MARKETS WITH NETWORK EXTERNALITIES: NON-COOPERATION VS. COOPERATION IN R&D

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Abstract

This paper examines three strategies for R&D investments in oligopoly markets with network externalities. The Cell project of the Sony-Toshiba-IBM R&D joint venture motivates our analysis and presentation. In addition to the particular characteristics that apply to the Cell project, we develop formal economic explanations for observed R&D investment strategies in markets with network externalities. Our analytical model suggests that the degree of product compatibility, initial market shares, and the intensity of the product-market competition are instrumental to the R&D strategy in these markets. The paper ties together the literature on information technologies, strategy, and economics, and derives optimal patterns of strategic behavior in the R&D (pre-production) stage in oligopoly markets with network externalities.

Keywords: Network externalities, Product innovation, Cooperation in R&D, Compatibility.

1 INTRODUCTION

In many information-goods markets such as those for computer hardware and software, video game hardware and software, and communication technologies, the utility that a user derives from a product increases as the number of users of identical or compatible products increases. In the economic literature, this is called network externalities or network effects. Despite the fact that these markets are characterized by very high rates of innovation, little theoretical and empirical work has been done on R&D and technology choice in the presence of network externalities (Katz and Shapiro, 1994). Actually, there are only three studies – Katz and Shapiro (1992), Regibeau and Rockett (1996), and Kristiansen (1998) – on the relationship between compatibility and product introduction/R&D. Two general results stem from these models: (i) compatibility results in the optimal timing of product introduction and (ii) incompatibility speeds up product introduction.

Network externalities make cooperation in R&D more important than ever (Shapiro and Varian, 1999). Following the seminal papers of Spence (1984), Katz (1986), and d'Aspremont and Jacquemin (1988), a large body of economic literature has developed over the last two decades on the possible benefits of cooperative R&D, but none of these studies has examined markets with network externalities. However, in addition to the well-known advantages, like risk sharing, pooling resources, and the prevention of duplicative effort and free riding, rival firms may cooperate in order to establish standards and create a single network of compatible products, even though they remain rivals and compete for their share of the network in the product market.

The Sony-Toshiba-IBM joint venture (STI), formed in 2001, with the intention of developing a supercomputer on a chip, can serve as an example of cooperation in R&D. The end of a major milestone in this joint venture – the Cell project, with a cost of about $400 million (Kirkpatrick, 2005), was announced last August and the technical details of the Cell chip, to be developed as a processor for the next-generation Sony PlayStation 3 game box, are now available at http://cell.scei.co.jp. The following features of the STI joint venture are noteworthy:

- Sony and IBM are the *only* rivals (with about equal shares) in the game box microprocessor market. Until now, Sony has been using home-built microprocessors for its PlayStation 2, while IBM is the supplier of the Intel-based processors for two of Sony's rivals in the video game market (Microsoft and Nintendo). Note, however, that Sony has chosen to cooperate with IBM in the STI not as a supplier, but as a partner for an extremely risky research project aimed at developing its next-generation game box.
- The Cell chip is designed to be the engine that will drive the next family of (non-Intel) computers – from game boxes and PDAs to supercomputers, that run with the same software (Kirkpatrick, 2005). Thus, Sony and IBM have started to build a new physical and virtual network based on a new standard. Having learned from previous mistakes, Sony and IBM had been attempting to establish a thriving open community around the Cell chip several years prior to the start of its commercial use (IBM expects to start selling the Cell-based computers in 2008).

The model of this paper could have been used to predict the formation of the STI R&D joint venture, a formation justified by our result that the profits of the two firms in a highly competitive duopoly market are minimal when market shares are equal. Furthermore, R&D investments in this case are "too large" (excessive) without leading to an increase in outputs or profits. Our model shows, however, that cooperation in R&D in this case will increase the profits of both firms and is socially desirable. These results may also be seen to be illustrated by the formation of Symbian in 1998 by Ericsson, Motorola, and Nokia as a joint venture to develop an operating system for mobile devices (Ernst and Halevy, 2000), or by IM Flash Technologies, the recently announced joint venture of the two big chip-making competitors, Intel and Micron Technology (The Economist, 2006).

Our model describes a static two-stage game[1] in a duopoly market, in which the firms' products are substitutes. In the first stage, the firms decide, non-cooperatively or cooperatively, on their R&D programs, while in the second stage they choose their outputs non-cooperatively. We analyze three alternative models. In the first, *non-cooperation in R&D*, each firm chooses an R&D program that maximizes its expected profits in the first stage of the game. In the other two models, the firms cooperate in the R&D stage and remain rivals in the second (production) stage. The cooperation in R&D in the second model takes the form of an *R&D cartel*, where the firms conduct their R&D activities separately, but coordinate their decisions by maximizing expected joint profits. The third model is an *R&D joint venture* type, where the firms jointly conduct R&D activities. In all three models the firms compete with each other during the second stage.

