AGRICULTURAL COOPERATIVES AND COST-REDUCING R&D IN THE AGRI-FOOD SYSTEM

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Abstract - This paper develops a sequential game theoretic model of heterogeneous producers to examine the effect of cooperative involvement on process innovation activity in the agricultural input-supplying sector. Analytical results show that the involvement of an open-membership cooperative in process innovation activity *can* be welfare enhancing and, thus, socially desirable. The presence of the co-op can increase the arrival rate of process innovations and productivity growth while reducing the price of agricultural inputs. The effectiveness of the co-op in innovation activity is determined by its initial market share and the size of the innovation 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 main focus of the economic literature on innovation 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 (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 cooperatives (co-ops) compete alongside IOFs, the effect of cooperative organizations on innovation activity and the impact of this activity on the equilibrium market conditions have not been considered. While previous studies have focused on the strategic interaction between co-ops and IOFs and the role that co-ops play in ensuring a competitive market, they have not considered the impact that the cooperative structure has on innovation activity in these mixed markets and the resulting impact of this activity on the rivals' cost structure and pricing decisions.[1]

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[1] A number of papers have examined the impact of agricultural cooperative involvement on prices and output in an oligopolistic market. Tennbakk considers the effect of a fixed membership marketing co-op on the equilibrium conditions of a Cournot oligopoly. Fulton and Giannakas examine an open membership consumer co-op that is involved in price competition in a model where consumers differ in their commitment to the co-op and an IOF. Sexton models a processing co-op that competes with an IOF, where the co-op and the IOF are spatially separated. He considers both an open and a closed membership co-op and analyzes the equilibrium conditions under different conjectural variations of the competing firms. Output competition between a co-op and an IOF is also considered by Karantininis and Zago, while Cotterill implicitly considers price competition between the two firms. None of these papers considered the innovation activity in the mixed oligopoly, however.

The objective of this paper is to examine the role of co-ops in process innovation activity and to determine the consequences of cooperative involvement for the innovation investment that is undertaken, the subsequent pricing behavior of the co-op and its competitors, and the social welfare resulting from this competition. Specifically, the paper examines the outcome of process innovation and price competition in a mixed duopoly where an open membership co-op and an IOF compete in supplying an input to agricultural producers.[2] The open membership co-op is chosen for analysis because of its prevalence among co-ops and particularly among input supply co-ops (Cook). To determine the impact of cooperative involvement on innovation activity, the case of a pure oligopoly is also analyzed and used as a benchmark for the analysis (note that since underinvestment in innovation is a standard result when IOFs engage in price (Bertrand) competition, the presence of a co-op has the potential to raise innovation activity). The paper also pays attention to the capital constraints that are typically thought to exist in cooperatives and their effect on innovation activity and social welfare.

The research reported in this paper fills an important gap in the literature on innovation activity in mixed duopolies, which to date has focused on either labor-managed firms (LMFs) or public firms. Specifically, since open membership input supply co-ops have different objectives than a public firm or an LMF, the model of a co-op is likely to yield different outcomes. For instance, while public firms are typically assumed to maximize total economic welfare (see, for example, Poyago-Theotoky, Delbono and Denicolò, and the references therein), a co-op considers only the welfare of its members. As will be seen in this paper, the result is that the impact of a co-op on total innovation expenditures and the distribution of these expenditures between the competing firms can differ from that of a public firm.

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[2] Part of the reason for the lack of research on cooperative involvement in innovative activity is the view that co-ops are largely concentrated in the vertical stages just before and just after the farm enterprise (Rogers and Marion). While supply and product handling co-ops may not engage in new product innovation, they do engage in process innovation. For example, CHS Cooperatives' Refined Fuel Distribution system uses GPS technology to allow fuel orders to be automatically generated whenever a member's fuel tank level falls below a pre-determined level (Cenex). Also on the supply side, Federated Co-operatives Limited has made major investments in an Efficient Consumer Response (ECR) system designed to remove costs from each step of the supply chain. One example of ECR is a cross-docking initiative in which suppliers deliver their products to FCL's food distribution centers where the products are then loaded directly onto FCL's delivery trucks (Fulton and Gibbings). Of course, process innovation is not limited to supply co-ops. A major marketing co-op, Ocean Spray, for instance, has worked with Microsoft to develop a Web-based retail audit solution running on Windows CE-based handheld PCs (Microsoft).

In addition, an open membership co-op is likely to make different decisions than would a closed membership co-op, as Sexton shows in his paper. Models of LMFs typically assume closed membership (see, for example, Neary and Ulph, Okuguchi and references therein). As well, since LMFs utilize an input supplied by their members (i.e., labor) to produce a product sold downstream, LMFs are more akin to marketing and processing co-ops than to the input supply co-ops examined in this paper (note that marketing and processing co-ops are more likely to have closed membership than are supply co-ops, thus further strengthening the distinction between these two types of cooperatives). In the model of this paper, the open membership co-op behaves in a different manner than does an LMF. This different behavior results in part because the co-op's optimal innovation effort is unresponsive to that of the IOF.

The rest of the paper is organized as follows. The next section describes the methodological framework of this study followed by the development of a simple model of horizontal differentiation where agricultural producers differ in the returns they receive from the use of inputs supplied by different agri-business firms. The paper then analyzes price and innovation competition between two profit-maximizing IOFs, followed by an examination of the effect of cooperative involvement on innovation activity, the pricing of agricultural inputs and the welfare of the groups. The section following examines the implications for the analysis of capital constraints faced by co-ops. Finally, the results are linked to the literature on innovation activity in mixed oligopolies before the concluding section of the paper.

Methodological Framework

The strategic interaction between the input suppliers in the pure and mixed oligopoly cases is modeled as a two-period sequential game. In *period 1*, the two agri-business firms make their innovation investment decisions that allow them to make process innovations and reduce their (marginal) cost of production. In *period 2*, the (post-innovation) production costs are fixed and the two rivals engage in price competition. Once the equilibrium prices have been determined, the agricultural producers make their purchasing decisions observing the prices of the two inputs.

To avoid Nash equilibria involving non-credible strategies, the different formulations of the game are solved using backward induction (Gibbons) – after deriving the producer demands for the inputs supplied by the two firms, the pricing behavior of the two input suppliers is analyzed first, and the solution to their innovation investment problem determines the subgame perfect equilibrium amount of innovation, pricing of the agricultural inputs, and farmers' purchasing decisions and welfare.

Producer Decisions and Welfare

In 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, and the technology adopted. Farmer heterogeneity in terms of production factors is a key component in our model and captures the differences in the relative returns received by farmers from the use of inputs supplied by different firms.

