

An Analysis of vertical relationships between seed and biotech companies

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By

Stéphane Lemarié and Shyama V. Ramani

Abstract

During the second half of the 1990's, the U.S. crop seed industry witnessed a spate of mergers between biotechnology firms and seed firms as genetically modified seeds came to be commercialized. Thereafter, the mergers continued to license out genetic traits to independent seed firms. This article examines the above phenomenon in the context of a sequential game, where a biotech firm as an upstream firm, approaches a duopolistic downstream seed market, taking into account that a GM seed confers a positive externality to the final user or farmer. The model demonstrates that in this context, there is always an incentive for a merger, and that it is in the interest of the merger to offer a license to an independent downstream firm for high degrees of product substitution in the downstream market.

Key words: *Vertical Integration, Foreclosure, Innovation, Biotechnology, Seed, Genetically Modified Organisms.*

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There have been many instances, where an upstream firm has created an innovation, which has then been transferred to a downstream firm, and developed into a new product for the final market. Furthermore, some such product innovations have had a positive impact on final demand, without changing the degree of product differentiation with respect to the existing products, due to the generation of a positive externality. A famous example is that of Intel. Since the last three decades, Intel has been supplying the computers and telecommunications industry with chips, boards, systems and software building blocks. A computer with an Intel microprocessor need not be different from one without. However, there are consumers who will choose the former as they perceive that a computer with an Intel microprocessor confers them a positive externality in terms of a high speed of computing. Other illustrations can be easily cited in the chemicals and pharmaceuticals industry¹. In agribusiness, the genetically modified seed or GM seed is one example, where upstream firms have produced an innovation, the integration of which by downstream firms has enhanced the utility obtained by the consumer, due to the generation of a positive externality. During the late 1980's, biotechnology firms in the U.S.A. revolutionized the technology of agricultural production by creating "genetic traits" that could be introduced into plants, to produce in turn, GM seeds. Farmers using GM seeds benefit from a positive externality in terms of incurring lower costs on pesticides and fertilizers or being less constrained by climatic and local soil conditions, as GM seeds need less chemicals for plant protection and are more resistant to adverse climatic and soil conditions.

An upstream firm armed with an innovation can commercialize it through an exclusive license to one downstream firm or issue non-exclusive license to a set of downstream firms. It can also merge with a downstream firm and the merger can sell its own final product with the innovative input, while keeping the option to license out the innovation to other downstream firms open. There is an extensive literature on the incentives for these different

¹ Another cited example is that of Gore, a company which has created different kinds of fabrics (crinkle free fabrics, fabrics for space travel, workwear and activewear) and sells its fabrics to a variety of retail and clothing manufacturers. A blazer with the label 'Goretex' serves for practical purposes the same function as a coat without Goretex. But customers wearing a Goretex blazer benefit from a positive externality in that its crinkle free. Finally, many illustrations can be found in the pharmaceutical industry, where new drugs with the same therapeutic effects but lower side effects, have been produced. Again, in these cases, in terms of therapeutic value, the innovation is equivalent to the existing product, but consumers benefit from the externality of being exposed to a lower degree of side effects when imbibing the innovation.

forms of vertical control and their subsequent effects on market competition and consumer welfare (some seminal models are Rey and Tirole (1986), Salinger (1988), Hart and Tirole (1990), Ordover, Saloner and Salop (1990)). However, none of these studies seem to have discussed the impact of upstream innovations, whose incorporation confers a positive externality on the final consumer without changing the degree of product differentiation with existing brands in the final market. This paper attempt to fill this gap.

The present paper develops a model in which an upstream firm develops an innovation and has to decide how to commercialize it among the downstream firms. The innovation exhibits the attributes described above. The upstream firm is dominant in the sense that it makes the decision about whether or not to merge, and whether or not to foreclose the market. The upstream rivals and other downstream firms do not participate in the bidding for a merger. The paper then examines the equilibrium in the downstream and upstream markets, as well as the incentives for vertical integration as a function of two variables : the existing degree of product differentiation in the downstream market and the increase in demand for the product of a downstream firm resulting from the integration of the innovative input.

Our model seems to be relevant for the case of the GM seeds market, because in the U.S.A., the commercialization of GM seeds was brought about through cooperation between two types of firms: upstream biotech firms and downstream seed firms. The biotech firms furnished the seed firms with grains of plants exhibiting certain desired genetic characteristics (such as tolerance to herbicides, resistance to insects etc.). Then the seed firms crossed these with selected existing plants, to develop new varieties of plants, that were optimal for the agronomic conditions of targeted regions and market segments. Prior to the biotech revolution, in the U.S.A., a distinct category of firms, “the breeders” had been creating new varieties of plants and these firms were often selling seeds as well. Then, with the emergence of biotechnology, knowledge of cellular and molecular biology came to be increasingly used to create new varieties, but this kind of competence was usually found in a biotech firm and not in a seed firm. On the other hand, a biotech firm, possessing a plant with a particular trait, could not sell it unless it was transferred onto the “elite varieties” developed by breeders for the different market segments. Furthermore, the upstream biotech firm needed the seed company in order to exploit its distribution channels.

Initially biotech firms, such as Monsanto, licensed out “genetic traits” to seed firms. It was felt that this would be the mode of integration of diffusion of GM seeds within the market for many years to come (Joly and Ducos 1993). However, such a vision was overruled in the second half of the 1990’s, when a spate of mergers and acquisitions occurred in the U.S. crop

seed sector. Leaders in the biotech and pesticide industries bought out seed firms at very high prices, far greater than the sales revenue of the seed firms at the time of acquisition (Bijman, 2001; Chataway and Tait, 2000; Just and Hueth, 1993). Most of these seed companies were leaders in the corn and soybean seed markets, for which the first biotech traits were developed. However, the acquisitions of seed companies did not stop the biotech companies from further licensing out of their GM trait to independent seed companies. Monsanto for instance, continued to license out its technology to independent seed firms like Pioneer and Golden Harvest.

In their survey of mergers and acquisitions in the crop seed sector, Rausser, Scotchmer and Simon (1999) propose three possible explanations. The mergers could have been motivated in order to exploit complementarity of assets, to internalise spillovers or to circumvent the impossibility of issuing complete and contingent contracts. The present paper is in line with the first explanation.

There are at least three papers in the industrial organization literature that treat questions similar to ours. Avnel and Barlet (2000) point out that in the previous literature, it has been implicitly assumed that integrated firms produce the final good with the same technology as non-integrated firms. They go on to develop a model in which foreclosure emerges due a technological choice of an upstream monopolist. Chen (2001) argues that vertical integration not only affects the upstream firm's and downstream firm's pricing incentives but also the incentives of downstream firms in choosing input suppliers. He then shows that if there is an upstream firm more efficient than others, then all downstream firms will buy from it, because by their action, they curb the incentives of the merger to be aggressive in the final market (since then the merger will lose its customers in the upstream market). Pepall and Norman (2001) consider an upstream market where firms produce differentiated but complementary products, that are combined in different ways by downstream firms to produce different products. They go on to examine the incentives for networks between suppliers and partial vertical integration and show that vertical foreclosure cannot be an equilibrium strategy in their model.

With respect to the above studies, the main distinguishing feature of the present paper is that it considers the impact on final demand and the degree of product substitution, as the explanatory variables with which to explain the strategy pursued by an upstream firm. Furthermore, foreclosure cannot arise due to the technology choice of an upstream firm, but is one of the strategic choices available to an upstream firm.

The present paper makes a contribution to two kinds of literature. First, it makes a contribution to the literature on the adoption of GM seeds and the evolution of the crop seeds market by demonstrating that even in the absence of contractual hazards or spillovers the acquisitions of seed firms enables biotechnology firms to enjoy higher returns on their technological assets. It proposes that the spate of mergers in the crop seed industry could be due to the high degree of product substitutability between conventional and GM seeds. Second, the present paper makes a contribution to the industrial organization literature on the private incentives for the creation of mergers. It illustrates another instance in which foreclosure emerges as an equilibrium phenomenon, namely when the degree of product substitutability between the innovation and the existing product is very low.

