as “imitating” (cf.  $(\alpha)$ ).

Since any monomorphic profile is absorbing under  $(\alpha)$ - $(\beta)$ , the imitation dynamics alone leads to a large multiplicity of possible long-run predictions, partly dependent on initial conditions. To remedy this wide indeterminacy, the customary approach in modern Evolutionary

<sup>6</sup>They are inessential to the analysis and may be largely dispensed with, at the cost of complicating the arguments substantially.

Theory is to introduce some small (but perpetual) noise into the model. Heuristically, we may conceive such a noise as the analogue of mutation in biological setups. In a more economic vein, it may be interpreted as either a “tremble” or the outcome of conscious experimentation. More precisely, what is postulated is that with some small and independent probability  $\varepsilon > 0$ , each firm adjusts its output marginally, upwards or downwards with, say, equal conditional probability.

Obviously, this “local perturbation” of the imitation dynamics has the potential of having the system visit *any* output profile in the state space. Or, at a more technical level, it makes the resulting stochastic process ergodic. This has the important consequence of rendering its long-run performance independent of initial conditions. That is, any possible influence of initial conditions will tend to vanish in the long run, as the system is eventually forced to visit any region of the state space independently of where it started.

Formally, this idea is captured by the fact that, for each  $\varepsilon > 0$ , the process induces a *unique* invariant distribution  $\mu_\varepsilon \in \Delta(\Gamma^n)$ , a probability measure on the state space  $\Gamma^n$ . This distribution summarizes the long-run behavior of the system in the following sense: almost surely (i.e. with prior probability one), any sample path of the process will visit each state  $\omega \in \Gamma^n$  with empirical frequencies that (in the long-run, independently of initial conditions) match the weight  $\mu_\varepsilon(\omega)$  of this state in the invariant distribution.

Naturally, we want to think of  $\varepsilon$  as small, in consonance with the idea that the associated noise indeed plays the role of a genuine perturbation of the model, i.e. it is *not* a driving force of the process. A precise way of capturing this idea is to focus on the limit distribution

$$\tilde{\mu} \equiv \lim_{\varepsilon \rightarrow 0} \mu_\varepsilon,$$

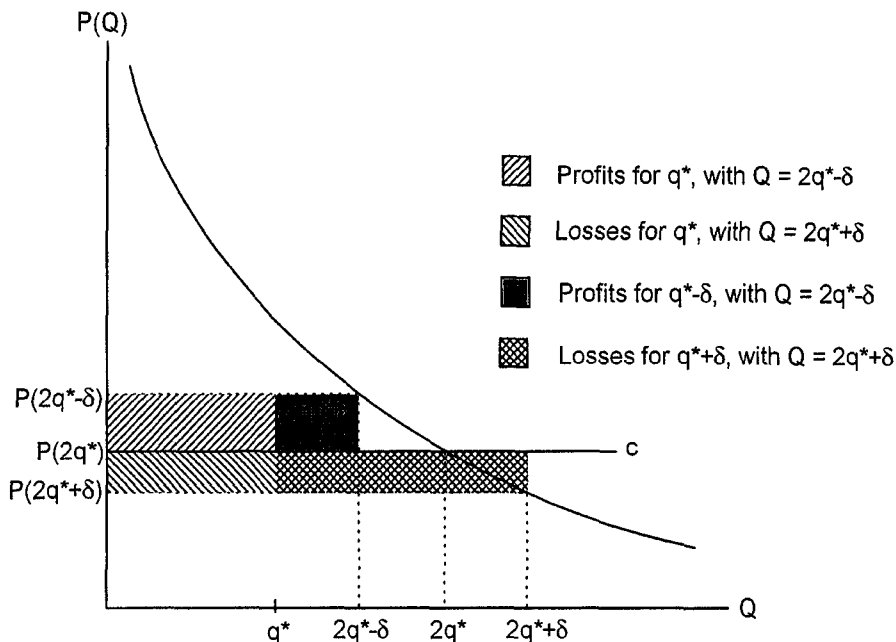
i.e., what could be labelled as the invariant distribution of the process for infinitesimal (albeit positive) noise.

