

# Are Cooperative R&D Agreements Good For The Society?

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## ABSTRACT

*Technological progress is crucial for economic growth and enhancement of standard of living in any economy. But firms often have insufficient incentive for R&D, because in spite of patent protection, the benefits of R&D are not always limited to the firms that initially conduct the R&D activities. Consequently, governments around the world often undertake industrial policies to promote collaborative R&D efforts between firms in order to increase R&D. This paper examines the implications of cooperative R&D agreements for the societal well being. The R&D and price decisions are analyzed using a Bertrand Duopoly Model in presence of product differentiation in a two-stage game. It is shown that under cooperative R&D agreements R&D and output levels are larger and prices are lower than under non-cooperation. For complementary and independent goods, these results are valid for any degree of R&D spillover and for substitute goods they may hold even for sufficiently small R&D spillover. These results are more general than D'Aspremont and Jacquemin (1988) who have shown that cooperative R&D levels exceed those under non-cooperation only for large R&D spillover. As for the level of social welfare, this paper finds the cooperative as well as the non-cooperative R&D output and price levels to be socially inefficient. However, cooperative R&D agreements tend to dominate non-cooperative R&D ventures in terms of social welfare. This result also holds for any degree of R&D spillover for complementary and independent goods and even for sufficiently small spillover in the case of substitute goods.*

**Keywords:** Cooperative R&D Agreements; Social Welfare; Bertrand Duopoly Model; Two Stage Game

## 1. INTRODUCTION

Importance of R&D efforts for the growing prosperity of a firm and an industry as well as for the aggregate economic growth can hardly be overstated. For the U.S., some econometric studies have established the "direct returns" to R&D (accruing to the firm or the industry undertaking the R&D activities) to be at par with returns to other investment. Still there may be insufficient incentive on the part of the firms to engage in R&D activities. In the U.S., for example, only 2 to 3% of GDP is invested in R&D.<sup>1</sup> This lack of private incentive lies in the partial non-excludability of the outcome of R&D. The benefits of R&D are not always limited to the firms that initially conduct the R&D activities. Frequently, a research yields a scientific knowledge whose potential uses may well surpass the applications of the specific firms. Furthermore, as Tyson (1990) notes, "Often, even with effective patent protection, competitors are able to copy or reverse - engineer a private innovation."

Such partial non-excludability of R&D outcomes generates technological spillovers. These spillover benefits are not limited to specific industries where R&D efforts are originally undertaken but spread across industry boundaries. Consequently, firms may lack incentive to engage in R&D activities since they do not receive any payment by other firms that benefit from their R&D and nor can they often prevent other firms from using the knowledge generated by their R&D.

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<sup>1</sup> See Grossman and Helpman (1991) and the Congressional Budget Office report (2005) for detailed discussions.

In view of the importance of R&D activities, it is not surprising that public policies may be designed to restore the private incentive for R&D efforts. Encouragement of cooperative R&D ventures between firms (as in Japan and Europe) and consequent liberalization of anti-trust measures are frequently advocated. In the U.S. the National Cooperative Research Act of 1984 is also designed to encourage firms to undertake cooperative R&D ventures. As Schacht (2012) notes: “The government has supported various efforts to promote cooperative research and development activities ...designed to increase the competitiveness of American industry and to encourage the generation of new products, processes, and services.”

However, the case for cooperative R&D ventures in restoring the private incentive for R&D may not be very straightforward. It has been argued, for example, that cooperative R&D agreements between firms may actually lead to a reduction in R&D levels by eliminating wasteful duplication of efforts (Katz (1986). Considering a Cournot duopoly producing a homogeneous good, where the cost-reducing R&D projects of one firm bring about cost reduction for the other firm, D’Aspremont and Jacquemin (1988) have, however, shown, inter alia, for large R&D spillover cooperative R&D agreements indeed lead to larger R&D levels. They have also demonstrated that both cooperative and non-cooperative R&D levels are ‘socially inefficient’.