Specifically, consider a producer whose net return depends on the agricultural input that is purchased from an agri-business firm. It is assumed that two suppliers – Supplier I and Supplier C – supply the input. The net returns earned by the farmer depend on the input employed in the production process. The returns differ because the nature of the input supplied by the two firms is different and because the prices charged by the two firms may be different. As well, farmers differ in the benefits that they receive from a particular input, since farmers differ in terms of attributes mentioned above.[3] To capture these elements, let $a \in [0, 1]$ denote the attribute that differentiates producers. A producer with attribute a has the following net returns function:

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

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

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[3] The framework for examining farmer heterogeneity developed in this paper is similar to that found in both Sexton and Fulton and Giannakas. Sexton examines the situation where farmers differ in their geographical location, while Fulton and Giannakas develop a model where consumers differ in their commitment to the co-op and IOF.

where Π_I^F and Π_C^F are the net returns associated with unit output production using the input supplied by

Supplier I and Supplier C, respectively; p_I and p_C are the price of the input supplied by Supplier I and

Supplier C, respectively; p^F is the farm price (net of all production costs except for the input) of the

output produced by the farmer; and μ is a non-negative agronomic factor associated with the use of the

input provided by the two suppliers. *Ceteris paribus*, Supplier C's input 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 the input provided by Supplier I.

To allow for positive market shares for the two agri-business firms, it is assumed that μ is greater

than or equal to the difference in input prices (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.[4] Each farmer produces one unit of the farm output and the choice of input supplier 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 the

net returns when Supplier I's input is purchased, while the upward sloping line shows the net returns when

Supplier C's input is purchased for different values of the differentiating attribute a (i.e., for different

farmers). 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 given by:

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

is indifferent between buying from Supplier I and buying from Supplier C – the net returns from using

these two inputs are the same. Producers "located" to the left of a_I (i.e., producers with $a \in [0, a_I)$)

purchase from Supplier I while those located to the right of a_I (i.e., producers with $a \in (a_I, 1]$) buy from

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[4] Note that this is a standard assumption in the literature of horizontal and vertical product differentiation (see Shy).

Supplier C. Aggregate producer welfare is given by the area underneath the effective net returns curve shown as the (bold dashed) kinked curve in Figure 1.

Since producers are uniformly distributed with respect to their differentiating attribute a, the level of a corresponding to the indifferent producer, a_I, also determines the share of farm output produced with the input provided by Supplier I. The share of farm output produced with the input provided by Supplier C is given by 1-a_I. Assuming fixed proportions between the input and farm output, a_I and 1-a_I 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 I, x_I, and Supplier C, x_C, respectively (Mussa and Rosen). In what follows, the terms "market share" and "demand" will be used interchangeably to denote x_I or/and x_C. Formally, x_I and x_C can be written as:

(3) $\qquad x_I = \dfrac{p_C + \mu - p_I}{2\mu}$

(4) $\qquad x_C = \dfrac{p_I + \mu - p_C}{2\mu}$

Benchmark Case: Innovation and Pricing Decisions in a Pure Oligopoly

Price Competition (2nd Stage of the Game)

Consider now the optimizing decisions of two profit-maximizing IOFs 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 the input that maximizes its profits given the price of the other supplier and the producer demand for its product. Specifically, Supplier i's problem (where i=I, C) can be written as:

(5) $\qquad \max_{p_i} \Pi_i\left(p_I, p_C\right) = \left(p_i - c_i\right)x_i$

where c_i represents Supplier i's constant marginal cost of producing its product. Recall that c_I and c_C are determined by the innovation decisions of the two input 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, Supplier I's best-response function (i.e., the profit-maximizing price of Supplier I) is given by $p_I = \dfrac{p_C + \mu + c_I}{2}$. Similarly, for any p_I, Supplier C's best-response function is $p_C = \dfrac{p_I + \mu + c_C}{2}$. Solving the best response functions of the two suppliers simultaneously and substituting p_I and p_C into equations (3) and (4) gives the Nash equilibrium prices and quantities for the two competitors as a function of marginal costs of producing the input, c_I and c_C, and the agronomic parameter μ, i.e.,

$$(6) \qquad p_I^* = \frac{3\mu + c_C + 2c_I}{3}$$

$$(7) \qquad x_I^* = \frac{3\mu + c_C - c_I}{6\mu}$$

$$(8) \qquad p_C^* = \frac{3\mu + 2c_C + c_I}{3}$$

$$(9) \qquad x_C^* = \frac{3\mu - c_C + c_I}{6\mu}$$

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

$$(10) \qquad \Pi_I^* = \frac{(3\mu + c_C - c_I)^2}{18\mu}$$

$$(11) \qquad \Pi_C^* = \frac{(3\mu - c_C + c_I)^2}{18\mu}$$

Innovation Competition (1ˢᵗ Stage of the Game)

At this stage, Supplier I and Supplier C seek to determine the optimal amount of innovation, t_I and t_C, respectively. Expenditures on process innovation at the beginning (1ˢᵗ stage) of the game enable the two firms to reduce their marginal cost of production (c_I and c_C), which can affect the firms' competitiveness (and profits) when they determine their prices in the 2ⁿᵈ stage of the game. The relationship between the amount of innovation and the marginal costs of producing the input is given by:

(12) $c_i(t_i) = c_i^0 - \beta t_i$

where c_i^0 is Supplier i's (strictly positive) marginal cost of producing the input prior to (and in the absence of) innovation activity (i.e., the *ex ante* marginal cost of production) and $t_i \geq 0$. The parameter β represents the effectiveness of innovation effort (i.e., the rate at which innovation effort is translated into process innovations for the two rivals).[5] For simplicity of exposition, β is normalized to equal 1. To close the model, we assume that innovation effort is costly for the two suppliers with the innovation costs being an increasing function of the amount of innovation (Shy), i.e.,

(13) $I_i(t_i) = \frac{1}{2} \psi t_i^2$

where ψ is a strictly positive scalar reflecting the size of innovation costs.

The problem of Supplier i at this stage of the game is the determination of innovation effort that maximizes its *total* profits, Π_i^T (i.e., profits from supplying the input, Π_i^*, minus innovation costs, I_i), i.e.,

(14) $\max\limits_{t_i} \Pi_i^T = \Pi_i^* - \frac{1}{2} \psi t_i^2$

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[5] 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 innovation 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 cooperative involvement in innovation activity remains unaffected.

To rule out unrealistic corner solutions involving zero post-innovation production costs for the two input suppliers, we assume that the innovation costs are such that $t_i < c_i^0$ – the firms' optimal innovation efforts are below the level that reduces their production costs to zero.[6] Solving the optimality conditions for the two suppliers, we derive their best response functions (i.e., the optimal amount of innovation as function of the other supplier's innovation effort) as:

(15) $t_I = \dfrac{3\mu + c_C^0 - c_I^0 - t_C}{9\mu\psi - 1}$ and

(16) $t_C = \dfrac{3\mu - c_C^0 + c_I^0 - t_I}{9\mu\psi - 1}$

Solving simultaneously the best response functions of the two input suppliers we derive the Nash equilibrium levels of innovation in the pure oligopoly as:

(17) $t_I^* = \dfrac{3\psi\left(3\mu + c_C^0 - c_I^0\right) - 2}{3\psi\left(9\mu\psi - 2\right)}$ $\left(= \dfrac{18\mu\psi x_I^0 - 2}{3\psi\left(9\mu\psi - 2\right)} \right)$

(18) $t_C^* = \dfrac{3\psi\left(3\mu - c_C^0 + c_I^0\right) - 2}{3\psi\left(9\mu\psi - 2\right)}$ $\left(= \dfrac{18\mu\psi x_C^0 - 2}{3\psi\left(9\mu\psi - 2\right)} \right)$

(19) $t_T^* = t_I^* + t_C^* = \dfrac{2}{3\psi}$

where $x_I^0 \left(= \dfrac{3\mu + c_C^0 - c_I^0}{6\mu} \right)$ and $x_C^0 \left(= \dfrac{3\mu - c_C^0 + c_I^0}{6\mu} \right)$ are the *ex ante* market shares of Supplier I and Supplier C, respectively, i.e., the market shares of the two suppliers prior to (and in the absence of) the innovation activity in period 1.

