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R&D Incentives in an Upstream-Downstream Structure

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R&D Incentives in an Upstream-Downstream Structure

Abstract

This paper studies R&D incentives of a non-producing firm in an upstream-downstream structure for three types of technologies, viz., upstream technology, downstream technology and common technology (which is usable in both streams). We consider both the cases of exogenous and endogenous innovation. In case of common technology innovation, we have also studied the effect of spillovers. In particular, we show that transfer to only upstream firm can be optimal. We have contrasted the results with those when an insider (i.e., upstream or downstream) firm is engaged in research. The size of the innovation can be larger compared to third firm R&D case. While there can be a conflict between private and socially optimal choice of technology, we show that socially optimal choice is implementable.

Keywords: Vertical structure; R&D and process innovation; Upstream, downstream and common technology innovation; Spillovers.

JEL Classification: D43; L13; O30.

R&D Incentives in an Upstream-Downstream Structure

1. Introduction

The importance of technology and technological progress is well recognised after the pioneering work of Solow (1957). Why some countries are growing fast while other countries are lagging behind is generally explained in terms of asymmetric technological development across countries. In another work, Solow (1956) has shown the importance of technological progress in raising the per capita income and economic growth. However, in his model, technological progress is exogenous. However, it is now well-known that technological progress is not like a falling manna from heaven; a well-coordinated and well directed effort is required for advancement of technology and knowledge. It involves huge expenses and efforts, yet the outcome is often uncertain, that is, there is no guarantee that after well-coordinated investment in research and development (R&D), a successful outcome will be achieved. Even when a success occurs in innovation, there is no guarantee that the R&D investors will be able to recover the R&D cost because of the problem of spillover and imitation of technology.

Then the important question is what determines the R&D incentive of a firm. Long ago Schumpeter (1943) tried to identify the link between market structure and R&D incentive of a firm. He propounded that 'creation of monopolies' is needed to induce firms to invest in R&D. This calls for patent protection of new innovations at least for a specified period. Towards the relation between market structure and R&D incentive the pioneering contribution is by Arrow (1962). It shows that a competitive firm has larger incentive for R&D than a monopoly firm. The reason is that the monopolist 'replaces himself' whereas a competitive firm emerges as a monopolist after innovation. However, if the incumbent monopolist is threatened by potential entrants who can acquire the new technology, the existing monopolist will have a larger incentive than an entrant has (Gilbert and Newberry, 1982). However, if uncertainty is incorporated in the model, Reinganum (1983) has shown, the result can be reversed. Reinganum has a series of works on the issues of market structure, innovation, diffusion and adoption. A summary is found in Reinganum (1989).

Since uncertainty plays a very significant role in the determination of R&D investment, economists have tried to model uncertainty in several ways. The simplest way is to consider that an innovation occurs with an exogenously given probability. However, the probability of success can be endogenized by assuming an R&D technology that non-negatively relates probability to R&D investment. Another standard approach is to introduce a dynamic process in the R&D interaction. The simplest of these models makes R&D expenditure and the associated probability of success a memory-less Poisson process. There are several works in the area of patent race where the R&D process is necessarily a memory-less Poisson process (see for instance, Loury, 1979; Dasgupta and Stiglitz, 1980; and Lee and Wilde, 1980). The main idea is that the probability of success depends only on the present expenditure by the firm and not on what had happened in the past. Dasgupta and Stiglitz (1981) also explored the avenue of R&D frequency and magnitude in alternative market structures in a long run set up with the possibility of entry and exit of firms.

We have already mentioned that existence of spillovers in R&D can affect R&D investment of an investor. The presence of spillovers implies that if one firm reduces its cost by its R&D investment, the other firms may enjoy a cost reduction in their production, at least partially, without any additional cost. This means that the investors can't appropriate the full benefit of its R&D investment due to spillovers. There are a number of works which discuss R&D interaction in an oligopoly with spillovers. These papers examine whether cooperative R&D can prevent under-investment in R&D. For instance, d'Aspremont and Jacquemin (1988) have considered a duopoly and have shown that when the R&D firms also compete non-cooperatively in the product market, cooperative R&D investment is higher than non-cooperative R&D investment. Suzumura (1992) has extended the work to the case of more than two interacting firms with more general spillover assumption. To the extent that R&D spillover can intensify competition in the product market, Shibata (2014) has explicitly modelled the impact of varying degree of competition on the relationship between market competition and R&D investment in the presence of spillovers.

Another important feature of technological innovation is that once an innovation occurs it possesses a public good character in the sense that the same technology once innovated can be used by many and simultaneously. Hence a private investor whose technology is protected by a patent has an incentive to license its technology to other firms and even sometimes to its product market rivals. There are a number of works that discuss R&D incentives of a firm given that it can license its technologies to the potential customers and thereby can appropriately charge a price for technology in the form of fee or royalty or both. This literature includes patent transfer under optimal contracts.

Among the earlier works, Katz and Shapiro (1985) have studied the incentive to innovate and license from an upstream research laboratory to two downstream rivals. The firm which acquires the patent from the upstream firm can license it to the non-owner by fixed fee and then they compete in the final product market. The upstream laboratory sells the patent by auctioning. It is shown that major innovations will not be licensed but minor innovations will be licensed between efficient firms.

Patent licensing from an outside innovator to an oligopoly is discussed in Kamien and Tauman (1986) and Katz and Shapiro (1986). The papers also discuss the number of licences to be issued. Wang (1998) has studied technology licensing in a duopoly where the innovator is an insider (i.e., producing firm). Shinkai et al. (2005) discuss licensing and R&D investment in the presence of partially complementary technology. Patent protection may not be perfect; hence an innovation can be invented around. Mukherjee (2006) studies the incentives to perform R&D in a duopoly structure where the producers themselves conduct R&D. The paper considers two situations, one where the rival can imitate the new technology, and the other where the patent holder can license the innovation to the rival by means of optimal royalty. In both cases, it is shown, the R&D incentives increase when there is patent protection. Technology licensing in a Stackelberg structure is discussed in Kabiraj (2004, 2005)

Very recently, Sinha (2016) has studied technology licensing to an asymmetric duopoly from an outsider R&D investor. The paper considers two types of technologies. The common technology, he defines, is the usual cost reducing process innovation, which reduces the unit cost of the users by the same amount. The other is a completely new technology. The paper considers optimal licensing contract. One important result of the paper is that for either technology the outsider firm does better by selling the patent of the non-drastic innovation to the efficient firm which then licenses it to its competitor. However, for drastic innovation the innovator sells the patent to either of the firms and there will be no further licensing. The prospect of licensing naturally affects the decision of R&D investor.

However, none of the works mentioned above discusses R&D incentives in an upstream-downstream structure. An upstream firm produces inputs for a downstream firm which produces final goods using upstream inputs and some other inputs. The upstream firm appropriately charges a per-unit price for its inputs, and the downstream firm decides the optimal price (and quantity) of the final product. Given this interrelation between the firms, any innovation that affects the production cost of the upstream or downstream firm will affect the decision of both firms. So we can think of a technology that reduces production cost of the upstream or downstream firm only or that of each stream firm. The latter case is possible when an innovation reduces production cost of a common input used by both the upstream and the downstream firms in the production of their respective goods. For instance, steel produced by the upstream firm is sold to the downstream firm producing locomotives, cars, furniture, etc. On the other hand, input like electricity is required for both upstream and downstream production. In the appropriate place (see section 2) we have defined formally what we mean by upstream, downstream and common technology innovation. The upstream technology innovation is relevant only to the upstream firm and it reduces upstream production cost, while downstream technology innovation relevant to downstream firm reduces downstream production cost. But in case of common technology innovation any stream firm, if it adopts the technology, can reduce its production cost.