Since R&D cooperation can take place between firms across many different industries, it is particularly important to analyze cooperative (and non-cooperative) R&D agreements between firms in presence of product differentiation; i.e., when the outputs of the firms may be substitutes, complements or independent goods. As Kodama (1992) points out, “...collective research in Japan is beginning to bring together companies from different industries rather than different companies within the same industry.” Kodama further notes that, in Japan, “In 1988, for instance, there were 27 cases of collective research in which just 1 of the 5 rival computer makers – Toshiba, Hitachi, Fujitsu, Mitsubishi, and NEC – took part with other industries;... Earlier in the decade, a typical joint research project would have included all 5-computer makers working together on an industry-specific problem. The same diversification trend is observable in other industries” as well.

In this paper cooperative and non-cooperative R&D efforts are viewed as strategic investments for “Bertrand” firms that compete by setting prices. Specifically, the behaviors of the firms are analyzed using a two-stage game. In the first stage, firms choose their own R&D levels. In the second stage firms choose the price levels. Taking the R&D levels as given, we first determine the Nash equilibrium in the second stage. Using the second stage solution the profits of the preceding stage are expressed in terms of the R&D levels. A Nash equilibrium for the first stage is then determined. This gives rise to a subgame perfect equilibrium in the two-stage game. In this paper such subgame perfect equilibrium under cooperative and non-cooperative R&D agreements, are characterized.

The plan of the paper is as follows. In the next section we determine the strategic cooperative and non-cooperative equilibrium R&D, output and price levels. It is shown that the R&D and output levels are larger and the prices are lower under R&D cooperation than under non-cooperation. For complementary and independent goods, these results are valid for any degree of R&D spillover and may hold even for sufficiently small R&D spillover with substitute goods. Turning to the welfare implications of R&D cooperation in Section 3, we show that cooperative as well as non-cooperative levels of R&D, outputs and prices are socially inefficient. However, in terms of social welfare the cooperative R&D agreements dominate the non-cooperative arrangements.

## **2. R&D COOPERATION AND NONCOOPERATION IN DIFFERENTIATED BERTRAND DUOPOLY**

Consider an industry with two firms producing differentiated goods. In order to obtain closed form solutions, we consider the following parameterization of the inverse demand function for the  $i^{\text{th}}$  firm:

$$p_i = \alpha - \beta x_i - \tau x_j \quad \alpha, \beta > 0 \quad i, j = 1, 2 \quad i \neq j \tag{1}$$

$x_i$  denotes the level of output produced by the  $i^{\text{th}}$  firm and  $p_i$  the corresponding price.

$\tau \begin{matrix} \geq \\ < \end{matrix} 0$  according as the goods are substitutes, independent or complements. It is further assumed<sup>2</sup> that  $\beta > |\tau|$ . The assumed symmetry of the demand functions adds to computational simplicity without sacrificing generality. This demand structure, except for the assumed symmetry, is used by Dixit (1979), Singh and Vives (1985) among others. Shubik and Levitan (1980) use a slightly different symmetric model.<sup>3</sup> We assume that firms behave as Bertrand duopolists and compete with each other by setting prices. The direct demand function corresponding to the above inverse demand function is given by:

$$x_i = a - bp_i + cp_j \quad i, j = 1, 2, i \neq j \tag{2}$$

where:

$$a = \frac{\alpha}{\beta + \tau} > 0, \quad b = \frac{\beta}{\beta^2 - \tau^2} > 0, \quad c = \frac{\tau}{\beta^2 - \tau^2}$$

$c \begin{matrix} > \\ < \end{matrix} 0$ , according as the goods are substitutes, independent or complements. Also, we make the reasonable assumption that the direct effect of a price change on demand is stronger than the cross effect; i.e.,  $b > c$ , which also follows from  $\beta > |\tau|$ .

As in D’Aspremont and Jacquemin, we assume a linear cost structure:

$$C_i(x_i, y_i, y_j) = [A - y_i - \theta y_j] x_i \quad \alpha > A, 0 < \theta < 1, i, j = 1, 2, i \neq j \tag{3}$$

