Discussion Paper No. 1069

ISSN (Print) 0473-453X
ISSN (Online) 2435-0982

ORGANIZATIONAL STRUCTURE AND TECHNOLOGICAL INVESTMENT

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Revised April 2020
November 2019

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Organizational structure and technological investment*

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April 22, 2020

*We thank Yusuke Zennyo and the seminar participants at Japan Association for Applied Economics (Nanzan University), Kagoshima University, and Waseda University for their valuable discussions and comments. We gratefully acknowledge the financial support from the Japan Society for the Promotion of Science (JSPS), KAKENHI Grant Numbers JP15H03349, JP15H05728, JP17H00984, JP18H00847, JP18K01519, JP18K01593, and JP19H01483, the Generalitat de Catalunya grant 2017SGR-711, the Severo Ochoa Programme grant number SEV-2015-0563, the MCIU and FEDER PGC2018-094348-B-I00, and Osaka University for its International Joint Research Promotion Program. The second author thanks the warm hospitality at MOVE, Universitat Autònoma de Barcelona where part of this paper was written and a financial support from the "Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation" by JSPS. The usual disclaimer applies.

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Organizational structure and technological investment

Abstract

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

JEL Codes: L22, L13, O32, C72.

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

1 Introduction

In this paper, we analyze how final good competition and R&D characteristics (in particular, the level of spillovers in knowledge and innovation) affect firms' decisions about their vertical structure under a general demand system. We investigate this question by proposing a downstream duopoly in which each of the downstream firms has an exclusive relationship with an independent supplier that engages in a process innovation with spillovers between the suppliers and downstream firms. We provide a complete formulation of the reasons for adopting an integrated or decentralized structure. To do it, we take into account how upstream suppliers create knowledge and how such knowledge interacts with market competition.

We think that our formulation helps understanding firms' decisions and, for example, may explain why the market structure in the automotive industry takes different vertical organizations in the US and Japan. First of all, this 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 (including designs and materials) which cause technological spillovers between them (Sako, 1996; Aoki and Lennerfors, 2013). Regarding the vertical structures, Japanese automobile manufacturers often separate the development and manufacturing of critical elements to independently managed entities, which still have close relations with those manufacturers (Ahmadjian and Lincoln, 2001). The degree of vertical integration in those manufacturers is smaller than that in their US counterparts (Cusumano and Takeishi, 1991). There are several explanations for the different degrees of vertical integration in the US and Japan (Dyer, 1996). Among these explanations, there are arguments based on various preferences over the vertical structure, such as the independence of outside suppliers (Scherer, 1980; Perry, 1989), or the fear of losing managerial control (Emerson, 1962, Pfeffer and Salancik, 1978). Another important aspect is the business culture: trust for suppliers in Japanese cultural norms is essential (Sako, 1991, and Hill, 1995).

In our model, we consider two competing vertical chains, each consisting of one upstream and one downstream sector. Each of the upstream sectors conducts R&D investment, which 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 firm's R&D cost may depend on its rival's R&D effort and that it exploits 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. Such spillovers may also decrease/increase the cost of the R&D effort of the rival. As for the R&D decision, under vertical integration, there is no coordination cost between the upstream and the downstream sectors. They share their common knowledge and provide all relevant information and effort to help each other to produce the optimal level of R&D for the vertical structure.[1] Non-integrated structures suffer from the lack of coordination, in our model in the form of bargaining power, and lead to an underinvestment in R&D activities (we can also interpret it as imperfect coordination). As argued by Armour and Teece (1980), more vertically integrated firms are more efficient at R&D.

We show that the equilibrium vertical structure depends on whether the situation belongs to one of four possible cases, which are defined by the two following criteria: (i) whether a firm's investment helps or harms the rival; (ii) whether firms' investments are strategic substitutes or strategic complements. These two criteria conform to four cases. We include

[1] The innovation process depends on the ability to monitor the latest market and technological developments and to integrate various sophisticated technologies. In the car industry, this can include know-how, commercially sensitive information, cooperation to develop new materials, safety-related innovations, or more complex products or components. It can also be related to trust or better monitoring or the difference between R&D in-house or outside. These are also significant concerns for the pharmaceutical and biotechnology industries, the service sector, and all industries with material suppliers such as beverage and food sellers or toy producers.

in Case 1, the situations where a firm's investment helps the rival, and investment levels are strategic substitutes. In the presence of spillovers, each firm may have an incentive to vertically separate in order to induce its rival to engage in more R&D. In these scenarios, the vertical structure allows firms to increase the free-riding on the rival investment. We call the following situation Case 2: a firm's investment helps the rival as in Case 1, and investment levels are strategic complements. There, each firm adopts a vertically integrated structure as a commitment to engage in a higher investment to induce its rival also to invest more. That is, aggressiveness for investment mutually fosters their efforts on investment. The third case, Case 3, refers to markets where a firm's investment harms the rival, and investment levels are strategic substitutes. There, each firm is better off by adopting a vertically integrated structure to engage in more investment, which induces its rival to invest less. That is, in this case, firms vertically integrate because the aggressiveness in R&D investment is essential to keep a strong competitive position in the downstream market. The last possible situation, Case 4, appears when a firm's investment harms the rival, and R&D investment levels are strategic complements. Then, each firm may have an incentive to vertically separate to induce its rival to invest less. In that way, a mutually beneficial equilibrium with lower investment levels through vertical separation(s) may happen.

To clarify the importance of the interplay between the degree of spillovers and the strategic nature of investment levels, we provide the following two comparisons. First, we compare Cases 1 and 2. Investments in both cases have strong positive spillovers, although the expected vertical structures are opposite: vertical separation may happen in Case 1, but vertical separation never occurs in Case 2. The difference comes from the characteristics of investment levels: strategic substitutes (Case 1) and strategic complements (Case 2). Second, we compare Cases 3 and 4. Investments in both cases have weakly positive or negative spillovers, although the expected vertical structures are opposite: vertical separation never happens in Case 3, but vertical separation may occur in Case 4. The difference comes from the characteristics of investment levels: strategic substitutes (Case 3) and strategic complements (Case 4). If we use the market environment in the seminal paper by d'Aspremont and Jacquemin (1988), we can treat only Cases 2 and 3, both of which lead to vertical integration if the two vertical chains use secret contracts with non-linear tariffs. Given the result, one may conclude that technological spillover does not affect the vertical structure. However, as we have checked, this conclusion is not appropriate if we take into account the strategic nature of investment levels (strategic substitutes and complements).