The three models are outlined in Section 2 and analyzed in Section 3. A brief summary of the results and a discussion of their relevance for policy purposes are given in Section 4.

2 THE MODELS

Formally, we posit two firms, each producing a single product. The two firms' products are substitutes. q_1 and q_2 denote the output of firm 1 and firm 2, respectively, and p_1 and p_2 denote the corresponding unit prices. The i-th firm's inverse demand function is:

(1) $$p_i = D_i^{-1}(q_i, q_j) = a_i + \Omega(z_i^0) - bq_i - dq_j, \quad j \neq i,\ i=1,2,$$

where $a_i > 0$, $0 < d < b$, and $\Omega(z_i^0) \geq 0$.

The parameter a_i is a function of the R&D outcome of firm i, which will be described below. The parameter b is a measure of the firm's own output effect on its price, whereas the parameter d is a measure of the effect of the rival firm's output on the firm's price. That is, the larger is d/b, the higher the degree of substitution between the two firms' products. The function $\Omega(z_i^0)$ exhibits the network effect on the demand function, and z_i^0 denotes the initial network size of firm i.

Following Katz and Shapiro (1985, 1992), network externalities are incorporated into the model as the network size of the compatible products: a larger network size leads to a higher upward shift of the demand function. We assume myopic expectations,[2] that is, the initial size of firm i's network, z_i^0, is defined by:

(2a) $$z_1^0 = S^0\eta + \omega S^0(1-\eta),$$

(2b) $$z_2^0 = S^0(1-\eta) + \omega S^0\eta,$$

where S^0 is the initial market size (the number of units sold in the market in the past), and η is firm 1's initial market share. That is, $S^0\eta$ is the installed base of firm 1, and $S^0(1-\eta)$ is the installed base of firm 2. The exogenous parameter ω, $0 \leq \omega \leq 1$, denotes the degree of compatibility between the two firms' products. When $\omega = 1$, the two products are fully compatible and, therefore, each firm's network includes the installed bases of both firms. When $\omega = 0$, the two products are incompatible and, therefore, each firm's network includes only its own installed base.[3] The network effect on firm i's demand, $\Omega(z_i^0)$, is assumed to be linear. The upward shift of firm i's demand function is higher, the larger its installed base and the higher the compatibility between the products.

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[1] Most R&D models include two stages (d'Aspremont and Jacquemin, 1988), three stages (Kristiansen, 1998; Ishii, 2004), or four stages (see Katz, 1986).

[2] There are two basic approaches to handling expectations: the myopic-expectations approach, which employs the present network size (see Regibeau and Rockett, 1996), and the fulfilled-expectations approach, which considers future network size (see Katz and Shapiro, 1992).

[3] Compatibility can be one-way or two-way. One-way compatibility happens, for example, when a component from one system works in the other, but the reverse is not true (see Katz and Shapiro, 1994, p. 105).

The R&D program yields *product* innovations which result in improved products and enhanced demand.[4] This setup is consistent with the fact that the production costs of information goods are low and, therefore, *process* innovations are less critical to a successful business in the information goods markets. Hence, during the first stage of the game each firm undertakes an R&D program in order to improve its product quality and/or functionality. We assume that the outcomes of the R&D programs in the first stage of the game are uncertain and, therefore, the firms' decision variables at this stage are the expected values and variances of the outcomes of the R&D programs. In the second stage, the outcomes of the R&D programs become known and shift the demand functions. A more successful R&D program leads to a higher upward shift of the demand function (see, for example, Tishler, 2002). That is, denoting the outcome of firm *i*'s R&D program by λ_i, a success of the R&D program implies $\lambda_i > 0$. If the R&D efforts of firm *i* fail, then $\lambda_i = 0$.

More specifically, we suppose that $\lambda_1 \sim f_1\, [E(\lambda_1), V(\lambda_1)]$ and $\lambda_2 \sim f_2\, [E(\lambda_2), V(\lambda_2)]$, where $E(\lambda_i)$ and $V(\lambda_i)$ denote the expected value and variance of λ_i, respectively. The values of $E(\lambda_i)$ and $V(\lambda_i)$ are bounded.[5] The effect of the R&D programs on the demand function is given by:

(3) $$a_i = a_0 + \Theta(\lambda_i), \qquad i=1,2,$$

where $a_0 > 0$ is a constant. The function $\Theta(\lambda_i)$ reflects the effect of firm *i*'s R&D program on the demand function for its product. This effect is larger, the larger the outcome of the firm's R&D program. For simplicity, we assume that this effect is linear.

The *i*-th firm's profits are

(4) $$\Pi_i = \pi_i - Cost(R\&D)_i, \quad i=1,2,$$

where π_i denotes operating profits and $Cost(R\&D)_i$ denotes the cost of the R&D program.

