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Competitiveness and R&D competition revisited

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ABSTRACT

This paper formulates a duopoly model of firms concerned with relative profits as well as their own profits and investigates the relationship between the degree of competitiveness in a market and R&D expenditure. We find a non-monotone relationship between the two variables. When the duopoly market is not particularly competitive and when it is highly competitive, R&D activities are intensified. Thus, we are able to obtain similar results to both the pro-competitive and the Schumpeterian views in a single framework. We also discuss the welfare implications of changing competitiveness and consider cases of oligopoly and R&D cooperation as extensions to our basic model.

1. Introduction

This paper formulates a duopoly model in which firms are concerned about relative profits as well as their own profits and investigates the relationship between the degree of competitiveness faced by firms and their R&D expenditure. We apply the relative profit approach to analyze the relationship between competition in the product market and innovation, in which economists have long been interested.[1] Traditionally, there have been two competing views and while many economists believe that monopoly yields intensive R&D (the Schumpeterian view), many others believe that competition yields intensive R&D (the pro-competitive view). Both groups have presented theoretical foundations and much empirical (and anecdotal) evidence to support their views.[2] We find a U-shaped relationship between the toughness of competition and the equilibrium level of R&D, that is, both competitive and monopolistic markets yield higher levels of R&D than "oligopolistic" markets. Thus, we are able to obtain results compatible with both views in a single framework.[3]

In our model, each firm i is assumed to maximize its relative profit $\pi_i - \alpha\pi_j$, where π_i is its own profit, π_j is its rival's profit, and $\alpha \in (-1,1)$. α can be directly interpreted as a measure of altruism or spite (or the extent to which decision makers within firms care about relative performance). An alternative interpretation of α, which we suggest, is that it is a parameter indicating the severity of competition.[4] Consider a symmetric Cournot duopoly, in which two firms independently choose their outputs for a homogeneous product market. In a symmetric situation, the equilibrium outcome for $\alpha = 1$ is identical to that in a perfectly competitive market.[5] By construction, the model is reduced to the standard Cournot case when $\alpha = 0$. If $\alpha = -1$, each firm chooses output to maximize joint profit, and thus, the outcome corresponds to that of collusion or monopoly.[6] Hence, $\alpha \in (-1,0)$ implies an intermediate competitiveness between monopoly and duopoly levels, and $\alpha \in (0,1)$ implies an intermediate competitiveness between

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[1] See Aghion et al. (2005). They show an inverse U-shaped relationship between the toughness of competition and the equilibrium level of R&D.

[2] For instance, see Schumpeter (1950) and Arrow (1962). See also Cabral (2000), Mateus and Moreira (2007), and works cited in these books.

[3] For an empirical support of this U-shaped relationship between the toughness of competition and the level of innovation activities, see Flath (2011).

[4] See also Shubik (1980), Vickers (1985), Brod and Shivakumar (1999), and Symeonidis (2000).

[5] The first-order condition for firm 1 is $p + p'(y_1 - y_2) - c_1' = 0$, where p is the inverse demand function, y_i is firm i's output, and c_1' is firm 1's marginal cost function. At the symmetric equilibrium with $y_1 = y_2$, this condition becomes $p - c_1' = 0$ (price is equal to marginal cost) and thus, the firm behaves as if it is a price taker.

[6] Choi and Lu (2009) and Lu (2011) discuss the case of $\alpha = 1$ in mixed oligopolies and present some interesting results.

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duopoly and the perfectly competitive levels. Thus, a larger α indicates a more competitive market.[7] The model enables us to treat competitiveness as a continuous variable, and it contains three standard models—monopoly, duopoly, and a perfectly competitive market—as special cases.

We find a non-monotone (U-shaped) relationship between the degree of competitiveness α and the level of innovation activities. Given a non-positive α, an increase in α reduces R&D. When α reaches a critical value, which is strictly larger than 0, the relationship is inverted. At and above the critical value of α, an increase in α increases the level of R&D. This result indicates that R&D activities occur more in both highly cooperative (α close to -1) and highly non-cooperative (α close to 1) industries, while they are less active in intermediate cases.[8] Furthermore, we compare equilibrium investment level with the second-best investment level; the equilibrium R&D level is excessive when $\alpha<0$, while it is insufficient when $\alpha>0$.

We then extend our basic analysis in two directions. First, we consider a joint R&D implementation, where firms cooperatively choose their R&D levels and then compete in the product markets. Collusion in the product market is illegal *per se*, however, it is possible for R&D cooperation to be allowed. Thus, this situation is worth discussing. We show that in this case, an increase in α reduces R&D. Second, we consider an oligopoly model. Here we show that an increase in α is less likely to stimulate R&D when there is a greater number of firms.

We now present the rationale for using the relative profit (performance) approach. It is often recognized that people tend to care about the performance of others as well as their own.[9] This concern may stem from the available incentive schemes or just from one's intrinsic interest. For instance, evaluations of managers' performances are often based on their relative as well as absolute performance (Murphy (1999)). In addition, outperforming managers often obtain better management positions through the job market. In this case, managers act in a way that responds to the relevant incentive schemes.

Moreover, the relative performance approach can be regarded as a variant of an "other-regarding" concern. A considerable amount of laboratory (experimental) research has provided evidence for occurrence of spiteful as well as reciprocal or altruistic behavior (Brandts et al. (2004), Cason et al. (2002), and Coats and Neilson (2005)).[10] Such concerns are closely related to relative performance evaluation. In our model, the parameter α can be interpreted as representing the degree of reciprocal preference. If α is positive, the firms envy their rivals' success. If α is negative, the firms have reciprocal (altruistic) payoff functions.[11] In our context, reciprocity and spitefulness can stem from genuine emotions and from incentive schemes. That is, this concern may be owning to either the available incentive schemes or just one's intrinsic interest.