For such infinitesimal noise, Vega-Redondo (1997) shows that the process spends “most of the time” in the Walrasian state  $\omega_{q^*}$  (cf. (1)). Formally:

**THEOREM 3** *For any  $\varepsilon > 0$ , the market-learning process described displays a unique invariant distribution  $\mu_\varepsilon \in \Delta(\Gamma^n)$ . Furthermore,  $\lim_{\varepsilon \rightarrow 0} \mu_\varepsilon(\omega_{q^*}) = \tilde{\mu}(\omega_{q^*}) = 1$ , where  $\omega_{q^*} = (q^*, q^*, \dots, q^*)$ .*

The intuition for this conclusion is illustrated for the simple case of a duopoly with constant marginal costs in Figure 1.

FIGURE 1  
Relative profits around a Walrasian equilibrium  
in a duopoly with constant marginal costs



Suppose that the market were in a Walrasian state  $(q^*, q^*)$ . If just one firm (say firm 1) experiments at this state, either the state  $(q^* - \delta, q^*)$  or  $(q^* + \delta, q^*)$  results. In each of these two cases, it is clear from Figure 1 that the firm producing an output different from  $q^*$  is the one that obtains the lowest profit of the two (either the lowest positive profit if it produces  $q^* - \delta$ , or the largest losses if it produces  $q^* + \delta$ ). Thus, if no further experimentation occurs for a long enough stretch of time, the original state  $(q^*, q^*)$  will be restored through imitation.

This indicates that the Walrasian state is stable in the presence of one firm alone experimenting with a different output. Of course, the same argument can be applied to conclude that each of the two states  $(q^* + \delta, q^* + \delta)$  or  $(q^* - \delta, q^* - \delta)$  neighboring the Walrasian state can be de-stabilized through a *single* experimentation towards the Walrasian output. Overall, this indicates that when the probability of experimentation is rather low, the system should spend most of the time in the Walrasian state, at least if attention is restricted to a small

enough vicinity of it. But even if we approach matters globally, it can be shown that a suitable elaboration of the previous argument leads to the following conclusion.

Consider any monomorphic state  $(q, q)$  with  $q \neq q^*$ . Then,

- i) if  $q > q^*$  (or  $q < q^*$ ), the state  $(q - \delta, q - \delta)$  (correspondingly, the state  $(q + \delta, q + \delta)$ ) can be reached after just *one* firm experimenting with the output  $q - \delta$  (respectively,  $q + \delta$ );
- ii) if  $q > q^*$  (or  $q < q^*$ ), the state  $(q + \delta, q + \delta)$  (correspondingly, the state  $(q - \delta, q - \delta)$ ) can only be reached if the *two* firms experiment.

The former assertions indicate that, even when the system is far from the Walrasian state, there is an inherent bias towards this state as opposed to the converse direction of change. That is, a “move” approaching the Walrasian state is much more likely (requires just one firm experimenting) than a move away from it (which requires the much more improbable event, for  $\varepsilon$  small, where the two firms experiment). In the end, this asymmetry has the dynamics gravitate towards  $\omega_{q^*}$ , the system expected to be found at this state in the long run with arbitrarily high probability (for  $\varepsilon$  small enough).

Theorem 3 indicates that a simple model of market dynamics based on imitation and occasional experimentation provides a clear-cut foundation for competitive behavior. It is important to emphasize that, unlike what is a customary rationale in this respect, there is no need here to resort to any (implicit or explicit) assumption that a rather large number of firms are involved in the market. Instead, the argument is solely dependent on the tenet that the environment is (or is perceived as being) so complex that firms are led to imitative rules of behavior.

So far, the model described is extremely simple and stylized. In particular, there are three features of it which seem to call for some generalization:

1. Firms should be allowed to differ in their underlying characteristics (e.g. cost conditions).
2. The technological scenario should be extended to the consideration of increasing returns.
3. Market dynamics should contemplate the possibility of entry and exit, linked to performance.

Each of these routes of generalization is briefly discussed in the following Subsection.

### 3.2 Generalizations

Of course, the imitation paradigm only represents a reasonable basis for modelling behavior if agents perceive themselves as essentially identical and, therefore, involved in a genuinely symmetric context. Otherwise, differences in performance could well be attributed to significant differences in underlying characteristics, thus providing no clear indication for revising behavior.

If one deals with asymmetric scenarios, the most straightforward generalization of the imitation paradigm is to have revision behavior (*not* interaction) segmented along the prevailing differences in agents' characteristics. Specifically, in the market environment considered here, this amounts to postulating that firms displaying different cost characteristics (their only source of asymmetry) recognize each other as such and tailor any revision of behavior to the experience they receive from meeting one of their own type.

