INNOVATION ACTIVITY IN A MIXED OLIGOPOLY: THE ROLE OF CO-OPERATIVES

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Abstract: This paper develops a sequential game theoretic model of heterogeneous producers to examine the effect of co-operative involvement on innovation activity in the agricultural input-supplying sector. Analytical results show that the co-operative involvement in R&D *can* be welfare enhancing and, thus, socially desirable. The presence of the co-op can increase the arrival rate of innovations and productivity growth while reducing the prices of agricultural inputs. The effectiveness of the co-op is determined by the size of R&D costs.

Innovation activity is a critical element of business conduct affecting the competitiveness of firms, the arrival rate of innovations in the economy, productivity growth and social welfare. The strategic interactions among innovating firms and their effect on innovating behavior have received considerable attention. In particular, the focus has been on R&D competition in a pure oligopoly (i.e., a small number of profit-maximizing, investor-owned firms (IOFs)), and the consequence of this competition for the structure of the market and the arrival rate of innovations. A key finding of studies on patent-races among IOFs is the so-called ε-preemption; an IOF that starts its innovation activity prior to its rivals (or an IOF that has been luckier in making an innovation) eventually becomes a monopolist (see Fudenberg et al; Grossman and Shapiro; Sutton; Delbono; Aoki; and Malueg and Tsutsui. For Schumpeterian models of innovation competition see Aghion and Howitt (1992, 1998); and Segerstrom, Avant, and Dinopoulos).

Despite the prevalence of mixed markets where co-operatives (co-ops) compete alongside IOFs, the effect of co-operative organizations on R&D activity has not been considered previously. Part of the reason for this lack of research is that co-ops have not traditionally played a major role in R&D activity. Indeed, the standard view has been that co-ops are largely concentrated in the vertical stages just before and just after the farm enterprise (Rogers and Marion). While co-ops are still largely concentrated near the farm gate, a number of them are taking steps to position themselves via their R&D activities. Important examples include Limagrain (Joly), Cebeco (Bijman and Joly), and Cosun (which owns 50% of Advanta; see Bijman) in Europe, while co-ops in the U.S. such as Ocean Spray have long been known for their R&D activity.

The objective of this paper is to examine the role of co-ops in innovation activity and determine the consequences of co-operative involvement for the arrival rate of innovations, the pricing behavior of oligopolists, and social welfare. Specifically, this paper examines the outcome of innovation competition in the context of a mixed duopoly where a co-op and an IOF compete in supplying an input (seed) to agricultural producers.

The strategic interaction between the co-op and the IOF is modeled as a three-period sequential game. In *period 1*, the two organizations make their R&D investment decisions that allow them to make process innovations and reduce their (marginal) cost of production. In *period 2*, the production costs are fixed and the two rivals engage in an intense price competition. Finally, in *period 3*, the agricultural producers make their purchasing decisions observing the prices of the two products. The case of a pure oligopoly is also analyzed and is used as a benchmark for determining the consequences of co-operative involvement in R&D.

To avoid Nash equilibria involving non-credible strategies, the different formulations of the game are solved using backward induction (Gibbons) – the problem of the farmers is considered first, the pricing behavior of the two input suppliers is analyzed next, and the solution to the R&D investment problem determines the subgame perfect equilibrium amount of R&D, pricing of agricultural inputs, and farmers’ purchasing decisions and welfare.

In addition to analyzing the role of co-ops in innovation activity, a distinct feature of this paper is that it relaxes the conventional assumption of producer homogeneity. Instead, farmers are postulated to differ in such things as the location and quality of land, education, experience, management skills, technology adopted etc. Farmer heterogeneity in terms of production factors is a key component in our model capturing the differences in the relative returns received by farmers from the use of the inputs supplied by the co-op and the IOF.

The rest of the paper is organized as follows. The next section presents a simple model of horizontal product differentiation where agricultural producers differ in the returns they receive from the use of inputs (e.g., seeds) sold by different agricultural input suppliers. The paper then analyzes price and innovation competition between two profit-maximizing input-supplying IOFs. The effect of co-operative involvement on innovation activity, the pricing of agricultural inputs and the welfare of the interest groups is examined before the concluding section of the paper.

Producer Decisions and Welfare

Consider a producer that is determining the input (seed) that will be used in his production process. As mentioned previously, farmers are assumed to differ in the returns they receive from using different inputs. Let $a \in [0, 1]$ denote the attribute that differentiates producers. A producer with attribute a has the following net returns function:

(1)

$$\Pi_I^F = p^F - \left(p_I^s + \lambda a\right) \qquad \text{If a unit of Supplier 1's seed is purchased}$$

$$\Pi_C^F = p^F - \left[p_C^s + \mu(1-a)\right] \qquad \text{If a unit of Supplier 2's seed is purchased}$$

where Π_I^F and Π_C^F are the net returns associated with unit output production using seed supplied by Supplier 1 and Supplier 2, respectively. The parameter p^F is the farm price (net of all production costs except for seed) for the output produced; p_I^s and p_C^s are the costs of the seeds supplied by Supplier 1 and Supplier 2, respectively; and λ and μ are non-negative agronomic factors associated with the use of seed supplied by Supplier 1 and Supplier 2, respectively. *Ceteris paribus*, the seed of Supplier 2 is more suitable to the production process of farmers with large values of the differentiating attribute *a* while producers with low values of *a* prefer utilizing seed of Supplier 1.

To allow for positive market shares of the two seeds, it is assumed that $\lambda \geq p_C^s - p_I^s$ and $\mu \geq p_I^s - p_C^s$ (see equations (3) and (4) below), while, to retain tractability of the model, the analysis assumes that producers are uniformly distributed between the polar values of *a*. The implications of relaxing this assumption to allow a concentration of producers at the ends of the spectrum (i.e., zero and one) are straightforward and are discussed throughout the text.

Each farmer produces one unit of the farm output and his input (seed) choice is determined by the relationship between Π_I^F and Π_C^F. Figure 1 illustrates the decisions and welfare of producers. The downward sloping curve graphs net returns when seed from Supplier 1 is used, while the upward sloping line shows the net returns when Supplier 2's seed is used for different levels of the differentiating attribute *a*. The intersection of the two net return curves determines the level of the differentiating attribute that corresponds to the indifferent producer. The producer with differentiating characteristic a_I^s given by:

$$(2) \qquad a_I^s : \Pi_I^F = \Pi_C^F \Rightarrow p^F - \left(p_I^s + \lambda a_I^s\right) = p^F - \left[p_C^s + \mu\left(1 - a_I^s\right)\right] \Rightarrow a_I^s = \frac{p_C^s + \mu - p_I^s}{\lambda + \mu}$$

is indifferent between buying from Supplier 1 and buying from Supplier 2 – the net returns from using these two seeds are the same. Producers "located" to the left of a_I^s (i.e., producers with

$a \in [0, a_I^s)$) purchase from Supplier 1 while those located to the right of a_I^s (i.e., producers with $a \in (a_I^s, 1]$) buy from Supplier 2. Aggregate producer welfare is given by the area underneath the effective net returns curve shown as the (bold dashed) kinked curve in Figure 1.

When producers are uniformly distributed with respect to their differentiating attribute *a*, the level of *a* corresponding to the indifferent producer, a_I^s, also determines the share of farm output produced with seed from Supplier 1. The share of farm output produced with seed from Supplier 2 is given by 1- a_I^s. Assuming fixed proportions between seed and farm output, a_I^s and 1- a_I^s give the market shares of the two input suppliers. By normalizing the mass of producers at unity, the market shares give the producer demands faced by Supplier 1, x_I^s, and Supplier 2, x_C^s, respectively (Mussa and Rosen). In what follows, the terms "market share" and "demand" will be used interchangeably to denote x_I^s or/and x_C^s. Formally, x_I^s and x_C^s can be written as:

(3) $$x_I^s = \frac{p_C^s + \mu - p_I^s}{\lambda + \mu}$$

(4) $$x_C^s = \frac{p_I^s + \lambda - p_C^s}{\lambda + \mu}$$

When the two input suppliers charge the same price to consumers (i.e., when $p_I^s = p_C^s$), x_I^s and x_C^s depend on the relative magnitude of the agronomic factors λ and μ. When λ is greater (smaller) than μ the demand faced by Supplier 1 is smaller (greater) than the demand faced by Supplier 2. Obviously, when λ equals μ, the two competitors split the market equally (i.e., $x_I^s = x_C^s = \frac{1}{2}$).

Comparative statics results can be shown graphically. A reduction in p_C^s shifts the Π_C^F curve upwards and increases x_C^s, while a reduction in p_I^s causes an upward shift of the Π_I^F curve and a reduction in x_C^s (i.e., $\frac{\partial x_C^s}{\partial p_C^s} < 0$ and $\frac{\partial x_C^s}{\partial p_I^s} > 0$). A decrease in the agronomic factor λ causes a rightward rotation of the Π_I^F curve through the intercept at $p^F - p_I^s$, which in turn increases the demand faced by Supplier 2 (i.e., $\frac{\partial x_C^s}{\partial \lambda} > 0$). Obviously, when λ is relatively low (i.e., $\lambda < p_C^s - p_I^s$), the Π_C^F curve lies underneath Π_I^F for all values of *a* and all producers buy from Supplier 1 (i.e., $x_C^s = 0$).

Panels *a* and *b* of Figure 2 graph the inverse demand curves faced by Supplier 1, $D(x_I^s)$, and Supplier 2, $D(x_C^s)$, respectively, and further demonstrate the strategic interdependence between the two suppliers of the input – the price of Supplier 1 is a direct argument in the demand faced by Supplier 2 and *vice versa*.

Note that the analysis can be easily modified to examine cases where farmers are not uniformly distributed with respect to their value of *a* but, rather, are concentrated at either end of the continuum. Specifically, when the distribution of producers is continuous (but not uniform), the market shares of the two input suppliers depend on its skewness, i.e., the more skewed is the distribution towards 1, the greater is the market share of (and the demand for) seed supplied by Supplier 2.

