Innovation and market power : the influence of GMOs on the seed product line strategy*

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Abstract

This paper analyzes the impact of a license agreement between an upstream biotech company and a downstream seed company on the product line of the seed company. The license concerns a patent protected Genetically Modified (GM) trait that can possibly be introduced in a seed variety. With royalty-based license, we show that the licensing strategy of the upstream company can lead the downstream company to practice second order price discrimination. When this strategy appears at the equilibrium, we show that the introduction of the innovative GM trait may lead to a welfare loss.

Keywords: price discrimination, licensing, GMOs

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1 Introduction

Genetically Modified (GM) seeds have been introduced in 1996 and have diffused rapidly since then. For example, nowadays in the US the percentage of acreages sowed with GM seeds is 89% for soybean, 61% for corn and 83% for cotton[1]. Despite their rapid diffusion, the GM seeds have raised several important economic concerns regarding the market power of the innovator. GM traits are patent protected so they entail a price premium. Farmers may be forced to pay this premium if non-GM varieties adapted to their region are no longer available or if they are baned to save their seeds. Then farmers' welfare might decrease and with it the total social welfare. Who gains and who looses from the introduction of GM seeds? Will GM seeds replace conventional seeds and if yes, is this undesirable? What shares of the global social benefit stemming from the innovation do the agbiotech and the seed companies capture through the price premium?

This paper analyzes the range of seed supply and its consequences on the social welfare and on the farmer's surplus after the introduction of a GM trait. On the one hand, a narrow range might force farmers to buy expensive GM seeds, no matter if they need or not their specific traits. On the other hand, a large range of products allows seed companies to price discriminate among farmers, and thus to extract their surplus. We analyze this tradeoff in a model in which farmers are heterogeneous with respect to the benefit they accrue from using different seeds. The model takes into account the specific two tier structure of the supply of GM seeds: upstream there is an agbiotech company that licenses a GM trait; downstream there is a seed company that detains a conventional seed in which it could further incorporate the GM trait, provided it accepts the license [2]. The range of seed supply is then an equilibrium that depends on the characteristics of the demand and the structure of the supply.

We show that price discrimination appears at the equilibrium if farmers are heterogeneous enough. When this is the case, the social gains from the introduction of the new technology are reduced or might be even negative, despite the enhanced efficiency of seeds with GM traits. The introduction of GM seeds drives up the prices of seeds, hurting farmers that prefer conventional seeds. Their drop in surplus is so drastic that drives down the total farmers' surplus from both markets. The increase in the suppliers' profits might not be enough to offset the overall drop in farmers' surplus. This is the case if farmers have different needs, but the technology is inefficient and the seeds, being similar, do not address them.

Conversely, a situation where a narrow range of seeds is available appears at the equilibrium if farmers are relatively homogeneous. In this case only GM seeds are sold. The increase in their price is moderated by the fact that these seeds have to reach all types of farmers, including those that have a low

[1]See the USDA-ERS web site for regular updated figures concerning the diffusion of GM seeds in the US : http://www.ers.usda.gov/Data/BiotechCrops/

[2]For example, Pioneer has to sign a license agreement with Monsanto to commercialize RoundUp Ready soybean seed and this agreement clearly influence the seed catalog of Pioneer.

preference for the GM trait. Then, the social welfare increases. Also, in most of the cases the total farmers' surplus increases as well: the benefit from using efficient seeds offsets the negative effect of higher seed prices. Yet, farmers that do not have a real need for the GM trait loose due to the increase in seed price.

Our results consequently show that farmers' total benefit is higher when narrower ranges of seeds are sold in the market, such as is the cases when only conventional seeds are available (before the introduction of the GM trait) or when only GM seeds are available (after the innovation): larger product lines allow producer companies to discriminate between farmers and thus to substract their surplus. In addition, farmers that do not necessarily need the GM trait may loose from its introduction. The actors that always gain from the innovation are the agbiotech and the seed companies.

The section 2 of this paper presents the related literature both in agricultural economics and industrial organization. Our model is presented in the section 3 and its results are presented in section 4 to 6.