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[6] It can be shown that if $\psi \leq \psi_I^+ = \dfrac{3\mu + c_C}{9\mu c_I^0}$, then Supplier I exerts maximum innovation effort, i.e., $t_I = c_I^0$, which results in $c_I = 0$. Similarly, if $\psi \leq \psi_C^+ = \dfrac{3\mu + c_I}{9\mu c_C^0}$, Supplier C's optimal innovation effort is $t_C = c_C^0$ and c_C falls to zero. In what follows we assume that ψ exceeds both ψ_I^+ and ψ_C^+.

Comparing equations (17) and (18) shows that the relative innovation activity of the two input suppliers in the pure oligopoly depends on their *ex ante* market shares which are determined, in turn, by the relative *ex ante* production costs. In particular, the firm with the lower costs of production at the beginning of the game, enjoys higher market share and invests more in process innovation activity, i.e.,

$$(20) \qquad c_I^0 \leq (>) c_C^0 \implies x_I^0 \geq (<) x_C^0 \implies t_I^* \geq (<) t_C^*$$

Equation (20) captures a standard result in the literature on innovation competition, namely that a firm with an initial advantage eventually becomes a monopolist (see for instance Fudenberg et al and Aoki). Specifically, put in a repeated interaction framework, equation (20) indicates that the firm with an initial cost advantage will enjoy an ever-increasing share of the market since it will undertake relatively higher process innovation activity which will further enhance its cost advantage and, thus, its future innovation activity relative to its rival.

Innovation and Pricing Decisions in a Mixed Oligopoly

In this scenario Supplier C is a cooperative that competes with a profit-maximizing IOF (Supplier I).

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

Similar to the pure oligopoly case, the problem of Supplier I in the 2ⁿᵈ stage of the game is to determine the input price that maximizes its profits given the price of the other supplier and the producer demand for its product. In fact, Supplier I's problem is the same as the one specified in equation (5) and the price that maximizes its profits is given by the equality of marginal revenues with marginal costs of production.

Thus, for any p_C, Supplier I's best-response function is given by $p_I = \dfrac{p_C + \mu + c_I}{2}$.

Unlike Supplier C in the pure oligopoly case, however, the objective of the co-op is to maximize the welfare of its members. Specifically, the problem of the co-op is to determine the price p_C that maximizes the welfare of producers that patronize the co-op at this stage of the game (shown by the shadowed area *MW* in Figure 1) subject to a non-negative profit constraint, i.e.,

$$(21) \quad \max_{p_C} MW\!\left(p_C, p_I\right) = \left(p^F - p_C\right)\!x_C - \frac{1}{2}\mu x_C^{\,2}$$
$$\text{s.t. } \Pi_C \geq 0 \Rightarrow p_C \geq c_C$$

where all variables are as previously defined. Note that equation (21) captures the open-membership nature of the co-op since the co-op takes into account the welfare of all producers that buy its product when determining its optimal strategy at this stage of the game.[7]

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 $p_C = c_C$. Solving the best response functions of the IOF and the co-op simultaneously we derive the Nash equilibrium prices for the inputs, p_I' and p_C'. Substituting p_I' and p_C' into equations (3) and (4) gives the Nash equilibrium quantities for the two competitors as a function of c_I, c_C, and μ. Mathematically, the Nash equilibrium prices and quantities in the price competition subgame are:[8]

$$(22) \quad p_I' = \frac{\mu + c_C + c_I}{2}$$

$$(23) \quad x_I' = \frac{\mu + c_C - c_I}{4\mu}$$

$$(24) \quad p_C' = c_C$$

$$(25) \quad x_C' = \frac{3\mu - c_C + c_I}{4\mu}$$

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

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[7] In an open membership co-op, membership is endogenous in that the decision to join the co-op is up to the producers – the co-op cannot prevent a particular producer from joining. Since the decision to purchase from the co-op is based on the relative returns obtained from purchasing the co-op's product or the IOF's product, a member in this period is effectively anyone that purchases from the co-op.

[8] It should be noted that even if the co-op considered only the welfare of a fixed group of members when pricing its product at stage two, the optimal strategy would still be to price the agricultural input at marginal cost. The reason is that the total welfare of this fixed group of producers is maximized when the input supplied by the co-op is priced at marginal cost. Thus, the equilibrium conditions at the pricing subgame are identical regardless of whether membership is endogenously or exogenously determined.

$$(26) \quad \Pi_I' = \frac{(\mu + c_C - c_I)^2}{8\mu}$$

$$(27) \quad \Pi_C' = 0$$

$$(28) \quad MW' = \left(p^F - c_C\right)x_C' - \frac{\mu x_C'^2}{2}$$

Note that, when compared to the pure oligopoly case, the co-op involvement reduces p_C, p_I

and x_I, while increasing x_C and producer welfare. This result holds for given costs of production c_I and

c_C, however. If the cooperative involvement affects the optimal amount of innovation undertaken by the

two suppliers, it will also affect their cost structures. The next section examines how 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 (1ˢᵗ Stage of the Game)

At this stage the two suppliers seek to determine the amount of innovation to reduce their cost of

production. Maintaining the same assumptions regarding the structure and size of innovation costs

(equation (13) and footnote 6) and the relationship between the amount of innovation and the marginal costs

of producing the input, we can determine the effect of cooperative involvement on innovation activity.

Similar to the pure oligopoly case, the problem of Supplier I (IOF) is to determine the amount of

innovation that maximizes its *total* profits, i.e.,

$$(29) \quad \max_{t_I} \Pi_I^T = \Pi_I' - \frac{1}{2}\psi t_I^2$$

In contrast, the problem of Supplier C (co-op) is to determine the innovation effort that

maximizes the *total* welfare of producers that are members of the co-op (i.e., patronize the co-op) at the

time the investment decisions are being made (i.e., at the beginning of the game). While the co-op knows

that its innovation activity will reduce the production cost (and price) of its product and will attract new

members to the co-op, the welfare of producers who might find it optimal to patronize the co-op *ex post*

(i.e., after the costly investment decisions have been made) is not accounted for by the cooperative. Instead, when the co-op determines its innovation effort at the beginning of the game (in period 1), it seeks to maximize only the welfare of producers that patronize its activity at that point in time.