Benchmark Case: Innovation and Pricing Decisions in a Pure Oligopoly

Price Competition (2nd Stage of the Game)

Consider now the optimizing decisions of the two profit-maximizing input suppliers that are involved in a Bertrand price competition (i.e., they choose their prices simultaneously). The problem of each supplier is to determine the price of seed that maximizes its profits given the price of the other supplier and the producer demand for its product (seed). Specifically, Supplier 1's problem can be written as:

(5)
$$\max_{p_I^s} \Pi_I\left(p_I^s,\, p_C^s\right) = \left(p_I^s - c_I\right)x_I^s$$
$$s.t.\;\; x_I^s = \frac{p_C^s + \mu - p_I^s}{\lambda + \mu}$$

where c_I represents the constant marginal cost of seed production of Supplier 1. Supplier 2's problem is:

(6)
$$\max_{p_I^s} \Pi_C\left(p_C^s,\, p_I^s\right) = \left(p_C^s - c_C\right)x_C^s$$
$$s.t.\;\; x_C^s = \frac{p_I^s + \lambda - p_C^s}{\lambda + \mu}$$

where c_C represents the constant marginal cost of seed production of Supplier 2. Recall that c_I and c_C are determined by the innovation decisions of the two suppliers at the first stage of the game and are fixed when the two IOFs choose their prices.

Solving the input suppliers' problems shows the standard result that profits are maximized at the price-quantity combination determined by the equality of the marginal revenue and the marginal cost of production. Specifically, for any p_C^s, the best-response function of

Supplier 1 (i.e., the profit-maximizing price of Supplier 1) is given by $p_I^s = \frac{p_C^s + \mu + c_I}{2}$.

Similarly, for any p_I^s, the best-response function of Supplier 2 is $p_C^s = \frac{p_I^s + \lambda + c_C}{2}$. Solving the best response functions of the two suppliers simultaneously and substituting p_I^s and p_C^s into equations (3) and (4) gives the Nash equilibrium prices and quantities for the two competitors as a function of marginal costs of seed production, c_I and c_C, and the agronomic parameters λ and μ, i.e.,

(7) $$p_I^{s*} = \frac{\lambda + c_C + 2(\mu + c_I)}{3}$$

(8) $$x_I^{s*} = \frac{\lambda + c_C + 2\mu - c_I}{3(\lambda + \mu)}$$

(9) $$p_C^{s*} = \frac{\mu + c_I + 2(\lambda + c_C)}{3}$$

(10) $$x_C^{s*} = \frac{2\lambda - c_C + \mu + c_I}{3(\lambda + \mu)}$$

The equilibrium profits of the two input suppliers from selling their seeds are then equal to:

(11) $$\Pi_I^* = \frac{(\lambda + c_C + 2\mu - c_I)^2}{9(\lambda + \mu)}$$

(12) $$\Pi_C^* = \frac{(2\lambda - c_C + \mu + c_I)^2}{9(\lambda + \mu)}$$

The best-response functions of the two suppliers and the determination of the Nash equilibrium prices are graphed in Figure 3. Figure 4 depicts the equilibrium prices, quantities and profits of the two suppliers.

Innovation Competition (1st Stage of the Game)

At this stage, Supplier 1 and Supplier 2 determine the optimal amount of R&D, t_I and t_C respectively. R&D at the beginning (1st stage) of the game enables the two firms to reduce their marginal cost of production (c_I and c_C) which might result in increased competitiveness (and profits) when they determine their prices at the 2nd stage of the game. The relationship between the amount of R&D and the marginal costs of producing the seeds is given by:

(13) $$c_i(t_i) = c_i^0 - \beta t_i \qquad (i = \text{I, C})$$

where c_i^0 is the marginal cost of seed production of Supplier *i* prior to (and in the absence of) R&D activity, and β represents the effectiveness of R&D effort (i.e., the rate at which R&D effort is translated into process innovations for the two rivals).[1] To close the model, we assume that R&D effort is costly for the two input suppliers with the R&D costs being an increasing function of the amount of R&D (see Shy), i.e.,

(14) $$I_i(t_i) = \frac{1}{2}\psi t_i^2 \qquad (i = \text{I, C})$$

where ψ is a strictly positive scalar reflecting the size of R&D costs.

The problem of Supplier 1 at this stage of the game is the determination of R&D effort that maximizes its *total* profits (i.e., profits from selling the seed, Π_I^*, minus the R&D costs, I_I) and can be written as:

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[1] While the assumption of deterministic process innovations is adopted in this paper, the model can be easily modified to examine the case of stochastic innovations (when R&D effort affects the *probability* that certain production cost reductions will be realized). While consideration of stochastic innovations changes the results quantitatively, the qualitative nature of our results regarding the effect of co-operative involvement in R&D activity remains unaffected.

$$(15)\qquad \max_{t_I} \Pi_I^T = \Pi_I^* - I_I(t_I) = \frac{\left(\lambda + c_c + 2\mu - c_I^0 + \beta t_I\right)^2}{9(\lambda + \mu)} - \frac{1}{2}\psi t_I^2$$
$$s.t.\ \ c_I(t_I) \geq 0 \Rightarrow t_I \leq \frac{c_I^0}{\beta}$$

Similarly, the problem of Supplier 2 can be expressed as:

$$(16)\qquad \max_{t_C} \Pi_C^T = \Pi_C^* - I_C(t_C) = \frac{\left(2\lambda - c_C^0 + \beta t_C + \mu + c_I\right)^2}{9(\lambda + \mu)} - \frac{1}{2}\psi t_C^2$$
$$s.t.\ \ c_C(t_C) \geq 0 \Rightarrow t_C \leq \frac{c_C^0}{\beta}$$

Solving the Kuhn-Tucker conditions for the two suppliers shows that their optimal R&D effort depends on the size of R&D costs, ψ. Specifically, for Supplier 1, if

$\psi \leq \psi_I^+ = \dfrac{2\beta^2(2\mu + \lambda + c_C)}{9(\lambda + \mu)c_I^0}$, then this supplier exerts maximum R&D effort, i.e.,

$$(17)\qquad t_I = \frac{c_I^0}{\beta}$$

Note that when R&D costs are low, the optimal R&D strategy of Supplier 1 is not function of the R&D effort exerted by Supplier 2. If, on the other hand, $\psi \geq \psi_I^+$, the optimal t_I is function of t_C and equals:

$$(18)\qquad t_I = \frac{2\beta\left(2\mu + \lambda - c_I^0 + c_C^0 - \beta t_C\right)}{9(\lambda + \mu)\psi - 2\beta^2}$$

Figure 5 graphs the determination of optimal t_I for the different R&D cost structures.

Similarly, for Supplier 2, when $\psi \le \psi_C^+ = \frac{2\beta^2(\mu + 2\lambda + c_I)}{9(\lambda+\mu)c_C^0}$, the optimal R&D effort is

(19) $$t_C = \frac{c_C^0}{\beta}$$

while when $\psi \ge \psi_C^+$, the optimal t_C is:

(20) $$t_C = \frac{2\beta(\mu + 2\lambda + c_I^0 - \beta t_I - c_C^0)}{9(\lambda+\mu)\psi - 2\beta^2}$$

Thus, when R&D costs are relatively low (i.e., $\psi \le \psi_I^+$ and $\psi \le \psi_C^+$) the Nash equilibrium total amount of R&D, t^T, equals:

(21) $$t^T = t_I + t_C = \frac{c_I^0 + c_C^0}{\beta}$$

In this case, the marginal costs of production of the two suppliers are zero ($c_I = c_C = 0$). Substituting zero for c_I and c_C in equations (7)-(10) gives the subgame perfect Nash equilibrium prices of seeds and market shares of the two suppliers.

On the other hand, when R&D costs are relatively high, the Nash equilibrium levels of R&D are derived by solving simultaneously the best response functions of the two suppliers shown in equations (18) and (20). Specifically, when $\psi \ge \psi_I^+$ and $\psi \ge \psi_C^+$,

(22) $$t_I^* = \frac{2\beta\left[3\psi(2\mu + \lambda - c_I^0 + c_C^0) - 2\beta^2\right]}{3\psi\left[9\psi(\lambda+\mu) - 4\beta^2\right]}$$

(23) $$t_C^* = \frac{2\beta\left[3\psi(\mu + 2\lambda + c_I^0 - c_C^0) - 2\beta^2\right]}{3\psi\left[9\psi(\lambda+\mu) - 4\beta^2\right]}$$

(24) $$t^T = t_I^* + t_C^* = \frac{2\beta}{3\psi}$$

The best-response functions of the two suppliers and the determination of the Nash equilibrium amounts of R&D when innovation costs are relatively high are graphed in Figure 6.

Innovation and Pricing Decisions in a Mixed Oligopoly: The Role of Co-operatives

In this scenario Supplier 2 is a co-operative that competes with an investor-owned, profit-maximizing firm (Supplier 1). In what follows, we will often refer to Supplier 1 as the IOF and to Supplier 2 as the co-op.

Price Competition in the Mixed Oligopoly (2nd Stage of the Game)

Similar to the pure oligopoly case, the problem of Supplier 1 in the 2nd stage of the game is to determine the price of seed that maximizes its profits given the price of the other supplier (here the co-op) and the producer demand for its product. In fact, Supplier 1's problem is the same as the one specified in equation (5) and the price that maximizes its profits is still given by the equality of marginal revenues with marginal costs of production. Thus, for any p_C^s, the best-response function of Supplier 1 (i.e., the profit-maximizing price of the IOF) is given by

$$p_I^s = \frac{p_C^s + \mu + c_I}{2}.$$

Unlike Supplier 2 in the pure oligopoly case however, the objective of the input-supplying co-op is to maximize the welfare of its members. Specifically, the problem of the co-op is to determine the price p_C^s that maximizes the welfare of producers that patronize the co-op (shown by the shadowed area MW in Figure 1) subject to a non-negative profit constraint. Given the price of the IOF, p_I^s, and producer demand schedule, x_C^s, the co-op's problem is:

$$\max_{p_c^s} MW\left(p_C^s, p_I^s\right) = \left(p^F - p_C^s\right)x_C^s - \frac{1}{2}\mu {x_C^s}^2$$

(25) $$s.t.\ \ x_C^s = \frac{p_I^s + \lambda - p_C^s}{\lambda + \mu}$$

$$\Pi_C \geq 0 \Rightarrow p_C^s \geq c_C$$

where all variables are as previously defined.

