Delegation in a spatial game with endogenous spillovers

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11 December, 2011

Abstract

In this paper, we combine elements from the two distinct streams of literature: one based on the analysis of strategic delegation, the other focussing on the modelling of endogenous R&D spillovers in a spatial competition framework. We distinguish between two kinds of delegation: Semi-Delegation and Full Delegation in the context of both endogenous spillovers and endogenous product differentiation. It is shown that Semi-Delegation encourages one firm to locate farther from the rival, and it will increase the product variety, foster firms to spend more on R&D, encourage firms to produce high-quality goods and render managers less aggressive, hence increase prices and profits, however, it never benefit consumers and it damages the social welfare. By contraries, under Full Delegation, owners choose the closer location pattern, managers decide to invest less on R&D and produce the low-quality goods. We highlight that Full Delegation is a more efficient strategy, which not only brings on the profits but improves the social welfare as well.

Keywords: Endogenous spillovers; Full Delegation; Semi-Delegation; Horizontal differentiation; Quality
JEL classification: O31; L13; L20; D43

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1 Introduction

Modern corporations are characterized by a separation of ownership and management, which is considered as the reason for deviation from profit maximization (Sklivas, 1987). There are two main objectives for delegation: the first one is that owners seek to use superior ability, by employing specialized and highly qualified managers to handle sophisticated operations; the second one is that owners can achieve gains from the delegation by means of choosing the strategic commitment. In this current paper, we study the latter objective by combining elements from the two distinct streams of literature: one based on the analysis of different types of strategic delegation, the other focussing on the modelling of endogenous R&D spillovers in spatial competition framework.

In the strategic delegation literature, the delegation introduced by Schelling (1960)[1] has received great attention in the industrial organization literature. Earlier theoretical work on delegation has shown that firms have a unilateral incentive to delegate tasks to independent agents. Representative papers initiated by Vichers (1985), Fershtman and Judd (1987), Sklivas (1987), Fershtman, Judd and Kalai (1991) show that in a two-stage Cournot quantity game, owners have incentives to delegate short-run decisions to their managers and in equilibrium, there are higher outputs than the classic Cournot game. This early work, nevertheless neglects the fact that there is another category of decisions which should be taken into consideration, regarding the long-term plans of the firm, such as Research and Development (henceforth R&D). Zhang and Zhang (1997)[2] are the first to introduce the model which combines strategic delegation with R&D under spillovers. They consider a three-stage game, where owners of the firms delegate the decisions of R&D investment and production quantities to managers. Managerial compensation is based on the performance measures (profits and sales). Each manager can make investments in R&D. These investments reduce their own production costs, but due to spillover effect, they also lower production costs of the rival firm. Bàcena-Ruiz and Olaizola (2006), Mitrokostas and Petrakis (2005) investigate different scopes of delegation in a Cournot duopoly model, discriminating between no delegation, full delegation and short-run delegation, where only market decisions were delegated and owners decided on cost reducing R&D themselves. Unlike Zhang and Zhang (1997) they excluded spillover effects and applied a different characterization of the R&D in-

[1] Schelling (1960) determines a situation where delegation is being used as a "self commitment device"

[2] The goal of Zhang and Zhang's analysis was to give a comparison of optimal level of R&D expenditures, production quantities, firm profits and welfare. They demonstrate that managerial delegation will lead to higher R&D investment, higher output, and lower profits in equilibrium compared to no delegation case, if spillover effect of R&D is small. We note that Kopel and Riegler (2006) show the results of Zhang and Zhang (1997) may not always hold true and the key results of their work are incorrect due to an improper handling of the first order conditions at the contracting stage. Nonetheless, Zhang and Zhang provide the basic framework to analyze the issue and have opened up an interesting avenue of research.

vestment. Little work has yet been done to analyze the effects in a differentiated price competition setting with delegation, when spillover effects on product qualities or production costs are explicitly modeled.

In the spillover literature, the notion of spillovers has been formalized by d'Aspremont and Jacquemin (1988) as well as by Kamien, Muller and Zang (1992) in the context of oligopolistic competition. In these papers, and even in the pioneer work of strategic delegation with R&D competition, spillovers are considered as "manna from heaven". They assume that a fixed and exogenously given portion of every firm's process R&D effort leaks and contributes to cost reduction or quality enhancement for other firms. Recently the study of spillovers is divided into two main avenues: "Impact-spillovers" and "Endogenous spillovers". "Impact-spillovers" highlights that spillovers are affected by different kinds of factors, such as absorptive capacity (Cohen and Levinthal, 1990), *ex-ante* adaptability and *ex-post* information sharing (Katsoulacos and Ulph, 1998), product substitutability and technological proximity (Lepape and Zhao, 2011). "Endogenous spillovers" emphasizes that there is a closer relationship between product differentiation and spillovers, specially in the spatial game. The papers embracing the notion of endogenous spillovers, claim that firms would be more likely to conduct research in common areas when they manufacture homogenous goods, because producing similar goods usually demands parallel technical solutions or common inputs. The common research enables competing firms to realize more technological opportunities. In addition, similar production processes allow firms to adapt the technological know-how they learn from one another to their own needs. Piga and Poyago-Theotoky (2005)[3] (hereafter referred to as PPT), Dey and Fu (2009)[4] combine the conventional spatial competition framework with the competitive process R&D in the presence of endogenous spillovers. The former regards the R&D process as quality-enhancing activity, and the latter considers it as cost-saving activity. They both relate the extent of spillovers to firms' product configuration. Our framework adopts the PPT model, and combines the strategic delegation with endogenous spillovers, in order to gain some insights into the interdependence of ownership structure, firm's location pattern, product variety, product quality and market competition.

The contribution of this paper is three-fold. First, we extend the strategic delegation game by introducing the endogenous spillovers. This allows us to study how

[3]Piga and Poyago-Theotoky formulate a three-stage non-cooperative game where two firms choose location, R&D and price, under the assumption that R&D spillovers depend on firms' location. The closer firms are to each other, the greater the benefit they receive from their rivals' efforts in quality-enhancing R&D.

[4]Dey and Fu formulate a three-stage model: in the first stage, two ex-ante duopolistic firms simultaneously choose the locations, and then they engage in competitive cost-reducing R&D in the seconde stage, finally they compete in price.

the ownership structure affects firms' locations[5], R&D as well as their price decisions in the context of both endogenous spillovers and endogenous product differentiation. The second contribution is that we distinguish between two kinds of delegation: Semi-Delegation, in which firms' owners delegate only short-run decisions to their managers; Full Delegation, in which owners delegate both short-run and long-run decisions. The third contribution is to draw on two major types of product differentiation.

Markets are characterized by both horizontal and vertical differentiation[6]. Vertical differentiation reflects that the competing firms produce distinct quality levels. And horizontal differentiation is characterized by different locations of the firms in a Hotelling linear city; alternatively, it reflects consumers' preferences for different brands in the product space. Within this framework, the location space is considered as the range of product variants; the firms' locations not only indicate the product variety but also reflect the extent of R&D spillovers; a consumer's location corresponds to his ideal product; the transportation cost is interpreted as the decrement of utility from not consuming the ideal product; and the effective R&D effort mirrors the product quality.