Model

Consider a perfectly competitive upstream market supplying a homogeneous input to a duopolistic downstream market, which in turn sells differentiated products in the final market. Let the two downstream firms be given by D_i or D_j with $i,j=1,2$. Let the degree of product differentiation or product substitutability between their goods be indicated by I . When $I=0$, the downstream firms are monopolists in two separate markets; and when $I=1$, their products are perfect substitutes in the same market. The marginal cost of production is normalized to zero in order to simplify the analysis and keep the focus on the demand parameters. The downstream firms compete in terms of their price. The price, product and profit of firm D_i are given by p_i, q_i and \mathbf{p}_i respectively. The demand function, $q_i(\cdot)$, and the profit function, $\mathbf{p}_i(\cdot)$, are specified as follows :

$$q_i = \mathbf{a} - p_i + I p_j \quad i,j = 1,2.$$

$$\mathbf{p}_i = q_i p_i, \quad i,j = 1,2.$$

Now, suppose one of the upstream firms develops an innovation (or a new technology) or a new firm enters the upstream market with an innovative input, which is different from the conventional input. It is assumed that the downstream market is not completely covered so that technological shocks have an impact on the final demand curves. Let the firm supplying the innovative input be indicated by Un . Any downstream firm integrating the innovative input in its product, manufactures a “new product”, whose degree of differentiation with respect to the product of its rival still remains I and whose marginal cost of production is also zero. However, the new product confers a positive externality on the final user.

Standard models of product differentiation indicate that in a dualistic market, whenever there is an augmentation in the utility of a product, its demand curve shifts up, while that of its substitute shifts down, assuming that the market is not completely covered. Thus, whenever only one of the downstream firms incorporates the innovative input, its demand curve shifts up, while the rival's demand curve shifts down. However, if both the downstream firms incorporate the innovative input, then the externality is equally conferred by all downstream products and the demand curves remain unchanged.

Let the upward shift in the demand curve when only one of the downstream firms incorporates the innovation be equal to \mathbf{D} . The rise in demand², \mathbf{D} , is less than \mathbf{a} . Let the integration of the innovation by firm Di be given by \mathbf{q}_i , where $\mathbf{q}_i=1$, if it is integrated by Di ; and $\mathbf{q}_i=0$, if it is not integrated by Di . Then the demand functions in the ex-post innovation period can be written as follows (see appendix for proof):

$$\begin{cases} q_1 = \mathbf{a} - p_1 + \mathbf{I} p_2 + \Delta(\mathbf{q}_1 - \mathbf{q}_2) \\ q_2 = \mathbf{a} - p_2 + \mathbf{I} p_1 + \Delta(\mathbf{q}_2 - \mathbf{q}_1) \end{cases}$$

where $\alpha > 0$; $\alpha > \Delta > 0$; and $0 < \mathbf{I} \leq 1$.

The commercialization of the innovation can now be modeled as a three stage game.

- In the first stage, the upstream firm Un chooses whether or not to integrate with one of the downstream firms, say $D1$ to form a merger M . When approached for a possible merger, $D1$ can either accept or refuse.
- In the second stage, the upstream firm (Un or M) decides upon its licensing strategy. If there is a vertical merger in the first stage, then M has a choice between whether or not to license the innovation to $D2$. If there is no vertical merger, then Un has the option to offer an exclusive license just to $D1$ or to offer a non-exclusive license to both $D1$ and $D2$. Again, when approached by Un with a license, the downstream firms $D1$ and $D2$ can either accept or refuse.
- In the third stage, the downstream firms ($D1$ and $D2$ or M and $D2$) compete in the final market using prices as their strategic variable.

² This in order to ensure a positive intercept of the demand curve or a positive demand for all products in the ex-post innovation period at zero prices.

Let the license value in the absence of a merger be given by v . Let the profit of the downstream firms and the upstream innovator, in the absence of a merger be given by \mathbf{p}_i , $i = 1, 2$; and \mathbf{p}_n respectively.

In order to distinguish the merger context, we index all the variables emerging under a merger by m . For instance, the technology choices of the downstream firms are given by $\mathbf{q}_1^m = 1$ and \mathbf{q}_2^m (which may equal 0 or 1). The profit, price, quantity and value of the license offered by the merger M are written as $\mathbf{p}_1^m, p_1^m, q_1^m$ and v^m . Similarly, the profit, price and quantity of the independent downstream firm, after a merger are given by \mathbf{p}_2^m, p_2^m and q_2^m .

The three stage game described above is now resolved using the standard method of backward induction.

Equilibrium in the Downstream Market

Let us first consider the situation, when there is no merger. Then the profit of the downstream firms are:

$$\mathbf{p}_i = q_i (p_i - \mathbf{q}_i v); i=1,2;$$

For any given license value v and technology choices \mathbf{q}_1 and \mathbf{q}_2 , the profit functions \mathbf{p}_1 and \mathbf{p}_2 can be differentiated with respect to prices p_1 and p_2 respectively, to get the first order conditions for profit maximization.

$$\frac{\partial \mathbf{p}_i}{\partial p_i} = \mathbf{a} + \mathbf{q}_i(v + \Delta) - \mathbf{q}_j \Delta + \mathbf{1} p_j - 2 p_i \quad i,j=1,2.$$

From these first order conditions, the best response functions $BR_i(p_j)$ can also be derived.

$$BR_i(p_j) = \left(\frac{\mathbf{1}}{2}\right) p_j + \left(\frac{\mathbf{a} + \mathbf{q}_i(v + \Delta) - \mathbf{q}_j \Delta}{2}\right) \quad i,j=1,2.$$

Clearly, $\frac{\partial BR_i}{\partial p_j} > 0$ and therefore the prices of the two final products are strategic complements in the sense enunciated by Bulow et al. (1985).

The Bertrand Nash equilibrium prices are then found by solving the first order conditions simultaneously. Then substituting the Nash equilibrium prices into the demand functions, the Nash equilibrium quantities are obtained. It can be noted that all Nash

equilibrium prices and quantities are functions of the technology choices of the downstream firms, q_1 and q_2 , the license value v charged by the upstream firm, and the degree of product differentiation I .

$$\left. \begin{aligned} p_1 &= \frac{y_0 + y_1 q_1 + y_2 q_2}{(4 - I^2)}; q_1 = \frac{y_0 + y_3 q_1 + y_2 q_2}{4 - I^2}. \\ p_2 &= \frac{y_0 + y_1 q_2 + y_2 q_1}{(4 - I^2)}; q_2 = \frac{y_0 + y_3 q_2 + y_2 q_1}{4 - I^2}. \\ \text{with } y_0 &= a(2 + I); y_1 = 2v + \Delta(2 - I); y_2 = Iv - \Delta(2 - I); \\ \text{and } y_3 &= -(2 - I^2)v + \Delta(2 - I). i, j = 1, 2. \end{aligned} \right\} (1)$$

Now, let us examine the downstream equilibrium under a merger. The profit of the merger, p_1^m and the independent downstream firm, p_2^m are given by the following:

$$p_1^m = q_1^m p_1^m + q_2^m q_2^m v^m$$

$$p_2^m = q_2^m (p_2^m - q_2^m v^m)$$

$$\text{where: } q_1^m = a - p_1^m + I p_2^m + \Delta(1 - q_2^m) \text{ and } q_2^m = a - p_2^m + I p_1^m + \Delta(q_2^m - 1).$$

The profit functions p_1^m and p_2^m can be differentiated with respect to p_1^m and p_2^m to get the first order necessary conditions for profit maximization shown below:

$$\frac{\partial p_1^m}{\partial p_1^m} = 0 \Rightarrow a - 2p_1^m + I p_2^m + \Delta(1 - q_2^m) + v^m I q_2^m = 0.$$

$$\frac{\partial p_2^m}{\partial p_2^m} = 0 \Rightarrow a + I p_1^m - 2p_2^m + \Delta(q_2^m - 1) + v^m q_2^m = 0.$$

As before, the best response functions are such that the two prices p_1^m and p_2^m are strategic complements. Solving the first order conditions simultaneously, the prices and quantities prevailing after a merger can also be ascertained.

$$\left. \begin{aligned} p_1^m &= \frac{y_0 + j_0 + j_1 q_2^m}{(4 - I^2)}; \quad q_1^m = \frac{y_0 + j_0 + j_3 q_2^m}{(4 - I^2)}; \\ p_2^m &= \frac{y_0 - j_0 + j_2 q_2^m}{(4 - I^2)}; \quad q_2^m = \frac{y_0 - j_0 + j_4 q_2^m}{(4 - I^2)}. \\ \text{where } y_0 &= a(2 + I); j_0 = \Delta(2 - I); \\ \text{and } j_1 &= 3Iv^m - \Delta(2 - I); j_2 = (2 + I^2)v^m + \Delta(2 - I); \\ \text{and } j_3 &= -I(1 - I^2)v^m - \Delta(2 - I); \quad j_4 = -2(1 - I^2)v^m + \Delta(2 - I). \end{aligned} \right\} (2)$$

Again, the prices observed in the final market depend on the value of the license, v^m , and the technology choice of the independent downstream firm, q_2^m , in the second stage.

