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Chapter 5

Evolution and market structure

5.1 Introduction

At this stage, we enter the part that is devoted to the formal modelling and simulation. As argued in chapter 2, evolutionary ideas are appealing when markets are perfectly competitive. Due to competitive pressures, firms are forced to produce efficiently. So, the more firms participate in the market, the more pressure this puts on a firm to perform well. However, here we are especially interested in an imperfect competitive market and in particular an imperfect market with quantity setting firms. In section 5.2, we will first give an overview of the literature, which gives us an idea of how evolution and oligopolistic markets can be modelled and we will also discuss in what way it makes sense to apply evolutionary game theory to oligopoly. The chapter ends with conclusions in section 5.3.

5.2 Overview of the literature

Chapter 2 posed the question whether profit maximization is necessary for firms to avoid the potential adverse effects of market selection forces. Support for the idea that competition enforces profit maximizing behavior has already been conjectured by e.g. Alchian (1950) and Milton Friedman (1953). From an evolutionary game perspective the interesting question is then whether profit maximization is inevitable for selecting those equilibria that coincide with rational behavior. Whereas perfect competitive markets support selection by market forces, studies examining this conjecture within imperfect competitive markets yield ambiguous results.

The literature now shows a direction towards investigating the issue of economic natural selection with respect to non-competitive markets and centers the analysis around the question whether the profit maximizing conjecture also pertains to such markets. In one of the first studies in this field, Conlisk (1980) investigates whether it is better to pursue profit maximization or to sustain market selection forces by implementing the relatively cheaper means of imitation. The players in Conlisk's model are parties in an unspecified market that have to make decisions about their choice vector: part of them are optimizers and the other part are imitators. Decision making based on imitation rules is cheaper since they do not involve costs in order to derive the optimal solution to a decision making problem. These costs could comprise information costs, search costs, calculation etc. (Conlisk, 1980)[1]. Imitators avoid these costs by mimicking the choice vector of the optimizers if that has proven to be successful. On the other hand, compared to optimizers, they make a loss by imperfections in observing the choices of the optimizers and by delays in the adjustment of their choice vector to that of successful optimizers.

The evolution of the optimizer-imitator mix is driven by the share optimizers have in the population and by the performance of optimizers relative to imitators. The larger the share and the better the relative performance, the larger the increase in the share of optimizers relative to imitators. The result is that, depending on parameter values, imitators may survive next to the optimizers[2]. In the words of Conlisk (1980, p.275): '[..] imitators may have as high a long-run 'fitness' as optimizers.'

More directly relevant for our problem setting is the contribution of Schaffer (1989) and the work that extends his results such as Vega-Redondo (1997), Alós-Ferrer *et al.* (1999, 2000), Tanaka (1999, 2000), Schenk-Hoppé (2000) and Rhode and Stegeman (2001). These studies focus on firms competing on oligopolistic markets. The Cournot and Bertrand oligopolistic behaviors and outcomes are the benchmark. They have to be compared with the results of models in which concepts of evolutionary game theory are applied. To give the

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[1] Conlisk mentions that both optimizers and imitators (non-optimizers) make mistakes, but the latter avoid the costs of making them.

[2] A similar result is obtained by Biais and Shadur (2000) who apply stochastic evolutionary game concepts to explore a non-competitive financial market. They find that due to bargaining power, irrational trading behavior can yield larger profits compared to rational behavior. Consequently, irrational traders do not get eliminated by market forces and may survive in the long-run.

flavor of the approach, we shall discuss Schaffer (1989) more extensively and the subsequent works more briefly.

The essence of Schaffer's (1989) paper is to demonstrate that Milton Friedman's (1953) conjecture of absolute profit maximization being an appropriate summary of the conditions for firm survival, does not hold in general. He does so by constructing counter examples where strategies of the 'absolute profit maximizing' type do not survive and where other strategies turn out to be evolutionary stable and consequently do survive. Schaffer's example illustrates that the outcomes of the evolutionary game model are sensitive to the assumptions about the strategies chosen and the character of the selection mechanism. The paper by Schaffer is discussed here because he uses the symmetric Cournot oligopoly to defend his case. Firms have identical constant marginal cost, zero fixed cost and the market demand function for the homogeneous output is downward sloping.

