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Bundling and Licensing of Genes in Agricultural Biotechnology

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Abstract

This paper examines the strategic incentive for gene holders to vertically integrate with seed companies, and with herbicide/insecticide oligopolies, given the unique institutional structure and relevant market in agricultural biotechnology. We model the case with homogeneous basic seeds, and investigate both pre-entry and post-entry equilibrium.

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1. Introduction

The advances in biotechnology provide a fast and dependable method of producing a plant with specific, desirable traits, so called genetically modified (GM) crops. While demand-side concerns remain a controversial issue, the world had seen a rapid growth in GM crops planted both in the developed and developing countries. Cost, yield and risk considerations have provided the supply side with strong incentives to adopt (Kalaitzandonakes 1999). In 1996 GM crops were first introduced for commercial production in 4.2 million acres in six countries. By 2002, GM crops grew to a total of 145 million acres in sixteen countries on six continents or 22% of the world's total cropland, a 35-fold increase in 7 years. The US is the largest adopter with 96.3 million acres, following by Argentina with 33.3 million acres, Canada with 8.6 million acres and China with 5.2 million acres in 2002. These four countries grow 99% of the global GM cropland.

Unlike a product innovation where the innovated product could be manufactured and sold to the consumers directly, the commercial value of genes is realized only through the sale of the GM plant in which the genes are incorporated with some basic germplasm. Under current patent law, both genes and the basic seed germplasm are patentable. Therefore, plant breeders need to make licensing deals for the desired genes if they would like to develop a GM seed with that gene. For example, Monsanto produces branded GM seeds with its YieldGard Bt gene and RR herbicide tolerance gene, individually or in a stacked system. It also licenses its genes to other breeders. Syngenta's seeds use a Bt gene from Monsanto and herbicide tolerance gene from Bayer

Crop Science. There are other possible players in this market. For example, if the trait provides a substitute for certain type of insecticide, the insecticide manufacturers get involved. If the trait is herbicide tolerance, the herbicide producers get involved, as their products are complementary to the gene.

The 1990s have seen a substantial number of mergers and acquisitions, and an increase in vertical and horizontal integration in the seed and pesticide industries. The four-firm concentration ratio (CR4) is 47% for pesticides industry in 1997, 21% for seed industry in 1999, and 100% for plant biotechnology industry in 1998. The concentration is higher in some specific markets. For instance, in 1998, Monsanto and Pioneer-HiBred (now owned wholly by DuPont) controlled 11% and 39% of the US seed corn market, respectively. For the US cotton market, two companies, Delta&Pine Land and Stoneville, had 71% and 16%, respectively, of the seed market (Hayenga and Kalaitzandonakes 1999). The concentration at the R&D stage is matched by concentration in terms of the number of patents held. The top four firms held 41% of the corn patents in 1996, 53% of the soybean patents in 1997, 77% of the tomato patents in 1997 and 38% of the Bt patents in 1998 (Graff et al. 2003). The major biotechnology companies are increasingly purchasing these seed companies as a source of seed material in which to insert the genes for input or output traits. For example, in 1997, Monsanto acquired a 30% share of the Brazilian corn seed market with the acquisition of Sementes Agroceres. With its 1998 purchase of Cargill's international seed division, Monsanto now controls over half the Argentine maize seed market.

The increasing vertical integrated industry structure may be affected by many factors. Rausser et al. (1999) argues that the restructuring has been technologically driven. In particular there may exist factors associated with the complementary assets and substitutability in agricultural biotechnology products, and those connected with intellectual property rights (e.g. Graff et al. 2002, Rausser et al. 1999). Intellectual property rights create pressures for greater vertical integration and strategic alliances and contracting, depending on the nature of the intellectual property and the rights associated with it. If IPR are well defined and transaction costs are low, contracting and strategic alliances are more likely. However, if IPR are not well defined, biotech companies might buy out seed companies rather than license genes to them. Vertical integration via consolidation may also be driven by parties' heterogeneous beliefs regarding the profitability of the industry (Goodhue et al. 2002).

This paper is motivated by the effort to examine the strategic incentive for licensing versus integrating forward, given the institutional structure and various relevant markets in the agricultural biotechnology industry. In the agricultural biotechnology industry, a common phenomenon is that a biotech company integrates with the seed sector and the chemical sector, while it also licenses its technology (gene) to other competitors. There are loose arguments in the existing literature that the vertical integration occurring in the agricultural biotechnology industry is motivated by strategic considerations. We formalize an analysis of the strategic incentives of partially integrating forward, in the specific case of GM seeds and the related chemical sectors.

This topic is important for policy maker and regulator who concern about the anticompetitive issues.

The paper is organized as the following: after the introduction, we develop a model for analyzing the licensing and vertical integration behavior among the gene holder and breeders. We then investigate the case where the gene is a chemical substitute and the case where the gene is a chemical complement, followed by a concluding discussion.