The salient properties of these Nash equilibrium prices as a function of the technology choices of the downstream firms, and the license value, are summarized below in five comments. The proofs follow from directly the Nash equilibrium price and quantity functions detailed in equations (1) and (2) and are given in the appendix.

Comment 1 : *When there is no merger, higher the value of the license, higher the price of the new product and this tendency is reinforced with the degree of integration of the innovation. After a merger, higher the value of the license, higher the price of the new product.*

For the firm integrating the innovation and paying the license fee, an augmentation of the license fee is equivalent to an increase in the cost of production, which in turn is translated into a higher price for the final product. Second, whenever one firm raises its price, given the strategic complementarity between the prices of the two firms, the other firm also raises its price.

Comment 2 : *Integration of the innovation by a downstream firm (with or without merger) always leads to an increase in the price of its output, i.e. $p_i(1, \mathbf{q}_j) > p_i(0, \mathbf{q}_j)$ $i, j=1, 2$; and, $p_2^m(1, 1) > p_2^m(1, 0)$.*

Whenever a downstream firm integrates the innovation, it has to pay a license fee, which increases the cost of production and further boosts its price.

Comment 3: *When there is complete adoption of the innovation, the price of the new product offered by the merger can be greater or less than the price of the new product offered by its competitor in the downstream market, i.e. $p_1^m(1,1) > = < p_1(1,1) = p_2(1,1)$ and $p_1^m(1,1) > = < p_2^m(1,1)$.*

When there is complete adoption of the innovation the prices are entirely determined by the parameters of market demand, Δ and I , which in turn determine the license values and the prices vary accordingly.

Comment 4: *When the new product is offered by only one firm in the downstream market, the price of the new product offered by the merger is always less than the price of the new product offered by the downstream firm under exclusive licensing, but greater than the price of the conventional product offered by the independent downstream firm i.e. $p_1^m(1,0) < p_1(1,0)$ and $p_1^m(1,0) > p_2^m(1,0)$.*

Since license values are eliminated through a merger, when there is only one firm offering the new product, a merger always offers the new product at a lower price than an independent downstream firm. However, in the case of a merger with foreclosure, the new product offers a positive externality to the consumer that the conventional product does not, and hence the merger can charge a higher price.

Comment 5 : *When the merger practices foreclosure, the price, quantity sold and profit of the merger are higher than that of the independent downstream firm.*

When there is a merger followed by foreclosure, the foreclosure increases the market power of the merger. This enables the merger to charge a higher price and produce a larger quantity. The increase in both price and quantity is proportional to the shift in final demand Δ , and leads to greater profits.

Before proceeding to examine the equilibrium in the upstream market we note that the impact of the price adjustments on the quantities supplied is difficult to ascertain in most of the cases. Since the prices of the downstream firms are strategic complements, they move in the same direction. When a product's price increases, its demand decreases, but if the price of the competing product increases at the same time, its demand increases, so that the final impact is difficult to predict.

Equilibrium in the upstream market

We now proceed to identify the value of the license offered by the upstream firm, Un or the merger, M in the second stage of the game. When there is no merger, the profit of the upstream firm Un is:

$$p_n = v(q_1q_1 + q_2q_2)$$

When Un acquires DI , the profit of the merger, p_1^m , given by the following:

$$p_1^m = q_1^m p_1^m + q_2^m q_2^m v^m$$

In both cases, the upstream firm chooses its license value so as to maximize its profit, given the Nash equilibrium prices and quantities in the third stage, i.e. the outcomes corresponding to the final market competition. Since the Nash equilibrium prices and quantities depend on the extent of adoption of the innovation among the downstream firms, the license value will also be influenced by the same. Thus, we can derive the license value as a function of the degree of adoption of the innovation, i.e. as $v(q_1, q_2)$ or v^m . For example, $v(1,0)$ corresponds to a situation without a merger, where there is a foreclosure with only firm DI being supplied with the innovation.

Proposition 1: *The licensing strategy of the upstream firm*

1.1 *The upstream firm offers the license $v(q_1, q_2)$ such that :*

$$v(1,0) = \text{Min} \{v^*(1,0), v^{\max}\};$$

$$v(1,1) = \text{Min} \{v^*(1,1), v^{\max}\};$$

$$\text{Where } v^{\max} = \frac{\Delta(2-I)}{(2-I^2)}, v^*(1,0) = \frac{a(2+I) + \Delta(2-I)}{2(2-I^2)} \text{ and } v^*(1,1) = \frac{a}{2(1-I)}.$$

1.2 *The merger offers the license v^m to the independent seed firm 2, such that:*

$$v^m = \text{Min} \{ \hat{v}^*, \hat{v}^{\max} \};$$

$$\text{Where } \hat{v}^* = \frac{(8+I^3)}{(8+I^2)} \left(\frac{a}{2(1-I)} \right) \text{ and } \hat{v}^{\max} = \frac{\Delta(2-I)}{2(1-I^2)}.$$

1.1) When the upstream firm Un makes a license offer v , a downstream firm can either accept or refuse. Therefore, Un must formulate its license value v so as to be acceptable to the downstream firm.

The Nash equilibrium profit of downstream firm Di can be written as follows.

$$\mathbf{p}_i(\mathbf{q}_i, \mathbf{q}_j) = (p_i - v\mathbf{q}_i)q_i = (q_i)^2 = \frac{(\mathbf{y}_0 + \mathbf{y}_3\mathbf{q}_i + \mathbf{y}_2\mathbf{q}_j)^2}{(4 - \mathbf{I}^2)^2} \quad i, j=1, 2.$$

For any value of \mathbf{q}_j , from the above, it is clear that Di will integrate the innovation and its profit will increase, if $\mathbf{y}_3 > 0$. This in turn is always true in turn, if :

$$v < \frac{\Delta(2 - \mathbf{I})}{(2 - \mathbf{I}^2)} = v^{\max}.$$

Therefore, when Un offers a license fee, v , to any firm Di , it must make sure that v is less than an upper bound v^{\max} , for otherwise the license will not be accepted by the downstream firm. The value v^{\max} is independent of the decision of the upstream firm to opt for or against foreclosure.

When the upstream firm wants to practise foreclosure, the optimal license fee, $v^*(1, 0)$ is one that maximizes its profit $\mathbf{p}_n(1, 0)$.

$$\underset{\{v\}}{\text{Max}} \mathbf{p}_n(1, 0) \equiv \underset{\{v\}}{\text{Max}} v q_1(1, 0) \equiv \underset{\{v\}}{\text{Max}} v (\mathbf{y}_0 + \mathbf{y}_3(v)).$$

Then:

$$\frac{\partial \mathbf{p}_n(1, 0)}{\partial v} = 0 \Rightarrow \mathbf{y}_0 + \mathbf{y}_3(v) - v(2 - \mathbf{I}^2).$$

From the first order condition, it can be inferred that $\mathbf{p}_n(1, 0)$ is maximized at $v^*(1, 0)$, where:

$$v^*(1, 0) = \frac{\mathbf{y}_0 + \Delta(2 - \mathbf{I})}{2(2 - \mathbf{I}^2)} = \frac{\mathbf{a}(2 + \mathbf{I}) + \Delta(2 - \mathbf{I})}{2(2 - \mathbf{I}^2)}.$$

Proceeding in exactly the same fashion, when Un wants to license out the innovation to both $D1$ and $D2$, the license value that maximizes $\mathbf{p}_n(1, 1)$ is derived as follows.

$$\underset{\{v\}}{\text{Max}} \mathbf{p}_n(1, 1) \equiv \underset{\{v\}}{\text{Max}} 2v q_1(1, 1) \equiv \underset{\{v\}}{\text{Max}} v (\mathbf{y}_0 + \mathbf{y}_3(v) + \mathbf{y}_2(v)); \text{ and :}$$

$$\frac{\partial \mathbf{p}_n(1, 1)}{\partial v} = 0 \Rightarrow \mathbf{y}_0 + \mathbf{y}_3(v) + \mathbf{y}_2(v) - v(2 - \mathbf{I}^2 - \mathbf{I}).$$

According to the first order condition, the above expression is maximized at $v^*(1,1)$ defined below.

$$v^*(1,1) = \frac{y_0}{2(2-I^2-I)} = \frac{a(2+I)}{2(2+I)(1-I)} = \frac{a}{2(1-I)}.$$

Note that for both optimization problems, the second order conditions are also satisfied at the optimal license fees $v^*(1,0)$ and $v^*(1,1)$. Hence the proposition.

