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## **COOPERATIVE R&D WITH DIFFERENTIATED PRODUCTS IN VERTICALLY RELATED INDUSTRIES**

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## **Abstract**

*This paper studies the impact of cooperative R&D on innovation, welfare, and profitability in vertically related industries where products are differentiated. The model incorporates two vertically related industries, with horizontal spillovers within each industry and vertical spillovers between the two industries. Upstream firms produce a homogeneous intermediate good, while downstream firms provide differentiated products. Three types of R&D cooperation are studied: no cooperation, horizontal cooperation, and vertical cooperation. The comparison of cooperation settings in terms of R&D and of profitability shows that although vertical cooperation yields higher innovation and welfare, it may lead firms to over-invest in R&D.*

**Key words :** Vertical spillovers, Horizontal spillovers, Product differentiation, R&D Cooperation.

**JEL classification :** L13, O32

## **Sommaire**

*Ce papier étudie l'impact de la R&D coopérative sur l'innovation, le bien-être et la rentabilité dans les industries verticalement liées où les produits sont différenciés. Le modèle incorpore deux industries verticalement liées, avec des externalités de recherche horizontales au sein de chaque industrie et des externalités de recherche verticales entre les deux industries. Les entreprises en amont produisent un bien intermédiaire homogène, tandis que les entreprises en aval vendent des produits différenciés. Trois types de coopération R&D sont étudiés: pas de coopération, coopération horizontale et coopération verticale. La comparaison des types de coopération en termes de R&D et de rentabilité montre que même si la coopération verticale donne lieu à une innovation et un bien-être plus élevés, elle peut conduire les entreprises à surinvestir dans la R&D.*

**Mots clés :** Externalités de recherche horizontales, Externalités de recherche verticales, Différenciation des produits, Coopération en R&D.

**Classification JEL :** L13, O32

## 1. INTRODUCTION<sup>1</sup>

The importance of industry clustering for innovation and the economic performance of industrialized countries due to remarkable access to knowledge spillovers has been largely stressed recently by the theoretical and empirical literature (Gilbert et al. 2008). Although the theoretical literature implies that potential gains to firms' cooperation are higher than no cooperation when horizontal spillovers are sufficiently high, the empirical literature points to the importance of vertical technological flows. The linkages between final good manufacturers and intermediate good producers are important for prosperous innovation (Hippel 1988; Riggs & Hippel 1994; Lee 1996).

Upstream industry requires developing and producing the intermediate goods to meet the requirement of downstream firms, which makes inter-industry spillovers inevitable. The bilateral exchanged information on new technology and materials helps R&D participating partners to adopt them quickly. Inter-industry spillovers are called vertical spillovers and usually are desirable and voluntary, whereas intra-industry spillovers, known as horizontal spillovers, often are undesirable and involuntary (Atallah, 2002). Peters (1995) shows that horizontal spillovers may increase or decrease R&D, whereas vertical spillovers increase R&D, profit, and welfare. According to d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Suzumura (1992), and Yi (1996), if horizontal spillovers are sufficiently high, a horizontal R&D cartel yields higher technological improvement and welfare, whereas vertical R&D cartels yield higher welfare than horizontal R&D cartels if horizontal spillovers between upstream firms are low.

Becker and Peters (1996) study the effect of R&D competition between two vertically related cooperation networks. They find that vertical spillovers not only stimulate the R&D process and competition between suppliers but also reduce the time of development and increase the probability for the retailers to be the first to introduce the new product to the market. Harhoff (1991) studies a two-industry model of R&D where the upstream industry is a monopolist and supplies an intermediate good to oligopolistic downstream firms, which compete in quantity and quality enhancing R&D. Downstream firms use vertical spillovers as a substitute for their own R&D. This helps them to reduce their R&D costs, increase the quality of their products and increase their output, which results in higher demand for the intermediate good. Thus, both industries benefit from vertical spillovers.

Adams and Mircea (2004) show that research joint ventures increase innovation. Röller et al. (1997) analyze the determinants of RJV formation and find that cost-sharing and technological similarities significantly affect firms' R&D cooperation strategies. Dyer and Ouchi (1993) find that consulting and exchanging information between a downstream firm and an upstream firm have a mutual impact on improving the productivity of both firms. They conclude that vertical cooperation is a significant advantage of Japanese firms' style partnerships, which leads them to succeed in the global marketplace.

Atallah (2002) and Ishii (2006) study cooperative R&D between vertically related industries with two suppliers and two retailers where both industries provide a homogeneous good.

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Atallah considers four possibilities for firms: to cooperate horizontally, vertically, generally<sup>2</sup>, or not to cooperate at all. He finds that no setting uniformly dominates other settings in terms of R&D, yet general cooperation yields the highest R&D and welfare when spillovers<sup>3</sup> are high. Ishii compares vertical R&D cartels, horizontal R&D cartels, vertical research joint ventures (RJVs), and non-cooperative R&D. He shows that vertical RJV yields the highest technological improvement. Although they considered a homogeneous product for both industries, in the real world a large variety of differentiated products are produced using a homogeneous intermediate good.

De Bondt et al. (1992) study a symmetric two-stage setting in which  $n$  firms sequentially choose cost-reducing R&D investment. They show that product differentiation is important in a cost-reducing game with spillovers. Product differentiation affects rivals' reactions with quantity competition, such that the knowledge spillovers of cost-reducing R&D are not inhibited as much as they would be with homogeneous products. Thus, the benefit of cooperative R&D depends not only on the information flows and the number of rivals but also on the degree of product differentiation.

The importance of knowledge spillovers for research success is stressed by most of the analyses. Indeed, the effects of innovation complementarities, absorptive capacities, and technical similarities reinforce the efficiency of spillovers. Clark et al. (1987) study the impact of vertical spillovers on product development performance in the auto industry, where products are differentiated. They find that saving time and engineering hours are one of the most important effects of vertical cooperation on product development. Harabi (2010) finds that the informal leakage of technological knowledge significantly affects innovation through vertical R&D cooperation in German manufactures. The study also highlights the importance of other key determinants of innovative activities, such as technological opportunities, appropriability conditions, and market demand. Cockburn and Henderson (1996) analyze the effects of spillovers on research productivity in the pharmaceutical industry and find that knowledge spillovers between research groups within and across pharmaceutical companies are important determinants of research productivity. Cassiman and Veugelers (1998, 1999) study the Belgian manufacturing industry and find that firms develop their R&D strategies to maximize their benefit from the technological information flows.

The majority of analyses that studied R&D cooperation found a positive impact of cooperative R&D on innovation (Brouwer & Kleinknecht 1999; Vanhaverbeke et al. 2002). Powell and Grodal (2005) provide an extensive analysis showing that cooperative R&D has a positive effect on a firm's innovation activity. Darby et al. (2003) find a positive effect of R&D cooperation on patenting by U.S. firms. Kremp and Mairesse (2004) show that cooperative R&D significantly and positively affects innovation by French firms. Lokshin et al. (2008) state that R&D cooperation of German firms has a positive effect on innovation while engaging in diversified R&D cooperation settings (different types of partners) affects innovation more significantly and positively. Aschhoff and Schmidt (2008) analyse the annual German innovation survey; they find that cooperation with competitors is profitable in terms of cost reductions. Löf and Heshmati (2002) study the evidence of cooperative R&D in the Swedish manufacturing industry and find that cooperation with competitors positively affects innovation output, while cooperation with suppliers restricts it. Winters and Stam (2007) show

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<sup>2</sup> General cooperation addresses a combination of horizontal and vertical cooperation.

<sup>3</sup> Spillovers address a combination of horizontal and vertical spillovers.

that R&D cooperation has a positive relationship with product and process innovation of high technology SMEs.

The results of both the theoretical and empirical studies show that the effect of product substitutability on firms' strategies of output and R&D has not been explored which implies more theoretical analysis is required.

This paper extends Atallah's (2002) and Ishi's (2006) analysis by considering differentiated products where all previous studies deal with homogeneous goods in both industries. Although previous analyses studied the ranking of cooperation settings in terms of R&D, there is no literature about the ranking of settings in terms of profitability. This paper makes several contributions to the literature. First, this is the first paper that investigates the impact of product differentiation and R&D cooperation on innovation and welfare in vertically related industries with vertical and horizontal spillovers. Second, the paper studies the impact of cooperative settings, spillovers, and product differentiation on firms' behaviour. Lastly, the paper studies the ranking of cooperation settings in terms of R&D and profitability in each industry. Ranking the cooperative structures in terms of profitability is important from a policy perspective, and is provided for the first time in this paper. The results from this paper may be able to indicate the potential role of R&D policy in stimulating R&D investment.

The model studied in this paper incorporates two vertically related duopolistic industries with horizontal spillovers (within each industry) and vertical spillovers (between the two industries) in a three-stage game theoretical framework. The upstream industry provides a homogeneous intermediate good, whereas the downstream industry produces differentiated products. Firms invest in cost-reducing R&D under different cooperative structures and then compete in output. Three different types of cooperation are considered: no cooperation, horizontal cooperation, and vertical cooperation.

The main findings of the paper are summarized as follows. Vertical spillovers positively affect R&D directly due to their cost-reducing effect and indirectly due to their effect on horizontal spillovers and cooperative structures. Horizontal spillovers may increase or decrease R&D investments under different cooperation settings. Comparing cooperative structures in terms of R&D shows that vertical cooperation dominates the others. Horizontal and vertical cooperation settings yield the same level of R&D if and only if horizontal spillovers are perfect. Comparing cooperative structures in terms of profitability shows that no setting dominates the others. The comparison shows that retailers and suppliers may have different types of cooperation preferences. The ranking of cooperation settings depends on the sign and magnitudes of horizontal competitive externalities, vertical competitive externalities, and product differentiation. Product differentiation influences firms' behaviour and affects the ranking of cooperative structures in terms of profitability.

The paper is organized as follows. Section 2 sets up and solves the model. The effects of spillovers and product differentiation on R&D and welfare are studied in section 3. Section 4 compares cooperation settings in terms of R&D and profitability. Section 5 discusses some policy related issues and conclusions.

