Ambitious and Motivated Managers in R&D Competition*

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Abstract

We investigate firms' incentive to employ non-profit maximizing managers in R&D competition. Based on evidences from business administration and psychology, we consider two kinds of characteristics of managers: (1) "ambitious" managers are biased toward a big innovation and (2) "motivated" managers are inclined to invest a lot in R&D. We find that both ambitious and motivated managers are employed under some conditions. There are two opposite reasons why they are employed due to the interplay between these two characteristics of managers.

Keywords: firm objective, non-profit maximization, personality of managers, innovation size, patent race, quality competition, delegation game

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1 Introduction

Profit maximization of firms is a very prevalent assumption about firms' behavioral rule in ecnomics. Friedman (1953) argues that profit maximization assumption can be supported because firms which do not maximize profits will die out.

There are many papers which deny this view and support non-profit maximization of firms[1]. However, to the best of our knowledge, no work addresses this problem in quality improving R&D competition.The importance of R&D is increasing. As is well known, the importance of quality improvement, rather than that of cost reduction, is getting larger due to the development of information knowledge industry. In addition, the investment on R&D is growing in many countries. Figure 1 shows Japanese and U.S. total expenditure on R&D. Despite the bankrupcy of Leaman brothers and the subsequent recession, it is on a clear increasing trend.

The objective of this paper is to fill this gap. Specifically, we combine the model about quality improving R&D competition (O'Donoghue (1998), Ishibashi and Matsumura (2006)) with delegation game(Fershtman and Judd (1987)) to see what kind of (potentially non-profit maximizing) managers are employed in a plausible equilibrium.

In such a competition, firms must choose both (1) the amount of investment and (2) the target of R&D. Firms can invest a lot or not so much, and they can either pursue a very innovative idea or try to make a steady improvement on their current product. We assume that an owner lets its firm commit to large values of both (1) and (2) by employing a manager with certain characteristics. We call a manager who commits to (1) as a "motivated" manager since such a person can be regarded as aspiring the success of the R&D, and one who commits to a large value of (2) as a "ambitious" manager. They are clearly non-profit maximizing managers since they take in consideration factors other than the profit. See Table 1 for the summary of the discussion in this parapraph.

Table 1: Classification of Managers

Investment / Target	Not Committed	Committed
Not Committed	"Profit Maximizing"	"Ambitious"
Committed	"Motivated"	"Ambitious&Motivated"

You may recall firms in IT business like Google or Apple. They are often seen as leaders of innovation and both motivated and ambitious toward

[1]The literature review on this topic is given in section 2

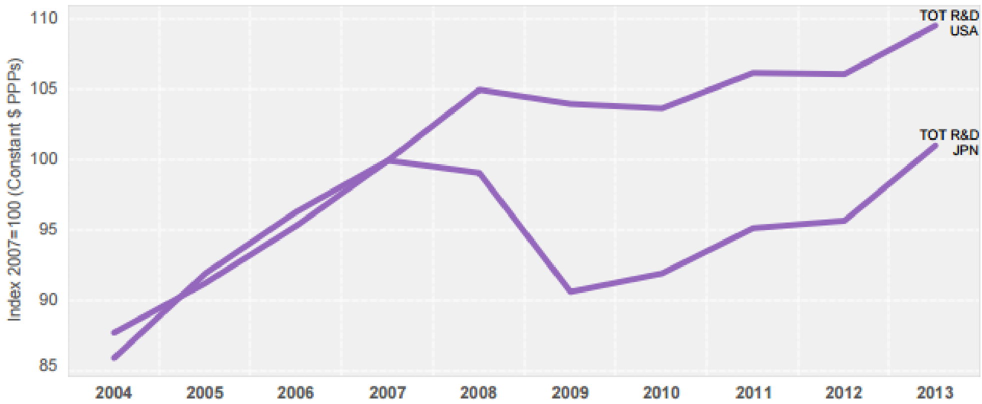

Figure 1: Japanese and U.S. total expenditure on R&D
Source: OECD Main Science and Technology Indicators Database, 2015/1

it. Another example is GE. GE clearly states in its homepage[2] that it will "invest a lot in R&D" and "pursue a truely innovative change." Of course, they maintain such image to, for instance, attract talented employees or to advertise themselves efficiently. However, even if these reasons are absent, such image may be maintained because of strategic reasons. This paper trys to explain the existence of such managers in this manner.

Some readers may want to have more comvincing evidence on whether such managers exist in actual markets. We claim that this is the case based on business administration and psychology literature. Brandstätter (1997) and Beugelsdijk and Noorderhaven (2005) show that self-employed people have different personality than general population and they are more willing to work hard and eager for a future success. Since many self-employed people work as a manager, this implies that managers may also have such characteristics. The more direct evidence is given by Howell and Higgins (1990). They analyze the personality of people who are in charge of a successful innovation. They find that they are likely to take a risk and commit to an achievement. This is in line with the argument in the previous paragraph.

Recall that the objective of this paper is to explain the existence of such managers in an equilibrium. It turns out that this work is successful in this regard, but it suggests that the existence depends on competition environment. In other cases, profit-maximizing managers are employed. How they differ from profit-maximizers depends on market conditions.