After the general setting, we present some examples to illustrate how final good market competition, spillover, and incentives in innovation interact to determine the equilibrium 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. A separated upstream sector in a vertical chain has a strong incentive for R&D if its bargaining power over the separated downstream sector is high. Even in this simple framework, we see that having a prediction about the equilibrium 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 preferable when they fall significantly. The final equilibrium is that both firms choose a non-integrated structure if, in this structure, the R&D incentives for both of them are still high. Asymmetric structures arise when one firm keeps the incentives, and the other does not, or when both have intermediary incentives.

Our conclusions are consistent with the comparison of the vertical organization in the Japanese and US car industries. Japanese suppliers have more substantial bargaining power over automobile assemblers than their US counterparts (Matsushima and Mizuno, 2013, Section 5.1). Also, the degrees of vertical integration in those manufacturers are smaller than those in their US counterparts (Cusumano and Takeishi, 1991). In sum, our paper provides a plausible explanation for the difference between the organizational structure of the Japanese and US automobile assemblers.

Some related papers provide useful frameworks to understand specific situations. The advantage of our paper is twofold: it gives a general property under an abstract form of competition and technology environments. It also clarifies how technological spillovers in the R&D process or the R&D results help to understand the adoption of different vertical structures.

The remainder of the paper is structured as follows. Section 2 explains the related literature. Section 3 describes the model. Section 4 considers the incentives for R&D under the vertical structures, whether integrated or separated. Section 5 classifies the possible market structures into e 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 6 concludes.

2 Literature review

Our paper considers market structure, R&D activities, and firms' vertical organization. It is related to three lines of research (see, Table 1 for a summary).

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, the papers mentioned above do not consider the R&D activities (including process and product innovations), which are indispensable for firms to obtain competitive advantages over their rivals. As a consequence, they ignore that these activities may be vital in 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 critical in the innovation process, whether there is vertical integration or not may have significant consequences.

Another relevant literature has also 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 our paper, we are interested in the effects of the market competition conditions and the R&D investment characteristics on the firms' organization decision. To our knowledge, the closer paper is Gupta (2008). This author extends his earlier article Gupta and Loulou (1998), in which considering two exclusive competing vertical chains, the manufacturers engage in process innovation without spillovers, and each of them has an exclusive relationship with an independent retailer.[3] Gupta (2008) adds knowledge spillovers in the unit cost of production of the model, which considers linear functional forms for the demand and the

[2] Milliou and Petrakis (2012, 2019) considered the effect of vertical integration by an upstream monopolist and a downstream firm under a downstream duopoly market with technology spillovers.

[3] There are a few papers less related to the consequences of market competition and R&D investment on the vertical organization. Wang et al. (2017) introduce price and quality sensitivities into a Gupta and Loulou (1998) model by using a linear demand system and considering the degree of consumer loyalty. Lin et al. (2014) consider a downstream duopoly circular-city model with a three-tier exclusive supply chain. However, technological spillovers of any type are out of scope in their papers.

marginal cost functions. He also assumes linear tariff contracts between the two chains in case of vertical separation. He shows that vertical integration by both chains is always an equilibrium outcome. Besides, he shows that, in his model, vertical separation by both chains is also an equilibrium outcome, if and only if the substitutability of their products is sufficiently high. Moreover, vertical separation by both chains induces high investment levels if the degree of spillover is large enough. In our paper, in addition to general spillovers on the R&D outcome, we also consider spillovers in the R&D process. Furthermore, we investigate a general set-up that allows us to focus on the strategic property of investment levels (strategic substitutes and complements) under a general demand system. Finally, and in contrast with Gupta (2008), we consider secret contracts with non-linear tariffs or lump-sum transfers in the case of vertical separation. Our results lead to more general and quite different conclusions on the firms' decisions on vertical integration or separation. Our results also imply that the difference between the vertical contracts between the upstream and the downstream sectors in separated structures in those previous papers, which assume linear contracts, and ours, in which we assume secret contracts with non-linear tariffs or lump-sum transfers, is crucial. In our model, vertical separation does not have a strategic effect on profits through the double marginalization problem, which is a critical factor in the previous papers that assume linear wholesale pricing.

[Table 1 about here]

3 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: an upstream sector and a downstream sector. When a firm integrates the two sectors vertically, the firm organizes them as a single entity, which takes into account the joint profits of the sectors. In contrast, if a firm separates the two sectors vertically, each of them has its own objective, and they negotiate the trading terms between them.

The R&D investment made by the upstream sector of a firm has a positive effect on the productivity of its downstream sector (e.g., it allows a reduction of production costs), and it may also affect the productivity of the rival's downstream sector or the cost of R&D of its upstream sector (that is, there may be knowledge and 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, the two upstream sectors simultaneously and non-cooperatively choose their own R&D investment effort e_i ($i = 1, 2$). If firm i chooses effort e_i and firm $j(\neq i)$ chooses e_j, then 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, that is, it allows for *spillovers at the R&D process stage*. We assume that firms' R&D efforts are publicly observable. Then, if firm i ($i = 1, 2$) is vertically separated, the two sectors in firm i negotiate a lump-sum transfer F_i from the downstream to the upstream sector.[4] If the negotiation breaks down, the downstream sector procures final goods from other competitive upstream firms without any technological advantage. In the third stage, the downstream sectors compete with their rivals in the final good market by using their available technological improvements.