2. Model

In the basic model, the production process involves trait development through gene innovation and seed production. We assume that, at this moment, firm *A* holds the patent for a specific gene, and the seed industry is duopoly in the short run. Thus, firms *B1* and *B2* (breeders) may produce and sell the basic seeds and the GM seeds if they get license of the gene from firm *A*. This gene could be any of the following two types: (1) gene as a substitute for a chemical input e.g. Bt gene, (2) gene as a complement to a chemical input, e.g. RR gene. Production of basic seed involves fixed entry costs K_i, and a marginal cost of c_i for firm i, $i = B1, B2$. The production of GM seed involves a very small marginal cost of inserting the gene into the seed, which is normalized to be zero. Both licensing negotiation and vertical integration involves certain amount of costs, which we denote as K_l and K_v, respectively.

The competition in the seed market is modeled as a three-stage game. In the first stage, firm *A* decides and commits whether to integrate forward and/or the number of

licenses to the breeders. In the second stage, firms A and B1, B2 decide simultaneous which products to offer; firms B1 and B2 decide whether to take the licensing offer if firm *A* decides to license its technology, and the negotiation incurs cost K_l. If firm A does integrate forward, then K_v is sunk. In the last stage, firms A, B1 and B2 simultaneously choose prices for their respective products.

Farmers are heterogeneous seed buyers. The heterogeneity of farmers relates to many factors. Such factors may include the acreage susceptibility to infestation, cropping history, husbandry practices, managerial skills, weather conditions, and soil types. We capture such heterogeneity through a continuously distributed infestation severity index, θ. θ is uniformly distributed over [0, 1]. Farmers are risk neutral and they know their types right before planting.

We also assume that each indexed farmer holds only one unit of cropland and only demands one unit of seed. Therefore, a farmer with a big farm could be viewed as several indexed farmers with their corresponding types. Farmers have zero value of the extra unit of seeds. The indexed farmers are with total measure 1.

There are a total of four possible products in the market, two GM seeds and two basic seeds (*B1* and *B2*). We denote the GM seed with gene *A* being inserted into *B1* seed as *A/B1* and the GM seed with gene *A* being inserted into *B2* seed as *A/B2*. A farmer of type θ has a valuation of $v_{Bi}(\theta)$ for a unit of basic seed *Bi*, and a valuation of $v_{A/Bi}(\theta)$ for a unit of GM seed *A/Bi*, where $i = 1, 2$. These values are net of the costs of buying and applying the chemical but gross of the costs of seeds.

Since the gene is input related, farmers' decision making needs to take into account of the price of the related inputs, which are exogenous unless specified else. Figure 1 to 2 illustrate farmers' decision making for the two types of genes we introduced earlier.

3. Analysis of chemical substitute gene

Figure 1 illustrates the case where the gene provides a substitute for certain insecticide. Farmers choose one of the three strategies: a) do nothing; b) spray insecticide after the emergence of infestation, a self-protection approach; and c) plant GM seed, a self-insurance approach.

***Assumptions*:**

1. Three firms: firm *A* owns the gene, firm *B1* and *B2* owns basic seed germplasms. Products are denoted by *A*, *B1*, and *B2*;
2. Marginal cost of producing *B1, B2* and the GM seed are equal, $c_1 = c_2 = c_{GM} = c$;
3. Production of basic seed involves fixed costs K_i, $i = B1, B2$. Licensing and vertical merger involve costs K_l, K_v, respectively;
4. Farmers differ by type θ. θ is uniformly distributed over [0, 1] with measure 1;
5. A farmer of type θ has an expected reservation value of $v_{Bi\_a}(\theta) = w - \alpha_1\theta$, for a unit of basic seed *Bi* if adopting strategy a ("do nothing"), and $v_{Bi\_b}(\theta) = w - f - \alpha_2\theta$, if adopting strategy b ("apply insecticide later"). $\alpha_1 > \alpha_2 > 0$, $f > 0$, and $\alpha_1 > \alpha_2 + f$;
6. A farmer of type θ has a reservation value of $v_{A/Bi}(\theta) = w$, for a unit of GM seed *A/Bi;*

7. Output price and other inputs prices (other than the seed price) are exogenous.

Assumption 2, 5, and 6 imply that the basic seeds B1 and B2 are perfect substitutes. Thus we omit the subscript in figure 1. Line (a) in the graph represents the farmers' expected virtual cost of adopting strategy a, $P_B + \alpha_1\theta$. The farmer of type 0 gets surplus of $w - P_B$. A farmer of type θ gets expected surplus of $w - P_B - \alpha_1\theta$.