In addition, this model can shed some light on the relationship between these two characteristics. As far as we know, no work uses two commitment device at once in delegation game. This may be because in a standard I.O.

[2] http://www.ge.com/jp/company/technology/ viewed on 15/11/15

models such as Cournot or Stackelberg, the number of choice variable is one and so they are not rich enough to accomodate two devices in a satisfactory manner. However, as we show later, two commitment devices(i.e. characteristics of managers) interact with each other. We believe that this approach can be used to understand strategic meanings of personality.

This paper is organized as follows. Section 2 reviews related literature. Section 3 introduces the two-stage model we use. The socially optimal situation is derived in section 4. The equilibrium of stage 2 is discussed in section 5. Section 6 discusses incentives to employ a biased manager. Section 7 concludes. All proofs are collected in the Appendix.

2 Literature Review

This paper is closely related to literature on non-profit maximization and so we see it first. Then, we briefly review literature on patent race.
Fershtman and Judd (1987) introduce "delegation game" in which an owner of the firm can employ a manager with non-profit maximizing objective. They show that non-profit maximizing firms can be better off. Schaffer (1989) and Bester and Güth (1998) use evolutionary game to prove that non-profit maximizing dominate the market in ESS(Maynard Smith (1982)) [3]. Vega-Redondo (1997) also adopts an evolutionary approach, but he uses stochastic evolutionary games as in Kandori et al. (1993) and Young (1993). He shows that if firms act to survive(i.e. to increase the relative profit), then Walrasian Behavior arises. This result is important but note that profit-maximization is not supported as a short-run behavioral rule, which is the focus of this paper. Kaneda and Matsui (2003) prove that, in some situations, non-profit maximizing firms make more profit than profit maximizers, although their model do not endogenously explain why firms may have non-profit maximizing motives,

All works mentioned above assume Cournot competition with homogenious goods. However, some recent papers apply non-profit maximization to other competition schemes. Fershtman and Gneezy (2001) introduce the delegation to ultimatum game and analyze experimentally wherther it is effective or not. Matsumura and Matsushima (2012) introduce a delegation game to Hotelling competition to show that promoting a smart city may be harmful. Siciliani et al. (2013) assume semi-altruistic health care providers and analyze the dynamics of the health care market. Kopel et al. (2014)

[3]Delegation game(Fershtman and Judd (1987)) and indirect evolutionary approach(Bester and Güth (1998)) have a close relationship. See Dufwenberg and Güth (1999).

consider firms which care about consumer surplus and evolutionary system to analyze the nature of surviving firms in Cournot competition with vertical and horizontal quality differentiation. However, in contrast to our work, they do not endogenize the quality choice.

Now, let us give a brief look at literature on patent race. O'Donoghue (1998) proposes a model which captures sequential quality competition in duopoly. Although he uses it to analyze the optimal length of patent protection, this model is flexible enough to analyze other research questions. For example, Ishibashi and Matsumura (2006) apply O'Donoghue (1998) model to show that public firms do not act optimally in terms of socoal welfare.

Based on this review, let me clarify the two novel points of this paper compared to previous works. First, this is the first model to introduce the delegation into the patent race model. Second, it deals with two commitment devices at once and so it is successful in explaining the relationship between them. All works mentioned above consider only one direction of deviation from profit maximization.

3 Model

Consider a two stage delegation game where the quality competition a lá O'Donoghue (1998) takes place in the second stage. This is a perfect information game and so the solution concept we employ is subgame perfect equilibrium(SPE, hereforth). We first describe stage 2 game and then go back to stage 1.

3.1 Stage 2

Notations used in this subsection follow those in Ishibashi and Matsumura (2006). There are two firms, firm 1 and firm 2. They compete in quality-improving R&D competition which lasts infinitely. Time is continuous and the interest rate is denoted by r.

At any moment, the firms sell their products in the market[4]. Their products are differentiated only in quality. The term "quality" captures all dimensions of the product and so it fully characterizes the product. We call the firm with a higher quality as "leader" and the other one as "follower." We define $\Gamma \geq 0$ as the quality gap between these two firms. The quality of each firm is determined as the result of the following R&D competition. At any moment, firm $i(=1,2)$ chooses two variables: the amount of R&D spending $x_i \in [0,\infty)$ and the targeted size of innovation $\Delta_i \in [0,\infty)$. We suppose that

[4]How they compete is discussed later in this subsection.

innovation occurs according to a Poisson process. Specifically, we define the probability of firm i achieves the innovation before the elapsed time τ to be $F_i(\tau) = 1 - e^{-g(x_i)h(\Delta_i)\tau}$. Note that the "instantaneous probability", that is, the probability of the success at any time t is $g(x_i)h(\Delta_i)$ due to the nature of Poisson process[5]. The function $g : \mathbb{R}_+ \to [0, 1]$ represents the relationship between the amount of R&D investment and the probability of success and we suppose $g'(x_i) > 0$ and $g''(x_i) < 0$. This means that the additional investment always increases the probability of success, but the increment becomes smaller and smaller. The function $h : \mathbb{R}_+ \to [0, 1]$ defines the relationship between the size of targeted innovation and the probability of success. We impose $h'(\Delta_i) < 0$ That is, the likelyhood of success decreases if you set a more ambitious target. There is some additional condition on $h(x)$[6].