In the traditional comparative static approach of Cournot oligopoly, the firms are profit maximizers with complete information on the industry demand function, on the quantities chosen by competitors and on their own cost functions. The market establishes the market clearing equilibrium price given the total amount of quantities supplied by the firms. Classical game theory has added the insight that the Cournot equilibrium is also a Nash equilibrium.

Schaffer drops the assumption that firms are fully informed on all relevant conditions. It is implicitly assumed that the information on the demand function is missing. Even though the firm has information on the quantity set by its competitor and on its own cost function, it is unable to calculate its profit maximizing quantity since the marginal revenue function is unknown. Instead, Schaffer introduces a strategy choice rule and a selection mechanism (survival rule). The selection mechanism implies that a successful (more profitable) strategy will see a growing number of firms following it and a less successful (less profitable) strategy will be decreasing in the firms applying it. This simply reflects monotonicity. To be more specific, at each time t denote p_{it} as the probability that player i survives market pressures to participate in the $t+1$ play of the game and π_{it} as the associated payoffs from the followed strategy. Schaffer imposes a restriction on this survival rule saying that at time t:

$$p_{it} > p_{jt} \Longleftrightarrow \pi_{it} > \pi_{jt},$$

which means that player i's chance of survival as opposed to player j is bigger if and only if player i's payoff exceeds the payoff of player j.

Schaffer introduces the term 'imitation' as a strategy choice rule and the players can use at most two different strategies. For a duopoly case (later generalized to a n-firm case), the example is given of each firm selling $Q^*/2$, which coincides with the symmetric zero-profit competitive solution; or one firm selling $Q^*/2$ and the other deviating from this. Schaffer then shows that the competitive solution is a stable evolutionary equilibrium in case of imitation of the strategy choice rules. The reasoning is as follows. Assume that firm A deviates its quantity q_A from the Walrasian equilibrium quantity q_A^*, while firm B sticks to its q_B^*. If $q_A < q_A^*$ the market price will rise *above* marginal and average cost, but since $q_A < q_B^*$ firm A will have lower profits than firm B. If $q_A > q_A^*$ the market price falls *below* marginal and average cost and firm A will incur a loss. However, since $q_A > q_B^*$, firm B's losses will be smaller. Therefore, strategies which deviate from q_A^*, q_B^* yield a lower payoff, implying that the Walrasian equilibrium $Q^* = q_A^* + q_B^*$ is evolutionary stable.

It should be noted that the result is the consequence of the assumption that relative profits are the condition for survival and not absolute profits. Although firm A might increase its absolute profits substantially by moving from the Walrasian equilibrium to a point on its reaction curve, absolute profits of its competitor would increase even more. On the other hand, if the initial position is a (symmetric) Cournot-Nash equilibrium $\overline{q}_A, \overline{q}_B$ in absolute profits, an increase in the quantity supplied by firm A from $\overline{q}_A$ to q_A^* would yield a lower payoff, but the payoff of firm B, which sticks to $\overline{q}_B$, would drop even more. As a result, the Cournot-Nash equilibrium $\overline{q}_A, \overline{q}_B$ is not an evolutionary stable solution.

Vega-Redondo (1997) extends Schaffer's (1989) result to a more general level and considers a n-firm Cournot market where firms produce a homogeneous good in the face of a downward sloping demand curve. The model does not differ from Schaffer (1989) in its basic assumptions. Firms are quantity setters and they switch from low profit strategies to high profit strategies (relative to competitors' profits). Compared to Schaffer, the refinement is that the model has a stochastic nature in terms of firms 'experimenting' in output levels with some small probability $\epsilon > 0$. Experimentation here means that there is a chance that firms supply a certain amount of output which deviates from the most successful (profitable) output choice.

Monotonicity in Vega-Redondo (1997) is represented by an increase in those output levels that yield higher profits. He points out that such adjustment dynamics may be viewed as a model of dynamic learning and as a stylized reflection of bounded rationality in a complex environment where imitating success could well be a reasonable rule of thumb. Then Vega-Redondo (1997) studies the long-run behavior of this system as the mutation rate vanishes ($\epsilon \rightarrow 0$) and finds that the evolutionary stable outcome is the symmetric Walrasian solution where price equals marginal costs and profits are zero.