Our analysis is conducted in a four-stage game. In the first stage, owners[7] choose their locations simultaneously. In the second stage, owners either decide on R&D effort or delegate this decision to managers, in which case, the owners choose a contractual parameter. Notice that the delegation at this stage also implies delegation of the price decision in the next stage. In the third stage, owners can decide to delegate the price decision or retain it for themselves. Finally, the decision-makers (either owners or managers) simultaneously decide the price. Overall, there are three alternative scenarios: No Delegation, Semi-Delegation and Full Delegation.

Both empirical evidence and various examples can be used to illustrate these two

[5]As the literature on spatial competition points out, the location of the firm can also be interpreted as product variety. This literature (see, for example, D'aspremont et al., 1979) usually considers that firms ought to be located within the city limits.

[6]For instance, apparel, garments and shoes have an amazingly rich combination of shapes, colours, materials, complementarities, seasonal and territorial specificities, appropriateness to social events, relative distance to ideals promoted by media, stylists and the showbusiness. The quality of the materials can often be seen as a vertical differentiation but some other elements are clearly horizontal, like shapes.

[7]In practice, owners make the most important location decision. There is the theoretical paper paying attention to this phenomenon, Bárcena-Ruiz and Casado-Izaga (2005) show that owners do have incentives to keep the decisions of firm location for themselves.

types of delegation. It is shown that in some companies, (*i.e.* BMW[8], Benetton[9] and Microsoft[10]), owners tend to delegate only short-run decisions to their managers, while they prefer to preserve control on the long-run decisions; by contraries, in some firms, top managers take both long-run and short-run decisions. For example, this is the case of Kraft, one of America's best-known brand names in food products (see Boyd, 1990).

Concerning managerial contracts, we adopt the incentive contracts consist of a combination of profits and market share. Much anecdotal evidence about the importance of market share motives emerged in the business press and management literature. A classic example is Jack Welch's General Electric, which publicly announced that its key objective is to be number one in all the markets in which it operates. Another example relates to media industries, where market share in terms of listeners (radio stations), readers (newspaper dailies) and viewers (TV channels) is the key to success. Moreover, from the empirical[11] viewpoint, Peck (1988) mentions that the market share is highly ranked in managers' objectives. In the survey for corporate objectives among 1000 American and 1031 Japanese top managers, Peck (1988) documents that increasing market share is ranked third in the American and second in the Japanese sample. All these arguments induce us to explore the delegation game with market share contracts[12].

In this paper, we shed light on the effects of strategic delegation in a Hotelling market with the endogenization of both product differentiation and R&D spillovers. This paper not only explores the issue of whether owners choose the strategic commitment

[8]The case of the BMW (Bavarian Motor Works) company illustrates the Semi-Delegation situation. In this company, in 1984, between 50 and 75% of the property of the firm was in the hands of the Quandt family who also held a very active position in the supervisory board of BMW; the remainder of the firm was owned by a group of European banks and employees of the firm. The owners of BMW were very much involved in the management of the firm (in their long-run decisions) but, at the same time, they delegate short run decisions such as marketing plans to the subsidiaries. As Jenster et al. (1990, p. 142) point out: Although the parent company, BMW in Munich, established broad guidelines, the subsidiaries are responsible for developing their own strategic objectives and marketing plans within their regions.

[9]In Benneton, the owners are very involved in the long-run decisions. As Jarillo and Martnez (1990, p. 72) explain: Benneton approved location of the shops and Luciano (the owner) personally oversaw the more strategic sites.

[10]Additional evidence is given by Microsoft, in this firm Bill Gates, the main owner, plays a dominant role in the strategic decisions of the firm. As The Economist (July 10th 1999, p. 88) read: Could any manager be more firmly entrenched at the head of his company than Bill Gates?

[11]Borkowski (1999) analyzes managerial performance evaluation on the basis of questionnaire data from 261 firms in servery countries (Canada, Germany, Japan, United Kingdom and the United States) and finds that market share often emerged as important.

[12]There are some theoretical papers focussing on the market share contracts. Jansen et al.(2007) and Ritz (2008) formalize the case of Market Share contracts. Their main result is that for the case of Cournot (Bertrand) competition, quantities (prices) set from managers compensated with Market Share contracts are higher than those set by strict profit-maximizing owners.

to achieve gains from the delegation, but also answers to question what type of delegations they prefer to adopt. We analyze the incentive contracts that the owners choose for their managers focussing on how owners may strategically manipulate such contracts and their effect on the degree of product differentiation and the level of spillovers. Furthermore, the analysis of consumer surplus and social welfare is taken into account. By this work, we are able to investigate whether the delegation policies benefit consumers and give rise to a higher level of social welfare.

It is found that Semi-Delegation increases the product variety, fosters firms to spend more on R&D, encourages firms to produce high-quality goods and renders managers less aggressive, hence increases prices and profits. However, both consumer surplus and social welfare decrease under this scenario. By contraries, under Full Delegation, owners choose the closer location pattern, managers decide to invest less on R&D and produce low-quality goods. We highlight that Full Delegation is a more efficient strategy, which not only brings on the profits but improves the social welfare as well.

The reminder of the paper is organized as follows. Section 2 describes the model and section 3 explores the equilibrium in three alternative scenarios. In section 4, we derive our main results. Then, section 5 relates to the analysis in terms of consumer surplus and social welfare. We offer some brief concluding remarks in section 6.

2 The Model

Consider a linear city along the unit interval $[0,1]$, where consumers are uniformly distributed along the interval. Firm i is allowed to locate at $y_i \in [0,1]$ and cannot change their locations in the future. Marginal costs of production c are assumed to be constant and identical for both firms. In what follows, we set $c = 0$ to simplify the analysis. Firms undertake R&D efforts in order to improve the quality of their product, and the R&D investment engaged by one firm may benefit the other firm at no cost *via* spillover effect. As a result of the spillover, a non-negative portion $\lambda \in [0,1]$ of the rival firm j' R&D input contributes to firm i's effective R&D. Firm i's effective R&D effort X_i can be represented as a function of both firms' R&D efforts $X_i = x_i + \lambda x_j$. The parameter λ is the spillover measure which indicates the level of leakage or appropriability. The spillover parameter λ is related to firms' locations (product configurations or characteristics). It is assumed that the greater the distance between two firms, the more differentiated the firms' products, the less the R&D spillovers[13]. Define $\lambda = 1 - y_j + y_i$ which is at a maximum when firms share the same location ($y_i = y_j$) and will be the minimum value

[13]The product characteristic choices of the firms define the areas in which they undertake R&D. When firms produce more similar products, their R&D areas are more likely to overlap. Therefore, this enables

when firms located at the market endpoints ($y_i = 0; y_j = 1$). In addition, there are diminishing returns to quality-improving R&D, the costs of R&D are given by $\frac{\gamma x_i^2}{2}$, where γ is a measure of effectiveness[14] of R&D.