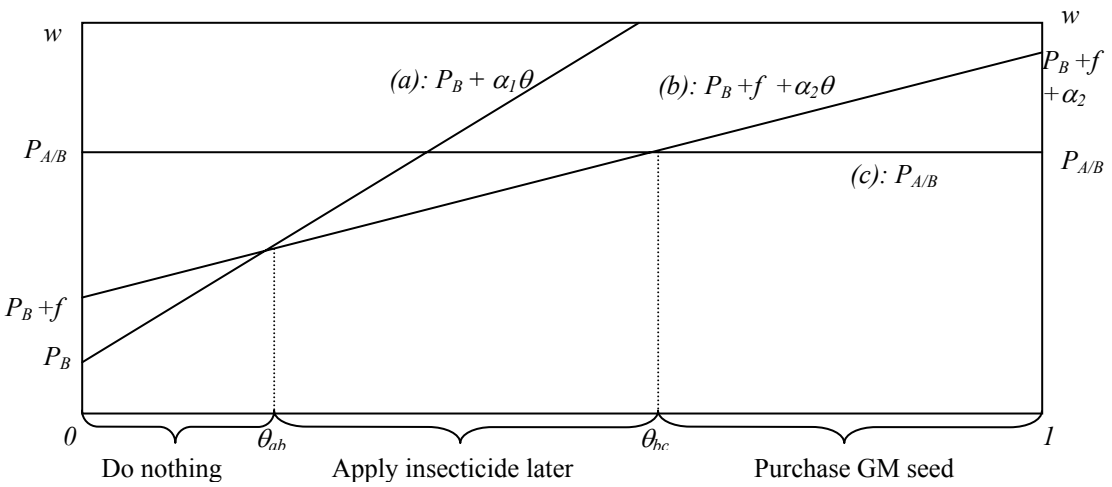
If the farmer chooses strategy b, he plants the basic seeds and applies insecticide after the infestation occurs. We assume that the output value is recovered fully by applying insecticides. The farmer incurs a cost per acre of $(f + \alpha_2\theta)$, where f is the fixed cost per unit land of spraying the chemical, and $\alpha_2\theta$ is the expected market cost of the chemical to eliminate type θ infestation. A farmer of type 0 gets surplus of $w - P_B - f$. A farmer of type θ gets expected surplus of $w - P_B - f - \alpha_2\theta$. Line (b) illustrates the expected virtual cost of strategy b, $P_B + f + \alpha_2\theta$.

If the farmer chooses strategy c, he plants the GM seed, and pays the premium at time 0 ($P_{A/B} > P_B$). The GM seed eliminate infestation if it occurs. The farmer gets surplus of $w - P_{A/B}$, which is invariant over types. Therefore, the virtual cost of strategy c, line (c), is a horizontal line at $P_{A/B}$.

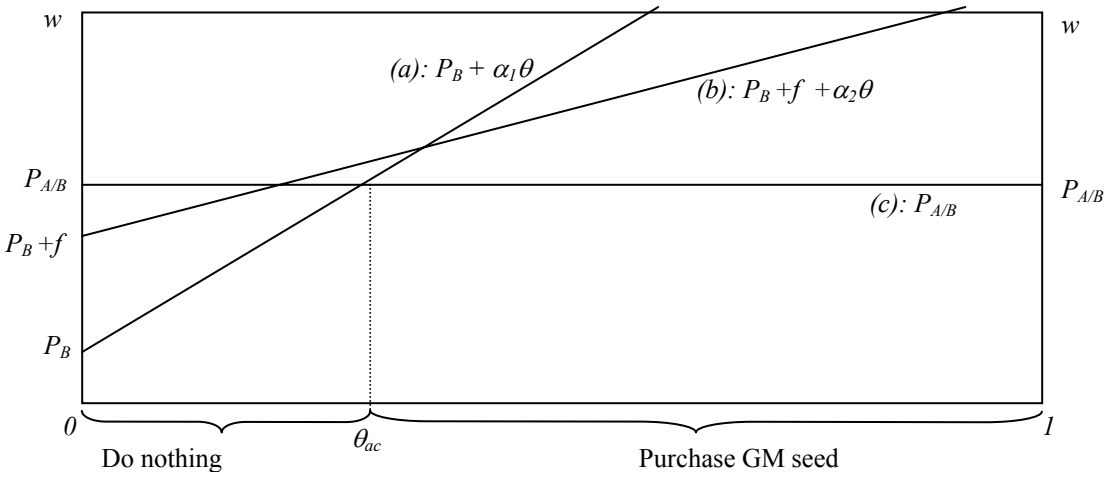
Figure 1 (I) is the case where three groups of farmers are observed while (II) is the case where only two groups of farmers are observed. θ_{ij} denotes the farmer' type who is indifferent between choosing strategy i and j. In panel (I), farmers whose type is smaller than θ_{ab} will choose strategy a. Farmers with types greater than θ_{bc} will choose

strategy c. Those lying in the interval (θ_{ab}, θ_{bc}) choose strategy b. Thus, if $\theta_{ab} > \theta_{bc}$, then farmers would rather choose between a and c, which is depicted in panel (II).

Figure 1. Farmers' purchasing decision, gene as chemical substitute, given P_B, $P_{A/B}$, f, α_1, α_2.



I. Three groups farmers, choosing a, b and c



II. Two groups farmers, choosing a and c

The Equilibrium

As discussed earlier, we model the production and pricing decisions of firms A, B1 and B2 as a three-stage game. Stage1: firm *A* chooses vertically integration and/or licensing; Stage 2: firms *A* and *B1, B2* decide simultaneous which products to offer; Stage 3: firms *A, B1* and *B2* chooses prices for their products. We solve for the equilibrium using the method of backward induction. Without loss of generality, we assume that if there is only one GM seed, then it is made of *A* and *B1*.