The model assumes that marginal production costs, c_i, are constant. Thus, without loss of generality we define a_0 in (3) to be equal to the constant of the demand function net of marginal production costs. That is, firm *i*'s operating profits are given by

(5) $$\pi_i = q_i p_i, \qquad i=1,2.$$

The cost of the R&D program of firm *i*, $Cost(R\&D)_i$, is assumed to be a quadratic function of the expected outcome of the program, $E(\lambda_i)$, that is:[6]

(6) $$Cost(R\&D)_i = \beta E(\lambda_i)^2 / 2, \qquad i=1,2,$$

where $\beta > 0$ is a known constant.

The three models (cases) that we compare in this study are as follows.

Non-cooperation in R&D **(**denoted by **N).** The firms act non-cooperatively in both the production and the R&D stages. Thus, market equilibrium is obtained in the following two-stage game:

Stage 1: Each firm chooses its R&D program $\{E(\lambda_i)$ and $V(\lambda_i)\}$ to maximize its expected profit, $E(\Pi_i)$, taking its rivals' R&D program as given.

Stage 2: Each firm chooses the output that maximizes its operating profits, π_i, taking the rival's output and the outcomes of its own and its rival's R&D (which were completed in stage 1) as given.

[4] Product innovations affect the demand for the products and process innovations affect production costs. Most studies in the economic literature examine the effects of process and product innovations separately. For example, Dasgupta and Stiglitz (1980a, 1980b), d'Aspremont and Jacquemin (1988), Suzumura (1992), and Ishii (2004) examine process innovation, while Katz and Shapiro (1992), Chou and Shy (1993) and Adams (2000) study product innovations. Only a handful of studies analyzes both process and product innovations (see, for example, Lunn, 1986; Levin and Reiss, 1988; Tishler, 2002).

[5] Clearly, $V(\lambda_i)>0$. The requirement that $E(\lambda_i)>0$ acknowledges that it is very unlikely a firm will ever choose a costly R&D program geared to zero success.

[6] This assumption reflects the existence of diminishing returns to R&D expenditures.

We solve the two-stage game by first solving the optimal outputs in the second stage; then, conditional upon the functional forms of the optimal outputs, we derive the optimal R&D programs in the first stage. Consider the operating profit of firm *i* at the second stage, conditional on λ_1 and λ_2:

(7) $$\pi_i(q_i,q_j) = p_i q_i = [a_0 + \theta\lambda_i + \Omega(z_i^0) - bq_i - dq_j]q_i, \qquad j\neq i,\ i=1,2.$$

It straightforward to show that the Nash-Cournot equilibrium is:

(8) $$q_i^* = \frac{2b[a_0 + \Omega(z_i^0) + \theta\lambda_i]}{4b^2 - d^2} - \frac{d[a_0 + \Omega(z_j^0) + \theta\lambda_j]}{4b^2 - d^2}. \qquad j\neq i,\ i=1,2.$$

Clearly, the optimal outputs in stage 2 are functions of the R&D outcomes, λ_1 and λ_2, which depend on the values of $\{E(\lambda_1),V(\lambda_1)\}$ and $\{E(\lambda_2),V(\lambda_2)\}$ that were chosen in stage 1. It is straightforward to show that the second-order conditions for profit maximization by each firm are satisfied.

The profits of firm *i*, Π_i, are equal to the firm's operating profit (derived in stage 2) net of the cost of the R&D program (to be decided in stage 1). The firms' operating profits are obtained by substituting (8) into (7). The costs of R&D are defined in (6). That is, the profit functions of firms 1 and 2 are:

(9) $$\begin{aligned}\Pi_i(\lambda_i,\lambda_j) &= \pi_i - Cost(R\&D)_i = \\ &= \frac{b}{[4b^2-d^2]^2}\left[2b\left(a_0 + \Omega(z_i^0) + \theta\lambda_i\right) - d\left(a_0 + \Omega(z_j^0) + \theta\lambda_j\right)\right]^2 - \frac{\beta E(\lambda_i)^2}{2}, \quad j\neq i,\ i=1,2.\end{aligned}$$

In stage 1, the outcomes of the R&D programs are still uncertain. Therefore, an equilibrium in expected R&D outcomes is obtained as follows. Firm 1 maximizes the expected value of its profit, $E(\Pi_1)$, with respect to $E(\lambda_1)$, taking $E^*(\lambda_2)$ as a given. Firm 2 maximizes $E(\Pi_2)$ under similar assumptions.