A model with these characteristics has been recently studied by Tanaka (1997). This author studies a market for an homogeneous good where firms display convex costs and confront a decreasing demand function. There are two types of firms: high-cost and low-cost, each of these associated to a different factor scaling their cost function. Imitation is conducted within each group along the lines described above, every firm experimenting as well with small independent probability.

Despite their very stylized form, such inter-firm asymmetries turn out to complicate the analysis quite substantially. However, Tanaka is able to show that the gist of Theorem 3 extends naturally to this context,<sup>7</sup> i.e. the unique long-run state of the process involves the dimorphic profile where firms play the unique symmetric (type-dependent) Walrasian output.

As will be recalled, Theorem 3 is established under the assumption that a Walrasian equilibrium exists (cf. (1)). Of course, this rules out the possibility that the production technology may exhibit increasing returns throughout. How are matters affected if the production technology displays *uniformly* increasing returns (i.e. decreasing marginal costs)? Alós *et al.* (1997) address this question, exploring as well the implications of allowing for population dynamics (i.e. firm entry and exit) in the market.

<sup>7</sup>The numbers of high- and low-cost firms are required not to differ too much, with the bounds in this respect determined by the corresponding cost differences

Very succinctly, their conclusions are as follows:

1) If the technology exhibits increasing returns throughout *and* the number of firms participating in the market remains fixed, the unique long-run state of the process has *all* (identical) firms producing at the level where marginal cost equals the market-clearing price. In this sense, even though Walrasian equilibrium does not exist under increasing returns, one obtains its natural counterpart where price equals marginal cost for all firms.

2) Concerning population dynamics, the natural assumption that adjustment by “outsiders” (i.e. entry) is significantly less frequent than that performed by incumbents (i.e. imitation, experimentation, and exit) leads to the following contrast:

- a) If production returns are decreasing, the unique long-run state has the market being at Walrasian equilibrium and “full capacity”, i.e. with the maximum number of firms that a competitive market can accommodate at no loss.<sup>8</sup>
- b) If production returns are uniformly increasing, the unique long-run state has a single firm adopting the monopoly output.

The former results underscore the essential insight arising from Vega-Redondo (1997), i.e. boundedly rational (imitating) behavior is a strong force leading market outcomes towards competitive behavior. Specifically, if technological conditions permit (e.g. if returns are uniformly decreasing), the introduction of population dynamics has the standard effect of ensuring that the population of firms in the market reaches its long-run competitive level with zero profits. Instead, if Walrasian behavior is not compatible with the underlying technological setup (returns are uniformly increasing), a “natural monopoly” is attained in the long run with a single firm fully exploiting the market. Somewhat paradoxically, such a monopoly situation is obtained through a chain of intermediate stages where former incumbent firms have been forced out of the market by a series of “competitive” (i.e. marginal cost pricing) outcomes.

These conclusions reflect a sharp (“knife-edged”) effect of technology on market structure that is essentially absent from the received Theory

<sup>8</sup>Of course, some *positive* fixed cost is assumed, so that the maximum number of firms that the market can admit is guaranteed to be finite

of Industrial Organization. In this literature (see, for example, the classical work by Novshek (1980)), the influence of technological conditions on the market outcome (in particular, on market structure) only arises as a much more gradual phenomenon.

Unfortunately, there is not much empirical evidence we can turn to in order to shed some light on these contrasting predictions. Instead, there is quite a substantial body of empirical work that, abstracting from the very long-run considerations involving population dynamics, has explored the relationship between market structure and competitive performance. In particular, this literature should allow us to clarify the following issue: Is competitive behavior such a robust and widespread phenomenon as the model described in Subsection 3.1 would suggest?

This question will be addressed in the following Section at two complementary levels. First, we shall focus on the experimental evidence on Cournot competition that has been obtained within laboratory setups. Second, we shall turn our attention to the wide variety of industry studies conducted across different countries in the last few years.

## 4. Market dynamics: facts

### 4.1 *Experimental evidence*

Despite the central role played by the Cournot model as the canonical approach to oligopolistic competition, it is surprising that there are only few instances where it has been carefully studied in laboratory experiments (cf. Holt (1995), Davis (1995), Rassenti *et al.* (1996) or Offerman *et al.* (1998)). Here, I shall focus on recent experimental work by Huck *et al.* (1997), whose approach best addresses our present concerns.