Solving the co-op's problem specified above shows that the optimality (Kuhn-Tucker) conditions for a maximum are satisfied when the co-op prices its product at marginal cost, i.e., *MW* is maximized when $p_C^s = c_C$.

Solving the best response functions of the IOF and the co-op simultaneously we derive the Nash equilibrium prices of the seeds, $p_I^{s'}$ and $p_C^{s'}$. Figure 7 graphs the best response functions and the determination of the Nash equilibrium prices in this mixed oligopoly case. Substituting $p_I^{s'}$ and $p_C^{s'}$ into equations (3) and (4) gives the Nash equilibrium quantities for the two competitors as a function of the marginal seed production costs, c_I and c_C, and the agronomic parameters λ and μ. Mathematically, the Nash equilibrium prices and quantities in the price competition subgame are:

(26) $$p_I^{s'} = \frac{\mu + c_I + c_C}{2}$$

(27) $$x_I^{s'} = \frac{\mu - c_I + c_C}{2(\lambda + \mu)}$$

(28) $$p_C^{s'} = c_C$$

(29) $$x_C^{s'} = \frac{\mu + 2\lambda + c_I - c_C}{2(\lambda + \mu)}$$

The profits of the two rivals from selling their seeds and the welfare of producers patronizing the co-op are then equal to:

(30) $$\Pi_I^{'} = \frac{(\mu - c_I + c_C)^2}{4(\lambda + \mu)}$$

(31) $$\Pi_C^{'} = 0$$

(32) $$MW^{'} = \left(p^F - c_C\right)\frac{\mu + 2\lambda + c_I - c_C}{2(\lambda + \mu)} - \frac{1}{2}\mu\frac{(\mu + 2\lambda + c_I - c_C)^2}{4(\lambda + \mu)^2}$$

The determination of the equilibrium prices and quantities is shown graphically in panels *a* and *b* of Figure 8. Substituting the equilibrium prices for p_I^s and p_C^s in Figure 1 determines the equilibrium a_I^s $(= x_I^{s'})$ and welfare of agricultural producers.

The equilibrium conditions presented above hold for $c_I \leq c_C + \mu$. Obviously, if $c_I > c_C + \mu$, the intercept of $D\left(x_I^s\right)$ lies underneath c_I and the supply of the seed is not profitable for the IOF, i.e., $x_I^s = 0$. In this case, the net returns curve Π_I^F becomes irrelevant (i.e., producers have no choice of buying the seed from the IOF) and producer welfare is given by the area underneath curve Π_C^F in Figure 1.

Note that, when compared to the pure oligopoly case, the co-op involvement reduces p_C^s, p_I^s and x_I^s, while increasing x_C^s and producer welfare. This result holds for given costs of production c_I and c_C, however. If the co-operative involvement affects the optimal amount of R&D undertaken by the two suppliers, it will also affect their cost structures. The next section examines whether the co-op involvement affects c_I and c_C through the process innovation activity of the two suppliers.

Innovation Competition in the Mixed Oligopoly (1[st] Stage of the Game)

At this stage the two suppliers determine the amount of R&D to reduce their cost of production. Maintaining the same assumptions regarding the structure of R&D costs (equation (14)) and the relationship between the amount of R&D and the marginal costs of producing the seeds (equation (13)), we can determine the effect of co-operative involvement on innovation activity in the market under concern.

Similar to the pure oligopoly case, the problem of Supplier 1 (IOF) is to determine the amount of R&D that maximizes its *total* profits, i.e.,

(33)
$$\max_{t_I} \Pi_I^T = \Pi_I^{'} - I_I(t_I) = \frac{\left(\mu - c_I^0 + \beta t_I + c_C\right)^2}{4(\lambda + \mu)} - \frac{1}{2}\psi t_I^2$$
$$s.t.\ c_I(t_I) \geq 0 \Rightarrow t_I \leq \frac{c_I^0}{\beta}$$

On the other hand, the problem of Supplier 2 (co-op) is to determine the R&D effort that maximizes *total* member surplus, i.e.,[2]

(34)
$$\max_{t_C} MW^T = MW^{'} - I_C(t_C) =$$
$$= \left(p^F - c_C^0 + \beta t_C\right)\frac{\left(\mu + 2\lambda + c_I - c_C^0 + \beta t_C\right)}{2(\lambda + \mu)} - \frac{\mu\left(\mu + 2\lambda + c_I - c_C^0 + \beta t_C\right)^2}{8(\lambda + \mu)^2} - \frac{1}{2}\psi t_C^2$$
$$s.t.\ c_C(t_C) \geq 0 \Rightarrow t_C \leq \frac{c_C^0}{\beta}$$

[2] Implicit in this formulation of the co-op's problem is the assumption that the co-op funds its R&D activity through some sort of membership fee. An alternative formulation could be the one where the co-op incorporates its R&D expenses into the price of the input. In such a case, the price charged by the co-op in the 2[nd] stage of the game equals the average cost of seed production (Ramsey pricing). While this pricing strategy of the co-op changes the results quantitatively (i.e., increases the price of the co-op's seed reducing, this way, both the market share of the co-op and the welfare of co-op members), the qualitative nature of the results concerning the effect of co-op involvement on innovation activity remains unaffected.

The Kuhn-Tucker conditions for the problems specified in equations (33) and (34) show that, similar to the case of pure oligopoly, the optimal amounts of R&D of the two input suppliers depend on the size of R&D costs, ψ. Specifically, for Supplier 1, if $\psi \leq \psi_I^{+'} = \frac{\beta^2(\mu + c_C)}{2(\lambda+\mu)c_I^0}$, then this supplier exerts maximum R&D effort, i.e.,

(35) $$t_I = \frac{c_I^0}{\beta}$$

If, on the other hand, $\psi \geq \psi_I^{+'}$, the optimal R&D effort of Supplier 1 is given by:

(36) $$t_I = \frac{\beta\left(\mu - c_I^0 + c_C^0 - \beta t_C\right)}{2(\lambda+\mu)\psi - \beta^2}$$

Figure 9 graphs the determination of optimal t_I for different R&D costs structures.

Similarly, for the co-op, when $\psi \leq \psi_C^{+'} = \frac{\beta^2\left[(2\lambda+\mu)(2\lambda+\mu+c_I) + 2(\lambda+\mu)p^F\right]}{4(\lambda+\mu)^2 c_C^0}$, the optimal t_C is:

(37) $$t_C = \frac{c_C^0}{\beta}$$

while, when $\psi \geq \psi_C^{+'}$, the co-op's optimal R&D effort is:

(38) $$t_C = \frac{\beta\left[(2\lambda+\mu)\left(2\lambda+\mu+c_I^0 - \beta t_I - c_C^0\right) + 2(\lambda+\mu)\left(p^F - c_C^0\right)\right]}{4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)}$$

Thus, when R&D costs are relatively low (i.e., $\psi \leq \psi_I^{+'}$ and $\psi \leq \psi_C^{+'}$), the Nash equilibrium total amount of R&D, t^T, equals:

$$(39) \qquad t^{T'} = t_I + t_C = \frac{c_I^0 + c_C^0}{\beta}$$

In this case, the marginal costs of production of the IOF and the co-op are zero ($c_I = c_C = 0$). Substituting zero for c_I and c_C in equations (26)-(29) we derive the subgame perfect Nash equilibrium prices of seeds and market shares of the two input suppliers.

On the other hand, when R&D costs are relatively high, the Nash equilibrium levels of R&D are derived by solving simultaneously the best response functions of the two suppliers shown in equations (36) and (38). Specifically, when $\psi \geq \psi_I^{+'}$ and $\psi \geq \psi_C^{+'}$:

$$(40) \qquad t_I^{'} = \frac{\beta\left\{\left(\mu - c_I^0 + c_C^0\right)\left[4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)\right] - \beta^2\left[(2\lambda+\mu)\left(2\lambda+\mu+c_I^0-c_C^0\right) + 2(\lambda+\mu)\left(p^F - c_C^0\right)\right]\right\}}{\left[4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)\right]\left[2(\lambda+\mu)\psi - \beta^2\right] - \beta^4(2\lambda+\mu)}$$

$$(41) \qquad \begin{aligned} t_C^{'} &= \frac{\beta\left\{\left[2(\lambda+\mu)\psi - \beta^2\right]\left[(2\lambda+\mu)\left(2\lambda+\mu+c_I^0-c_C^0\right) + 2(\lambda+\mu)\left(p^F - c_C^0\right)\right] - \beta^2(2\lambda+\mu)\left(\mu - c_I^0 + c_C^0\right)\right\}}{\left[4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)\right]\left[2(\lambda+\mu)\psi - \beta^2\right] - \beta^4(2\lambda+\mu)} \\ &= \frac{2\beta(\lambda+\mu)\left[(2\lambda+\mu)\left[\psi\left(2\lambda+\mu+c_I^0-c_C^0\right) - \beta^2\right] + \left[2(\lambda+\mu)\psi - \beta^2\right]\left(p^F - c_C^0\right)\right]}{\left[4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)\right]\left[2(\lambda+\mu)\psi - \beta^2\right] - \beta^4(2\lambda+\mu)} \end{aligned}$$

$$(42) \qquad t^{T'} = t_I^{'} + t_C^{'} =$$

$$= \frac{2\beta\left\{\left[(\lambda+\mu)\psi - \beta^2\right]\left[(2\lambda+\mu)\left(2\lambda+\mu+c_I^0-c_C^0\right) + 2(\lambda+\mu)\left(p^F - c_C^0\right)\right] + \left(\mu - c_I^0 + c_C^0\right)\left[2(\lambda+\mu)^2\psi - \beta^2(3\lambda+2\mu)\right]\right\}}{\left[4(\lambda+\mu)^2\psi - \beta^2(4\lambda+3\mu)\right]\left[2(\lambda+\mu)\psi - \beta^2\right] - \beta^4(2\lambda+\mu)}$$

The best-response functions of the two suppliers and the determination of the Nash equilibrium amounts of R&D when innovation costs are relatively high are graphed in Figure 10.