Since the final license value offered by the upstream firm will be the minimum of what is acceptable for the downstream firms and what is optimal for the upstream firm, we have :

$$v(0,1) = \text{Min} \{ v^{\max}, v^*(1,0) \}; \text{ and } v(1,1) = \text{Min} \{ v^{\max}, v^*(1,1) \}.$$

1.2) The merger sets the license value so as to maximize its profit, $p_1^m(1,1)$, i.e.

$$\text{Max}_{\{v\}} p_1^m(1,1) \equiv \text{Max}_{\{v\}} \left[p_1^m(1,1)q_1^m(1,1) + v^m q_2^m(1,1) \right]$$

From the first order necessary conditions, the optimal license value can be derived as :

$$\hat{v}^* = \frac{(8+I^3)}{(8+I^2)} \left(\frac{a}{2(1-I)} \right).$$

Again the merger can offer the above license value only if it is acceptable to the downstream independent firm $D2$. The maximum license value that will be acceptable to $D2$ is one that leaves it a positive profit. Thus, we have:

$$p_2^m = (p_2^m - v^m q_2^m)q_2^m = (q_2^m)^2 = \left[\frac{y_0 - j_0 + j_4 q_2^m}{(4-I^2)} \right]^2.$$

Therefore, $D2$ will integrate the innovation, if and only if, j_4 is positive, which means that :

$$v < \frac{\Delta(2-I)}{2(1-I^2)} = \hat{v}^{\max}.$$

As before, the upstream firm has to choose the lower of the two license fees \hat{v}^* and \hat{v}^{\max} . This completes our proof of proposition 1.

The commercialization strategy of the upstream firm

We will now examine the licensing strategy and the vertical integration strategy of the innovator in four propositions. The proofs of the propositions 2-5 are detailed in the appendix. Here we state the propositions and provide the intuition behind the proofs.

Proposition 2: Exclusive vs. non-exclusive licensing when there is no merger

When the upstream firm does not initiate a merger, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation $1 > \mathbf{I} > 0$, such that for all $\mathbf{I} > \mathbf{I}^$ the upstream firm issues non-exclusive licenses to both downstream firms and for all $\mathbf{I} < \mathbf{I}^*$ the upstream firm offers an exclusive license only to $D1$. For any value of market size \mathbf{a} , there exists a value of the shift in the demand curve, $\Delta_{\mathbf{a}}$, such that for all $\Delta \geq \Delta_{\mathbf{a}}$, $\mathbf{I} > 0$.*

When the upstream firm moves from exclusive licensing to non-exclusive licensing, its profit changes from $v(1,0)q_1(1,0)$ to $2v(1,1)q_1(1,1)$. Thus, its licensing strategy hinges upon two effects :

- The impact on the quantities sold in the final market, i.e. whether $2 \cdot q_1(1,1)$ is greater or smaller than $q_1(1,0)$.
- The impact on the value of the license that can be charged on the downstream firms, i.e. $v(1,1)$ as compared to $v(1,0)$.

Actually, it can be shown that whenever the upstream firm moves from exclusive licensing to non-exclusive licensing of the innovation, quantities in the final market fall, i.e. $q_1(1,1) < q_1(1,0)$ and the value of the license issued to the downstream firm either falls or remains the same, i.e. $v(1,1) \leq v(1,0)$.

Under non-exclusive licensing there are two downstream firms which buy the innovation. Furthermore, when the degree of product substitutability λ is very high, it can be shown that $2 \cdot q_1(1,1) > q_1(1,0)$ and $v(1,1) = v(1,0)$. Clearly, in this case, Un will not practise exclusive licensing.

When the degree of product substitutability λ is very low or when the downstream firms operate in almost separate markets, and the shift in the demand curve \mathbf{D} is very large, the upstream can extract almost as much from exclusive licensing as from non-exclusive licensing, i.e. $2v(1,1) < v(1,0)$. In this case, since we know that quantities in the final market

always fall with complete adoption of the innovation, i.e. $q_1(1,1) < q_1(1,0)$, it pays the upstream firm not to issue licenses for the innovation to all downstream firms.

Proposition 3: Foreclosure or non-foreclosure under a merger

Under a merger, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation $1 > \mathbf{I}2 > 0$, such that for all $\mathbf{I} > \mathbf{I}2$ the merger issues a license to the independent downstream firm and for all $\mathbf{I} < \mathbf{I}2$ the merger practises foreclosure.

According to traditional industrial organization theory, when a merger is formed, if it offers the input to all downstream firms, then it has to compete more aggressively in the downstream market and it will make losses, which it may or may not recuperate in the upstream market. Hence the rationale for foreclosure. However, in many of the new models of vertical integration, including ours, the merger may not always have an incentive to foreclose the market.

Under a merger, there is no foreclosure if :

$$\begin{aligned} \mathbf{p}_1^m(1,1) &> \mathbf{p}_1^m(1,0) \\ \Leftrightarrow q_1^m(1,1)p_1^m(1,1) + q_2^m(1,1)v^m &> q_1^m(1,0)p_1^m(1,0) \\ \Leftrightarrow q_2^m(1,1)v^m &> q_1^m(1,0)p_1^m(1,0) - q_1^m(1,1)p_1^m(1,1) \end{aligned}$$

The left hand side of the above equation represents the gains in the upstream market, while the right hand side indicates the potential losses in the downstream market that could result from more aggressive competition. When the degree of product substitution between the two products is very high, or the downstream market competition is high, the merger can extract very high license values from the independent downstream firm. Then the gains in the upstream market offset the losses in the downstream market. However, when the degree of product substitution between the two products is low, then the license revenue decreases and cannot offset the downstream losses, and hence, foreclosure is preferred by the merger.

Proposition 4: Incentive for merger under complete adoption

Under non-foreclosure or complete adoption of the innovation, there is always an incentive to merge.

When a merger is formed, the merger partners are motivated by the prospect of having a stronger position in the downstream market. However, there can be a loss on the upstream market because the innovation is sold to fewer downstream firms. Much will depend on whether or not the license value goes up or down after the merger. In the case of our model, when there is complete adoption of the innovation, the gains in the downstream market always exceed the losses in the upstream market. In this case, there is an incentive for a merger because the profit of the merger is greater than the profit of the corresponding partners in the absence of a merger.

Proposition 5 : Incentive for merger under partial adoption

When the innovation is adopted only by one downstream firm, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation, $1 > \mathbf{I}3 > 0$, such that for all $\mathbf{I} > \mathbf{I}3$ there is no incentive for a merger and for all $\mathbf{I} < \mathbf{I}3$ there is an incentive for a merger.

When the innovation is distributed to only one downstream firm, then the incentive for the creation of a merger depends solely on the downstream market. There is an incentive when a firm can make more revenue from sales in the downstream market as a merger than as an exclusive licensee.

