

Competitiveness and R&D competition revisited*

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March 27, 2012

Abstract

This paper formulates a duopoly model in which firms care about relative profits as well as their own profits and investigate the relation between the degree of competitiveness and R&D expenditure. We find a non-monotone relationship between the degree of competitiveness and their R&D levels. When the duopoly market is less competitive or much competitive, R&D activities are intensified. Thus, our result explains the pro-competitive view and the Schumpeterian view consistently.

JEL classification numbers: L21, O31, L13

Key words: competitiveness, innovation, Schumpeterian view, pro-competitive view

*An earlier version of this paper was circulated under the title “Relative performance and R&D competition.” We would like to thank Federico Etro, Debashis Pal, and seminar participants at Kwansai Gakuin University, Osaka University, Osaka City University, and University of Tokyo for their helpful comments. The first and the second authors gratefully acknowledge financial support from the Japanese Ministry of Education, Science and Culture. Needless to say, we are responsible for any remaining errors.

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1 Introduction

This paper formulates a duopoly model in which firms care about relative profits as well as their own profits and investigate the relation between the degree of competitiveness and R&D expenditure. We apply the relative profit approach to the analysis of the relationship between product market competition and innovation, which economists have long been interested in.¹ Traditionally, many researchers believe that monopoly yields intensive R&D (Schumpeterian view), and many other believe that competition yields intensive R&D (pro-competitive view). Both have presented many theoretical foundations and empirical (and anecdotal) evidences supporting their views.² We find U-shaped relationship between toughness of competition and the equilibrium level of R&D, i.e., both competitive and monopolistic situations yield higher levels of R&D than ‘oligopolistic’ situations. Thus, our result explains both views consistently.³

The outline of our model is as follows. Firm i 's payoff is its relative profit $\pi_i - \alpha\pi_j$, where π_i is its own profit, π_j is the rival's profit, and $\alpha \in (-1, 1)$. We can interpret α as a parameter indicating severity of competition.⁴ $\alpha = 0$ indicates the standard Cournot case, $\alpha = 1$ indicates the perfectly competitive case (related to the Bertrand case), and $\alpha = -1$ indicates the monopoly case.⁵ Thus, a larger α indicates a more competitive market.⁶ The model setting enables us to treat competitiveness as a continuous variable, and this model

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

² See, e.g., Schumpeter (1950) and Arrow (1962). See also Mateus and Moreira (2007), Cabral (2000), and works cited in these books.

³ For the empirical support of this U-shaped relationship between 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 Choi and Lu (2009) and Lu (2011) discuss the case of $\alpha = 1$ in mixed oligopolies and present some interesting results.

⁶ Under the standard conditions in Cournot, the ratio between profit margin (price minus marginal cost) and the price, called as Lerner index, is decreasing in α . This index is intensively used in the empirical literature as a measure of competitiveness in product markets.

contains three standard models—Cournot, Bertrand, and monopoly— as special cases.

We find a non-monotone (U-shaped) relationship between the degree of competitiveness α and the innovation activities. Given a nonpositive α , an increase in α reduces R&D. When α reaches a critical value (which is strictly larger than 0), the relationship is inverted. From the critical value of α , an increase in α increases the levels of R&D. This result indicates that R&D activities are quite active in both highly cooperative (α is close to -1) and highly noncooperative (α is close to 1) societies, while they are less active in the intermediate cases.⁷

We 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. In general, collusion in the product market is *per se* illegal, while it is possible for R&D cooperation to be allowed. Thus, this situation is worth discussing. It is shown that in this situation, an increase in α reduces R&D. Second, an oligopoly model is considered. It is shown that an increase in α is less likely to stimulate R&D when the number of firms is larger.