We consider a general reduced form for the profits obtained in the third stage: The downstream sector in firm i obtains the gross profit $V^i(e_i, e_j)$ if the downstream sector in firm i uses the technological improvements created by the upstream sector in firm i, otherwise,

[4] 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 payment scheme is optimal when the contract terms are private information within the two sectors of the vertical chain (so-called secret contracts) and that after transferring the R&D outcome, the upstream sector does not involve in the production of the final good. A related discussion is available in Section 3.2 of Caillaud and Rey (1995) (see also Hart and Tirole (1990) and Rey and Tirole (2007) for discussions of secret contracts). In addition, Rockett (1990) explains situations in which licensors of new technology face difficulties in collecting per production fees from licensees.

it obtains $\bar{V}^i(e_j) \equiv V^i(0, e_j)$, which does not depend on the technological improvements made by the upstream sector i. Expressions $V^i(e_i, e_j)$ and $\bar{V}^i(e_j)$ may depend on the rivals investment effort, indicating firm i can experience *spillovers in the production stage* under the available technology of the downstream firms. This assumption means that the spillovers of the production process in the downstream market depend on the technological improvements that the downstream sectors use. For illustrative purposes, in the examples of Section 5.3, we present particular functional forms of $V^i(e_i, e_j)$ by assuming that competition in the final good market follows the standard Cournot for markets with different characteristics in terms of demand, spillovers and bargaining power in case of vertical separation.

Thus, in the second stage, in firm i, if the downstream sector uses the technology of the upstream sector, firm i's net profit is

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

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 their own effort,

(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: $\Pi_{ii}^i(e_i, e_j) \equiv \partial^2 \Pi^i/\partial e_i^2 < 0$.

4 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 organizational structures of both firms.

4.1 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).

4.2 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 downstream to the upstream 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 upstream sector's profit is $F_i - I^i(e_i, e_j)$ and the downstream sector's profit is $V^i(e_i, e_j) - F_i$. If the negotiation fails, then the upstream sector's profit is $-I^i(e_i, e_j)$ and the downstream sector's profit is $\bar{V}^i(e_j)$. Thus, if the negotiation succeeds, the net surplus of the negotiation is $V^i(e_i, e_j) - \bar{V}^i(e_j)$.

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 upstream sector in firm i

is β^i, with $\beta^i \in (0,1)$, exogenously given.[5] Thus, the fixed fee F_i is characterized by

$$(1-\beta^i)(F_i - 0) = \beta^i(V^i(e_i, e_j) - F_i - \bar{V}^i(e_j))$$
$$\text{or} \qquad F_i = \beta^i(V^i(e_i, e_j) - \bar{V}^i(e_j)),$$

which allows to substitute F_i into the profit function.[6] Anticipating the terms of the agreement, the upstream sector in firm i maximizes the following expression with respect to e_i:

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

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. 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 a separated upstream sector to invest is weaker than that of an integrated firm.

The first-order condition of the previous maximization is

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

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 indicates Separation).

4.3 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

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

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

integrated or separated, for $i, j = 1, 2$ and $j \neq i$.

5 Organizational structure decision

First, we investigate the basic properties of the iso-profit curve in the effort's space and the investment reaction function. Then, by using the characteristics of these functions, we classify the market structures into four cases. Finally, we further investigate the equilibrium organizational structures by using parametric examples.

5.1 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 upstream sector is smaller than 1. To understand whether this distortion is profitable for the firm, that is, whether vertical separation is preferable, 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, 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

$$\frac{d\left(\dfrac{de_j}{de_i}\right)}{de_i} = -\frac{\Pi_{ii}^i \Pi_j^i - \Pi_i^i \Pi_{ji}^i}{\left(\Pi_j^i\right)^2}. \tag{8}$$

By (A4) we know that $\Pi_{ii}^i < 0$. Moreover, at the optimal effort $e_i^I(e_j)$ chosen by an integrated firm i, $\Pi_i^i\left(e_i^I, e_j\right) = 0$, Therefore, at this best reply, 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 $\Pi^i_j > 0$. The convexity of firm i's iso-profit curve is equivalent to the fact that firm j's investments benefit firm i. Conversely, the concavity of firm i's iso-profit is equivalent to having that firm j's investments harm firm i.

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:

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

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

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 net 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,

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

The two inequalities in (9) and (10) mean that firms' investment levels are strategic substitutes if and only if the cross partial derivative of the net profit is negative. Also, firms' investment levels are strategic complements if and only if the cross partial derivative of the net profit is positive.

We mention a remark on the relation between spillover and the slope of reaction functions, $e_i(e_j)$. Without spillovers in the R&D process, which is via $I^i(e_i, e_j)$, the cross partial derivative of the profit concerning the investment efforts only depends on its effect on net profits, via the market competition and the cost function that may present spillovers in knowledge (e.g., d'Aspremont and Jacquemin, 1988). If there are positive (resp. negative)

R&D spillovers, a positive (resp. negative) term will be added to the effect via the net profit, making it more likely that the slope of the reaction functions $e_i(e_j)$ is positive (resp. negative). However, having positive or negative R&D spillovers is not enough for deducing the slope of the reaction function of investment efforts when there are knowledge spillovers.

5.2 Possible cases

From the previous discussion, four cases can arise depending on the signs of Π^i_j and Π^i_{ij}. 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 in Figure 1.

[Figure 1 about here]

We discuss the four cases point to point.

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.

In this case, the rival's investment helps the firm (or equivalently to the convexity of iso-profit curves), and it does it more if the degree of technological spillover is high. Also, investment levels are strategic substitutes. Therefore, at stage 1, each firm faces the following trade-off. On the one hand, a high level of R&D investment directly gives a better position in the market. Such a high investment level can be achievable by adopting vertical integration. On the other hand, each firm can increase the rival's investment by committing to a lower investment level (strategic substitution). Such beneficial commitment is attainable by adopting vertical separation. The trade-off between the two effects will depend on the size of the spillover effects, in such a way that we should expect vertical integration if those spillovers are low, and vertical separation if they are high.

Case 2. 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.

Here, the rival's investment helps the firm, and investment levels are strategic complements. Each firm directly profits from its R&D investment and also benefits indirectly, since investing more induces its rival to invest more. In this situation, vertical integration is superior.

Case 3. 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.

In these market situations, a rival's investment harms the firm, and investment levels are strategic substitutes. The direct and indirect effects of investment will make aggressive investment attractive for firms. Such an aggressive investment is attainable by adopting vertical integration at stage 1.

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.

In this case, the rival's investment harms the firm, and investment levels are strategic complements. Then, a higher investment level has a direct effect on the firm's competitiveness but induces the rival to invest more. The latter indirect effect harms the firm. As a result of this trade-off, the decision of each firm for vertical separation or integration at stage 1 depends on whether the degree of strategic complementarity is high or low.

We summarize the above discussion in the following theorem (the proof is relegated to the Appendix).