Assume each firm has a principal (*i.e.* owner, board of directors, shareholder) and an agent (*i.e.* manager, CEO), the principals wish to maximize profits but delegate decision-making to agents, who receive strategic incentive contracts and maximize their compensation. Concretely, owner i wants to maximize the firm's profit $\pi_i = p_i D_i - \frac{\gamma}{2} x_i^2$ and has the option to hire a manager to make the short-run price and (or) the long-run R&D investment decisions.

A manager's objective function[15] in the product market places weight on both profits and market share and is given by

$$U_i = \pi_i + \theta_i \frac{D_i}{D_i + D_j}$$

where the weight θ_i is a number chosen by owner i in order to maximize his profit. Notice that there is no constraint for θ_i. Compensation contracts are publicly observable and have the form $A_i + B_i U_i$, where A_i represents his fixed salary, $B_i U_i$ equals a performance-related bonus with $B_i > 0$. Since manager i is risk-neutral, he acts to maximize U_i and the values of A_i and B_i are irrelevant. It is worth while to note that D_i is not only the quantity supplied by firm i but also the market share of firm i because the total demand $(D_i + D_j)$ is normalized to 1. Therefore, the manager's objective function can be rewritten as $U_i = \pi_i + \theta_i D_i$.

The timing of the game is as follows:

I Owners choose the location simultaneously.

II Owners either decide on R&D effort or delegate this decision to managers, in which case, the owners choose a contractual parameter θ_i; Delegation at this stage also implies delegation of the price decision in the next stage.

III Owners can decide to delegate the price decision or retain it for themselves.

IV Decision-makers (either owners or managers) simultaneously decide the price.

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each firm to harness the knowledge leaked from the other's R&D. See detail in working paper Dey and Fu (2009)

[14] As γ increases, the expenditure required for a firm to obtain a given quality increases.

[15] The results presented are unchanged if the objective function is instead written as $U_i = \theta_i \pi_i + (1 - \theta_i) \frac{D_i}{D_i + D_j}$, since what matters is only the relative weight on the performance measures. The formulation in the main text simplifies the notation.

Notice that the contracts (incentive schemes) can not be renegotiated and they become common knowledge[16] once they are signed. Overall, there are three alternative scenarios: No Delegation, Semi-Delegation and Full Delegation. The first is that in which no decision is delegated to managers; the second refers to the case in which owners delegate only short-run price decisions to their managers; and the third one is related to the case where owners delegate both short-run price and long-run R&D investment decisions.

Suppose a consumer located at $s \in [0,1]$, who decides to buy one unit from firm i, receives a utility $v + X_i - p_i - t(s - y_i)^2$ if this consumer purchases the product from the firm located at a point y_i and pays a price p_i. Note that $t > 0$ an index of the transportation cost[17] per unit, indicates the degree of consumer heterogeneity. The basic reservation utility $v > 0$ is sufficiently large so that the market[18] is fully covered. The effective R&D X_i is transformed into consumer's value so that $v + X_i$ is the highest price a consumer would pay for the product, on the other hand, X_i can be in effect interpreted as quality enhancement which differs the products vertically. This vertical differentiation is endogenously determined by firm's locations chosen by owners and R&D efforts chosen by either owners (in case of No Delegation, Semi-Delegation) or managers (in case of Full Delegation). Furthermore, the firm's locations also represent the characteristics of products (horizontal differentiation). The distance between the two firms determines the extent of spillover. Thereby, the positions of firm not only horizontally reflect product's characteristics and vertically affect the product's quality, but also mirror the degree of spillovers. This innovative aspect allows us to investigate three different categories of delegation in the context of both endogenous spillovers and endogenous product differentiation of two major types.

[16]The assumption that incentive contracts become common knowledge when the contract is signed is necessary. If this assumption is not considered, the contracts cannot act as commitment devices (see Katz, 1991). Fershtman and Judd (1987) argue that incentive contracts are costlier variables to change than price, and therefore remain unaltered for a substantial amount of time (while price decisions are being changed), and they are likely to be observed by rivals.

[17]The quadratic cost assumption is invoked in order to guarantee existence of equilibrium. This assumption is also used in other papers that study spatial competition between firms, for exemple, Neven (1985), Tabuchi and Thisse (1995), Brekke and Straume (2004) and Liang and Mai (2006). It is well known that linear transport costs lead to severe problems of existence of equilibrium in the price subgame. See D'Aspremont et al.,(1979).

[18]To avoid any arbitrage between consumers, assume that the transaction costs for the resale of goods are prohibitively high.

3 Equilibrium and Analysis

In this section, we solve for the sub-game perfect equilibrium of this multi-stage game by backward induction. Before the resolution of the model, we first of all define the demands for the two firms. The surplus from purchasing a unit from firm i to a consumer located at s, is $v-p_i-t(s-y_i)^2+X_i$, and the surplus for buying from firm j is $v-p_j-t(s-y_j)^2+X_j$. By determining the consumer who is indifferent between the two firms, we can derive the respective demands of firm i and firm j.

$$D_i = s = \frac{(p_j-p_i)-(X_j-X_i)}{2t(y_j-y_i)} + \frac{y_j+y_i}{2}$$
$$D_j = 1-s = 1-\frac{(p_j-p_i)-(X_j-X_i)}{2t(y_j-y_i)} - \frac{y_j+y_i}{2}$$

3.1 No Delegation (Benchmark case)

In this scenario, none of owners delegate the decisions to managers, thus, owners sequentially choose firm's locations, R&D efforts and prices. This benchmark case coincides with the work realized by PPT (2005)[19] who do not focus on the issue of managerial delegation. The solution concept is the sub-game perfect equilibrium by backward induction. We begin with analyzing the last stage.

Price stage

The profit functions for firm i and firm j are given by

$$\pi_i = p_i D_i - \frac{\gamma x_i^2}{2}$$
$$\pi_j = p_j D_j - \frac{\gamma x_j^2}{2} \tag{1}$$

Owners simultaneously and independently decide the price to maximize their profits. From the first order conditions (henceforth "FOC") we obtain the equilibrium prices:

$$p_i = \frac{1}{3}\left[X_i - X_j + t\left(y_j - y_i\right)\left(2 + y_i + y_j\right)\right]$$
$$p_j = \frac{1}{3}\left[X_j - X_i + t\left(y_j - y_i\right)\left(4 - y_i - y_j\right)\right] \tag{2}$$

[19] The results presented by Piga and Poyago-Theotoky (2005) are relevant only for a very small range of the transportation cost parameter, namely $t \in \left(\frac{2}{9}, \frac{5+\sqrt{13}}{9}\right)$. In order to avoid this restriction problem on the value of transportation cost, we introduce the parameter γ which refers to the index of effectiveness of R&D.

