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ORGANIZATIONAL STRUCTURE AND TECHNOLOGICAL INVESTMENT

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Organizational structure and technological investment

Abstract

We analyze firms' decisions to adopt a vertical integrated or decentralized structure taking into account the characteristics of both the final good competition and the R&D process. We consider two vertical chains, where R&D is conducted by upstream sectors. R&D investment determines the production costs of the downstream sector and has spillovers on the rivals' costs. In a general setup, we show that equilibrium organizational structure depends on whether the situation considered belongs to one of four possible cases and we study how final good market competition, spillover, and incentives in innovation interact to determine the optimal vertical structure.

JEL Codes: L22, L13, O32, C72.

Keywords: R&D, Vertical separation, Market structure, Spillover

1 Introduction

Given its importance to the determination of firms' structures, the relationship between vertical organization, market competition, and innovation has attracted considerable interest. Although firms' decisions on vertical coordination are key strategic decisions that seem to depend heavily on industrial environment, the decisions adopted by firms can be very different even in situations that share common features.

In markets with similar market characteristics, firms may select quite different vertical structures. For example, almost all automobile manufacturers, except Tesla, do not directly sell their own products to final consumers but mainly contract with local car dealers to distribute those products, although some of them make partial use of internet channels. In addition, the car industry heavily depends on external suppliers for the interiors (such as overhead, lighting, or doors) and other car components. Those manufacturers obviously engage in many types of R&D, which cause technological spillovers between them (Sako, 1996; Aoki and Lennerfors, 2013). Dell, one of the leading PC manufacturers, mainly sells its products through its direct distribution channels including physical sites and web sites, although other large PC manufacturers, including HP Inc. and NEC, mainly sell their own products through independent retailers.[1] R&D and technological spillover in this industry are recognized as key factors to enlarge companies' profitabilities (Png, 2017). IKEA, a worldwide furniture retailer, is completely vertically integrated, from producing furniture to retailing, unlike many furniture retailers that concentrate on the final consumer segment. Even in the furniture industry, knowledge spillovers through spatial proximity are observed (Maskell, 1998). Zara, a worldwide apparel company, is fully integrated from production to retailing in contrast with Uniqlo, a worldwide apparel retailer that collaborates with outside

[1] Dell also uses some selective large retailers to distribute its products, and HP Inc. opens its own web site to sell its products directly, although the percentages of sales via those distribution channels are not large.

makers including Toray and Asahi Kasei, which are able to produce high-quality textiles, to supply final products to consumers.

Many papers have provided motives for vertical integration or disintegration by considering the features of the final good market in which firms interact (Bonanno and Vickers, 1988; Ziss 1995; Gal-Or, 1999; Choi and Yi, 2000; Chen, 2001, 2005; Lin, 2006; Matsushima, 2009). However, in the examples mentioned above, a feature to consider is that the R&D activities (including process and product innovations), which are indispensable for firms to obtain competitive advantages over their rivals, may be concentrated on the upstream or the downstream section. In the case of the car industry, upstream firms may have a leading role in the innovation process, although knowledge spillovers related to those activities are often inevitable. Then, when the upstream section is key in the innovation process, whether the firm is integrated or not may have important consequences.

Previous literature has studied several effects of vertical structures on the R&D process. Bolton and Whinston (1993) is the pioneering study of the effect of vertical integration on downstream investments. Buehler and Schmutzler (2008) investigated the impact of vertical integration on investment incentives when only downstream firms make cost-reducing investments.[2] Chen and Sappington (2010) showed that vertical integration enhances upstream research efforts under downstream Cournot competition but may decrease those research efforts under Bertrand competition. Liu (2016) studied the impact of vertical integration on investment incentives when both upstream and downstream firms make innovative investments.

In this paper, we are interested on analyzing how final good competition and the R&D characteristics (in particular, the level of spillovers in knowledge and the incentives for innovation effort) affect firms' decisions about their vertical structure. We consider a complete

[2] Milliou and Petrakis (2012) considered the effect of vertical integration by an upstream monopolist and a downstream firm under a downstream duopoly market with technology spillovers.

Types of papers	Related papers
Market structure ⇒ Vertical integration	Bonanno and Vickers (1988), Ziss (1995), Gal-Or (1999), Choi and Yi (2000), Chen (2001,2005), Lin (2006), Matsushima (2009), and so on.
Vertical integration ⇒ R&D incentives	Bolton and Whinston (1993), Buehler and Schmutzler (2008), Chen and Sappington (2010), Liu (2016).
Market structure and R&D technology ⇒ Vertical integration	Gupta and Loulou (1998), Gupta (2008), Lin et al. (2014), Wang et al. (2017), Our paper.

Table 1: Related papers

formulation for the reasons for adopting an integrated or decentralized structure, by taking into account how knowledge is created and its interaction with market competition. We borrow the framework of Gupta (2008) who added knowledge spillovers to his earlier paper (Gupta and Loulou, 1998) in which two competing manufacturers engage in process innovation without spillovers, and each of them has an exclusive relation with an independent retailer.[3] That is, he investigated a bilateral duopoly market with knowledge spillovers. Although they consider linear demand systems and linear tariff contracts, we consider a general demand system and nonlinear tariff contracts in the exclusive vertical relations.[4] Because of the difference between the vertical contracts in those previous papers (linear contracts) and ours (nonlinear contracts), vertical separation in our paper does not have a strategic effect on profits through the double marginalization problem, which is a key factor in the previous papers.

[3] Related to papers that belong to the third type in Table 1, Lin et al. (2014) considered a downstream duopoly circular-city model with a three-tier exclusive supply chain. Wang et al. (2017) incorporated price and quality sensitivities into a Gupta and Loulou (1998) type duopoly supply chain model by using a linear demand system.