Taking the expected value of Π_i with respect to λ_i and λ_j yields:

(10) $$E\left(\Pi_i(\lambda_i,\lambda_j)\right) = \frac{b}{\left[4b^2-d^2\right]^2}\begin{bmatrix}\left(2b(a_0+\Omega(z_i^0)-d(a_0+\Omega(z_j^0)\right)^2 + \\ +2\theta\left(2b(a_0+\Omega(z_i^0)-d(a_0+\Omega(z_j^0)\right)[2bE(\lambda_i)-dE(\lambda_j)]+ \\ +4b^2\theta^2E(\lambda_i)^2 + 4b^2\theta^2V(\lambda_i) - 4bd\theta^2E(\lambda_i)E(\lambda_j) - 4bd\theta^2\operatorname{cov}(\lambda_i,\lambda_j)+ \\ +d^2\theta^2E(\lambda_j)^2 + d^2\theta^2V(\lambda_j)\end{bmatrix} - \\ -\frac{\beta E(\lambda_1)^2}{2}, \ j\neq i,\ i=1,2.$$

It is straightforward to show that there exists a unique solution in expected R&D outcomes:

(11) $$E^*(\lambda_i^N) = \frac{4b^2\theta}{A_1^N A_2^N}B_i^N, i=1,2, \quad \text{where}$$

(12) $$A_1^N \equiv \beta(4b^2-d^2)(2b-d) - 4b^2\theta^2, \ A_2^N \equiv \beta(4b^2-d^2)(2b+d) - 4b^2\theta^2,$$

(13) $$B_i^N \equiv A_1^N a_0 + [(A_1^N + A_2^N)/2]\Omega(z_i^0) - [(A_1^N - A_2^N)/2]\Omega(z_j^0), \ j\neq i,\ i=1,2.$$

The second-order conditions for profit maximization require $8b^3\theta^2/(4b^2-d^2)^2 < \beta$.

R&D Cartel (denoted by **C**)**.** Here, the firms conduct their R&D activities separately, but coordinate their R&D decisions so as to maximize their joint profits. Thus, market equilibrium is obtained in the following two-stage game:

Stage 1: Each firm chooses its R&D program $\{E(\lambda_i)$ and $V(\lambda_i)\}$ to maximize the two firms' expected joint profits, $E(\Pi_i + \Pi_j)$, taking its rivals' R&D program as given.

Stage 2: Each firm chooses the output that maximizes its operating profits, π_i, taking the rival's output and the outcomes of its own and its rival's R&D programs (which were completed in stage 1) as given.

The solution to the two-stage game starts by first solving the optimal outputs in stage 2. Clearly, cooperation in R&D affects the second-stage solution only through the firms' optimal R&D decisions. Therefore, the optimal second-stage solution is given by (8). The joint profits of firms 1 and 2 are:

(14)
$$\Pi_1(\lambda_1,\lambda_2)+\Pi_2(\lambda_1,\lambda_2)=(\pi_1-Cost(R\&D)_1)+(\pi_2-Cost(R\&D)_2)=$$
$$=\frac{b}{[4b^2-d^2]^2}\Big(\big[2b\big(a_0+\Omega(z_1^0)+\theta\lambda_1\big)-d\big(a_0+\Omega(z_2^0)+\theta\lambda_2\big)\big]^2+$$
$$+\big[2b\big(a_0+\Omega(z_2^0)+\theta\lambda_2\big)-d\big(a_0+\Omega(z_1^0)+\theta\lambda_1\big)\big]^2\Big)-\frac{\beta\big(E(\lambda_1)^2+E(\lambda_2)^2\big)}{2}.$$

In stage 1, the outcomes of the R&D programs are still uncertain. Therefore, the equilibrium in expected R&D outcomes is obtained as follows. *F*irm 1 maximizes the expected value of the joint profits, $E(\Pi_1+\Pi_2)$, with respect to $E(\lambda_1)$, taking $E^*(\lambda_2)$ as given. Firm 2 maximizes $E(\Pi_1 + \Pi_2)$ under similar assumptions. It is straightforward to show that there exists a unique solution satisfying $\partial[E(\Pi_1+\Pi_2)]/\partial E(\lambda_i) = 0$, for which

(15) $$E^*(\lambda_i^C)=\frac{2b\theta}{A_1^C A_2^C}B_i^C,\ i=1,2,$$ where

(16) $$A_1^C\equiv\beta(2b-d)^2-2b\theta^2,\ A_2^C\equiv\beta(2b+d)^2-2b\theta^2,$$

(17) $$B_i^C\equiv A_1^C a_0+[(A_1^C+A_2^C)/2]\Omega(z_i^0)-[(A_1^C-A_2^C)/2]\Omega(z_j^0),\ j\neq i,\ i=1,2.$$

The second-order conditions for profit maximization require $2b\theta^2(4b^2+d^2)/(4b^2-d^2)^2<\beta$.

R&D Joint Venture (denoted by **JV**)**.** As in case C, the firms maximize their joint profits in the first stage, but contrary to cases N and C, they conduct their R&D activities jointly. Thus, market equilibrium is obtained in the following two-stage game:

Stage 1: The two firms form an R&D joint venture and jointly choose the single R&D program {$E(\lambda)$ and $V(\lambda)$} that maximizes their expected joint profits, $E(\Pi_i + \Pi_j)$.