In the spirit of Schaffer (1989) and Vega-Redondo (1997) is the model of Rhode and Stegeman (2001). Alike Vega-Redondo (1997), their evolutionary adjustment dynamic is stochastic. The model assumes a symmetric differentiated duopoly exhibiting a quadratic cost function and linear demand curve. Firms mimic the output level that proved to be the best and sometimes also experiment. Basically Rhode and Stegeman (2001) find the same result as Vega-Redondo (1997). The Darwinian selection dynamic typically does not select the strategy that earns the highest (absolute) average payoffs. In the evolutionary equilibrium, quantities exceed the Cournot-Nash quantities. Next to Cournot behavior Rhode and Stegeman also analyze Bertand behavior where Darwinian like firms set prices. They find that the game generates the same evolutionary stable equilibrium as the Cournot game.

Vega-Redondo's (1997) work has inspired other authors to extend the model. For instance, Alós-Ferrer *et al.* (1999) study a market with n firms that produce a homogenous good and all face the same technology. Firms base their production decision on imitation rules and also allow for experimentation. Imitation here implies choosing those outputs that yielded the highest profits in the preceding period. Experimentation is defined as stated above. They consider two paths of analysis. In the first path, the industry size is fixed. This case converges to the long-run Walrasian equilibrium, provided that production represents decreasing returns to scale. The result does not hold when there are increasing returns. They subsequently endogenize the industry size by incorporating an entry/exit mechanism[3]. In the increasing returns to scale case, the industry size can expand in the long-run and profits are negatively related with the population size. When there are increasing returns, the market evolves towards the monopoly case with a relatively high profit level.

Other extensions of Vega-Redondo (1997) are Alós-Ferrer *et al.* (2000) and Schenk-Hoppé (2000). They focus on a Bertrand oligopoly and Cournot oligopoly respectively. One result of the price competition model of Alós-Ferrer *et al.* (2000), with firms producing a homogeneous good given a technology with decreasing returns to scale, is that the Walrasian equilibrium is found to which they refer to as 'central prices'. The other finding of Alós-Ferrer *et al.* (2000) is

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[3] They call this population turnover.

that under imitation and experimentation Bertrand-Nash equilibria are found where firms have positive profits, i.e., the long-run zero profit Walrasian outcome does not appear. In the Bertrand model firms imitate successful behavior in terms of setting those prices associated with the highest pre-period profits. Experimentation here means that with positive probability, a firm may deviate from this pricing policy by setting another price instead. Schenk-Hoppé (2000) considers a Cournot oligopoly where decision making is also based on imitation and experimentation as defined above. He examines the long-run outcome as the rate of experimentation approaches zero and shows that for *any* finite number of firms the Walrasian outcome is established.

Tanaka (1999) extends Vega-Redondo (1997) by including cost asymmetries, distinguishing high and low cost firms that produce a homogeneous good. By differentiating costs, the market is divided into two subpopulations: a subpopulation of low cost firms and a subpopulation consisting of high cost firms. The sizes of these two subpopulations are assumed to be fixed. The strategies of the firms are their production levels and the dynamics is based on imitating the strategy with the highest payoff in the previous period. Tanaka then determines the long-run equilibrium output levels for both the high and low cost population and finds that in both subpopulations the long-run evolutionary stable output level coincides with the competitive Walrasian solution, provided that marginal costs are increasing. Alternatively, in Tanaka (2000), symmetric firms produce differentiated goods. He finds that in both the price setting game and the quantity setting game, the corresponding strategies (prices and quantities respectively) are stochastically stable and are equivalent[4].

Vega-Redondo (1997) modeled a single population of firms who all display imitating behavior and so explicitly assumes a homogeneous population. An alternative approach has been taken by Schipper (2001) who models a single heterogeneous population, implying a mix of imitators and optimizers. The N-firm oligopoly is divided into two subpopulations: a group of imitators and a group of optimizers. Imitators choose the quantity with the higher pre-period payoff whereas optimizers play best-responses. Schipper finds that, on average, imitators perform better than optimizers. The outcome is basically similar to the previous mentioned result of Conlisk (1980).

Qin and Stuart (1997), Hehenkamp *et al.* (1999) and Hehenkamp and

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[4] In particular, Tanaka (2000) defines the stochastic stable outcome as the so-called 'globally surviving strategy' which is 'a strategy that, if adopted by a single mutant, can invade any configuration where the population monomorphically adopts some other strategy' (Tanaka, 2000, p.237).