The Effect of Co-operative Involvement on Innovation Activity

After having determined the subgame perfect equilibrium conditions in the pure and mixed oligopolies, we can now examine the effect of co-operative involvement on R&D activity and the welfare of the groups involved (i.e., agricultural producers and input suppliers). The consequences of co-operative involvement can be summarized in the two propositions below.

PROPOSITION 1: *When innovation costs are relatively low, co-operative involvement does not affect the total amount of R&D in the market. The pricing strategy of the co-op, however, reduces the prices of the agricultural input faced by producers and the profits of the IOF, while increasing the market share of the co-op, and the welfare of all producers - members and non-members of the co-op.*

Proof: It has been shown that, when innovation costs are relatively low, both suppliers will undertake the maximum amount of R&D and reduce their production costs to zero. This is true in both the pure and the mixed oligopoly cases. However, even though the level of innovation activity in the mixed oligopoly is the same as in the pure oligopoly, the involvement of the co-operative that maximizes member welfare reduces the prices of the seeds (p_I^s and p_C^s), the market share of Supplier 1 (x_I^s), and the profits of the two suppliers (Π_I and Π_C), while increasing the market share of Supplier 2 (co-op), x_C^s , and the welfare of all agricultural producers – members and non-members of the co-op (compare equations (17), (19) and (21) with equations (35), (37) and (39) respectively, summarized in Table 1).

The situation regarding innovation activity is different when R&D costs are relatively high. Specifically,

PROPOSITION 2: *When innovation costs are relatively high, co-operative involvement can increase the arrival rate of innovations in the economy and social welfare. Specifically, the presence of the co-op can increase the total amount of R&D in the market - the agricultural co-op invests more than the IOF in the pure* *oligopoly does and this increase in R&D can outweigh the reduced R&D investment by the IOF that competes with a co-op. Coupled with the pricing strategy of the (member) welfare maximizing co-op, the increased innovation activity results in reduced input prices faced by farmers, and increased welfare of all agricultural producers (members and non-members of the co-op). This increase in producer welfare under a mixed oligopoly exceeds the reduction in suppliers' profits making the co-operative involvement in the production of the agricultural input social welfare enhancing.*

Proof: The effect of co-op involvement on the equilibrium amounts of R&D undertaken by the two agricultural input suppliers is shown graphically in Figures 11 and 12. Figure 11 depicts the R&D reaction functions (best response functions) of the two input suppliers in the pure and mixed oligopoly cases. It is shown that, when compared to the reaction function of the profit-maximizing Supplier 2 in the pure oligopoly, the reaction function of the co-op is shifted outwards while rotating rightwards. The incentives to innovate are greater for the co-op because it internalizes the effect of reduced costs and prices (due to process innovation) on member welfare.

On the other hand, the co-op involvement reduces the marginal profitability of R&D investment for Supplier 1 – the reaction function of Supplier 1 is shifted inwards while rotating leftwards relative to the reaction function of this same supplier when it competes with another profit-maximizing IOF. These changes in the reaction functions due to the co-op involvement result in increased R&D investment by Supplier 2 (the co-op in the mixed oligopoly) and reduced investment by Supplier 1 (IOF in both the pure and the mixed oligopolies), i.e., $t_I^{'} < t_I^{*}$ and $t_C^{'} > t_C^{*}$. The effect of co-operative involvement on the incentives of the IOF (Supplier 1) to undertake R&D is also depicted in Figure 12. As it is clearly shown in this Figure, the co-op involvement reduces the marginal benefits from R&D investment of the IOF, which, for given R&D costs, results in reduced R&D effort.

Regarding the effect of co-operative involvement on *total* R&D activity, the analysis shows that it depends on the size of the R&D costs. In particular, it can be shown that if $\psi \leq \frac{\beta^2(2\mu+3\lambda)}{2(\lambda+\mu)^2}$, the increase in $t_C \left(= t_C^{'} - t_C^{*}\right)$ due to co-op involvement exceeds the reduction in $t_I \left(= t_I^{*} - t_I^{'}\right)$ resulting in increased total R&D investment activity in the market (i.e., $t_T^{'} > t_T^{*}$).

Note that while the co-op involvement *can* increase the amount of R&D undertaken by the input suppliers, it is not necessary that total R&D increases for farmers to benefit from the presence of the co-operative – even if the total amount of R&D falls in the mixed oligopoly, producer welfare can still increase in the presence of the co-op. In particular, as long as $|\Delta t_I| - |\Delta t_C| < \frac{\mu + 2\lambda + c_I^p - c_C^p}{3\beta}$ (where c_I^p and c_C^p are the equilibrium costs of production of the two suppliers in the pure oligopoly case), the price charged by Supplier 1 falls in the mixed oligopoly (i.e., $p_I^{s'} < p_I^{s*}$) and, given that p_C^s is also reduced, all producers (members and non-members of the co-op) realize an increase in their welfare.

The effect of the co-operative involvement on the pricing of the agricultural input, is shown graphically in Figure 13. Specifically, when Supplier 2 is a co-op instead of an IOF, its best response function is constant at c_C (i.e., it is not a function of the price charged by Supplier 1). On the other hand, the reduced R&D effort of Supplier 1 in the mixed oligopoly increases its production cost and causes a parallel upward shift of its best response function in the 2nd stage of the game. When $|\Delta t_I| - |\Delta t_C| < \frac{\mu + 2\lambda + c_I^p - c_C^p}{3\beta}$, the outcome is the reduced price of both seeds.

The reduction in prices of the two seeds increases producer welfare by area ΔMW in panel *c* of Figure 14, while the fact that the reduction in p_C^s exceeds the reduction in p_I^s results in reduced market share of Supplier 1 (IOF) in the mixed oligopoly case.[3] The effect of co-operative involvement on the equilibrium prices and quantities of the two seeds and the profits of the two input suppliers is shown graphically in panels *a* and *b* of

[3] When the assumption of a uniform distribution of producers is relaxed, the welfare and market effects of co-op involvement depend on the skewness of the distribution. *Ceteris paribus*, the greater is the number of producers with relatively high values of *a*, the greater is the share of producers patronizing the co-op, the greater is x_C^s, and the greater are the producer welfare gains from co-operative involvement.

Figure 14. Note that the increase in farmer welfare exceeds the reduction in suppliers' profits, indicating that the presence of the co-op increases total economic welfare in this market.

At this point, it should be noted that, while our analysis assumes that input suppliers have the same R&D cost structure and R&D effectiveness (parameters ψ and β, respectively), our model can be easily modified to allow for differences in R&D costs and/or differences in R&D effectiveness between the co-op and the IOF. The implications of introducing differences in ψ and/or β are quite straightforward – the greater are the R&D costs for the co-op and/or the lower is the co-op's ability to transform resources into process innovations, the lower are the productivity and social welfare gains from the presence of the co-op. In this context, strategies/policy initiatives directed towards reducing the costs and/or enhancing the effectiveness of co-operative R&D can be welfare enhancing and, thus, socially desirable.

Conclusions

This paper develops a sequential game theoretic model of heterogeneous producers to examine the effect of co-operative involvement on innovation activity in the agricultural input-supplying sector. Specifically, the paper analyzes the consequences of co-operative involvement for the arrival rate of innovations, the pricing of agricultural inputs, and social welfare in the context of a mixed duopoly where a co-op and an IOF compete in supplying an input to agricultural producers.

Analytical results show that the co-operative involvement in R&D *can* be welfare enhancing and, thus, socially desirable. The presence of the co-op can increase the arrival rate of innovations and productivity growth while reducing the prices of agricultural inputs. The effectiveness of the co-op is shown to be dependent upon the size of the costs associated with process innovations – the size of the R&D costs.

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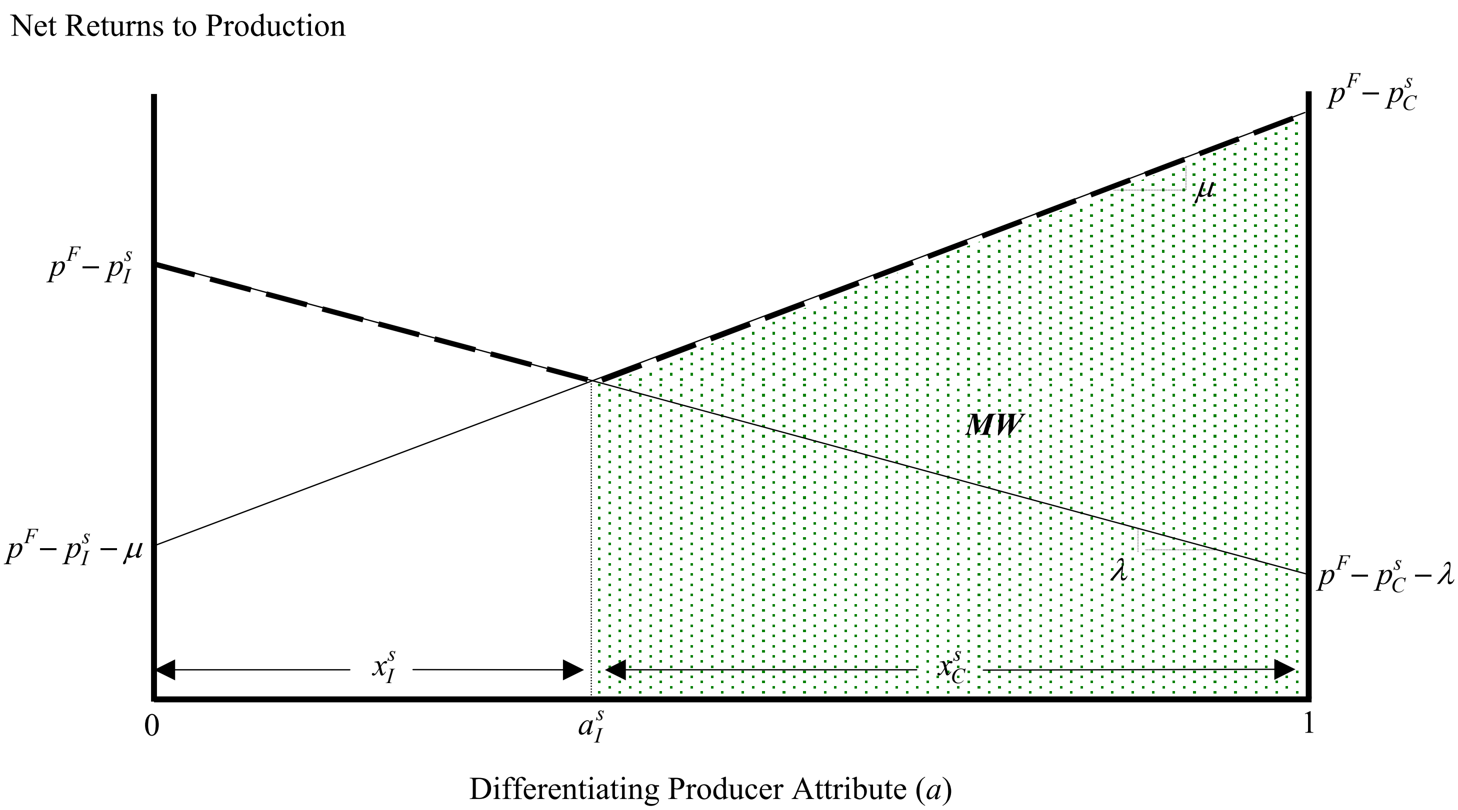