Theorem 1 *In Cases 2 and 3, regardless of the rival firm's vertical structure, a firm prefers vertical integration to vertical separation. In Case 1 (respectively, Case 4), there exists a*

$\hat{\beta}_k^i \in (0,1)$ (respectively, $\tilde{\beta}_k^i \in (0,1)$) such that for firm i, vertical separation is preferable if $\beta^i \geq \hat{\beta}_k^i$ (respectively, $\beta^i \geq \tilde{\beta}_k^i$) and the organizational structure of firm j is $k \in \{I, S\}$, where $i, j = 1, 2$, $j \neq i$, I and S represent vertical 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 $\Pi_{ii}^i \Pi_j^i < \Pi_i^i \Pi_{ji}^i$.

Remark (Possibilities of non-exclusive vertical chains) Although we have considered exclusive vertical chains, let us briefly discuss a scenario in which a separated upstream sector in a vertical chain can supply to the downstream sector of the rival vertical chain (we call the ability "the dual supply capability"). Assume that each upstream sector incurs adjustment costs, τ, to supply to the downstream sector of the rival vertical chain, due to firm-specific relationship.

The game discussed here also has three stages: In the first stage, firms simultaneously and non-cooperatively determine their organizational structures: vertically separated or integrated. In addition to the decision, if a firm vertically separates, it also determines whether the relationship between the upstream and downstream sectors is exclusive or not.[7] The exclusive relationship is the same as that in the main model. The non-exclusive relationship means that the upstream sector can supply to the competing downstream sector in the rival vertical chain. In the second stage, each of the two upstream sectors simultaneously and non-cooperatively choose their own R&D investment effort e_i ($i = 1, 2$). Then, after the upstream sectors made the R&D investments, if firm i ($i = 1, 2$) vertically separates, the two sectors in firm i negotiate a lump-sum transfer F_i from the downstream to the upstream

[7] Milliou (2008) considers a downstream monopoly model with an endogenous choice of exclusive vertical relationship.

sector in firm i. Note that if both firms vertically separate, the disagreement profit of the downstream sector in firm i differs from that in the main model because it can potentially procure from the upstream sector in the competing vertical chain. The disagreement profit of this downstream sector in firm i is $\bar{V}^i(e_j) = V^i(e_j - \tau, e_j) - f_i$ or $\bar{V}^i(e_j) = V^i(0, e_j)$, which reflects the effort, e_j, the adjustment cost of the upstream sector in firm j, τ, and an off-path lump-sum payment for the upstream sector j, f_i. Finally, each of the downstream sectors competes with its rivals in the final good market by using their available technological improvements.

Because both $V^i(e_j - \tau, e_j) - f_i$ and $V^i(0, e_j)$ are independent of e_i, the maximization problem of the upstream sector of firm i ($i = 1, 2$) in the second stage is the same as that in the main model (see (4)). Therefore, the possibility of non-exclusive relationship does not change the investment incentives of the two upstream sectors.

5.3 Illustrating examples

To illustrate how different parameter combinations determine the decision on vertical separation or integration, we consider a very simple example. Two identical firms compete in quantities in a market with the following inverse demand,

$$p = \frac{3}{2} - q_1 - q_2, \tag{11}$$

where q_i is the quantity supplied by firm i ($i = 1, 2$). Note that we can derive qualitatively similar results under price competition with the linear demand system (Dixit, 1979; Singh and Vives, 1984).Firms may invest in a cost-reducing R&D process. As a result of this process, the marginal cost of firm i, c_i, is given as

$$c_i(e_i, e_j) = 1 - (e_i + \theta e_j), \tag{12}$$

where e_i and e_j are the effort levels of firms i and j ($i, j = 1, 2,\ j \neq i$), and $\theta \in [0, 1]$ is an exogenous parameter.

The first term of $c_i(e_i, e_j)$ is an *ex ante* marginal cost level (normalized to 1); the second term is the degree of marginal cost reduction, which includes the degree of production process spillovers, θ. $c_i(e_i, e_j)$ in (12) is essentially equivalent to the expression for the marginal cost in d'Aspremont and Jacquemin (1988).

We assume that the R&D investment cost of firm i is given as

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

where $\delta \in [-1, 1]$ is an exogenous parameter indicating spillovers at the R&D stage.

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

$$V^i(e_i, e_j) = \frac{(3/2 + c_j(e_i, e_j) - 2c_i(e_i, e_j))^2}{9}. \tag{14}$$

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

$$\begin{aligned} \Pi^i &= V^i(e_i, e_j) - I^i(e_i, e_j) \\ &= \frac{(1/2 - (e_j + \theta e_i) + 2(e_i + \theta e_j))^2}{9} - (2e_i^2 - \delta e_i e_j). \end{aligned} \tag{15}$$

Before we present parametric examples of the four cases listed in Section 5.2, we mention the scenario, in which there is no spillover in any stage (production and R&D), i.e., $\theta = \delta = 0$. Without spillovers, 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, a situation of strategic substitutes. This scenario belongs to Case 3, where for any bargaining power of separated upstream sectors, the firms vertically integrate in equilibrium.

The shapes of iso-profit curves and reaction functions Following the classification in Section 5.2, we now show four numerical examples generated by the parameter values summarized in Table 2:

[Table 2 about here]

After we explain the four cases, in Section 5.3.3, we consider the equilibrium organizational structure for any (β^1, β^2) to see the effect of the bargaining power.

5.3.1 Parametric examples of Cases 1 and 2 ($\theta = 1$)

From (12) and (13), the marginal cost and investment cost of firm i are given as

$$c_i = 1 - (e_i + e_j), \quad I^i(e_i, e_j) = 2e_i^2 - \delta e_i e_j, \tag{16}$$

where $\delta \leq 0$. The functions in (16) have the following two features. First, there are significantly positive spillovers in production, $\theta = 1$, in such a way firm j's investment effort equally improves the efficiencies of firms j and i. In other words, the cost-reducing efforts of the firms are a public good. Second, there are negative spillovers of investment costs, $\delta \leq 0$, in such a way that the investment effort of a firm increases the investment cost of the rival.