As in most laboratory-controlled setups, the scenario studied by Huck *et al.* is particularly simple. It involves just four given subjects (“firms”) that display constant marginal costs, confront a (truncated) linear demand function, and are repeatedly set to play under unchanged conditions. Of course, this context is substantially simpler than real-world market environments. However, the reason why it may be judged as a useful scaled-down version of them is two-fold:

- 1) On the one hand, we may view the relatively unsophisticated behavior exhibited by mostly inexperienced subjects in such a experimental

context as a convenient “reproduction” of an analogous asymmetry (i.e. *relative* unsophistication) displayed by experienced firms when facing complex (real-world) market environments.

2) Moreover, even if the aforementioned asymmetry were not genuinely applicable to such experimental setups under “base conditions”, one can impose it exogenously by suitably modulating the availability of information enjoyed by the agents.

As suggested by (2), Huck *et al.* (1997) study five alternative scenarios (or treatments) in their experiments.

In two of them (labelled BEST and FULL), subjects are completely informed of market and cost conditions. Moreover, after every round, each of them is communicated what were the previous market price, *aggregate* quantity, and *own* profits (in BEST) or, additionally (in FULL), the *complete* array of individual quantities previously chosen by all of them.

Two other treatments (labelled NOIN and IMIT) provided subjects much less information. In NOIN, they knew virtually nothing but their *own* past profits. Instead, in IMIT, they were informed every round of what had been the previous *array* of individual profits earned by all of them. In either case, subjects were *not* aware of market or cost conditions, and even ignored whether the underlying circumstances remained unchanged throughout.

Finally, the treatment IMIT+ was as IMIT above, except that in it subjects were informed of some essential *qualitative* features of their environment. Specifically, they knew that the scenario would remain constant throughout each treatment and that *all* firms would face exactly symmetric (cost and demand) conditions.

Not surprisingly, the experimental evidence varied quite significantly across different treatments. All of them involved a series of 40 consecutive rounds. In BEST and FULL, subjects eventually approximated<sup>9</sup> total quantities that exceeded the Cournot outcome but were nevertheless substantially lower than competitive (i.e. Walrasian) magnitudes – more so in BEST than in FULL. In both cases, standard deviations were around 10% of average quantities. This evidence stands in rough accord with the intuitive and customary understanding of the Cournot

<sup>9</sup> All our statements here pertain to averages and standard deviations associated to the last twenty rounds of each treatment, when subjects may be reasonably conceived as having partially “learned” about the environment.

model, despite some upwards systematic deviation of its Nash equilibrium.

On the other hand, treatments NOIN and IMIT displayed much larger total quantities: in NOIN, slightly below the competitive level; in IMIT, nearly 50% larger than it. However, the standard deviations in each case were quite significant: around 25% in NOIN, nearly 30% in IMIT. As the authors explain, it appeared that in this case (mostly in the latter treatment) subjects experienced substantial “problems understanding the situation as they made losses in almost all periods.”

Motivated by such seeming lack of understanding on the part of subjects, IMIT+ was conceived as an alternative imitation-inducing treatment where subjects are enriched with essential qualitative information on the environment (recall above). Indeed, subjects turn out to use this additional information effectively since, compared to IMIT, both total quantities as well as their standard deviations fall drastically in IMIT+.

Specifically, Huck *et al.* (1997) find that in treatment IMIT+ subjects approximate the Walrasian outcome quite closely: average quantities remain within less than 3% of their competitive levels. On the other hand, standard deviations lie around 15% of these quantities. Even though these deviations stay moderately significant, they are substantially lower than in the treatments IMIT or NOIN (see above).

Overall, the evidence reported for the latter treatment seems to provide a good empirical basis for the theoretical predictions derived from the model of Subsection 3.1. This model is formulated implicitly under the following twin postulates:

†) Agents’ environment is very complex relative to their own capabilities of understanding it. Consequently, the only information on the state of the system which agents may *usefully* resort to consists of what all of them previously did and earned.

‡) Agents are aware to live within a largely symmetric environment. Therefore, the information of what others did and earned in the past is indeed reasonably indicative of what each of them may expect if imitating their behavior.