Figure 1. Producer decisions and welfare

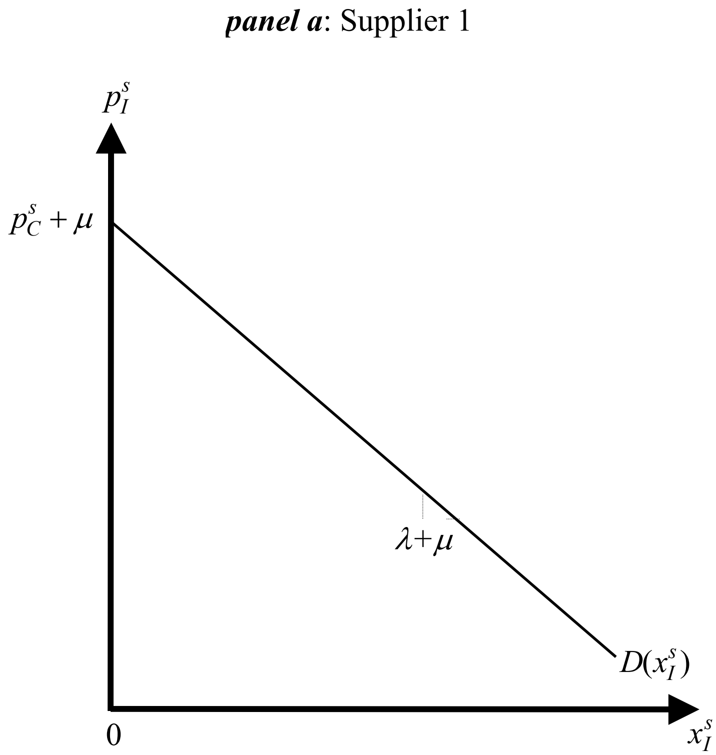

Figure 2. Producer demands for seeds

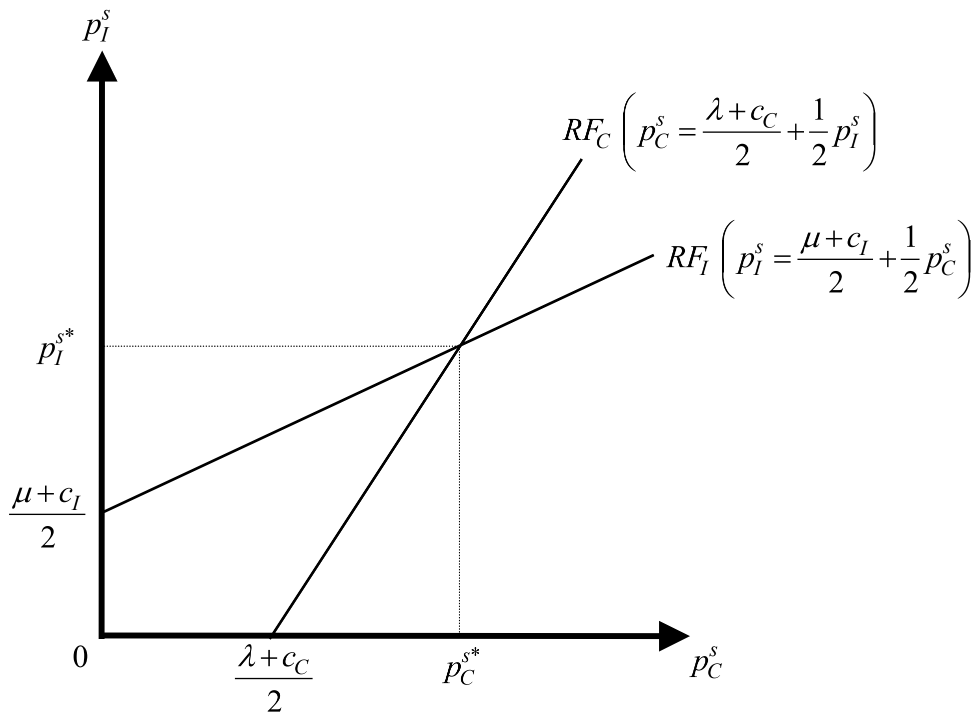

Figure 3. Reaction functions and Nash equilibrium seed prices in the pure oligopoly