We add some comments on rationales for discussing objective functions on the basis of relative profit (performance). First, relative performance, especially in a positive α case, is quite important from the viewpoint of evolutionary stability.⁸ Second, owners of firms often have incentives for adopting a positive α in the context of strategic commitment games (Kockesen et al., 2000). Third, the parameter α represents the degree of reciprocal preference. If α is positive, the firms envy the rivals' success. If α is negative, the firms have reciprocal (altruism) payoff functions.⁹ Through the direct interpretation of α , our result sheds some

⁷ Although the literature on strategic R&D competition is fairly abundant, 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), Matsumura (1995), and Lahiri and Ono (1999). Note that, Symeonidis (2000) only investigates the range of α (λ in his paper) is $[-1, 0]$ ($\lambda \in [0, 1]$ in his model). He do not investigate highly competitive cases.

⁸ See Alchian (1950) and Vega-Redondo (1997). Vega-Redondo (1997) also shows that Cournot competition with relative performance objectives yields the Bertrand outcome even in duopoly, and this outcome is evolutionary stable.

⁹ The parameter α is closely related to the “coefficient of effective sympathy” used by Edgeworth (1881)

light on how reciprocal and negative reciprocal attitudes affect R&D. Given the pure selfish preferences of firms, an introduction of minor spiteful preferences reduces their innovative activities, but an introduction of significant spiteful preferences stimulates their innovation.¹⁰

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 expenditures. Section 4 provides the analysis of joint R&D implementation. In Section 5, the basic model is extended to the case of oligopoly. We discuss welfare implications in Section 6. Section 7 concludes this paper. All proofs are relegated to the Appendix.

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. 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 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 $\alpha \in (-1, 1)$. We can interpret α as a parameter indicating severity of competition. The 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 c''_i is positive and sufficiently large so as to satisfy the second-order condition at the first stage. We also assume that $\lim_{I \rightarrow 0} c'(I) = -\infty$ and $\lim_{I \rightarrow \infty} c'(I) = 0$ so as to ensure the interior

and "coefficient of cooperation" used by Cyert and DeGroot (1973). For discussions on non-profit maximizing preferences in this context, see Bolton and Ockenfels (2000) and Fehr and Schmidt (1999).

¹⁰ The payoff functions that are based on relative wage or relative wealth status have also been intensively discussed in the macroeconomics context. Keynes (1936) discussed the rigidity of nominal wage based on relative wage. See also Akerlof and Yellen (1988), Corneo and Jeanne (1997, 1999), and Futagami and Shibata (1998). The relative performance approach is 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, the possibility that governments care about their relative performance as well as absolute performance is pointed out. See, among others, Grieco et al. (1993) and Mastanduno (1991).

solution at the first stage.

3 Equilibrium Analysis and the U-shaped Relationship

In this section, we study a situation where two firms maximizing relative profits compete in the market. The game is solved by backward induction. In the second stage competition, given the investments I_i of two firms, each firm independently chooses its output to maximize the relative profit U_i . The first-order condition is as follows:

$$a - 2y_i - (1 - \alpha)y_j = c_i \quad (i = 1, 2, i \neq j). \quad (1)$$

Obviously, the second-order condition is satisfied. Arranging this equation, we obtain the following reaction function:

$$y_i = R_i(y_j : \alpha) = \frac{a - c_i - (1 - \alpha)y_j}{2}. \quad (2)$$

By solving the first-order condition, the second stage equilibrium outputs are obtained:

$$y_1^E = \frac{(1 + \alpha)a - 2c_1 + (1 - \alpha)c_2}{(1 + \alpha)(3 - \alpha)}, \quad y_2^E = \frac{(1 + \alpha)a - 2c_2 + (1 - \alpha)c_1}{(1 + \alpha)(3 - \alpha)}. \quad (3)$$

The resulting profit of firm i is given by

$$\pi_i^E(c_i, c_j) = \frac{[(1 - \alpha)a - (2 - \alpha)c_i + c_j][(1 + \alpha)a - 2c_i + (1 - \alpha)c_j]}{(3 - \alpha)^2(1 + \alpha)} - I_i. \quad (4)$$

Note that when $c_i = c_j$ and $\alpha = 1$, $\pi_i^E(c_i, c_j) = -I_i$, that is, Bertrand outcome appears.