## **2. THE MODEL**

There are two identical upstream suppliers ( $s_1, s_2$ ) providing a homogeneous input. There are

two symmetric downstream retailers ( $r_1, r_2$ ) transforming the homogeneous input into the final product using a (one to one) fixed coefficient technology and competing a la Cournot. The final good may be differentiated. A representative consumer consumes both goods,  $r_1$  and  $r_2$ . Undertaking no R&D, suppliers acquire a constant unit production cost of  $s$  and sell the input to retailers at a unit price of  $t$ , the wholesale price. Retailers pay the suppliers  $t$  for each unit purchased and incur an additional internal production cost of  $r$ . Lastly, retailers sell the product to consumers at price  $p$ . The consumer consumes goods  $y_{r1}$  and  $y_{r2}$  and maximizes her utility function subject to the budget constraint ( $M = p_1 y_{r1} + p_2 y_{r2} + y_0$ ) where  $y_0$  is the numeraire. The consumer's utility function is given by

$$U = a(y_{r1} + y_{r2}) - \frac{(y_{r1}^2 + y_{r2}^2)}{2} - b y_{r1} y_{r2} + y_0$$

where  $y_{ri}$  denotes retailer  $i$ 's output and  $b \in [0,1]$  is an index indicating the degree of product substitutability (negatively related to product differentiation). Final goods are homogeneous if  $b = 1$ , imperfect substitutes if  $0 < b < 1$  and independent when  $b = 0$ . Maximizing utility over  $y_{r1}$  and  $y_{r2}$  yields the retailers' demand functions. Thus, retailers face the following linear inverse demand system.

$$p_i(y_{ri}, y_{rj}) = a - y_{ri} - b y_{rj} \quad i=1,2$$

Firms can undertake cost-reducing R&D activities. The dollar cost of  $x$  units of R&D for firm  $i$  is  $u x_i^2$ , where  $x_i$  represents the R&D output of firm  $i$ , and  $u > 0$  is a cost parameter. Assume that  $u$  is sufficiently high for the profit function to be strictly concave, and sufficiently low for firms to undertake strictly positive amounts of R&D. Total R&D is denoted by  $X$ :

$$X = x_{r1} + x_{r2} + x_{s1} + x_{s2}$$

Each unit of R&D conducted by a firm reduces its own cost by one dollar, reduces the cost of its competitor by  $h$  dollars (horizontal spillovers), and reduces the cost of each firm in the other industry by  $v$  dollars (vertical spillovers), with  $h, v \in [0,1]$ .  $h$  and  $v$  can be different for many reasons such as different absorptive capacities, different technological similarities, the different efficiency of communication channels, etc. The unit cost for downstream firm  $i$  is:

$$c_{ri} = t + r - x_{ri} - h x_{rj} - v(x_{s1} + x_{s2}) \quad i=1,2$$

The unit cost of an upstream firm is:

$$c_{si} = s - x_{si} - h x_{sj} - v(x_{r1} + x_{r2}) \quad i=1,2$$

The final cost of each firm depends on the R&D choices of all firms. Suppliers and retailers mutually benefit from R&D activities of one another through vertical spillovers, while competitors benefit from R&D investments of each other through horizontal spillovers. Higher R&D leads to lower cost and consequently higher output. Moreover, higher output increases the value of R&D to a firm since more units of output benefit from the cost reduction effects.

To ensure that unit costs are non-negative, parameters are assumed to be such that

$$r > x_{r1} + h x_{r2} + v(x_{s1} + x_{s2})$$

$$s > x_{s1} + h x_{s2} + v(x_{r1} + x_{r2})$$

The game has three stages. In the first stage, each firm decides on its R&D simultaneously. In the second stage, upstream firms choose their output competing a la Cournot, anticipating the derived demand curve of the downstream industry. In the third stage, downstream firms choose their output levels competing a la Cournot, taking the wholesale price as given.

## 2.1 Output stage

In the third stage retailers choose their output to maximize their own profit non-cooperatively.

### 2.1.1 Third stage

In the third stage, retailer  $i$ 's problem is:

$$\max_{y_{ri}} \pi_{ri} = (p_i(y_{ri}, y_{rj}) - c_{ri})y_{ri} - ux_{ri}^2 \quad i=1,2 \quad (1)$$

Given that retailers are symmetric, they have symmetrical behaviour. Maximizing and solving the two f.o.c. simultaneously yields:

$$y_{ri} = \frac{(2-b)[(a-r-t)+v(x_{s1}+x_{s2})]+(2-bh)x_{ri}-(b-2h)x_{rj}}{(4-b^2)} \quad i=1,2 \quad (2)$$

$$p_i = \frac{(2-b)[a+(1+b)(r+t-v(x_{s1}+x_{s2}))]-[(2-b^2-bh)x_{ri}+(b+2h-b^2h)x_{rj}]}{(4-b^2)} \quad i=1,2$$

Total output is the sum of downstream firms' output,  $Y = y_{r1} + y_{r2}$ .

From Eq. (2), the inverse demand curve of suppliers is derived as:

$$t(y_{si}, y_{sj}) = \frac{(1+h)(x_{r1}+x_{r2})-(2+b)(y_{si}+y_{sj})+2[(a-r)+v(x_{s1}+x_{s2})]}{2} \quad i=1,2 \quad (3)$$

### 2.1.2 Second stage

In the second stage, each supplier  $i$  non-cooperatively chooses its own output,  $y_{si}$ , to maximize its profit considering the derived inverse demand of retailers, Eq.(3). Thus, supplier  $i$  solves the following problem:

$$\max_{y_{si}} \pi_{si} = (t(y_{si}, y_{sj}) - c_{si})y_{si} - ux_{si}^2 \quad i=1,2 \quad (4)$$

Since suppliers are identical and produce a homogeneous intermediate good, they will hold identical positions ex-post. Maximizing and solving the two f.o.c. yields:

$$y_{si} = \frac{2(a-r-s)+(1+h+2v)(x_{r1}+x_{r2})+2(2-h+v)x_{si}+2(2h+v-1)x_{sj}}{3(2+b)} \quad i=1,2$$

Considering that each unit purchased from suppliers is transformed into one unit provided by retailers, total output is the same for upstream and downstream industries. Thus, total output is:

$$Y = \frac{2[2a-2r-2s+(1+h+2v)(x_{r1}+x_{r2})+(1+h+2v)(x_{s1}+x_{s2})]}{3(2+b)}$$

and the final price is:

$$p = \frac{a(4+b)+2(1+b)(r+s)-(1+b)(1+h+2v)(x_{r1}+x_{r2})-(1+b)(1+h+2v)(x_{s1}+x_{s2})}{3(2+b)}$$

where the wholesale price charged by suppliers is:

$$t = \frac{2(a-r+2s)+(1+h-4v)(x_{r1}+x_{r2})-2(1+h-v)(x_{s1}+x_{s2})}{6}$$

## 2.2 R&D stage

In the first stage of the game, all firms choose their R&D investments simultaneously. To capture the variety of cooperative structures, three scenarios are considered in the first stage. The first scenario is non-cooperative R&D (*NC*), so that each firm chooses its R&D to maximize its own profit. The second scenario is horizontal cooperative R&D (*HC*) where firms cooperate with their competitors. The third scenario is vertical cooperative R&D (*VC*), in which suppliers cooperate with retailers. Denote the R&D set of all firms as  $\beta \equiv \{x_{r1}, x_{r2}, x_{s1}, x_{s2}\}$ . The profit of a downstream firm can be rewritten as

$$\pi_{ri}(\beta) = [p_i(\beta) - c_{ri}(\beta)]y_{ri}(\beta) - ux_{ri}^2 \quad i=1,2$$

and the profit of an upstream firm is

$$\pi_{si}(\beta) = [t(\beta) - c_{si}(\beta)]y_{si}(\beta) - ux_{si}^2 \quad i=1,2$$

Therefore, welfare is also a function of R&D since

$$W(\beta) = (\pi_{r1}(\beta) + \pi_{r2}(\beta) + \pi_{s1}(\beta) + \pi_{s2}(\beta)) + CS.^4$$

In the first stage, under *NC* each firm chooses its R&D to maximize its own profit. Each retailer solves the following problem:

$$\max_{x_{ri}} \pi_{ri}(\beta) \quad i=1,2 \quad (5)$$

while each supplier faces the following problem:

$$\max_{x_{si}} \pi_{si}(\beta) \quad i=1,2 \quad (6)$$

Maximizing and simultaneously solving these four f.o.c., we obtain R&D under *NC*:

$$x_{ri}^{NC} = \frac{(a-r-s)[2(5-h+4v)-b(5h+4v-1)]}{(72u-26-2h(8-5h)-9b^3u-68v+4hv-32v^2+b[(h(4+5h)-1)+36u+2v+14hv+8v^2]-2b^2[h^2+9u+h(v-1)-(2+5v+2v^2)])} \quad i=1,2$$

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<sup>4</sup> Consumer surplus is defined as  $CS = U(y_0, y_{r1}, y_{r2}) - (p_1 y_{r1} + p_2 y_{r2} + y_0)$ .

$$x_{si}^{NC} = \frac{2(4-b^2)(a-r-s)(2-h+v)}{(72u-26-2h(8-5h)-9b^3u-68v+4hv-32v^2+b[(h(4+5h)-1)+36u+2v+14hv+8v^2]-2b^2[h^2+9u+h(v-1)-(2+5v+2v^2)])} \quad i=1,2$$

Under *HC*, competitors in each industry choose their R&D to maximize their joint profits. Thus, in the downstream industry retailers solve

$$\max_{x_{r1}, x_{r2}} (\pi_{r1}(\beta) + \pi_{r2}(\beta)) \quad (7)$$

and in the upstream industry suppliers solve

$$\max_{x_{s1}, x_{s2}} (\pi_{s1}(\beta) + \pi_{s2}(\beta)) \quad (8)$$

Maximizing and simultaneously solving these four f.o.c., we obtain R&D under *HC*:

$$x_{ri}^{HC} = \frac{4(a-r-s)(1+h+2v)}{(9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b(h^2-18u+(1+2v)^2+2h(1+2v)))} \quad i=1,2$$

$$x_{si}^{HC} = \frac{2(a-r-s)(1+h+2v)(2+b)}{(9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b(h^2-18u+(1+2v)^2+2h(1+2v)))} \quad i=1,2$$

Under *VC* each retailer cooperates with one supplier. Given that suppliers are identical and produce a homogeneous intermediate good, it is immaterial which retailer cooperates with each supplier. Without loss of generality, let  $r_i$  cooperate with  $s_i$  ( $i=1,2$ ).

$$\max_{x_{ri}, x_{si}} (\pi_{ri}(\beta) + \pi_{si}(\beta)) \quad i=1,2 \quad (9)$$

Following the maximization of Eq (9), we obtain R&D under *VC*:

$$x_{ri}^{VC} = \frac{(a-r-s)[14+b-b^2+h(2-5b-b^2)+2v(8-2b-b^2)]}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)+b^2[5+4h-h^2-18u+2v(7+h)+8v^2]+b[1+h(8+7h)+36u+10v+22hv+16v^2]} \quad i=1,2$$

$$x_{si}^{VC} = \frac{(a-r-s)(4-2b)[5+2b-h(1+b)+v(b+4)]}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)+b^2[5+4h-h^2-18u+2v(7+h)+8v^2]+b[1+h(8+7h)+36u+10v+22hv+16v^2]} \quad i=1,2$$

### 3. THE IMPACTS OF SPILLOVERS AND PRODUCT DIFFERENTIATION ON R&D AND WELFARE

This section addresses the effects of vertical and horizontal spillovers on innovation, output, and welfare where products are differentiated and cooperative<sup>5</sup> structures are varied.