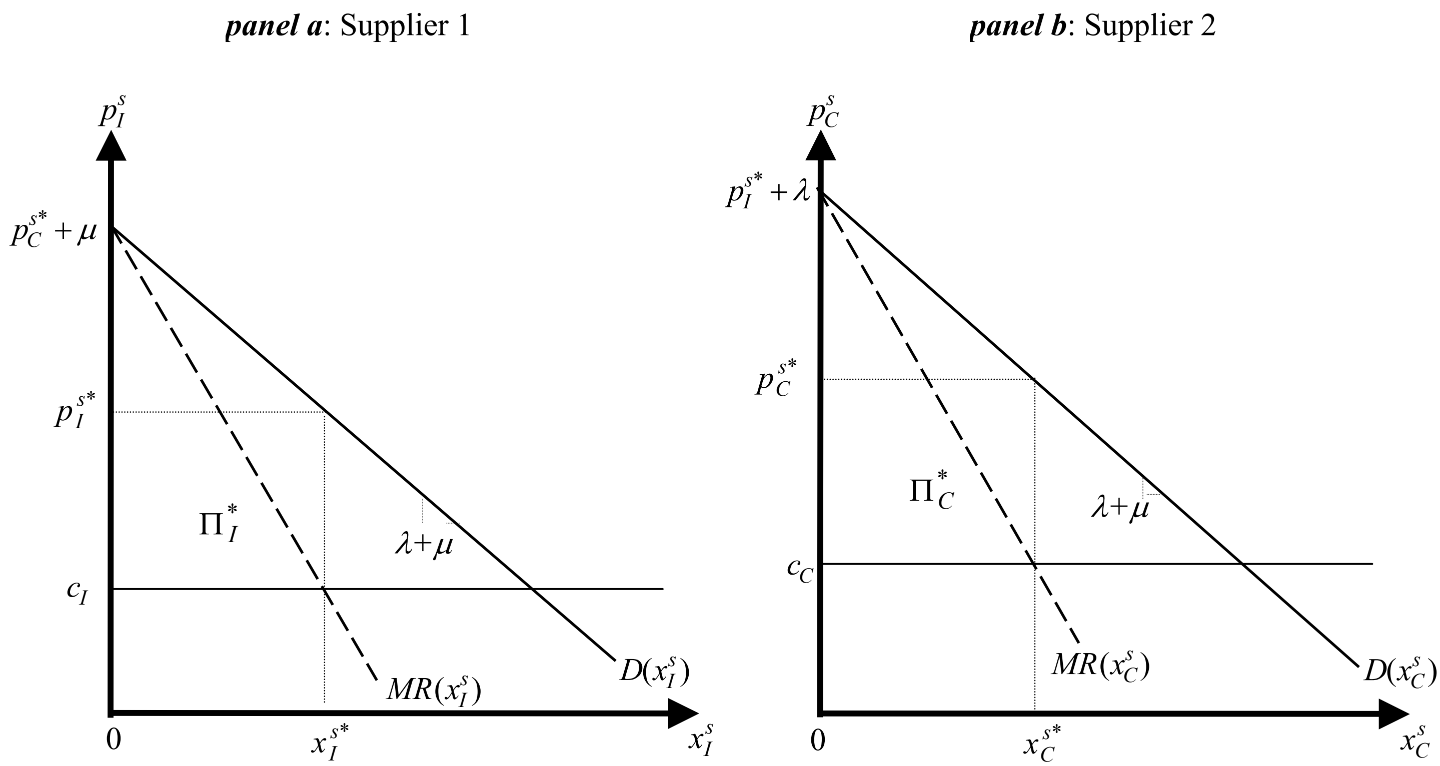

Figure 4. Pricing of seeds in a pure oligopoly

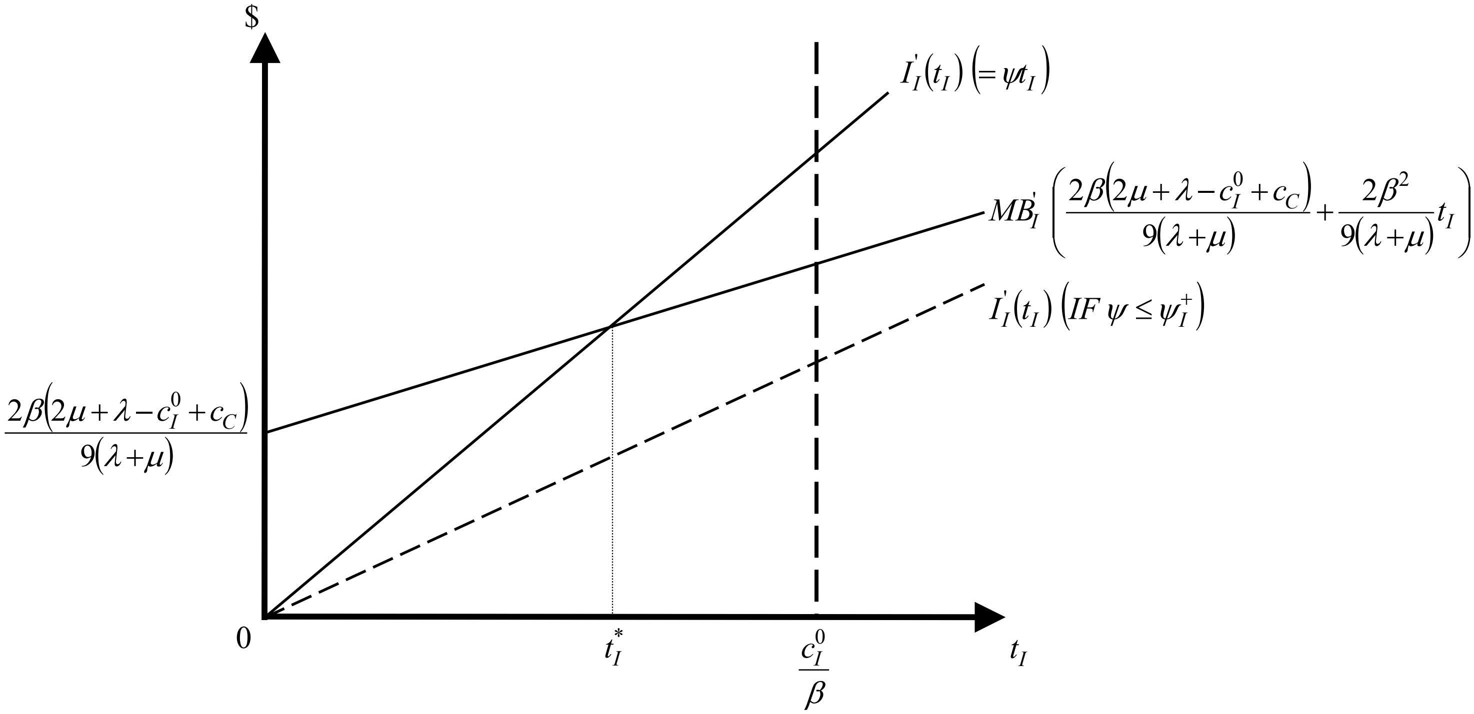

Figure 5. Determination of optimal R&D strategy (i.e., best response function) by Supplier 1 in the pure oligopoly

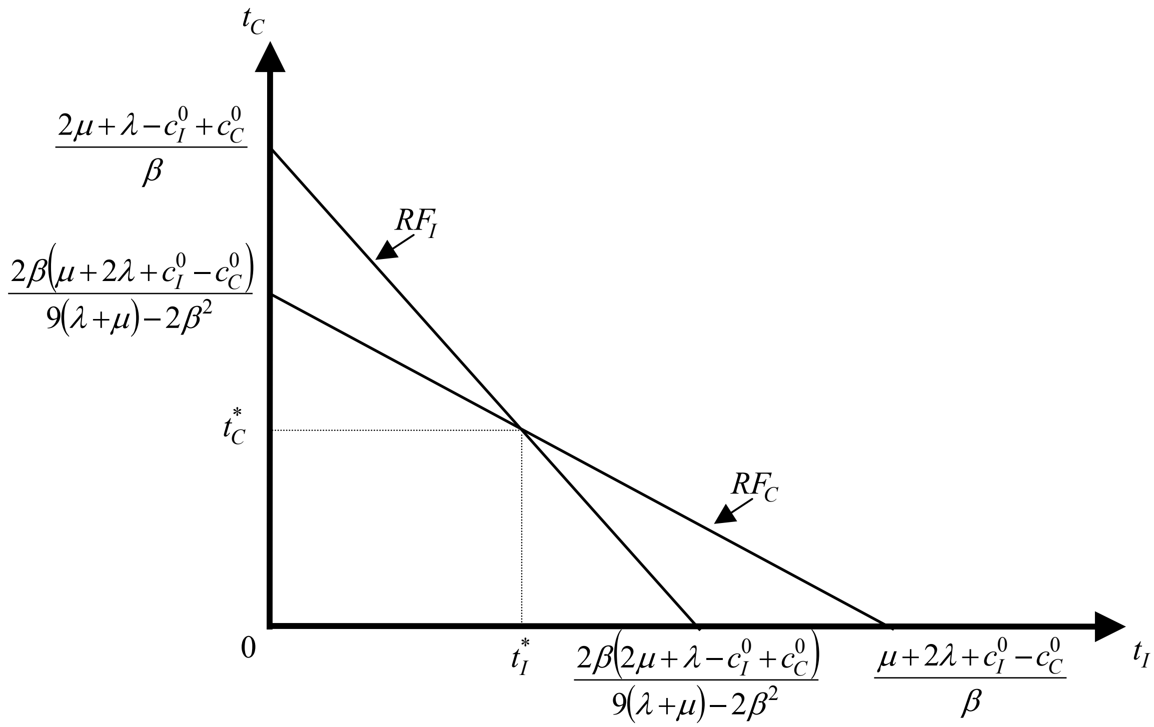

Figure 6. Reaction functions and Nash equilibrium amounts of R&D in the pure oligopoly (when $\psi \geq \psi_I^+$ and $\psi \geq \psi_C^+$)

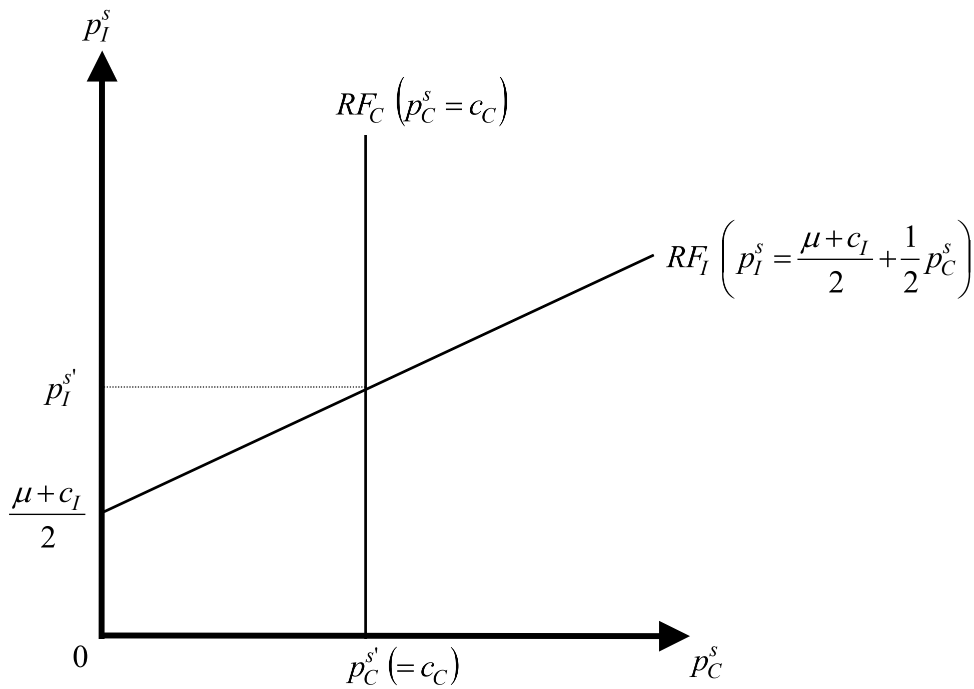

Figure 7. Reaction functions and Nash equilibrium seed prices in the mixed oligopoly