Next, we consider the first stage R&D competition. In this stage, each firm i independently chooses I_i so as to maximize $U_i = \pi_i^E - \alpha\pi_j^E$. We restrict our attention to the symmetric equilibrium because the sufficiently large c_i'' guarantees that the unique equilibrium is symmetric. The first-order condition is

$$-\frac{[(1 + \alpha)a - 2c_i + (1 - \alpha)c_j][4 - 3\alpha + \alpha^2]}{(3 - \alpha)^2(1 + \alpha)}c_i' = 1. \quad (5)$$

The second-order condition is satisfied. On substituting $c_1 = c_2 = c$ into (5), we have that $-G(\alpha)c' = 1$ must be satisfied, where

$$G(\alpha) := \frac{(a-c)(4-3\alpha+\alpha^2)}{(3-\alpha)^2}.$$

Let I^E denote the equilibrium R&D investment level. A larger G and a larger $|c'|$ imply a higher marginal benefit of R&D. Since the payoff function is assumed to be concave with respect to I_i (c'' is large enough), a larger G (as well as larger $|c'|$) yields a higher level of the equilibrium R&D investment.

We discuss how α affects the equilibrium R&D level. We find a non-monotone relationship between the equilibrium level of R&D (I^E) and the weight of relative performance (α).

Proposition 1 *Suppose that two firms compete in a product market, and they make their R&D investments independently. Then, the equilibrium R&D investment level I^E is decreasing in α for $\alpha < 1/3$ and is increasing in α for $\alpha > 1/3$.*

We explain the intuition behind Proposition 1. Since y_i^E is increasing in α , the cost-minimizing level of R&D, which is derived by minimizing $c_i y_i^E + I_i$, is increasing in α . Thus, for the purpose of cost minimization (minimization of production cost plus R&D cost), firm i has a stronger incentive for R&D when α is larger. On the other hand, firm i has a weaker incentive for innovation for strategic purposes.¹¹ From (2), we have that $|R'_i|$ is decreasing in α . This implies that the strategic value of R&D is decreasing in α . The former dominates when α is large, while the latter dominates when α is small. This yields the U-shaped relationship between α and the equilibrium R&D level.

The implications of Proposition 1 are as follows. Both aggressive competition (the case where α is close to 1) and a collusive situation (the case where α is close to -1) yield high levels of R&D.¹² Our result is related to two influential views on the relationship between

¹¹ From (3) we see that an increase in I_i (a decrease in c_i) decreases y_j^E , and it results in an increase in π_i ($i, j \in \{1, 2\}$, $i \neq j$). This is the strategic value of R&D. For this strategic effect of R&D, see Brander and Spencer (1983).

¹² For the relationship between α and market competition, see the rationale in the second last paragraph of the introduction.

competitiveness and R&D.¹³ One view is the Schumpeterian view. The monopoly yields intensive R&D investments. The other is the pro-competitive view. Severe competition accelerates innovation. Researchers have presented many theoretical foundations and empirical (or anecdotal) evidences supporting both views. Using a single model, we explain that both views can be accurate.

In our setting, R&D is minimized when $\alpha = 1/3$. Starting Cournot competition ($\alpha = 0$), a slight increase in α decreases R&D investments, while a large increase in α increases them. Thus, an envy society (positive α) in which people care about their relative performances as well as their absolute performances can yield either more or less aggressive R&D activities.

4 Joint R&D Implementation

The question is whether or not our result depends on the assumption about the formation of R&D activities. Then, we consider the case in which two firms cooperatively determine their investment level I to maximize their joint profits,¹⁴ while they noncooperatively compete in the product market.¹⁵ Some points of the basic model are modified. Each firm has a common marginal cost $d(I)$ that depends on the joint R&D investment I . We assume that each firm pays half of the joint R&D cost I . Thus, firm i 's profit is given by

$$\Pi_i = (a - Y)y_i - d(I)y_i - \frac{I}{2}.$$

It is assumed that $d'(I) < 0$ and $d''(I)$ is positive and sufficiently large. We also assume that $\lim_{I \rightarrow 0} d'(I) = -\infty$ and $\lim_{I \rightarrow \infty} d'(I) = 0$ so as to ensure the interior solution at the first