Step 1. Market equilibrium in stage 3.

In the subgame where the product set is (A/B1, B2), a farmer of type θ gets the surplus from different strategies as follows:

a) $w - \alpha_1\theta - P_B$,

b) $w - f - \alpha_2\theta - P_B$,

c) $w - P_{A/B}$.

A farmer of type θ will choose

Strategy (a): plant basic seed and use no insecticide later iff

(IC) $w - \alpha_1\theta - P_B \geq max\ [w - P_{A/B}, w - f - \alpha_2\theta - P_B]$

(IR) $w - \alpha_1\theta - P_B \geq 0$;

Strategy (b): plant basic seed and apply insecticide later iff

(IC) $w - f - \alpha_2\theta - P_B \geq max\ [w - P_{A/B}, w - \alpha_1\theta - P_B]$

(IR) $w - f - \alpha_2\theta - P_B \geq 0$;

Strategy c): plant GM seed and use no insecticide iff

(IC) $w - P_{A/B} \geq max\ [w - f - \alpha_2\theta - P_B,\ w - \alpha_1\theta - P_B]$

(IR) $w - P_{A/B} \geq 0$.

The incentive compatibility (IC) constraints suggest that if a farmer chooses a strategy, it must be true that the farmer derives more surplus from that strategy than from any of the other two strategies. The individual rationality (IR) constraints suggest that the farmers must be better off adopting that strategy than giving up farming. We assume w is big enough such that IR constraints are always not binding, i.e. the market is fully covered.

Therefore, by setting IC constraints binding, we find the critical value of θ's, where a farmer of type θ_{ab} is indifferent between choosing strategy a and b, θ_{bc} for strategy b and c, and θ_{ac} for strategy a and c.

$\theta_{ab,} = f/(\alpha_1 - \alpha_2)$,

$\theta_{bc} = [(P_{A/B} - P_B) - f]/\alpha_2$.

$\theta_{ac} = (P_{A/B} - P_B)/\alpha_1$.

We first assume that $\theta_{ab} < \theta_{ac} < \theta_{bc}$, as illustrated in figure 1 panel (I). We observe three groups of farmers. Hence, the demand for the basic seeds are θ_{bc} and the demand for the GM seed are $(1 - \theta_{bc})$. Therefore, the gene/breeder's problem is to choose $P_{A/B}$ to

$$Max\ \pi = (P_{A/B} - c)(1 - \theta_{bc}).$$

Firm B2's problem is to choose P_B to

$$Max\ \pi = (P_B - c)\theta_{bc}.$$

The first order conditions of above profit functions give the following best response functions,

$P_{A/B}(P_B) = 0.5(P_B + f + c + \alpha_2)$,

$P_B(P_{A/B}) = 0.5(P_{A/B} + c - f]$.

Therefore, the equilibrium prices and profits, gross of the fixed costs, are

$P^*_{A/B} = 1/3(f + 3c + 2\alpha_2)$,

$P^*_B = 1/3(\alpha_2 + 3c - f]$.

$\pi_{A/B} = (f + 2\alpha_2)^2/9\alpha_2$,

$\pi_{B2} = (\alpha_2 - f)^2/9\alpha_2$.

In order for $\theta_{bc} > 0$ (i.e. ensure the existence of strategy b farmers), we must have $(P_{A/B} - P_B) - f > 0$. Thus, it must be that $P^*_{A/B} - P^*_B > f \Rightarrow \alpha_2 > f$. Thus, $P^*_B = 1/3(\alpha_2 + 3c - f] > c$, the basic seed price is above the marginal cost.

Now let's suppose that the subgame is (A/B1, B1, B2). The basic seed price is driven down to the marginal price. Therefore, the market equilibrium is, $P^*_{A/B} = 1/2(f + 2c + \alpha_2)$, $P^*_B = c$, $\pi_{A/B} = (f + \alpha_2)^2/4\alpha_2$, $\pi_{B2} = 0$.

If the subgame is (A/B1, B1), the monopoly prices and profits will be $P^*_{A/B} = P^*_B = w$, $\pi_{A/B} = (w - c)$, $\pi_{B2} = 0$. It can be verified that the monopoly profit is higher than earlier cases.

Step 2. Compare the payoffs and choose stage 2 strategy.