When firm i succeeds in an innovation of size Δ_i, it acquires the right to use it exclusively and discloses the relevant information of the innovation. Since it is protected by the patent, the other firm cannot use the newest technology. However, since both firms know the information of the newest one, the next R&D occurs based on the new one. Let the quality of firm i's good be q_i and assume that the initial point is $q_1 = q_2 = 0$. See Figure 2. Starting from the initial startpoint, they engage in the R&D competition. If one firm succeeds, it enjoys the quality gap of that amount Γ until the next success of either firm. However, the next competition is based on the new startpoint which stands on the newest innovation. If the firm i is a leader and succeeds in R&D again, then the quality gap Γ becomes $\Gamma + \Delta_i$. If it is the follower and it succeeds in the innovation prior to its rival, then firm i becomes a leader with the quality gap Δ_i. Notice that this competition describes the situation where every information on the newest technology is disclosed and the length of the patent protection is potentially infinite. Therefore, the length of the protection(O'Donoghue (1998)) or non-progressive R&D investments(Cardon and Sasaki (1998)) are not considered in this model for simplicity.

Now, we turn to the description of the static competition in the output market. Normalize the marginal cost of both firms to be zero. At all times, each comsumer buys at most one unit of goods and receive utility $q - p$ from consuming the good with quality level q at price p. Each firm simultaneously

[5]The probability is defined by $F_i'(t)/(1 - F_i(t))$. Computing this yields the result. Although the definition involves time t, the instantaneous probability $g(x_i)h(\Delta_i)$ does not include it. This is well known the memoryless property of Poisson process.

[6]h has to satisfy the following conditions: (i)for all $\beta \in \mathbb{R}_+$, the solution to $h'(\Delta)(\Delta - \beta) + h(\Delta) = 0$ is determined uniquely. This is a simplifying assumption. (ii)for all $\beta \in \mathbb{R}_+$, at the point x s.t. $h'(x)(x - \beta) + h(x) = 0$, $h''(x)(x - \beta) + 2h'(x) < 0$ This condition is required to satisfy the second order conditions which appear later in all cases.

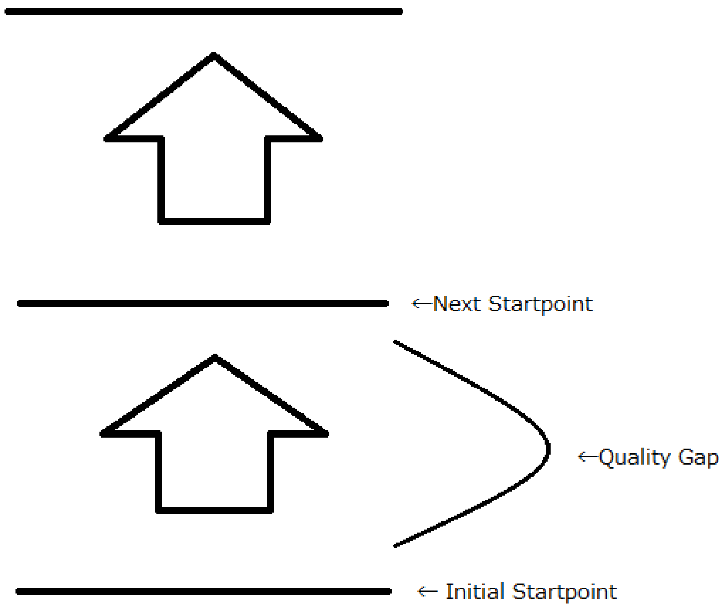

Figure 2: Sequential Innovation

and independently chooses its price to maximize the profit[7].

Denote the price of firm i by p_i. A consumer buys a good from firm i if $q_i - p_i > q_j - p_j$ and $q_i - p_i \geq 0$ where $j \neq i$. Suppose the firm i is the leader with the quality gap $\Gamma > 0$. Then, by the analogous argument to that in the Bertland competition, the result of this game would be $p_j = 0$ and $p_i = p_j + \Gamma - \epsilon$ where $\epsilon > 0$ is infinitesimally small. This implies that firm i earns (almost equal to) Γ and firm j earns nothing. If $\Gamma = 0$, both firms earn 0 by the same argument as above. Note that the gross surplus is $q - p$(consumer surplus) $+p$(producer surplus) $= q$.

3.2 Stage 1

In this subsection we describe the game in stage 1. Here, a version of delegation game(Fershtman and Judd (1987)) takes place. For each firm $i = 1, 2$, there is a owner who seeks to maximize firm i's profit and they employ a manager so that the achieved profit in stage 2 is maximized. A manager can be potentially biased toward R&D decisions. A manager is "motivated" if he is committed to invest a lot and is "ambitious" if committed to target a large innovation size.(See Table 1 for the summary of this argument).

More specifically, we assume the following situation. A owner of firm i can choose the "motivated" parameter $\alpha_i \in [0, 1 - \epsilon]$ and the "ambitious" parameter $\beta_i \in [0, \infty)$ where $\epsilon > 0$ is an arbitrary small positive number.

The "mental cost of the investment" to firm i's manager is given by $1 - \alpha_i$.

[7]Even nonprofit maximizers act to maximize profit in the static competition. This is because the commitment is applied only to R&D spending and the target of R&D as we see in the following subsection.