**PROPOSITION 1.** *The impact of vertical spillovers on R&D, output, and welfare is always positive and independent of product substitutability.*

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<sup>5</sup> Detailed analysis and proofs are in the appendix.

Table 1 shows the results of Proposition 1.

	No Cooperation	Horizontal Cooperation	Vertical Cooperation
$\partial x_{ri}/\partial v$	+	+	+
$\partial x_{si}/\partial v$	+	+	+
$\partial X/\partial v$	+	+	+
$\partial Y/\partial v$	+	+	+
$\partial W/\partial v$	+	+	+

An increase in vertical spillovers reduces the production costs of all firms under any type of cooperation. Retailers benefit from higher  $v$  due to its cost reduction effect and through access to a greater quantity of input.

$$\begin{aligned} \partial c_{ri}(h, v, \beta(h, v))/\partial v < 0,^6 \text{ while } \partial \pi_{ri}/\partial c_{ri} < 0 \text{ and } \partial \pi_{ri}/\partial y_{ri} > 0 & \quad i=1,2 \\ \partial c_{si}(h, v, \beta(h, v))/\partial v < 0,^7 \text{ while } \partial \pi_{si}/\partial c_{si} < 0 \text{ and } \partial \pi_{si}/\partial y_{si} > 0 & \quad i=1,2 \end{aligned}$$

This encourages them to increase their output and thereby, increase their demand for the intermediate good which benefits suppliers as well. Higher output increases the net benefit of R&D, inducing a further increase in R&D. Higher output is also associated with higher consumer surplus and welfare.

Thus, an increase in vertical spillovers always increases innovation, output, and welfare. These findings are consistent with those of Peters (1995), Steurs (1994, 1995) and Atallah (2002); however, those authors considered only homogeneous goods.

**PROPOSITION 2.** *The impact of vertical spillovers on firms' behaviour depends on product substitutability and horizontal spillovers in each equilibrium. An increase in vertical spillovers increases retailers' innovation less than suppliers' regardless of substitutability. Nevertheless, suppliers and retailers increase their innovation efforts equally under different cooperation settings in response to changes in horizontal spillovers and substitutability.*

Although higher  $v$  increases R&D by all firms, when final goods are substitutes ( $b > 0$ ), retailers increase their R&D less than suppliers. However, firms in both industries tend to increase their R&D equally when goods are independent.

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$$\begin{aligned} {}^6 \frac{\partial c_{ri}(h, v, \beta(h, v))}{\partial v} &= \left( \frac{\partial c_{ri}(h, v, \beta(h, v))}{\partial v} + \frac{\partial c_{ri}(h, v, \beta(h, v))}{\partial t(h, v, \beta(h, v))} \frac{\partial t(h, v, \beta(h, v))}{\partial v} + \sum_{i=1,2} \frac{\partial c_{ri}(h, v, \beta(h, v))}{\partial x_{ri}(h, v)} \frac{\partial x_{ri}(h, v)}{\partial v} + \right. \\ &\quad \left. \sum_{i=1,2} \frac{\partial c_{ri}(h, v, \beta(h, v))}{\partial x_{si}(h, v)} \frac{\partial x_{si}(h, v)}{\partial v} \right) \end{aligned}$$

$$\text{where } \frac{\partial t(h, v, \beta(h, v))}{\partial v} = \left( \frac{\partial t(h, v, \beta(h, v))}{\partial v} + \sum_{i=1,2} \frac{\partial t(h, v, \beta(h, v))}{\partial x_{ri}(h, v)} \frac{\partial x_{ri}(h, v)}{\partial v} + \sum_{i=1,2} \frac{\partial t(h, v, \beta(h, v))}{\partial x_{si}(h, v)} \frac{\partial x_{si}(h, v)}{\partial v} \right).$$

$${}^7 \frac{\partial c_{si}(h, v, \beta(h, v))}{\partial v} = \left( \frac{\partial c_{si}(h, v, \beta(h, v))}{\partial v} + \sum_{i=1,2} \frac{\partial c_{si}(h, v, \beta(h, v))}{\partial x_{ri}(h, v)} \frac{\partial x_{ri}(h, v)}{\partial v} + \sum_{i=1,2} \frac{\partial c_{si}(h, v, \beta(h, v))}{\partial x_{si}(h, v)} \frac{\partial x_{si}(h, v)}{\partial v} \right).$$

As soon as the products become substitutes ( $b > 0$ ), competition between retailers increases which reduces  $p$  (a direct and an indirect effect,  $\partial p(b, (\beta(b)))/\partial b < 0$ ).<sup>8</sup> Higher  $b$  changes the position (the intercept and the slope through  $x_{ri}$  and  $x_{si}$ ) of the demand curve of the retailers. Indeed, the convexity of the profit function induces retailers to produce less output when the price is low. Thus, retailers reduce their output, their R&D, and their demand for the intermediate good. Although higher product substitutability reduces the demand for the intermediate good, it increases the wholesale price ( $\partial t(\beta(b))/\partial b > 0$ )<sup>9</sup> which mitigates the negative effect of  $b$  on suppliers' profit. This reflects the power of suppliers. Indeed, retailers suffer from an increase in  $b$  more than suppliers. Finally, the sum of the positive effects of higher  $v$  and the negative effects of  $b$  on profits induces retailers to increase their R&D less than suppliers.

Under *NC* and *VC* firms are worried about the information leakage to their competitor. When products are independent, retailers may neglect  $h$ , whereas suppliers providing a homogeneous intermediate good are concerned about the flow of the technological information to their competitors. In consequence, when  $h$  is sufficiently high and goods are independent, an increase in  $v$  induces retailers and suppliers to increase their R&D equally.

Although under *HC* firms internalize  $h$ , an increase in  $v$  induces suppliers and retailers to increase their R&D equally when goods are independent. Suppliers increase their R&D more than retailers when goods are substitutes since  $b$  has a significant negative effect on retailers' net benefit of R&D.

- (1) Under any type of cooperation,  $\frac{\partial x_{ri}}{\partial v} < \frac{\partial x_{si}}{\partial v}$  if  $0 < b \leq 1$ .
- (2) Under *NC* and *VC*,  $\frac{\partial x_{ri}}{\partial v} = \frac{\partial x_{si}}{\partial v}$  if  $b = 0$  and  $h = 1$ .
- (3) Under *HC*,  $\frac{\partial x_{ri}}{\partial v} = \frac{\partial x_{si}}{\partial v}$  if  $b = 0$ .
- (4) Under *VC*,  $\frac{\partial x_{ri}}{\partial v} = \frac{\partial x_{si}}{\partial v}$  if  $b = 1$ .

Moreover, under *VC* partners internalize  $v$  which boosts the benefit of its cost reduction effects, inducing suppliers to increase their R&D more than retailers when goods are independent or imperfect substitutes. When both industries produce a homogeneous product, their marginal gain from R&D is equal. Thus, they increase their R&D equally.

### PROPOSITION 3.

- (i) *An increase in horizontal spillovers reduces R&D by all firms under NC, and increases R&D by all firms under HC independent of substitutability. This always increases R&D by retailers under VC if products are independent; however, it reduces R&D by them when products are substitutes and vertical spillovers are sufficiently low. Suppliers increase their R&D efforts if vertical spillovers are high and vice versa if vertical spillovers are sufficiently low, independent of substitutability.*

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<sup>8</sup>  $\frac{\partial p(b, (\beta(b)))}{\partial b} = \left( \frac{\partial p(b, (\beta(b)))}{\partial b} + \sum_{i=1,2} \frac{\partial p(b, (\beta(b)))}{\partial x_{ri}(b)} \frac{\partial x_{ri}(b)}{\partial b} + \sum_{i=1,2} \frac{\partial p(b, (\beta(b)))}{\partial x_{si}(b)} \frac{\partial x_{si}(b)}{\partial b} \right)$ .

<sup>9</sup>  $\frac{\partial t(\beta(b))}{\partial b} = \left( \sum_{i=1,2} \frac{\partial t(\beta(b))}{\partial x_{ri}(b)} \frac{\partial x_{ri}(b)}{\partial b} + \sum_{i=1,2} \frac{\partial t(\beta(b))}{\partial x_{si}(b)} \frac{\partial x_{si}(b)}{\partial b} \right)$ .

(ii) *An increase in horizontal spillovers increases welfare and output under HC and VC independent of substitutability. This increases welfare and output under NC if products are independent, whereas it reduces them if products are substitutes.*

Under *NC*, an increase in  $h$  lessens the R&D of all firms. Higher  $h$  reduces the net benefit of R&D since it reduces the rival's cost. Thus, firms in both industries reduce their R&D. The reduction in R&D increases firms' production costs<sup>10</sup> and consequently affects firms' output and prices.<sup>11</sup> Additionally, higher  $b$  boosts competition between retailers, reduces price and induces them to reduce their output due to the convexity of the profit function which requires firms to decrease (increase) their output when the price decreases (increases). Ultimately, the sum of these two effects determines output. Higher output is associated with higher consumer surplus and welfare. Thus, consumer surplus and welfare are reduced when the sum of the effects of  $h$  and  $b$  on output is negative; otherwise, they are increased. Table 2 summarizes the results of Proposition 3.