The assumption that the co-op considers only its period one membership reflects the problem that open membership co-ops have in getting future members to pay for innovation activities. As a number of authors have pointed out (see, for example, Cook, and Porter and Scully), the poorly defined property rights (e.g., the lack of tradable shares) in the open membership co-op make it difficult for the benefits of future members to be reflected in the decisions made today. In this paper, the model assumes that innovation activity is financed through a membership fee levied on the existing membership (see footnote 9). The implication is that the future membership cannot be used as a source of funds and consequently their welfare is not considered when innovation decisions are made. As will be seen, this inability of the co-op to fully internalize the benefits that will accrue to future members has important implications for co-op's innovation effort. Formally, the problem of the co-op can be expressed as:

$$(30) \quad \max_{t_C} MW^T = MW^{0'} - \frac{1}{2}\psi t_C^2 = \left(p^F - c_C\right)x_C^{0'} - \frac{\mu x_C^{0'2}}{2} - \frac{1}{2}\psi t_C^2$$

where $x_C^{0'}\left(=\dfrac{3\mu - c_C^0 + c_I^0}{4\mu}\right)$ is the *ex ante* market share of the co-op, i.e., the share of producers that patronize the co-op prior to (and in the absence of) the innovation activity in period 1.[9] The best response functions of the two input suppliers are:

$$(31) \quad t_I = \frac{\mu + c_C^0 - c_I^0 - t_C}{4\mu\psi - 1} \quad \text{and}$$

$$(32) \quad t_C = \frac{3\mu - c_C^0 + c_I^0}{4\mu\psi}$$

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[9] As noted in the text, implicit in this formulation of the co-op's problem is the assumption that the co-op funds its innovation activity through some sort of fixed membership fee that is elicited at the beginning of the game and is irrecoverable (sunk) once incurred. An alternative formulation could be the one where the co-op incorporates the innovation expenses into the price of its product. In such a case, the price charged by the co-op in the 2nd stage of the game equals the average cost of providing its product (Ramsey pricing). Consideration of this pricing strategy of the co-op reduces the tractability of the analysis considerably, however.

Solving simultaneously the best response functions of the two suppliers we derive the Nash equilibrium levels of innovation in the mixed oligopoly as:

$$(33) \quad t_I' = \frac{4\mu\psi\left(\mu + c_C^0 - c_I^0\right) - \left(3\mu - c_C^0 + c_I^0\right)}{4\mu\psi(4\mu\psi - 1)} \quad \left(= \frac{(4\mu\psi + 1)x_I^{0'} - 1}{\psi(4\mu\psi - 1)}\right)$$

$$(34) \quad t_C' = \frac{3\mu - c_C^0 + c_I^0}{4\mu\psi} \quad \left(= \frac{x_C^{0'}}{\psi}\right)$$

$$(35) \quad t_T' = t_I' + t_C' = \frac{8\mu^2\psi - \left(3\mu - c_C^0 + c_I^0\right)}{2\mu\psi(4\mu\psi - 1)} \quad \left(= \frac{4\mu\psi - 2x_C^{0'}}{\psi(4\mu\psi - 1)}\right)$$

where $x_I^{0'}\left(= \dfrac{\mu + c_C^0 - c_I^0}{4\mu}\right)$ is the *ex ante* market share of the IOF.

Comparing equations (33) and (34) shows that, similar to the pure oligopoly case, the relative innovation activity of the two input suppliers depends on their *ex ante* market shares – the firm with the greater market share at the beginning of the game will exert the higher innovation effort. Unlike the pure oligopoly case, however, there is not a one-to-one correspondence between the *ex ante* market shares and the costs of production at the beginning of the game. In particular, even if the co-op has higher *ex ante* production costs, it can still invest more than the IOF since, because of its pricing strategy, it can enjoy a relatively higher market share. Specifically, the relative innovation activity of the two rivals in the mixed oligopoly is determined as follows:

$$(36) \quad c_I^0 + \mu \leq (>)c_C^0 \;\Rightarrow\; x_I^{0'} \geq (<)x_C^{0'} \;\Rightarrow\; t_I' \geq (<)t_C'$$

Put in a repeated interaction framework, equation (36) shows that if the initial cost difference $(c_C^0 - c_I^0)$ is greater (less) than μ, the result will be ever-increasing (-decreasing) cost differences between the two firms and an ever-decreasing (-increasing) market share for the co-op since the co-op will be investing less and less (more and more) in innovation activity relative to the IOF.

The Effect of Cooperative 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 cooperative involvement on innovation activity and the welfare of the

groups involved (i.e., agricultural producers and input suppliers). The effect of co-op involvement on the

equilibrium amounts of innovation undertaken by the two agricultural input suppliers is shown

graphically in Figure 2.

Figure 2 depicts the innovation reaction functions (best response functions) of the two input

suppliers in the pure and mixed oligopoly cases (equations (15), (16), (31) and (32)) when innovation

costs are relatively high (see footnote 6).[10] It is shown that, when compared to the reaction function of the

profit-maximizing Supplier C in the pure oligopoly (RF_C^i), the reaction function of the co-op ($RF_C^{i'}$) is

shifted outwards while rotating rightwards so that it becomes vertical at $\dfrac{x_C^{0'}}{\psi}$. At the same time,

cooperative involvement affects the profitability of investment in process innovation by the IOF. In

particular, the presence of the co-op shifts the reaction function of Supplier I $RF_I^{i'}$ inwards along the

t_C axis while rotating it rightwards relative to the reaction function of this same supplier when it competes

with another profit-maximizing IOF (i.e., RF_I^i in Figure 2). The outcome of these changes in the reaction

functions is increased innovation activity of the co-op relative to Supplier C in the pure oligopoly, i.e.,

(37) $t_C' > t_C^*$

This result arises because, compared to an IOF in the pure oligopoly, the co-op internalizes the

effect of reduced costs and prices (due to process innovation) on the welfare of its members, thus

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[10] Recall that when innovation costs are relatively low both suppliers will exert maximum innovation effort and reduce their production costs to zero. This is true in both the pure and the mixed oligopoly cases suggesting that, under these conditions, cooperative involvement does not affect the total amount of innovation in the market. However, even though the level of innovation activity in the mixed oligopoly is the same as in the pure oligopoly, the pricing strategy of the co-op reduces the prices of the agricultural input and the profits of the IOF, while increasing the market share of the co-op, and the welfare of all agricultural producers – members and non-members of the co-op.

providing the co-op with a greater incentive to innovate.

Note that the vertical nature of $RF_C^{i'}$ means that the member welfare-maximizing innovation effort of the co-op, t_C', does not depend on the innovation effort exerted by Supplier I. The equilibrium innovation effort of the co-op is determined instead by its *ex ante* market share (i.e., the market share at the beginning of the game, $x_C^{0'}$) and the size of the innovation costs, ψ. In particular, a *ceteris paribus* increase in $x_C^{0'}$ will result in increased t_C'.