If α_i is larger than zero, it means that a manager regards the investment cost as lower than the real cost and hence he is committed to a larger investment than when he is a profit maximizer.

The "mental size of innovation" to the manager of firm i is denoted as $\Delta_i - \beta_i$. This is the perceived size of innovation to manager of firm i. If β_i is large, he is not pleasant with the innovation size he achieves compared to a profit-maximizing owner is. Therefore, large β_i means the manager is committed to a large innovation size. A owner can alter the outcome of stage 2 by altering α_i and β_i of a manager he employs. Both owners simultaneously choose these parameters to maximize profits.

4 Social Planner's Problem

As a benchmark, we discuss the socially optimum outcome. Since stage 1 affects only the parameter of the objective functions, it does not matter in finding the social optimum. Therefore, we focus on stage 2 in this section.

Let $q(t)$ be the quality of the leader at time t and $x_i(t)$ and $\Delta_i(t)$ be firm i's R&D spending and the targeted size of innovation at time t, respectively. Since the social surplus from the output market is $q(t)$ and the R&D spendings of each firm is the only cost, the social welfare W is given by

$$W = \int_0^\infty q(\tau)e^{-r\tau}d\tau - \sum_{i=1}^{2}\int_0^\infty x_i(\tau)e^{-r\tau}d\tau \tag{1}$$

Note that once some innovation is made, it benefits comsumers forever. Therefore, the discounted sum of the social gain of the innovation is Δ_i/r and the expected gross social gain is $g(x_i)h(\Delta_i)\Delta_i/r$. $g(x_i)h(\Delta_i)$ is the instantaneous probability of success. Thus, the expected total social surplus EW is given by

$$EW = \sum_{i=1}^{2}\int_0^\infty [\frac{g(x_i(\tau))h(\Delta_i(\tau))\Delta_i(\tau)}{r} - x_i(\tau)]e^{-r\tau}d\tau \tag{2}$$

SInce the situation is time-invariant, the optimal choices for the social planner are also time independent. Therefore, by partially differentiating (2), we get the socially optimum action plan $(x_i^{sc}, \Delta_i^{sc})$. They satisfy the first order conditions[8]:

$$h(\Delta_i) + h'(\Delta_i)\Delta_i = 0 \tag{3}$$

$$-1 + \frac{g'(x_i)h(\Delta_i)\Delta_i}{r} = 0 \tag{4}$$

[8]Under the assumptions made so far, the second order conditions are also satisfied.

5 Equilibrium of Stage 2

To find a SPE, we first find a nash equilibrium in stage 2. Since the strategies depend on the history of the game, there are in general many equilibria and equilibrium selection problem arises. Here, we claim Markov Perferfect Equilibrium(MPE, hereforth) is a suitable solution concept in this context. MPE is an equilibrium constituted by strategies which are contingent only on state variables. That is, players do not have to look back the whole history and the current state provides enough information to determine the action. Due to this nature, MPE has the following properties: (a)collusion is not feasible and firms compete in every state (b) the amount of information to be processed is small and so cognitively easy to conduct (c) due to its simplicity, it may serve as a focal point. Ishibashi and Matsumura (2006) also adopt MPE as a solution concept in this vein. We can show that there is a very simple MPE in this game.

Proposition 1. In stage 2, there is a MPE in which, for all α_i and $\beta_i, i = 1, 2,$ each firm takes a particular action regardless of the state variables.

Proof. See Appendix. □

Proposition 1 states that there is a MPE which does not depend even on state variables and firms take a constant action. It does not depend on the quality gap Γ, time t, and even whether a firm is the leader or the follower. This is particularly simple to work with and superior in the advantages of MPE described above. Below, we assume that this MPE is realized in stage 2 and derive a SPE which induces this MPE in stage 2.

In the appendix, we show that the actions taken satisfy the following first order conditions: for $i = 1, 2, j \neq i$,

$$\frac{g'(x_i)h(\Delta_i)(\Delta_i - \beta_i)}{r + g(x_j)h(\Delta_j)} = 1 - \alpha_i \tag{5}$$

$$h'(\Delta_i)(\Delta_i - \beta_i) + h(\Delta_i) = 0 \tag{6}$$

From these equations, we get the following lemma:

Lemma 2. For $i = 1, 2, j \neq i$, fix the opponent's action x_j and Δ_j. Then, $\partial\Delta_i/\beta_i > 0$ and $\partial x_i/\alpha_i > 0$.

Proof. See Appendix. □

This lemma confirms the interpretation discussed in section 3.2 that α_i and β_i correspond to the commitment to the spendings of the R&D investment and the target size of the innovation, respectively. Given the opponent's action, the larger value of each parameter yields the intended change.

For later use, we define the profit of firm i, π_i. For $i = 1, 2, j \neq i$,

$$\pi_i = \frac{g(x_i)h(\Delta_i)\Delta_i}{r + g(x_j)h(\Delta_j)} - x_i \tag{7}$$

6 Incentives for employing a biased manager

Supposing that the MPE discussed in the previous section realizes in stage 2, we move on to the analysis of stage 1. Recall that what we want to see is whether ambitious and motivated firms survive in R&D competition. The reasons and mechanisms about the result is also of interest. For this purpose we want to find a SPE of this game. However, since we have not specified the functional forms it is impossible to get a SPE in a specific form. To keep the generality as much as possible, we will derive some sufficient conditions for the existence of ambitious and motivated firms by focusing on "local" deviation from the current state. We also use a numerical example with specified functions to illustrate "global"results.