¹³ Economists have long been interested in the relationship between product market competition and innovation. See Aghion et al. (2005). They show an inverse U-shaped relationship between toughness of competition and the equilibrium level of R&D. Traditionally, many researchers believe that monopoly yields intensive R&D (monopoly view), while many others believe that competition yields intensive R&D (competition view). Both have presented many theoretical foundations and empirical (or anecdotal) evidences supporting their views. See, for example, Schumpeter (1950) and Arrow (1962). See also Mateus and Moreira (2007), Cabral (2000), and the works cited in these books.

¹⁴ We can show that Proposition 2 holds true in n -firm oligopoly too.

¹⁵ Explicit collusion in product markets is usually illegal, while cooperation at the R&D stage is often permitted by anti-monopoly legislations.

stage.

We consider a two-stage game. In the first stage, the firms choose their R&D level cooperatively. In the second stage, they noncooperatively produce perfectly substitutable commodities.

We now solve the game. The second stage competition has already been discussed in the previous section: all that needs to be done now is replace $c(I)$ with $d(I)$. In the first stage, the firms choose the investment level I . The first-order condition is as follows:

$$-\frac{2(a-d)(1-\alpha)}{(3-\alpha)^2}d'(I) = 1. \quad (6)$$

The left-hand side in (6) is the marginal benefit of their joint R&D investment and the right-hand side in (6) is the marginal cost of the investment. Let I^C denote the equilibrium R&D investment level. Define $H(\alpha) := 2(a-d)(1-\alpha)/(3-\alpha)^2$. Because of the concavity of the payoff function, which is guaranteed by the assumption of sufficiently large d'' , a larger H implies a higher level of investment. We investigate how α affects the equilibrium R&D level. In contrast to the case of noncooperative investment, we find a monotone relationship between the R&D level and the weight of relative performance α .

Proposition 2 *Suppose that two firms compete in a product market, and they make their R&D investments cooperatively. Then, the equilibrium R&D investment level I^C is decreasing in α for $-1 < \alpha < 1$.*

We explain the intuition behind Proposition 2. A decrease in d (the common cost of two firms) lowers the price. Since $dp/dd = 2/(3-\alpha)$, dp/dd is increasing in α . In other words, when α is large, a cost reduction by R&D reduces the equilibrium price substantially; thus, firms lose incentives for R&D. This yields a smaller R&D level as α is larger.

5 Oligopoly

In this section, we move back to the model with noncooperative investment and discuss an oligopoly version. Regarding the payoff function based on relative performance, there are

several different formulations: (a) each firm cares about the average profits of the rivals (the other firms); (b) each firm cares about the highest profit firms among the rivals; and (c) each firm has one specific rival as a benchmark firm and cares about its profit only. Since all formulations yield exactly the same results in our model, we adopt the first formulation.

There are $n(\geq 3)$ symmetric firms and they engage in the two-stage game formulated in Section 2. According to formulation (a), the payoff of firm i ($i = 1, 2, \dots, n$) is given by:

$$U_i = \pi_i - \frac{\alpha}{n-1} \sum_{j \neq i} \pi_j.$$

Let $\beta := \alpha/(n-1)$. If we interpret β as an indicator of the degree of envy or altruism, it is natural to assume that $\beta \in (-1, 1)$. On the other hand, if we interpret β as an indicator of the degree of competition, it is natural to assume that $\beta \in (-1, 1/(n-1))$, because the case where $\beta = 1/(n-1)$ corresponds to the perfect competition.