Now the question is: which firm will take up the R&D activity? Consider that there is a third firm, call R&D firm, which invests in R&D activity. If it cannot take up more than one R&D project at a time due to budget constraint, it will take up the project either for upstream technology innovation, or downstream technology innovation, or for the common technology innovation. In that case the question is: which technology innovation will it go for? How does the incentive depend on the market structure, that is, whether the market is integrated or disintegrated? In case of common technology innovation, will it transfer to only upstream firm or downstream firm, or to both stream firms? In case of common technology transfer there is a possibility of spillovers of knowledge. How does it affect the R&D decision? From the social point of view which project (upstream or downstream innovation) is more valuable? We discuss these issues in the present paper. It is also possible to think that the innovator is an insider instead of being an independent R&D firm. In this case the upstream technology will be innovated by the upstream firm and the downstream technology by the downstream firm. However, the common technology possibly can be innovated by either firm. Which firm will then have larger incentives for R&D? We also extend the analysis when the innovation is endogenous, that is, the size of the innovation is determined endogenously. We consider only process innovation.

Thus in this paper we consider interaction of upstream and downstream firms and an R&D firm. In our analysis we have also discussed the case when R&D investment is done by an insider, that is, upstream or downstream firm. The R&D incentives can differ in these two situations. In this study we come up with the following results. We find that the incentive of an outside innovator is higher for the upstream technology than for the downstream technology, provided the cost of the upstream technology innovation is not too high. The profit of the innovator could further be larger if the market is integrated. We have also shown that the socially optimal choice of technology can differ from the one which is privately optimal. In the case of common technology innovation there is the possibility of spillovers of knowledge. It is shown that with spillovers the common technology is licensed to only one firm, although it has the option to license to both. We, however, restrict to the assumption that technology can be transferred only at a non-discriminatory price. Since in our case technology transfer is equivalent to sale of the patent, we consider transfer against a fixed fee only. When the innovation size is endogenized, we have fully characterized the size and the choice of technology. In this case we find that when the innovation is carried out by the downstream firm in common technology, the size of the innovation can be higher than that when the outsider firm or the upstream firm innovates. In this paper we are concerned with the questions like which firm develops the technology, which technology be developed, what changes are brought about by endogeneity and spillovers, etc. All these are important issues in the context of choice of R&D investment.

There are some recent papers which also discuss R&D incentives of a firm in a vertical structure, hence are related to our present work. At least two papers may be mentioned here. First consider the paper by Chen and Sappington (2010). It considers a framework of one upstream input supplier and two downstream firms; the upstream monopolist is also allowed to compete with the downstream competitors. The paper shows that how the vertical industry structure may influence upstream process innovation depends on the form of downstream competition. The vertical integration will increase R&D incentive if there is Cournot competition in the downstream market, but it will fall under Bertrand competition. Saboori-Memar and Gotz (2013), on the other hand, consider a bilateral duopoly set up with two (upstream) manufacturers and two (downstream) retailers; but only one firm, either from upstream or from downstream, can invest in R&D. Given that the firms produce and sell differentiated products, the paper shows that the incentives to invest in process R&D depends on the intensity of both inter-brand and intra-brand competition.

In contrast, in our paper there is monopoly in each stream, hence competition is not playing any role. We focus on the vertical structure and the externalities associated with it. R&D investment in our paper is made by an independent third firm. We discuss different types of technological innovations in this context. It can be specific to upstream production or downstream production, or can be a common technology innovation relevant to both stream of firms. The size of the process innovation is exogenously fixed or endogenously determined, and there are spillovers in case of common technology innovation. We study how each of these factors may affect the R&D decision. We have contrasted our results with those when insider is the innovator.

The layout of the paper is the following. In section 2 we set up the model and present the benchmark results. In section 3 we discuss R&D incentives of an R&D firm for upstream and downstream technology innovations. Section 4 introduces common technology innovation with and without spillovers. Finally, section 5 concludes the paper. Some proofs are relegated to appendix.

2. Analytical Framework

Consider a vertical structure with one upstream input producing firm and one downstream final good producer. The upstream firm (U) produces input B at a unit cost $b > 0$ and sells it to the downstream firm (D) at an appropriate price per unit, say w. The downstream firm, in addition to B inputs, uses some other inputs (call them together C) for which it has an additional cost of c and it produces the final good using both B and C.

We assume that R&D investment will reduce either upstream or downstream production cost or both stream production costs. We define that an innovation that results in reducing upstream production cost is called upstream technological innovation. Similarly, downstream technological innovation reduces downstream production cost. Therefore, upstream or downstream technology is specific to the respective stream. On the other hand, we define a common technology innovation that would result in reducing production cost of any stream that uses the technology.[1] To define these more formally, let us consider the following.

Let us suppose that the upstream firm produces B using a specific input X, and a common input E (like electricity), and the downstream firm produces final goods using the upstream input B, the common input E, and a specific input, Y. Let us assume that initially X, Y and E are available in the market at unit prices u, d and r respectively. Alternatively, we may assume

[1] It will be clear very soon that the concept of common technology we are introducing in this paper is different from the concept used in Sinha (2016).

that these are produced in-house by the respective firms at those cost. Hence, initially we have $b = u + r$ and $c = d + r$, and the unit cost of downstream final good production is $c + w$.

We may then define a technology that reduces the use of X input in B production as the upstream technological innovation. Similarly, a technology that reduces the use of Y input is the downstream technological innovation. If X and Y are initially produced by the upstream and downstream firm respectively, we can alternatively define the upstream and downstream technological innovations as follows. Technology that reduces production cost of X (that is, u) is the upstream technological innovation. Similarly, technological innovation that reduces production cost of Y (hence d) is the downstream technological innovation. If we denote by ε, ($\varepsilon > 0$), the size of the innovation, that is the extent of cost reduction by a technological innovation, then in either way defined, an upstream technological innovation reduces the unit cost of producing input B from b to $b - \varepsilon$, and a downstream technological innovation reduces the cost of downstream final good production by the amount ε by means of reducing c to $c - \varepsilon$.

Finally, to define a common technological innovation (which will be useful for both upstream and downstream production) we restrict to the assumption that there is a common input E (like electricity) required to produce each stream of output, and that both stream firms first produce the common input in-house and then this input is used to produce the end product of that stream. Then a technological innovation that reduces the unit cost of the common input production is called common technological innovation. Since such a technology results in reducing cost of the common input from r to $r - \varepsilon$, ultimately this actually reduces b to $b - \varepsilon$ and c to $c - \varepsilon$ if this technology is adopted. For our analysis we restrict to the assumption that ε cannot exceed b or c (that is, $0 < \varepsilon \leq \min\{b, c\}$)

We further assume that the market demand function is linear and in inverted form given by

$$P = a - Q \qquad (1)$$

where $a > 0$ is the demand parameter representing market size and Q is quantity demand at price P. The technology parameters b and c are determined by the current technologies of the respective input production. We assume $a > b + c$. To simplify the notations we denote $\alpha = a - b - c$. Then the pre-innovation equilibrium, as the benchmark case, is presented below.