Stage 2: Each firm chooses the output that maximizes its operating profits, π_i, taking the rival's output and the outcome of the R&D program (which was completed in stage 1) as given.

The solution to the two-stage game starts by first solving the optimal outputs in stage 2. Again, cooperation in R&D affects the second-stage solution only through the firms' optimal R&D decisions. Therefore, the optimal second-stage solution is given by (8). Since the firms choose a single R&D program, λ substitutes for λ_1 and λ_2. The joint profits of firms 1 and 2 are given by:

(18)
$$\Pi_1(\lambda)+\Pi_2(\lambda)=(\pi_1+\pi_2)-Cost(R\&D)=$$
$$=\frac{b}{[4b^2-d^2]^2}\Big(\big[2b\big(a_0+\Omega(z_1^0)+\theta\lambda\big)-d\big(a_0+\Omega(z_2^0)+\theta\lambda\big)\big]^2+$$
$$+\big[2b\big(a_0+\Omega(z_2^0)+\theta\lambda\big)-d\big(a_0+\Omega(z_1^0)+\theta\lambda\big)\big]^2\Big)-\frac{\beta E(\lambda)^2}{2}.$$

In stage 1, the outcome of the R&D program is still uncertain. Therefore, the optimal expected R&D outcome is chosen to maximize the expected value of the firms' joint profits, $E(\Pi_1 + \Pi_2)$. Taking the expected value of $\Pi_1 + \Pi_2$ with respect to λ, it is straightforward to show that there exists a unique solution satisfying $\partial[E(\Pi_1+\Pi_2)]/\partial E(\lambda) = 0$:

(19) $$E^*(\lambda^{JV})=\frac{2b\theta}{A^{JV}}[2a_0+S^0(1+\omega)],$$ where

(20) $$A^{JV} \equiv \beta(2b+d)^2 - 4b\theta^2 .$$

The second-order condition for profit maximization requires $4b\theta^2/(2b+d)^2 < \beta$.

3 COMPARISON OF MODELS

Given the results in Section 2, we compare the industry's levels of optimal expected R&D outcomes, outputs, profits and social welfare for the three models (cases).[7]

3.1 Industry's aggregate level of expected outcomes

Proposition 1.[8]

Cases **N** and **C**: $E^*(\lambda_1^N)+E^*(\lambda_2^N) > E^*(\lambda_1^C)+E^*(\lambda_2^C)$.

Cases **N** and **JV**: $E^*(\lambda_1^N)+E^*(\lambda_2^N) < E^*(\lambda^{JV})$ for any $4b\theta^2/(2b+d)^2 < \beta < 4b^2\theta^2/[d(2b+d)^2]$ (when $0 < d/b < \sqrt{2}(\sqrt{2}-1)$) or $8b^3\theta^2/(4b^2-d^2)^2 < \beta < 4b^2\theta^2/[d(2b+d)^2]$ (when $\sqrt{2}(\sqrt{2}-1) \le d/b < (3-\sqrt{5})$).

$E^*(\lambda_1^N)+E^*(\lambda_2^N) > E^*(\lambda^{JV})$ for any $\beta > 4b^2\theta^2/[d(2b+d)^2]$ (when $0 < d/b < (3-\sqrt{5})$), or $\beta > 8b^3\theta^2/(4b^2-d^2)^2$ (when $(3-\sqrt{5}) \le d/b < 1$).

Cases **C** and **JV**: $E^*(\lambda_1^C)+E^*(\lambda_2^C) < E^*(\lambda^{JV})$.

To better understand the ways in which the different forms of cooperation in R&D affect the industry's level of R&D investments, consider the "symmetric" case (which in our model can be obtained by setting either $\omega = 1$, i.e. the size of the firm's network includes the installed bases of both firms, or $\eta = 0.5$, i.e. the firms have the same installed bases). Figure 1 presents the industry's aggregate levels of expected R&D outcomes for the three cases described in Section 2 (**N**, **C**, **JV**) as functions of the substitution effect, d/b.[9]

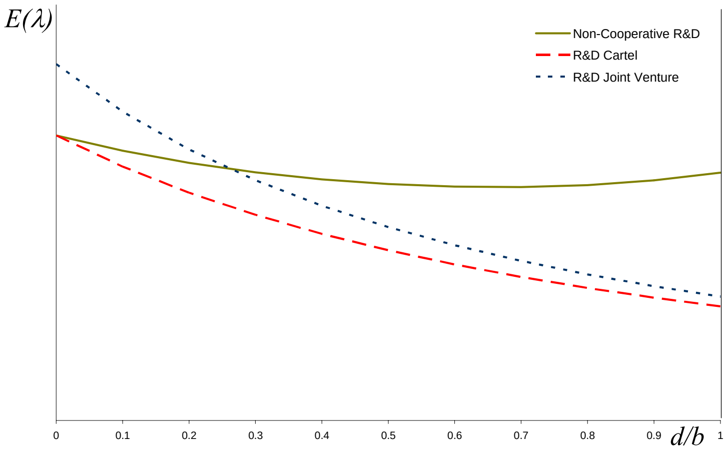

Figure 1. The industry's aggregate levels of expected R&D outcomes.