Consider the second stage competition (quantity competition). The first-order condition of each firm is as follows:

$$a - 2y_i - (1 - \beta) \sum_{j \neq i} y_j = c_i. \quad (7)$$

The reaction function of firm i is as follows:

$$y_i = R_i(Y_{-i} : \beta) = \frac{a - c_i - (1 - \beta)Y_{-i}}{2}, \quad (8)$$

where $Y_{-i} = \sum_{j \neq i} y_j$. Summing each side in (7) for all firms, we have

$$na - 2Y - (1 - \beta)(n-1)Y = \sum_i c_i. \quad (9)$$

Rearranging (9), the second stage total output is obtained:

$$Y = \frac{na - \sum_i c_i}{2 + B}, \quad (10)$$

where

$$B := (1 - \beta)(n - 1).$$

Note that Y is increasing in β . From (7) and (10), we have the second stage output of each firm:

$$y_i^E = \frac{(1 + \beta)a - (1 + \beta + B)c_i + (1 - \beta) \sum_{j \neq i} c_j}{(1 + \beta)(2 + B)}.$$

The equilibrium profit of firm i given the first stage actions of firms is denoted by

$$\pi_i^E = \frac{\{a[1 - (n - 1)\beta] - (1 + B)c_i + \sum_{j \neq i} c_j\} [(1 + \beta)a - (1 + \beta + B)c_i + (1 - \beta) \sum_{j \neq i} c_j]}{(1 + \beta)(2 + B)^2} - I_i.$$

Consider the first stage competition. Each firm i maximizes $U_i = \pi_i^E - \beta \sum_{j \neq i} \pi_j^E$ with respect to I_i . We again restrict our attention to the symmetric equilibrium. Differentiating U_i with I_i , and then substituting $c_j = c$ for all firms we obtain

$$-J(\beta, n)c' = 1,$$

where

$$J(\beta, n) := \frac{(a - c)(\beta + \beta^2 + 2n - 2\beta^2 n - \beta n^2 + \beta^2 n^2)}{(2 + B)^2}.$$

Then, we have the following result.

Proposition 3 *Suppose that $n(\geq 3)$ firms compete in a market, and they make their R&D investments independently. Then, the equilibrium R&D investment level I^E is decreasing in β for $\beta < \bar{\beta}$ and is increasing in β for $\beta > \bar{\beta}$, where $\bar{\beta} := (n - 1)/(n + 1)$.*

The threshold value of β in Proposition 3 is increasing in n . This indicates that an increase in β (and so α) is more likely to decrease R&D investments when n is large. As we discussed in Section 3, an increase in α has two countervailing effects. On the one hand, an increase in α increases the equilibrium output of each firm and stimulates R&D. On the other hand, an increase in α reduces $|R'_i|$ and so reduces the strategic value of R&D. The former effect becomes weaker when n is large, and thus, the latter effect more likely dominates the former when n is large.

6 Welfare Analysis

In this section, we examine welfare implications in duopoly with non-cooperative investment. The equilibrium investment level is compared to the second-best investment level. Social welfare W is the consumer surplus plus profit of firms:

$$W := \int_0^Y p(y)dy - p(Y)Y + \pi_1 + \pi_2.$$

Suppose that the social planner cannot control the competition in the second stage and can control only I , the R&D investment level of each firm (the second-best problem). This problem is intensively discussed in the literature of R&D competition. Let I^* denote the second-best R&D level.¹⁶ We compare I^* with I^E , the equilibrium R&D investment level.

The first-order condition for the social planner is given by

$$\frac{dW^E}{dI_1} = - \left[\frac{4a + 2a\alpha - 2a\alpha^2 - 11c_1 + 5\alpha c_1 + 7c_2 - 7\alpha c_2 + 2\alpha^2 c_2}{(3 - \alpha)^2(1 + \alpha)} \right] c_1' - 1 = 0. \quad (11)$$

Since c_i'' is positive and sufficiently large, the second-order condition is satisfied. Substituting $c_1 = c_2 = c$ into (11), we have that $-K(\alpha)c' = 1$ must be satisfied, where

$$K(\alpha) := \frac{2(a - c)(2 - \alpha)}{(3 - \alpha)^2}.$$

A larger K implies a higher level of I^* , and $I^* > (<)I^E$ if and only if $K(\alpha) > (<)G(\alpha)$ (the definition of $G(\alpha)$ is given in Section 3).