<u>Lemma 1</u>. *Post-entry equilibrium: At the pure-strategy Nash equilibrium of subgame with product set (A/B1, B2), $P_B > c$, and both firms earn more than in the subgame with product set (A/B1, B1, B2).*

Proof: The intuition behind lemma 1 is straightforward. If there are two incumbents in the basic seed market, Bertrand competition leads to zero profits if the two basic seeds are perfect substitutes. If gene holder reach exclusive licensing deals or vertically integrated forward with one of the basic seed company, bundling (supplying the GM seed only) create product differentiation. Therefore the price of the basic seed could be raised above the marginal cost. Firm B2 makes positive profits even its market size is smaller than before. Meanwhile, the GM seed supplier is happy to see the increased price of the basic seed, as it means that their products are relatively "cheaper" than before. They could raise the price of GM seed while having a bigger market share. Thus in the equilibrium, both firms are better off. The result is driven by the fact that by committing to pure bundling (A/B1), the basic seed market is less competitive. This intuition applies to the case where farmers either purchase GM seeds or plant the basic seed and do nothing (Figure 1, panel II). The necessary and sufficient condition is $\theta_{bc} \leq \theta_{ab} \Rightarrow (P_{A/B} - P_B) \geq f\alpha_1/(\alpha_1 - \alpha_2)$, The critical value of farmer's type is θ_{ac}. We may show that firms are still better off when the gene/breeder commit to the GM seed only and firm B2 commit to the basic seed only. Lemma 1 still holds. QED.

Lemma 2. Pre-entry Equilibrium: Firm A/B1 would like to deter firm B2's entry to the basic seed market. The deterrence may be done through unbundling commitment, selling (A/B1, B1).

Proof: Without loss of generality, we assume that firm A and firm B1 reach exclusive agreement before firm B2 decides on entering the basic market or not. If firm B2 does not enter the basic seed market, firm A/B1 will do best as a monopolist (earning the highest payoff). Since firm B2 incurs a fixed entry cost K to the basic seed market, it will enter the market only if the payoff could cover the entry cost. Our analysis above shows that bundling (selling GM only) will raise firm B2's payoff compared to unbundling (selling both GM and the basic seed) where firm B2 earns zero. Thus, bundling serves as an entry encourage mechanism. QED.

Lemma 3. Breeders will only take the exclusive license if the basic seeds are perfect substitutes to the farmer.

Proof: Now we consider licensing only. If the license is nonexclusive, and l is the licensing fee, the subgame is either (A/B1, A/B2, B1, B2), or (A/B1, A/B2). The unique pure strategy Nash equilibrium is for each firm to charge $P^*_{A/B} = c + l$, $P^*_B = c$, $\pi_{B1} = \pi_{B2} = 0$, $\pi_A = l*(1-\theta_{bc})$. Firms B1 and B2 obtain zero profits, while they incur the extra negotiation cost of K_l. Therefore they are not going to take the non-exclusive offer. QED.

Lemma 3 suggests that if the breeder does not think the gene holder could credibly commit to exclusively licensing the technology, it may turn down the licensing offer even if it is in the name of "exclusive". Therefore, the gene holder has to use

vertical merger to acquire access to the basic seed germplasm in order to commercialized its gene innovation.

<u>Lemma 4</u>. *Whether there exist markets for insecticide (strategy b) depends on the prices of the basic seed and the GM seed, and the price of the insecticide, and does not depend on the severity of infestation.*

Proof: Market for insecticide exists only if $\theta_{ab} < \theta_{bc}$ (see figure 2.1). Since $\theta_{ab,} = f/(\alpha_1 - \alpha_2)$, $\theta_{bc} = [(P_{A/B} - P_B) - f]/\alpha_2$, the demand for the insecticide will be greater if: 1) the more expensive the GM seed is relative to the basic seed, or 2) the cheaper the insecticide is (α_2 smaller), or 3) the cheaper the fixed cost of insecticide application is (f smaller). For example, if $\theta_{ab} > \theta_{bc}$, reduction in insecticide price will tilt down line (b), which will drive θ_{ab} to the left of θ_{bc}. This is consistent to the observation that since the adoption of Bt crops, the market price of insecticide has dropped by about one half. QED.

Step 3. Determine stage 1 strategy.

From lemmas 1 and 3, we have the following:

<u>Proposition 1</u>. *At the pure-strategy equilibrium of the full model, if the breeders are in the basic market already, the gene holder always vertically integrated with one of the breeders, either via exclusive licensing, or via acquisition. The integrated firm always provides GM seed only. The unintegrated firm sells all the basic seeds.*

The intuition of proposition 1 is as follows. When a new technology is available, the innovator wishes to have as many as possible applications if the royalty rate is fixed. However, no breeder is interested in introducing the new product if it expects its rival to

do so. In the breeder's market, the current competition already left the breeders with zero profits. If a breeder expects its rival to take the license, it will also expect the rival to supply only GM seeds and it will be made better off by earning positive profits. The unlicensed breeder does not want to take the license to destroy the product differentiation just established. Therefore, it will not take the offer if it expects its rival to do so. The innovator encourages adoption by offering exclusive license or integrating forward with one of the incumbents. The welfare effects are ambiguous. While the basic seed farmers are worse off as they face with a higher seed cost, the users of the new technology are better off, because they have a choice of the new variety.

Proposition 2. If an integrated firm is about to introduce a GM seed to a new market, it will introduce both the GM seed and the basic seed so as to foreclose the new market from any potential entry.

Proposition 2 is essentially developed from lemma 2. Since Bertrand competition will serve as a strong entry deterrence device, the unbundling strategy (selling both the GM seed and basic seed) will be preferred by the incumbent integrated firm.