We consider two situations: (i) $\alpha_1 = \alpha_2 = 0, \beta_1 = \beta_2 = \beta^* \geq 0$ (ii) $\alpha_1 = \alpha_2 = \alpha^* \geq 0, \beta_1 = \beta_2 = 0$. We analyze if there is an incentive for firm i to increase α_i in (i) and for it to increase β_i in (ii). In words, (i) corresponds to the situation where firms may be ambitious but not motivated. We examine if there is an incentive for a owner to employ a more motivated manager. Similarly, (ii) is the situation where firms may be motivated but not ambitious. Again, an incentive for a owner to hire a more ambitious manager is examined.

6.1 Incentive to employ a motivated manager

First, we examine the situation (i). Differentiate π_i w.r.t. α_i and evaluate it at $\alpha_1 = \alpha_2 = 0, \beta_1 = \beta_2 = \beta^* \geq 0$ For $i = 1, 2, j \neq i$, we get

$$\frac{\partial \pi_i}{\partial \alpha_i} = \frac{\partial x_i}{\partial \alpha_i}\left(\frac{g'(x_i)h(\Delta_i)\Delta_i}{r + g(x_j)h(\Delta_j)} - 1\right) - \frac{\partial x_j}{\partial \alpha_i}\frac{g(x_i)g'(x_i)h(\Delta_i)^2}{(r + g(x_j)h(\Delta_j))^2} \tag{8}$$

From (5) and our assumptions,

$$\frac{g'(x_i)h(\Delta_i)\Delta_i}{r+g(x_j)h(\Delta_j)} - 1 = \frac{g'(x_i)h(\Delta_i)\beta^*}{r+g(x_j)h(\Delta_j)} \geq 0 \tag{9}$$

$$\frac{g(x_i)g'(x_i)h(\Delta_i)^2}{(r+g(x_j)h(\Delta_j))^2} > 0 \tag{10}$$

Therefore, when $\beta^* = 0$, $\partial\pi_i/\partial\alpha_i > 0$ if and only if $\partial x_j/\partial\alpha_i < 0$. This means that the opponent decreases its investment as a response to a increase in α_i. This effect is due to "credible threat" in commitment as seen in standard games with non-profit maximizing preferences(Fershtman and Judd (1987), Dufwenberg and Güth (1999), Fershtman and Gneezy (2001), Kopel et al. (2014)). For example, in Cournot duopoly when faced with a motivated firm, the opponent decreases its output since the price becomes lower than usual due to the motivated firm. When $\beta^* > 0$, $\partial\pi_i/\partial\alpha_i$ can be positive even in the absence of this effect since the increase in α_i effectively increases the probability of success of the innovative project. However, Proposition 3 states that this is not likely.

Proposition 3. Suppose $\alpha_1 = \alpha_2 = 0, \beta_1 = \beta_2 = \beta^* \geq 0$ and the MPE discussed in Proposition 1 realizes in stage 2. Then, for $i = 1, 2, j \neq i$, $\partial x_j/\alpha_i \lesseqqgtr 0$ and $\partial x_i/\alpha_i \gtreqqless 0$ if and only if $h(\Delta_i)(-g'(x_i)^2 - g(x_i)g''(x_i)) - rg''(x_i) \gtreqqless 0$

Proof. See Appendix. □

Proposition 3 implies that without "credible threat", firm i do not increase its amount of investment even if α_i increases. To understand this seemingly contradictory result, you should recall that whether a threat is effective or not depends not only on the sender but also the receiver. Since two firms are competeing, the optimal reaction to the increase in the opponent's probability of success may be to invest more so that it can recover the probability of winning the race. Therefore, the increase in α_i may induce more investment of the opponent and so it does not work as a "threat." This result cannot be obtained by a standard Cournot competition with delegation. Note that this does not mean that the increase in α_i is useless in mitigating the loss due to high β^*. It is indeed effective in some cases. Proposition 3 states it is effective only when the threat is present.

Next, let's interpret the condition in Proposition 3. It says that the threat is present if and only if $h(\Delta_i)(-g'(x_i)^2 - g(x_i)g''(x_i)) - rg''(x_i) > 0$. As we discussed above, whether the threat is effective depends both on the sender and the receiver. The function g is used by both of them. It determines the strength of the threat by the sender and the effect of the response by the receiver. This is why seemingly complicated condition arises. Note that when the interest rate r is high the condition will be satisfied. High r means that only the immediate success matters for firms. So, high α_i induces a huge increase in x_i and so the threat becomes effective.

Combining (8) and Proposition 3, we get Theorem 4. Theorem 4 summarizes the argument so far in this subsection.

Theorem 4. Suppose $\alpha_1 = \alpha_2 = 0, \beta_1 = \beta_2 = \beta^* \geq 0$ and the MPE discussed in Proposition 1 realizes in stage 2. Then, $\partial\pi_i/\partial\alpha_i > 0$ if and only if $h(\Delta_i)(-g'(x_i)^2 - g(x_i)g''(x_i)) - rg''(x_i) > 0$.

