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Markets in equilibrium with firms out of equilibrium: A simulation study

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Abstract

We explore the effect of the limited ability to process information on the convergence of firms toward equilibrium. In the context of a Cournot oligopoly with a unique and symmetric Nash equilibrium, firms are modeled as adaptive economic agents through a genetic algorithm. Computational experiments show that while market production is close to equilibrium, firm production is relatively far from the individual equilibrium level. This pattern of firm heterogeneity is not an artifact of random elements built into the decisional process. Instead, it comes from the market interaction of firms with cognitive limitations.

JEL classification: C72; D83; C63

Keywords: Cournot oligopoly; Bounded rationality; Genetic algorithms; Individual heterogeneity

Many experimental studies have documented that when subjects are given identical monetary incentives they often choose different actions. We mention three instances among many. Bossaert and Plott (2000) study financial markets where individual portfolio holdings are predicted to be identical and report persistent individual differences. In the appropriation of a common-pool resource, individual choices are remarkably different one from another. Ostrom et al. (1994) carefully document this pattern. While reviewing voluntary public good contribution experiments, Ledyard (1995) poses as a puzzle the wide heterogeneity of individual contributions.[1]

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[1] See Bossaert and Plott (2000, Fig. 16), Ledyard (1995, pp. 170–173). Other studies have reported a similar pattern; see for instance Palfrey and Prisbrey (1997), Saijo and Nakamura (1995), Casari and Plott (2003, Fig. 5).

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We claim that a powerful source of such individual heterogeneity could be the limited ability of agents to process information. To support this claim, simulation results are presented in a Cournot oligopoly where firms are modeled as adaptive economic agents with limited knowledge of the task and limited memory. These firms experiment with new strategies, and they learn from experience. We implement an evolutionary approach through a genetic algorithm, where firms are identical in their level of bounded rationality and where the equilibrium discovery process has a random element.

The strategic environment adopted is simple and exhibits a unique symmetric equilibrium that makes it hard for firm heterogeneity to persist, yet, simulation results show that boundedly rational although identical firms are heterogeneous in their strategy choice. In order to understand the forces that generate this pattern, an extensive sensitivity analysis was performed in two dimensions: degree of noise and rationality. Contrary to what one might expect, we show that the heterogeneity result is not simply a consequence of the random elements contained in the genetic algorithm. Moreover, with a rise in the memory capabilities and in the ability to evaluate potential strategies, individual differences decline. In the limit case of full rationality, there is a convergence toward the canonical result of uniform individual behavior.

The main goal of the paper is to use genetic algorithm firms to replicate some qualitative features in the experimental literature. In addition, an in-depth analysis of genetic algorithms as economic models is provided.[2] Genetic algorithms have been used in economics as a black box to model boundedly rational agents. This paper goes beyond that by assessing the impact of several key parameters in the model and showing the interplay between random search and degree of rationality. A major point is that for a large class of genetic algorithm firms, the discovery of the market equilibrium is much easier than the discovery of the individual equilibrium strategy.

The paper is organized as follows. The Cournot model and simulations parameters are outlined in Section 1. The decision-making process of the individual-learning genetic algorithm is explained in Section 2. The main result regarding individual heterogeneity is in Section 3, along with the discussion on the random element. In Sections 4 and 5 we explore changes in rationality levels with respect to pre-play evaluation of new strategies and by varying working memory constraints. Conclusions are in Section 6.

1. The Cournot model

The strategic environment is a standard Cournot oligopoly game, $\Gamma(N, (S_i)_{i \in N}, (\pi_i)_{i \in N})$. A firm i produces quantity $x_i \in [0, \lambda]$. All N firms simultaneously choose a production level, and then a market price pr is determined through the clearing of market demand and supply. The inverse demand function is $\text{pr}(X) = d - bX$, where $X = \sum_{i=1}^{N} x_i$ and d, $b > 0$, and the cost function is $c(x_i) = hx_i$, which is linear and identical for all firms. Hence, the profit function is $\pi_i = x_i(d - bX) - hx_i$. Firms face the same incentive structure for T interactions without carry-over from one period to the next.

The Nash equilibrium of the game for profit maximizing firms is $X^* = (1/(N+1))((d - Nh)/b)$ and $\text{pr}^* = (1/(N+1))(d - Nh)$. The game has a continuous strategy space and a unique, symmetric, and evolutionary stable Nash equilibrium. In other words, this game provides ideal conditions to facilitate convergence toward the Nash equilibrium outcome both at the aggregate and individual levels. The parameter values adopted are $N = 8$, $\lambda = 50$, $h = 5/2$, $d = 23/2$, $b = 1/16$,

[2] A full description of the working of a genetic algorithm (GA) is given in the textbooks of Holland (1975), Goldberg (1989), and Mitchell (1996). For issues specific to Economics see the excellent study of Dawid (1996).