Table 2. *Summary of comparative statics (h)*

	<i>No Cooperation</i>	<i>Horizontal Cooperation</i>	<i>Vertical Cooperation</i>
$\partial x_{ri}/\partial h$	–	+	+ if $b = 0$ $\pm$ if $b > 0$
$\partial x_{si}/\partial h$	–	+	$\pm$
$\partial X/\partial h$	–	+	$\pm$
$\partial Y/\partial h$	$\pm$	+	+
$\partial W/\partial h$	$\pm$	+	+

Under *HC*, firms within each industry choose their R&D cooperatively and maximize their joint profits. Thus, intra-industry firms, internalizing  $h$ , may not worry about the information leakage to the rival, benefit from higher  $h$  and increase their R&D. Higher R&D is associated with lower production cost which induces firms to increase their output. Higher output is associated with higher consumer surplus and welfare.

Under *VC*, higher  $h$  reduces the production cost of the rival and thereby, reduces the net benefit of R&D to the firm. From the retailers' perspective, when goods are independent, the information leakage is negligible. Thus, retailers increase their R&D since the private gains from R&D offset the negative effects of higher  $h$ . As  $b$  increases, competition between retailers

$$^{10} \frac{\partial c_{ri}(h,v,\beta(h,v))}{\partial h} = \left( \frac{\partial c_{ri}(h,v,\beta(h,v))}{\partial h} + \frac{\partial c_{ri}(h,v,\beta(h,v))}{\partial t(h,v,\beta(h,v))} \frac{\partial t(h,v,\beta(h,v))}{\partial h} + \sum_{i=1,2} \frac{\partial c_{ri}(h,v,\beta(h,v))}{\partial x_{ri}(h,v)} \frac{\partial x_{ri}(h,v)}{\partial h} + \sum_{i=1,2} \frac{\partial c_{ri}(h,v,\beta(h,v))}{\partial x_{si}(h,v)} \frac{\partial x_{si}(h,v)}{\partial h} \right)$$

$$\text{and } \frac{\partial c_{si}(h,v,\beta(h,v))}{\partial h} = \left( \frac{\partial c_{si}(h,v,\beta(h,v))}{\partial h} + \sum_{i=1,2} \frac{\partial c_{si}(h,v,\beta(h,v))}{\partial x_{ri}(h,v)} \frac{\partial x_{ri}(h,v)}{\partial h} + \sum_{i=1,2} \frac{\partial c_{si}(h,v,\beta(h,v))}{\partial x_{si}(h,v)} \frac{\partial x_{si}(h,v)}{\partial h} \right).$$

$$^{11} \frac{\partial p(h,v,\beta(h,v))}{\partial h} = \left( \frac{\partial p(h,v,\beta(h,v))}{\partial h} + \sum_{i=1,2} \frac{\partial p(h,v,\beta(h,v))}{\partial x_{ri}(h,v)} \frac{\partial x_{ri}(h,v)}{\partial h} + \sum_{i=1,2} \frac{\partial p(h,v,\beta(h,v))}{\partial x_{si}(h,v)} \frac{\partial x_{si}(h,v)}{\partial h} \right)$$

$$\text{and } \frac{\partial t(h,v,\beta(h,v))}{\partial h} = \left( \frac{\partial t(h,v,\beta(h,v))}{\partial h} + \sum_{i=1,2} \frac{\partial t(h,v,\beta(h,v))}{\partial x_{ri}(h,v)} \frac{\partial x_{ri}(h,v)}{\partial h} + \sum_{i=1,2} \frac{\partial t(h,v,\beta(h,v))}{\partial x_{si}(h,v)} \frac{\partial x_{si}(h,v)}{\partial h} \right).$$

becomes intense, the negative effect of outgoing information to the rival dominates the positive effect of incoming knowledge spillovers which induces retailers to reduce their R&D when  $h$  is high and  $v$  is low. However, retailers increase their R&D when  $v$  is high enough to mitigate the negative impact of  $h$ . An increase in  $h$  affects suppliers significantly since they produce a homogeneous input and are concerned about the information leakage to their competitor. Thus, suppliers increase their R&D when  $v$  is high enough to mitigate the negative effects of  $h$ ; otherwise, they reduce their R&D. VC internalizes  $v$  which boosts its cost reduction effects, offsets the sum of the effects of higher  $h$  and  $b$  on output, and thereby induces firms to increase their output. Higher output is associated with higher consumer surplus and welfare.

**PROPOSITION 4.** *The impact of horizontal spillovers on firms' behaviour depends on horizontal spillovers and product substitutability in each equilibrium.*

Although higher  $h$  decreases R&D in both industries under NC, when final goods are independent, retailers decrease their R&D less than suppliers. This result shows that suppliers producing a homogeneous good are worried about the information leakage to their competitors, while retailers providing independent products are not concerned about higher  $h$ . Although profits are negatively affected by  $b$ , the effects on retailers' profits (through lower output and higher  $t$ ) are more than the effects on suppliers' profits (through lower demand, but higher  $t$ ). Thus, higher  $h$  reduces retailers' profit more than suppliers' and induces retailers to reduce their R&D more than suppliers when goods are substitutes.

- (1) Under NC,  $\left| \frac{\partial x_{ri}}{\partial h} \right| < \left| \frac{\partial x_{si}}{\partial h} \right|$  if  $b = 0$
- (2) Under NC,  $\left| \frac{\partial x_{ri}}{\partial h} \right| > \left| \frac{\partial x_{si}}{\partial h} \right|$  if  $b > 0$

Under HC, higher  $h$  increases R&D by all firms. Competitors internalize  $h$  and benefit from higher  $h$ . When final goods are independent suppliers and retailers increase their R&D equally since their marginal benefit from R&D is equal. However, as  $b$  increases, suppliers increase their R&D more than retailers. This result reflects the sum of effects of  $b$  and  $h$  along with the effects of cooperative structures on firms' behaviour. Although higher  $h$  increases firms' benefit through its cost reduction effect (under HC), higher  $b$  reduces firms' net benefit of R&D. Although the sum of the effects of  $h$  and  $b$  on firms' benefit is positive, the effects on suppliers' are more than on retailers'. Thus, when goods are substitutes, suppliers increase their R&D more than retailers.

- (1) Under HC,  $\frac{\partial x_{ri}}{\partial h} = \frac{\partial x_{si}}{\partial h}$  if  $b = 0$
- (2) Under HC,  $\frac{\partial x_{ri}}{\partial h} < \frac{\partial x_{si}}{\partial h}$  if  $b > 0$

Under VC, retailers and suppliers internalize  $v$ . Internalizing  $v$  mitigates the negative effects of  $h$  on firms' marginal profit of R&D. When goods are independent, retailers are not concerned about  $h$ . Thus, an increase in  $h$  induces retailers to increase their R&D. Suppliers providing a homogeneous input are worried about the information leakage to their competitors. Therefore, suppliers increase their R&D only if  $h$  is sufficiently low and  $v$  is high enough; otherwise, they reduce their R&D. When goods are imperfect substitutes, competition between retailers is severe which affects retailers' output, and thereby affects suppliers. Suppliers providing a homogeneous input are worried about the flow of knowledge spillovers to their competitors. Indeed, an increase in  $h$  reinforces these effects, such that suppliers reduce their R&D when  $v$  is not high enough to mitigate the negative effect of  $h$ . As a result, an increase in  $h$  induces retailers to increase their R&D more than suppliers when goods are imperfect substitutes. When

goods are homogenous, inter-industry firms' net benefit of R&D is equal, and thereby higher  $h$  induces them to increase (decrease) their R&D equally when  $h$  is low (high) and  $v$  is high (low) enough.

- (1) Under VC,  $\frac{\partial x_{ri}}{\partial h} > \frac{\partial x_{si}}{\partial h}$  if  $b = 0$ ,  $h$  is sufficiently low and  $v$  is high enough; otherwise,  $\frac{\partial x_{si}}{\partial h} < 0$ .
- (2) Under VC,  $\frac{\partial x_{ri}}{\partial h} > \frac{\partial x_{si}}{\partial h}$  if  $b > 0$ .
- (3) Under VC,  $\frac{\partial x_{ri}}{\partial h} = \frac{\partial x_{si}}{\partial h}$  if  $b = 1$ .

#### 4. COMPARISON OF COOPERATIVE STRUCTURES

In this section, cooperation settings are compared in terms of R&D and profitability. This comparison is essential to determine the appropriate choices of R&D cooperation with respect to associated technological improvement, profit, and welfare. This comparison helps firms to decide to cooperate with whom if they tend to cooperate. This also helps the regulator to introduce policies to encourage firms participating in a cooperative setting associated with higher innovation and welfare.

**PROPOSITION 5.** *The ranking of cooperation settings in terms of R&D depends on product substitutability and spillovers.*

- (i)  $(X_{VC} = X_{HC}) > X_{NC}$  iff  $h = 1$ , independent of substitutability.
- (ii)  $X_{VC} > X_{NC} > X_{HC}$  if  $h$  is sufficiently low; otherwise  $X_{VC} > X_{HC} > X_{NC}$ . The results are independent of substitutability.

Although ranking cooperation settings in terms of R&D requires a numerical method for parameter values, the same results are attainable by an analytical study of the sign and magnitudes of competitive externalities internalized by each cooperative structure. Internalizing the effect of a firm's R&D on the profit of other firms is the key to this analysis.

Horizontal competitive externalities ( $HCEs$ )<sup>12</sup> represent the marginal effect of a firm's R&D on the profit of its competitor ( $HCE_{ri} = \partial \pi_{ri}(\beta) / \partial x_{rj}$ <sup>13</sup> and  $HCE_{si} = \partial \pi_{si}(\beta) / \partial x_{sj}$ <sup>14</sup> where  $i = 1, 2$ ).  $HCEs$  are positive (negative) when an increase in R&D by a firm increases (decreases) the profit of the competitor. Moreover, an increase in R&D by a firm increases (decreases) the profit of its competitor when  $h$  is high (low).  $HCE_{ri}$  is negative if  $(10 + b)h +$

<sup>12</sup>  $HCE_{ri}$  ( $HCE_{si}$ ) refers to horizontal competitive externalities of retailers (suppliers).