Substituting the equilibrium prices *Eqs.* (2), into the expressions for profits *Eqs.* (1), we obtain:

$$\pi_i = \frac{\left[X_i - X_j + t(y_j - y_i)(2 + y_j + y_i)\right]^2}{18t(y_j - y_i)} - \frac{\gamma x_i^2}{2}$$
$$\pi_j = \frac{\left[X_j - X_i + t(y_j - y_i)(4 - y_j - y_i)\right]^2}{18t(y_j - y_i)} - \frac{\gamma x_j^2}{2} \tag{3}$$

R&D (quality) stage

We now explore firms' equilibrium R&D decisions in this stage, with a given location profile (y_i, y_j). Using the expressions for profits derived *Eqs.* (3), in addition, the expressions for effective R&D $\Big(X_i = x_i + (1 - y_j + y_i)x_j$ and $X_j = x_j + (1 - y_j + y_i)x_i\Big)$, after taking *FOC*s[20]we obtain the equilibrium R&D efforts.

$$x_i = \frac{(y_j - y_i)\left[3t\gamma(2 + y_i + y_j) - 2(y_j - y_i)\right]}{3\gamma\left[9t\gamma - 2(y_j - y_i)\right]}$$
$$x_j = \frac{(y_j - y_i)\left[3t\gamma(4 - y_i - y_j) - 2(y_j - y_i)\right]}{3\gamma\left[9t\gamma - 2(y_j - y_i)\right]} \tag{4}$$

Based on the expressions of R&D efforts established $\big(Eqs.\ (4)\big)$, firms' profits can be written as the following function of their locations:

$$\pi_i = \frac{(y_j - y_i)\left[9t\gamma - (y_j - y_i)\right]\left[3t\gamma(2 + y_i + y_j) - 2(y_j - y_i)\right]^2}{18\gamma\left[9t\gamma - 2(y_j - y_i)\right]^2}$$
$$\pi_j = \frac{(y_j - y_i)\left[9t\gamma - (y_j - y_i)\right]\left[3t\gamma(4 - y_i - y_j) - 2(y_j - y_i)\right]^2}{18\gamma\left[9t\gamma - 2(y_j - y_i)\right]^2} \tag{5}$$

Location stage

In the absence of managerial delegation, firms' location patterns affect their payoffs through two avenues: A firm's location pattern alters its incentive to conduct R&D as well as the resultant product quality, while it further affects the firm's pricing strategy in the product market. In this stage, owners simultaneously choose their locations (y_i and y_j) to maximize their profits. The expressions *Eqs.* (5) allow us to investigate the equilibrium of the location game. Taking *FOC*s and then restricting the resulting solution to

[20]Note that the condition $t > \frac{2}{9\gamma}$ is necessary to guarantee the equilibrium exitance under No Delegation scenario.

Equilibrium Values	No Delegation (superscript "N")
R&D investment	$x_i^N = x_j^N = \frac{3t\left[2+3t\gamma-\sqrt{3t\gamma(2+3t\gamma)}\right]}{2(2+3t\gamma)}$
Quality	$X_i^N = X_j^N = \frac{3t^2\gamma\left[8+9t\gamma\sqrt{3t\gamma(2+3t\gamma)}-3t\gamma(2+9t\gamma)\right]}{2t\gamma(2+3t\gamma)\left[2+3t\gamma+\sqrt{3t\gamma(2+3t\gamma)}\right]}$
Price	$p_i^N = p_j^N = \frac{9t^2\gamma\left[2+3t\gamma-\sqrt{3t\gamma(2+3t\gamma)}\right]}{2(2+3t\gamma)}$
Profit	$\pi_i^N = \pi_j^N = \frac{9t^2\gamma}{4(2+3t\gamma)}$

Table 1: Equilibrium values under No Delegation

a symmetric one, we obtain the following equilibrium[21]:

$$y_i = \frac{4-12t\gamma-27t^2\gamma^2+9t\gamma\sqrt{3t\gamma(2+3t\gamma)}}{4(2+3t\gamma)}$$
$$y_j = \frac{4+24t\gamma+27t^2\gamma^2-9t\gamma\sqrt{3t\gamma(2+3t\gamma)}}{4(2+3t\gamma)} \tag{6}$$

By making use of *Eqs.* (6), we can compute the equilibrium levels for all other relevant variables. These values are shown in Table 1.

3.2 Semi-Delegation

According to Semi-Delegation, price decisions are delegated to managers, while owners decide themselves the quality-improving R&D investments. Thus, after the locational decisions are made, owners decide about their R&D efforts, and then set the incentive schemes for their managers. Finally, managers compete by setting the prices.

Price stage

We begin with the price chosen by managers who seek for the maximization of their utilities:

$$U_i = p_i D_i - \frac{\gamma x_i^2}{2} + \theta_i D_i$$
$$U_j = p_j D_j - \frac{\gamma x_j^2}{2} + \theta_j D_j \tag{7}$$

[21] In general, we obtain two sets of candidate equilibrium locations. The one displayed in main text satisfies the stability condition, the other one dissatisfies the stability condition, thus, it is eliminated.

It is straightforward to show that the product prices chosen by managers are given:

$$p_i = \frac{1}{3}\left[X_i - X_j + t(y_j - y_i)(2 + y_i + y_j) - (2\theta_i + \theta_j)\right]$$
$$p_j = \frac{1}{3}\left[X_j - X_i + t(y_j - y_i)(4 - y_i - y_j) - (\theta_i + 2\theta_j)\right] \quad (8)$$

We emphasize that the difference between these expressions of price $\left(Eqs.\ (8)\right)$ and the price expressions in Benchmark case $\left(Eqs.\ (2)\right)$ is the term $-(2\theta_i + \theta_j)$ for firm i and $-(\theta_i + 2\theta_j)$ for firm j. Evidently, owners are able to manipulate the managers' behaviors by the incentive scheme: the positive value of incentive parameters reduce the prices chosen by managers, on the contrary, the negative value of contract can increase the price. We will make the in-depth analysis of incentive scheme in the following section.

Contracting stage

At the contract stage, owner establishes his manager's incentive contract, which consists of a linear combination of profit and market share. The owner's objective here is to manipulate his manager's contract such that, given the rival's contract, his profit is maximized. Substituting the *Eqs.* (8) into the profit functions *Eqs.* (1), we can derive the the expressions of firms' profits with regard to the contracts, R&D efforts and product locations *i.e.* $\pi_i(y_i, y_j, x_i, x_j, \theta_i, \theta_j)$. The owners choose the incentive schemes in order to maximize the firms' profits:

$$\max_{\theta_i} \pi_i(y_i, y_j, \theta_i, \theta_j, x_i, x_j)$$
$$\max_{\theta_j} \pi_j(y_i, y_j, \theta_i, \theta_j, x_i, x_j)$$

We obtain:

$$\theta_i = \frac{1}{5}\left[X_j - X_i - t(y_j - y_i)(4 + y_i + y_j)\right]$$
$$\theta_j = \frac{1}{5}\left[X_i - X_j - t(y_j - y_i)(6 - y_i - y_j)\right] \quad (9)$$