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[7] Note that the comparison for each pair of market structures (non-cooperation vs. R&D cartel; non-cooperation vs. joint venture; R&D cartel vs. joint venture) is done on a somewhat different region (since the regions in which such a comparison is meaningful are different across the three pairs of market structures being compared).
[8] The proof, omitted here for brevity, is available from the authors upon request.
[9] This example employs the following parameter values: $a_0 = S^0 = 300$, $\theta = 1$, $\beta = 0.3$.

Figure 1 demonstrates that the two firms may use the cooperative arrangement (R&D joint venture or cartelization) to restrict their R&D levels when product-market competition (measured by the size of the substitution effect, *d/b*; see, Tirole, 1988) is intense, and to increase their R&D levels when product-market competition is weak (i.e. the substitution effect is small). This result corroborates much of the theoretical literature (see, for example, Katz, 1986). Non-cooperation in R&D raises the industry's aggregate level of R&D investments if the intensity of the product-market competition is substantial (i.e. for $2/3 < d/b < 1$). For example, Suzumura (1992) found the R&D level to be *socially excessive* at the margin in a non-cooperative game and *socially too small* at the margin in an R&D cartel. We find here that an R&D joint venture may result in a welfare-improving level of R&D investment (larger than that of the R&D cartel but smaller than that of non-cooperative R&D).

3.2 Industry's aggregate level of expected outputs

Proposition 2. [10]

Cases **N** and **C**: $E(q_1^{N*}) + E(q_2^{N*}) > E(q_1^{C*}) + E(q_2^{C*})$.

Cases **N** and **JV**: $E(q_1^{N*}) + E(q_2^{N*}) < E(q_1^{JV*}) + E(q_2^{JV*})$.

Cases **C** and **JV**: $E(q_1^{C*}) + E(q_2^{C*}) < E(q_1^{JV*}) + E(q_2^{JV*})$.

Using the "symmetric" example presented above, we demonstrate the effects of the different forms of cooperation in R&D on the industry's level of expected outputs.[11] Figure 2 exhibits the industry's aggregate levels of expected outputs in the different cases as functions of the substitution effect, *d/b*.

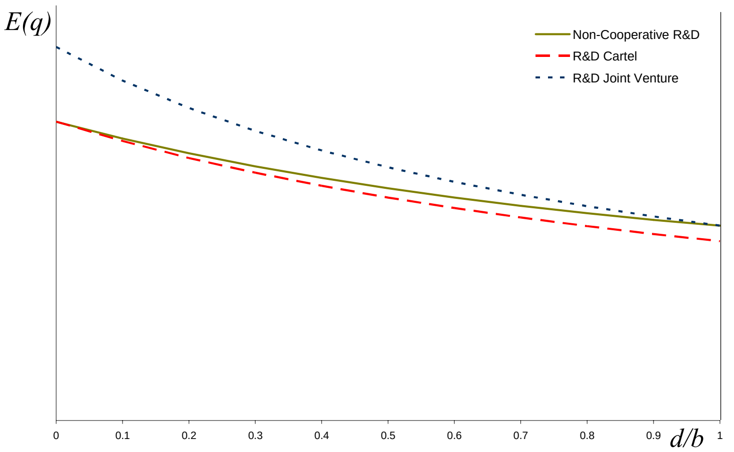

Figure 2. The industry's aggregate levels of expected outputs.

Clearly, the industry's aggregate level of expected outputs is highest if the two firms form an R&D joint venture.

Combining the results of Sections 3.1 and 3.2 shows that a higher industry level of R&D investments leads to higher industry production under cooperation in R&D (in any form). However, under non-cooperation in R&D, the industry's level of R&D investments increases, while its level of outputs decreases as the intensity of the product-market competition increases, provided this intensity is already significant ($2/3 < d/b < 1$). Therefore, if the firms do not cooperate, their R&D efforts are ineffective when the competition in the market is intense, since an increase in R&D spending does not result in an increase in output.

[10] The proof, omitted here for brevity, is available from the authors upon request.
[11] Proposition 2 generalizes this example to the full range of the possible parameter values.

3.3 Industry's aggregate level of expected profits

Proposition 3.[12]

Cases **N** and **C**: $E^*(\Pi_1^N)+E^*(\Pi_2^N)<E^*(\Pi_1^C+\Pi_2^C)$.

Cases **N** and **JV**: $E^*(\Pi_1^N)+E^*(\Pi_2^N)<E^*(\Pi_1^{JV}+\Pi_2^{JV})$.