We now state welfare implications.

Proposition 4 *Suppose that two firms compete in a market, and they make their R&D investments independently. Then,*

- (i) I^* is increasing in α for $-1 < \alpha < 1$.
- (ii) $I^* < I^E$ for $-1 < \alpha < 0$, and $I^* > I^E$ for $0 < \alpha < 1$.

¹⁶ We implicitly assume that the second-best outcome is symmetric. This holds true for sufficiently large c_i'' .

Proposition 4(i) states that the second-best R&D level is increasing in the parameter α . This result is very intuitive. The larger the output each firm yields, the greater is the social benefit of R&D; further a larger α yields the larger output.

Proposition 4(ii) states that when α is negative (the market is collusive), the equilibrium R&D is excessive, while a positive α yields insufficient R&D. We explain the intuition. When α is negative, the output level is low. Thus, the social gain of R&D is small, while firms make relatively large investments in R&D (see Proposition 1). This yields excessive investment. The social optimal level of R&D is increasing in α and its equilibrium level is decreasing in α for $\alpha \leq 1/3$, $I^E - I^*$ is decreasing in α ; it happens to be zero when $\alpha = 0$. An increase in α from zero yields the insufficient investment ($I^E < I^*$). See Figure 1.

[Figure 1 AROUND HERE]

7 Concluding Remarks

This paper proposes a tractable oligopoly model that incorporates both positive and negative reciprocal preference of firms. Our model can be applied to the analysis of the relationship between product market competition and innovation, which economists have long been interested in. We investigate the two-stage R&D game in oligopoly markets where firms' payoffs depend on both absolute and relative profits. Firm i 's payoff is $\pi_i - \alpha\pi_j$, where π_i is its own profit, π_j is the rival's profit, and $\alpha \in (-1, 1)$. We can interpret α as a parameter indicating severity of competition. We find the U-shaped relationship between α and the levels of R&D investments when the firms choose the levels of R&D investments independently. That is, both competitive and monopolistic situations yield higher levels of R&D than oligopolistic situations. Thus, our result explains the following well-known views consistently: monopoly yields intensive R&D (Schumpeterian view) and competition yields intensive R&D (pro-competitive view). We also show that the second-best R&D level is increasing in α , and it is more likely to exceed the equilibrium R&D level when α is large.

We think that we can interpret α as a measure of altruism or spite (or how much decision

makers in firms care about relative performance). It is often recognized that one tends to care about the performance of other people as well as one's own performance. This concern may either stem from the available incentive schemes or from just one's intrinsic interest. For instance, evaluations of managers' performances are often based on their relative performance as well as their absolute performance (Murphy (1998)). Outperforming managers often obtain good positions in management job markets. In this case, these managers act in a way that allows them to meet the relevant incentive schemes. Moreover, a considerable amount of laboratory (experimental) research has pointed out spiteful behavior as well as reciprocal or altruistic behavior, which is closely related to the objective functions of agents based on relative performance (Brandts *et al.* (2004), Cason *et al.* (2002), and Coats and Neilson (2005)). These reciprocal and spiteful preferences often stem from genuine emotions or incentive schemes. Based on our results, we can say that reciprocal and spiteful preferences foster R&D incentives.

The model setting discussed here smoothly connects industrial organizations and preferences of firms. It contains Bertrand and Cournot competition as special cases, and a larger α indicates tougher competition in product markets. Therefore, it connects the standard Cournot situation with the standard Bertrand situation in a peculiar way. Incorporating heterogeneity of firms is an important research topic. This is a considerable future research.