<sup>13</sup>  $\frac{\partial \pi_{ri}(\beta)}{\partial x_{rj}} = \frac{\partial \pi_{ri}(\beta)}{\partial y_{ri}(\beta)} \frac{\partial y_{ri}(\beta)}{\partial x_{rj}} + \frac{\partial \pi_{ri}(\beta)}{\partial p(\beta)} \frac{\partial p(\beta)}{\partial x_{rj}} - \frac{\partial \pi_{ri}(\beta)}{\partial c_{ri}(\beta)} \frac{\partial c_{ri}(\beta)}{\partial x_{rj}} =$   

$$\frac{(10h+8v-2-b(5-h+4v))(a-r-s+(1+h+2v)(x_{r1}+x_{r2}))+((1+h+2v)(x_{s1}+x_{s2}))}{9(2-b)(2+b)^2}.$$

<sup>14</sup>  $\frac{\partial \pi_{si}(\beta)}{\partial x_{sj}} = \frac{\partial \pi_{si}(\beta)}{\partial y_{si}(\beta)} \frac{\partial y_{si}(\beta)}{\partial x_{sj}} + \frac{\partial \pi_{si}(\beta)}{\partial t(\beta)} \frac{\partial t(\beta)}{\partial x_{sj}} - \frac{\partial \pi_{si}(\beta)}{\partial c_{si}(\beta)} \frac{\partial c_{si}(\beta)}{\partial x_{sj}} =$   

$$\frac{2(2h+v-1)(a-r-s+(1+h+2v)(x_{r1}+x_{r2}))+((1+h+2v)(x_{s1}+x_{s2}))}{9(2+b)}.$$

$(8 - 4b)v - (2 + 5b) < 0$  and  $HCE_{si}$  is negative if  $(2h + v - 1) < 0$ . Although  $h$  and  $v$  have positive effects on  $HCEs$ , product substitutability negatively affects them. The effect of  $b$  on  $HCE_{ri}$  is stronger than its effect on  $HCE_{si}$ . Comparing industries'  $HCEs$  shows that  $HCE_{si} > HCE_{ri}$ , and the difference decreases with  $b$ .  $HC$  internalizes  $HCEs$ .

Vertical competitive externalities ( $VCEs$ )<sup>15</sup> represent the marginal effect of a firm's R&D on the profits of firms in the other industry ( $VCE_{ri} = \partial\pi_{ri}(\beta)/\partial x_{si}$ <sup>16</sup> and  $VCE_{si} = \partial\pi_{si}(\beta)/\partial x_{ri}$ <sup>17</sup> where  $i = 1, 2$ ). This externality is always positive, provided that the higher R&D of a firm always increases the benefits of its supplier (customer). Product substitutability has a negative effect on  $VCEs$ . The effect on  $VCE_{ri}$  is stronger than it is on  $VCE_{si}$ . Comparing industries'  $VCEs$  shows that  $VCE_{si} = VCE_{ri}$  when goods are independent; otherwise  $VCE_{si} > VCE_{ri}$ . Comparing  $HCEs$  and  $VCEs$  shows that  $VCEs \geq HCEs$ , such that they are equal when  $h = 1$ .

In consequence, internalizing a positive externality boosts R&D, whereas internalizing a negative externality reduces R&D. Thus, the cooperation setting which internalizes greater positive competitive externalities yields higher R&D.

The first part of Proposition 5 states that  $(X_{VC} = X_{HC}) > X_{NC}$  iff  $h = 1$ .  $VC$  internalizes  $VCEs$  which are always positive and increase R&D. No externality is internalized by  $NC$ . Thus,  $VC$  always yields higher R&D than  $NC$  does.  $HC$  internalizes  $HCEs$  which may be positive or negative. If and only if  $h = 1$ ,  $VCEs = HCEs$ , and thereby,  $VC$  and  $HC$  yield the same level of R&D. However,  $VC$  yields higher R&D than  $HC$  if  $h < 1$ . Ultimately, comparing these settings shows that  $(X_{VC} = X_{HC}) > X_{NC}$  if  $h = 1$ .

Part *ii* of Proposition 5 states that  $X_{VC} > X_{NC} > X_{HC}$  when spillovers are low. Obviously,  $VC$  yields the highest R&D by internalizing the positive  $VCEs$  for any values of  $h$  and  $v$ . Comparing  $NC$  and  $HC$ , we note that  $NC$  internalizes no externalities and  $HC$  internalizes  $HCEs$  which can be positive or negative. When  $h$  is sufficiently low,  $HCEs$  are negative. Internalizing these negative externalities reduces joint profits and induces firms to decrease their R&D. Therefore, when  $h$  is sufficiently low  $NC$  yields higher R&D and  $X_{VC} > X_{NC} > X_{HC}$ . When  $h$  is high, its externalities are positive. These positive  $HCEs$  are still less than the positive  $VCEs$  for any value of the parameters. Internalizing the positive  $HCEs$  induces competitors to increase their R&D and yields  $X_{VC} > X_{HC} > X_{NC}$ . Higher R&D is associated with a higher output which reflects a higher value of cost reduction. Thus, we can conclude that the same ranking is observed for welfare.

Moreover, higher  $b$  reduces competitive externalities, increases the required threshold of spillovers<sup>18</sup> to turn  $HCEs$  positive. Note that  $VCEs$  are always positive and greater than  $HCEs$ .

<sup>15</sup>  $VCE_{ri}$  ( $VCE_{si}$ ) refers to vertical competitive externalities of retailers (suppliers).

$$^{16} \frac{\partial\pi_{ri}(\beta)}{\partial x_{si}} = \frac{\partial\pi_{ri}(\beta)}{\partial y_{ri}(\beta)} \frac{\partial y_{ri}(\beta)}{\partial x_{si}} + \frac{\partial\pi_{ri}(\beta)}{\partial p(\beta)} \frac{\partial p(\beta)}{\partial x_{si}} - \frac{\partial\pi_{ri}(\beta)}{\partial c_{ri}(\beta)} \frac{\partial c_{ri}(\beta)}{\partial x_{si}} = \frac{2(1+h+2v)(a-r-s+(1+h+2v)(x_{r1}+x_{r2})+(1+h+2v)(x_{s1}+x_{s2}))}{9(2+b)^2}$$

$$^{17} \frac{\partial\pi_{si}(\beta)}{\partial x_{ri}} = \frac{\partial\pi_{si}(\beta)}{\partial y_{si}(\beta)} \frac{\partial y_{si}(\beta)}{\partial x_{ri}} + \frac{\partial\pi_{si}(\beta)}{\partial t(\beta)} \frac{\partial t(\beta)}{\partial x_{ri}} - \frac{\partial\pi_{si}(\beta)}{\partial c_{si}(\beta)} \frac{\partial c_{si}(\beta)}{\partial x_{ri}} = \frac{2(1+h+2v)(a-r-s+(1+h+2v)(x_{r1}+x_{r2})+(1+h+2v)(x_{s1}+x_{s2}))}{9(2+b)}$$

<sup>18</sup> For example: If  $b = 0$ , ( $13h + 8v < 5$ ) then  $X_{VC} > X_{NC} > X_{HC}$ , otherwise  $X_{VC} > X_{HC} > X_{NC}$ ; if  $b = 0.5$ , ( $h + 0.53v < 0.47$ ) then  $X_{VC} > X_{NC} > X_{HC}$ , otherwise  $X_{VC} > X_{HC} > X_{NC}$ ; and if  $b = 1$ , ( $23h + 10v < 13$ ) then  $X_{VC} > X_{NC} > X_{HC}$ , otherwise  $X_{VC} > X_{HC} > X_{NC}$ .

Thus, higher  $b$  has no significant effect on the ranking of cooperation settings in terms of R&D and just influences the required threshold of  $h$  and  $v$  to keep the ranking unchanged.

Now, the question arises whether firms tend to cooperate vertically voluntarily. Is  $VC$  associated with the highest profit for all firms? To answer these questions we study the ranking of cooperation settings in terms of profitability.

**PROPOSITION 6.**

- (i) *If products are independent:  $\pi_{ri}^{VC} > \pi_{ri}^{NC} > \pi_{ri}^{HC}$  when  $h = 0$  and  $v = 0$ ;  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$  when  $0 \leq h < 1$  and  $v > 0$ ;  $(\pi_{ri}^{VC} = \pi_{ri}^{HC}) > \pi_{ri}^{NC}$  when  $h = 1$ .*
- (ii) *If products are imperfect substitutes:  $\pi_{ri}^{NC} > \pi_{ri}^{VC} > \pi_{ri}^{HC}$  when  $h = 0$  and  $v = 0$ ;  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$  when  $h = 0$  and  $v = 1$ ;  $\pi_{ri}^{HC} > \pi_{ri}^{VC} > \pi_{ri}^{NC}$  when  $h = 1$  and  $v = 0$ .*
- (iii) *If products are homogenous:  $\pi_{ri}^{HC} > \pi_{ri}^{NC} > \pi_{ri}^{VC}$  when  $h = 0$  and  $v = 0$ ;  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$  when  $h = 0$  and  $v = 1$ ;  $\pi_{ri}^{HC} > \pi_{ri}^{VC} > \pi_{ri}^{NC}$  when  $h = 1$  and  $v = 0$ .*

The analytical results to rank the cooperation settings in terms of profitability are attained by focusing on the impact of  $h$ ,  $v$ , and  $b$  on firms' R&D along with the effects of internalized competitive externalities on profit. The comparison rests on the signs and magnitudes of  $h$ ,  $v$ , and  $b$  as well as  $HCEs$  and  $VCEs$ . Although firms benefit from knowledge spillovers through their cost reduction effects, the benefit is substantial when they are large, such that the incoming knowledge spillovers dominate the outgoing technological information. Additionally, higher  $b$  boosts competition between retailers, negatively affects market demand and reduces retailers' profits.