[4] Leahy and Neary (2005) also considered R&D problems under a general demand system in the context of research joint ventures, which differs from the scope of our paper.

We consider two vertical chains, each consisting of one upstream and one downstream sector. The R&D is conducted by the upstream sector, and it determines the production costs of the downstream sector in converting the input into the final good. The existence of cross-firm R&D spillovers implies that a chain can exploit the knowledge acquired through its own as well as its rival's research effort and build on it. In our model, spillovers may increase the effectiveness of an upstream sector's research effort in reducing the production costs of the downstream sector of the rival and may also reduce/increase the cost of the R&D effort of the rival. In an integrated structure, full internalization of the upstream sector's R&D decisions determines the investment decisions. In a separated structure, all the effects of the investment decision are not internalized by the upstream sector. As a result, the investment levels will be lower than in the former case. Under oligopoly, this underinvestment may be profitable for a firm depending on the type and the size of the spillovers.

We show that the conclusions depend on whether the situation considered belongs to one of four possible cases. Then, we present some examples to illustrate how final good market competition, spillover, and incentives in innovation interact to determine the optimal vertical structure. We consider a market with linear demand where there is Cournot competition and firms are symmetric in all dimensions except the incentives for R&D in the separated structure. Even in this simple framework we see that having a prediction of the optimal structure based on the type of market competition alone is risky. For example, the range of parameters over which a vertically separated structure is an equilibrium strategy for a firm depends on how incentives change when the chain is separated. A vertically separated structure is more profitable than a vertically integrated one if the incentives to conduct R&D do not decrease too much in a decentralized organization, and integration is optimal when they decrease significantly. The final equilibrium is that both firms choose an integrated (non-integrated) structure if, in this structure, the R&D incentives for both of them are still high (low). Asymmetric structures arise when one firm keeps the incentives and the other does not, or when both have intermediary incentives.

The remainder of the paper is structured as follows. Section 2 explains the model. Section 3 considers the incentives for R&D under the vertical structures, whether integrated or separated. Section 4 classifies the possible market structures into four cases that depend on the iso-profit curves and the reaction functions of the firms in the R&D investment stage. Then, we provide some parametric examples to explain how changes of incentives to conduct R&D influence the equilibrium vertical structures. Section 5 concludes.

2 Basic model

Consider a situation in which two firms or vertical chains, 1 and 2, produce a final good and invest in R&D before the final good market competition. In our model, each firm consists of two sectors: a manufacturing sector and a retail sector. When the two sectors are vertically integrated in a firm, they are organized in a single entity, which takes into account the joint profits. In contrast, if the two sectors are vertically separated, each of them has its own objective and they negotiate the trading terms between them.

The R&D investment made by a firm has a positive effect on the productivity of its manufacturing sector (e.g., it allows a reduction of production costs), and it may also affect the productivity of the rival's manufacturing sector (that is, there may be technological spillovers).

We analyze the following three-stage game: In the first stage, firms simultaneously and non-cooperatively determine their organizational structures: vertically separated or integrated. In the second stage, each of the two manufacturing sectors simultaneously and non-cooperatively choose their own R&D investment effort e_i ($i = 1, 2$). We explain how these efforts affect the profits of the two firms. Firm i's investment cost is denoted by $I^i(e_i, e_j)$, which allows for spillovers among the firms' R&D effort costs. We assume that firms' R&D efforts are publicly observed. Then, after the R&D investments are made, if firm i ($i = 1, 2$)

is vertically separated, the two sectors in firm i negotiate a lump-sum transfer F_i from the retail to the manufacturing sector in firm i.[5] If the negotiation breaks down, the retail sector procures final goods from other competitive manufacturers without any technological advantage. That is, the retail sector in firm i does not benefit from technological improvements of the investments at all. In the third stage, each of the retail sectors compete with their rivals in the final good market by using their available technological improvements.

Below, we consider a general reduced form for the profits obtained in the third stage although, for illustrative purposes, in the examples of Section 4.3, we take particular forms of competition in the final good market such as the standard Cournot or Bertrand ones. The retail sector in firm i obtains the gross profit $V^i(e_i, e_j)$ if the retail sector in firm i uses the technological improvements created by the manufacturing sector in firm i, otherwise, it obtains $\bar{V}^i \equiv V^i(0, e_j)$, which does not depend on the technological improvements that are not available to it.

In the second stage, in firm i, if the retail sector uses the technology of the manufacturing sector, firm i's net profit is

$$\Pi^i(e_i, e_j) \equiv V^i(e_i, e_j) - I^i(e_i, e_j). \tag{1}$$

For the analysis of the first and second stage, we assume that the cost function of R&D effort and the gross profit that firm i obtains in the Nash equilibrium of the third stage, for $i = 1, 2$, satisfy the following assumptions:

(A1) $V^i(e_i, e_j)$ and $I^i(e_i, e_j)$ are twice continuously differentiable with respect to its own effort,

[5] We assume that the payment between the two sectors is a fixed amount; that is, there is no royalty as a function of the production of the final good. This is optimal when the contract terms are privately known within the two sectors of the vertical chain and that after transferring the R&D outcome, the manufacturing sector is not involved in the production of the final good. A related discussion is available in Section 3.2 of Caillaud and Rey (1995). In addition, Rockett (1990) explains situations in which licensors of new technology face difficulties in collecting per production fees from licensees.

(A2) $V^i(e_i, e_j)$ is increasing in its own effort in R&D: $V_i^i(e_i, e_j) \equiv \partial V^i(e_i, e_j)/\partial e_i > 0$,

(A3) $I^i(e_i, e_j)$ is increasing and convex in its own effort: $I_i^i(e_i, e_j) \equiv \partial I^i(e_i, e_j)/\partial e_i > 0$, $I_{ii}^i(e_i, e_j) \equiv \partial^2 I^i(e_i, e_j)/\partial e_i^2 \geq 0$, and

(A4) $\Pi^i(e_i, e_j)$ is concave in its own effort: $\Pi_{ii}^i(e_i, e_j) \equiv \partial^2 \Pi^i/\partial e_i^2 < 0$.