R&D (quality) stage

In this stage, owners choose their R&D efforts non-cooperatively, taking locations (y_i, y_j) as given. Using the expressions of incentive schemes derived in the previous stage $\left(Eqs.\ (9)\right)$ and expressions for effective R&D $\left(X_i = x_i + (1 - y_j + y_i)x_j\right)$, after taking

Equilibrium Values	Semi-Delegation (superscript "S")
R&D investment	$x_i^S = x_j^S = \frac{5t\gamma\left[4+5t\gamma-\sqrt{5t\gamma(4+5t\gamma)}\right]}{2\gamma(4+5t\gamma)}$
Quality	$X_i^S = X_j^S = \frac{5\left[t\gamma(25t\gamma-4)\sqrt{5t\gamma(4+5t\gamma)}+16t\gamma-5t^2\gamma^2(6+25t\gamma)\right]}{4\gamma(4+5t\gamma)}$
Contract	$\theta_i^S = \theta_j^S = \frac{25t^2\gamma\left[\sqrt{5t\gamma(4+5t\gamma)}-(4+5t\gamma)\right]}{4(4+5t\gamma)}$
Price	$p_i^S = p_j^S = \frac{25t^2\gamma\left[(4+5t\gamma)-\sqrt{5t\gamma(4+5t\gamma)}\right]}{2(4+5t\gamma)}$
Profit	$\pi_i^S = \pi_j^S = \frac{25t^2\gamma}{2(4+5t\gamma)}$

Table 2: Equilibrium values under Semi-Delegation

*FOC*s, we hence obtain the equilibrium R&D efforts:

$$\begin{aligned} x_i &= \frac{2(y_j-y_i)\left[5t\gamma(4+y_i+y_j)-4(y_j-y_i)\right]}{5\gamma\left[25t\gamma-4(y_j-y_i)\right]} \\ x_j &= \frac{2(y_j-y_i)\left[5t\gamma(6-y_i-y_j)-4(y_j-y_i)\right]}{5\gamma\left[25t\gamma-4(y_j-y_i)\right]} \end{aligned} \tag{10}$$

Location stage

Retrospect to the first stage, the owners decide the firms' locations to maximize their profits, anticipating how this choice will affect their subsequent choices of R&D and price. We concentrate on symmetric equilibria outcomes to obtain analytical solutions. Making use of the expressions for R&D effort $\big(Eqs.\ (10)\big)$ and putting them into owners' objective functions and then taking *FOC*s, we obtain the equilibrium locations:

$$\begin{aligned} y_i &= \frac{16-5t\gamma\left[16+25t\gamma-5\sqrt{5t\gamma(4+5t\gamma)}\right]}{8(4+5t\gamma)} \\ y_j &= \frac{16+5t\gamma\left[24+25t\gamma-5\sqrt{5t\gamma(4+5t\gamma)}\right]}{8(4+5t\gamma)} \end{aligned} \tag{11}$$

To ensure that the firms' locations chosen by owners lie in the interior market and satisfy the condition $0 \leq y_i \leq y_j \leq 1$, we restrict the value of transportation cost t to $\underline{t} < t \leq \bar{t}$ with $\underline{t} = \frac{5}{18\gamma}$ and $\bar{t} = \frac{2(9+\gamma\sqrt{21})}{75\gamma}$. This assumption guarantees the overall game (three alternative scenarios).

The equilibrium R&D efforts, managerial contracts, prices, qualities and profits are shown in Table 2.

3.3 Full Delegation

In this scenario, owners delegate both the long-run R&D decisions and the short-run price decisions to managers. Accordingly, owners first of all choose the firms' positions, and then decide the incentive schemes to maximize the firms' profits. The managers take charge of R&D and price decisions on owner's behalf.

Price stage

The managers will choose prices so as to maximize their objective functions which depend upon the linear combination of profit and market share. It is straightforward to derive the same expressions of price as the previous Semi-Delegation scenario.

R&D (quality) stage

The managers choose R&D efforts in this stage. Using *Eqs.* (8), we rewrite the managers' rewards as function of R&D efforts, contracts and firms' locations.

$$U_i = \frac{A^2 - 2x_i(y_j - y_i)A + x_i^2(y_j - y_i)(y_j - y_i - 9t\gamma)}{18t(y_j - y_i)} \tag{12}$$

$$\text{with } A = (y_j - y_i)\left[x_j - t(2 + y_i + y_j)\right] - \theta_i + \theta_j$$

$$U_j = \frac{B^2 - 2x_j(y_j - y_i)B + x_j^2(y_j - y_i)(y_j - y_i - 9t\gamma)}{18t(y_j - y_i)} \tag{13}$$

$$\text{with } B = (y_j - y_i)\left[x_i - t(4 - y_i - y_j)\right] - \theta_i + \theta_j$$

From the *FOC*s of the managers' rewards, we derive

$$\begin{aligned} x_i &= \frac{3t\gamma(y_j - y_i)(2 + y_i + y_j) - 2(y_j - y_i)^2 + 3\gamma(\theta_i - \theta_j)}{3\gamma\left[9t\gamma - 2(y_j - y_i)\right]} \\ x_j &= \frac{3t\gamma(y_j - y_i)(4 - y_i - y_j) - 2(y_j - y_i)^2 + 3\gamma(\theta_j - \theta_i)}{3\gamma\left[9t\gamma - 2(y_j - y_i)\right]} \end{aligned} \tag{14}$$

Contracting stage

Each owner seeks to maximize his profit by properly choosing the weight in the manager's contract. The contracts are given

$$\begin{aligned} \theta_i &= -\frac{(y_j - y_i)\left[9t\gamma - 4(y_j - y_i)\right]\left[9t\gamma(4 + y_i + y_j) - 14(y_j - y_i)\right]}{9\gamma\left[45t\gamma - 14(y_j - y_i)\right]} \\ \theta_j &= -\frac{(y_j - y_i)\left[9t\gamma - 4(y_j - y_i)\right]\left[9t\gamma(6 - y_i - y_j) - 14(y_j - y_i)\right]}{9\gamma\left[45t\gamma - 14(y_j - y_i)\right]} \end{aligned} \tag{15}$$

Equilibrium Values	Full Delegation (superscript "F")
R&D investment	$x_i^F = x_j^F = \frac{3t\gamma\left[3(13+6t\gamma)-\sqrt{121+36t\gamma(14+9t\gamma)}\right]}{20\gamma(14+9t\gamma)}$
Quality	$X_i^F = X_j^F = \frac{3t\gamma\left[\sqrt{121+36t\gamma(14+9t\gamma)}(162t^2\gamma^2+261t\gamma-140)-2916t^3\gamma^3-6966t^2\gamma^2-1359t\gamma+5460\right]}{50\gamma(9t\gamma+14)^2}$
Contract	$\theta_i^F = \theta_j^F = \frac{9t^2\gamma\left[\sqrt{121+36t\gamma(14+9t\gamma)}-3(13+6t\gamma)\right]\left[2\sqrt{121+36t\gamma(14+9t\gamma)}-(8-9t\gamma)\right]}{50(14+9t\gamma)^2}$
Price	$p_i^F = p_j^F = \frac{9\left[18t^2\gamma^2-t\gamma\sqrt{121+36t\gamma(14+9t\gamma)}+39t\gamma\right]\left[27t^2\gamma^2+t\gamma\sqrt{121+36t\gamma(14+9t\gamma)}+31t\gamma\right]}{25\gamma(9t\gamma+14)^2}$
Profit	$\pi_i^F = \pi_j^F = \frac{9t^2\gamma\left[11\sqrt{121+36t\gamma(14+9t\gamma)}+271+252t\gamma\right]}{20(14+9t\gamma)^2}$

