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Oligopoly game: Price makers meet price takers☆

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ABSTRACT

The paper studies an oligopoly game, where firms can choose between price-taking and price-making strategies. On a mixed market price takers are always better off than price makers, though the profits of both types decline in the number of price takers. We investigate and confront two possibilities of firms' decisions about their types: forward-looking equilibrium reasoning and backward-looking individual learning. We find that the Cournot outcome is the only equilibrium prediction and it is learnable if firms are sufficiently sensitive to profit differences. However, with a larger number of firms, a unilateral deviation from Cournot behavior becomes profitable. Under learning this incentive creates a space for permanent oscillations over different markets with a positive but low number of price takers.

1. Introduction

Oligopolies are very complex market structures. Consider, for example, an established industry where a homogeneous good is produced by several profit-maximizing firms with identical cost structure and where both demand and cost structure is a common knowledge. There is no one, commonly agreed descriptive model of firms' behavior even for this idealized environment. Firms might take into account how their production decisions affect prices, as they do in Cournot competition or if they collude. Or, at another extreme, firms may take price as given and behave competitively. Even if price-making behavior brings firms higher profits,[1] the recent literature casts doubts on whether this behavior will actually be observed. A celebrated result by Vega-Redondo (1997) states that the Cournot-Nash equilibrium is *not* evolutionary stable. That is if firms use trial and error and adapt via imitation of the most profitable firm, the dynamic process moves them away from the Cournot outcome and bring the market to the Walrasian point, which corresponds to the equilibrium under price-taking

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[1] In particular, among all non-collusive outcomes, the firms have the highest profit in the Cournot–Nash equilibrium when they are price makers.

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firms. Results in Huang (2003, 2007) show that a firm that deviates from collusive behavior unilaterally to be a price taker will earn a higher profit than the non-deviating collusive firms.

In this paper we contribute to the literature by studying market dynamics when firms decide to be one of the two *types* (price maker or price taker) and reconsider the choice over time on the basis of own and, in some cases, all firms' past experience. Methodologically our paper belongs to the growing literature on heuristic switching models in which boundedly rational myopic agents switch between several modes of behavior (see Brock and Hommes, 1997, Anufriev and Hommes, 2012 and Hommes, 2013). It is also closely related to the literature on reinforcement learning in games (see Erev and Roth, 1998 and Camerer and Ho, 1999). We place our paper in the current literature on oligopolies in Section 2.

To focus on the firms' decisions about their types, we study the simple and standard case of linear demand and linear marginal cost oligopoly as introduced in Section 3. The firms know the demand and cost functions and produce a perishable homogeneous good. Production takes time which means that price-taking firms should form expectations about the next period price to make their production decisions. Price makers know the market composition and produce optimally given this composition. We shall mostly assume that the expectations of price takers are naive, though the case of perfect foresight is also discussed.[2] We are interested in the question whether there exists a market composition under which firms would be, in some sense, satisfied with their types. If such composition does not exist, then we are interested in the time-invariant distribution over types that arises in the long-run and corresponding dynamics of price, total output and relative profits of price-taking and price-making firms. In our model price takers have a higher steady-state profit than price makers in any market with both types. However, when the number of price takers in the market is too high, the equilibrium becomes unstable and price dynamics converge to a 2-cycle where price makers have much higher average profit than price takers. Given these features, we analyze different versions of the model with firms choosing their types endogenously.

In Section 4 we use game-theoretic approach where firms choose their types in a *strategic* way, by considering their steady-state profits and choosing the best type given the other firms' types. We introduce a notion of *compositionally stable markets*, which are Nash equilibria in pure strategies of a game where firms choose their types once and for all. We prove that, with an additional requirement of price dynamics converging to the steady state, the only stable market composition is when each firm is a price maker. Thus, we find support for the Cournot equilibrium but not for the Walrasian equilibrium or for mixed markets where both types coexist. However, we also show that when the number of firms in the industry increases, the Cournot market will eventually lose its compositional stability, as every firm in this market would be better off by becoming a single price taker.

Section 5 is concerned with *backward-looking* firms' behavior, when each firm makes decision repeatedly, based on profits received in the past. As intuition suggests, when the Cournot market is compositionally stable, then simulations with backward-looking learning tend to converge to the Cournot market. When the Cournot market is compositionally unstable, dynamics do not converge to a fixed composition. In this case we observe oscillations in price and quantities caused by a cyclical switching between types. The number of price takers is typically low to guarantee price stability. At the same time, price makers cannot drive price takers out of the market as price takers earn higher profits than price makers.

Section 6 summarizes the paper. Proofs of some results are presented in the Appendix and additional simulations can be found in the Online Appendix.

2. Literature review

Our paper belongs to a growing economic literature that deals with *behavioral* oligopolies. Instead of taking an equilibrium point in the strategy space as a granted outcome of firms' interaction, it studies dynamical aspects of firms' *learning* processes, i.e., firms' adaptive behavior that occurs in actual time. In this literature firms are boundedly rational either because they do not have sufficient information or computational abilities to play an equilibrium strategy or because they may fail to coordinate with their competitors on playing an equilibrium profile.[3] In this literature firms often rely on some behavioral rules that map their past information to new actions. A typical research question is whether the dynamics generated by the interaction between boundedly rational firms would converge and, if so, where. The literature can be divided into three interrelated streams.

The first stream focuses on *adaptive learning* of strategic firms. Price-making firms form expectations about the production of the rest of the industry and optimize under their expectations. Expectations are formed based on historical observations. Firms are boundedly rational either because they ignore contemporaneous adjustment by their competitors, or because they have incomplete information about the industry demand function, or both. Indeed, the so-called "naive" adjustment, when every firm plays the best reply to the total production of its competitors in the previous period goes back to Cournot (1838), who focused on a limiting point of such process.[4] Theocharis (1960) and Hahn (1962) among others, derived several results on the convergence of naive adjustment dynamics to the Cournot–Nash equilibrium. More sophisticated

[2] If all firms are price takers in our model, we obtain a well-known *cobweb model* that became a standard model to introduce and investigate various expectation schemes, see, e.g., Nerlove (1958), Muth (1961), Bray and Savin (1986), Chiarella (1988), Hommes (1994) and Brock and Hommes (1997). If cobweb dynamics converges, it converges to the Walrasian equilibrium. If all firms are price makers, an immediate outcome is the Cournot–Nash equilibrium.

[3] See Bischi et al. (2009), Armstrong and Huck (2010) and Kirman (2011) for recent overviews of various branches of this literature. A related field of "behavioral industrial organization" focuses on consequences of cognitive biases of consumers.

[4] That is why naive adjustment is often called Cournot best response dynamics.

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