3 Stage 2: R&D investment

We study the second stage decision for the two possible organizational forms that a firm can adopt. We obtain a firm's best response function when it is vertically integrated, and when it is vertically separated. Note that firm i's best response function does not depend on firm j's organizational form, only on firm j's R&D investment. Of course, the equilibrium decision of firm i in the R&D stage will depend on the organization structures of both firms.

3.1 Best response function of a vertically integrated firm

When firm i is vertically integrated, the two sectors in firm i are organized as one entity and they make decisions together. The first-order condition of the maximization of $\Pi^i(e_i, e_j)$ with respect to e_i is

$$\Pi_i^i(e_i, e_j) = V_i^i(e_i, e_j) - I_i^i(e_i, e_j) = 0. \tag{2}$$

From equation (2), and assuming that the solution is interior, we can obtain the best response function of firm i to any investment level of the rival that we denote $e_i^I(e_j)$, where the superscript refers to the type of organizational structure (here, Integration).

3.2 Best response function of a vertically separated firm

When firm i is vertically separated, the two sectors negotiate a lump-sum transfer F_i from the retail to the manufacturing sector in firm i. Because the agreement is negotiated after the R&D investment takes place, the R&D cost is sunk. If the negotiation succeeds, the manufacturing sector's profit is $F_i - I^i(e_i, e_j)$ and the retail sector's profit is $V^i(e_i, e_j) - F_i$. If the negotiation fails, then the manufacturing sector's profit is $-I^i(e_i, e_j)$ and the retail sector's profit is $\bar{V}^i$. Thus, if the negotiation succeeds, the net surplus of the negotiation is $V^i(e_i, e_j) - \bar{V}^i$.

We assume that, given (e_i, e_j), F_i is the outcome of a (possibly asymmetric) Nash bargaining negotiation where the bargaining power of the separated manufacturing sector in firm i is β^i, with $\beta^i \in (0, 1)$, exogenously given.[6] Thus, the fixed fee F_i is characterized by

$$
\begin{aligned}
&(1-\beta^i)(F_i - 0) = \beta^i(V^i(e_i, e_j) - F_i - \bar{V}^i) \\
or \quad &F_i = \beta^i(V^i(e_i, e_j) - \bar{V}^i).
\end{aligned}
$$

Anticipating the terms of the agreement, the manufacturing sector in firm i maximizes the following expression with respect to e_i:

$$F_i - I^i(e_i, e_j) = \beta^i(V^i(e_i, e_j) - \bar{V}^i) - I^i(e_i, e_j). \tag{3}$$

The maximization problem is equivalent to

$$\max_{e_i} \quad \beta^i V^i(e_i, e_j) - I^i(e_i, e_j). \tag{4}$$

The functional form differs from that in which firm i is integrated.[7] The coefficient of $V^i(e_i, e_j)$ is β^i in the separation case, while it is 1 in the integration case. Given that $\beta^i < 1$, the incentive of the separated manufacturing sector to invest is weaker than that of an integrated firm.

The first-order condition of the previous maximization is

$$\beta^i V^i_i(e_i, e_j) - I^i_i(e_i, e_j) = 0. \tag{5}$$

[6] β^i is likely to be large if the manufacturing sector is more important than the retail sector in terms of size or weight in the production process. β_i is also more likely to be large if in the manufacturing sector is less competitive (e.g., there are fewer firms) than the retail sector.

[7] We could also interpret β^i as the pre-established share of the final profit. If the manufacturing sector in firm i gains $\beta^i(V^i(e_i, e_j) - \bar{V}^i)$, which is contingent on the R&D outcomes, from the R&D input, β^i is interpreted as the profit-sharing ratio of the manufacturing sector in firm i.

If the solution is interior, equation (5) provides the best response function $e_i^S(e_j)$ of a vertically separated firm i to any investment level of the rival (the superscript represents Separation).

3.3 R&D equilibrium

The equilibrium R&D decisions (e_1^*, e_2^*) are the ones that satisfy $e_1^{BR}(e_2^*) = e_1^*$ and $e_2^{BR}(e_1^*) = e_2^*$, where $e_i^{BR}(e_j) = e_i^I(e_j)$ or $e_i^{BR}(e_j) = e_i^S(e_j)$ depending on whether firm i is vertically integrated or separated.

4 Organizational structure decision

First, we investigate the basic properties of the iso-profit curve and the reaction function. Then, by using them, we classify the market structures into four cases. Finally, we further investigate the equilibrium organizational structures by using parametric examples.

4.1 Iso-profit curve and reaction function

As we have seen in the previous section, vertical separation induces a distortion in the incentive to invest in R&D, whenever the bargaining power of the manufacturing sector is smaller than 1. To understand whether this distortion is profitable for the firm; that is, whether vertical separation is optimal, it is useful to analyze the slope of the iso-profit curve and the slope of the reaction function $e_i^I(e_j)$ at the equilibrium (e_1^*, e_2^*).

First, to analyze the slope of the iso-profit curve, totally differentiating $\Pi^i(e)$, we obtain:

$$\Pi_i^i de_i + \Pi_j^i de_j = 0. \tag{6}$$

From this expression, we compute the slope of the iso-profit curve:

$$\frac{de_j}{de_i} = -\frac{\Pi_i^i}{\Pi_j^i}. \tag{7}$$

Note that $\Pi_i^i > 0$ for $e_i < e_i^I(e_j)$ and $\Pi_i^i < 0$ for $e_i > e_i^I(e_j)$.