Table 3: Equilibrium values under Full Delegation

Location stage

Owners decide on the locations of firms in order to maximize their profits. By solving this problem, we get

$$\begin{aligned} y_i &= \frac{140-9t\gamma\left[29+18t\gamma-\sqrt{121+36t\gamma(14+9t\gamma)}\right]}{20(14+9t\gamma)} \\ y_j &= \frac{140+9t\gamma\left[49+18t\gamma-\sqrt{121+36t\gamma(14+9t\gamma)}\right]}{20(14+9t\gamma)} \end{aligned} \tag{16}$$

Then the equilibrium levels for all other relevant variables are shown in Table 3.

4 Results

By using the outcomes established in the previous section, we compare[22] three alternative delegation strategies in terms of firm's location, R&D spillovers, product quality, market price and profit.

4.1 Firm's location

Each owner chooses his firm's location before subsequently conducting R&D activity and marketing the product decided by either himself or his manager. The impact of location configuration decision is two-fold: on the one hand, it determines the extent of product (horizontal) differentiation; on the other hand, the location choice affects the

[22]The comparison of all relevant equilibrium values is based on the assumptions: the R&D effectiveness measure positive ($\gamma > 0$) and the transportation cost in the interval $(\underline{t}, \bar{t})$, with $\underline{t} = \frac{5}{18\gamma}$ and $\bar{t} = \frac{2(9+\gamma\sqrt{21})}{75\gamma}$

ability of the firm to obtain beneficial R&D spillovers. Specifically, distinctly differentiated products restrict R&D (knowledge) spillovers, while more homogeneous products allow firms to take advantage of more information flow.

Through the comparison of optimal locations in different scenarios[23], we find the following result:

Result 1 $\quad 0 \leq y_i^S < y_i^N < y_i^F < \frac{1}{2} < y_j^F < y_j^N < y_j^S \leq 1$

The firms' equilibrium location pattern balances the tradeoff they face between the benefit from softened price competition by furthering product differentiation and the benefit from softened R&D competition by reducing differentiation. We find that the distance between firm i and firm j in Full Delegation case is closer than the one in No Delegation case. It has been shown that, as the benefits from the rival's R&D effort prevail over the gains from weakening the price competition, within Full Delegation, therefore, owners always have more incentive to position their products closer to each other.

We also find the Semi-Delegation strategy encourages one firm to locate farther from the rival. In particular, the firms could locate at the two respective extremity of market that generates the minimal spillover effect when the transportation rate is equal to the upper bound[24] $\bar{t}$. In addition, it is clear that firms never share the same place which gives rise to the maximal spillovers.

As the extent of spillovers $\lambda = 1 - y_j + y_i$ depends upon the firms' locations, more precisely, the distance between competing firms, it is straightforward to derive the following result:

Result 2 $\quad 1 > \lambda^F > \lambda^N > \lambda^S \geq 0 \ \textit{and} \ 0 > \frac{\partial \lambda^N}{\partial t} > \frac{\partial \lambda^F}{\partial t} > \frac{\partial \lambda^S}{\partial t}$

It is shown that the extent of spillover (or the distance between competing firms) is a decreasing (or an increasing) function of transportation cost. Therefore, the geographical and researchful isolation is preferred when firms are protected by higher transport cost. There are two factors influencing this result. On the one hand, firms want to locate as far as possible from each other to relax price competition. On the other hand, locational proximity benefits firms, because they can learn more from each

[23] i.e. *Eqs.* (6) for No Delegation and *Eqs.* (11) for Semi-Delegation and *Eqs.* (16) for Full Delegation

[24] As shown in previous Analysis section, the lower and upper bounds of transportation cost are respectively $\frac{5}{18\gamma}$ and $\frac{2(9+\gamma\sqrt{21})}{75\gamma}$

other's quality-enhancing R&D. It is the interplay between these two factors, the centrifugal force that leads firms to locate apart and the centripetal force that induces them to locate at a proximity to benefit from spillovers. The lower the transportation cost, the closer to each other firms locate and the more they benefit from each other's R&D. It is clear that the traditional centrifugal force that would make firms locate as far away as possible from each other is partly offset by the centripetal force that induces them to locate closer. In addition, the higher the transportation cost, the less consumers perceive the two products as substitutes. Therefore, firms enjoy a local monopoly power which in turn allows them to invest in quality-enhancing R&D that increases consumer surplus.

In equilibrium, compared to benchmark case, Full Delegation strategy gives rise to higher R&D spillovers, whereas, Semi-Delegation strategy leads to lower spillovers. When owners delegate the short-term price decisions, the spillover rate function is the most sensitive, firms have the most incentives to locate separately following an augmentation of transport cost. In case of Full Delegation, owners have less incentives to position firms far away compared to Semi-Delegation, because the gains from a closer location pattern within Full Delegation are greater than that within Semi-Delegation, this effect reduces the tendency to separate.

4.2 Research and Development effort

By comparing the equilibrium levels of R&D effort in different scenarios[25], we obtain:

Result 3 $x^S > x^N > x^F > 0$

As demonstrated in the previous subsection, Semi-Delegation strengthens firms' incentives for product differentiation and propels firms to further segregate the market; by contraries, Full Delegation encourages firms to position closely in order to reduce the product heterogeneity and to reinforce the R&D sharing. Thus, the delegation of different types influences the choice of firm's location, in turn, affects the R&D spillovers, and will indirectly have an effect on R&D investment. For instance, Semi-Delegation has firms located further away from each other, thereupon decreases firms' knowledge spillovers, which weakens firms' incentives to free-ride on each other and forces firms to step up their individual R&D efforts. In case of Full Delegation, firms are located closer, two opposite effects come into play sharply. A lower level of differentiation forces the firms to charge a lower price, while diluted R&D competition leads to less R&D investment. Evidently, the firms within Full Delegation spend less on R&D due

[25] See Table 1, 2 and 3

to the sufficiently "large" spillover effect, while firms within Semi-Delegation have to spend more on R&D because of the "small" spillover effect.

It is worth noting that in Semi-Delegation case, firms possibly locate at the endpoints ($y_i = 0; y_j = 1$). This phenomenon corresponds to the remark of Kamien and Zang (2000) who state that firms choose firm-specific R&D approaches to offset exogenous spillovers.