Part *i* of Proposition 6 states that retailers' profit producing independent goods is ranked as  $\pi_{ri}^{VC} > \pi_{ri}^{NC} > \pi_{ri}^{HC}$  if  $h = v = 0$ . When products are independent, retailers are not concerned about the information leakage to their competitors and increase their R&D to benefit from its cost reduction effect. Note that  $VCE_{ri}$  is positive, whereas  $HCE_{ri}$  is negative when  $h = v = 0$ . Indeed, suppliers providing a homogeneous input are strongly sensitive to the knowledge spillovers to their rivals. When  $h = 0$ , suppliers increase their R&D which benefits retailers through the positive  $VCE_{ri}$ . Thus, retailers benefit from  $VC$ , whereas they suffer from  $HC$  internalizing the negative  $HCE_{ri}$ .  $NC$  internalizes no externality. Thus,  $\pi_{ri}^{VC} > \pi_{ri}^{NC} > \pi_{ri}^{HC}$ . As spillovers increase,  $HCE_{ri}$  turns positive, yet  $VCE_{ri} > HCE_{ri}$ . Thus,  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$ . Moreover,  $HCE_{ri} = VCE_{ri}$  when  $h = 1$  which results in  $\pi_{ri}^{VC} = \pi_{ri}^{HC} > \pi_{ri}^{NC}$ .

Part *ii* of Proposition 6 states that  $\pi_{ri}^{NC} > \pi_{ri}^{VC} > \pi_{ri}^{HC}$  when products are imperfect substitutes and  $h = v = 0$ . When products are substitutes, competition between retailers is strong. Thus, retailers reduce their output and demand of the intermediate good which negatively affects suppliers' profit and thereby, influences suppliers' R&D. Thus,  $VC$  may lead firms to overinvest. Indeed,  $HCE_{ri}$  is negative when spillovers are low, and thereby leads firms to underinvest. Although  $VC$  yields higher profit than  $HC$ , the highest profit is attained by  $NC$  internalizing no externality since  $NC$  prevents retailers from overinvesting, which may occur under  $VC$ . Thus,  $\pi_{ri}^{NC} > \pi_{ri}^{VC} > \pi_{ri}^{HC}$ . Higher  $v$  benefits firms and mitigates the negative effects of  $b$  on profit. When  $v = 1$ , firms benefit from R&D activities of one another and increase their R&D which turns  $HCE_{ri}$  positive, such that  $VCE_{ri} > HCE_{ri}$ . Moreover,  $HCE_{ri}$  is positive up to the point where  $b \leq 2/3$  if  $h = 0$  and thereby,  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$ . When  $h = 1$  and  $v$  is

sufficiently low, retailers gain higher profit by internalizing  $HCE_{ri}$  than by internalizing  $VCE_{ri}$  since  $HCE_{ri} > VCE_{ri}$  up to the point where  $b \leq 2/3$ , and thereby,  $\pi_{ri}^{HC} > \pi_{ri}^{VC} > \pi_{ri}^{NC}$ .

Part *iii* of Proposition 6 states that  $\pi_{ri}^{HC} > \pi_{ri}^{NC} > \pi_{ri}^{VC}$  when goods are homogenous,  $h = v = 0$ . When goods are homogenous, competition between retailers is intense, which induces retailers to reduce their output and demand of the intermediate good, which negatively affects suppliers' profit and influences their R&D. In this context,  $VC$  may lead firms to over-invest.  $NC$  also may lead them to over-invest due to strong competition; however,  $VC$  is associated with a greater over-investment which reduces retailers' profits.  $HC$  internalizes the negative  $HCE_{ri}$  which is mitigated by  $b$  when products are homogenous. Thus, retailers benefit from  $HC$  since it prevents them from over-investing. Comparing the settings shows that  $\pi_{ri}^{HC} > \pi_{ri}^{NC} > \pi_{ri}^{VC}$ . When  $v = 1$ , internalizing  $v$  reinforces its positive effects, increasing the net benefit of R&D to all firms. Thus,  $VC$  is more profitable to both industries since  $VCE_{ri} > HCE_{ri}$  and thus  $\pi_{ri}^{VC} > \pi_{ri}^{HC} > \pi_{ri}^{NC}$ .

Proposition 6 shows that retailers attain the highest profit under  $VC$  when goods are independent and spillovers are sufficiently low. Higher  $b$  affects firms' R&D due to its effects on output. Higher  $b$  mitigates the effects of horizontal competitive externalities.  $NC$  is associated with higher profits by preventing retailers from over-investing when goods are imperfect substitutes and spillovers are sufficiently low. Furthermore,  $NC$  and  $VC$  may induce retailers to over-invest when products are homogeneous and spillovers are sufficiently low. In this case, retailers gain higher profit under  $HC$ . The negative effects of over-investing on retailers' profit more than offset the gains associated with the cost reduction effects of R&D.  $VC$  leads retailers to the highest profit when  $v$  is high enough.

Now, consider the profit of suppliers providing a homogeneous intermediate good where their output level is affected by retailers' output. Although higher  $b$  reduces the demand of the intermediate good, higher  $b$  increases the wholesale price which reflects the power of suppliers.

### PROPOSITION 7.

- (i) *If goods are independent:  $\pi_{si}^{HC} > \pi_{si}^{NC} > \pi_{si}^{VC}$  when  $h = 0$  and  $v = 0$ ;  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$  when  $h = 0$  and  $v = 1$ ;  $(\pi_{si}^{VC} = \pi_{si}^{HC}) > \pi_{si}^{NC}$  when  $h = 1$ .*
- (ii) *If goods are imperfect substitutes:  $\pi_{si}^{NC} > \pi_{si}^{VC} > \pi_{si}^{HC}$  when  $h = 0$  and  $v = 0$ ; otherwise,  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$ .*
- (iii) *If goods are homogenous:  $\pi_{si}^{VC} > \pi_{si}^{NC} > \pi_{si}^{HC}$  when  $h = 0$  and  $v = 0$ ; otherwise,  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$ .*

Part *i* of Proposition 7 states that  $\pi_{si}^{HC} > \pi_{si}^{NC} > \pi_{si}^{VC}$  when final products are independent and spillovers are sufficiently low. In this case, suppliers benefit from higher demand and have enough incentive to increase their R&D and benefit from its cost reduction effects when  $h$  is sufficiently low. Retailers also increase their R&D to benefit from its cost reduction effects. Although  $HCE_{si}$  is negative when  $h = 0$ , suppliers benefit from internalizing these negative  $HCE_{si}$  since it mitigates suppliers' concerns about the flow of the knowledge spillovers to the competitor, and prevents them from over-investing. This result shows that  $VC$  may induce suppliers to over-invest which reduces profits. Although  $NC$  internalizes no externality, suppliers benefit from  $NC$  since it also prevents them from over-investing. The over-investment under  $VC$  is stronger than under  $NC$ . Thus,  $\pi_{si}^{HC} > \pi_{si}^{NC} > \pi_{si}^{VC}$ . As  $v$  increases, yet

$h$  is sufficiently low, firms increase their R&D further. Additionally, when  $v = 1$ , firms benefit from internalizing  $VCE_{si}$  which reinforces the cost reduction effects of  $v$ . Vertical spillovers also mitigate the negative  $HCE_{si}$ , such that  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$ . Ultimately,  $HCE_{si} = VCE_{si}$  when  $h = 1$  which results in  $\pi_{si}^{VC} = \pi_{si}^{HC} > \pi_{si}^{NC}$ .

Part *ii* of Proposition 7 states that  $\pi_{si}^{NC} > \pi_{si}^{VC} > \pi_{si}^{HC}$  when products are imperfect substitutes and  $h = v = 0$ . When products are substitutes, competition between retailers is strong. Thus, retailers reduce their output which affects suppliers' output as well. These effects reduce firms' incentive to increase their R&D and thereby,  $VC$  leads firms to over-invest. Furthermore,  $HCE_{si}$  is negative due to the low spillovers. Internalizing these negative competitive externalities leads suppliers to under-invest which reduces suppliers' profit. In this case,  $VC$  yields higher profit than  $HC$ , while  $NC$  internalizing no externality yields the highest profit to suppliers since  $NC$  prevents them from over-investing and (or) under-investing. Thus,  $\pi_{si}^{NC} > \pi_{si}^{VC} > \pi_{si}^{HC}$ . Higher  $h$  and  $v$  increase the net benefit of R&D, more than offset the effects of  $b$  on profit, and positively affect firms' incentive to increase their R&D. Thus,  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$  when spillovers are high enough.

Part *iii* of Proposition 7 states that  $\pi_{si}^{VC} > \pi_{si}^{NC} > \pi_{si}^{HC}$  when products are homogenous and  $h = v = 0$ . When products are homogenous, competition between firms is intense. This reduces firms' incentive to increase their R&D.  $NC$  internalizes no externality, yet boosts competition and induces suppliers to over-invest.  $HC$  internalizes the negative  $HCE_{si}$ , inducing suppliers to under-invest.  $HC$  reduces suppliers' profit (by under-investing) more than  $NC$  does (by over-investing). In this case,  $VC$  prevents suppliers from the overinvestment associated with  $NC$  and thereby, suppliers attain the highest profit under  $VC$ . Thus,  $\pi_{si}^{VC} > \pi_{si}^{NC} > \pi_{si}^{HC}$ . As spillovers increase, firms have enough incentive to increase their R&D,  $HCE_{si}$  turns positive and  $\pi_{si}^{VC} > \pi_{si}^{HC} > \pi_{si}^{NC}$ .

Proposition 7 shows that when goods are independent and spillovers are sufficiently low,  $VC$  leads suppliers to over-invest. To avoid over-investing, suppliers tend to  $HC$ . However,  $HC$  leads suppliers to under-invest when products are imperfect substitutes, yet spillovers are sufficiently low. These results reflect the effects of  $b$  on firms' R&D.  $VC$  yields the highest profit for suppliers when products are homogenous. Choosing an appropriate cooperative setting under different levels of spillovers and product substitutability is critical to profit maximizing firms to choose the adequate innovation efforts.

## 5. CONCLUSION

This paper aims to study the impact of cooperative R&D on innovation, welfare, and profitability in vertically related industries where products are differentiated, with horizontal and vertical spillovers. A two-industry framework is considered, where upstream firms produce a homogeneous intermediate good and sell it to downstream firms. Downstream firms produce differentiated products.

Although vertical spillovers always increase R&D, horizontal spillovers may increase or decrease them. Vertical spillovers have a multiplied positive impact on R&D by stimulating horizontal spillovers and through the cooperative structure. Inter-industry firms always benefit from higher innovation efforts of one another. The impact of horizontal spillovers on R&D depends on the cooperative structure, horizontal and vertical spillovers and product substitutability. Firms' behaviour is affected by the cooperative structure, spillovers and

product substitutability. Retailers and suppliers have different responses to a change in spillovers and product substitutability. Although higher product differentiation mitigates retailers' concerns about horizontal spillovers, it has no significant effect on suppliers.