Since the innovation by the co-op is a strategic substitute to the innovation by the IOF (recall the downward sloping $RF_I^{i'}$ in Figure 2), the increase in $x_C^{0'}$ will reduce the innovation effort of Supplier I $(\frac{\partial t_I'}{\partial x_C^{0'}} < 0$ - see equation (33)). Comparing equations (17) and (33) shows that, when $x_C^{0'}$ exceeds $\frac{2\mu\psi(18\mu\psi + 1) - 2}{5\mu\psi(12\mu\psi + 3) - 6}$, Supplier I invests less in innovation when it competes with a co-op than when it competes with another IOF, i.e.,

$$(38) \qquad x_C^{0'} \geq (<)\frac{2\mu\psi(18\mu\psi + 1) - 2}{5\mu\psi(12\mu\psi + 3) - 6} \Rightarrow t_I' \leq (>)t_I^*$$

The decrease in t_I' due to an increase in $x_C^{0'}$ outweighs the increase in t_C' (caused by this same increase in $x_C^{0'}$) indicating that an increase in $x_C^{0'}$ reduces total innovation activity in the mixed oligopoly $(\frac{\partial t_T'}{\partial x_C^{0'}} < 0$ - see equation (35)).[11] Thus, the greater is the initial market share of the co-op, the lower is the total innovation activity of the two rivals. Comparing equations (19) and (35) shows that when $x_C^{0'}$

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[11] Total innovation activity falls with an increase in $x_C^{0'}$ because the co-op maximizes *ex ante* member welfare (i.e., the welfare of producers that are members when the investment decisions are made) and does not internalize the effect of its innovation decisions on the welfare of producers that find it optimal to patronize the co-op *after* the investment decisions are made (and the consequent cost and price reductions have been realized). It can be shown that if the co-op was to maximize *ex post* member welfare, total innovation activity in the mixed oligopoly exceeds the one in the pure oligopoly, i.e., $t_T' > t_T^* \quad \forall x_C^{0'}$ (the results are available from the authors upon request).

exceeds $\dfrac{1+2\mu\psi}{3}$, total innovation activity in the mixed oligopoly falls below that in the pure oligopoly

indicating that cooperative involvement reduces the total innovation effort in the market, i.e.,[12]

(39) $\quad x_C^{0'} \leq (>) \dfrac{1+2\mu\psi}{3} \;\Rightarrow\; t_T' \geq (<) t_T^*$

It is important to note that, while cooperative involvement *can* increase the amount of innovation

undertaken by the input suppliers, it is not necessary that total innovation has to increase for farmers to

benefit from the presence of the cooperative – even if the total innovation effort falls in the mixed

oligopoly, producer welfare can still increase in the presence of the co-op. In particular, as long as $x_C^{0'}$ is

less than $\dfrac{1+2\mu\psi+3\mu\psi(4\mu\psi-1)x_C^*}{3}$, $t_T^* - t_T' < \dfrac{3\mu - c_C^* + c_I^*}{3}$ (where c_C^* and c_I^* are the equilibrium

costs of production of the two suppliers in the pure oligopoly case), the price charged by Supplier I falls

in the mixed oligopoly (i.e., $p_I' < p_I^*$) and, given that p_C is also reduced, all producers (members and

non-members of the co-op) realize an increase in their welfare. In particular,

(40) $\quad x_C^{0'} \leq (>) \dfrac{1+2\mu\psi+3\mu\psi(4\mu\psi-1)x_C^*}{3} \;\Rightarrow\; t_T^* - t_T' \leq (>) \dfrac{3\mu - c_C^* + c_I^*}{3} \;\Rightarrow\; p_I' \leq (>) p_I^*$

The effect of the cooperative involvement on the pricing of the agricultural input is shown

graphically in Figure 3 that depicts the price reaction functions of the two input suppliers and the

determination of the Nash equilibrium prices in the pure and mixed oligopoly cases. Specifically, when

Supplier C is a co-op instead of an IOF, its best response function ($RF_C^{p'}$) is constant at c_C (i.e., it is not

a function of the price charged by Supplier I). For Supplier I, a reduction in innovation effort in the mixed

oligopoly case (see equation (38)) increases its production cost and causes a parallel upward shift of its

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[12] Alternatively, expression (39) indicates that total innovation activity falls in the mixed oligopoly (i.e., $t_T' < t_T^*$)

when $\psi < \dfrac{3x_C^{0'} - 1}{2\mu}$.

best response function in the 2nd stage of the game (compare RF_I^p and $RF_I^{p'}$ in Figure 3). When

$t_T^* - t_T' < \dfrac{3\mu - c_C^* + c_I^*}{3}$, the outcome is the reduced price of *both* inputs.

The reduction in the prices of both inputs increases producer welfare by area ΔPW in Figure 4, while the fact that the reduction in p_C exceeds the reduction in p_I results in a reduced market share of Supplier I (IOF) in the mixed oligopoly case. Note that, due to the marginal cost pricing of the co-op and the reduced price-cost margin of the IOF in the mixed oligopoly, 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.

However, p_I increases in the mixed oligopoly when $t_T^* - t_T' > \dfrac{3\mu - c_C^* + c_I^*}{3}$. In this case, producers that are not patronizing the co-op see a reduction in their welfare and they would be better off if an IOF were to replace the co-op.

The Effect of Capital Constraints on Cooperative Innovation

The analysis of the mixed oligopoly in the previous section examined a critical co-op feature, namely that its ownership structure provides it with a different objective function (i.e., the maximization of member welfare) than an IOF. In addition to altering the objective function, the co-op's ownership structure has other implications for its innovation decisions. Due to its collective nature and to limitations on its members' ability and/or incentive to provide capital, a co-op might face capital constraints (Chaddad and Cook). Property right and free-rider problems might make internal financing difficult to attract[13] while the inability of external investors to exercise control over the co-op's assets might make external financing costly. The impact of the capital constraint problem on the co-op's innovation decision can be examined using the framework of analysis developed above.

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[13] For instance, while the potential for free-rider problem exists (each member would like to see the other members make the investment while not having to make the investment themselves), all of the stage one membership would be willing to make the investment if this is required of *all* members (since making the investment is beneficial to each member). Solving the problem of how all members can be made to pay the fee that finances the innovation activity may be one of the reasons for the higher cost of capital faced by the co-op.

In particular, the difficulties that a co-op might have in raising capital for innovation activity can be examined by increasing ψ_C relative to ψ_I (where ψ_C and ψ_I are the parameters of the innovation cost function for the co-op and IOF, respectively). That is, the capital constraint problem can be viewed as a situation in which the co-op's effective cost of innovation has increased relative to that of the IOF. Simply put, the more binding is the capital constraint, the higher is the opportunity cost of capital, and hence the larger is ψ_C. Of course, the co-op's cost of innovation may be higher (or lower) than the IOF for other reasons. In the analysis that follows, the examination of higher co-op innovation costs is used to capture the impact of the capital constraint problem as well as any other factors that raise the co-op's cost of acquiring capital for innovation activity.

The implications of introducing differences in innovation costs between the co-op and the IOF in our analysis are quite straightforward – the greater are the innovation costs for the co-op, the lower are the potential productivity and social welfare gains from the presence of the co-op. In particular, an increase in ψ_C causes a parallel inward shift of its innovation best response function ($RF_C^{i'}$ in Figure 2).[14] The outcome is reduced innovation activity by the co-op and this reduction outweighs the increased amount of innovation undertaken by the IOF because the absolute value of the slope of $RF_I^{i'}$ is less than 1. Thus, increased innovation costs of the co-op reduce the total innovation activity in the market – the greater are the innovation costs of the co-op, the lower is the total amount of innovation undertaken by the two rivals.