We now mention the evolutionary approach that may support our non-profit-maximizing approach. Vega-Redondo (1997) formulates an evolutionary game of quantity-setting oligopoly, in which each firm imitates the behavior of the firm that earns the largest profit. He shows that the Walrasian outcome, not the Cournot outcome, appears in the unique evolutionarily stable state. His result supports our discussion of the case where $\alpha=1$. However, this yields the lowest equilibrium profits and the owners of the firms may have incentives to alter this situation. Kockesen et al. (2000) consider a two-stage strategic commitment game where the owners of the firms choose α and then firms face quantity competition. They show that owners choose a positive α for strategic purposes. Vega-Redondo (1997) considers irrational players and Kockesen et al. (2000) consider rational owners and managers, and thus, these two polar approaches rationalize there being a non-zero α (non-profit-maximizing behavior).

The rest of this paper is organized as follows. Section 2 formulates our basic model. In Section 3, we demonstrate the U-shaped relationship between α and R&D expenditure. Section 4 presents the welfare implications. Section 5 gives two extensions of the basic model. Finally, Section 6 concludes this paper. All proofs are relegated to the Appendix A.

2. The Basic Model

We formulate a two-stage symmetric duopoly model. In the first stage, firm i ($i=1,2$) chooses its R&D level, I_i. At the beginning of the second stage, each firm observes the rival's R&D level. In the second stage, firms produce perfectly substitutable commodities, for which the market demand function is given by $p=a-Y$ (price as a function of quantity), where Y is the total output of the two firms. Let y_i denote the output of firm i. Firm i's marginal production cost c_i depends on I_i. Each firm i chooses y_i independently.

The payoff of firm i ($i=1,2$) is given by $U_i=\pi_i-\alpha\pi_j$ ($i\neq j$), where π_i is the profit of firm i and $\alpha\in(-1,1)$. Firm i's profit π_i is given by $\pi_i=(a-Y)y_i-c_i(I_i)y_i-I_i$. It is assumed that $c_i'\leq 0$ and that c_i'' is positive and sufficiently large so as to satisfy the second-order condition at the first stage. We also assume that $\lim_{I\to 0} c'(I)=-\infty$ and $\lim_{I\to\infty} c'(I)=0$ so as to ensure an interior solution at the first stage.

A direct interpretation of α is as the degree of envy. As stated earlier, we can also interpret α as a parameter indicating the severity of competition. We now explain how this interpretation is justified. The first-order condition of firm i is as follows:

$$p(Y)+p'(Y)y_i-c_i-\alpha p'(Y)y_i=0.$$

The outcome is symmetric, that is, $y_i=y_j$, when $c_i=c_j$ (indeed, the marginal cost must be symmetric in the equilibrium path of our model). Then, we have;

$$p(Y)+(1-\alpha)p'(Y)y_i-c_i=0.$$

By construction, this yields the standard Cournot outcome when $\alpha=0$. If $\alpha=1$, then the above equation becomes $p=c_i$; the marginal cost pricing rule applies. Therefore, the behavior of each firm is as if the market is perfectly competitive. Thus, we cannot distinguish between the "full-envy" case and the perfectly competitive case by comparing the resulting behavior. If $\alpha=-1$, then the above equation becomes $p(Y)+p'(Y)Y-c_i=0$, which corresponds to the first-order

[7] Under the conditions in the standard Cournot model, the ratio between the profit margin (price minus marginal cost) and the price, referred to as the Lerner index, is decreasing in α. This index is used extensively in the empirical literature as a measure of competitiveness in product markets. A larger α accelerates competition but it may induce collusive behavior in a repeated game context, because more severe competition enhances the punishment effect for deviations from the collusive behavior. Matsumura and Matsushima (2012) show that an increase in α makes a cartel less stable in repeated game contexts. This result also suggests that a larger α indicates more intensive competition (and a less collusive market).

[8] Although there is extensive literature on strategic R&D competition, most papers assume Cournot competition, where firms maximize their own profits. See, among others, Brander and Spencer (1983), Spence (1984), d'Aspremont and Jacquemin (1988), Suzumura (1992), Kamien et al. (1992), Lahiri and Ono (1999), and Kitahara and Matsumura (2006). Note that, Symeonidis (2000) only investigates α in the range of $[-1,1)$; he does not investigate highly competitive cases.

[9] Payoff functions based on relative wage or relative wealth status have also been much discussed within macroeconomics. Keynes (1936) discusses the rigidity of the nominal wage based on relative wages. See also Akerlof and Yellen (1988), Corneo and Jeanne (1997, 1999), and Futagami and Shibata (1998). The relative performance approach is also important in political science. Obviously, a party cares about the number of votes obtained, not in absolute terms but in relative terms. In addition, in the context of international policies, there is a possibility that governments care about their relative performance as well as their absolute performance. See, among others, Grieco et al. (1993) and Mastanduno (1991).

[10] Bolton and Ockenfels (2000) and Fehr and Schmidt (1999) examine another type of other-regarding concern, inequality aversion.

[11] The parameter α is closely related to the "coefficient of effective sympathy" used by Edgeworth (1881) and the "coefficient of cooperation" used by Cyert and DeGroot (1973).