For any $\delta \leq 0$, the iso-profit curve of firm i is convex with respect to e_i. In contrast, the slope of the reaction function depends on the magnitude of negative spillovers in investment costs, δ. If the magnitude is strong (resp. weak), that is, if $\delta < -2/9$ (resp. $-2/9 < \delta \leq 0$), the reaction function is downward (upward) sloping.[8] A substantially negative δ means that the substitutability of their efforts in the R&D process is large, implying that their efforts levels are strategic substitutes if the value of δ is low enough.

When the degree of negative spillovers in R&D is significant, the market structure belongs to Case 1. As shown in Theorem 1, the equilibrium vertical structure depends on the bargaining power β^i in case of separation. If β^i is sufficiently close to 1, the combination of the positive spillovers in the production process and the negative spillovers in the R&D process induces the firms to adopt vertical separation as a credible commitment to engage in lower investment efforts, which cause the rivals to invest more.

[8] The net profit of firm i is

$$\Pi_i = \frac{(1 + 2e_i + 2e_j)^2}{36} - (2e_i^2 - \delta e_i e_j).$$

The first-order and cross-partial derivatives are

$$\frac{\partial \Pi_i}{\partial e_i} = \frac{1 - 34e_i + (2 + 9\delta)e_j}{9}, \quad \frac{\partial^2 \Pi_i}{\partial e_i \partial e_j} = \frac{2 + 9\delta}{9}.$$

The cross-partial derivative is negative (resp. positive) if and only if $\delta < -2/9$ (resp. $-2/9 < \delta \leq 0$).

When the degree of negative spillovers in R&D is small, say, for instance, $\delta = 0$, the situation with perfect production spillovers in d'Aspremont and Jacquemin (1988) belongs to Case 2. In this case, for whatever bargaining power in case of separation, the firms adopt vertical integration in equilibrium. Their R&D investments translate into a universal reduction in production costs, and investment levels are strategic complements. The firms employ vertical integration to commit to investing more credibly.

Proposition 1 *When the market is defined by equations* (11) *and* (16)*, and for sufficiently large* $\beta = \beta^1 = \beta^2$*, then in equilibrium the firms adopt vertical separation if* $\delta < -2/9$*; otherwise they select vertical integration.*

5.3.2 Parametric examples of Cases 3 and 4 ($\theta = 0$)

From (12) and (13), the marginal cost and investment cost of firm i are given as

$$c_i = 1 - e_i, \quad I^i(e_i, e_j) = 2e_i^2 - \delta e_i e_j, \tag{17}$$

where $\delta \geq 0$. The functions in (17) have the following two features. First, there are no spillovers in production costs, $\theta = 0$, in such a way firm j's investment effort affects only its marginal production cost but does not affect the marginal cost of firm i. In other words, the cost-reducing efforts of the firms are private goods. Second, there are positive spillovers of investment costs, $\delta > 0$, in such a way that the investment effort of a firm decreases the investment cost of the rival.

In all these situations, i.e., for all $\delta \geq 0$, the iso-profit curve of firm i is concave with respect to e_i. As in Section 5.3.1, the slope of the reaction function depends on the magnitude of the positive spillovers in the R&D process, δ. If the positive spillovers are weak (resp. strong), that is, $0 < \delta < 4/9$ (resp. $\delta > 4/9$), the reaction function is downward (resp. upward) sloping.[9] A higher δ means that the complementarity of their efforts through the

[9] The net profit of firm i is

$$\Pi_i = \frac{(1 + 4e_i - 2e_j)^2}{36} - (2e_i^2 - \delta e_i e_j).$$

positive spillovers is larger. This relation implies that the complementarity overrides the substitutability induced by market competition. As a result, their investment efforts become strategic complements if the value of δ is high.

When the positive spillovers in investment costs are small, say, for example, $\delta = 0$, the standard Cournot competition without any spillover situation belongs to Case 3. Vertical separation merely diminishes the investment level of the separated firm, which weakens its competitiveness but strengthens the rival's competitiveness.

When the positive R&D spillovers are significant, the situation belongs to Case 4. Due to the considerable spillovers of investment efforts, a decrease in e_i induces a reduction in e_j. As indicated in Theorem 1, the equilibrium vertical structure depends on the bargaining power β^i in case of separation. For a sufficiently large β^i, the combination of the positive spillovers in the production process and the effect through the Cournot market interaction induces the firms to adopt vertical separation, because choosing vertical separation works as a credible commitment to engage in lower investment efforts, which cause the rival to invest less.

Proposition 2 *When the market is defined by equations* (11) *and* (17)*, and for sufficiently large $\beta = \beta^1 = \beta^2$, then in equilibrium the firms adopt vertical separation if $\delta > 4/9$; otherwise they choose vertical integration.*

In sum, comparing the results obtained in Sections 5.3.1 and 5.3.2, we conclude that (i) significantly positive spillovers of production costs with significantly negative spillovers of investment costs (Case 1) and (ii) significantly large positive spillovers of investment costs without spillovers of production costs (Case 4) lead to similar outcomes. The outcome is that

The first-order and cross-partial derivatives are

$$\frac{\partial \Pi_i}{\partial e_i} = \frac{2 - 28e_i - (4 - 9\delta)e_j}{9}, \quad \frac{\partial^2 \Pi_i}{\partial e_i \partial e_j} = -\frac{4 - 9\delta}{9}.$$

The cross-partial derivative is negative (resp. positive) if and only if $\delta < 4/9$ (resp. $4/9 < \delta \leq 1$).

the firms choose vertical separation if the bargaining power in case of separation is sufficiently large. The next section, Section 5.3.3, further investigates the role of the bargaining power in a simple Case 1 scenario.

5.3.3 Generalized values of β^i in Case 1

Which of the four cases appears depends only on the demand and cost parameters. In Cases 2 and 3, in which the two firms employ vertical integration to invest more, the value of β^i does not matter in the decisions of vertical structure in equilibrium. Contrary to the two cases, in Cases 1 and 4, in which vertical separation may work as a commitment device to invest less, the parameter β^i is a critical parameter that influences the decisions of vertical separation because the value of β^i represents the incentive for the investment of the separated upstream sector in vertical chain i (see (4)).