The second derivative of the iso-profit curve is

$$\frac{d\left(\dfrac{de_j}{de_i}\right)}{de_i} = -\frac{\Pi^i_{ii}\Pi^i_j - \Pi^i_i\Pi^i_{ji}}{\left(\Pi^i_j\right)^2}. \tag{8}$$

By (A4) we know that $\Pi^i_{ii} < 0$. Moreover, at the Nash equilibrium of the R&D game, $\Pi^i_i = 0$. Therefore, at the Nash equilibrium (e^*_1, e^*_2), the iso-profit curve of firm i is concave with respect to e_i if and only if $\Pi^i_j < 0$; and it is convex if and only if $\Pi^i_j > 0$.

Second, to find the slope of the reaction function $e^I_i(e_j)$, we substitute e_i by $e^I_i(e_j)$ into (2) and differentiate the expression with respect to e_j to obtain:

$$\frac{\partial^2\Pi^i(e_i,e_j)}{\partial e_i^2}\frac{de^I_i(e_j)}{de_j} + \frac{\partial^2\Pi^i(e_i,e_j)}{\partial e_i \partial e_j} = 0$$

$$or \qquad \frac{de^I_i(e_j)}{de_j} = -\frac{\Pi^i_{ij}(e_i,e_j)}{\Pi^i_{ii}(e_i,e_j)}.$$

Because the denominator of the latter fraction is negative, we see that:

$$\frac{de^I_i(e_j)}{de_j} \gtreqless 0 \text{ iff } \Pi^i_{ij}(e) \gtreqless 0. \tag{9}$$

Thus, the cross partial derivative of the gross profit is the key factor related to the slope of the reaction function. We can derive the same property as equation (9) for the argument on the slope of the reaction function under separation, $e^S_i(e_j)$; that is,

$$\frac{de^S_i(e_j)}{de_j} \gtreqless 0 \text{ iff } \Pi^i_{ij}(e) \gtreqless 0. \tag{10}$$

4.2 Possible cases

From the previous discussion, four cases can arise depending on the signs of Π^i_j and Π^i_{ij}:

Case 1. The iso-profit curve of each firm is convex with respect to its investment level and the reaction function of each firm is downward sloping.

Case 2. The iso-profit curve of each firm is concave with respect to its investment level and the reaction function of each firm is downward sloping.

Case 3. The iso-profit curve of each firm is convex with respect to its investment level and the reaction function of each firm is upward sloping.

Case 4. The iso-profit curve of each firm is concave with respect to its investment level and the reaction function of each firm is upward sloping.

To illustrate the classification, and to see how it may affect the choice of the organizational structure at stage 1, we present four graphical examples.

[Figure 1 about here]

We look at Case 1 in Figure 1. For firm 1, given the reaction function of firm 2, $e_2(e_1)$, a slight leftward shift of $e_1(e_2)$ decreases its investment level but increases its profit. This implies that firm 1 can increase its profit if it can commit to slightly diminish its investment. The logic works also in Case 4 although it does not in Cases 2 and 3.

Before we discuss how vertical separation may work as a device to change the incentives for investment in the vertical chains, we show the following theorem (the proof is delegated to the Appendix).

Theorem 1 *In Cases 2 and 3, regardless of the rival firm's vertical structure, the optimal organizational structure of a firm is a vertically integrated structure.*

In Case 1 (respectively, Case 4), there exists a $\hat{\beta}^i_k \in (0,1)$ (respectively, $\tilde{\beta}^i_k \in (0,1)$) such that for firm i ($i = 1, 2$), a vertically separated structure is optimal if $\beta^i \geq \hat{\beta}^i_k$ (respectively, $\beta^i \geq \tilde{\beta}^i_k$) and the organizational structure of firm j is $k \in \{I, S\}$, where I and S represent Integration and Separation.

Let us note that for Case 1 (respectively, Case 4), Theorem 1 shows the existence of $\beta^1 < 1$ at which firm 1 prefers vertical separation to integration under assumptions A1 to A4. However, for the existence of the unique threshold value $\hat{\beta}_k^1$ (respectively, $\tilde{\beta}_k^1$), a more demanding condition on the profit function is needed: the global convexity of firm 1's iso-profit curves. This condition is guaranteed under the assumption $\Pi_{ii}^i \Pi_j^i < \Pi_i^i \Pi_{ji}^i$.

4.3 Example

To illustrate how vertical separation changes the incentives of R&D investments, we consider a duopoly under quantity competition with cost-reducing investments. The inverse demand is

$$p = h - q_1 - q_2, \tag{11}$$

where h is a positive constant and q_i is the quantity supplied by firm i ($i = 1, 2$). Note that we can derive qualitatively similar results even under price competition with the linear demand system (Dixit, 1979; Singh and Vives, 1984).[8] The marginal cost of firm i, mc_i, is given as

$$mc_i(e_i, e_j) = c - (e_i + \theta e_j)^\alpha, \tag{12}$$

where e_i and e_j are the effort levels of firms i and j ($i, j = 1, 2,\ j \neq i$), and c, $\theta \in [0, 1]$ and $\alpha \in (0, \infty)$ are exogenous parameters. The first term of mc_i is an *ex ante* marginal cost level; the second term is the degree of marginal cost reduction. For example, if $\alpha = 1$, $mc_i = c - e_i - \theta e_j$, which is equivalent to the expression for the marginal cost in d'Aspremont and Jacquemin (1988). We assume that the investment cost of firm i is given as

$$I^i(e_i, e_j) = 2e_i^2. \tag{13}$$

The gross profit of firm i in the second stage is given as

$$V^i(e_i, e_j) = \frac{(h + mc_j(e_i, e_j) - 2mc_i(e_i, e_j))^2}{9}. \tag{14}$$

[8] The linear demands are derived by the representative consumer's utility $U(q_1, q_2) = a(q_1 + q_2) - (q_1^2 + 2sq_1q_2 + q_2^2)/2 + m$, where s is the degree of product homogeneity and m is the numéraire. The demand functions are

$$q_i = \frac{(1 - s)a - p_i + sp_j}{1 - s^2}, \quad i, j = 1, 2,\ j \neq i.$$

The net profit of firm i in the first stage is given as

$$\Pi^i = V^i(e_i, e_j) - I^i(e_i, e_j) = \frac{(h - c - (e_j + \theta e_i)^\alpha + 2\left((e_i + \theta e_j)^\alpha\right))^2}{9} - 2e_i^2. \tag{15}$$