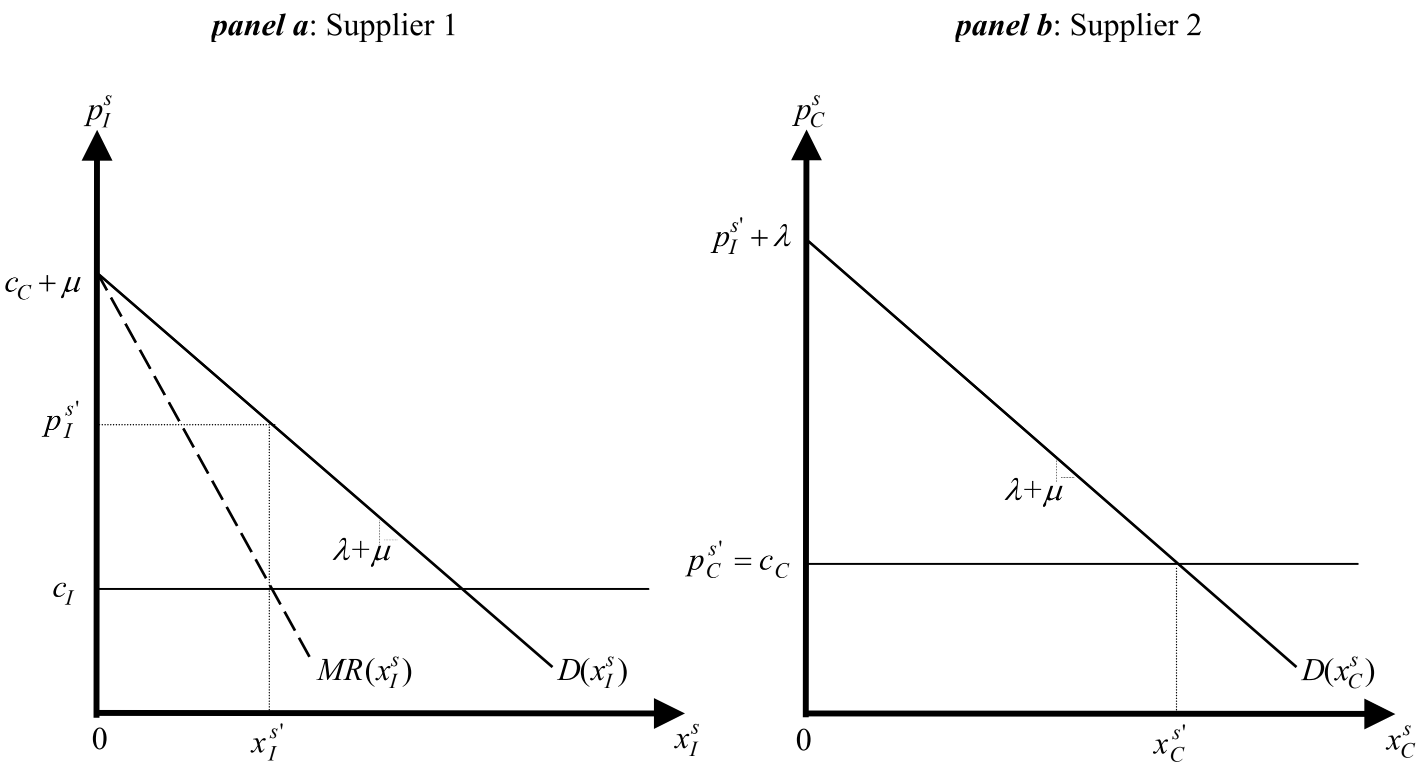

Figure 8. Pricing of seeds in the mixed oligopoly

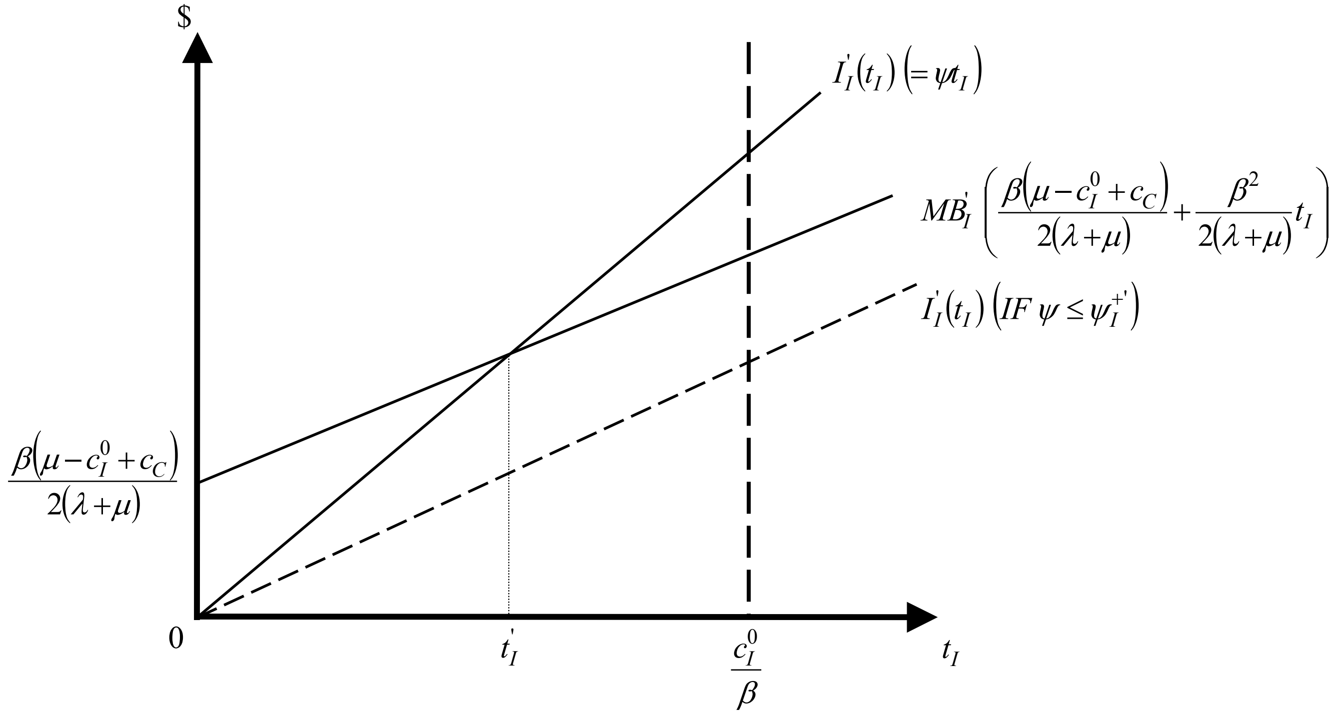

Figure 9. Determination of optimal R&D strategy (i.e., best response function) by Supplier 1 in the mixed oligopoly

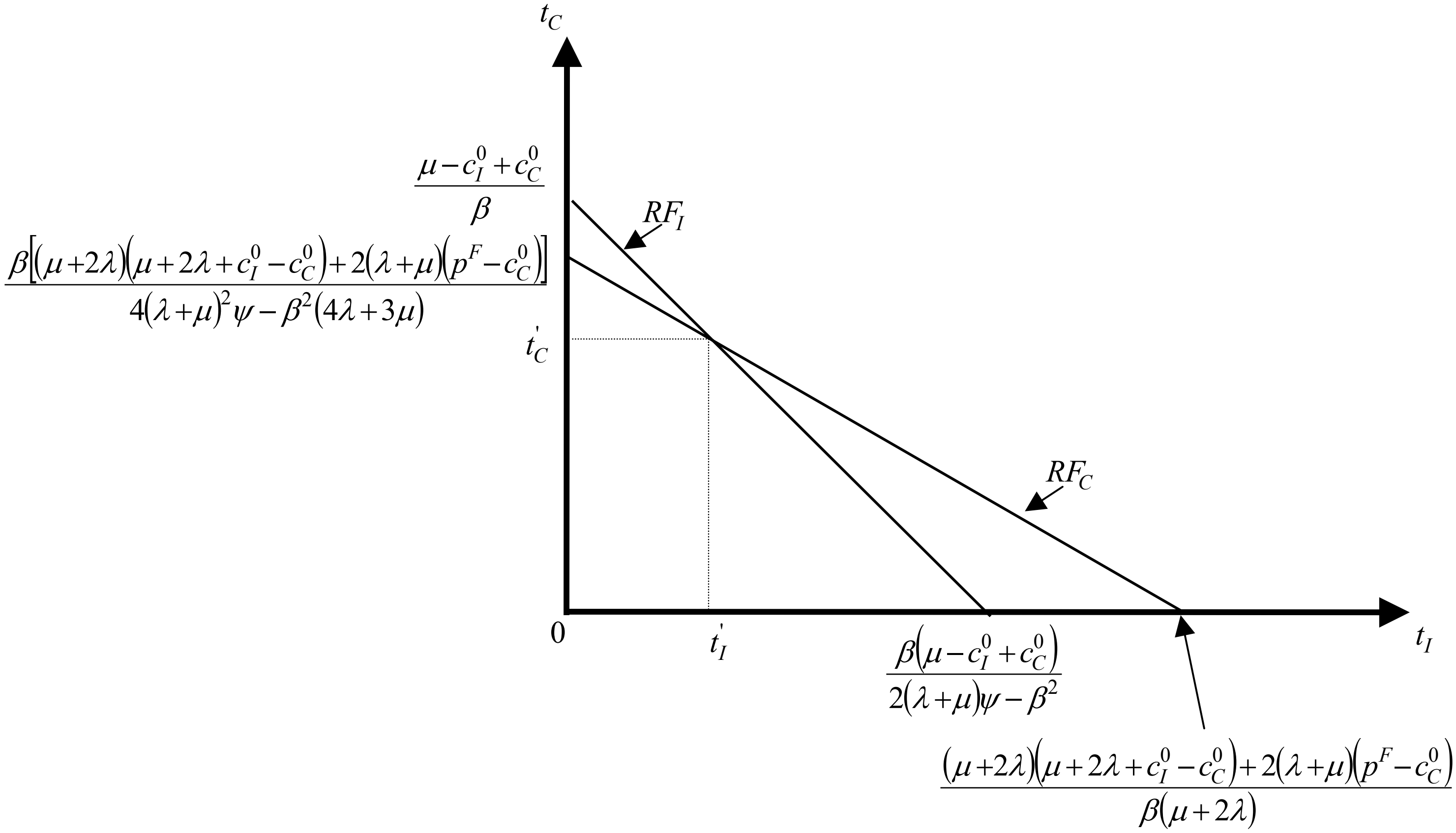

Figure 10. Reaction functions and Nash equilibrium amounts of R&D in the mixed oligopoly (when $\psi \geq \psi_I^{+'}$ and $\psi \geq \psi_C^{+'}$)

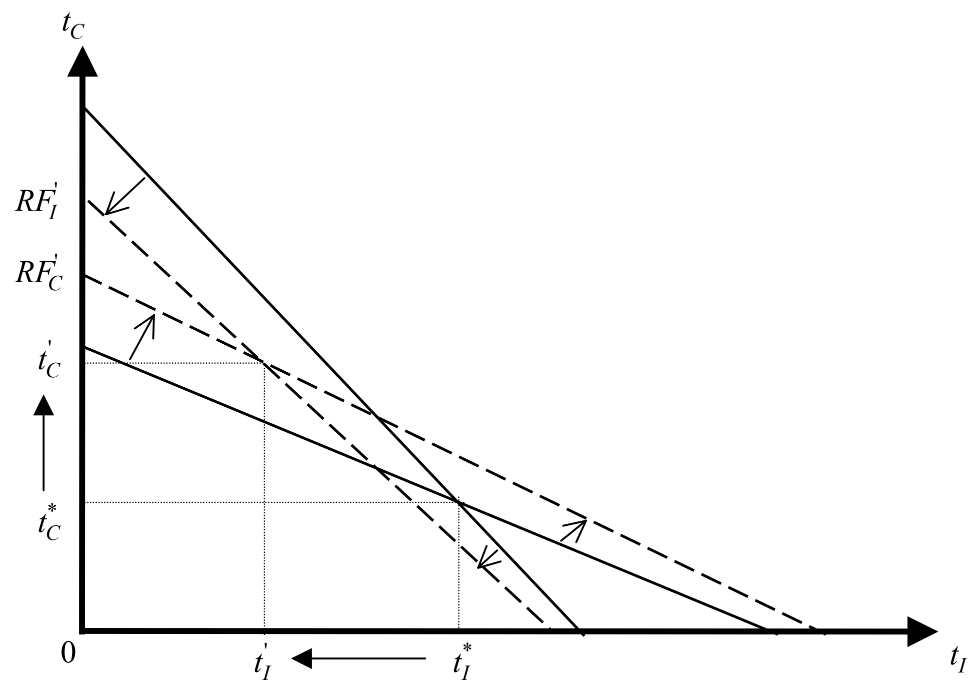

Figure 11. Effect of co-operative involvement on R&D activity (relatively high R&D costs)