<u>Benchmark Case: Pre-innovation equilibrium</u>

Let w be the price charged by U to D for selling input B. Then for any w, the marginal cost as faced by D is $w + c$. Hence its problem is:

$$\max_{Q}(a - Q)Q - (w + c)Q$$

The F.O.C. to this problem will yield

$$Q(w) = \frac{a-w-c}{2} \tag{2}$$

The SOC is necessarily satisfied. Now given firm D's behaviour by (2), U's problem is:

$$\max_{w}(w - b)Q(w)$$

The optimal w to the problem can be easily solved to get

$$w^0 = \frac{(a-c+b)}{2} \tag{3}$$

Given our notation $\alpha = a - b - c$, the optimal values of the respective variables are obtained as follows:

$$w^0 = \frac{\alpha+2b}{2}, \quad Q^0 = \frac{\alpha}{4}, \quad P^0 = \frac{(3a+b+c)}{4}$$

Finally, the initial payoffs of U and D are:

$$\pi_U = \frac{\alpha^2}{8} \text{ and } \pi_D = \frac{\alpha^2}{16} \tag{4}$$

If we consider the integrated market structure, then the integrated firm will face the marginal cost $b + c$. Hence its problem is:

$$\max_{Q}(a - Q)Q - (b + c)Q$$

Then the optimal values of Q, P and profit of the integrated firm will be:

$$Q_I = \frac{\alpha}{2}, \qquad P_I = \frac{a+b+c}{2}, \qquad \pi_I = \frac{\alpha^2}{4} \tag{5}$$

In the following sections we shall now study incentives for innovation under different scenarios. We assume that R&D investment is made by an independent research firm (R) which is a non-producing firm. However, we also derive implications of the results if the relevant technology is innovated by the upstream or downstream (as the case may be) firm. In the analysis we shall consider the cases when the size of the innovation is exogenously specified and the outcome is deterministic and when the size of the innovation is endogenously determined.

3. R&D Incentives for Upstream and Downstream Innovations

In this section we discuss R&D incentives for upstream and downstream technology innovations under two scenarios, viz., innovation is exogenous, and innovation is endogenous. The size of the innovation denoted by $\varepsilon > 0$ is the extent of cost reduction for the respective technologies. We assume that innovation is done by an R&D firm which after innovation transfers the technology to the respective firm to whom it is relevant. Here transfer is equivalent to sale of patent, hence transfer occurs against a fixed fee. However, the innovator is assumed to have limited fund for R&D investment; so it cannot take up more than one investment project at a time.

3.1 Exogenous Innovation and R&D Incentives

Let us assume that if the independent R&D firm, R, invests in either upstream or downstream technology, it comes up with an innovation which reduces the unit cost of production of that stream by an exogenously specified amount $\varepsilon > 0$. We restrict to $0 < \varepsilon \leq \min\{b, c\}$. The corresponding R&D investments required for this size of the upstream and downstream technological innovations are respectively I_U and I_D. Firm R is not a producing firm; hence it can enjoy rent only by transferring its technology. Since technology transfer occurs against a payment of fixed fee by the transferee, the innovator's incentive for a particular technology is measured by the maximum amount it can extract from the respective upstream or downstream firm. If the upstream technology is innovated, the upstream firm comes up with marginal cost $b - \varepsilon$; similarly, the downstream technology results lowering c to $c - \varepsilon$.

When the upstream firm adopts the innovated upstream technology, its gross payoff (before deduction of fee for the technology) as a function of the relevant parameters is $\pi_U(b - \varepsilon, c) = \frac{(\alpha+\varepsilon)^2}{8}$. Similarly, the gross payoff of the downstream firm using downstream technology is $\pi_D(b, c - \varepsilon) = \frac{(\alpha+\varepsilon)^2}{8}$. Hence the maximum fee that the R&D firm can extract from its upstream innovation is

$$F_U = \pi_U(b-\varepsilon, c) - \pi_U(b,c) = \frac{(\alpha+\varepsilon)^2}{8} - \frac{\alpha^2}{8} = \frac{\varepsilon(2\alpha+\varepsilon)}{8} \quad (6)$$

Similarly, the downstream technology will generate a maximum fee of the amount

$$F_D = \pi_D(b, c-\varepsilon) - \pi_D(b,c) = \frac{(\alpha+\varepsilon)^2}{16} - \frac{\alpha^2}{16} = \frac{\varepsilon(2\alpha+\varepsilon)}{16} \quad (7)$$

So if $F_U \geq I_U$ and $F_D \geq I_D$, both the technologies will be feasible. The incentives of the R&D firm for these technologies are respectively, $(F_U - I_U)$ and $(F_D - I_D)$. Note that $F_U > F_D$.

Proposition 1: *When both the technologies are feasible, the R&D firm will have a larger incentive for upstream technology innovation whenever* $(F_U - F_D) \geq (I_U - I_D)$*, otherwise downstream innovation will occur.*

Corollary 1: *If* $I_U \leq I_D$*, upstream technology innovation is necessarily preferred by the R&D firm.*

The implication of this result is that if upstream innovation is not much costly compared to downstream innovation, then upstream innovation is likely to occur.

One important feature of the upstream-downstream structure is that when one stream firm adopts the technology, the other stream firm necessarily gains. For example, if U adopts the upstream technology, the downstream firm gains by the amount

$$\Delta\pi_D^U = \pi_D(b-\varepsilon, c) - \pi_D(b,c) = \frac{(\alpha+\varepsilon)^2}{16} - \frac{\alpha^2}{16} = \frac{\varepsilon(2\alpha+\varepsilon)}{16} \quad (8)$$

When D adopts the downstream technology, the downstream firm gains by the amount

$$\Delta\pi_U^D = \pi_U(b, c-\varepsilon) - \pi_U(b,c) = \frac{(\alpha+\varepsilon)^2}{8} - \frac{\alpha^2}{8} = \frac{\varepsilon(2\alpha+\varepsilon)}{8} \quad (9)$$

Therefore, technology adoption is gainful to both, irrespective of whether it is upstream or downstream technological innovation.

To the question of whether the innovator prefers integrated structure or disintegrated structure, we find that under integration whichever be the technology adopted by the integrated firm, its gross payoff is the same and is equal to $\pi_I(b+c-\varepsilon) = \frac{(a-b-c+\varepsilon)^2}{4}$. Hence the maximum fee under integrated market structure, that can be extracted, is

$$F_I = \pi_I(b+c-\varepsilon) - \pi_I(b+c) = \frac{(a-b-c+\varepsilon)^2}{4} - \frac{(a-b-c)^2}{4} = \frac{\varepsilon(2\alpha+\varepsilon)}{4} \quad (10)$$

Since we have $F_I > F_U > F_D$, we have the following proposition.

Proposition 2: *For any innovation, upstream or downstream, integrated structure generates a larger incentive for R&D than the disintegrated structure does.*

In Proposition 1 we have already seen that the R&D firm will go for upstream innovation (downstream innovation) depending on whether $(F_U - F_D) \geq (<)(\, I_U - I_D)$. However, consumers are indifferent between these technologies because the total amounts of the final good produced under these technologies are the same. Then the question is: which technology is socially more valuable? Note that

$$\pi_U(b-\varepsilon, c) + \pi_D(b-\varepsilon, c) = \pi_U(b, c-\varepsilon) + \pi_D(b, c-\varepsilon) \tag{11}$$

that is, gross industry profit under each of upstream and downstream technology is the same, hence socially most valuable innovation is the one which has lower innovation costs. Therefore, downstream innovation will be socially more valuable if $I_D < I_U$. This may lead to market failure in the sense that private incentive for upstream innovation can be larger although upstream innovation cost is higher. This is the case when $(F_U - F_D) > (\, I_U - I_D)$ but $I_D < I_U$. One implication of this result is that by means of a suitable contract on transfer payment it is possible to implement the socially most valuable project.