When firm i is vertically separated, the objective of its separated manufacturing sector is given as

$$\Pi_U^i = \beta^i[V^i(e_i, e_j) - \bar{V}^i] - I^i(e_i, e_j), \tag{16}$$

where $\beta^i \in (0,1)$ is the bargaining power of the manufacturing sector. The maximization problem of the separated upstream sector is equivalent to the following problem:

$$\max_{e_i} \ \beta^i V^i(e_i, e_j) - I^i(e_i, e_j). \tag{17}$$

The shapes of iso-profit curves and reaction functions Following the classification in Section 4.2, we now show three numerical examples: Case 1 (convex and downward sloping), Case 2 (concave and downward sloping), and Case 3 (convex and upward sloping). Note that we omit Case 4 (concave and upward sloping) because it cannot be generated in this example for parameters satisfying Assumption 3.

In Sections 4.3.1 and 4.3.2, we set $\beta^1 = \beta^2 = 1/2$, and relax the parameter setting in Section 4.3.3. We set $h - c = 1/2$. We generate the different cases by taking different values for α, and θ.

4.3.1 Parametric example of Case 1 ($\alpha = 1/5$, $\theta = 1$)

The marginal cost of firm i and its investment cost are

$$mc_i = c - (e_i + e_j)^{1/5}. \tag{18}$$

The efforts of the firms have a public good nature when $\theta = 1$ in the sense that e_i reduces not only the marginal cost of firm i but also that of firm j. The concavity of $(e_1 + e_2)^\alpha$ substantially influences the incentives of the firms to reduce their marginal costs. When the value of α is small enough (the concavity of $(e_1 + e_2)^\alpha$ is significant), only one of the firms' efforts is sufficient to achieve a reasonable level of cost reduction, implying that their efforts have a public good nature. Under the cost structure, the reaction function of each firm is downward sloping (see the left-hand side of Figure 2).

[Figure 2 about here]

The iso-profit curve of firm i is convex with respect to e_i because an increase in firm j's investment equally improves the efficiencies of firms j and i, benefiting firm i. Under the cost structure, vertical separation is a credible commitment not to invest sufficiently, which induces the rival to invest more (compare the intersection of $e_1(e_2)$ and $e_2(e_1)$ with that of $\hat{e}_1(e_2)$ and $e_2(e_1)$ in the left-hand side of Figure 2).

We also check what happens if another firm (firm 2) vertically separates given that firm 1 vertically separates (see the right-hand side of Figure 2). The separation substantially decreases the investment level of firm 2 although this induces firm 1 to invest more. The latter positive effect is not sufficient for firm 2 to compensate the negative effect of its investment shrinkage (note that (e_1, e_2) on the left-hand region of $\pi_2(e_1, e_2) = \hat{\pi}_2$ achieves a lower profit than $\hat{\pi}_2$ that passes through the investment pair in which only firm 1 vertically separates). The following proposition summarizes the discussion.

Proposition 1 *Under the equations* (11), (12), *and* (13) *with the parameter specification in Section 4.3, only one of the firms vertically separates if* $\alpha = 1/5$ *and* $\theta = 1$. *In other words, if cost-reducing efforts have a public good nature, vertical separation can appear in equilibrium.*

We briefly mention the welfare property of vertical separation in Case 1. Because the cost reduction in Case 1 has a public good nature, the realized investment levels are lower than the socially optimal levels even under the no vertical separation case. In addition, executing vertical separation always reduces total investment levels and then lowers the industry level efficiency more. In Case 1, therefore, vertical separation decreases the total surplus.

4.3.2 Parametric example of Cases 2 and 3 ($\alpha = 1$)

(Case 2, $\theta = 0$; Case 3, $\theta = 1$): We consider two cases: $\theta = 0$ and $\theta = 1$. We also set $\beta^i = 1/2$ ($i = 1, 2$) again. The former case captures the standard duopoly competition with cost reduction under no spillovers. The latter captures the situation in d'Aspremont and Jacquemin (1988) under perfect spillovers. In the former case ($\theta = 0$), vertical separation only diminishes the investment level of the separated firm, which weakens its competitiveness but strengthens the rival's competitiveness (see the left-hand side of Figure 3). In the latter case ($\theta = 1$), although their investments are completely cooperative, vertical separation diminishes both the investment levels of the firms, which weakens their profitabilities (see the right-hand side of Figure 3). Thus, we conclude that both firms vertically integrate under Cases 2 and 3. The following proposition summarizes the discussion.

Proposition 2 *Under the equations* (11), (12), *and* (13) *with the parameter specification in Section 4.3, no firm vertically separates if* $\alpha = 1$ *and* $\theta = 0$ *or* $\theta = 1$.

[Figure 3 about here]

4.3.3 Generalized values of β^i in Case 1 ($\alpha = 1/5$, $\theta = 1$)

Up to this point, we have imposed β^i ($i = 1, 2$) at 1/2 to show a possibility that vertical separation occurs. Now, we relax our constraint on the values of β^i. We allow any parameters of $\beta^i \in [0, 1]$ to check how the values of β^i influence the vertical structure in equilibrium. Except for the relaxation of the two parameters β^i, we use the same parameters as in Section 4.3.1. Figure 4 summarizes the realized vertical structure, which depends on the values of β^i.[9]

[9] The mathematica file to derive Figure 4 is available upon request.