2 Related literature

Several articles have already analyzed the impact of the introduction of GM seeds in a framework in which the market power of the innovator is explicitly considered (Sobolevsky et al., 2005; Falck-Zepeda et al., 2000; Shi, 2009). The first two contributions are derived from Moschini and Lapan (1997) who showed that, with respect to a situation in which research and development is done in a competitive environment, the welfare gains stemming from the innovation are reduced when the innovator has market power. These papers do not analyze the interaction between biotech and seed companies and the price discriminatory strategies that may be pursued by the former type of companies. Closer to our study is the work of Shi (2009) who models the interaction between an upstream biotech producer and a downstream seed sector. Unlike in our model, she assumes duopoly competition in the seed market and focuses on the incentives of the upstream and downstream firms to integrate to lessen competition, and on their consequences on the seed offer (i.e. on the product line choice of seed producers). On the contrary, in this study we abstract from the issue of vertical integration to analyze more particularly the impact of the licensing strategy of the upstream company on the product line of the downstream company. A royalty based license is considered in this model and its level is endogenous[3]. We also analyze the consequences of this strategic interaction on the welfare impact of the introduction of GM seed, while Shi's analysis is limited to the firm strategy at the equilibrium.

Our analysis is, more generally, related with the IO literature on product differentiation and price discrimination. This model is in the line with the work of Mussa and Rosen (1978) and Maskin and Riley (1984) that analyze the price

[3] Shi (2009) consider a fixed fee and exogenous license. Combined with the assumption of Bertrand competition, the upstream companies earn no profit as soon as the GM seed is sold by two competitors.

discrimination strategy of a monopoly based on product quality. However, we consider a different context with two successive monopolies where the upstream monopoly, through its royalty level, affects the downstream monopoly's incentives to pursue price discriminatory strategies. Setups with two layers of market power, where firms might price discriminate between consumers, have been considered by Dobson and Waterson (1996) using linear pricing and by Avenel and Caprice (2006) using a two part tariff. Much like Shi (2009) in these models the downstream sector is controlled by an oligopoly and not by a monopoly. Thus they do not isolate the incentive to price discriminate consumers from the strategic interaction between downstream firms (both papers) and between upstream firms (only Dobson and Waterson, 1996).

3 The model

We analyze in this model the behavior of two successive monopolies: an agbiotech company (the upstream monopoly) that owns a patent on a GM trait and that offers a license to a seed company (the downstream monopoly). The seed company has already developed a conventional variety, n, and can further develop a GM variety, g, by introducing the GM trait in it. The two types of seeds are characterized by their ability, x_i ($i = n, g$), to stand a pest. The economic interest of the GM trait lies on its efficiency, so $x_n < x_g$.

The seed company detains a technology that allows it to produce both the conventional and the GM varieties at similar costs. For simplicity we normalize them to 0. Therefore the marginal cost of producing the conventional variety is 0 and the marginal cost of producing a GM variety is equal to the royalty, r, paid by the seed company to the agbiotech company. Note that $r = 0$ corresponds to the case where the seed company is a subsidiary of the agbiotech company. We use this case as a benchmark. Given the cost of the license, r, and farmers' demand described below, the seed company decides the range and the prices of the products sold.

The market is represented by two segments of equivalent size, normalized to 1/2. In segment s ($s = 1, 2$), each farmer faces a pest problem of magnitude θ_s with $0 \leq \theta_1 < \theta_2 \leq 1$. When using variety i ($i = n, g$), a farmer in this segment gets an utility

$$u_{is}(p_i) = 1 - \theta_s(1 - x_i) - p_i, \tag{1}$$

where p_i is the price of product i charged by the seed company. We assume that the same product cannot be sold at two different prices. Hence the seed company can discriminate between farmers only by selling two different products, thus by the means of a third degree price discrimination. Given that farmers from the same segment confront the same pest magnitude and face the same prices, they get the same utility from buying seeds i. Thus all farmers in a segment prefer the same type of seed.

Each farmer has also the opportunity to choose an external alternative which provides an utility u_e. u_e is uniformly distributed on $[0, \bar{u}]$ for each segment.

Because of the uniform distribution of u_e the demand for product i in segment s is linear and decreasing in p_i :

$$D_{is}(p_i) = \begin{cases} 0 & \text{if } u_{is}(p_i) < u_{js}(p_j), \\ \dfrac{1-\theta_s(1-x_i)-p_i}{2\bar{u}} & \text{otherwise} \end{cases} \tag{2}$$

($j \neq i$). For the sake of simplicity and without loss of generality we assume hereafter that $x_n = 0$.

The sequence of decisions is defined in three stages. First, the agbiotech defines the royalty rate, r. Second, the seed company accepts or refuses the license agreement and chooses its product line. Three product lines are possible: (N) when only the conventional seed is sold, (B) when both the conventional and the GM seed are sold, (G) when only the GM seed is sold. At last (third stage), the seed company decides the prices of each product and sales occur. The model is solved backward.