4.3 Quality

Markets are in general characterized by both horizontal and vertical differentiation. In this framework, horizontal differentiation is determined by the different locations of the firms, while vertical differentiation is captured by the consideration that the firms produce distinct product qualities, endogenously specified and denoted by X_i and X_j. Let us now compare the SPNE values of effective R&D efforts, *viz.* product quality, under the three alternative delegation scenarios. The expressions of X^N, X^S and X^F are respectively shown in Table 1, 2 and 3.

Result 4 $\quad X^S > X^N > X^F > 0$

There are two factors which affect the quality index "X": the one is the spillover effect which is endogenously characterized by owners' locational decisions; the other one is the R&D efforts of two competing firms, which are chosen by owners under No and Semi-Delegation, particularly chosen by managers under Full Delegation. Evidently, the former factor is completely controlled by owners, however, the latter one could be determined by managers. According to Result 4, the product quality is higher if the owners control both factors, by contraries, the quality is lower if the managers decide the R&D factor. Furthermore, combined with the Result 1, it is deduced that Semi-Delegation generates higher product variety and higher product quality, by contrast, Full Delegation leads to lower variety and lower quality, from the perspective of product differentiation[26].

4.4 Incentive scheme

In this framework, there are two cases where ownership and management are separated in the form of the Semi-delegation and Full Delegation respectively. The owners make

[26]In contrast with the horizontal differentiation chosen by owners, the vertical differentiation is determined by owners' locational decisions and managers' R&D decisions under Full Delegation scenario.

the incentive schemes and announce the managers' contracts publicly and simultaneously, and after observing the contracts, the managers maximize the payoff given the reward contracts. By comparing the equilibrium incentive parameters in two aforementioned cases, we obtain the following result:

Result 5 $\theta^S < \theta^F < 0$

Firstly, we find that in equilibrium the incentive contracts parameters are negative. This result corresponds to some cases where it may be advantageous to ask manager to decrease market share. For example, if a firm is able to identify certain customers (or market segments) that are unprofitable, it may drop those customers and lose market share[27] while improving profitability.

It is shown that each owner sets a negative value of incentive parameter. We first focus upon the intuition behind the result under Semi-Delegation: The incentive contract θ_i just affects the subsequent price decision, a higher value of θ_i gives rise to a lower price p_i, because the manager tends to put more stress on the market share. The rival firm j moves far away from the market center to escape the tougher competition resulting from the higher value of θ_i. Since the strategic is complementarity, on anticipating this fact, each owner will set a lower incentive scheme parameter in order to mitigate the subsequent price competition.

When the owners delegate both short-run price and long-run R&D decisions, the incentive contract θ_i play an important role not only in the price stage but also in the R&D stage. A higher value of incentive parameter leads to a lower price p_i and a stronger effective R&D effort X_i, because the manager tends to attach more importance to market share. This lower price p_i and the stronger effective R&D effort X_i will influence the owners' location choices. Two firms tend to move far away towards the endpoint of market so as to soften price competition, but they expect that they can benefit more R&D effort exerted by his rival from closer locations. Due to these two conflicting effects, owners will decide a higher value of incentive scheme θ^F (compared to θ^S) by anticipating the aforementioned fact.

By comparing the expressions at price stage under No Delegation *Eqs.* (2) to that under Delegation (Semi- and Full Delegation) *Eqs.* (8), the differences are the term $-(2\theta_i + \theta_j)$ for firm i and $-(2\theta_j + \theta_i)$ for firm j. Since owners set the negative weight

[27]There are some other examples which illustrate the reasons not to increase market share: 1. Overall profits may decline if market share is gained by increasing promotional expenditures or by decreasing prices; 2. A small niche player may be tolerated if it captures only a small share of the market. If that share increases, a larger, more capable competitor may decide to enter the niche; 3. Antitrust issues may arise if a firm dominates its market.

on market share in equilibrium, it discloses that the managerial contracts make the managers less aggressive and accordingly increase the price.

4.5 Price

By comparing the equilibrium prices under three different scenarios, we have the following result.

Result 6

$$\begin{cases} p^S > p^N \geq p^F > 0 & t \in (\underline{t}, \tilde{t}\,] \\ p^S > p^F > p^N > 0 & t \in (\tilde{t}, \bar{t}\,] \end{cases}$$
$$with\ \ \tilde{t} = 0.31018\tfrac{1}{\gamma}$$

At first glance, Semi-Delegation generates the highest level of price. The reason is two-fold: first, the weakening of price competition because of the large distance between firms; on the other hand, due to weak spillover extent, the firm benefits less from his rival's R&D effort so that the firm has to invest more on R&D. Since the R&D effort is costly, managers ought to increase the price in order to compensate the excessive spending. Consequently, the price is the highest under Semi-Delegation scenario.

The ambiguous relationship between p^N and p^F is caused by two conflicting effects: The one is that, following an increase of distance between firms, the competition in price becomes soft, the decreasing spillover weakens the R&D free-ride and forces firms to carry on more individual R&D efforts. The softened price competition and the costly R&D efforts boost the equilibrium price. Thus, it is clear that the price is reduced by the decreasing distance between firms. The other one is the effect of delegation which renders the managers less aggressive so as to increase the price due to negative value of incentive parameter. Precisely, the increase of transportation cost generates the diminution of incentive parameter value, in turn, strengthens this delegation effect. From the equilibrium location under No Delegation to the one under Full Delegation, the distance between competing firms is shortened, accordingly, the former effect diminishes the price but the latter has the price increased. When the transportation cost is sufficiently large ($t > \tilde{t}$), the delegation effect will prevail over the aggregate influences of softened price competition and costly R&D efforts, thus, the equilibrium price under Full Delegation can be higher. This is the reason that we derive the equilibrium price ranking depending upon the transport cost.

4.6 Profit

The comparison in terms of profits, allow us to analyze whether it is in the interest of owners to delegate the short-run decision or both short- and long-run decisions to managers. Three scenarios have already been looked into and the firms' profits are shown in Table 1, 2 and 3 respectively.

Result 7 $\pi^S > \pi^F > \pi^N > 0$

It is straightforward to show that the profit of managerial firms is always higher than the profit of owner-managed (or entrepreneurial) firms. In particular, the Semi-Delegation strategy results in higher level of profit without ambiguity than Full Delegation.

Although the equilibrium price under Full Delegation is not always higher than the price in benchmark case (see Result 6), the managerial firms within Full Delegation are more profitable than entrepreneurial firms on all occasions. This is because the gains from Full Delegation largely in the form of free-ride effect on R&D prevail over the losses from the intensified price competition. What firms economize in terms of R&D investment sufficiently compensates the losses from lower price due to furious price competition. Thus, the Full Delegation strategy is more profitable than No Delegation.

To sum up, Full Delegation lets the firms adopt a closer location pattern, invest less on R&D and produce the low-quality goods. By contraries, Semi-Delegation encourages the firm to locate farther from the rival and to spend more on R&D, thereupon, firms produce the high-quality goods and generate the highest level of profit amongst three possible delegation scenarios. In the following section, we will investigate how Semi- and Full Delegation strategies influence the consumer surplus and social welfare.