[Figure 4 about here]

Recall that Figure 4 takes a Cournot competition situation in which firms are symmetric in all dimensions except the incentives for R&D in the separated structure (the values of the other parameters correspond to Case 1). In the space (β^1, β^2), both firms adopt a vertically separated structure in equilibrium if the bargaining power of the manufacturing sector of both firms is high enough (the incentives to invest in R&D are high). When β^i of both firms is low, in equilibrium both firms will chose to be integrated. Asymmetric organizations arise in equilibrium when one firm has a manufacturing sector with high bargaining power (this firm chooses a separate structure) and the other firm's manufacturing sector has low incentives to invest in R&D (this firm chooses to be vertically integrated). Asymmetric equilibrium can also arise for intermediate values of bargaining power. Consider the 45° line (where $\beta^1 = \beta^2 = \beta$): for low values of β in equilibrium no firm separates, for high values of β both adopt separate structures and for intermediary values, in equilibrium, one separates and the other does not (the case $\beta^1 = \beta^2 = 1/2$ lies in this region). The following proposition summarizes the discussion.

Proposition 3 *Under the equations* (11)*,* (12)*, and* (13) *with the parameter specifications* $h - c = 1/2$*,* $\alpha = 1/5$ *and* $\theta = 1$*, if* $\beta^1 = \beta^2 = \beta > 0.456$*, at least one of the firms vertically separates.*

5 Conclusion

In any oligopolistic industry, understanding why firms adopt an integrated or separated structure has attracted a great deal of attention. Various arguments have been put forward to explain the gains that firms will derive from meeting their input requirements internally or externally (see Table 1 in the Introduction). However, we are still far from understanding the whole picture, and there is no simple and clear reason to explain the firms' decision to integrate or not.

In this paper, we stress the role played by incentives to invest and spillovers for the organizational structure of firms. We attempt to clarify part of the discussion by considering a general and flexible framework that allows us to understand how the combination of the characteristics of final good market competition and those of the R&D process (incentives and spillovers) make the strategy of integration superior or inferior to the strategy of adopting a separated structure.

In our model, the forces at work come from the profits of the firms (as a function of the demand and the market competition), the R&D decisions, and R&D technological spillovers in the industry, and the incentives to perform R&D in a firm are higher within an integrated structure. In a separated structure, where the two sectors negotiate a lump-sum transfer, the incentives to invest in R&D depend on the bargaining power of the firm's manufacturing sector. We show that the organizational structure that is superior depends on whether the situation belongs to one of four cases. These cases are defined by the concavity or convexity of the firms' iso-profit curves with respect to the R&D investment efforts and by the downward or upward slope of the R&D investment reaction functions. Even if incentives to invest in R&D decrease, we show that a vertically separated structure is optimal in two of the four cases provided that the bargaining power of the manufacturing sector is sufficiently high. We also show that even in completely symmetric environments, it can be the case that in equilibrium, firms adopt different organizational structures.

Our analysis allows us to clarify the fact that it is not possible to reach conclusions on which vertical integration strategy is better without considering both technological and competitive perspectives together. In fact, as we have illustrated in Section 4.3, it is not possible to conclude that the optimal level of integration depends negatively on the degree of spillovers in the industry. Technological environments in the industry really matter. Our paper is a first step toward clarifying the importance of technological environments in order to consider the optimal organizational structures of firms in oligopolistic markets. We have omitted a number of important issues that also determine the firms' optimal organization decision. Further research will contribute to resolving these difficult questions about why some firms decide to integrate their sectors and others separate them.

Appendix

Proof of Theorem 1: In Case 1, irrespective of firm 2's vertical structure, vertical separation in firm 1 causes a leftward shift of firm 1's reaction function, inducing a left-upward shift of the Nash equilibrium due to the downward sloping of firm 2's reaction function.[10] Because the slope of firm 1's iso-profit curve is zero and the slope of firm 2's best response is negative at the original Nash equilibrium, there is an $\epsilon > 0$ such that $(e_1^* - \epsilon, \bar{e}_2)$ is on firm 1's iso-profit curve passing through the original Nash equilibrium (e_1^*, e_2^*) and $\bar{e}_2 < e_2^{BR}(e_1^* - \epsilon)$. We obtain $\Pi^1(e_1^*, e_2^*) = \Pi^1(e_1^* - \epsilon, \bar{e}_2) < \Pi^1(e_1^* - \epsilon, e_2^{BR}(e_1^* - \epsilon))$ because $\Pi_2^1 > 0$. Because firm 1's best response $e_1^{BR}(e_2)$ is continuous and increasing in β^1 for any e_2, the above inequalities imply that there exists $\hat{\beta}_k^1 < 1$, such that firm 1 prefers vertical separation to the integration for any $\beta^1 \in [\hat{\beta}_k^1, 1)$, where $k \in \{I, S\}$ represents the organizational structure of firm 2, Integration or Separation.

In Case 2, irrespective of firm 2's vertical structure, vertical separation in firm 1 causes a leftward shift of firm 1's reaction function, inducing a left-upward shift of the Nash equilibrium due to the downward sloping of firm 2's reaction function. We check the effect of the left-upward shift on firm 1 with two steps. A leftward shift of the equilibrium point from

[10] The shift of the Nash equilibrium referred to in this proof is guaranteed by the condition

$$\left|\frac{de_2^k(e_1)}{de_1}\right| < \left|\frac{1}{de_1^I(e_2)/de_2}\right| \quad (k = I, S),$$

which implies that irrespective of firm 2's organization structure, the slope of firm 1's best response is steeper than that of firm 2's best response. This condition seems innocuous because it guarantees the stability of the Nash equilibrium. The numerical examples presented later satisfy this condition.

the original Nash equilibrium decreases the profit of firm 1. Moreover, an upward shift of e_2 further decreases the profit of firm 1 ($\Pi^1_2 < 0$). Therefore, a left-upward shift of the Nash equilibrium through vertical separation harms firm 1. We can apply the same logic to the effect of vertical separation on firm 2.

