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Technological Spillovers, Relative Absorptive Capacity and R and D Cooperation

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Abstract: Much of the prior research on R and D cooperation has focused on the role of technological spillovers, in this paper we extend our understanding of R and D cooperation by considering relative absorptive capacity, a firm's ability to value, assimilate and utilize new external knowledge. The model incorporates horizontal spillovers, vertical spillovers and relative absorptive capacity and four types of R and D cooperation are studied: no cooperation, horizontal cooperation, vertical cooperation and simultaneous horizontal and vertical cooperation and the private incentives for R and D cooperation are addressed. It is found that upstream firms and downstream firms have divergent interests regarding the choice of cooperative settings and that technological spillovers and relative absorptive capacity increase the likelihood of the emergence of cooperation in a decentralized equilibrium.

Key words: Vertical spillovers, horizontal spillovers, relative absorptive capacity, R and D cooperation

INTRODUCTION

There is by now a huge body of literature dealing with various aspects of innovative R and D with much attention focused on technological spillovers. Almost all of the studies in the strategic alliances literature deal with horizontal spillovers between competing firms. Spillovers between upstream firms and downstream firms, which I call vertical spillovers, are one instance of inter-industry spillovers. Jorde and Teece in 1990 stress that a significant number of industries, most notably in Europe and Japan, are characterized by vertical R and D collaborations. Harabi (1997) reports for German firms that in the majority of all cases, R and D takes places in cooperation between the supplier and the buyer. Cassiman and Veugelers (2002) find that there is a significant relation between external information flows and the decision to cooperate in R and D. Firms that rate generally available external information sources as more important inputs to their innovation process are more likely to be actively engaged in cooperative R and D agreements. At the same time, firms that are more effective in appropriating the results from their innovation process, are also more likely to cooperate in R and D. Petrakis and Poyago-Theotoky (2002) introduce pollution into a non-tournament model ofR and Dwith spill- overs and show that when the emissions tax is exogenous, the optimalR and Dsubsidy can be negative, i.e. there should be a tax onR and D, depending on the extent of the appropriability problem and the degree of environmental damage. Ishii (2004) analyzes the effects of cooperative R and D in two vertically related duopolies, which are two final-good manufacturers and two input suppliers, with horizontal and vertical spillovers. Vertical R and D cartels yield a larger social welfare than non-cooperative R and D and, if the horizontal spillover rate between the input suppliers is not sufficiently high, than horizontal R and D cartels. Lambertini and Rossini (2009) reassess the respective gains from R and D cooperation and competition in a Cournot duopoly where firms adopt a concave cost-reducing R and D technology. R and D cooperation is socially superior to independent ventures for any spillover level, provided the cost of R and D financing is sufficiently high. Montoro-Sanchez *et al.* (2011) find that knowledge spillovers have a positive impact on firm propensity to innovate and on the probability of firms engaging in inter-organisational R and D collaboration. Furthermore, firm location within an STP is found to influence the intensity of the effect of spillovers on innovation and on R and D cooperation. Thus, the magnitude of the effects of spillovers differs according to the type of the spillover. Chen and Chen (2011) shows that vertical spillover effect doesn't bring apparent benefit to downstream enterprises as in the imagination, the critical point of vertical spillover under vertical RJV is lower that independent R and D, vertical spillover effect harms the interests of the enterprises which joint vertical RJV. Cason and Gangadharan (2013) use a laboratory experiment to examine if sellers successfully coordinate to fund a joint research project to reduce their costs andhow this collaboration affects their pricing behavior. And the results show that although participants usually cooperate when given an opportunity,cooperationis observed less frequently when they also competeinthe market. Communication improves coopera-tion inall environments, particularly when the market is present.

By technological spillovers, a firm can acquire information created by others without paying for that information in a market transaction. However, Cohen and Levinthal (1990) highlight that the benefits of technological spillovers for a firm depend on it's own ability to identify, assimilate and utilize external knowledge, which is called absorptive capacity. Nieto and Quevedo (2005) analyse the influence of technological opportunity, knowledge spillovers and absorptive capacity on the innovative efforts developed by firms. It is demonstrated that the absorptive capacity variable determines innovative effort to a greater extent than the other variables and shown that absorptive capacity has a moderating effect on the relationship between technological opportunity and innovative effort. In this paper, we extend our understanding of R and D cooperation by considering relative absorptive capacity.