The reduction in the co-op's innovation due to higher innovation costs increases its cost of providing the input, c_C , and thus, the price faced by agricultural producers, p_C . Graphically, the increased price of the co-op can be seen as a rightward shift of the co-op's price reaction function $RF_C^{p'}$ in Figure 3. Since the IOF's price reaction function, $RF_I^{p'}$, is upward sloping (i.e., the price of the co-op is a strategic complement to the price charged by the IOF), the increase in p_C causes p_I to also increase,

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[14] Note that when innovation costs differ between the two rivals, the best response functions of the IOF and the co-op can be derived by substituting ψ_I and ψ_C for ψ in equations (31) and (32), respectively.

albeit to a lesser degree.[15] This greater increase in p_C results in a reduced market share of the co-op, while the fact that both the IOF's and the co-op's prices increase means that all producers lose when co-op's innovation costs rise.

Relative to the pure oligopoly outcome of innovation competition, it can be shown that when the co-op's innovation costs are above a critical level $\psi_C^x = \dfrac{3\psi_I(2\mu\psi_I - 1)x_C^{0'}}{2\mu\psi_I(3x_C^{0'} - 1) - 1}$, the total innovation activity in the mixed oligopoly falls below that in the pure oligopoly (i.e., $t_T' < t_T^*$). As long as the innovation costs are below $\psi_C^{xx} = \dfrac{3\psi_I(2\mu\psi_I - 1)x_C^{0'}}{2\mu\psi_I(3x_C^{0'} - 1) - 1 - 3\mu\psi_I(4\mu\psi_I - 1)x_C^*}$, however, $t_T^* - t_T' < \dfrac{3\mu - c_C^* + c_I^*}{3}$, and both the IOF's and the co-op's prices will fall in the mixed oligopoly (see Figure 3), i.e., cooperative involvement increases the welfare of all agricultural producers when $\psi_C < \psi_C^{xx}$.[16] However, if ψ_C exceeds ψ_C^{xx}, then p_I increases in the mixed oligopoly and producers that are not patronizing the co-op see a reduction in their welfare. Thus, if the co-op's innovation costs are sufficiently large, some of the producers would be better off if a lower-cost IOF were to replace the co-op.

Interpreting the Results: A Link to the Literature

Before concluding the paper, it is useful to compare and contrast our findings with the results of the literature on innovation activity in mixed oligopolies mentioned in the introductory section of the paper. In particular, this section focuses on total innovation expenditures in the mixed duopolies, on the distribution of R&D expenditures between the competing firms, and on the ability of firms that pursue objectives other than profit-maximization to effectively compete with an IOF.

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[15] The increase in p_I is less than the increase in p_C for two reasons. First, the slope of $RF_I^{p'}$ is less than 1 and, second, the increased innovation activity of the IOF reduces c_I and, thus, the intercept of $RF_I^{p'}$ in Figure 3.

[16] Expressed in terms of the initial market share of the co-op, the results show that total innovation falls in the mixed oligopoly (i.e., $t_T' < t_T^*$) when $x_C^{0'} > \dfrac{(1 + 2\mu\psi_I)\psi_C}{3\psi_I[2\mu(\psi_C - \psi_I) + 1]}$. As long as $x_C^{0'} < \dfrac{[(1 + 2\mu\psi_I) + 3\mu\psi_I(4\mu\psi_I - 1)x_C^*]\psi_C}{3\psi_I[2\mu(\psi_C - \psi_I) + 1]}$, however, input prices fall in the presence of the co-op (since $t_T^* - t_T' < \dfrac{3\mu - c_C^* + c_I^*}{3}$) and producer welfare rises.

Similar to Poyago-Theotoky, who finds that the introduction of a public firm leads to a reversal of the underinvestment in R&D that occurs in a pure oligopoly, the analysis in this paper shows that the introduction of a co-op can also lead to increased R&D activity, providing certain conditions are met (see equation (39)). The basic result that R&D spending can increase follows directly from the somewhat similar objective functions of the public firm and the co-op (each incorporates the welfare of at least some of those consuming the good). In Poyago-Theotoky's model, the fact that the public firm fully internalizes the costs and benefits of R&D activity means that total R&D spending always increases. [17] In the model of this paper, however, an increase in total R&D spending does not always occur. The reason is that the open membership co-op can only partially internalize the costs and benefits of innovation, thus underscoring the importance of modeling this specific organizational attribute. This partial internalization occurs because the membership that funds the innovation activity *ex ante* is less than the group of producers that benefit from the innovation. As mentioned previously (see footnote 11), innovation activity will always increase if the impact of innovation on the *ex post* membership is fully accounted for when the innovation decisions are being made.

Like Poyago-Theotoky, this paper also shows that the co-op invests more than its IOF counterpart does in the pure oligopoly (see equation (37)). Unlike the IOF that reduces its innovation activity when competing with a public firm however, an IOF competing with a co-op can either increase or decrease its innovation activity relative to the pure oligopoly case (see equation (38)). Finally, similar to the case examined in Poyago-Theotoky, an increased investment by the co-op in the mixed market crowds out IOF investment. Because the co-op more fully internalizes the benefits of innovation than does an IOF operating in the same market, the co-op will exert higher innovation effort than its IOF counterpart provided that the (production and innovation) costs of the two firms are the same (see equation (36)). Since the rival's innovation is a strategic substitute to the profit-maximizing innovation of the IOF in both this

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[17] In Poyago-Theotoky's model, the underinvestment in R&D in the pure duopoly case results because each firm can easily imitate innovations discovered by the other firm. When innovations are not easily imitated and firms engage in a patent race, the pure duopoly results in over investment. Under these circumstances, Delbono and Denicolò show that a public firm can result in reduced R&D expenditures, again because the public firm more fully internalizes the costs and benefits. See Beath et al. for a general model of these results for the pure duopoly case.

paper and in Poyago-Theotoky's paper, an increase in innovation activity by the co-op/public firm results in reduced expenditures by the IOF (recall the downward sloping reaction function $RF_I^{i'}$ in Figure 2).

The observation that rival innovation expenditures are strategic substitutes to the innovation effort of the IOF provides a link to the paper by Neary and Ulph. In their paper, Neary and Ulph show that a labor-managed firm (LMF) cannot be forced from the market by an IOF, a result that derives directly from the difference in the strategic nature of innovation expenditures by the LMF and the IOF – while innovation by the LMF is a strategic substitute to the innovation by the IOF, the IOF's innovation effort is a strategic complement to the amount of innovation undertaken by the LMF (an outcome that derives directly from the LMF's closed membership). The result is that increased innovation by the IOF leads to increased innovation expenditures by the LMF, which in turn leads to decreased innovation by the IOF.