In Case 3, irrespective of firm 2's vertical structure, vertical separation in firm 1 causes a leftward shift of firm 1's reaction function, inducing a left-downward shift of the Nash equilibrium due to the upward sloping of firm 2's reaction function. We check the effect of the left-downward shift on firm 1 by two steps. A leftward shift of the equilibrium point from the original Nash equilibrium decreases the profit of firm 1. Moreover, a downward shift of e_2 also decreases the profit of firm 1 ($\Pi^1_2 > 0$). Therefore, a left-downward shift of the Nash equilibrium through vertical separation harms firm 1. We can apply the same logic to the effect of vertical separation on firm 2.

In Case 4, irrespective of firm 2's vertical structure, vertical separation in firm 1 causes a leftward shift of firm 1's reaction function, inducing a left-downward shift of the Nash equilibrium due to the downward sloping of firm 2's reaction function. Because the slope of firm 1's iso-profit curve is zero and the slope of firm 2's best response is positive at the original Nash equilibrium, then there is an $\epsilon > 0$, such that $(e_1^* - \epsilon, \bar{e}_2)$ is on firm 1's iso-profit curve passing through the original Nash equilibrium (e_1^*, e_2^*) and $\bar{e}_2 > e_2^{BR}(e_1^* - \epsilon)$. We obtain $\Pi^1(e_1^*, e_2^*) = \Pi^1(e_1^* - \epsilon, \bar{e}_2) < \Pi^1(e_1^* - \epsilon, e_2^{BR}(e_1^* - \epsilon))$ because $\Pi^1_2 < 0$. Because firm 1's best response $e_1^{BR}(e_2)$ is continuous and increasing in β^1 for any e_2, the above inequalities imply that there exists $\tilde{\beta}^1_k < 1$, such that firm 1 prefers vertical separation to the integration for any $\beta^1 \in [\tilde{\beta}^1_k, 1)$, where $k \in \{I, S\}$ represents the organizational structure of firm 2, Integration or Separation. **Q.E.D.**

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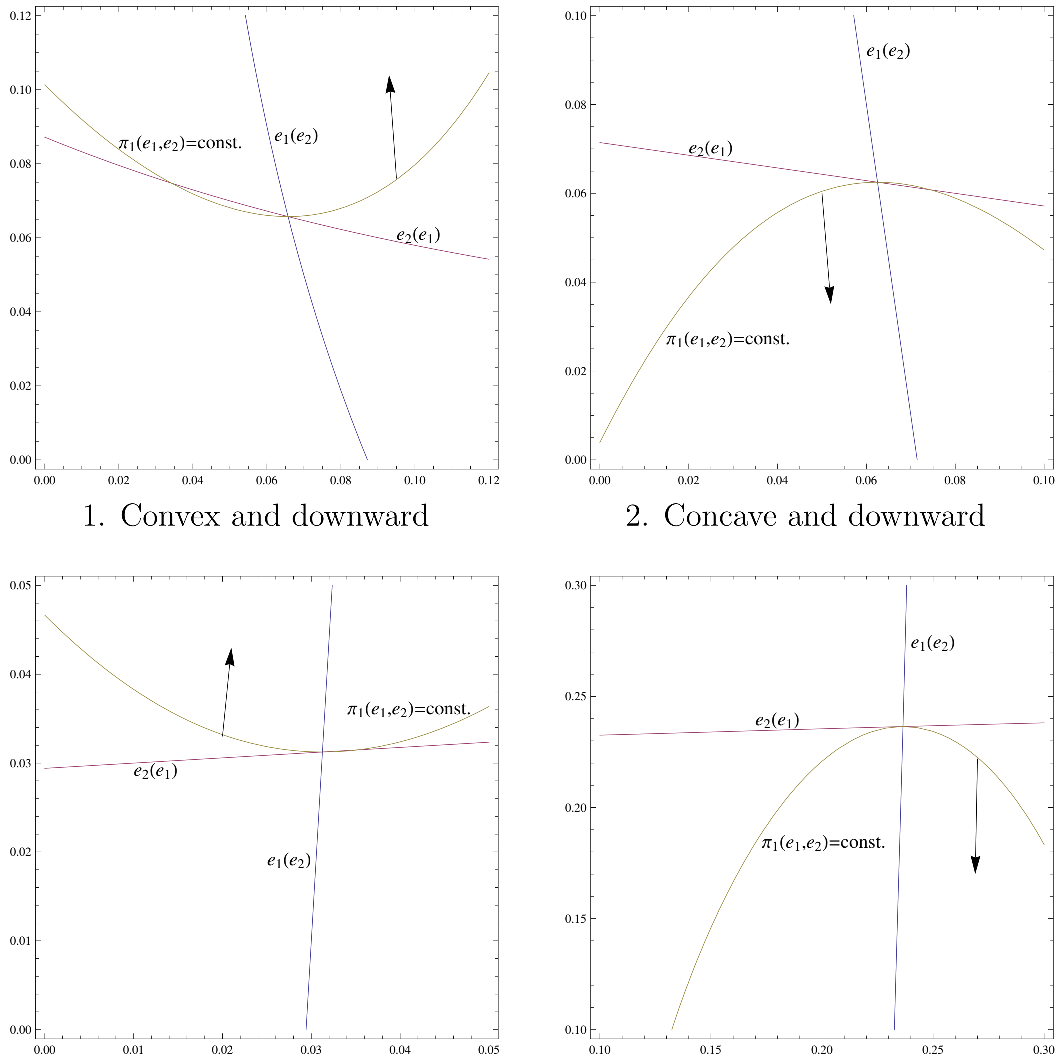
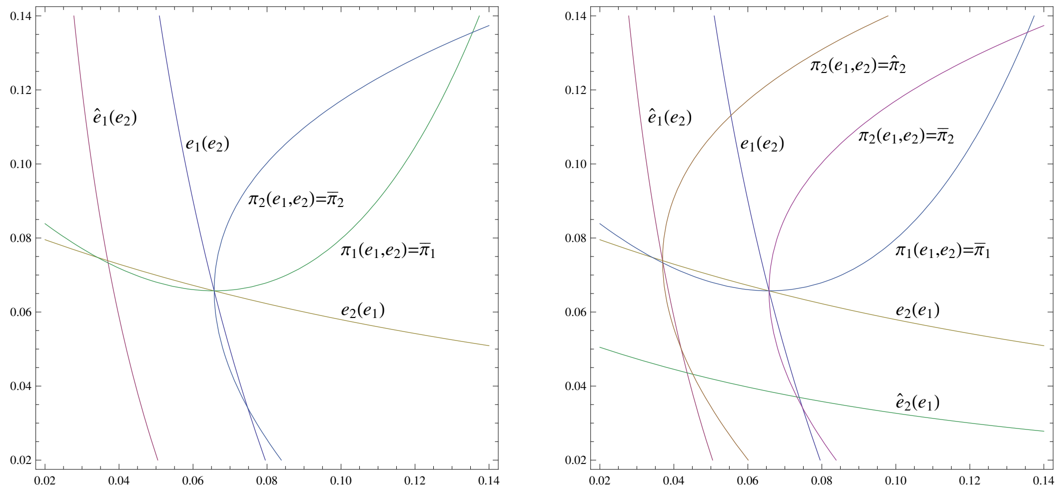