The main objective of this paper is to analyze the functioning and determinants of R and D cooperation and relate them to technological spillovers and relative absorptive capacity. This paper incorporates a large number of issues: horizontal spillovers, vertical spillovers, relative absorptive capacity, R and D cooperation. While this complicates the analysis and presentation of the results, I believe that omitting any of these variables would obscure some of the most important parts of the problem, such as the interplay between R and D cooperation, spillovers and absorptive ability.

The study is organized as follows. Section 2 presents and solves the model. Comparative statics are studied in section 3. In section 4 the different types of cooperation are compared in terms of R and D. Section 5 concludes. Comparison of cooperative structures.

THE MODEL

Consider a two-tier industry with three upstream firms indexed by u_i, i = 1, 2, 3 and three downstream firms indexed by d_j, j = 1, 2, 3. Upstream firms supply an intermediate good to the downstream firms whose output of the final product is Q_d. If no R and D is undertaken, upstream firms incur a constant unit production cost of c_u and sell the input at a unit price of p_u to downstream firms. Downstream firms pay the upstream firms p_u for each unit bought and incur an additional internal production cost of c_d. Finally, downstream firms compete in Cournot fashion in the market, sell the final product to consumers at price p_d and face the linear inverse demand:

$$p_d = a - Q_d \tag{1}$$

where $Q_d = \sum_{j=1}^{3} q_{dj}$, q_{dj} denotes downstream firm's i output.

Upstream firms and downstream firms all can engage in cost-reducing R and D activities. The dollar cost of x units of R and D for firm i is μx_i^2, where x represents the R and D output of firm i and $\mu<0$ represents a cost parameter. It means that the unit production cost of upstream firm i and downstream firm j will be reduced x_{uj} and x_{dj}, repectively, if the R and D of the upstream firm i and the downstream firm j is μx^2_{ui} and μx^2_{di}. It is assumed that μ is sufficiently high for the profit function to be concave and sufficiently low for firms to choose strictly positive amounts of R and D.

Each unit of R and D by a downstream firm reduces its own cost by one dollar, reduces the cost of each of its competitors by h_1 dollars (horizontal spillovers among downstream firms) and reduces the cost of each upstream firm by v dollars (vertical spillovers). Each unit of R and D by a upstream firm reduces its own cost by one dollar, reduces the cost of each of its competitors by h_2 dollars (horizontal spillovers among downstream firms) and also reduces the cost of each downstream firm by v dollars (vertical spillovers), with $h_1, h_2, v\in[0,1]$. The spillovers h_1, h_2 and v can differ for many factors: different levels of technological complementarities, differences in the efficiency of communication channels and linkages between the degree of information leakage and the type of inter-firm interaction.

Cohen and Levinthal (1990) view absorptive capacity as a firm-level construct and define it as a firm's ability to recognize the value of new, external knowledge, assimilate it and apply it to commercial ends.

Lane and Lubatkin (1998) shift the unit of analysis of absorptive capacity from the firm-level to the "student-teacher" pairing firms (the learning dyad) and argue that the ability of a firm to learn from another firm is jointly determined by the relative characteristics of the student firm and the teacher firm. The put out that a firm's relative absorptive capacity depends upon: (a) the specific type of new knowledge offered by the teacher firm; (b) the similarity between the student and the teacher firm's compensation practices and organizational structures; and (c) the student firm's familiarity with the teacher firm's set of organizational problems. Base on the definition, we can easy know that the relative absorptive capacity both among upstream firms and downstream firms is one and assume that the relative absorptive capacity between a upstream firm and a downstream firm is g.