5 Consumer surplus and Social Welfare

As we have shown, Semi-Delegation is the most profitable strategy. We reflect on the analytic outcomes of the rest of important economic indicators and investigate whether a such strategy may also increase the consumer surplus or social welfare. It is thus interesting to compare the equilibrium ownership structure with the socially most preferred ownership structure, in order to establish the correspondence between social and private incentives for strategic delegation.

Let "CS" denote consumer surplus[28] and “W" represent social welfare. Consumer surplus and social welfare are given by

$$CS = \int_0^{D_i} \left[v - p_i - t(y - y_i)^2 + X_i\right] dy + \int_{D_i}^1 \left[v - p_j - t(y_j - y)^2 + X_j\right] dy$$
$$W = \int_0^{D_i} \left[v - t(y - y_i)^2 - \frac{1}{2}x_i^2\right] dy + \int_{D_i}^1 \left[v - t(y_j - y)^2 - \frac{1}{2}x_j^2\right] dy$$

Since No Delegation is considered as a benchmark, the CS and W in benchmark case will be the standard level. If the strategic delegation generates a higher level than standard level, this delegation refers to the strategy which reinforces the social incentive; otherwise, it refers to the strategy that harms collective gains. We highlight the composition of CS and W for the different scenarios in **Appendix A**.

By comparing the consumer surplus and the social welfare under different scenarios, we derive:

Result 8 $\quad CS^N > CS^F > CS^S \quad and \quad W^F > W^N > W^S$

Combined with the analysis in terms of profits (see Result 7), we demonstrate that the delegations are profitable for firms, however they are never beneficial to consumers. Full Delegation is the efficient strategy which generates the highest level of social welfare. In Semi-Delegation case, the high price certainly leads to the decrease of consumer surplus and aggregate surplus, in spite of high product quality.

When owners direct the managers to make the short-run price decisions, this type of delegation will increase the product variety (horizontal differentiation), foster firms to spend more on R&D, encourage firms to produce high-quality goods and render the manager less aggressive, hence increase prices and profits. Because of the high level of horizontal differentiation, to some extent that firms would be less likely to conduct research in common areas and owners adopt the firm-specific R&D investment. This spending on R&D generates less synergy and results in the vast R&D cost. Consequently, both consumer surplus and social welfare decrease, and they are inferior to the standard levels (No Delegation: CS^N and W^N). There is the sharp conflict between private profits and collective gains under Semi-Delegation.

By contraries, under Full Delegation, owners choose the closer location pattern. The impact of owners' locational decisions is two-fold: first, it determines the lower extent

[28]The effective R&D "X_i" is transformed into consumer's value, that is interpreted as quality (enhancement).

of horizontal differentiation; second, it reflects the high level of spillover. A high level of spillover causes firms to free-ride on their rivals' R&D, and erodes their incentive to conduct competitive R&D. Thus, firms have less interest to improve the product quality. It is detrimental to consumer surplus on the one hand, while being propitious to firms on the other hand. A lower level of horizontal differentiation forces firms to face intensified price competition so that firms cut down the price. This benefits consumers on a large scale, and then enhance the social welfare. We highlight that Full Delegation is a more efficient strategy, which not only brings on the profits but improves the social welfare as well.

6 Concluding remarks

To our knowledge, this is the first research that studies the issue of strategic delegation in the presence of both endogenous product (horizontal and vertical) differentiation and endogenous R&D spillovers. And the results of this model provide important implications for the real practice of delegation. Within this framework, the linear combination of firm's profit and its market share is regarded as managers' objectives, and the owners decide the firm's location pattern and whether to delegate the tasks (such as R&D investment, price) or not.

Existing literature regarding strategic delegation with R&D, considers that firm's owners alternative decisions are either Full Delegation or No Delegation. We introduce a interesting and realistic scenario "Semi-Delegation" where firms' owners delegate the short-run decisions and retain the long-run decisions themselves. Our analysis shows that Semi-Delegation encourages one firm to locate farther from the rival and the firms could locate at the two respective extremity of market. Semi-Delegation increases product differentiation, fosters firms to spend more on R&D, encourages firms to produce high-quality goods and renders managers less aggressive, hence increases prices and profits. However, both consumer surplus and social welfare decrease. By contraries, Full Delegation is a more efficient strategy, which not only brings on the profits but improves the social welfare as well.

In addition, there are several possible extensions we find worth pursuing, *e.g.,* (1) the contracts can be chosen sequentially by owners in asymmetric cases, (2) different costs of carrying out R&D affect the benefits of delegation, (3) the effect of different performance measures (relative profit, output, sales, *etc.*) can be studied in this framework.

Appendix A

No Delegation:

$$CS^N = \frac{\gamma\left(t\left(-3\gamma\left(t\left(-81\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}+243t\gamma(t\gamma+2)+92\right)-24v\right)+405\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}+140\right)+48v\right)-72\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}}{24\gamma(3t\gamma+2)}$$

$$W^N = \frac{t\left(54\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}-\gamma\left(3t\left(\gamma\left(-81\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}+27t(\gamma(9t\gamma+2)+2)-16\right)+18\right)+27\sqrt{3}\sqrt{t^3\gamma^3(3t\gamma+2)}+4\right)\right)}{24\gamma(3t\gamma+2)}+v$$

Semi-Delegation:

$$CS^S = \frac{\gamma\left(t\left(-5\gamma\left(t\left(-375\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}+75t\gamma(25t\gamma+64)+1568\right)-96v\right)+4050\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}+1888\right)+384v\right)-480\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}}{96\gamma(5t\gamma+4)}$$

$$W^S = \frac{-9375t^4\gamma^4+2t\left(\gamma\left(-75\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}+240v\gamma-16\right)+300\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}\right)-3000t^3(\gamma+1)\gamma^2+5t^2\gamma\left(\gamma\left(375\sqrt{5}\sqrt{t^3\gamma^3(5t\gamma+4)}+112\right)-240\right)+384v\gamma}{96\gamma(5t\gamma+4)}$$

Full Delegation:

$$CS^F = \frac{3\left(-4374t^5\gamma^5-19440t^4\gamma^4-280\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+9t^3\gamma^3\left(27\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}-3778\right)\right)+19600v\gamma}{100\gamma(9t\gamma+14)^2}$$
$$+\frac{t\left(9t\gamma\left(891\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+2700v\gamma-12379\right)+2889\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+75600v\gamma+93380\right)}{300(9t\gamma+14)^2}$$

$$W^F = v-\frac{3t\left(4374t^4\gamma^5+11664t^3\gamma^4+t\gamma^2\left(-459\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+2862t-3395\right)-117\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}\right)}{100\gamma(9t\gamma+14)^2}$$
$$-\frac{t\left(81t^2\gamma^2\left(-27\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+108t+754\right)-486t\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+945\sqrt{t^2\gamma^2\left(324t^2\gamma^2+504t\gamma+121\right)}+22167t+4900\right)}{300(9t\gamma+14)^2}$$

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