4 Seed price equilibrium with a given product line

We first consider the cases where only one type of seed is supplied (product lines N and G). At a given price, p_i ($i = n, g$), the demand for seeds of type i is higher in market 1 than in market 2 (follows from (2)). This is because farmers on market 2, facing a more severe pest problem than farmers on market 1, extract lower utility from that crop and therefore are more prone to choose alternative cultures. Consequently, if the price is low ($p_i < 1-\theta_2(1-x_i)$), the demand for seeds i is positive on both markets. With intermediate prices ($1-\theta_2(1-x_i) < p_i < 1-\theta_1(1-x_i)$) there is a positive demand only on the first market. At last, there is no demand at high prices ($p_i > 1-\theta_1(1-x_i)$).

Let

$$\tilde{\theta}_{1n} = \theta_2(1+\sqrt{2}) - \sqrt{2},$$

$$\tilde{r}_G = 1-(1-x_g)\frac{\theta_2(1+\sqrt{2})-\theta_1}{\sqrt{2}} \quad \text{and} \quad \bar{r}_G = 1-\theta_1(1-x_g).$$

The optimal pricing strategy of the seed company is defined in the following lemma.

Lemma 1. *If the seed company sells only conventional seeds, it will cover both markets if $\theta_1 > \tilde{\theta}_{1n}$, and only market 1 if $\theta_1 < \tilde{\theta}_{1n}$. The price of conventional seeds will be P_n^* in the first case and p_{n1}^* in the latter case, where*

$$P_n^* = \frac{2-(\theta_1+\theta_2)}{4} \quad \textit{and} \quad p_{n1}^* = \frac{1-\theta_1}{2}.$$

If the seed company sells only GM seeds, it will cover both markets if it pays a low royalty ($r < \tilde{r}_G$), and only market 1 for intermediate royalty levels

($r \in [\tilde{r}_G, \bar{r}_G]$). *There will be no sale if* $r > \bar{r}_G$. *The corresponding prices of GM seeds will be* P_g^* *and* p_{g1}^*, *respectively, where*

$$P_g^* = \frac{2(1+r) - (\theta_1 + \theta_2)(1 - x_g)}{4} \quad \textit{and} \quad p_{g1}^* = \frac{(1+r) - \theta_1(1 - x_g)}{2}.$$

Proof. See appendix A. □

With conventional seeds, if farmers in market 1 face a mild pest (θ_1 small), they have relatively higher demand and are willing to pay higher prices compared to farmers in market 2. Consequently, the seed company is prone to charge high prices, prices at which no farmer in market 2 is willing to buy its seeds. With GM seeds, an increase in the royalty level leads to an increase in price. At intermediary levels of the royalty the price becomes too high for farmers that face a sever pest to get positive utility from their crop. If the royalty increases even further, at one point even market 1 disappears.

In order to simplify the presentation, from here on we focus only on the cases in which the demand for the conventional seed on market 2 is high enough so that, if the GM variety is not available, it is sold on both markets. A sufficient condition for that is:

$$\tilde{\theta}_{1n} < 0 \qquad \Leftrightarrow \qquad \theta_2 < 2 - \sqrt{2}. \tag{3}$$

Under this condition, when r is relatively high so the GM seeds are sold only in market 1 ($r \in [\tilde{r}_G, \bar{r}_G]$), the profit than the seed company gets is lower that the profit it would earn by selling conventional seeds on both markets (for a proof see Appendix B). To simplify further the presentation, in what follows we disregard all dominated price equilibria. Consequently, when the seed company offers only one type of seed (product lines N or G) we consider only the cases when this seed is sold in both markets.

We now consider the case where both types of seeds are sold (product line B). In each market, at a given price, the demand for GM seeds is higher than the demand for conventional seeds. However, the difference is larger in market 2, where the pest pressure is higher. Hence, if the two types of seeds are sold in equilibrium, the conventional one is sold in market 1 and the GM is sold in market 2, where it has a higher, positive impact on the demand. The optimal pricing strategy of the seed company is defined in the following lemma.