The unit cost of production of an upstream firm is:

$$c'_{ui} = c_u - x_{ui} - h_2\sum_{j\neq i}^{3} x_{uj} - gv\sum_{i=1}^{3} x_{dj} \tag{2}$$

The unit cost of production of a downstream firm is:

$$c'_{di} = p_u + c_d - x_{di} - h_1\sum_{j\neq i}^{3} x_{dj} - gv\sum_{i=1}^{3} x_{sj} \quad (3)$$

Consequently, the final unit cost of a firm depends on its R and D choice as well as on that of all other firms. Downstream firms benefit from upstream firms' R and D through a reduction in the cost of their input and vertical spillovers. Upstream firms benefit from downstream firms' R and D through the reduction in buyers' cost, relative absorptive capacity and through vertical spillovers. Note that whereas R and D expenses are independent of output, its benefits are linked to output, since the higher output is, the higher the number of units that benefit from cost reduction.

Parameters are assumed to be such that the following nonnegativity constraints are satisfied:

$$c_u \succ x_{ui} - h_2\sum_{j\neq i}^{3} x_{uj} - gv\sum_{i=1}^{3} x_{dj},$$
$$c_d \succ x_{di} - h_1\sum_{j\neq i}^{3} x_{dj} - gv\sum_{i=1}^{3} x_{sj}$$

These constraints ensure that production costs after R and D is undertaken are strictly positive. The game has three stages: one R and D stage and two output stages. In the first stage all firms decide on their R and D simultaneously. In the second stage upstream firms compete in Cournot, taking into account the derived demand curve of the downstream industry. In the third stage there is a Cournot game among all downstream firms, taking the price of the intermediate good as given. The price of the intermediate good is determined by Cournot competition in the upstream industry, based on the derived demand curve of buyers. In horizontal models of R and D investments, the output game is generally assumed to be simultaneous. Here, however, the vertical structure of the market implies that sellers are Stackelberg leaders.

The third stage: We begin with the third stage where downstream firms decide non-cooperatively on their output, guaranteeing the perfectness of the equilibrium. Downstream firms' i problem is:

$$\text{Max}_{q_{di}}\pi_{di} = (p_d - c'_{di})q_{di} - \mu x_{di}^2 \quad (4)$$

Given that buyers are identical ex ante, they take the same decisions ex post. Simultaneous maximization of (3) for i = 1, 2, 3 and solving of the 3 first order condition yields:

$$q_{di} = \frac{1}{4}[(a - p_u - c_d) + (3 - 2h_1)x_{di} - (1 - 2h_1)\sum_{j\neq i}^{3} x_{dj} + gv\sum_{i=1}^{3} x_{ui}] \quad (5)$$

Substituting for q_{dj} from Eq. 5 into Eq. 1, we get the downstream firm's price:

$$p_d = \frac{1}{4}[a + 3(p_u + c_d) - (1 + 2h_1)\sum_{i=1}^{3} x_{di} + 3gv\sum_{i=1}^{3} x_{ui}] \quad (6)$$

From Eq. 5, we derive the inverse demand curve upstream firms face:

$$p_u = \frac{1}{3}[(a - c_d) + (1 + 2h_1)\sum_{i=1}^{3} x_{di} + 3gv\sum_{i=1}^{3} x_{ui} - 4Q_d] \quad (7)$$

The second stage: In the second stage of the game, upstream firms decide non-cooperatively on their output based on the derived inverse demand of upstream firms (7). Upstream firms *i* solves the following problem:

$$\text{Max}_{q_{ui}}\pi_{ui} = (p_u - c'_{ui})q_{ui} - \mu x_{ui}^2 \quad (8)$$

The identical costs of upstream firms imply that they will occupy identical positions ex post. Maximization and simultaneous solving of the 3 first order condition yields:

$$\text{Max}_{q_{ui}}\pi_{ui} = (p_u - c'_{ui})q_{ui} - \mu x_{ui}^2 q_{ui} = \frac{1}{16}[3(a - c_d - c_u) + (1 + 2h_1 + 3gv)\sum_{i=1}^{3} x_{di} + 3(3 - 2h_2 + gv)x_{ui} + 3(2h_2 + gv - 1)\sum_{j\neq i}^{3} x_{uj}] \quad (9)$$

Given that each unit bought from upstream firms is transformed into one unit sold by downstream firms to consumers, total output is the same for upstream and downstream industries. Total output is:

$$Q_d = Q_u = \frac{1}{16}[9(a - c_d - c_u) + 3(1 + 2h_1 + 3gv)\sum_{i=1}^{3} x_{di} + 3(1 + 2h_2 + 3gv)\sum_{i=1}^{3} x_{ui}] \quad (10)$$