The advent of the new technology, GM seed will decrease the demand for insecticide. Demand for insecticide decrease from $(1-\theta_{ab})$ to $(\theta_{bc} - \theta_{ab})$. Moreover, those users who switches to GM seeds are also farmers with heavy demand for insecticide when GM seed is not available. Therefore, we have the following proposition:

<u>Proposition 3</u>. The insecticide producer has incentive to integrate forward with the gene/breeder and supplies only GM seed.

Proof. We examine the profits/joint profits of the insecticide producer and gene/breeder under different strategies. For simplicity, we assume the insecticide production cost be zero, and the insecticide producer is a monopolist. We argue that if the gene/breeder integrates with the insecticide producer, and supply the GM seed only, its payoff will be maximized.

Market for insecticide exists only if $\theta_{ab} < \theta_{bc}$ (see figure 1), where $\theta_{ab,}= f/(\alpha_1 - \alpha_2)$, and $\theta_{bc} = [(P_{A/B} - P_B) - f]/\alpha_2$. The integrated firm's problem is to

$$\underset{P_{A/B}}{Max} \quad \pi = (P_{A/B} - c)(1 - \theta_{bc}) + \int_{\theta_{ab}}^{\theta_{bc}} \alpha_2 \theta d\theta .$$

If the integrated firm supplies both the GM and the basic seeds, $P_B = c$. The equilibrium prices and profits are $P^*_{A/B} = c + \alpha_2$, $P^*_B = c$, $\pi_{A/B} = f + (\alpha_2 - f)^2/2\alpha_2 - \alpha_2 f^2/[2(\alpha_1 - \alpha_2)^2]$, and $\pi_{B2} = 0$.

If the integrated firm supplies only GM seed, then the equilibrium prices and profits are solved as $P^*_{A/B} = 1/3(f + 3c + 3\alpha_2)$, $P^*_B = 1/3(1.5\alpha_2 + 3c - f]$, $\pi_{A/B} = (\alpha_2 + f/3)(0.5\alpha_2 + f/3)/\alpha_2 + (\alpha_2 - 2f/3)^2/2\alpha_2 - \alpha_2 f^2/[2(\alpha_1 - \alpha_2)^2]$, and $\pi_{B2} = (0.5\alpha_2 - f/3)^2/\alpha_2$.

Recall the equilibrium when the subgame is (A/B1, B2), and the pesticide firm is not integrated with the gene/breeders, $P^*_{A/B} = 1/3(f + 3c + 2\alpha_2)$, $P^*_B = 1/3(\alpha_2 + 3c - f]$. $\pi_{A/B} = (f + 2\alpha_2)^2/9\alpha_2$, and $\pi_{B2} = (\alpha_2 - f)^2/9\alpha_2$.

Comparing the three equilibrium outcomes, when firms integrate and supply only GM seed, both GM seed price and the basic seed price are strictly greater than those

obtained when the chemical sector is not integrated. The joint profits of the gene/breeder and the insecticide producer are greater too. The insecticide producer has incentive to integrate forward as long as the additional joint profits will be greater than the integration costs. QED.

The intuition of proposition 2 is as the following. The insecticide sale will go up if farmers who use strategy a switch to b, i.e. θ_{ab} shifts to the left, or farmers who use strategy c switch to b, i.e. θ_{bc} shifts to the right. θ_{ab} and θ_{bc} is determined by the GM seed price premium over the basic seed and the insecticide prices. The integrated firm's first order condition of its profit maximization includes the term for the seed market and the term for the insecticide market. If the firm raises the GM seed price by one unit, it would drive θ_{bc} to the right, which means that the insecticide revenue will increase, and sales in the GM seed market may go down. The gain in the insecticide sector partially offsets the loss in the GM sale. Therefore, the integrated firm has more incentive to price GM seed less aggressively. On the other hand, the insecticide price is unlikely to go down, because if it does, the lower price will cause θ_{bc} shifting to the right, the price decrease in insecticide is at an extra cost of loss in the GM market. As a consequence, the optimal price of GM seed is almost always higher and the joint profits will be higher. The switch point of strategy a and b, θ_{ab}, is determined by the relative slope of the damage function and the insecticide spraying cost. Price of the basic seed won't affect it. Therefore, there is no incentive for the integrated firm to drive down the basic seed price. The integrated firm would still prefer exclusively licensing and pure bundling, i.e. it supplies only the GM seed.

4. Analysis of chemical complement gene

The analysis of the case where the gene is a chemical complement follows almost the same approach as in the previous section. Figure 2 illustrates the case where the gene serves as a complementary product for certain herbicide. Farmers have three strategies available: a) do nothing; b) spray herbicide at time 0, a self-insurance approach; and c) plant GM seed and apply herbicide later, a self-protection approach.