Leiniger (1999) also determine the evolutionary stability of both equilibrium prices and equilibrium quantities in Bertrand and Cournot markets respectively. Their approach is different from the preceding reviewed studies since they analyze the evolutionary stable outcomes based on optimization according to best-reply dynamics, as usually applied in the industrial organization literature. It implies that firms have information about the demand conditions and the quantities and prices of competitors. Moreover, they also know their own cost function. Given the quantities or prices set by competitors, the firm chooses its own profit maximizing quantity or price. In other words, each firm moves along its reaction curve. So, the approach of this second group of authors is basically different from the first group which has built on Schaffer (1989) and Vega-Redondo (1997). All three studies focus on the static concept of evolutionary stable strategy (see section 2.3.4) and a symmetric homogenous output market. Qin and Stuart (1997) model a product market where firms do not face any capacity constraints. Moreover, they presume a concave demand structure. They find that the Cournot equilibrium is an evolutionary stable strategy, whereas the price equilibrium in Bertrand sense is not.

Hehenkamp and Leiniger (1999) comment on the Bertrand result obtained by Qin and Stuart (1997) by arguing that in such markets also the consumers have to be explicitly modelled as a population since they too act strategically by searching for the lowest price. Hence, Hehenkamp and Leiniger (1999) put forth that the evolutionary stable strategy concept lacks predictive power for analyzing long-run behavior in a classic imperfect price-setting environment. In the model of Hehenkamp *et al.* (1999), natural selection also occurs between firms that play according to optimization postulates. Subsequently, given this dynamic specification, in the Cournot case they find support for convergence to the Cournot-Nash equilibrium. Furthermore, for Bertrand markets, the final equilibrium reflects a price that slightly exceeds the marginal costs of production.

The long-run outcome in non-competitive market environments has also been experimentally investigated. In particular, determining how information requirements affect learning, which in turn influence the final equilibrium outcome, seems to be a relevant line of research here. For example, Huck *et al.* (1999) investigate learning dynamics in a Cournot market. They find that when players have more information about demand and cost conditions, the behavior becomes less competitive, whereas competition is enhanced if players have more information about the profits and quantities of its direct competitors. This competition effect is due to imitation of successful behavior. This outcome implies a support for Vega-Redondo's (1997) result. An equivalent result is obtained by Huck *et al.* (2000). Next to considering a Cournot market, they also focus on the Bertrand game. Basically, by revealing more information about competitor's profits, quantities and prices, the level of competition increases. However, the competition effect is stronger in Bertrand than in Cournot environments.

5.3 Concluding remarks

In chapter 2, which introduced the theory of evolutionary games, it came forward that the methodology is quite appealing to analyze strategic interaction in market environments characterized by perfect competition. In such non-concentrated markets the pressure comes from the firm's direct competitors and forces to produce efficiently (profit maximization) in order to survive (natural selection argument). In this thesis, we explicitly focus on a concentrated market structure instead. This chapter explored how evolutionary game theory can be used in such a market setting. An overview of the main literature dealing with economic natural selection within imperfect competitive markets has been given. Whether profit maximization conjectures also pertain to such markets is the key issue of this literature and is restricted to basic Cournot and Bertrand models. The general finding is that the outcome in imperfect competitive markets, where quantity and price decisions are based on imitation of successful competitors' decisions, is often of the Walrasian type. That is, the long-run outcome constitutes a marginal-cost pricing equilibrium. The literature that has been reviewed here on the firm's choice of quantities (in Cournot markets) or prices (in Bertrand markets) do not discuss the strategic choice out of a set of *different technologies*, which is a central issue in the thesis.

The experimental studies support the conclusions of the theoretical research. The group of authors following the trail set out by Schaffer (1989) and Vega-Redondo (1997), analyze firms which have limited information about market conditions and base their decision on the examples of competitors. They find as a rule that the Walrasian equilibrium is the evolutionary stable outcome. On the other hand, Qin and Stuart (1997), among others, assume complete information on all relevant market conditions. They find the Cournot-Nash equilibrium as the evolutionary stable outcome. Moreover, they also obtain a finding that Bertrand oligopoly may have an evolutionary stable outcome which deviates little from the Walrasian outcome. This too is supported by results obtained in the experimental literature.