Substituting for Q_d from Eq. 10 into Eq. 1, we get the downstream firm's price:

$$p_d = \frac{1}{16}[7a + 9(c_u + c_d) - 3(1 + 2h_1 + 3gv)\sum_{i=1}^{3} x_{di} - 3(1 + 2h_2 + 3gv)\sum_{i=1}^{3} x_{ui}] \quad (11)$$

and the price charged by upstream firms is:

$$p_u = \frac{1}{12}[3(a - c_d + 3c_u) - (1 + 2h_1 - 9gv)\sum_{i=1}^{3} x_{di} - 3(1 + 2h_2 - gv)\sum_{i=1}^{3} x_{ui}] \quad (12)$$

Substituting for p_u from Eq. 12 into Eq. 5 and 3, we get the downstream firm i output and the unit cost of production:

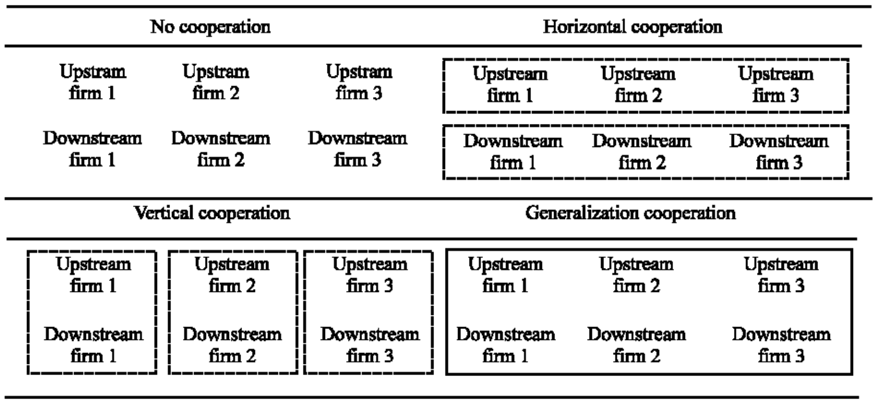

Fig. 1: Types of cooperation

$$q_{di} = \frac{1}{48}[9(a - c_d - c_u) + (35 - 26h_1 + 9gv)x_{di} + (22h_1 - 13 + +9gv)\sum_{j\neq i}^{3} x_{dj} + 3(1 + 2h_2 + 3gv)\sum_{i=1}^{3} x_{ui}] \quad (13)$$

$$c'_{di} = \frac{1}{12}[3(a + 3c_d + 3c_u) + (2h_1 - 9gv - 11)x_{di} + (1 - 10h_1 - 9gv)\sum_{j\neq i}^{3} x_{dj} - 3(1 + 2h_2 + 3gv)\sum_{i=1}^{3} x_{ui}] \quad (14)$$

The first stage: In the first stage of the game all firms decide simultaneously on R and D levels. Whereas output is always chosen non-cooperatively, four types of cooperation will be considered for R and D decisions (Atallah, 2002): a non-cooperative (NC), a generalized cooperative (GC), a horizontal cooperative (HC) and a vertical cooperative (VC). Figure 1 illustrates the different cooperation types. Note that in all four environments the source and destination (and also the level) of spillovers is independent. That is, even when there are cooperating groups of firms, spillovers originate and end at individual firms.

Horizontal cooperation (HC) represents cooperation with upstream firms or downstream firms, while vertical cooperation (VC) represents cooperation between upstream and downstream firms. Generalized cooperation (GC) reflects the complexity of some research joint ventures: with the multiplication of research projects, firms may be adopting more than one structure simultaneously. Firms may engage in HC on one project and in VC on another project. Many cooperative agreements involve both horizontal and vertical linkages. For instance, cooperation with a competitor may involve working with its suppliers.