This paper derives a somewhat similar result – as long as the co-op does not face too much of an initial cost disadvantage (see equation (36)), it can compete effectively with an IOF and can continue to operate in the industry. However, survival of the co-op is not assured under all conditions. If the co-op's initial market share is too low, the co-op can eventually be driven from the market, since the smaller is the market share, the less is the innovation undertaken and the less competitive is the co-op vis-à-vis the IOF. This contrasting result to that in Neary and Ulph derives directly from the vertical nature of the co-op's reaction function, which in turn stems from the difficulty that open membership co-ops have in getting future members to finance innovation activity. Thus, the co-op's organizational structure has important implications for its behavior and success in the market.

Concluding Remarks

This paper develops a sequential game theoretic model of heterogeneous producers to examine the effect of cooperative involvement on innovation activity in the agricultural input-supplying sector. Specifically, the paper analyzes the consequences of the involvement of an open membership cooperative 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 cooperative involvement in innovation activity *can* be productivity and welfare enhancing. The presence of the member welfare-maximizing co-op – which replaces a profit-maximizing IOF – can increase the arrival rate of innovations and productivity growth while reducing the prices of agricultural inputs. The effect of cooperative involvement, however, depends on the initial market share of the co-op and the size of its innovation costs.

In particular, the greater is the initial market share of the co-op, the greater is its innovation activity and the lower is the IOF's innovation activity. The reduction in IOF's innovation effort outweighs the co-op's increased innovation, resulting in total innovation falling with an increase in the co-op's initial market share. Total innovation effort also falls when the co-op faces higher innovation costs than the IOF. When the initial market share of the co-op or/and its innovation costs are too high, cooperative involvement is shown to reduce the amount of innovation below the level that would emerge under a pure oligopoly and the possibility arises that at least some producers would be better off in the absence of the input-supplying co-op.

In addition to identifying the ramifications from cooperative involvement in innovation activity, the results of this paper underscore the importance of costs in allowing the co-op to survive and meet its members' needs. A co-op is vulnerable to being driven from the market by an IOF if it is unable to keep pace with the IOF in terms of lowering its marginal cost of production; alternatively, it can be successful if it is able to make the required investments in innovative activity. As a result, cooperatives are correct to focus attention on capital availability and member willingness to invest, since these are critical to the co-op's ultimate survival. As well, since the amount of innovation undertaken by the cooperative affects the prices charged by both it and the IOF, and consequently the profits of the IOF and the welfare of all agricultural producers, the factors affecting co-op innovation activity are of interest to all players in the agricultural industry.

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Net Returns to Production

$p^F - p_C$

μ

$p^F - p_I$

Π_I^F

Π_C^F

MW

$p^F - p_C - \mu$

μ

$p^F - p_I - \mu$

x_I

x_C

0   a_I 1
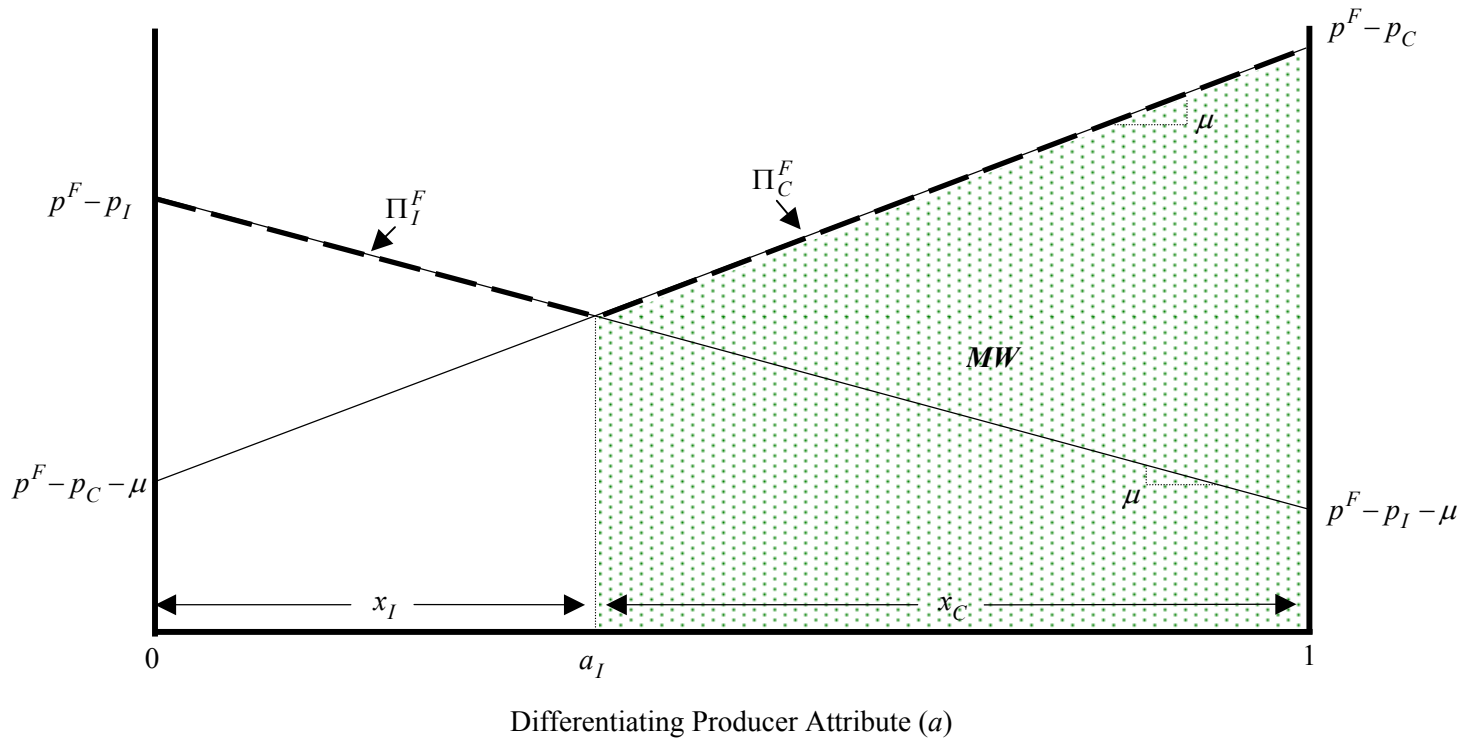
Differentiating Producer Attribute (a)
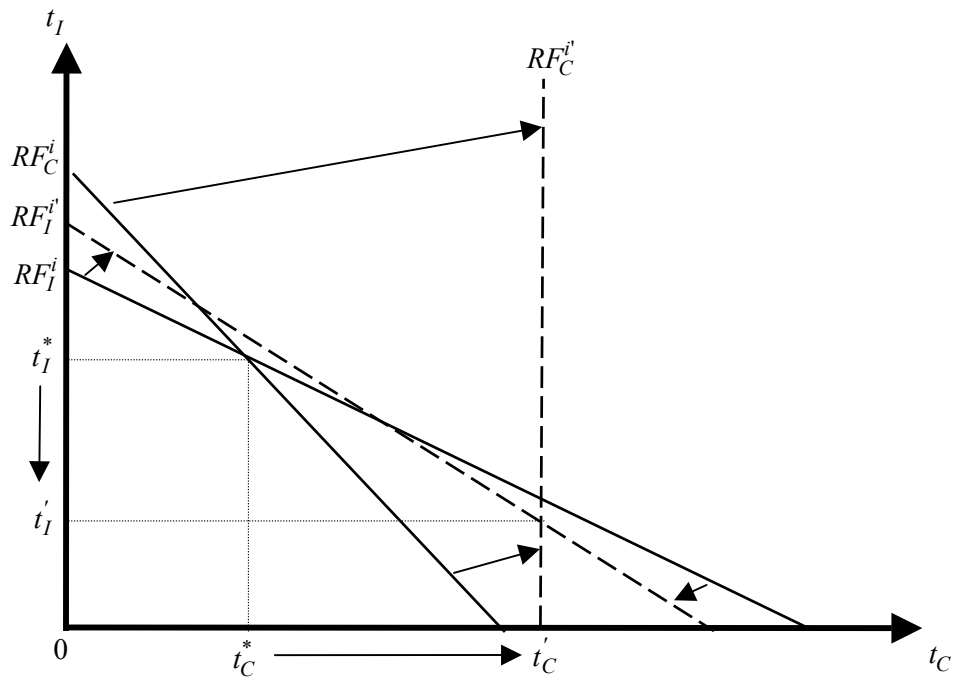
Figure 1. Producer decisions and welfare