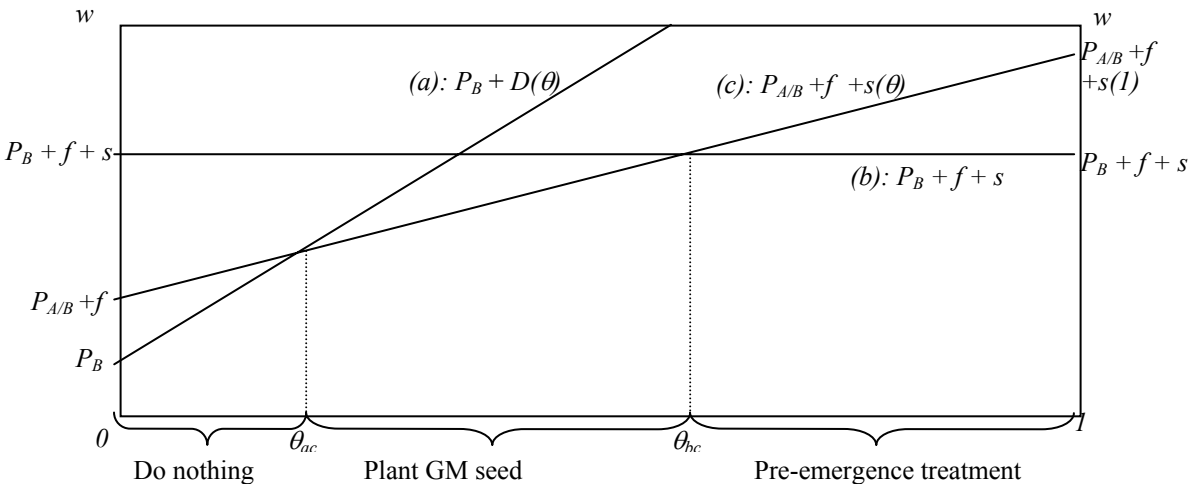
If the farmer chooses strategy a, he does nothing to control the weed. The expected damage caused by infestation for a farmer of type θ is $D(\theta)$, where $D(0) = 0$, $D'(\theta) > 0$. A farmer of type 0 gets surplus of $w - P_B$. A farmer of type θ gets expected surplus of $w - P_B - D(\theta)$. Line (a) is the expected virtual cost of strategy a, $P_B + D(\theta)$.

If the farmer chooses strategy b, he treats the cropland at time 0, which is assumed to ensure weed-free later. Farmers could not apply herbicide later after the crop sibling comes out, as it will kill both the weed and the crop. The amount of herbicide used in the pre-emergence treatment, s, is assumed to be fixed and invariant over types. The farmer incurs a total cost per acre of $(f + s)$, where $f > 0$ is the fixed cost per unit land of spraying the crop, and $s > 0$ is the market cost of the chemical for pre-emergence treatment. The farmer gets surplus of $w - P_B - f - s$, which is invariant over types. Therefore, line (b), the virtual cost of strategy b, is a horizontal line at $P_B + f + s$.

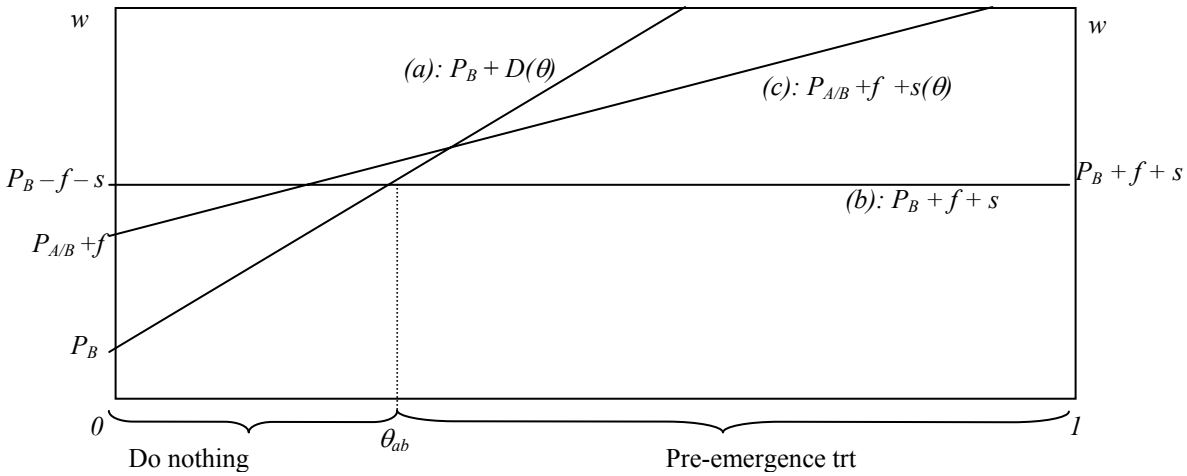
If the farmer choose strategy c, he pays the premium at the beginning ($P_B < P_{A/B}$) and the GM seed enables him to apply the herbicide later according to level of weed grown in the field. He incurs an expected cost per acre of $(f + s(\theta))$, where $f > 0$ is the fixed cost per acre of spraying the crop, and $s(\theta)>0$ is the expected market cost of the

chemical applied by farmer of type θ, and $s(0) = 0$, $D'(\theta) > s'(\theta) > 0$. A farmer of type 0 gets surplus of $w - P_{A/B} - f$. A farmer of type θ gets expected surplus of $w - P_{A/B} - f - s(\theta)$. Line (c) is the expected virtual cost of strategy c), $P_{A/B} + f + s(\theta)$. Line (c) touches the right-hand-side axis at $P_{A/B} + f + s(1)$.