Postulate (†) is imposed by the experimental design of treatments IMIT and IMIT+, where the information available to agents is restricted in the way required. On the other hand, Postulate (‡) is reflected

as well by the design of the second (enriched) treatment IMIT+, since agents in it are explicitly informed of the perfect symmetry of the situation. The discussion carried out in Section 2 on the foundations of the “Imitation Paradigm” suggests that, under such conditions, agents should be expected to base their adjustment on the imitation of successful behavior. This is precisely the behavioral paradigm embodied by the theoretical model presented in Subsection 3.1. Thus, since the theoretical and experimental contexts display such underlying parallels, it is reassuring to find that, as explained, theoretical predictions and experimental evidence are also largely consistent.

#### 4.2 Field evidence

One of the most widespread (“folk”) ideas pervading the traditional Theory of Industrial Organization is that “market concentration hampers competition”. Indeed, such a tenet can be provided with precise and formal content within the customary model of Cournot competition in a variety of alternative ways. For example, it can be shown (see Encaoua and Jacquemin (1980)) that, in any Cournot equilibrium  $(\hat{q}_1, \hat{q}_2, \dots, \hat{q}_n)$ , the average deviation of marginal cost from the market-clearing price (the so-called *Lerner Index*):

$$\mathfrak{L}(\hat{q}_1, \hat{q}_2, \dots, \hat{q}_n) \equiv \sum_{i=1}^n \hat{\alpha}_i \frac{P(\hat{Q}) - C'_i(\hat{q}_i)}{P(\hat{Q})}$$

is proportional to the *Herfindahl Concentration Index*:

$$H(\hat{\alpha}) \equiv \sum_{i=1}^n (\hat{\alpha}_i)^2,$$

where  $\hat{Q} \equiv \sum_{j=1}^n \hat{q}_j$ ,  $C'_i(\hat{q}_i)$  denotes the marginal cost of firm  $i$  and  $\hat{\alpha}_i \equiv \frac{\hat{q}_i}{\hat{Q}}$  stands for its market share.<sup>10</sup>

Despite such clear-cut theoretical foundation for the effect of concentration on (the lack of) competition, recent field studies of inter-industry performance provide no solid empirical basis for it. Admittedly, when Bain (1951) first addressed this question in a systematic

<sup>10</sup>Similar conclusions obtain if firms have prices as their strategic variables but they are involved in a two-stage game where they first have to decide on capacities. For, in that case, Kreps and Scheinkman (1983) have shown that subgame perfect equilibria yield Cournot outcomes

manner (using field data on leading U.S. firms for the 1936-40 period), he did find some support for the “natural idea” that concentration facilitates collusion. However, since then, the large number of empirical studies that have investigated the issue through more extensive and elaborate studies have come to a quite different view. In fact, as explained by Schmalensee (1989) in his Handbook contribution (see also Geroski (1981)), the large body of recent evidence on these matters can be summarized as follows (Schmalensee’s (1989, p. 976) *stylized fact* 4.5):

“The relation, if any, between seller concentration and profitability is weak statistically and the estimated concentration effect is usually small. The estimated relation is unstable over time and space and vanishes in many multivariate studies.”

This empirical regularity can be interpreted as providing some support for one of the main points stressed by the model discussed in Section 3, namely, that strategic considerations (in the classical game-theoretic sense) may be of only subsidiary importance in shaping firm behavior within (complex) market environments.

The former crucial point notwithstanding, it is evident that firms do differ quite significantly in their profit rates. In particular, if one surveys firm performance across different industries, a significant correlation is found between profitability and market share (cf. Weiss (1974)). How can this be reconciled with the above *stylized fact* (i.e. the *lack* of strong correlation between concentration and profitability)? In a rather sharp change of focus, this may be done by invoking the so-called *Demsetz’s Hypothesis*.

In a very influential paper, Demsetz (1973) criticized the intense efforts displayed by “[q]uantitative work in Industrial Organization ... [towards] the task of searching for monopoly...” In his view, this represented “...a dangerous base upon which to build a public policy towards business.” Rather than attributing most of the extraordinary profits earned by firms in many industries to the exploitation of monopoly power, Demsetz proposed that much of it had to be understood instead as the result of idiosyncratic efficiency advantages. Naturally, he argued, one must expect efficient firms to enjoy a large market share and relatively high profits. In general, therefore, high profits should

not be understood as the outcome of a privileged position of market dominance.