When the new product is offered by only one firm in the downstream market, the price of the new product offered by the merger is always less than the price of the new product offered by the exclusive licensee (comment 4). On the other hand, the quantity of the new product sold by the merger is greater than that by the exclusive licensee (equations (1) and (2)). Therefore, the ranking of the profit under these two contexts depends on the parameters of market demand. When the degree of product substitution is very high, the resulting high degree of downstream market competition leads to so much price slashing by the merger that it is the less preferred option. When the markets are more separate or the degree of product substitution is lower, there is less of a price cut, and the increased quantity sold compensates for it. In this case, there is an incentive for the creation of a merger.

Illustration by simulations

Figure 1 illustrates the profit earned by the upstream firm under the four strategic possibilities: merger with foreclosure, merger without foreclosure, non-merger with exclusive licensing and non-merger with non-exclusive licensing for the parameter values:

Figure 1 : Profit of the upstream firm under different licensing strategies

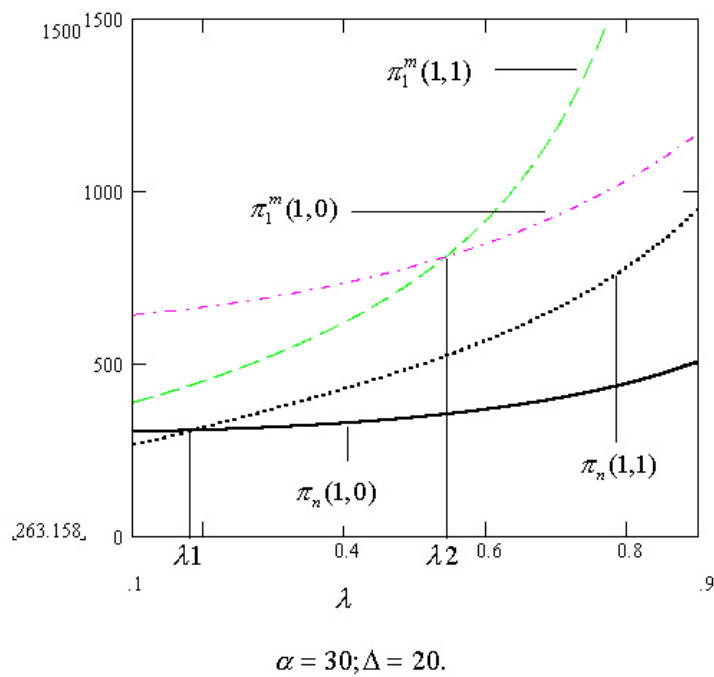
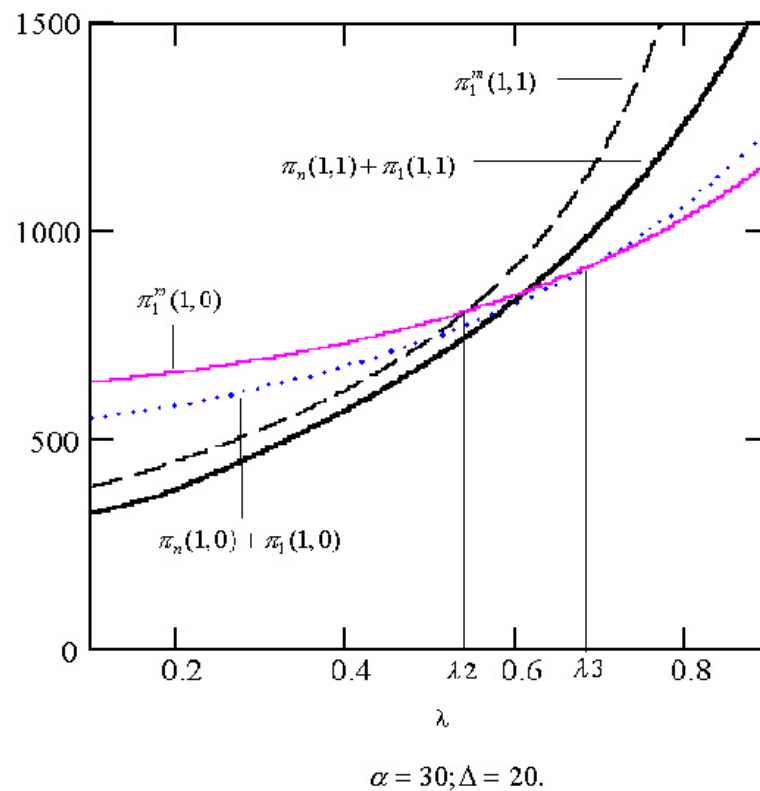


Figure 2 : Incentive for mergers under different degrees of product substitution



$\alpha = 30; \Delta = 20$. It illustrates proposition 2 that for values of λ greater than $I1$, the upstream firm will issue non-exclusive licensing in the absence of a merger. Simulations reveal that for $\alpha = 30$, Δ has to be greater than or equal to 18 (approximately) so that $I1 > 0$. For lower values of Δ the upstream firm opts for non-exclusive licensing for all values of λ . The figure also illustrates proposition 3, and indicates that for all for values of λ greater than $I2$ the merger will offer the innovation to the independent downstream firm also.

Then figure 2 illustrates the profit earned by the merger and the profit earned by the merger partners in the ex-ante period, there being an incentive for the creation of the merger when the former exceeds the latter. Proposition 4 is verified by the figure, as the profit function of the merger without foreclosure ($\mathbf{p}_1^m(1,1)$) lies above the sum of the profit functions of the upstream firm and downstream firm with non-exclusive licensing ($\mathbf{p}_n(1,1) + \mathbf{p}_1(1,1)$) for all values of I . Finally, proposition 5 is also confirmed as the profit function of the merger with foreclosure ($\mathbf{p}_1^m(1,0)$) cuts the sum of the profit functions of the upstream and downstream firms with exclusive licensing ($\mathbf{p}_n(1,0) + \mathbf{p}_1(1,0)$) at $I3$.

The given simulations yield the following result, which holds true for all possible parameter values.

Simulation Result : $0 \leq I_1 < I_2 < I_3$.

In other words, a merger to offers the innovation to all downstream firms at a higher degree of product substitution than an independent upstream firm (i.e. $I_2 > I_1$). This could be because a merger gives more market power at the downstream level, and therefore it can withhold the innovation from rivals in the downstream market more than an independent upstream firm.

Second, the simulation result implies that if a merger with foreclosure earns a higher profit than a merger without foreclosure, then there is always an incentive for the formation of a merger with foreclosure (i.e. $I_3 > I_2$). It may be recalled that there is an incentive for the creation of a merger with foreclosure, whenever the merger earns a higher revenue from sales of the new product as compared to an exclusive licensee. Now, when the merger with foreclosure generates a higher profit than a merger without foreclosure, then it pays the upstream firm not to have complete adoption of the innovation by the downstream firms. In this case, the merger earns a higher profit than the exclusive licensee because of the elimination of license fees (or elimination of double marginalization).

However, these results cannot be proved analytically, since the profit under the different configurations depend on the license values and the license values may not be a continuous function of the parameter configurations (as they are a minimum of two possible values).

Nash equilibrium of the Mergers game

Finally, let us turn to the sequential Nash equilibrium of the given game. Clearly, there are four possible outcomes that can serve as candidates for being a Nash equilibrium. For easy reference, let us label them as follows.

- NE1: Un merges with $D1$ and practises foreclosure. The downstream firm $D1$ accepts the offer.
- NE2: Un merges $D1$ and issues a license to $D2$. The downstream firm $D2$ accepts the offer.

- NE3: Un exclusively licenses out the innovation to downstream firm $D1$ without initiating a merger. The downstream firm $D1$ accepts the offer.
- NE4: Un licenses out the innovation to both the downstream firms without initiating a merger. Both downstream firms accept the offer.

Proposition 6: Nash equilibrium of the game

For any configuration of parameters (\mathbf{a}, Δ), for all $\mathbf{I} > \mathbf{I}2$ the Nash equilibrium of the game is outcome NE2 (merger with licensing) and for all $\mathbf{I} < \mathbf{I}2$ the Nash equilibrium of the game is outcome NE1 (merger with foreclosure). Outcomes NE3 and NE4 can never be a Nash equilibrium of the game.

According to proposition 4, a merger with licensing (NE2) is always preferred by the upstream firm to non-exclusive licensing (NE4). This implies that outcome NE4 can never be a Nash equilibrium.