Higher product substitutability always increases competition between retailers, affects the position of the demand curve, induces retailers to reduce their output and the demand of the intermediate good. Although the reduction in demand affects suppliers' net benefit of R&D, the power of suppliers mitigates the effect by increasing the wholesale price.

Comparing cooperative settings in terms of R&D shows that vertical cooperation always dominates the others. When horizontal spillovers are perfect, horizontal cooperation and vertical cooperation yield the same level of R&D. The second best cooperation setting in terms of R&D and welfare is non-cooperative R&D if spillovers are sufficiently low; otherwise, horizontal cooperation leads to the second best. Horizontal cooperation decreases R&D and welfare when spillovers are sufficiently low. This result does not necessarily hold when one of the spillovers is high. The ranking of cooperation settings rests on the sign and magnitudes of competitive externalities, spillovers and product substitutability. Product substitutability affects the required threshold of spillovers. Higher product differentiation yields higher output and R&D by all firms under any type of cooperation.

An important question that arises in the study of cooperation settings is their relative importance to firms' decisions. Cooperation settings were compared in terms of profitability. It was shown that profitability is affected by the sign and magnitudes of competitive externalities, product substitutability, as well as horizontal and vertical spillovers. The result indicates that retailers and suppliers have no common interest to voluntarily form vertical cooperation. Although suppliers always gain the highest profit under vertical cooperation when final goods are homogenous, retailers attain the highest profit under vertical cooperation only if vertical spillovers are sufficiently high. Moreover, vertical cooperation may induce firms to over-invest, which reduces profits.

The study of cooperative R&D and of protecting innovation certainly is important for technology policy issues. Drawing policy recommendations requires prudence since it deals with many practical issues like asymmetric information between firms and regulators. However, the model suggests some considerations on R&D policy with respect to the incentives of cooperation settings' perspective.

The model suggests that the selection of cooperation settings and of incentives to cooperate is imperative to the analysis of R&D levels. The model indicates that vertical cooperation is associated with the highest innovation and welfare. The regulator should favour policies to encourage vertical cooperation. The optimal policy varies based on spillovers and product substitutability.

The model has many possible extensions. A critical determinant of cooperative R&D is the level of knowledge spillovers. The importance of differentiating between outgoing technical knowledge and incoming technological information has not been addressed by the paper. It was assumed that the flow of horizontal (vertical) spillovers between firms in both industries is the same. In the real world, absorptive capacity, the pace and scope of technological change, and communication channels are different among firms (industries) which leads to different levels of knowledge spillovers. Moreover, downstream firms dealing with the final consumer may bear more vertical spillovers, whereas upstream firms providing a homogenous

intermediate good may develop more horizontal spillovers. This, in turn, may affect the symmetry of horizontal and vertical spillovers.

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## APPENDIX

$$x_{ri}^{NC} = \frac{(a-r-s)(2(h-5-4v)+b(5h+4v-1))}{26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2-b[4h+5h^2+36u+2v+14hv+8v^2-1]+2b^2[h^2+9u+h(v-1)-(2+v)(1+2v)]} \quad (A1)$$

$$x_{si}^{NC} = \frac{2(4-b^2)(a-r-s)(-2+h-v)}{26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2-b[4h+5h^2+36u+2v+4hv+8v^2-1]+2b^2[h^2+9u+h(v-1)-(2+v)(1+2v)]} \quad (A2)$$

$$X^{NC} = \frac{(2(a-r-s)(10h-b(1-5h-2b(2-h+v)-4v)-16v-26))}{26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2-b[4h+5h^2+36u+2v+14hv+8v^2-1]+2b^2[h^2+9u+h(v-1)-(2+v)(1+2v)]} \quad (A3)$$

$$Y^{NC} = \frac{12u(4-b^2)(a-r-s)}{(72u-9b^3u-68v+4hv-32v^2-26-2h(8-5h)+b[4h+5h^2+36u+2v+14hv+8v^2-1]-2b^2[h^2+9u+h(v-1)-(2+v)(1+2v)])} \quad (A4)$$

$$W^{NC} = \frac{2u(a-r-s)^2\{36b^3u(b^2-8)+4b[26h-5h^2+144u+16v(1+h)+16v^2-5]-2b^4[2h^2-45u-4h(2+v)+2(2+v)^2]-4[89+17h^2-360u+8v(13+4v)-2h(37+20v)]+b^2[127+7h^2-720u+8v(17+2v)-2h(59+52v)]\}}{(26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2-b[4h+5h^2+36u+2v+14hv+8v^2-1]+2b^2[h^2+9u+h(v-1)-(2+v)(1+2v)])^2} \quad (A5)$$

$$p^{NC} = \frac{a[26+2h(8-5h)-48u+3b^3u+68v-4hv+32v^2-b(h(4+5h)+12u+2v+14hv+8v^2-1)+2b^2(h^2+6u-h(1-v)-(2+v)(1+2v))]-6u(2-b)(1+b)(2+b)(r+s)}{(26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2-b(4h+5h^2+36u+2v+14hv+8v^2-1)+2b^2(h^2+9u+h(v-1)-(2+v)(1+2v)))} \quad (A6)$$

$$x_{ri}^{HC} = \frac{4(a-r-s)(1+h+2v)}{9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)]} \quad (A7)$$

$$x_{si}^{HC} = \frac{2(2+b)(a-r-s)(1+h+2v)}{9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)]} \quad (A8)$$

$$X^{HC} = \frac{(4(4+b)(a-r-s)(1+h+2v))}{9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)]} \quad (A9)$$

$$Y^{HC} = \frac{12u(2+b)(a-r-s)}{(9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)]} \quad (A10)$$

$$W^{HC} = \frac{4u(a-r-s)^2\{9u(1+b)(2+b)^2-2(4h^2-9u(2+b)^2+8h(1+2v)+4(1+2v)^2)+(2+b)^2(-2+9(2+b)u-8v-2(h(2+h)+4hv+4v^2))\}}{(9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)])^2} \quad (A11)$$

$$p^{HC} = \frac{[6u(1+b)(2+b)(r+s)]+au(4+b)[-2+3(2+b)-8v-2[h(2+h)+4hv+4v^2]]}{9b^2u-8(h+2v)^2-4(2+4h-9u+8v)-2b[h^2-18u+(1+2v)^2+h(2+4v)]} \quad (A12)$$

$$x_{ri}^{VC} = \frac{(a-r-s)(b[b+5h+bh+2v(2+b)-1]-2(7+h+8v))}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)-b^2(h^2-4h+18u-2v(7+h)-8v^2-5)+b(1+h(8+7h)+36u+10v+22hv+16v^2)} \quad (A13)$$

$$x_{si}^{VC} = \frac{2(2-b)(a-r-s)[5-h+b(2-h+v)+4v]}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)-b^2(h^2-4h+18u-2v(7+h)-8v^2-5)+b(1+h(8+7h)+36u+10v+22hv+16v^2)} \quad (A14)$$

$$X^{VC} = \frac{2(a-r-s)(34-2h-b(1+7h+b(5-h+4v)-8v)+32v)}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)-b^2[h^2-4h+18u-2v(7+h)-8v^2-5]+b[1+h(8+7h)+36u+10v+22hv+16v^2]} \quad (A15)$$

$$Y^{VC} = \frac{12u(4-b^2)(a-r-s)}{72u-34-32h-9b^3u-100v+2(h-16v)(h+2v)-b^2[h^2-4h+18u-2v(7+h)-8v^2-5]+b[1+h(8+7h)+36u+10v+22hv+16v^2]} \quad (A16)$$

$$W^{VC} = \frac{4u(a-r-s)^2\{27b^5u-2b^3[7+h(8+h)+108u+22v+10hv+16v^2]+4b[13+h(50+h)+108u+76v+52hv+64v^2]-b^4[17+5h^2-81u-4v(5+2v)+2h(7+2v)]-4[149+5h^2-324u-2h(13+8v)+16v(17+8v)]+3b^2[61-3h^2-216u+32v(3+v)-h(26+32v)]\}}{(34+32h-72u+9b^3u+100v-2(h-16v)(h+2v)+b^2[h^2-4h+18u-2v(7+h)-8v^2-5]-b[1+h(8+7h)+36u+10v+22hv+16v^2])^2} \quad (A17)$$

$$P^{VC} = \frac{u(b-2)(1+b)(2+b)(r+s)+a\{34+32h-48u+3b^3u+100v-2(h-16v)(h+2v)+b^2[h^2-4h+18u-2v(7+h)-8v^2-5]-b[1+h(8+7h)+12u+10v+22hv+16v^2]\}}{34+32h-72u+9b^3u+100v-2(h-16v)(h+2v)+b^2[h^2-4h+18u-2v(7+h)-8v^2-5]-b[1+h(8+7h)+36u+10v+22hv+16v^2]} \quad (A18)$$

### Proof of Proposition 1.

Taking the derivatives of Eqs A1, A2, A3, A4, and A5 with respect to  $v$  and evaluating the result shows that  $\partial x_{ri}^{NC}/\partial v > 0$ ,  $\partial x_{si}^{NC}/\partial v > 0$ ,  $\partial X^{NC}/\partial v > 0$ , and  $\partial Y^{NC}/\partial v > 0$ . To prove that  $\partial W^{NC}/\partial v > 0$ , evaluating the validity of  $u$  is required. Thus,  $P^{NC}$  for the same parameter values must be evaluated to find whether  $u$  meets the required threshold. Note that output is positive iff  $a > r + s$ . Evaluating  $P^{NC}$  and  $W^{NC}$  at the same parameter values shows that the required  $u$  making  $\partial W^{NC}/\partial v > 0$  is met.

Taking the derivatives of Eqs A7, A8, A9, A10, and A11 with respect to  $v$  and evaluating the result shows that  $\partial x_{ri}^{HC}/\partial v > 0$ ,  $\partial x_{si}^{HC}/\partial v > 0$ ,  $\partial X^{HC}/\partial v > 0$ , and  $\partial Y^{HC}/\partial v > 0$ . To prove that  $\partial W^{HC}/\partial v > 0$ , evaluating the validity of  $u$  is required. Thus,  $P^{HC}$  at the same parameter values must be evaluated to find whether  $u$  meets the required threshold. Evaluating  $P^{HC}$  and  $W^{HC}$  at the same parameter values shows that for any value of parameters, the required value for  $u$  making  $\partial W^{HC}/\partial v > 0$  is met.