In the NC, each firm chooses its R and D so as to maximize its own profits, given that other firms do the same. The problems of downstream firm *i* and upstream firm are:

$$\text{Max}_{x_{ui}} \pi_{ui}, \ \text{Max}_{x_{di}} \pi_{di} \quad (15)$$

Maximization and simultaneous solving of the 3+3 first order conditions of (15) yield research efforts in the NC by each upstream firm and each downstream firm:

$$x_{ui}^{NC} = \frac{12(3 - 2h_2 + gv)(a - c_d - c_u)}{256\mu - 12(3 - 2h_2 + gv)(1 + 2h_2 + gv) - (1 - 2h_1 + 3gv)(35 - 26h_1 + gv)}$$

$$x_{di}^{NC} = \frac{(35 - 26h_1 + 9gv)(a - c_d - c_u)}{256\mu - 12(3 - 2h_2 + gv)(1 + 2h_2 + gv) - (1 - 2h_1 + 3gv)(35 - 26h_1 + gv)}$$

In the HC there is intra-industry cooperation but no inter-industry cooperation. Upstream firms and downstream firms solve, respectively:

$$\text{Max}_{x_{ui}} \sum_{i=1}^{3} \pi_{ui}, \ \text{Max}_{x_{di}} \sum_{i=1}^{3} \pi_{di} \quad (16)$$

Simultaneous solving of the 3+3 first order conditions of (16) yields research efforts in the HC by each upstream firm and each downstream firm:

$$x_{ui}^{HC} = \frac{32(1 + 2h_2 + 3gv)(a - c_d - c_u)}{512\mu - (1 + 2h_2 + gv)^2 - 9(1 + 2h_1 + 3gv)^2}$$

$$x_{di}^{HC} = \frac{9(1 + 2h_1 + 3gv)(a - c_d - c_u)}{512\mu - (1 + 2h_2 + gv)^2 - 9(1 + 2h_1 + 3gv)^2}$$

COMPARATIVE STATICS

The question addressed in this section is: what is the effect of changes in technological spillovers and relative absorptive capacity on R and D, under four types of cooperation? Table 1 summarizes the comparative statics of the model. Proposition summarises.

Table 1: Summary of comparative statics

	No cooperation	Horizontal cooperation	Vertical cooperation	Generalized cooperation
$\partial x_{ui}/\partial v$	+	+	+	+
$\partial x_{di}/\partial v$	+	+	+	+
$\partial x_{ui}/\partial g$	+	+	+	+
$\partial x_{di}/\partial g$	-	+	±	+
$\partial x_{ui}/\partial h_1$	-	+	±	+
$\partial x_{di}/\partial h_1$	-	+	±	+
$\partial x_{ui}/\partial h_2$	±	+	±	+
$\partial x_{di}/\partial h_2$	±	+	±	+
$\partial x^2_{ui}/\partial g \partial v$	+	+	+	+
$\partial x^2_{di}/\partial g \partial v$	+	+	+	+
$\partial x^2_{ui}/\partial h_1 \partial h_2$	±	+	±	+
$\partial x^2_{di}/\partial h_1 \partial h_2$	±	+	±	+
$\partial x^2_{ui}/\partial h_1 \partial v$	-	+	±	+
$\partial x^2_{di}/\partial h_2 \partial v$	-	+	±	+
$\partial x^2_{ui}/\partial h_2 \partial v$	±	+	±	+
$\partial x^2_{di}/\partial h_2 \partial v$	±	+	±	+

- Vertical spillover *v* always increases R and D by all upstream firms and downstream firms under four types of cooperation
- Relative absorptive capacity g always increases R and D by all upstream firms and downstream firms under four types of cooperation
- Horizontal spillovers among downstream firms h_1 increase R and D by all upstream firms and downstream firms under the generalized cooperative(GC) and the horizontal cooperative (HC), reduce R and D by all upstream firms and downstream firms under the non-cooperative(NC) and have an ambiguous effect on R and D under vertical cooperative (VC)
- Horizontal spillovers among upstream firms h_2 increase R and D by all upstream firms and downstream firms under the generalized cooperative(GC) and the horizontal cooperative (HC) and have an ambiguous effect on R and D under non-cooperative(NC) and vertical cooperative (VC)
- Under four types of cooperation, g and v reinforce the positive effects on R and D of each other
- Under the generalized cooperative (GC) and the horizontal cooperative (HC), h_1 and h_2 reinforce the positive effects of each other
- Under the non cooperative, v reinforces the negative effect of h_1 and h_1 mitigates the positive effect of v. Under generalized cooperative(GC) and horizontal cooperative (HC), h_1 and v reinforce the positive effects of each other.
- Under generalized cooperative(GC) and horizontal cooperative (HC), h_2 and v reinforce the positive effects of each other