Let us turn to the option of exclusive licensing or NE3. From proposition 2, we know that for all $\mathbf{I} > \mathbf{I}1$, non-exclusive licensing (NE4) is preferred to exclusive licensing (NE3). Therefore, NE3 can never be a Nash equilibrium when $\mathbf{I} > \mathbf{I}1$. Proposition 5 states that for all $\mathbf{I} < \mathbf{I}3$ there is an incentive for a merger with foreclosure (NE1). Since $\mathbf{I}1 < \mathbf{I}3$, for all $\mathbf{I} < \mathbf{I}1$, a merger with foreclosure (NE1) is preferred to exclusive licensing (NE3). Thus, NE3 can never be a Nash equilibrium for either $\mathbf{I} > \mathbf{I}1$ or $\mathbf{I} < \mathbf{I}1$.

This leaves the two strategic options, merger with foreclosure (NE1) and merger without foreclosure (NE2) as candidates for Nash equilibrium. Proposition 3 states that for $\mathbf{I} < \mathbf{I}2$ a merger with foreclosure (NE1) yields higher profit than one with licensing (NE2). Therefore, for $\mathbf{I} < \mathbf{I}2$, a merger with foreclosure (NE1) is the Nash equilibrium and for $\mathbf{I} > \mathbf{I}2$ a merger without foreclosure (NE2) is the Nash equilibrium outcome. These Nash equilibrium strategies are also sub-game perfect by construction.

Conclusion

The commercialisation of genetically modified seeds requires the competencies of two types of firms: upstream biotech firms and downstream seed firms. Ex-ante, different commercialisation strategies are possible, including a possible merger between the biotech firm and the seed firm and the foreclosure of the intermediate market for the genetic trait. In the U.S. crop seeds market, a number of biotech firms merged with seed firms, but there was

no foreclosure of the upstream market. The objective of this paper was to explain the spate of mergers (without foreclosure) in the crop seed industry, taking into account the fact that a GM seed conferred a positive externality on final users without significantly changing the degree of product differentiation in the downstream market.

The present paper showed that the final form of vertical control accompanying the commercialisation of GM seeds is greatly influenced by the parameters of the final market demand. There is always incentive for a merger between a biotech firm and a seed firm. When the degree of product substitutability between the GM seed and the conventional seed is high there is no foreclosure, otherwise there is. This would then be the explanation proposed by the present model to explain the spate of mergers without foreclosure in the crop seed industry.

Though our purpose was to understand why there were so many mergers in the crop seed industry to commercialise innovations by biotechnology firms, clearly our model can be used in other contexts as well, to study the commercialisation of innovations emerging in the upstream market. In such cases, our model indicates that any demand enhancing innovation gives rise to an incentive for a merger. Furthermore, if the degree of product differentiation is low, a merger with foreclosure is the equilibrium outcome.

The present paper can be modified or extended in many ways. The final form of market competition can be in terms of quantities i.e. Cournot instead of Bertrand, but this is not likely to change our results significantly. The upstream firm can offer a two-tiered price (with a fixed component as well as a variable component). This would probably introduce some parameter ranges where there is no incentive for a merger. Such a scheme was not considered in this paper, as we first wanted to study the simplest possible model. Finally, the focus of the paper was on demand parameters, leaving out the supply ones such as cost of production. This is another factor whose influence on the incentives on merger and foreclosure can be examined.

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Appendix

To prove : *The demand functions in the ex-post innovation period are of the form :*

$$q_i = \mathbf{a} - p_i + \mathbf{I}p_j + \Delta(\mathbf{q}_i - \mathbf{q}_j).$$

Proof: Let us consider the simple Hotelling model of horizontal differentiation. There are two firms, forming the downstream segment, located at two ends of a linear city of length 1. There are N consumers distributed uniformly around the city. Firm 1 is located at $x=0$ and firm 2 is located at $x=1$. Consumers have a transportation cost of t per unit of length travelled and they either buy 1 unit or do not buy at all. Let p_1 and p_2 denote the prices charged by the firms. Let s_1 and s_2 be the surplus enjoyed by the consumer, when he is consuming good 1 and good 2 respectively. Then the utility function of the consumer at location x , $0 < x < 1$ is given as follows:

$$\begin{cases} s_1 - p_1 - tx & \text{if he buys from firm 1.} \\ s_2 - p_2 - t(1-x) & \text{if he buys from firm 2.} \\ 0 & \text{otherwise.} \end{cases}$$

We assume that there exists a consumer at \tilde{x} , $0 < \tilde{x} < 1$, who is indifferent between buying from firm 1 and firm 2, i.e. :

$$s_1 - p_1 - t\tilde{x} = s_2 - p_2 - t(1 - \tilde{x}) \Leftrightarrow \tilde{x}(p_1, p_2) = \frac{s_1 - s_2 - p_1 + p_2 + t}{2t}$$

Then the demands for the products of the two firms are :

$$D_1(p_1, p_2) = N\tilde{x}(p_1, p_2) = N \left(\frac{s_1 - s_2 - p_1 + p_2 + t}{2t} \right)$$

$$D_2(p_1, p_2) = N[1 - \tilde{x}(p_1, p_2)] = N \left(\frac{s_2 - s_1 - p_2 + p_1 + t}{2t} \right)$$

Let us suppose that if an innovative input offered by an upstream firm is integrated in any downstream product, it increases the surplus from final consumption by s . Thus, if firm 1 alone integrates the innovative input, then $D_1(p_1, p_2)$ shifts up by $\frac{sN}{2t}$, and $D_2(p_1, p_2)$ shifts down by the same. However, if both firms integrate the innovation, then the demand functions remain the same.

Comment 1 : *When there is no merger, higher the value of the license, higher the price of the new product and this tendency is reinforced with the degree of integration of the innovation. After a merger, higher the value of the license, higher the price of the new product.*

Proof: From equations (1) and (2) presenting the Nash equilibrium prices with or without a merger we have :

$$\frac{\partial p_i}{\partial v} = \frac{2\mathbf{q}_i + \mathbf{l}\mathbf{q}_j}{(4 - \mathbf{l}^2)} > 0; \quad \frac{\partial p_1^m}{\partial v} = \frac{3\mathbf{l}\mathbf{q}_2^m}{(4 - \mathbf{l}^2)} > 0; \quad \frac{\partial p_2^m}{\partial v} = \frac{(2 + \mathbf{l}^2)\mathbf{q}_2^m}{(4 - \mathbf{l}^2)} > 0.$$

Comment 2 : *Integration of the innovation by a downstream firm (with or without merger) always leads to an increase in the price of its output, i.e. $p_i(1, \mathbf{q}_j) > p_i(0, \mathbf{q}_j)$ $i, j=1, 2$; and, $p_2^m(1, 1) > p_2^m(1, 0)$.*

$$\text{Proof: } p_i(1, \mathbf{q}_j) - p_i(0, \mathbf{q}_j) = \frac{\mathbf{y}_1}{4 - \mathbf{l}^2} > 0. \quad p_2^m(1, 1) - p_2^m(1, 0) = \frac{\mathbf{j}_2}{4 - \mathbf{l}^2} > 0.$$

Comment 3: *When there is complete adoption of the innovation, the price of the new product offered by the merger can be greater or less than the price of the new product offered by its competitor in the downstream market, i.e. $p_1^m(1, 1) > = < p_1(1, 1) = p_2(1, 1)$ and $p_1^m(1, 1) > = < p_2^m(1, 1)$.*

$$\text{Proof: } p_1^m(1, 1) < p_2^m(1, 1) \Rightarrow \mathbf{j}_0 + \mathbf{j}_1(1, 1) < -\mathbf{j}_0 + \mathbf{j}_2(1, 1) \Rightarrow 0 < v^m(1 + \mathbf{l}^2 - 3\mathbf{l}) .$$

The above equation is true when $\mathbf{l}=0$, but not when $\mathbf{l}=1$. Hence the proposition.

$$\begin{aligned} p_1^m(1, 1) < p_1(1, 1) &\Leftrightarrow \mathbf{y}_0 + \mathbf{j}_0 + \mathbf{j}_1(1, 1) < \mathbf{y}_0 + \mathbf{y}_1(1, 1) + \mathbf{y}_2(1, 1) \\ &\Leftrightarrow 3\mathbf{l}v^m < (2 + \mathbf{l})v(1, 1) . \end{aligned}$$

Thus, the impact of the merger will depend on the license values.