Now, we consider a market with $\theta = 1$, $\delta = -1$, and any parameters of $\beta^i \in [0, 1]$ to check how the values of β^1 and β^2 influence the equilibrium vertical structure. Except for the relaxation of the two parameters β^i and the imposition of $\delta = -1$, we use the same parameters as in Section 5.3.1. By a numerical analysis, we obtain Figure 2.[10]

[Figure 2 about here]

Proposition 3 summarizes Figure 2, where the functions $\beta^j_S(\beta^i)$ for $i, j = 1, 2$ are increasing and such that $\beta^j_S(1) = 0.648$, and $\beta^j_S(0.629) = 0.629$:

Proposition 3 *When the market is defined by equations* (11) *and* (16)*, and for* $\delta = -1$*,*

(i) if $\beta^i > 0.648$ *and* $\beta^j > \hat{\beta}^j_S(\beta^i)$ *for* $i, j = 1, 2$ *(*$j \neq i$*) where* $\hat{\beta}^i_S(\beta^j)$ *for* $i, j = 1, 2$ *(*$j \neq i$*) is in Figure 2, then the firms vertically separate (area B in Figure 2);*

(ii) if $\beta^i > 0.648$ *and* $\beta^j < \hat{\beta}^j_S(\beta^i)$*, then firm* i *separates and firm* j *integrates (areas* O_i *(*$i = 1, 2$*) in Figure 2);*

[10] The mathematica file to derive Figure 2 is available upon request.

(iii) if $\hat{\beta}^i_S(\beta^j) \le \beta^i \le 0.648$ for $\beta^i > 0.629$ $(i, j = 1, 2,\ j \ne i)$, there are two possible equilibria in which either the two firms separate or the two integrate (area BN in Figure 2);

(iv) otherwise, in equilibrium no firm separates (area N in Figure 2).

Proposition 3 shows how the equilibrium organizational structure varies as a function of the values of bargaining power, (β^1, β^2), in case of separation. Part *(ii)* of Proposition 3, in particular, shows that when β^1 and β^2 are very different, asymmetric organizational structures arise.

Proposition 3 is complementary to the explanation in Matsushima and Mizuno (2013) who show that vertical separation is more likely to appear in equilibrium if the bargaining power of independent complementary input suppliers is high. The existence of multiple suppliers is the key ingredient that leads to vertical separation in Matsushima and Mizuno (2013). Contrary to their setting, we do not assume multiple inputs but formulate the interaction between upstream sectors in two competing vertical chains, and show that technological spillover can be a driving force of vertical separation. The consideration of technological spillover is plausible, given that there are suppliers' associations in the Japanese automobile industry (see Sako, 1996; Aoki and Lennerfors, 2013). In addition to this fact, some major parts suppliers join in multiple suppliers' associations (Sako 1996, p.656), those of which foster mutual learning among parts suppliers (Sako, 1996, p.664).

As summarized in Matsushima and Mizuno (2013, Section 5.1), the Japanese suppliers have stronger bargaining power over automobile assemblers than their US counterparts. Also, the degrees of vertical integration in those manufacturers are smaller than those in their US counterparts (Cusumano and Takeishi, 1991). In sum, our paper is another plausible explanation for the difference between the organizational structure of the Japanese and US automobile assemblers.

5.3.4 Discussion

In Sections 5.3.1–5.3.3, we consider spillovers of investment costs to express market environments in which vertical separation can happen. We briefly discuss a duopoly competition without spillovers of investment costs to explain the fact that spillovers of investment costs in themselves are not essential for vertical separation to occur.

Let us consider the inverse demand in (11) and the following marginal cost and investment cost of firm i:

$$c_i = 1 - (e_i + e_j)^{1/5} \text{ and } \ I^i(e_i, e_j) = 2e_i^2. \tag{18}$$

In this scenario, there is no spillover at the R&D stage (as Cases 2 and 3 in Table 2, $\delta = 0$). Also, the efforts of the firms have a public good nature (as in Section 5.3.1, $\theta = 1$) in the sense that e_i reduces the marginal cost of firm j as much as that e_i reduces the marginal cost of firm i. However, the marginal cost is not linear in e_i and e_j.

For functional forms of the type $(e_1 + e_2)^\alpha$ with $\alpha < 1$, the marginal cost is concave with respect to e_i. The concavity 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), as it is the case for $\alpha = 1/5$, only one of the firms' efforts is sufficient to achieve a reasonable level of cost reduction. This implies that the iso-profit curve is convex with respect to its investment level. In addition, the reaction curve is downward sloping, in such a way that this scenario belongs to Case 1.[11] As a consequence, following Theorem 1 and along with Proposition 1, firms adopt vertical separation if the upstream sectors' bargaining power is large enough.

Proposition 4 *When the market is defined by equations* (11) *and* (18)*,*

[11] Just remember that in Section 5.3.1, with linear production costs, full spillovers of the production process ($\theta = 1$), and no spillovers of R&D process ($\delta = 0$), the reference case is Case 2. Then the only equilibrium is that both firms vertically integrate.

(i) if $\beta^1 > \hat{\beta}^1_S(\beta^2)$ and $\beta^2 > \hat{\beta}^2_S(\beta^1)$, where $\hat{\beta}^i_S(\beta^j)$ is in Figure 3, the firms vertically separate (area B in Figure 3);

(ii) if $\beta^i > 0.456$ and $\beta^j \leq 0.456$ or if $\beta^i > \hat{\beta}^i_S(\beta^j)$ and $0.456 < \beta^j \leq \hat{\beta}^j_S(\beta^i)$, then firm i vertically separates and firm j vertically integrates (area O_i $(i = 1, 2)$ in Figure 3);

(iii) if $0.456 < \beta^i \leq \hat{\beta}^i_S(\beta^j)$ for $i, j = 1, 2$ $(j \neq i)$, there are two possible equilibria in which one of the two firms separates and the other integrates (area O_{12} in Figure 3);

(iv) otherwise, in equilibrium no firm separates (area N in Figure 3).

This illustrates the importance of the functional form of the market and the robustness of the conclusions obtained with linear functional forms.[12]

[Figure 3 about here]

The relation between the equilibrium organizational structures and the parameters of bargaining power, β^1 and β^2, is similar to that in Proposition 3 except for the existence of asymmetric equilibria (area O_{12}) in Proposition 4.