Firm i’s R&D activity lowers its unit cost of production. But as postulated by Hartwick (1984), firm i can also imitate the invention of firm j at a cost lower than what would be required to spend in order to invent the new process by itself. Thus firm j’s R&D activity also lowers the unit cost of production for firm i.  $\theta$  measures the extent of such R&D spillover from one firm to the other. The direct cost of R&D for the i<sup>th</sup> firm is given by:

$$g_i(y_i) = \frac{\epsilon y_i^2}{2}, \quad \epsilon > 0, i = 1, 2. \tag{4}$$

The profit function for the i<sup>th</sup> Bertrand duopolist can now be written as:

$$\bar{\pi}_i = [a - bp_i + cp_j]p_i - [A - y_i - \theta y_j][a - bp_i + cp_j] - \frac{\epsilon y_i^2}{2} \quad i, j = 1, 2 \quad i \neq j \tag{5}$$

The strategic behavior of the firms is analyzed in terms of a two-stage game. In the first stage, each firm decides its own R&D level. In the second stage, given the R&D levels, each firm chooses their prices. Two types of strategic R&D decisions are considered. First, we consider a non-cooperative (strategic) R&D decision where

2 Note that  $\beta = \tau > 0$  implies that the goods are homogeneous. As it has been pointed out in Singh and Vives for  $\beta = \tau$  the demand system may not be well defined.

3 The underlying utility function that generates this demand structure is similar to the one suggested by Dixit (1979). It is assumed that in the economy there is a monopolistic sector with two firms producing differentiated goods  $x_1$  and  $x_2$  (with prices  $p_1$   $p_2$ ) and a competitive numeraire sector whose output is  $m$ . The utility function of the representative consumer is separable and linear in  $m$ . Thus the demand structure of (1) arises out of the utility function:  $U = m + \alpha(x_1 + x_2) - \frac{1}{2}(\beta x_1^2 + 2\tau x_1 x_2 + \beta x_2^2)$ .

each firm independently decides its own R&D level in the first stage of the game. We also consider a cooperative (strategic) R&D decision where the firms cooperate in their R&D decision stage to maximize their joint profit.

In the non-cooperative game, using the relevant first order conditions we first determine the equilibrium pricing strategy for given R&D levels,  $y_1$  and  $y_2$ :

$$p_i^B = \frac{1}{\Omega} [K - b(2b + c\theta)y_i - b(2b\theta + c)y_j] \quad i, j = 1, 2 \quad i \neq j$$

where:  $\Omega = 4b^2 - c^2 > 0$  and  $K = (a + bA)(2b + c)$  (6)

Substituting the pricing strategy of (6) in (5), the profits at the preceding stage can be determined to be:

$$\pi_i^* = \frac{b}{\Omega^2} \left[ (K - A\Omega) + (2b^2 - c^2 - bc\theta)y_i + (2b^2\theta - bc - c^2\theta)y_j \right]^2 - \frac{\varepsilon y_i^2}{2} \quad i, j = 1, 2 \quad i \neq j$$
 (7)

Maximizing the profit level by choosing  $y_1$  and  $y_2$  we calculate the equilibrium non-cooperative R&D and price levels as:

$$y_i^{B*} = \frac{(K - A\Omega)(2b^2 - c^2 - bc\theta)}{\left(\frac{\Omega^2 \varepsilon}{2b}\right) - (2b^2 - c^2 - bc\theta)(2b^2 - c^2 - bc)(1 + \theta)} \quad i = 1, 2$$
 (8)

$$p_i^{B*} = \frac{1}{\Omega} \left[ K - \frac{(K - A\Omega)(2b^2 + bc)(2b^2 - c^2 - bc\theta)(1 + \theta)}{\left(\frac{\Omega^2 \varepsilon}{2b}\right) - (2b^2 - c^2 - bc\theta)(2b^2 - c^2 - bc)(1 + \theta)} \right] \quad i = 1, 2$$
 (9)

As for the cooperative R&D agreements, in the first stage of the game the firms choose the R&D levels so that the joint profit,  $\hat{\pi} (= \frac{\pi_1^*}{\pi_1} + \frac{\pi_2^*}{\pi_2})$  is maximized. The equilibrium cooperative R&D and price levels can thus be found to be:

$$\hat{y}_i^B = \frac{(K - A\Omega)(2b^2 - bc - c^2)(1 + \theta)}{\left(\frac{\Omega^2 \varepsilon}{2b}\right) - (2b^2 - bc - c^2)^2(1 + \theta)^2} \quad i = 1, 2$$
 (10)

$$\hat{p}_i^B = \frac{1}{\Omega} \left[ K - \frac{(K - A\Omega)(2b^2 + bc)(2b^2 - bc - c^2)(1 + \theta)^2}{\left(\frac{\Omega^2 \varepsilon}{2b}\right) - (2b^2 - bc - c^2)^2(1 + \theta)^2} \right] \quad i = 1, 2$$
 (11)

The levels of R&D, price, and output for the non-cooperative and cooperative agreements can now be compared. Theorem 1 summarizes the results.