Comment 4: *When the new product is offered by only one firm in the downstream market, the price of the new product offered by the merger is always less than the price of the new product offered by the downstream firm under exclusive licensing, but greater than the price of the conventional product offered by the independent downstream firm i.e. $p_1^m(1, 0) < p_1(1, 0)$ and $p_1^m(1, 0) > p_2^m(1, 0)$.*

Proof:
$$p_1^m(1,0) < p_1(1,0) \Leftrightarrow \mathbf{y}_0 + \mathbf{j}_0 < \mathbf{y}_0 + \mathbf{y}_1$$

$$\Leftrightarrow 0 < 2v(1,0) \text{ which is always true.}$$

Next, $p_1^m(1,0) > p_2^m(1,0) \Rightarrow \mathbf{y}_0 + \mathbf{j}_0 > \mathbf{y}_0 - \mathbf{j}_0$ which is always true.

Comment 5 : *When the merger practices foreclosure, the price, quantity sold and profit of the merger are higher than that of the independent downstream firm.*

Proof : Comment 4 showed that the price charged by the merger for the new product is higher than the price charged for the conventional product by the independent downstream firm, whenever foreclosure is practiced. Furthermore, a simple examination of the Nash equilibrium quantities after a merger given in equations (2) reveals that the quantity sold by the merger is also greater. Hence, the profit made by a merger is higher than that by the independent downstream firm.

Proposition 2: Exclusive vs. non-exclusive licensing when there is no merger

When the upstream firm does not initiate a merger, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation $1 > \mathbf{I} > 0$, such that for all $\mathbf{I} > \mathbf{I}^$ the upstream firm issues non-exclusive licenses to both downstream firms and for all $\mathbf{I} < \mathbf{I}^*$ the upstream firm offers an exclusive license only to $D1$. For any value of market size \mathbf{a} , there exists a value of the shift in the demand curve, Δ_a , such that for all $\Delta \geq \Delta_a$, $\mathbf{I} > 0$.*

Proof: We establish four simple lemmas. Then using these lemmas the proposition becomes evident.

Lemma 1: For all \mathbf{D}, \mathbf{I} , $q_1(1,0) > q_1(1,1)$.

Proof:
$$q_1(1,0) - q_1(1,1) > 0 \Leftrightarrow [\mathbf{y}_0 + \mathbf{y}_3(1,0)] - [\mathbf{y}_0 + \mathbf{y}_3(1,1) + \mathbf{y}_2(1,1)]$$

$$\Leftrightarrow \mathbf{y}_3(1,0) - \mathbf{y}_3(1,1) - \mathbf{y}_2(1,1) > 0$$

$$\Leftrightarrow \begin{bmatrix} -(2 - \mathbf{I}^2)v(1,0) + \Delta(2 - \mathbf{I}) \\ +(2 - \mathbf{I}^2)v(1,1) - \Delta(2 - \mathbf{I}) \\ -\mathbf{I}v(1,1) + \Delta(2 - \mathbf{I}) \end{bmatrix} > 0$$

$$\Leftrightarrow \Delta(2 - \mathbf{I}) + (2 - \mathbf{I}^2 - \mathbf{I})v(1,1) - (2 - \mathbf{I}^2)v(1,0) > 0.$$

Only the last term is negative. It takes on its maximum value when $v(1,0) = v^{\max}$, and in this case the above equation becomes:

$$\Leftrightarrow \Delta(2 - I) + (2 - I^2 - I)v(1,1) - (2 - I^2) \frac{\Delta(2 - I)}{(2 - I^2)} > 0.$$

The above is always true and hence the proof.

Lemma 2: For all \mathbf{D} , $2q_1(1,1) > q_1(1,0)$ at $\mathbf{I} = 1$.

Proof: $2q_1(1,1) - q_1(1,0) > 0 \Leftrightarrow [2\mathbf{y}_0 + 2\mathbf{y}_3(1,1) + 2\mathbf{y}_2(1,1)] - [\mathbf{y}_0 + \mathbf{y}_3(1,0)] > 0$.

$$\Leftrightarrow \mathbf{y}_0 - 2(2 - I^2 - I)v(1,1) + (2 - I^2)v(1,0) - \Delta(2 - I) > 0.$$

At $\mathbf{I} = 1$ the above equation becomes :

$$\Leftrightarrow 3\mathbf{a} + v^{\max} - \Delta > 0;$$

$$\Leftrightarrow 3\mathbf{a} + \Delta - \Delta > 0;$$

which is always true.

Lemma 3 : At $\mathbf{I} = 1$, $v(1,1) = v(1,0) = v^{\max}$.

Proof: Since $\mathbf{a} > \Delta$, we have:

$$v(1,0) = \text{Min} \{v^*(1,0), v^{\max}\} = \text{Min} \left\{ \frac{\mathbf{a} \cdot (2 + I) + \Delta(2 - I)}{2(2 - I^2)}, \frac{\Delta(2 - I)}{(2 - I^2)} \right\} = \frac{\Delta(2 - I)}{2(2 - I^2)} = v^{\max}.$$

And at $\mathbf{I} = 1$, $v^*(1,1) = \infty$ and hence $v(1,1) = v^{\max}$.

Lemma 4 : At $\mathbf{I} = 0$, $\lim_{\Delta \rightarrow \mathbf{a}} v(1,0) - 2v(1,1) = v^{\max} - 2v(1,1) = 0$.

Proof: At $\mathbf{I} = 0$, $2 \cdot v(1,1) = \mathbf{a}$ and $v^{\max} = \mathbf{D}$. And hence the proof.

Now we can proceed to the proof of the proposition:

From lemma 2 and lemma 3, we know that at $\mathbf{I} = 1$, we have :

$$2q_1(1,1)v(1,1) - q_1(1,0)v(1,0) > 0 \Leftrightarrow \mathbf{p}_n(1,1) > \mathbf{p}_n(1,0).$$

From lemma 1 and lemma 4, we know that at $\mathbf{I} = 0$, we have:

$$2q_1(1,1)v(1,1) - q_1(1,0)v(1,0) < 0 \Leftrightarrow \mathbf{p}_n(1,1) < \mathbf{p}_n(1,0).$$

Then proposition (2) follows from continuity of the profit functions.

Proposition 3: Foreclosure or non-foreclosure under a merger

Under a merger, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation $1 > I > 0$, such that for all $I > I_2$ the merger issues a license to the independent downstream firm and for all $I < I_2$ the merger practises foreclosure.

Proof : Under a merger, there is no foreclosure if :

$$\mathbf{p}_1^m(1,1) > \mathbf{p}_1^m(1,0)$$

$$\Leftrightarrow q_1^m(1,1)p_1^m(1,1) + q_2^m(1,1)v^m > q_1^m(1,0)p_1^m(1,0)$$

From equation (2) we can compute :

$$q_1^m(1,1) = \frac{\mathbf{y}_0 - I(1 - I^2)v^m}{(4 - I^2)} > q_2^m(1,1) = \frac{\mathbf{y}_0 - 2(1 - I^2)v^m}{(4 - I^2)}.$$

Therefore we can write :

$$q_1^m(1,1)p_1^m(1,1) + q_2^m(1,1)v^m > q_2^m(1,1)[p_1^m(1,1) + v^m].$$

Let the lowest possible value of quantity sold in the final market by the independent downstream firm after the merger be $q_2^{\min}(1,1)$. Then in the following lemma we will show that : $q_2^{\min}(1,1)[p_1^m(1,1) + v^m] > q_1^m(1,0).p_1^m(1,0)$ at $I = 1$. Then by transitivity we will have :

$$q_1^m(1,1)p_1^m(1,1) + q_2^m(1,1)v^m > q_1^m(1,0)p_1^m(1,0) \quad (3)$$

and the proposition will then be proved.

Lemma: $q_2^{\min}(1,1)[p_1^m(1,1) + v^m] > q_1^m(1,0).p_1^m(1,0)$ at $I = 1$.