The conclusions in Propositions 3 and 4 differ due to the difference in how investment efforts reduce the marginal cost under the two cost structures: the first one is (16) with $\delta = -1$ in Section 5.3.3 and the second one is (18) in Section 5.3.4. In both structures, if its opponent vertically separates, adopting vertical separation has three direct effects on the firm: (i) under-investment from the viewpoint of the vertical chain, (ii) a lower reduction in production cost, and (iii) a reduction of its investment cost. The first effect is similar in the two cost structures. The second one is milder in the first cost structure due to the linearly of the marginal cost. The third one, the only positive, is larger in the first cost structure due to the direct spillover of investment costs. In addition to these three direct

[12] The mathematica file to derive Figure 3 is available upon request.

effects, the adoption of vertical separation has an indirect impact on the rival's investment. In essence, the indirect impact enhances the rival's effort, which recovers the loss from the second direct effect and enlarges the investment cost spillover in the first cost structure. This positive indirect effect is larger in the first cost structure due to the linearity of c_i. However, the investment cost spillover partially offsets the gain from this positive effect. In total, adopting vertical separation is less costly in the first cost structure in Section 5.3.3, in which the marginal cost is linear in efforts. As a result, in the first cost structure there is the area BN in which a firm follows its opponent adoption of vertical separation, and the multiple symmetric equilibria can emerge.

6 Conclusion

In oligopolistic industries, understanding why firms adopt vertical integration or separation has attracted a great deal of attention. However, we are still far from understanding the whole picture, and there is no apparent and straightforward reason to explain the firms' decisions to integrate or not. Various authors explain the gains that firms will derive from meeting their input requirements internally or externally (see Section 2). In addition to the market structure, some authors include process R&D among the determinants. Very few consider the possible spillovers of knowledge generated in the analysis. To the best of our knowledge, none has investigated cases in which efforts for R&D in themselves also have positive/negative spillovers at the R&D stage. Our paper is a first step toward clarifying the importance of the technological environment when we consider the equilibrium organizational structures of firms in oligopolistic markets.

In this paper, we stress the interaction between incentives for R&D, the spillovers associated with these processes, and firms' decisions for their organizational structures. In this attempt, we consider a general and flexible framework for market competition environments, spillovers of production costs, and those of R&D costs. This framework allows us to present the conditions that determine the firms' organization decisions, and 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 vertical separation.

In our model, the forces at work come from the market conditions (as a function of the demand and the market competition), how the production cost depends on the R&D decisions, and the spillovers of production costs and R&D processes. Those factors interact with the fact that the incentives to perform R&D in a vertical chain are higher in vertical integration.

We show that the equilibrium organizational structure depends on whether the situation belongs to one of four cases. Those of which depend on whether R&D investments are mutually beneficial or not and whether investment efforts are strategic substitutes or complements. When R&D investments are mutually helpful, and investment efforts are strategic substitutes or when R&D investments are not mutually beneficial, and investment efforts are strategic complements, vertical separation can emerge. In the remaining two cases, however, vertical separation never occurs in equilibrium. In the former two cases, the degrees of upstream sectors' bargaining power in the two vertical chains are critical for a vertical separation to emerge or not. If the degree of an upstream sector's bargaining power in a vertical chain is sufficiently high, the vertical chain decides to vertically separate. Conversely, if the degree of an upstream sector's bargaining power in a vertical chain is not high, this vertical chain is more likely to integrate vertically. Interestingly, even in entirely symmetric environments, it can be the case that in equilibrium, two vertical chains 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. For example, as we have illustrated in Section 5.3, it is not possible to conclude that the level of integration depends negatively on the degree of spillovers in the industry. Technological environments in the industry matter. Therefore, our model is a warning about the importance of knowledge and R&D spillovers that the previous literature on vertical organizations has not considered. This caveat can be useful for empirical studies on firms' behavior because bypassing the R&D decisions and its spillovers may induce such researchers to support market competition as a cause of realized vertical structure for which R&D investments are accountable.

We have omitted several important issues that also determine the firms' optimal organization decisions. 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.[13] 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 $\bar{e}_2 < e_2^k(e_1^* - \epsilon)$, where $k \in \{I, S\}$ represents the organizational structure of firm 2, Integration or Separation. We obtain $\Pi^1(e_1^*, e_2^*) = \Pi^1(e_1^* - \epsilon, \bar{e}_2) < \Pi^1(e_1^* - \epsilon, e_2^k(e_1^* - \epsilon))$ because $\Pi_2^1 > 0$. Because firm 1's best response $e_1^S(e_2)$ is continuous and increasing in β^1 for any e_2 (see (5)), the above

[13] 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.

inequalities imply that there exists $\hat{\beta}_k^1 < 1$, such that firm 1 prefers vertical separation to the integration for any $\beta^1 \in [\hat{\beta}_k^1, 1)$.

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 the original Nash equilibrium decreases the profit of firm 1. Moreover, an upward shift of e_2 further decreases the profit of firm 1 ($\Pi_2^1 < 0$). 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 ($\Pi_2^1 > 0$). 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 $\bar{e}_2 > e_2^k(e_1^* - \epsilon)$, where $k \in \{I, S\}$ represents the organizational structure of firm 2, Integration or Separation. We obtain $\Pi^1(e_1^*, e_2^*) = \Pi^1(e_1^* - \epsilon, \bar{e}_2) < \Pi^1(e_1^* - \epsilon, e_2^k(e_1^* - \epsilon))$ because $\Pi_2^1 < 0$. Because firm

1's best response $e_1^S(e_2)$ is continuous and increasing in β^1 for any e_2 (see (5)), the above inequalities imply that there exists $\tilde{\beta}_k^1 < 1$, such that firm 1 prefers vertical separation to the integration for any $\beta^1 \in [\tilde{\beta}_k^1, 1)$. **Q.E.D.**