To discriminate between the two alternative lines of causation, Demsetz (1973) himself and subsequently many others set out to conduct empirical studies where *both* concentration and market share (or firm size) were simultaneous candidate variables competing for explanatory power. A summary of this line of research has been condensed by Schmalensee (1989, p. 984) in the following *stylized fact*:<sup>11</sup>

“In samples of U.S. firms or business units that include many industries, market share is strongly correlated with profitability; the coefficient of concentration is generally negative or insignificant in regressions including market share.”

The above stylized fact reinforces the idea that concentration *per se* (i.e. classical strategic considerations) should *not* be conceived as the key aspect underlying differential profits. Rather, as Demsetz suggested, the important role played by firms’ market shares in explaining differential profit performance indicates that inter-firm asymmetries in production efficiency may be a more significant factor in this respect. From an evolutionary perspective, the model proposed by Tanaka (1997) – recall Subsection 3.2 – provides a simple learning-based framework that explains profit heterogeneity along these lines.

## 5. Summary

This paper started out with the premise that most market contexts are very complex environments where agents (in particular, firms) are forced to adopt behavioral rules that are only very boundedly rational (at least, relative to the richness of the scenario). To explore the implications of this tension between the cognitive limitations of agents and the complexity of the environment, our attention first turned to a very stylized setup: a large population of individuals who face a series of independent two-armed bandit problems. We argued that whatever was required for behavioral rules to be “robust” in this basic scenario should carry over to more intricate contexts (in particular, those of a strategic nature).

<sup>11</sup>In fact, as Schmalensee (1989) also indicates, conclusions in this respect are only mixed when the evidence pertains to firms and industries outside the United States

Already in such a simple decision context, we found good theoretical reasons to single out a specific kind of behavior, i.e. the set of *imitative* rules that reflect “gradual” adjustment. For, if one minimally insists that any selected behavioral rule should be evolutionarily stable, it turns out that only this kind of gradual imitative behavior meets the requirement (Theorem 2). That is, only such behavior happens to be robust (i.e. will prevail) in the face of alternative rules that may compete for resources (or attention) within the population at large.

This sharp conclusion was then taken to bear on a model of market interaction among Cournot (quantity-setting) oligopolists. Postulating that firms not only adjust their behavior on the basis of imitative (gradual) rules but also “experiment” occasionally, we concluded that the induced stochastic process spends most of the time in the competitive state, i.e. in the output configuration where every firm produces its Walrasian output (Theorem 3). This basic result implicitly relies on the following stylized assumptions: all firms are *ex ante* identical, their population is kept fixed (i.e. there is no entry or exit), and technological possibilities are convex. However, as it was briefly outlined, all these assumptions can be substantially generalized, the gist of the analysis remaining essentially unaffected. This completed the first part of the paper, whose focus was on “theory”.

Then, the second part moved on to contrast the theoretical insights thus obtained with the “facts”. In this respect, two sources of evidence were considered: laboratory experiments and field inter-industry studies.

Concerning the former, we looked for experimental Cournot setups where the information conditions enjoyed by the subjects had been modulated to approximate those of real-world environments. In particular, we focused on an experimental design where, at each stage, players were informed of the actions and payoffs previously displayed all of them but *not* of the underlying market demand or cost conditions. Under these circumstances, the paths of play materialized in these experiments were reported to match rather well the predictions of our theoretical model. Specifically, when the information conditions of subjects were as indicated, the “market outcome” happened to lie, on average, in the vicinity of the Walrasian state.

To close the paper, our attention turned towards inter-industry studies of market performance, with special emphasis on the issue of whether

or not available evidence reflects the strategic aspects emphasized by the classical approach to oligopoly. In this respect, a particularly suitable test is afforded by an empirical assessment of how important is the effect of market concentration on firm profitability. Contrary to what is a common belief on this question, we explained that existing evidence suggests that it is interfirm differences in productivity, not varying degrees of concentration across different industries, that explain the lion's share of profit differentials. Thus, from this perspective as well, an evolutionary approach to the study of oligopoly appears to receive some further support.

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## Abstract

*En este artículo exploro la cuestión de cómo la racionalidad acotada afecta al funcionamiento de los mercados. Esta tarea se desarrolla a dos niveles complementarios. Primeramente, adopto un enfoque teórico y repaso un conjunto de modelos que sugieren que el comportamiento de las empresas bajo racionalidad acotada habría de basarse en la imitación y, como consecuencia, inducir resultados competitivos. A continuación, discuto la solidez empírica de esta conclusión, resumiendo tanto evidencia experimental como de campo que la apoya.*