Proposition 3: *Private incentive and social incentive for innovations may conflict; however, the socially most valuable innovation project is implementable.*

To conclude this subsection, consider that instead of the third firm, the upstream and the downstream firms are the innovators of the respective technologies. Then which firm will have a larger incentive when only one firm can do R&D for the respective technology? Our result will be the same, that is, the upstream or downstream firm will just behave as the third R&D firm; however, the surplus due to innovation will be retained by the respective firm. But, as we have already noted, if one firm innovates and adopt the technology the other firm will also gain.

3.2 Endogenous Innovation and R&D Incentives

In the previous subsection we have assumed that the size of the innovation, ε, is exogenously specified. In the present section we endogenize the choice of ε. Therefore, the R&D firm will accordingly decide its investment and determine the size of the innovation, that is, the extent of cost reduction. However, we continue to assume that the innovation is deterministic.

Let the R&D technology be given by the following quadratic function:

$$I_i(\varepsilon) = \beta_i \frac{\varepsilon^2}{2}, \quad i = U, D \tag{12}$$

This states that to innovate the i-th technological innovation (where the subscripts U and D stand for upstream and downstream technology respectively) of size ε an amount of I_i investment is required in R&D. The function is increasing and strictly convex reflecting decreasing returns to scale. We consider R&D investment by the third firm and also by U or D firm.

The first stage R&D investment by the R&D firm determines the size of the innovation ε. Once ε is known, the analysis on transfer and adoption of technology is the same as before. After innovating the technology of stream i $(i = U, D)$, the maximum revenue (as transfer price) that the R&D firm can capture from the transferee is F_i, $i = U, D$, as given by the expressions (6) and (7). Hence the first-stage problem is

$$\max_{\varepsilon} \pi_R^i \equiv F_i(\varepsilon) - I_i(\varepsilon), \quad i = U, D$$

Solving the problem, the optimal innovation size will be:

$$\varepsilon_R^U = \frac{\alpha}{4\beta_U - 1} \text{ and } \varepsilon_R^D = \frac{\alpha}{8\beta_D - 1} \tag{13}$$

provided $\beta_U > (\frac{1}{4})$ and $\beta_D > (\frac{1}{8})$. The corresponding payoffs of the R&D firm are:

$$\pi_R^U = \frac{\alpha^2}{8(4\beta_U - 1)} \text{ and } \pi_R^D = \frac{\alpha^2}{16(8\beta_D - 1)} \tag{14}$$

Suppose $\beta_U = \beta_D = \beta$, that is R&D technology is identical for both stream technological innovations. Then assuming $\beta > 1/4$, we have always $\varepsilon_R^U > \varepsilon_R^D$ and $\pi_R^U > \pi_R^D$. Hence we can write the following proposition.

Proposition 4: *Suppose the R&D technology for each of upstream and downstream technological innovation is identical. Then the size of the upstream innovation will always be larger compared to downstream innovation and also upstream technology innovation is always preferred to downstream technology innovation.*

This therefore states that although the innovation technology is the same for both streams, the R&D firm will invest more in upstream technology innovation. In general, we have the following result.

Proposition 5: *The size of the upstream innovation will be larger than that of the downstream innovation iff* $\beta_D > \beta_U/2$ *(that is, downstream technology is relatively costlier). But upstream innovation will be preferred to downstream innovation iff* $\beta_D > \frac{4\,\beta_U+1}{16}$.

This result describes all possible innovation cost situations and the corresponding technology choice of the R&D firm. Hence it is possible that the R&D firm prefers the costly innovation. Figure 1 depicts all possible situations. For instance, in the shaded region, the innovator prefers upstream technology innovation although the optimal downstream size of the innovation could be larger.

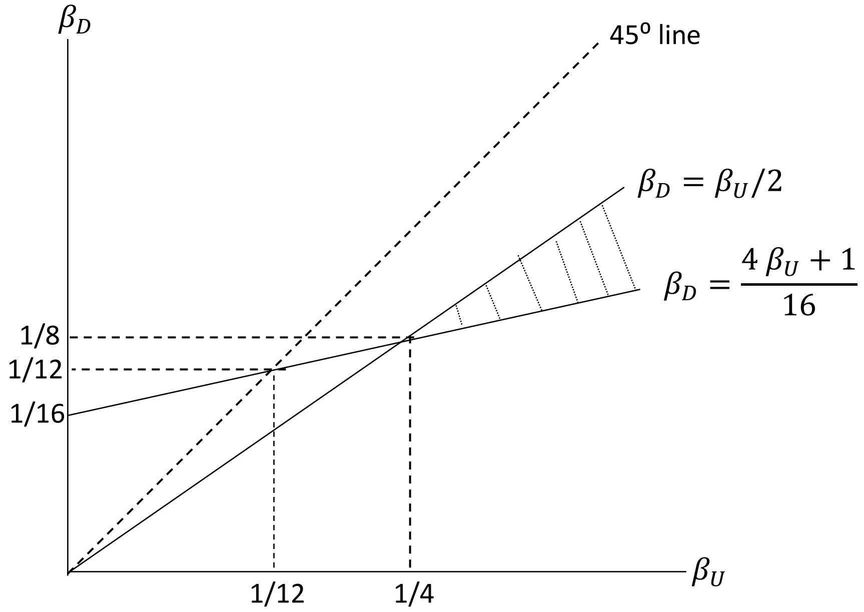

Figure 1: Size of innovation and the corresponding profitability

We may now raise the following question. If, instead of the independent third firm, the insider firm, U or D, be involved in R&D activity, would the size of the innovation be larger?

Suppose innovation decision is taken at the beginning before U and D are involved in any input trade contract. In this case the role performed by the upstream/downstream firm is just like that by the third firm; hence, as far as the size of the innovation is concerned, it will remain unaffected compared to the innovation by the third firm. Under this situation the third firm's profit is just captured by the respective U or D. Thus if U is involved in innovation, the size of the innovation will be

$$\varepsilon_U = \frac{\alpha}{4\beta_U - 1} = \varepsilon_R^U$$

The corresponding payoffs of U and D will be

$$\tilde{\pi}_U^U = \frac{4\beta_U}{(4\beta_U - 1)}\frac{\alpha^2}{8} \text{ and } \tilde{\pi}_D^U = \left\{\frac{4\beta_U}{(4\beta_U - 1)}\right\}^2 \frac{\alpha^2}{16}$$

Then we must have $\tilde{\pi}_U^U = \pi_R^U + \pi_U^U$ (that is, the sum of profits of R and U when firm R innovates).

Similarly, if D is involved in innovation, we have,

$$\varepsilon_D = \frac{\alpha}{8\beta_D - 1} = \varepsilon_R^D$$

with the corresponding payoffs are

$$\tilde{\pi}_D^D = \frac{8\beta_D}{(8\beta_D - 1)}\frac{\alpha^2}{16} \text{ and } \tilde{\pi}_D^U = \left\{\frac{4\beta_U}{(4\beta_U - 1)}\right\}^2 \frac{\alpha^2}{16}$$

and $\tilde{\pi}_D^D = \pi_R^D + \pi_D^D$.