An increase in v and g increases R and D by all firms under four types of cooperation. As v and g increases, the flow of spillovers between the two industries and all firms' relative absorptive capacity increases, reducing the costs of all firms; this reduction in costs translates into an increase in output. This increase in output increases the value of cost reduction, inducing a further increase in R and D.

Under the non-cooperative (NC), an increase in h_1 reduces the private benefit from R and D, thereby reducing R and D by all firms. Under Generalized Cooperative (GC) and the Horizontal Cooperative (HC), there is intra-industry cooperation and, consequently the positive externality is internalized: an increase in h_1 and h_2 increases R and D by all firms.

There is an interaction between the effects of g and v, h_1 and h_2, h_1 and v, h_2 and v. Under four types of cooperation, $\partial x^2_{ui}/\partial g \partial v \succ 0$ and $\partial x_{di}/\partial g \partial v \succ 0$, meaning that g and v reinforces the positive effect of each other. Under Generalized Cooperative (GC) and Horizontal Cooperative (HC), $\partial x_{ui}/\partial h_1 \partial h_2 \succ 0$, $\partial x^2_{ui}/\partial h_1 \partial h_2 \succ 0$, $\partial x^2_{ui}/\partial h_1 \partial v \succ 0$, $\partial x^2_{di}/\partial h_1 \partial v \succ 0$, $\partial x^2_{ui}/\partial h_2 \partial v \succ 0$, $\partial x^2_{di}/\partial h_2 \partial v \succ 0$, meaning that h_1 and h_2, h_1 and v, h_2 and v, reinforces the positive effect of each other.

However, further analysis shows that the effect of a simultaneous increase in h_1 and v under the non-cooperation tends to become negative as competition intensifies, due to the negative effect of non internalized h_1 on R and D. Therefore, when the diffusion of technological information to vertically related firms makes this information available to competitors and this (horizontal) externality is not internalized, it is preferable to limit the diffusion of information.

CONCLUSIONS

This study focused on vertical inter-industry spillovers, horizontal intra- industry spillovers, relative absorptive ability and R and D cooperation between firms. First, vertical spillover and relative absorptive ability always increase R and D by all upstream firms and downstream firms and they reinforce the positive effects on R and D of each other, under four types of cooperation.

Second, under the non-cooperative(NC), an increase in horizontal spillovers among downstream firms reduces the private benefit from R and D, thereby reducing R and D by all firms. Under Generalized Cooperative (GC) and the Horizontal Cooperative (HC), there is intra-industry cooperation and, consequently the positive externality is internalized: an increase in horizontal spillovers among downstream firms or horizontal spillovers among downstream firms increases R and D by all firms.

Third, we discuss the interaction between the effects of vertical spillovers, horizontal spillovers and relative absorptive ability. It is found that vertical spillovers and relative absorptive ability reinforces the positive effect of each other under four types of cooperation and meaning that horizontal spillovers among downstream firms and horizontal spillovers among downstream firms and vertical spillovers, horizontal spillovers among downstream firms and vertical spillovers, reinforces the positive effect of each other under Generalized Cooperative (GC) and Horizontal Cooperative (HC).

Finally, further analysis shows that the effect of a simultaneous increase in horizontal spillovers among downstream firms and vertical spillovers under the non-cooperation tends to become negative as competition intensifies, due to the negative effect of non internalized horizontal spillovers among downstream firms on R and D.

The model has more than one possible extensions. An important type of vertical cooperation that has not been addressed by the paper is vertical cooperation when the upstream sector is the developer of the innovation and the downstream sector is the user of the innovation. It was assumed that upstream and downstream firms conducted the same type of research. In real markets, downstream firms are closer to the final user and may be engaged in more applied research, whereas upstream levels may be conducting more fundamental research.

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