The following Example 5 gives a touch of the global result to supplement the argument.

Example 5. Let $r = 0.05, g(x) = 1 - e^{-x}, h(\Delta) = 1/(1+\Delta)^2$ and let $\beta_1 = \beta_2 = 0$. Owners can choose α to maximize their profit. The equilibrium values are $\alpha_1 = \alpha_2 \simeq 0.31$ and so they become motivated. Each firm produces about 0.71 while that of the socially optimal level is about 0.8 from (3) and (4). On the other hand the amount each firm produces is 0.64 without delegation. Therefore, the welfare loss is grealty mitigated. □

6.2 Incentive to employ an ambitious manager

Next, we analyze the case (ii): $\alpha_1 = \alpha_2 = \alpha^* \geq 0, \beta_1 = \beta_2 = 0$ and see if there is an incentive for an owner to employ a biased manager. We differentiate π_i w.r.t. β_i to obtain

$$\begin{aligned}\frac{\partial\pi_i}{\partial\beta_i} =& -\frac{\partial x_j}{\partial\beta_i}g'(x_j)h(\Delta_j)\frac{g(x_i)g'(x_i)h(\Delta_i)}{(r+g(x_j)h(\Delta_j))^2} \\ &+ \frac{\partial x_i}{\partial\beta_i}(\frac{g'(x_i)h(\Delta_i)\Delta_i}{(r+g(x_j)h(\Delta_j))} - 1) \\ &+ \frac{\partial\Delta_i}{\partial\beta_i}g(x_i)\frac{h'(\Delta_i)\Delta_i + h(\Delta_i)}{r+g(x_j)h(\Delta_j)} \end{aligned} \tag{11}$$

With (5) and (6), we can use a version of envelope theorem to obtain

$$\frac{\partial\pi_i}{\partial\beta_i} = -\frac{\partial x_j}{\partial\beta_i}g'(x_j)h(\Delta_j)\frac{g(x_i)g'(x_i)h(\Delta_i)}{(r+g(x_j)h(\Delta_j))^2} + \frac{\partial x_i}{\partial\beta_i}\alpha^* \tag{12}$$

We can easily see that $-g'(x_j)h(\Delta_j)g(x_i)g'(x_i)h(\Delta_i)/(r+g(x_j)h(\Delta_j))^2 < 0$. Therefore, the incentive $\partial\pi_i/\partial\beta_i$ can be again divided into two parts. The term with $\partial x_j/\partial\beta_i$ is the effect of "threat" and that with $\partial x_i/\partial\beta_i$ corresponds to the "own" effect. If the threat is effective, it is beneficial for firm i as well as in the previous subsection. The own effect is beneficial if $\partial x_i/\partial\beta_i < 0$ and $\alpha^* > 0$. When $\alpha^* > 0$ firms engage in a severe competition in the amount of the investment. Higher β_i may be an effective way to get out of this competition. This is what the second term captures.

Readers may guess that the situation is similar to that in the previous subsection and that there is an incentive if and only if "credible threat" is present. However, theorem 6 show that this is not the case. To the ease of exposition, we utilize the symmetry to get $x_1 = x_2 = x, \Delta_1 = \Delta_2 = \Delta$ and let $g(x_1) = g(x_2) = g, h(\Delta_1) = h(\Delta_2) = h$.

Proposition 6. Suppose $\alpha_1 = \alpha_2 = \alpha^* \geq 0, \beta_1 = \beta_2 = 0$ and the MPE discussed in Proposition 1 realizes in stage 2. Then, $\partial x_j/\beta_i \lesseqgtr 0$ if and only if $(g')^2(h''\Delta + 2h') + g''h'\Delta \lesseqgtr 0$, and $\partial x_i/\beta_i \gtreqless 0$ if and only if $(g'')^2(h''\Delta + 2h') + g(g')^3h(h')^2/(r+gh)^2 > 0$.

Proof. See Appendix. □

Although the conditions are hard to interpret, we can see that the value of the project plays a crucial role. For example, large g', small g'', and small h' given $h''\Delta + 2h'$ imply an effective threat. Large r also implies it and the intuition behind it is the same as in Proposition 4.

Compare this result to Proposition 4. We confirm that the directions of the own effect and the threat effect depend on different conditions. Therefore, which term is dominant is crucial in deciding the sign of $\partial\pi_i/\partial\beta_i$. We see this poing later in Example 7. Since β_i affects both (5) and (6) this complication arises.

At first sight, $\partial x_i/\partial\beta_i < 0$ may seem to be a strange situation. Verbally, this means that a manager invests less in the R&D project if he gets more ambitious, which sounds like a contradiction. However, this may be possible. As we saw in Lemma 2, ambitious manager sets a more innovative target. It increases the return of the one success but decreases the probability of success at the same time. Since the project's value is determined by its return and the probability of success, it may decrease the value of the R&D project. Hence, the amount of spendings in R&D investment may decrease as a manager gets more ambitious.

As we stated, the sign of $\partial\pi_i/\partial\beta_i$ depends on which term in (12) is dominant and the related condition becomes too messy. So, we will not present it explicitly. Instead, we give an example to show that which term is dominant is impornant.