Now consider the following interesting scenario. Since downstream technology is used only after the upstream firm's decision regarding input sell, the downstream firm may be involved in technology innovation only after it has signed a contract with the upstream firm regarding input purchase. Thus here firm D optimizes over its profit with respect to ε when the upstream input price, w, is already decided. So in the first stage U decides w, then D decides its innovation investment in R&D, and so decides ε, and finally in the third stage it decides its sell of final goods.

Given the demand function (1), and ε and w in the earlier stages, its optimal quantity sell will be $Q(w, \varepsilon) = \frac{a - w - (c - \varepsilon)}{2}$, with the corresponding payoff function, $\pi_D(w, \varepsilon) = \frac{\{a - w - (c - \varepsilon)\}^2}{4}$. Then its second stage problem is:

$$\max_{\varepsilon} \pi_D(w, \varepsilon) - I_D(\varepsilon)$$

which yields

$$\hat{\varepsilon}_D(w) = \frac{a - w - c}{2\beta_D - 1},$$

with the corresponding

$$\hat{Q}_D(w) = \frac{\beta_D(a-w-c)}{2\beta_D-1} \quad \text{and} \quad \hat{\pi}_D(w) = \frac{\beta_D(a-w-c)^2}{2(2\beta_D-1)}.$$

Finally, in the first stage, the upstream firm's problem is:

$$\max_{w}(w-b)\hat{Q}_D(w)$$

This gives equilibrium input price to be charged by the upstream firm to the downstream firm,

$$w = \frac{a+b-c}{2}$$

The corresponding optimal innovation is

$$\hat{\varepsilon}_D = \frac{\alpha}{2(2\beta_D-1)} \tag{15}$$

and the payoffs of the firms are

$$\hat{\pi}_D = \frac{2\beta_D}{(2\beta_D-1)}\frac{\alpha^2}{16} \quad \text{and} \quad \hat{\pi}_U = \frac{2\beta_D}{(2\beta_D-1)}\frac{\alpha^2}{8} \tag{16}$$

Now, compared to the case when R innovates, under the present situation when D innovates, the size of the innovation goes up, that is, $\hat{\varepsilon}_D > \varepsilon_R^D$. The downstream firm comes up with a larger payoff, and the upstream firm also benefits.

4. Incentives for Common Technology Innovation

In this section we consider the possibility of a common technology innovation by the independent R&D firm. By definition, a common technology can be used by both stream firms. Common technology innovation in our analysis basically saves the use of common input in production. So any improvement in the method of production of such an input ultimately reduces production cost of that stream. In the following subsections we discuss R&D incentives of an R&D firm when the size of the innovation is exogenous and also when it is endogenous. We also consider the possibility of spillovers, that is when one stream firm adopts the technology, the other stream firm comes up with a reduction of production cost with no R&D investment.

4.1 Incentives for R&D Investment in a Common Technology

There are inputs, like electricity, coal, etc which are used in both upstream and downstream production. Hence we can think of technology innovations which reduce unit cost of such an input and hence both the streams can reap the benefit of innovation. In this subsection we assume that the R&D firm invests in reducing unit cost of the common input. The firm which adopts the technology faces a reduction of marginal cost by the amount, ε; $0 \leq \varepsilon \leq r$. Then the problem of the innovator is whom to transfer the technology and at what price. By means of its pricing for technology, firm R will decide whether it will transfer to upstream firm only, or downstream firm only, or to both firms (at non-discriminatory price). The game is the following. After innovation occurs, the patentee sets a price (i.e., fee), say $F > 0$, for the technology. Then both upstream and downstream firms simultaneously decide whether they will accept the transfer and pay for the technology. Finally, the upstream-downstream game is played.

For notational convenience, let 1 denote `acceptance' and 0 denote `non-acceptance' of the technology. Then $\pi_U(1,0)$ and $\pi_D(1,0)$ denote respectively gross profit (before deduction of fee for the technology) of the upstream and downstream firms when the upstream firm has adopted the technology but the downstream firm has not. Similarly, the other payoffs are defined for any combination of 1 and 0.

The net payoffs of the upstream and downstream firms after third stage of play is given by the following payoff matrix, assuming U is the row player and D is the column player.

U \ D	1	0
1	$\pi_U(1,1) - F, \pi_D(1,1) - F$	$\pi_U(1,0) - F, \pi_D(1,0)$
0	$\pi_U(0,1), \pi_D(0,1) - F$	$\pi_U(0,0), \pi_D(0,0)$

Payoff Matrix 1

We have, $\pi_U(1,1) = \frac{(\alpha+2\varepsilon)^2}{8}$, $\pi_D(1,1) = \frac{(\alpha+2\varepsilon)^2}{16}$, $\pi_U(1,0) = \frac{(\alpha+\varepsilon)^2}{8}$, $\pi_D(1,0) = \frac{(\alpha+\varepsilon)^2}{16}$,

$\pi_U(0,1) = \frac{(\alpha+\varepsilon)^2}{8}$, $\pi_D(0,1) = \frac{(\alpha+\varepsilon)^2}{16}$, $\pi_U(0,0) = \frac{\alpha^2}{8}$ and $\pi_D(0,0) = \frac{\alpha^2}{16}$.

Define

$$F_1 = \pi_U(1,1) - \pi_U(0,1) = \frac{\varepsilon(2\alpha+3\varepsilon)}{8} \qquad (17.1)$$

$$F_2 = \pi_D(1,1) - \pi_D(1,0) = \frac{\varepsilon(2\alpha+3\varepsilon)}{16} \tag{17.2}$$

$$F_3 = \pi_U(1,0) - \pi_U(0,0) = \frac{\varepsilon(2\alpha+\varepsilon)}{8} \tag{17.3}$$

$$F_4 = \pi_D(0,1) - \pi_D(0,0) = \frac{\varepsilon(2\alpha+\varepsilon)}{16} \tag{17.4}$$

Comparing those four values, we have $F_1 > F_3 > F_4$, and $F_1 > F_2 > F_4$. But

$$F_2 \geq (<) F_3 \Leftrightarrow \varepsilon \geq (<)\ 2\alpha \tag{18}$$

So we discuss the equilibrium outcome under the following two assumptions.

Assumption 1: $\boldsymbol{\varepsilon < 2\alpha}$

This assumption means that $F_4 < F_2 < F_3 < F_1$. The equilibrium outcome of the third stage game under this assumption is summarized in the following proposition.

Proposition 6: *Given assumption 1, (i) $\forall F \leq F_2$, strategy combination (1, 1) is the unique Nash equilibrium; (ii) $\forall F, F_2 < F \leq F_3$, strategy combination (1,0) is the unique Nash equilibrium; and (iii) $\forall F > F_3$, strategy combination (0,0) is the unique Nash equilibrium. Strategy combination (0,1) can never be an equilibrium outcome.*

Proof: See Appendix A. The result is shown in Figure 1.

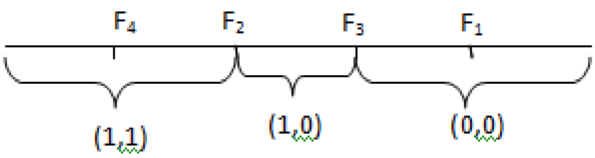

Figure 1: NE when $\boldsymbol{\varepsilon < 2\alpha}$

Now depending on the choice of F and given the third stage outcome, whether the upstream or downstream firm or both firms will adopt the transferred technology depends on the value of F. Proposition 6 defines the choice of the firms. Now consider the determination of F by the patentee in the first stage.