Appendix: Proofs

Proof of Proposition 1: Differentiating $G(\alpha)$ with respect to α , we have

$$\frac{dG(\alpha)}{d\alpha} = \frac{(a-c)(3\alpha-1)}{(3-\alpha)^3}. \quad (12)$$

(12) is negative for $\alpha < 1/3$ and positive for $\alpha > 1/3$. This implies that given $c_1 = c_2 = c$, the marginal benefit of R&D is decreasing (increasing) in α for $\alpha < (>) 1/3$. This yields Proposition 1. **Q.E.D.**

Proof of Proposition 2: Differentiating $H(\alpha)$ with respect to α , we have

$$\frac{dH(\alpha)}{d\alpha} = -\frac{2(a-d)(1-\alpha)}{(3-\alpha)^3}. \quad (13)$$

(13) is negative for $-1 < \alpha < 1$. **Q.E.D.**

Proof of Proposition 3: We prove this proposition along the same lines as Proposition 1.

Differentiating $J(\beta, n)$ with respect to β , we have

$$\frac{\partial J(\beta, n)}{\partial \beta} = \frac{(a-c)(n-1)^2(1+\beta-n+\beta n)}{[2+(1-\beta)(n-1)]^3}. \quad (14)$$

Note that $(a-c)$ and $2+(1-\beta)(n-1)$ is always positive. Hence, (14) is negative for $1+\beta-n+\beta n < 0$ and positive for $1+\beta-n+\beta n > 0$. A simple calculation leads us to

$$\frac{\partial J(\beta, n)}{\partial \beta} < 0 \text{ for } \beta < \frac{n-1}{n+1} \text{ and } \frac{\partial J(\beta, n)}{\partial \beta} > 0 \text{ for } \beta > \frac{n-1}{n+1}.$$

This implies that given $c_j = c$ for all j , the marginal benefit of R&D is decreasing (increasing) in β for $\beta < (>) (n-1)/(n+1)$. This yields Proposition 3. **Q.E.D.**

Proof of Proposition 4: (i) Differentiating $K(\alpha)$ with respect to β , we have

$$\frac{dK(\alpha)}{d\alpha} = \frac{2(1-\alpha)(a-c)}{(3-\alpha)^3}.$$

This implies that $dK/d\alpha > 0$ for all $\alpha \in (-1, 1)$. Thus, we have Proposition 4(i).

(ii) Note that $I^* > (<)I^E$ if and only if $K(\alpha) > (<)G(\alpha)$. The simple calculation leads us to

$$K(\alpha) - G(\alpha) = \frac{(a - c)(1 - \alpha)\alpha}{(3 - \alpha)^2}.$$

This implies Proposition 4(ii).

Q.E.D.

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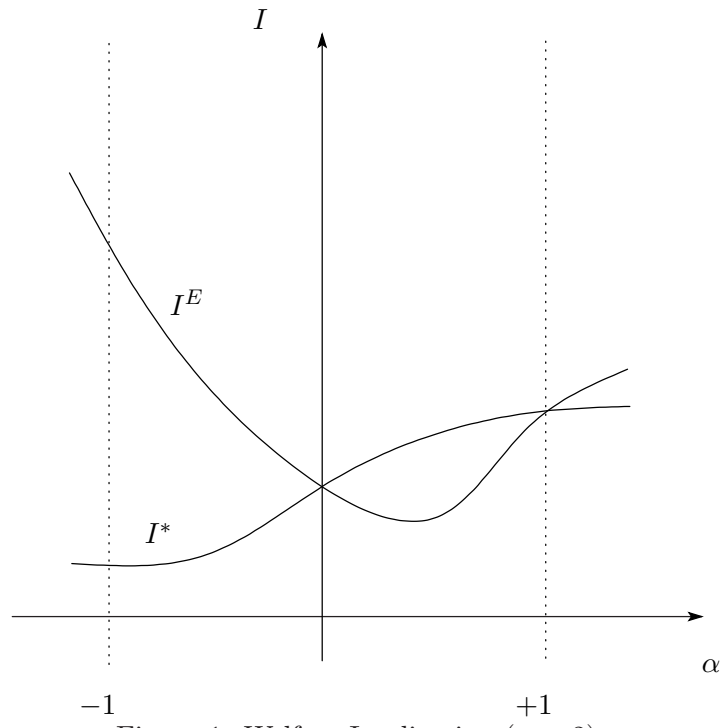


Figure 1: Welfare Implication ($n = 2$)