Note that q_2^m is decreasing in v^m and therefore attains its lowest value at

$$v^m = \hat{v}^{\max} = \frac{\Delta(2 - I)}{2(1 - I^2)}. \text{ Then } q_2^m \text{ at } \hat{v}^{\max} \text{ is equal to } q_2^{\min}(1,1) = \frac{\mathbf{y}_0 - 2(1 - I^2)\hat{v}^{\max}}{(4 - I^2)} = \frac{\mathbf{y}_0 - \mathbf{j}_0}{(4 - I^2)}$$

Then equation (3) can be written as :

$$\begin{aligned} & \frac{\mathbf{y}_0 - \mathbf{j}_0}{(4 - I^2)} [p_1^m(1,1) + v^m] > \left[\frac{\mathbf{y}_0 + \mathbf{j}_0}{(4 - I^2)} \right]^2 \\ \hat{U} & \frac{\mathbf{y}_0 - \mathbf{j}_0}{(4 - I^2)} \left[\frac{\mathbf{y}_0 + v^m(4 + 3I - I^2)}{(4 - I^2)} \right] > \left[\frac{\mathbf{y}_0 + \mathbf{j}_0}{(4 - I^2)} \right]^2 \\ & \hat{U} v^m (4 + 3I - I^2) > \frac{(\mathbf{y}_0 + \mathbf{j}_0)^2}{(\mathbf{y}_0 - \mathbf{j}_0)} - \mathbf{y}_0 \end{aligned} \quad (4)$$

The lemma always holds at $I = 1$ since the right hand of equation (4) is a constant function of I , the left hand side is an increasing function of I and $\lim_{I \rightarrow 1} v^m = \infty$.

At $I = 0$, we have :

$$q_1^m(1,0) = p_1^m(1,0) = \frac{\mathbf{a} + \Delta}{2};$$

$$q_1^m(1,1) = p_1^m(1,1) = \frac{\mathbf{a}}{2}.$$

At $I = 0$, the downstream gains from foreclosure are :

$$q_1^m(1,0)p_1^m(1,0) - q_1^m(1,1)p_1^m(1,1) = \frac{2\mathbf{a}\Delta + \Delta^2}{4}.$$

At $I = 0$, the upstream losses from foreclosure are : $q_2^m(1,1)v^m = \frac{2\mathbf{a}v^m - 2(v^m)^2}{4}$. Clearly, the upstream losses from foreclosure are less than the downstream gains from foreclosure as $v^m \leq \Delta$. Hence the proposition.

Proposition 4: Incentive for merger under complete adoption

Under non-foreclosure or complete adoption of the innovation, there is always an incentive to merge.

Proof: There is an incentive for a merger if:

$$\mathbf{p}_1^m(1,1) \geq \mathbf{p}_n(1,1) + \mathbf{p}_1(1,1).$$

$$\Leftrightarrow p_1^m(1,1)q_1^m(1,1) + q_2^m(1,1)v^m \geq v(1,1)[q_1(1,1) + q_2(1,1)] + [p_1(1,1)q_1(1,1) - v(1,1)q_1(1,1)].$$

$$\Leftrightarrow p_1^m(1,1)q_1^m(1,1) + q_2^m(1,1)v^m \geq q_1(1,1)[v(1,1) + p_1(1,1)]$$

$$\Leftrightarrow p_1^m(1,1)q_1^m(1,1) - p_1(1,1)q_1(1,1) \geq q_1(1,1)v(1,1) - q_2^m(1,1)v^m. \quad (5)$$

In the following two lemmas, we will prove that equation (5) holds for $I = 0$ and for $I = 1$. Then by continuity of the price and quantity functions, it implies that the above equation holds true for all values of I .

Lemma 1 : At $I = 0$, $p_1^m(1,1)q_1^m(1,1) - p_1(1,1)q_1(1,1) > q_1(1,1)v(1,1) - q_2^m(1,1)v^m$.

When $I = 0$, we have :

$$v^m = v = v' = \min\left\{\frac{\mathbf{a}}{2}, \Delta\right\};$$

$$p_1^m(1,1) = q_1^m(1,1) = \frac{\mathbf{a}}{2}; \quad q_2^m(1,1) = \frac{\mathbf{a} - v'}{2};$$

$$p_1(1,1) = \frac{\mathbf{a} + v'}{2}; \quad q_1(1,1) = \frac{\mathbf{a} - v'}{2}.$$

Then, $p_1^m(1,1)q_1^m(1,1) - p_1(1,1)q_1(1,1) = \frac{v'^2}{2}$; and $q_1(1,1)v(1,1) - q_2^m(1,1)v^m = 0$. Hence the lemma.

Lemma 2 : For $\mathbf{I} = 1$, $p_1^m(1,1)q_1^m(1,1) - p_1(1,1)q_1(1,1) > q_1(1,1)v(1,1) - q_2^m(1,1)v^m$.

When $\mathbf{I} = 1$, we have :

$$v^m > v(1,1);$$

$$p_1^m(1,1) = \mathbf{a} + v^m; \quad q_1^m(1,1) = q_2^m(1,1) = \mathbf{a};$$

$$p_1(1,1) = \mathbf{a} + v(1,1); \quad q_1(1,1) = \mathbf{a}.$$

Then, $p_1^m(1,1).q_1^m(1,1) - p_1(1,1)q_1(1,1) = \mathbf{a}(v^m - v(1,1)) > 0$;

and $q_1(1,1)v(1,1) - q_2^m(1,1)v^m = -[\mathbf{a}(v^m - v(1,1))] < 0$. Hence the lemma.

Given lemma 1 and lemma 2, the proposition follows from continuity of the profit functions.

Proposition 5 : Incentive for merger under partial adoption

When the innovation is adopted only by one downstream firm, for any configuration of parameters (\mathbf{a}, Δ) , there exists a degree of product differentiation, $1 > \mathbf{I} > 0$, such that for all $\mathbf{I} > \mathbf{I}^3$ there is no incentive for a merger and for all $\mathbf{I} < \mathbf{I}^3$ there is an incentive for a merger.

Proof: Under foreclosure there is an incentive for a merger if :

$$\mathbf{p}_1^m(1,0) \geq \mathbf{p}_n(1,0) + \mathbf{p}_1(1,0);$$

$$\Leftrightarrow p_1^m(1,0)q_1^m(1,0) \geq v(1,0)q_1(1,0) + [p_1(1,0)q_1(1,0) - v(1,0)q_1(1,0)]$$

$$\Leftrightarrow p_1^m(1,0)q_1^m(1,0) \geq p_1(1,0)q_1(1,0) \quad (6)$$

It can be noted that : $p_1^m(1,0) = q_1^m(1,0) = \frac{\mathbf{y}_0 + \mathbf{j}_0}{(4 - \mathbf{I}^2)}$. Let $\frac{\mathbf{y}_0 + \mathbf{j}_0}{(4 - \mathbf{I}^2)} = z$.

Then we can write :

$$p_1(1,0) = z + a \text{ where } a = \frac{2v(1,0)}{4 - I^2};$$

$$\text{and } q_1(1,0) = z - b \text{ where } b = \frac{(2 - I^2)v(1,0)}{4 - I^2};$$

Then there is an incentive for a merger, or equation (6) holds, i.e. if :

$$\begin{aligned} z^2 &\geq z^2 + z(a - b) - ab \\ \Leftrightarrow \frac{zv(1,0)[2 - I^2 - 2]}{4 - I^2} + \frac{2(2 - I^2)(v(1,0))^2}{4 - I^2} &\geq 0. \\ \Leftrightarrow -zI^2 + 2(2 - I^2)v(1,0) &\geq 0. \end{aligned} \tag{7}$$

Notice that at $I = 0$, equation (7) becomes $4v(1,0) \geq 0$, which is always true.

Again, when $I = 1$, $z = 3a + \Delta$ and $v(1,0) = \Delta$.

Hence, at $I = 1$, equation (7) becomes $-3a + \Delta \geq 0$, which is false since $a > \Delta$.

This means that at $I = 0$, there is an incentive for mergers under foreclosure; however, under $I = 1$ there is no incentive for a merger under foreclosure. Then the proposition follows from continuity of the profit functions.