Let I_C be the cost of innovating this common technology. Given Proposition 4, the fee can never be set at a level higher than F_3, because at such a fee none of U or D will adopt the technology.

To implement (1,1) as the unique Nash equilibrium, the optimal fee will be $F = F_2$, and under this situation both U and D will adopt the new technology. Therefore the R&D firm's gross profit from this innovation is $\pi_R(F_2;(1,1)) = 2F_2 = \frac{\varepsilon(2\alpha+3\varepsilon)}{8}$. To implement (1,0) as the unique Nash equilibrium, the optimal fee is $F = F_3$, hence the gross payoff of the patentee is $\pi_R(F_3;(1,0)) = F_3 = \frac{\varepsilon(2\alpha+\varepsilon)}{8}$. Hence, given assumption 1, the first stage optimal fee will be $F = F_2$ so that both U and D take the license and patentee gets a net payoff of $(2F_2 - I_C)$.

Assumption 2: $\boldsymbol{\varepsilon > 2\alpha}$

Under this assumption we have $F_4 < F_3 < F_2 < F_1$.

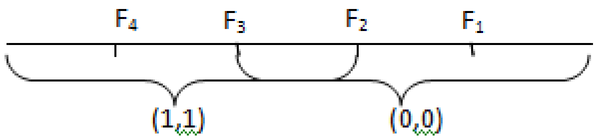

Figure 2: NE when $\boldsymbol{\varepsilon > 2\alpha}$

We have already noted (see Appendix A) that (0,1) can never be an equilibrium because $F_1 \nless F_4$. Now under the assumption $\varepsilon > 2\alpha$, we have also $F_3 < F_2$; hence (1,0) can also never figure in equilibrium. Therefore, transfer to a single firm will never be an equilibrium outcome. So either the technology will be transferred to both or none.

We can easily check that if $F \leq F_3$, then (1,1) is the only possible equilibrium, and if $F > F_2$, (0,0) is the only possible equilibrium. But if $F \epsilon [F_3, F_2]$, both (1,1) and (0,0) are Nash equilibria. See Figure 2. To resolve the choice between these two Nash equilibria we may assume that both will prefer (1,1) to (0,0) if simultaneously

$$\pi_U(1,1) - F \geq \pi_U(0,0) \text{ and } \pi_D(1,1) - F \geq \pi_D(0,0)$$

that is, if

$$F \leq \min\{\pi_U(1,1) - \pi_U(0,0), \pi_D(1,1) - \pi_D(0,0)\} = \min\left\{\frac{\varepsilon(\alpha+\varepsilon)}{2}, \frac{\varepsilon(\alpha+\varepsilon)}{4}\right\} = \frac{\varepsilon(\alpha+\varepsilon)}{4}$$

We can further check that $F_3 < F_2 < \frac{\varepsilon(\alpha+\varepsilon)}{4}$. Therefore, if a fee $F = F_2$ is charged, both U and D will prefer the transferred technology to no technology. Therefore, the optimal fee for the transferred technology to be charged by the patentee is $F = F_2$ and both U and D will accept the license, and patentee will get a net payoff of $(2F_2 - I_C)$.

Summarizing this subsection, we have the following result.

Proposition 7: *If $I_C < 2F_2$, the R&D firm has incentive for innovating the common technology. It will set a price F_2 for the transferred technology and both upstream and downstream firms will adopt the transferred technology.*

4.2 Common Technology with Spillovers

In this subsection we consider the scenario where one firm adopts a new technology, knowledge underlying the new technology is partially spilled over to the other firm. Consider transfer of the common technology to either upstream or downstream firm. This reduces the unit cost of the transferee by an amount $\varepsilon > 0$. Then with spillover effect, we assume that the other firm will enjoy a cost reduction of an amount $\sigma\varepsilon$, $\sigma \in [0,1]$. Clearly, $\sigma = 1$ means 100% spillover of knowledge, and $\sigma = 0$ implies absence of any spillover. If there is no technology transfer or if the technology is transferred to both firms, there is no spillover gain additionally. In contrast, if U alone gets the transfer, its corresponding marginal cost of production will be $(b - \varepsilon)$ and that of the downstream firm will be $(c - \sigma\varepsilon)$. Similarly, when D gets the transferred technology, its marginal cost is $(c - \varepsilon)$ and that of the upstream firm is $(b - \sigma\varepsilon)$. Then given that the R&D firm innovates the technology, it can fix the technology pricing in such a way that either one firm or both firms adopt the technology. The corresponding payoffs of the firms will be given in the Payoff Matrix below. In the different expressions below, the superscript S stands for the case under spillovers.

U \ D	1	0
1	$\pi_U^S(1,1) - F$, $\pi_D^S(1,1) - F$	$\pi_U^S(1,0) - F$, $\pi_D^S(1,0)$
0	$\pi_U^S(0,1)$, $\pi_D^S(0,1) - F$	$\pi_U^S(0,0)$, $\pi_D^S(0,0)$

Payoff Matrix 2

where, $\pi_U^S(1,1) = \frac{(\alpha+2\varepsilon)^2}{8}$, $\pi_D^S(1,1) = \frac{(\alpha+2\varepsilon)^2}{16}$, $\pi_U^S(1,0) = \frac{(\alpha+(1+\sigma)\varepsilon)^2}{8}$, $\pi_D^S(1,0) = \frac{(\alpha+(1+\sigma)\varepsilon)^2}{16}$, $\pi_U^S(0,1) = \frac{(\alpha+(1+\sigma)\varepsilon)^2}{8}$, $\pi_D^S(0,1) = \frac{(\alpha+(1+\sigma)\varepsilon)^2}{16}$, $\pi_U^S(0,0) = \frac{\alpha^2}{8}$ and $\pi_D^S(0,0) = \frac{\alpha^2}{16}$.

Correspondingly, we define,

$$F_1^S = \pi_U^S(1,1) - \pi_U^S(0,1) = \frac{\varepsilon[2\alpha+(3+\sigma)\varepsilon](1-\sigma)}{8} \tag{19.1}$$

$$F_2^S = \pi_D^S(1,1) - \pi_D^S(1,0) = \frac{\varepsilon[2\alpha+(3+\sigma)\varepsilon](1-\sigma)}{16} \tag{19.2}$$

$$F_3^S = \pi_U^S(1,0) - \pi_U^S(0,0) = \frac{\varepsilon[2\alpha+(1+\sigma)\varepsilon](1+\sigma)}{8} \tag{19.3}$$

$$F_4^S = \pi_D^S(0,1) - \pi_D^S(0,0) = \frac{\varepsilon[2\alpha+(1+\sigma)\varepsilon](1+\sigma)}{16} \tag{19.4}$$

We have necessarily,

$$F_1^S > F_2^S \ \forall\sigma < 1 \ \text{ and } \ F_3^S > F_4^S \ \forall\sigma$$

Then comparing F_2^S and F_3^S, we can write the following lemma.

Lemma 1: $\exists\sigma^* \in (0,1)$ such that if and only if $\sigma < \sigma^*$ and $\varepsilon > 2\alpha$, we have $F_2^S > F_3^S$; otherwise, $F_2^S < F_3^S \ \forall\sigma\epsilon[0,1]$.

Proof. See Appendix B.