Example 7. As in Example 5, let $r = 0.05, g(x) = 1-e^{-x}, h(\Delta) = 1/(1+\Delta)^2$ and let $\beta_1 = \beta_2 = 0$. The equilibrium values are $\alpha_1 = \alpha_2 \simeq 0.31$. The question is that, at $\alpha_1 = \alpha_2 \simeq 0.31, \beta_1 = \beta_2 = 0$, does each firm have an incentive to become slightly more ambitious? The answer is Yes. To see this, we substitute specific values into (12). It turns out that $\partial x_j/\partial \beta_i \simeq 0.016$, $\partial x_i/\partial \beta_i \simeq -0.027$ and $g'(x_j)h(\Delta_j)g(x_i)g'(x_i)h(\Delta_i)/(r + g(x_j)h(\Delta_j))^2 \simeq 0.495$. Substituting these into (12), the value is about 0.01 and so positive. Here, "own effect" beats the negative effect from the threat term. Here, as opposed to the intuition, increasing β_i is a "humble" action and so induces more investments of the opponent. Even so, own effect is stronger in this case. $\square$

Theorem 8. Let $r = 0.05, g(x) = 1 - e^{-x}, h(\Delta) = 1/(1 + \Delta)^2$. Then, in the SPE which induces the MPE discussed in Theorem 1, ambitious and motivated managers are employed.

Proof. See Appendix. $\square$

Combining Theorem 4, Example 5 and Example 7, we get Theorem 8. We argued in the introduction that ambitious and motivated managers are observed in quality competition. Theorem 8 explains their existence.

7 Concluding Remarks

There are ambitious and motivated managers in R&D competition. The results are the following. (1) When managers are ambitious, motivated managers are employed under some conditions. Likewise, when managers are ambitious, motivated managers are employed under some conditions. (2) Being motivated alleviates the loss from being ambitious and being ambitious does that from being motivated. So, biased managers may be employed despite the presence of "threatening commitment." (3) Becoming ambitious may increase or decrease R&D spending. This is because targetting a large innovation may not profitability of the R&D project. Depending on which is the case, there are two opposite reasons why ambitious managers may be employed. (4) There is a case where ambitious and motivated managers are employed in the equilibrium. We find that profit maximizing managers can be employed, but both ambitious and motivated managers are employed in some situations.

Of course, there are many limitations to this paper. First, the discussion is limited to local incentives and there is few discussion about global incentives. Second, this does not explicitly derive an equilibrium. Third, it is better for other aspects of R&D competition, such as R&D to avoid infringement of others' patents(Cardon and Sasaki (1998)) to be included. Fourth, the relationship to other approaches such as models using stochastic evolution(Vega-Redondo (1997)) remain untouched. Fifth, although the current paper adopts a two-stage game, richer dynamics of the market should be taken into consideration as in Kopel et al. (2014). They are left for future research.

A Proofs.

Proof of Proposition 1. Due to the symmery, we can focus on firm $i = 1, 2$ without loss of generality. Suppose firm i is the follower and firm $j \neq i$'s action x_j, Δ_j are constant in all states. This determines the instantaneous probability of success of firm j to be $g(x_j)h(\Delta_j)$. Therefore, the discount rate to firm i becomes $r+g(x_j)h(\Delta_j)$. The instantaneous perceived expected gain from R&D is $g(x_i)h(\Delta_i)(\Delta_i - \beta_i)$ and the psychological cost of investment is $(1-\alpha_i)x_i$. Therefore, the net benefit of from the R&D is

$$\frac{g(x_i)h(\Delta_i)(\Delta_i - \beta_i)}{r + g(x_j)h(\Delta_j)} - (1-\alpha_i)x_i \tag{13}$$

(13) does not depend on the value of t or Γ, it is optimal for firm i to take a constant action. Differentiating (13) gives FOCs (5) and (6).

Suppose firm i is the leader. If it succeeds in R&D it enjoys additional quality gap Δ_i until the opponent succeeds in R&D. Therefore, the increment in the gain is the same amount as before. Since the cost structure is the same, the net benefit can again be described by (13). Therefore, the optimal strategies do not depend even on whether firm i is the leader or the follower. $\square$

Proof of Lemma 2. Δ_i has to satisfy (6). Applying Implicit Function Theorem to (6) yields

$$\frac{\partial \Delta_i}{\partial \beta_i} = \frac{h'(\Delta_i)}{h''(\Delta_i)(\Delta_i - \beta_i) + 2h'(\Delta_i)} > 0 \tag{14}$$

From (6), Δ_i is uniquely determined under our assumptions. So, we can treat it as a parameter. Implicit Function Theorem applied to (5) gives

$$\frac{\partial x_i}{\partial \alpha_i} = \frac{-g''(x_i)h(\Delta_i)(\Delta_i - \beta_i)}{r + g(x_j)h(x_j)} > 0 \tag{15}$$

$\square$

Proof of Proposition 3. Exploiting symmetry. we focus on the incentive of firm i and let $x_1 = x_2 = x$, $\Delta_1 = \Delta_2 = \Delta$, $g(x_1) = g(x_2) = g$, and $h(\Delta_1) = h(\Delta_2) = h$ at the initial equilibrium. Since $\beta_1 = \beta_2 = 0$, Δ_1 and Δ_2 are determined by (6). Therefore, the equations to be considered are

$$\frac{g'(x_i)h(\Delta-\beta^*)}{r+g(x_j)h} = 1-\alpha_i$$
$$\frac{g'(x_j)h(\Delta-\beta^*)}{r+g(x_i)h} = 1-\alpha_j$$