Taking the derivatives of Eqs A13, A14, A15, A16, and A17 with respect to  $v$  and evaluating the result shows that  $\partial x_{ri}^{VC}/\partial v > 0$ ,  $\partial x_{si}^{VC}/\partial v > 0$ ,  $\partial X^{VC}/\partial v > 0$ , and  $\partial Y^{VC}/\partial v > 0$ . To prove that  $\partial W^{VC}/\partial v > 0$ , evaluating the validity of  $u$  is required. Thus,  $P^{VC}$  at the same parameter values must be evaluated to find whether  $u$  meets the required threshold.

### Proof of Proposition 2.

$$\frac{\partial x_{si}^{NC}}{\partial v} - \frac{\partial x_{ri}^{NC}}{\partial v} > 0 \text{ thus, } \frac{\partial x_{si}^{NC}}{\partial v} > \frac{\partial x_{ri}^{NC}}{\partial v}. \text{ If } b = 0 \text{ and } h = 1, \text{ then } \frac{\partial x_{si}^{NC}}{\partial v} = \frac{\partial x_{ri}^{NC}}{\partial v}.$$

$$\frac{\partial x_{si}^{HC}}{\partial v} - \frac{\partial x_{ri}^{HC}}{\partial v} > 0 \text{ thus, } \frac{\partial x_{si}^{HC}}{\partial v} > \frac{\partial x_{ri}^{HC}}{\partial v}. \text{ If } b = 0, \text{ then } \frac{\partial x_{si}^{HC}}{\partial v} = \frac{\partial x_{ri}^{HC}}{\partial v}.$$

$$\frac{\partial x_{si}^{VC}}{\partial v} - \frac{\partial x_{ri}^{VC}}{\partial v} > 0 \text{ thus, } \frac{\partial x_{si}^{VC}}{\partial v} > \frac{\partial x_{ri}^{VC}}{\partial v}. \text{ If } h = 1, \text{ then } \frac{\partial x_{si}^{VC}}{\partial v} = \frac{\partial x_{ri}^{VC}}{\partial v}.$$

### Proof of Proposition 3.

Taking the derivatives of Eqs A1, A2, A3, A4, and A5 with respect to  $h$  and evaluating the result shows that  $\partial x_{ri}^{NC}/\partial h < 0$ ,  $\partial x_{si}^{NC}/\partial h < 0$ ,  $\partial X^{NC}/\partial h < 0$ ,  $\partial Y^{NC}/\partial h \leq 0$ , and  $\partial W^{NC}/\partial h \leq 0$ . To evaluate the validity of  $u$ ,  $P^{NC}$  must be evaluated at the same parameter values which shows that  $u$  can be either higher or lower than the required threshold and thereby  $\partial Y^{NC}/\partial h \leq 0$  and  $\partial W^{NC}/\partial h \leq 0$ .

Taking the derivatives of Eqs A7, A8, A9, A10, and A11 with respect to  $h$  and evaluating the result shows that  $\partial x_{ri}^{HC}/\partial h > 0$ ,  $\partial x_{si}^{HC}/\partial h > 0$ ,  $\partial X^{HC}/\partial h > 0$ ,  $\partial Y^{HC}/\partial h > 0$ , and  $\partial W^{HC}/\partial h > 0$ .

Evaluating  $P^{HC}$  and  $W^{HC}$  at the same parameter values shows that for any value of  $b$  the required value for  $u$  making  $\partial W^{HC}/\partial h > 0$  is met.

Taking the derivatives of Eqs A13, A14, A15, A16, and A17 with respect to  $h$  and evaluating the result shows that  $\partial x_{ri}^{VC}/\partial h > 0$ ,  $\partial x_{si}^{VC}/\partial h \leq 0$ ,  $\partial X^{VC}/\partial h \leq 0$ ,  $\partial Y^{VC}/\partial h > 0$ , and  $\partial W^{VC}/\partial h > 0$ . Evaluating  $P^{VC}$  at the same parameter values as  $\partial x_{si}^{VC}/\partial h$  and  $\partial X^{VC}/\partial h$  to examine the validity of  $u$  shows that  $u$  can be either higher or lower than the required threshold for  $\partial x_{si}^{VC}/\partial h$  and  $\partial X^{VC}/\partial h$ . Thus,  $\partial x_{si}^{VC}/\partial h \leq 0$  and  $\partial X^{VC}/\partial h \leq 0$ .

#### Proof of Proposition 4.

To prove that  $\partial x_{si}^{NC}/\partial h > \partial x_{ri}^{NC}/\partial h$ , consider  $\frac{\partial x_{si}^{NC}}{\partial h} - \frac{\partial x_{ri}^{NC}}{\partial h}$ . Evaluating the equation requires evaluating the validity of  $u$  at the same parameter values. It shows that if  $b = 0$ , then  $u$  is lower than the threshold and thereby  $\frac{\partial x_{si}^{NC}}{\partial h} < \frac{\partial x_{ri}^{NC}}{\partial h}$ . If  $b > 0$ , then  $u$  is higher than the threshold and thereby  $\frac{\partial x_{si}^{NC}}{\partial h} > \frac{\partial x_{ri}^{NC}}{\partial h}$ .

To prove that  $\partial x_{si}^{HC}/\partial h > \partial x_{ri}^{HC}/\partial h$ , consider  $\frac{\partial x_{si}^{HC}}{\partial h} - \frac{\partial x_{ri}^{HC}}{\partial h}$ . Evaluating the equation shows that the difference increases with  $b$  and reaches zero when  $b = 0$ .

To prove that  $\partial x_{si}^{VC}/\partial h > \partial x_{ri}^{VC}/\partial h$ , consider  $\frac{\partial x_{si}^{VC}}{\partial h} - \frac{\partial x_{ri}^{VC}}{\partial h}$ . Evaluating the equation shows that the difference is negative, decreases with  $b$ , and reaches zero when  $b = 1$ .

#### Proof of Proposition 5.

To prove that  $X_{VC} = X_{HC} > X_{NC}$ , first consider  $X_{VC} - X_{HC}$  which is always positive and reaches zero when  $h = 1$ . If  $h < 1$ , then  $X_{VC} > X_{HC}$ . Now, consider  $X_{VC} - X_{NC}$ . Evaluating the equation shows that  $X_{VC} > X_{NC}$ .

From the above  $X_{VC} - X_{HC}$  is always positive. Now, consider  $X_{HC} - X_{NC}$  which shows that it is positive when  $h$  is high; otherwise, it is negative.

$$\pi_{ri}^{NC} = \frac{u(a-r-s)^2(36b^4u-4b(5-h+4v)(1-5h-4v)-b^2(25h^2+288u+(1-4v)^2-10h(1-4v))-4(h^2-144u-2h(5+4v)+(5+4v)^2))}{[26+2h(8-5h)-72u+9b^3u+68v-4hv+32v^2+b(1-h(4+5h))+36u+2v+14hv+8v^2]+2b^2(h^2+9u-h(1-v)-(2+v)(1+2v))]^2} \quad (A19)$$

$$\pi_{ri}^{HC} = \frac{4u(-a+r+s)^2(9(2+b)^2u-4h^2-8h(1+2v)-4(1+2v)^2)}{[-9b^2u+8(h+2v)^2+4(2+4h-9u+8v)+2b(h^2-18u+(1+2v)^2+h(2+4v))]^2} \quad (A20)$$

$$\pi_{ri}^{VC} = \frac{u(a-r-s)^2[2b^3(1+h+2v)(1-5h-4v)-4b(1-5h-4v)(7+h+8v)+3b^2(9+7h(2-h)-96u+16v(2+v))-b^4(h^2-36u+(1+2v)^2+h(2+4v))-4(h^2-144u+2h(7+8v)+(7+8v)^2)]}{[34+32h-72u+9b^3u+100v-2(h-16v)(h+2v)+b^2(-5-4h+h^2+18u-2(7+h)v-8v^2)-b(1+h(8+7h))+36u+10v+22hv+16v^2]^2} \quad (A21)$$

#### Proof of Proposition 6.

To prove Proposition 6 for each set of parameter values, evaluating the differences between profits is required (i.e. consider  $\pi_{ri}^{VC} - \pi_{ri}^{NC}$  if  $b = h = v = 0$  shows that for these parameter values  $\pi_{ri}^{VC} > \pi_{ri}^{NC}$ ).

$$\pi_{si}^{NC} = \frac{(2u(4-b^2)^2(a-r-s)^2(-2h^2+9u(2+b)+4h(2+v)-2(2+v)^2))}{(26+2(8-5h)h-72u+9b^3u+68v-4hv+32v^2-b(-1+h(4+5h))+36u+2v+14hv+8v^2)+2b^2(h^2+9u+h(-1+v)-(2+v)(1+2v))]^2}$$

(A22)

$$\pi_{si}^{HC} = \frac{2u(2+b)^2(a-r-s)^2(-2+9u(2+b)-8v-2(h(2+h)+4hv+4v^2))}{(-9b^2u+8(h+2v)^2+4(2+4h-9u+8v)+2b(h^2-18u+(1+2v)^2+h(2+4v)))^2} \quad (A23)$$

$$\pi_{si}^{VC} = \frac{2u(2-b)^2(a-r-s)^2(-50+20h+72u+9b^3u-2(h-4v)^2-80v-2b^2(h^2-27u-2h(2+v)+(2+v)^2)-4b(h^2-27u+(2+v)(5+4v)-h(7+5v)))}{(34+32h-72u+9b^3u+100v-2(h-16v)(h+2v)+b^2(-5-4h+h^2+18u-2(7+h)v-8v^2)-b(1+h(8+7h)+36u+10v+22hv+16v^2))^2} \quad (A24)$$

### Proof of Proposition 7.

To prove Proposition 7 for each set of parameter values, evaluating the differences between profits is required (i.e. consider  $\pi_{si}^{HC} - \pi_{si}^{NC}$  if  $b = h = v = 0$  shows that for these parameter values  $\pi_{ri}^{HC} > \pi_{ri}^{NC}$ ).