Therefore, when $\varepsilon > 2\alpha$ and $\sigma < \sigma^*$, we have the ranking, $F_1^S > F_2^S > F_3^S > F_4^S$. This is exactly the same ranking as in the case of `without spillovers' under $\varepsilon > 2\alpha$ (see Figure 2). Hence, our result is same as before, that is, the R&D firm, after innovation, will charge a price F_2^S for the technology and both U and D will adopt the technology.

On the other hand, with spillovers we come up with interesting results when either $\varepsilon < 2\alpha$ or $\sigma > \sigma^*$ (or both) in which case we have $F_2^S < F_3^S \ \forall\sigma\epsilon[0,1]$. But since pair-wise comparison for other F^S values depends on σ, in this case it is not possible in general to rank all F^S values for all intermediate values of σ. So we consider the comparison for $\sigma \cong 1$, that is, for σ close to one.

Lemma 2: For $\sigma \cong 1$, we have only one possible ranking, viz., $F_2^S < F_1^S < F_4^S < F_3^S$.

Proof: When $\sigma \cong 1$, we have (i) $F_1^S < F_3^S$, (ii) $F_1^S < F_4^S$, and (iii) $F_2^S < F_4^S$ (see Appendix B). Also we have $F_2^S < F_3^S$ (by Lemma 1), and $F_1^S > F_2^S$ and $F_3^S > F_4^S$ (hold always). All these together give the result.

For the given Payoff Matrix 2 and Lemma 2, we have the following result.

Proposition 8: *Given* $\sigma \cong 1$, *the optimal strategies of the upstream and downstream firms are: (i) (1,1) is a NE if* $F \leq F_2^S$, *(ii) (1,0) is a NE if* $F \in (F_2^S, F_3^S]$, *(iii) (0,1) is a NE if* $F \in (F_1^S, F_4^S]$, *and (iv) (0,0) is a NE if* $F > F_3^S$.

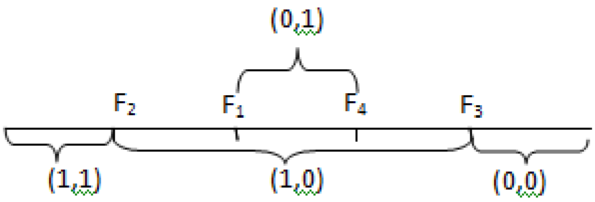

Figure 3: NE when $\sigma \cong 1$

The results are shown in Figure 3. Note that with zero spillover, (0,1) can never be a Nash equilibrium outcome, but with large enough spillover effect, (0,1) can now be a possibility of Nash equilibrium of the game.

The R&D firm which decides its optimal transfer strategy sets the price of the technology to maximize its payoff. Then implementing (1,1) as a NE outcome, its optimal pricing will be $F = F_2^S$ and the corresponding profit is $\pi_R^S(F_2^S;(1,1)) = 2F_2^S - I_C$. Since $F_3^S > F_4^S$, therefore, (1,0) corresponds a larger profit than (0,1). Then to implement (1,0), the best price is $F = F_3^S$ with corresponding profit $\pi_R^S(F_3^S;(1,0)) = F_3^S - I_C$. It will never charge a price above F_3^S, because in that case no one will accept the technology transfer offer. It is now easy to check that for $\sigma \cong 1$, $F_3^S > 2F_2^S$. Hence we have the following proposition.

Proposition 9: *If the spill-over effect is large enough, the optimal decision of the patentee is to set a price* $F = F_3^S$ *for its innovation; then only the upstream firm, not the downstream firm, will adopt the innovation.*

Intuition of the result is the following. Since each of U and D has an incentive to gain from spillovers if the other firm accepts the technology, the innovator will offer it to the firm from whom it can extract the larger payoff. Hence the innovator will offer it to U.

4.3 Endogenous Common Technology Innovation

In this subsection to focus on endogenous innovation, we assume away any possibility of spillovers of R&D innovation. We have earlier shown that for any exogenous innovation of common technology of size ε, the (independent) R&D firm can charge $F_2(\varepsilon)$ (see Proposition 7) to each of upstream and downstream firm for transferring its technology. Therefore, when innovation size is endogenous, it is determined from the following problem

$$\max_{\varepsilon}\ \pi_R^C = 2F_2(\varepsilon) - I_C(\varepsilon)$$

where $F_2(\varepsilon) = \frac{\varepsilon(2\alpha+3\varepsilon)}{16}$ and $I_C(\varepsilon) = \beta_C \frac{\varepsilon^2}{2}$. The optimal level of innovation to this problem is

$$\varepsilon_R^C = \frac{\alpha}{4\beta_C - 3}, \quad \text{provided} \quad \beta_C > 3/4 \qquad (20)$$

and the corresponding payoff of the research firm is $\pi_R^C = \frac{\alpha^2}{8(4\beta_C - 3)}$.

If the upstream firm goes for innovating the common technology, it has three sources of gain. First, if it does not license the technology to the downstream firm, it can just gain from using the innovation for its production, because it reduces the cost to $(b - \varepsilon)$. This increases its profit by the amount $\{\pi_U(1,0) - \pi_U(0,0)\}$. To that extent the downstream also benefits because its profit also increases by the amount $\{\pi_D(1,0) - \pi_D(0,0)\}$. Second, when it licenses the technology to the downstream firm, it can extract, as license fee, an amount $\{\pi_D(1,1) - \pi_D(1,0)\}$. Third, when downstream firm uses the technology, the upstream firm by means of its input pricing can gain an additional amount of $\{\pi_U(1,1) - \pi_U(1,0)\}$. Hence its incentive for innovation is the sum of all those gains minus the R&D cost. Therefore, the size of the innovation is determined from the following maximization problem,

$$\max_{\varepsilon}\{\pi_U(1,1) - \pi_U(0,0)\} + \{\pi_D(1,1) - \pi_D(1,0)\} - I_C(\varepsilon)$$

This solves for the optimal size of the innovation given by,

$$\varepsilon_U^C = \frac{5\alpha}{8\beta_C - 11}, \ \text{provided} \ \beta_C > \left(\frac{11}{8}\right) \qquad (21)$$

Therefore, when $\beta_C > \left(\frac{11}{8}\right)$, we must have $\varepsilon_U^C > \varepsilon_R^C$.

Similarly, if firm D takes up the innovation project, the optimal innovation size is solved from the following problem,

$$\max_{\varepsilon}\{\pi_D(1,1) - \pi_D(0,0)\} + \{\pi_U(1,1) - \pi_U(0,1)\} - I_C(\varepsilon)$$

This gives the optimal innovation,

$$\varepsilon_D^C = \frac{2\alpha}{4\beta_C - 5}, \text{ provided } \beta_C > 5/4 \tag{22}$$

Again, under this condition, $\varepsilon_D^C > \varepsilon_R^C$. Finally, if $\beta_C > (\frac{11}{8})$, we have, $\varepsilon_U^C > \varepsilon_D^C$.

Proposition 10: *If common technology innovation is relatively costly (that is, β_C is relatively larger), insider firms will invest more than that of an independent R&D firm.*

5. Conclusion

This paper studies innovation incentives of an R&D firm in an upstream-downstream structure. We consider three possible technological innovations. The technology which is relevant only for upstream production is defined as upstream technology innovation. Similarly, the technological innovation relevant only for downstream production is downstream technology innovation. Finally, we define common technology innovation to mean a technology relevant for both upstream and downstream production. All are process innovations in the sense that such an innovation ultimately lowers the unit cost of production of the relevant stream. We have considered both the cases of exogenous and endogenous innovation. In our model the R&D firm is an independent third firm, so it is a research lab different from the upstream and downstream firm. However, we have contrasted our results with those when the upstream or downstream firm itself is the innovator of the relevant technology.