**Theorem 1:**

(i) If the goods are either complementary or independent, the R&D levels under cooperative agreements exceed those under non-cooperation, regardless of the extent of R&D spillover; if the goods are substitutes then even for sufficiently small spillover, the cooperative R&D levels may exceed the non-cooperative R&D levels provided  $\theta > \frac{bc}{2b^2 - c^2}$ ; (ii) under the same conditions as in (i) the prices under cooperation are less than those under non cooperation; (iii) under the same conditions as in (i) the output levels under cooperation exceed those under non- cooperation.

**Proof:**

(i) From (8) and (10)

$$\hat{y}_i^B > y_i^{B*}, \quad i = 1, 2$$

if  $(2b^2 - bc - c^2)(1 + \theta) > (2b^2 - c^2 - bc\theta)$

or, if  $\theta > \frac{bc}{2b^2 - c^2}$

The assertions follow immediately by noting that  $c \begin{matrix} < \\ = \\ > \end{matrix} 0$  according as the goods are complementary, independent or substitutes and  $b > c/$ .

(ii) Follows from the proof of (i) and direct comparison of (9) and (11).

(iii) Using the proof of (ii) and noting the symmetry of (9) and (11) we can determine the output levels under non-cooperation and cooperative arrangements as

$$x_i^{B*} = a - (b - c)p_i^{B*} \quad i = 1, 2 \tag{12}$$

$$\hat{x}_i^B = a - (b - c)\hat{p}_i^B \quad i = 1, 2 \tag{13}$$

The assertion in (iii) follows from direct comparison of (12) and (13).

**3. WELFARE IMPLICATIONS**

In this section we discuss the welfare implications of the cooperative and non-cooperative R&D arrangements. For the welfare analysis, following Singh and Vives and D'aspremont and Jacquemin, we define social welfare  $W$  as the sum of total producer surplus and consumer surplus. Since all the equilibria that have been determined so far are symmetric.

$$p_i = p_j = p, \quad x_i = x_j = x, \quad y_i = y_j = y \quad i, j = 1, 2, i \neq j$$

Consequently the social welfare function can be written as:

$$w = 2(\alpha - A)x - (\beta + \tau)x^2 + 2(1 + \theta)xy - \varepsilon y^2 \tag{14}$$

The efficient individual R&D and output can be calculated as:

$$y^{**} = \frac{(\alpha - A)(1 + \theta)}{(\beta + \tau)\varepsilon - (1 + \theta)^2} \tag{15}$$

$$x^{**} = \frac{1}{(\beta + \tau)} [(\alpha - A) + (1 + \theta)y^{**}] = \frac{(\alpha - A)\varepsilon}{(\beta + \tau)\varepsilon - (1 + \theta)^2} \tag{16}$$

The corresponding efficient price level  $P^{**}$  is determined to be

$$p^{**} = A - \left[ \frac{(\alpha - A)(1 + \theta)^2}{(\beta + \tau)\varepsilon - (1 + \theta)^2} \right] \tag{17}$$

The efficient levels of R&D, output and price obtained above provide the benchmarks for evaluating efficiency of cooperative and non-cooperative R&D arrangements. Theorem 2 shows that when measured against these benchmarks, cooperative R&D agreements, although not socially efficient, turn out to be relatively more efficient than non-cooperative R&D.