1. Convex and downward
2. Concave and downward
3. Convex and upward
4. Concave and upward

Figure 1: Four possible cases

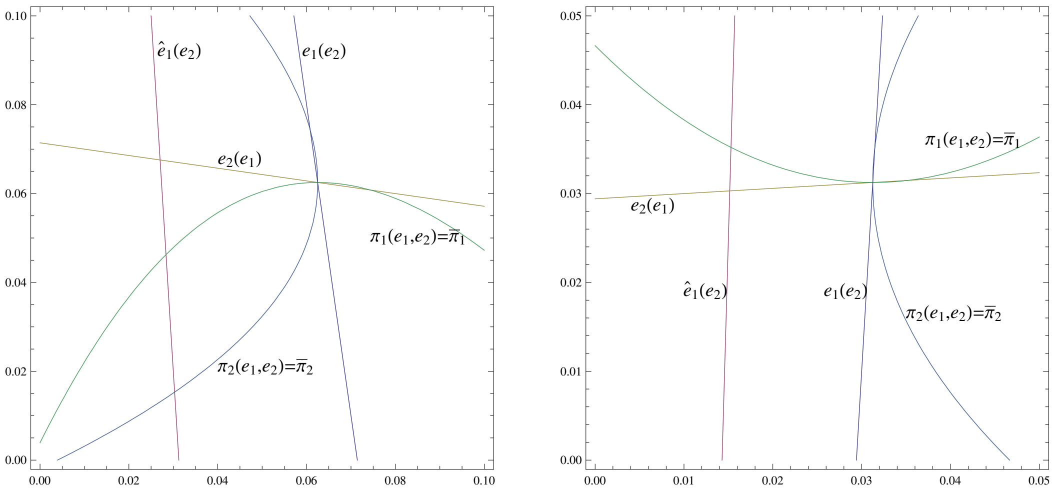
(The arrow indicates the direction of increasing profit for firm 1)



$(\alpha = 1/5,\, \theta = 1)$

$\hat{e}_i(e_j)$ is the reaction function when firm i is vertically separated

Figure 2: Case 1 (Investments have a public good nature)



$(\alpha = 1,\ \theta = 0)$ $(\alpha = 1,\ \theta = 1)$

Figure 3: Cases 2 and 3 (Spillover a la d'Aspremont and Jacquemin (1988))

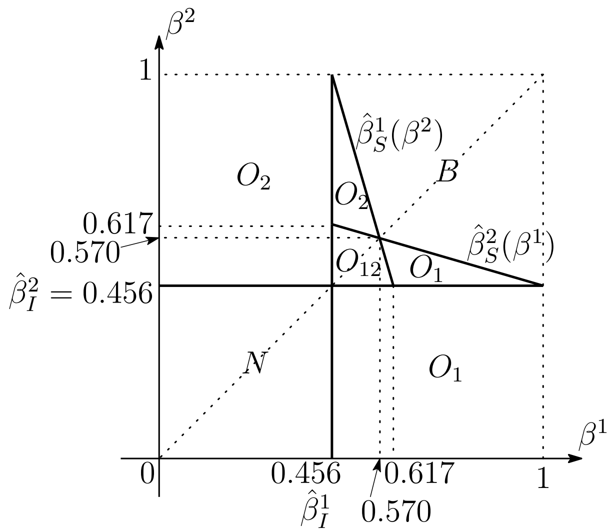


Figure 4: Realized vertical structure under Case 1 ($\alpha = 1/5$, $\theta = 1$)

Note B: Both separate; O_1: Only firm 1 separates; O_2: Only firm 2 separates; O_{12}: Only one of the firms separates; N: No firm separates. (The threshold curves $\hat{\beta}_S^i(\beta^j)$ are not straight lines).