When it is the choice between the upstream and downstream technology, our result shows that the R&D firm prefers upstream innovation to downstream innovation provided that the upstream innovation cost is not too large compared to downstream innovation cost. However, when both innovations are feasible, the R&D incentive is always larger under integrated market structure compared to disintegrated structure. As far as the choice of technology is concerned we have shown that there can be a conflict between private and social incentive. Technology which is less costly to innovate is socially more valuable, but the private incentive for the expensive technology may be larger. If a suitable transfer payment mechanism is introduced, socially most valuable innovation can be implemented.

When the size of the innovation is endogenously determined, upstream innovation is always larger if the R&D technology is the same for both the innovations. Under this situation, however, the R&D firm may go for downstream innovation. It occurs when R&D is relatively less costly.

We have also discussed the question of whether the innovation size could be larger if instead of the independent firm the R&D activity is done by the insider upstream or downstream firm. We have shown that so long the R&D investment decision is taken before any contract on the input pricing is written by the upstream and downstream firms, the size of the innovation will be the same. But if the downstream firm is engaged in R&D but the decision on R&D investment occurs only after U and D have written the contract on input pricing, the size of the downstream innovation will be larger. In all the cases, however, whether upstream or downstream firm innovates, both firms will gain.

When the R&D firm is involved in innovation of the common technology, it decides whether to transfer the technology to only upstream or downstream firm or to both. We have shown that when innovation is exogenous, it will set the technology transfer price in such a way that both firms adopt the technology. But the result will be completely different if we introduce spillover effect of technology transfer, which occurs if the technology is transferred to only one firm. We show that with spillover effect large enough, only the upstream firm will be transferred the technology. Finally, whether the size of the innovation will be larger or not when the insider firm is engaged in R&D depends on the R&D technology. In particular, innovation will be larger under independent R&D firm if innovation is not much costly.

To summarize, the R&D investment depends not only on the market structure, but also on whether innovation is done by the independent firm or by an insider firm, whether R&D is too expensive, and also on the nature of technology, that is, whether it is upstream technology, downstream technology or common technology. Also whether there are spillover effects or not is an important consideration to determine the technology transfer policy. While uncertainty is an important factor to determine the R&D outcome, in the present model we have considered the case of deterministic R&D only. In the whole analysis we have considered technology transfer under a fixed fee contact. But there can be situations when royalty licensing or two-part tariff licensing will dominate fee licensing. Obviously, implications of the results will depend on the licensing contract chosen. We leave these issues for future research.

For the given payoff matrix we derive Nash equilibrium strategy pair.

Case 1: (1,1) is a Nash Equilibrium iff

$$\pi_U(1,1) - F \geq \pi_U(0,1) \text{ and } \pi_D(1,1) - F \geq \pi_D(1,0)$$

$$\text{i.e., } F \leq \min\{\pi_U(1,1) - \pi_U(0,1),\ \pi_D(1,1) - \pi_D(1,0)\} = \min\{F_1, F_2\} = F_2 \quad \text{(A.1)}$$

Case 2: (1,0) is a Nash Equilibrium iff

$$\pi_U(1,0) - F \geq \pi_U(0,0) \text{ and } \pi_D(1,0) \geq \pi_D(1,1) - F$$

$$\text{i.e., } F \in [\pi_D(1,1) - \pi_D(1,0),\ \pi_U(1,0) - \pi_U(0,0)] = [F_2, F_3] \quad \text{(A.2)}$$

For having an $F > 0$ in this interval, it is necessary that $F_2 < F_3 \Leftrightarrow \varepsilon < 2\alpha$.

Case 3: (0,1) is a Nash Equilibrium iff

$$\pi_U(0,1) \geq \pi_U(1,1) - F \text{ and } \pi_D(0,1) - F \geq \pi_D(0,0)$$

$$\text{i.e., } F \in [\pi_U(1,1) - \pi_U(0,1),\ \pi_D(0,1) - \pi_D(0,0)] = [F_1, F_4] \quad \text{(A.3)}$$

Clearly, this interval is empty because $F_1 > F_4$. So (0,1) can never be a Nash equilibrium.

Case 4: (0,0) is a Nash Equilibrium iff

$$\pi_U(0,0) \geq \pi_U(1,0) - F \text{ and } \pi_D(0,0) \geq \pi_D(0,1) - F$$

$$\text{i.e., } F > \max\{\pi_U(1,0) - \pi_U(0,0),\ \pi_D(0,1) - \pi_D(0,0)\} = \max\{F_3, F_4\} = F_3 \quad \text{(A.4)}$$

Now consider assumption $\varepsilon < 2\alpha$. Then $\forall F \leq F_2$, strategy combination (1, 1) is the unique Nash equilibrium because (A.1) holds but (A.2) and (A.4) do not hold. Similarly, $\forall F, F_2 < F \leq F_3$, strategy combination (1, 0) is the unique Nash equilibrium because only (A.2) holds but neither (A.1) nor (A.4) holds. Finally, $\forall F > F_3$, strategy combination (0,0) is the unique Nash equilibrium because only (A.4) holds but (A.1) and (A.2) do not hold. Under assumption $\varepsilon > 2\alpha$, since $F_2 > F_3$, (1,0) cannot happen to be a Nash equilibrium.

Appendix B

We have

$$F_2^S - F_3^S = \frac{\varepsilon}{16}[-2\alpha(1 + 3\sigma) + \varepsilon(1 - 6\sigma - 3\sigma^2) \quad \text{(B.1)}$$

Then at $\sigma = 0$, $F_2^S - F_3^S = \frac{\varepsilon}{16}(\varepsilon - 2\alpha)$; hence $F_2^S(0) \geq (<) F_3^S(0) \Leftrightarrow \varepsilon \geq (<)\ 2\alpha$, and at $\sigma = 1$, $F_2^S - F_3^S = -\frac{\varepsilon}{2}(\varepsilon + \alpha) < 0$. Further, $\frac{\partial}{\partial\sigma}(F_2^S - F_3^S) < 0\ \forall\sigma \in [0,1]$.

Hence when $\varepsilon > 2\alpha$,

$$\exists\sigma^* \in (0,1) \mid F_2^S > (<) F_3^S \Leftrightarrow \sigma < (>) \sigma^*$$

This proves Lemma 2.

We have

$$F_1^S - F_3^S = \frac{\varepsilon}{8}[-4\alpha\sigma + \varepsilon(2 - 4\sigma - 2\sigma^2)] \quad \text{(B.2)}$$

$$F_1^S - F_4^S = \frac{\varepsilon}{16}[2\alpha(1 - 3\sigma) + \varepsilon(5 - 6\sigma - 3\sigma^2)] \quad \text{(B.3)}$$

$$F_2^S - F_4^S = \frac{\varepsilon}{16}[-4\alpha\sigma + \varepsilon(2 - 4\sigma - 2\sigma^2)] \quad \text{(B.4)}$$

It is easy to check that at $\sigma = 0$, each of (B.2), (B.3) and (B.4) is positive, and at $\sigma = 1$, each of them is negative. Finally all of them are falling function of σ. Hence for σ close to one, we must have (i) $F_1^S < F_3^S$, (ii) $F_1^S < F_4^S$, and (iii) $F_2^S < F_4^S$.

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