Cases **C** and **JV**: At the optimal solution, $E^*(\Pi_1^C+\Pi_2^C)<E^*(\Pi_1^{JV}+\Pi_2^{JV})$.

Figure 3 presents the industry's aggregate levels of expected profits in the different cases (**N**, **C**, **JV**) as functions of the substitution effect, *d/b*, using the "symmetric" case presented in Section 3.1.

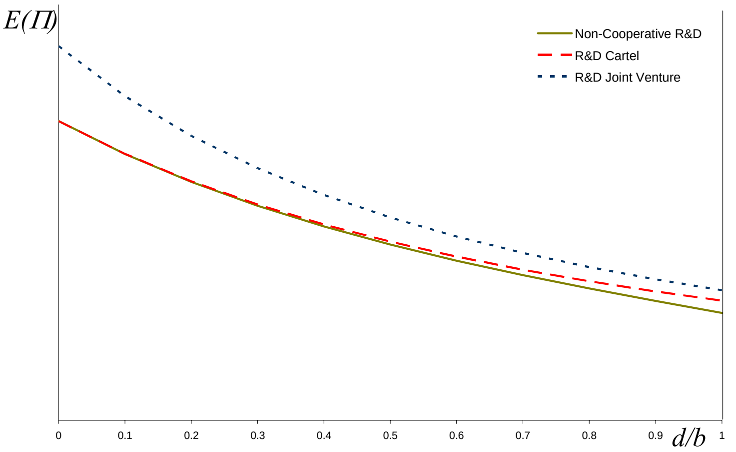

Figure 3. The industry's aggregate levels of expected profits.

Clearly, expected profits are higher under cooperation. That is, the private incentives to cooperate in R&D (in any form) are sufficient when the products of the two firms are fully compatible or they both have the same installed bases. Furthermore, an R&D joint venture is always the preferable form of cooperation (this result can be shown to hold for the general case, that is, $\omega \neq 1$ and $\eta \neq 0.5$).

Combining the results of Sections 3.1-3.3 shows that a higher industry level of R&D investments leads to a higher industry level of profits under cooperation in R&D (in any form) when the products of the two firms are fully compatible or they both have the same installed bases. However, in the case of non-cooperation in R&D, the industry's level of R&D investments increases, while its level of profits decreases as the intensity of product-market competition increases, provided this intensity is already significant ($2/3 < d/b < 1$).

3.4 Expected level of social welfare

Social welfare equals consumer surplus plus the two firms' profits. Given the firms' inverse demand functions in (1), the expected level of social welfare at the optimal first-stage solution is given by

$$E(SW)=\int_0^{E(q_1^*)}\left(a_0+\Omega(z_1^0)+\theta E^*(\lambda_1)-bx-dE(q_2^*)\right)dx+\int_0^{E(q_2^*)}\left(a_0+\Omega(z_2^0)+\theta E^*(\lambda_2)-bx-dE(q_1^*)\right)dx-$$
$$-Cost(R\&D)_1-Cost(R\&D)_2=$$

[12] Here we compare the industry's aggregate levels of profits for the "symmetric" case. The proofs of the general and "symmetric" cases are available from the authors upon request.

(21) $$= E^*(\Pi_1) + E^*(\Pi_2) + \frac{b}{2}E(q_1^*)^2 + \frac{b}{2}E(q_2^*)^2 .$$

Substituting the models' outcomes (i.e. the optimal expected levels of the firms' profits and outputs) into (21) yields the expected levels of social welfare. Proposition 4 compares the social welfare across the three models (**N**, **C**, **JV**) for the "symmetric" case, i.e. when the network effect on the firm's inverse demand function is the same for both firms ($\omega = 1$ or $\eta = 0.5$). In this case the firms' private incentives to cooperate in R&D are sufficient, and an R&D joint venture is the preferred form of cooperation, from the firms' point of view, as shown in Section 3.3.

Proposition 4. [13]

Cases **N** and **C**: $E(SW^N) > E(SW^C)$ for any $\beta > 2b\theta^2(4b^2 + d^2)/(4b^2 - d^2)^2$ (when $0 < d/b < 2\sqrt{3}(2-\sqrt{3})$) and $\beta > b\theta^2(4b - 3d)/[2(2b+d)^2(b-d)]$ (when $2\sqrt{3}(2-\sqrt{3}) \le d/b < 1$).

$E(SW^N) < E(SW^C)$ for any $2b\theta^2(4b^2 + d^2)/(4b^2 - d^2)^2 < \beta < b\theta^2(4b - 3d)/[2(2b+d)^2(b-d)]$ (when $2\sqrt{3}(2-\sqrt{3}) \le d/b < 1$).

Cases **N** and **JV**: $E(SW^N) < E(SW^{JV})$.

Cases **C** and **JV**: $E(SW^C) < E(SW^{JV})$.

Figure 4 presents the expected levels of social welfare in the different cases as functions of the substitution effect, *d/b*, using the "symmetric" case presented in Section 3.1.