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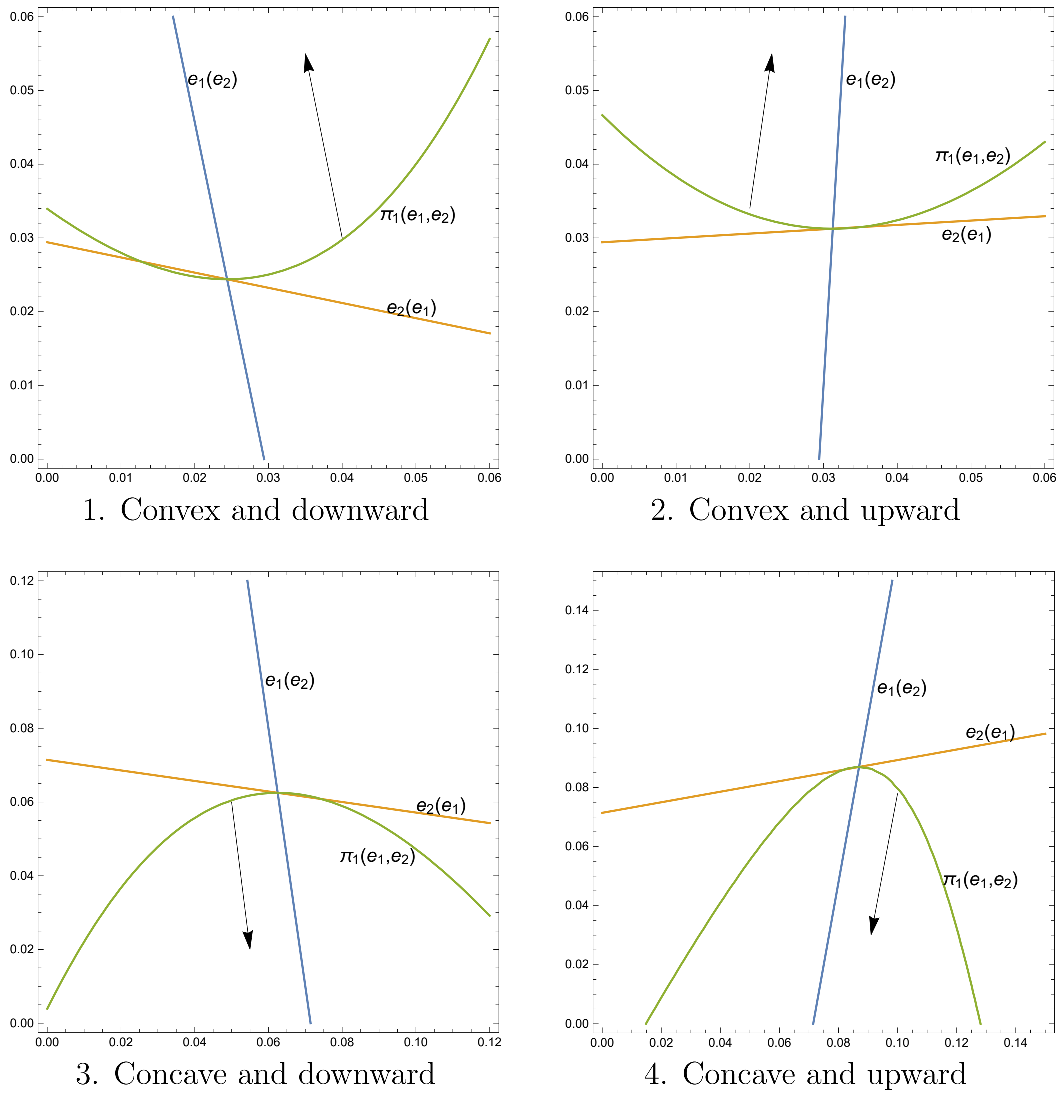
Question	Papers
Market structure **⇒ Vertical integration**	Bonanno and Vickers (1988), Ziss (1995), Gal-Or (1999), Choi and Yi (2000), Chen (2001,2005), Lin (2006), Matsushima (2009), and so on.
Vertical integration **⇒ R&D incentives**	Bolton and Whinston (1993), Buehler and Schmutzler (2008), Chen 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 literature

Example of	θ	δ
Case 1	1	-1
Case 2	1	0
Case 3	0	0
Case 4	0	1

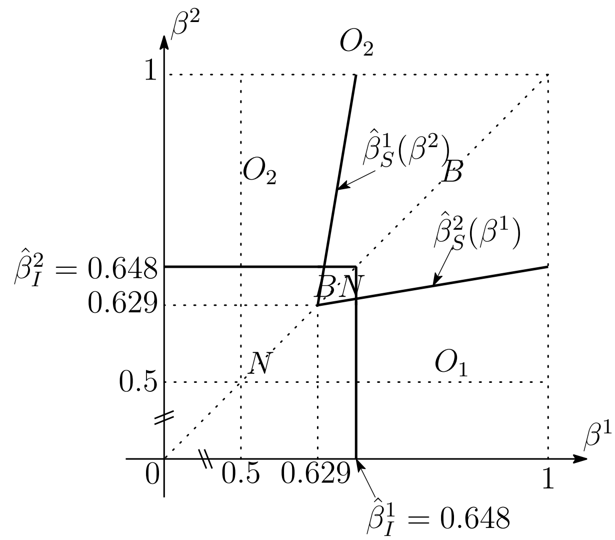
Table 2: Parametric examples for the four cases



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

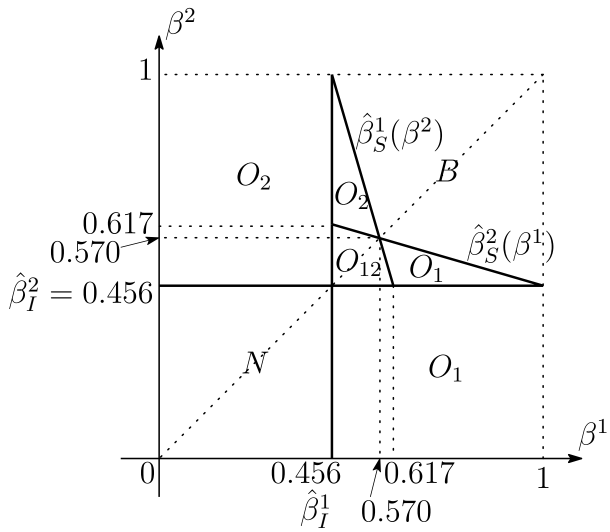
Note Horizontal axis: e_1; Vertical axis: e_2;
The arrow indicates the direction of increasing profit for firm 1.

Figure 1: Iso-profit curves and reaction functions in the effort space defining the four possible cases



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

Figure 2: Equilibrium vertical structures under Case 1 ($\theta = 1$, $\delta = -1$)



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).

Figure 3: Equilibrium vertical structures under Case 1 ($\alpha = 1/5$, $\theta = 1$)