Figure 2. Effect of cooperative involvement on innovation activity
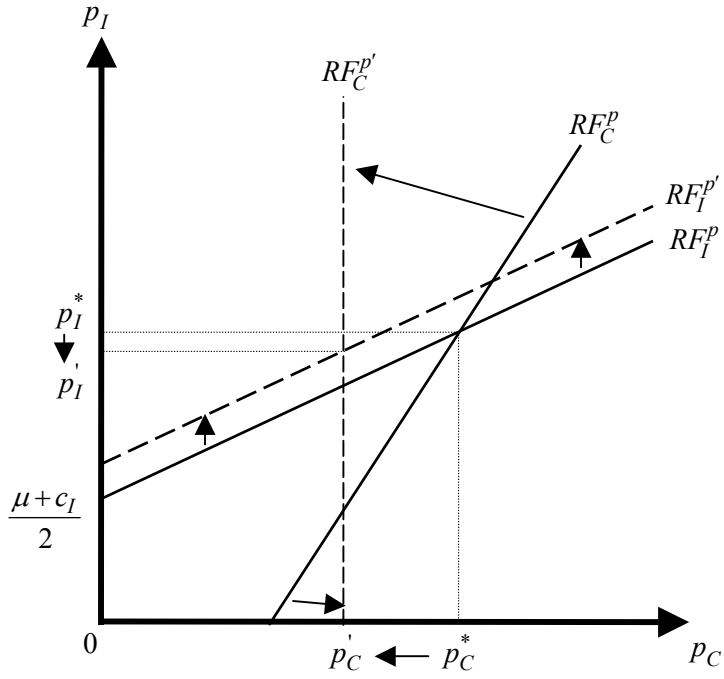
Figure 3. Effect of cooperative involvement on input pricing ($t_T^* - t_T^{'} < \dfrac{3\mu - c_C^* + c_I^*}{3}$)

Net Returns

$p^F - p_C'$

$p^F - p_C^*$

$p^F - p_I'$

$p^F - p_I^*$

ΔPW

x_I'

x_I^*

x_C'

x_C^*

0

a_I'

a_I^*

1

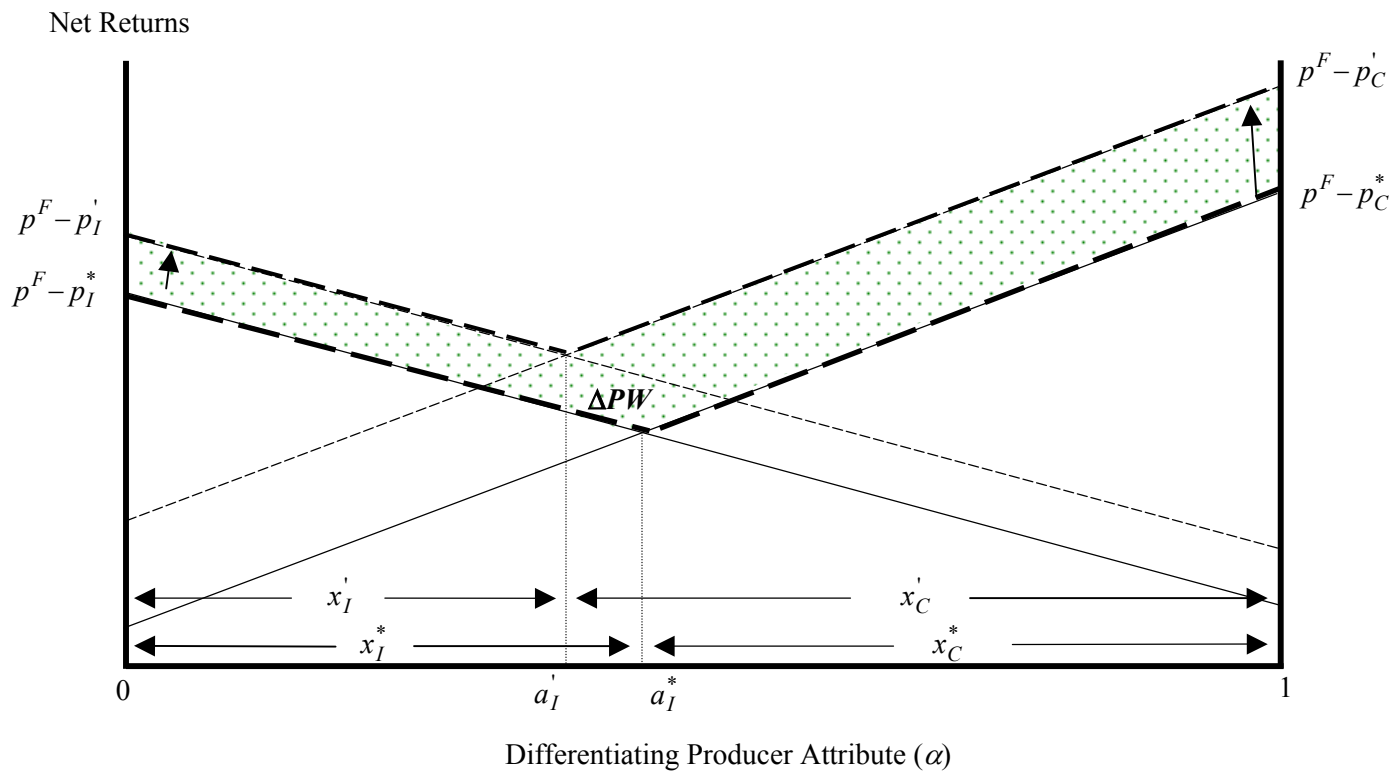Differentiating Producer Attribute (α)

Figure 4. Market and welfare effects of cooperative involvement in innovation ($t_T^* - t_T' < \dfrac{3\mu - c_C^* + c_I^*}{3}$)