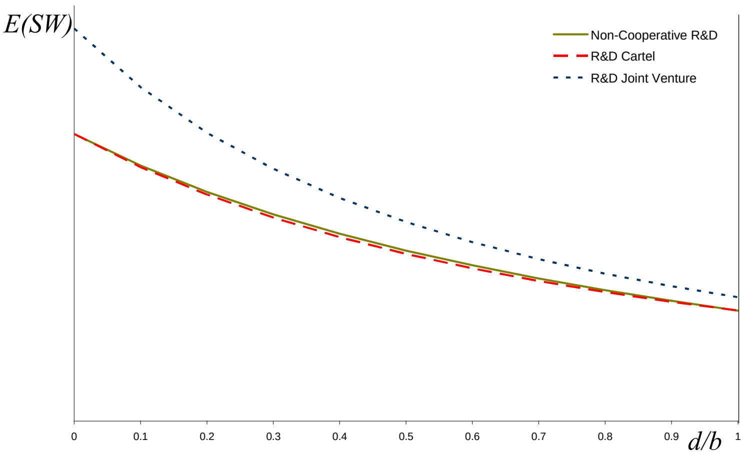

Figure 4. Expected social welfare.

Clearly, the R&D joint venture dominates the other two models, as it yields the highest firm profits <u>and</u> social welfare, when the products of the two firms are fully compatible or they both have the same installed bases.[14] An R&D cartel is the least desirable of the three models. The results presented here and in Section 3.1 also imply that the industry's level of R&D investments under non-cooperation in R&D is socially excessive, since the highest industry R&D investments lead to the lowest producer profits and social welfare when product-market competition is very intense.

[13] The proof, omitted here for brevity, is available from the authors upon request.
[14] Note, however, that this result need not always hold for a non-symmetric case. It is possible to construct examples, albeit for extreme values of the parameters, in which a joint venture is not the socially preferred strategy.

4 CONCLUSIONS

The firms may use the cooperative arrangement (R&D joint venture or cartelization) to restrict their R&D levels when product-market competition (measured by the size of the substitution effect) is intense, and to increase their R&D levels when product-market competition is weak (i.e. the substitution effect is small). Non-cooperation in R&D raises the industry's aggregate level of R&D investments if the intensity of the product-market competition is substantial. Furthermore, a higher industry level of R&D investments leads to higher industry production under cooperation in R&D (in any form). However, under non-cooperation in R&D, the industry's level of R&D investments increases, while its level of outputs decreases as the intensity of the product-market competition increases, provided this intensity is already significant. Therefore, if the firms do not cooperate, their R&D efforts are ineffective when the competition in the market is intense, since an increase in R&D spending does not result in an increase in output. For example, Suzumura (1992) found the R&D level to be *socially excessive* at the margin in a non-cooperative game and *socially too small* at the margin in an R&D cartel. We find here that an R&D joint venture may result in higher profits and a welfare-improving level of R&D investment (larger than that of the R&D cartel but smaller than that of non-cooperative R&D). This last result is very relevant for the STI joint venture discussed above.

In the case of fully compatible products, we show that an R&D joint venture leads to higher industry profits and social welfare. However, the *lower* the degree of compatibility, the more likely it is that the profits of the two firms will be *higher* if they do not cooperate in R&D, when the cost of R&D programs is relatively high and the firms' installed bases are very different. This result emphasizes the additional advantage of cooperation in R&D in markets with network externalities; firms may need to form an R&D joint venture in order to establish market standards and create a single network of compatible products (see Farrell and Saloner 1988). Thus, comparing two markets with similar high levels of product-market competition, but with *different degrees of compatibility* between products, it is more likely that the firms will choose to cooperate in R&D when the products are close to being fully compatible, and they will choose not to cooperate when the degree of compatibility is low.

On the other hand, if there are two independent markets for products that are close to being fully compatible, it is more likely that the firms in these markets will conduct R&D cooperatively. Katz (1986) observed that when the product markets are independent, cooperation raises welfare whenever some sharing of R&D is feasible. In our models, sharing of R&D is certainly feasible since cooperation in R&D enhances compatibility of the firms' products. Confirming Katz's findings, we show that an R&D joint venture formed by the producers of independent products is *socially desirable*.

Our results suggest that an R&D joint venture dominates an R&D cartel, as it yields higher firm profits and social welfare.[15] The intuitive reason is that an R&D cartel does not allow sharing either R&D costs or R&D outcomes. Furthermore, an R&D joint venture dominates non-cooperation in R&D and the R&D cartel, since it yields the highest firm profits and social welfare when the products of the two firms are fully compatible or they both have the same installed bases. Therefore, a regulator may tolerate, or even encourage, the formation of R&D joint ventures in markets that accord with our suppositions.

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[15] In the R&D literature, an R&D cartel is the most common form of cooperation in R&D.

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