Figure 2. Farmers' purchasing decisions, gene as chemical complement, given P_B, $P_{A/B}$, f, s, $s(\theta)$, and $D(\theta)$.



I. Three groups farmers, choosing (a), (b) and (c)



II. Two groups farmers, choosing (a) and (b)

Figure 2 (I) is the case where three groups of farmers are observed while (II) is the case where only two groups of farmers are observed. In panel (I), farmers with type lower than θ_{ac} will choose strategy a. Farmers with types greater than θ_{bc} will choose strategy b. Those lies in (θ_{ac}, θ_{bc}) chooses strategy b. Thus, if $\theta_{ac} > \theta_{bc}$, then farmers would rather choose between a and b, which is depicted in panel (II).

Farmers adopt strategy a when the infestation severity index is close to zero, and choose to treat the cropland before the weed emergence when the infestation severity index is close to the upper bound. The introduction of herbicide tolerance GM seed has both plus and minus effect on the total use of chemical. The dominant effect is determined by the relative density distribution of the farmer's type. The GM seed adoption increases the consumption of the chemical by farmers with types in (θ_{ac}, θ_{ab}). Without the GM seeds, these groups of farmers choose "doing nothing". It also decreases the consumption of the chemical by farmers with types in (θ_{ab}, θ_{bc}). This group of farmers used to adopt the "pre-emergence treatment" strategy, in which all the cropland is treated equally and to the maximum effective extent. With GM seed, the chemical is applied according to the level of weed occurred, therefore less chemical is needed for the treatment of these lands. The dominant effect is determined by the relative density distribution of farmers in those two regions and their level of chemical usage. On the other hand, since the GM technology virtually ties the chemical use to the seed, the chemical producer of that certain herbicide gains the whole market of (θ_{ab}, θ_{bc}). The loss in (θ_{ab}, θ_{bc}) due to farmers' switch from strategy b to c is shared by all the suppliers in the

chemical market if it is highly competitive. Therefore, the tied herbicide producer's sale will boost in general.

The trait royalty (or technology fee) will affect the demand for the GM seed. If the premium is lower, then $[\theta_{ac}, \theta_{bc}]$ is wider. If the chemical producer integrates with the gene/breeder, then it captures its rent either via the sale of the chemical or via the sale of GM seeds. If it has market power in the chemical sector (for example, it holds a unique patent of that chemical), then we argue that it will reap the rent from the chemical sale. A higher chemical price shifts line (b) up and tilts line (c) up in figure 2. If, however, the chemical sector is highly competitive (for example, the patent on the herbicide is expired), then an increase in the integrated firm's chemical price will not affect line (b) very much. The integrated firm would reap the rent from the GM seed sale (increasing prices of GM seed, while keeping the chemical price low).

5. Summary and conclusions

The study is motivated by an effort to understand the observed substantially increasing vertical and horizontal integration in the seed and pesticide industries since the 1990s. While the existing literature argues that the concentration may be driven by technology factor, by intellectual property pressure, or by parties' heterogeneous belief, we try to investigate it from the strategic perspective. We develop a simple model in which the basic seeds are perfect substitute and the breeder market is oligopolistic, and examine the case where the gene is a chemical substitute and the case where the gene is a chemical complement.

We find that if the market already exists, i.e. the breeders are already in the market, then the dominant strategy for the gene holder is to exclusively license to one of the breeders and commit to bundling by selling only the GM seed. If the exclusive commitment is not credible to the breeder such that it declines the licensing offer, the gene holder will integrate forward with one of the breeder in order to commercialize its gene innovation. If, however, that the market does not exist, i.e. the breeders need to bear entry cost if they decide to enter the new market, then the gene holder's dominant strategy is to integrate with a breeder and commit to unbundling, i.e. selling both GM seed and the basic seed in the new market. The potential entrants would be deterred because of the suicidal price competition if they choose to enter. If the gene is a chemical complement, then the chemical firm has strong incentive to integrate forward with the gene holder/breeder. Whether the integrated firm will reap the rent through the sale of the chemical or the sale of the GM seed depends on the market competition level in the chemical sector and the distribution of farmer's type.

This paper, however, is subject to several limitations, which also imply our future studies. Our analysis has been made on speculation of the relevant market. An empirical study on the relevant market, including the product scope and geographic locations, will be very helpful for improving our analytical model. Secondly, the simple model presented here may be not enough to examine the trade-off between licensing and integration forward in the more relevant case, where the basic seeds are most likely differentiated for farmers. Moreover, we would like to find out whether there exists parameter spaces that integrating (bundling) plus licensing becomes the dominant

strategy. In another word, the gene company may integrate forward partially so as to commit to “bundling”. With the commitment in place, the seed companies may find it optimal to accept the licensing offers, which would be otherwise suboptimal.

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