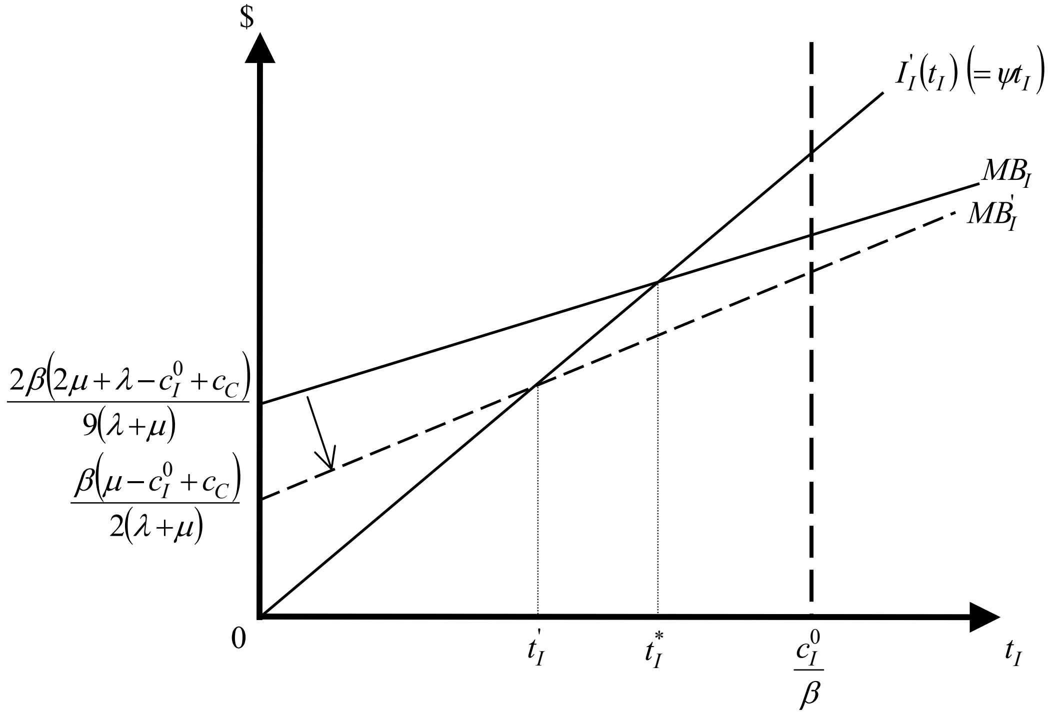

Figure 12. Effect of co-operative involvement on IOF's R&D incentives

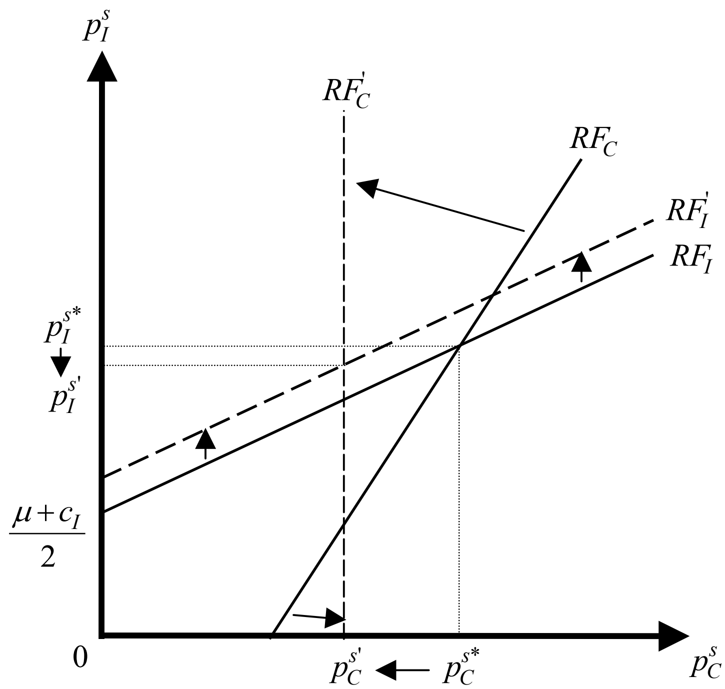

Figure 13. Effect of co-operative involvement on seed pricing ($|\Delta t_I| - |\Delta t_C| < \frac{\mu + 2\lambda + c_I^p - c_C^p}{3\beta}$)

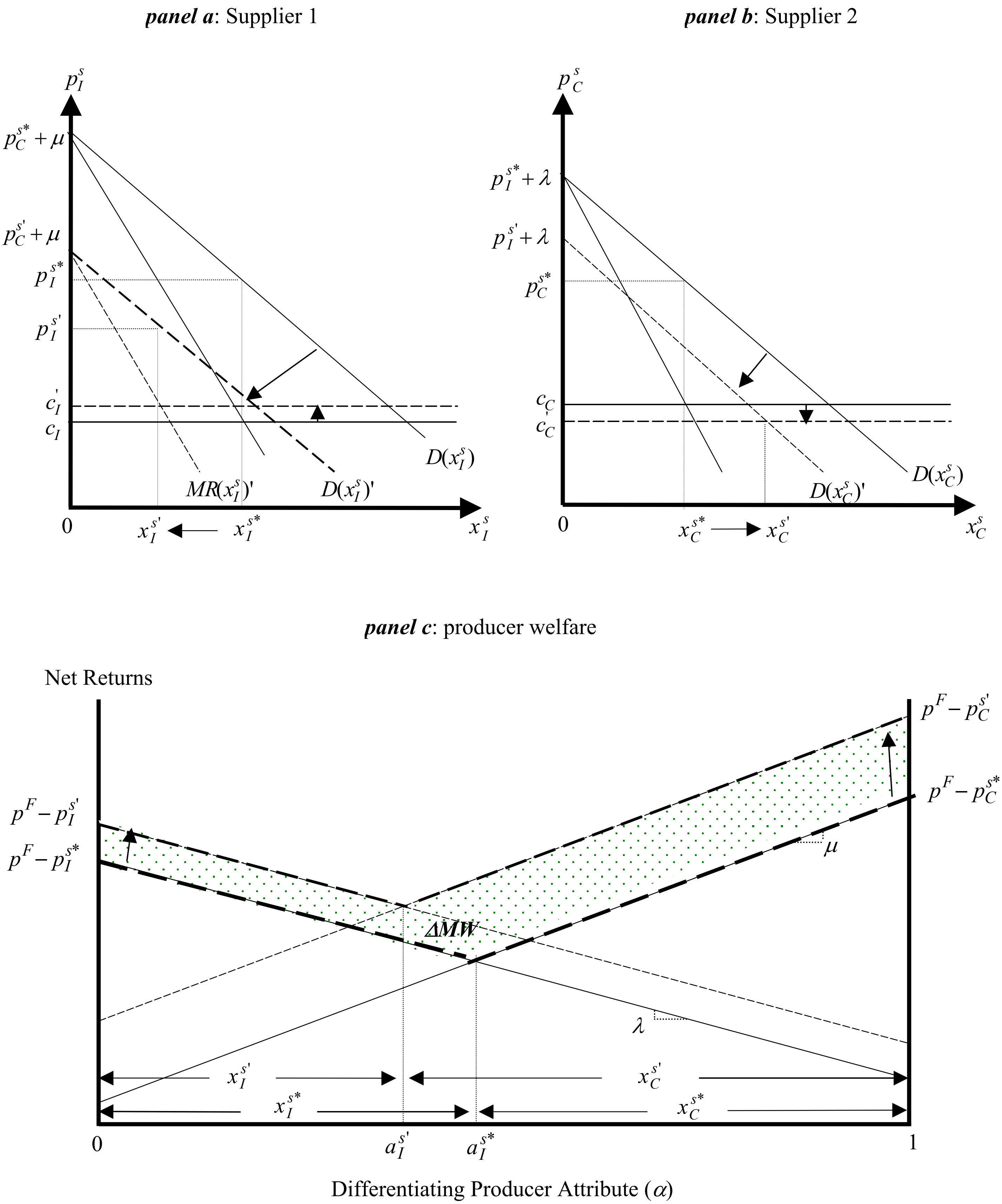

Figure 14. Market and welfare effects of co-operative involvement in R&D

Table 1. The Effect of co-operatives when R&D costs are low

	Pure Oligopoly		Mixed Oligopoly
t_I	$\frac{c_I^0}{\beta}$	=	$\frac{c_I^0}{\beta}$
t_C	$\frac{c_C^0}{\beta}$	=	$\frac{c_C^0}{\beta}$
c_I	0	=	0
c_C	0	=	0
p_I^s	$\frac{2\mu+\lambda}{3}$	>	$\frac{\mu}{2}$
p_C^s	$\frac{\mu+2\lambda}{3}$	>	0
x_I^s	$\frac{2\mu+\lambda}{3(\lambda+\mu)}$	>	$\frac{\mu}{2(\lambda+\mu)}$
x_C^s	$\frac{\mu+2\lambda}{3(\lambda+\mu)}$	<	$\frac{\mu+2\lambda}{2(\lambda+\mu)}$
Π_I	$\frac{(2\mu+\lambda)^2}{9(\lambda+\mu)}$	>	$\frac{\mu^2}{4(\lambda+\mu)}$
Π_C	$\frac{(\mu+2\lambda)^2}{9(\lambda+\mu)}$	>	0
MW		<	$\frac{(\mu+2\lambda)\left[4p^F(\lambda+\mu)-\mu(\mu+2\lambda)\right]}{8(\lambda+\mu)^2}$
PS		<	