**Theorem 2:**

(i)  $y^{**} > \hat{y}^B > y^{B*}$ , (ii)  $x^{**} > \hat{x}^B > x^{B*}$ , and (iii)  $p^{**} < \hat{p}^B < p^{B*}$ . The first set of inequalities in (i), (ii), and (iii) holds for any degree of R&D spillover regardless whether the goods are substitutes, complementary or independent while the second set of inequalities holds for any degree of R&D spillover if the goods are either complementary or independent and even for sufficiently small spillover with  $\theta > \frac{bc}{2b^2 - c^2}$  (or, equivalently,

$$\theta > \left[ \frac{\tau}{2\beta - \frac{\tau^2}{\beta}} \right] \text{) in the case of substitute goods.}$$

**Proof:**

(i) The cooperative Bertrand R&D level in (10) can be simplified to be:

$$\hat{y}^B = \frac{(\alpha - A)(1 + \theta)}{\frac{(2\beta - \tau)^2(\beta + \tau)}{2\beta(\beta - \tau)}\varepsilon - (1 + \theta)^2} \tag{18}$$

Comparing (18) with (15) one can conclude that:

$$y^{**} > \hat{y}^B$$

if  $(\beta - \tau)^2 + \beta^2 > 0$

which is true for any value of  $\tau$  and independent of  $\theta$ . Also, by Theorem 1,  $\hat{y}^B > y^{B^*}$  for any degree of R&D spillover if the goods are complementary or independent and even for sufficiently small spillover with  $\theta > \frac{b^c}{2b^2 - c^2}$  or equivalently with  $\theta > \frac{\tau}{\left[2\beta - \frac{\tau^2}{\beta}\right]}$ .

(ii) Note that using (10) and (11), the cooperative output can be expressed as:

$$\hat{x}^B = \frac{\beta}{(\beta + \tau)(2\beta - \tau)} \left[ (\alpha - A) + (1 + \theta)\hat{y}^B \right] \tag{19}$$

In view of (15), (16) and (i) above,  $x^{**} > \hat{x}^B$

if  $(\beta - \tau) > 0$

which is true for any value of  $\tau$  and independent of  $\theta$ . Also, by Theorem 1, under the conditions specified in (i)  $\hat{x}^B > x^{B^*}$ .

(iii) Follows from (9), (11), (17), (ii) above, and Theorem 1.

In Japan and Europe firms for long have enjoyed a relaxed treatment of collaborative R&D ventures. Recently, also in the U.S. a number of public policy measures have been taken to encourage firms to undertake cooperative R&D ventures. The National Cooperative Research Act of 1984 is one such policy measure. In view of Theorem 2 one can now make a case for encouraging cooperative R&D ventures. The result is summarized in Theorem 3.

**Theorem 3:**

In terms of social welfare (measured as the sum of consumer's surplus and producer's surplus) cooperative R&D agreements dominate the respective non-cooperative R&D ventures when the goods are either complements or independent. For substitute goods the same result holds even for sufficiently small R&D spillover with:

$$\theta > \frac{\tau}{\left(2\beta - \frac{\tau^2}{\beta}\right)}$$

**Proof:**

Follows from Theorem 2 and the social welfare function in (14).

It may seem counter-intuitive that the collusive R&D agreements between firms may lead to more favorable levels of R&D, output, price, and finally final social welfare, as compared with non-cooperative, purely competitive R&D decisions, but the benefits of cooperative R&D decisions result from R&D spillovers, which act as positive externalities and lower costs of other firms. Cooperative R&D agreements help internalize these externalities and thus increase the levels of R&D, output and social welfare.

#### 4. CONCLUSIONS

In this paper we have examined the implications of cooperative R&D agreements in presence of product differentiation using a Bertrand duopoly model. The R&D and price decisions are analyzed using a two-stage game. It has been shown that under cooperative R&D agreements R&D and output levels are larger and prices are lower than under non-cooperation. For complementary and independent goods these results are valid for any degree of R&D spillover and may hold even for sufficiently small R&D spillover with substitute goods. These results are more general than D'Aspremont and Jacquemin who have shown that for a Cournot duopoly producing a homogeneous good, cooperative R&D levels exceeds those under non-cooperation only for large R&D spillover. These results also suggest that cooperation for developmental research that tends to have lower R&D spillover than basic research can also lead to increased R&D efforts.

As for social welfare, the cooperative as well as the non-cooperative R&D, output and price levels have been found to be socially inefficient. However, cooperative R&D agreements tend to dominate non-cooperative R&D ventures in terms of social welfare. The result holds for any degree of R&D spillover for complementary and independent goods and even for sufficiently small spillover in the case of substitute goods.

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**NOTES**