Applying Implicit Function Theorem to these equations, we get

$$\begin{pmatrix} -g'(x_j)h\frac{g'(x_i)h(\Delta-\beta^*)}{(r+g(x_j)h)^2} & g''(x_i)\frac{h(\Delta-\beta^*)}{r+g(x_j)h} \\ g''(x_j)\frac{h(\Delta-\beta^*)}{r+g(x_i)h} & -g'(x_i)h\frac{g'(x_j)h(\Delta-\beta^*)}{(r+g(x_i)h)^2} \end{pmatrix} \begin{pmatrix} \frac{\partial x_j}{\partial \alpha_i} \\ \frac{\partial x_i}{\partial \alpha_i} \end{pmatrix} = \begin{pmatrix} -1 \\ 0 \end{pmatrix} \tag{16}$$

Therefore, we can obtain $\partial x_j/\partial\alpha_i$ and $\partial x_i/\partial\alpha_i$ from Cramer's rule. Simple calculation shows that the numerators of them are positive and negative, respectively. Therefore, the signs of them are opposite and depend on the numerator. Since

$$\begin{vmatrix} -g'(x_j)h\frac{g'(x_i)h(\Delta-\beta^*)}{(r+g(x_j)h)^2} & g''(x_i)\frac{h(\Delta-\beta^*)}{r+g(x_j)h} \\ g''(x_j)\frac{h(\Delta-\beta^*)}{r+g(x_i)h} & -g'(x_i)h\frac{g'(x_j)h(\Delta-\beta^*)}{(r+g(x_i)h)^2} \end{vmatrix} < 0 \Leftrightarrow h(-g'^2 - gg'') - rg'' > 0 \tag{17}$$

holds, we get the result. $\square$

Proof of Proposition 6. Thanks to symmetry, we can focus on the incentive for firm i to increase β_i. Since $\beta_j = 0$, Δ_j is determined by (6) and so can be treated like an exogenous parameter. The equations we consider are

$$\frac{g'(x_i)h(\Delta_i)(\Delta_i-\beta_i)}{r+g(x_j)h(\Delta_j)} = 1-\alpha_i$$
$$\frac{g'(x_j)h(\Delta_j)(\Delta_j-\beta_j)}{r+g(x_i)h(\Delta_i)} = 1-\alpha_j$$
$$h(\Delta_i)(\Delta_i-\beta_i)+h(\Delta_i) = 0 \tag{18}$$

Let $x_1 = x_2 = x$, $\Delta_1 = \Delta_2 = \Delta$, $g(x_1) = g(x_2) = g$, and $h(\Delta_1) = h(\Delta_2) = h$. Applying the Implicit Function Theorem to (18) we get

$$\begin{pmatrix} -\frac{g'^2h^2\Delta}{(r+gh)^2} & g''\frac{h\Delta}{(r+gh)^2} & \frac{g'(h'\Delta+h)}{r+gh} \\ g''\frac{h\Delta}{(r+gh)^2} & -\frac{g'^2h^2\Delta}{(r+gh)^2} & \frac{gg'hh'\Delta}{(r+gh)^2} \\ 0 & 0 & h''\Delta+2h' \end{pmatrix} \begin{pmatrix} \frac{\partial x_j}{\partial\beta_i} \\ \frac{\partial x_i}{\partial\beta_i} \\ \frac{\partial\Delta_i}{\partial\beta_i} \end{pmatrix} = \begin{pmatrix} \frac{g'h}{r+gh} \\ 0 \\ h' \end{pmatrix} \tag{19}$$

From (6), the top-right element of the leftmost matrix is 0. To compute $\partial x_j/\partial\beta_i$ and $\partial x_i/\partial\beta_i$ we again resort to Cramer's rule. A tedious calculation shows that the denominator is always positive. Therefore, their signs depend on the numerator. We can obtain the result by computing the determinants of matrix which are designated by the Cramer's rule. □

Proof of Theorem 8. From Theorem 4, profit-maximization is not suported in an equilibrium. Example 7 shows that, if the only device used is α then the equilibrium is vulnerable to a slight increase in β. Therefore, what remains to show is that the situation where β is the only device cannot be supported in an equilibrium.

We show this by using Proposition 3. Fix any β^*. The condition for the existence of the incentive to increase α becomes $1+r(1+\Delta)-2e^{-x} > 0$ where $x_1 = x_2 = x$ and $\Delta_1 = \Delta_2 = \Delta$ due to the symmetry at the equilibrium. From Lemma 2, $\Delta \geq 1$ holds. From (6), we get $\Delta = 2\beta + 1$. Substituting this into (5) and solving for x, we get $x = log(20(2+\beta)/21)$. Since $\beta^* \geq 0$, x is larger than $log(40/21)$. So, $1 + r(1+\Delta) - 2e^{-x} > 0$ always holds. That is, for any $\beta^* \geq 0$, there is an incentive to become more motivated. □

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