Lemma 2. *If the seed company sells the two products, there is a unique price equilbrium that, depending on the royalty level, corresponds to one of the following configurations:*
(B1) if the royalty is low ($r < min[\tilde{r}_{B1}, \bar{r}_{B1}]$), *the price equilibrium is*

$$p_n^{B1} = \frac{(2+r) - \theta_1(1+2x_g) - \theta_2(1-x_g)}{4} \quad \textit{and} \quad p_g^{B1} = w_n^{B1} + x_g\theta_1$$

These prices are such that the incentive constraint on market 1 is binding.
(BS) if the royalty level is intermediate ($\tilde{r}_{B1} < r < min[\tilde{r}_{B2}, \bar{r}_{B2}]$), *the price*

equilibrium is (p^*_{n1}, p^*_{g2}). *These prices corresponds to the independent maximization on the two markets.*
(B2) if the royalty level is high ($\tilde{r}_{B2} < r < \bar{r}_{B2}$), *the price equilibrium is*

$$p_n^{B2} = \frac{(2+r) - \theta_1 - \theta_2(1+x_g)}{4} \quad \textit{and} \quad p_g^{B2} = w_n^{B2} + x_g\theta_2$$

These prices are such that the incentive constraint on market 2 is binding.

Proof. See appendix C. □

Figure 1 illustrates the conditions of lemma 2 that lead to the different configurations of price equilibria with a product line B [4].

The natural candidate for the equilibrium is (p^*_{n1}, p^*_{g2}): the seed company chooses independently the prices of type n and of type g that maximize its profits on market 1 and 2, respectively. However, in order for these prices to form the equilibrium, they should be incentive compatible for farmers: the conventional seed has to be preferred on market 1 ($u_{n1}(p^*_{n1}) \geq u_{g1}(p^*_{g2})$), and the GM seed has to be preferred on market 2 ($u_{g2}(p^*_{g2}) \geq u_{n2}(p^*_{n1})$). These two constraints are satisfied only for intermediary royalty levels ($\tilde{r}_{B1} < r < \tilde{r}_{B2}$), where

$$\tilde{r}_{B1} = x_g\theta_2 + (1-2x_g)(\theta_2 - \theta_1) \qquad \text{and} \qquad \tilde{r}_{B2} = x_g\theta_2 + (\theta_2 - \theta_1).$$

At low royalty levels, the difference between p^*_{n1} and p^*_{g2} is low so that farmers in both markets prefer the GM seed. The incentive constraint in market 1 is violated. The price equilibrium in (B1) is then defined by maximizing the seed company's profit on a binding market 1 constraint: $p_g - p_n \geq x_g\theta_1$. Conversely, the difference between p^*_{n1} and p^*_{g2} is so high with high royalty levels that all farmers prefer the conventional seed. The incentive constraint in market 2 is violated. The price equilibrium in (B2) is then defined by maximizing the seed company's profit on a binding market 2 constraint: $p_g - p_n \leq x_g\theta_2$.

Last, the rationality constraint of the farmers needs to be satisfied at the price equilibrium. This condition holds if farmers in market 2 have positive utility, which is the case if the royalty is lower than a maximum value, $\bar{r}$. This maximum value depends on the precise configuration, (B1), (BS) or (B2):

$$\bar{r}_{B1} = 2 + \theta_1(1-2x_g) - 3\theta_2(1-x_g)$$
$$\bar{r}_{BS} = 1 - \theta_2(1-x_g)$$
$$\bar{r}_{B2} = 2 + \theta_1 - \theta_2(3-x_g)$$

5 Product line strategy of the seed company

In this section we analyze the product line strategy of the seed company at a given royalty level, r.

We start by considering the benchmark case, namely the situation in which the upstream biotech company is integrated with the seed company.

[4]Note that figure 1 presents a placement of curves that is valid as long as $x_g < 1 - \theta_2/2$. Conversely, if $x_g > 1 - \theta_2/2$ then we always have $\tilde{r}_{B1} < \bar{r}_{B1}$ so $\bar{\theta}_{1B1} < 0$.

Lemma 3. *A vertically-integrated company that develops both GM traits and seeds sells only GM seeds.*

Proof. See appendix D. □

In this benchmark, the equilibrium in the downstream market has the properties described by lemma 1 and lemma 2 when there is no royalty payment ($r = 0$). If only one type of seed is sold, an integrated company prefers to sell GM rather than conventional seeds because they have higher demand while the production costs are identical. Yet, the company may want to discriminate and sell different types of seeds in different markets. In this case the incentive constraint of farmers in market 1 requires that the price of the GM seeds is above the price of the conventional seeds by a certain margin. The unconstrained optimal price of GM seeds in market 2 is $p^*_{g2} = \frac{(1+r)-\theta_2(1-x_g)}{2}$. Without royalty this price is close to the unconstrained optimal price of conventional seeds in market 1, $p^*_{n1} = \frac{1-\theta_1}{2}$ (in fact it may even become smaller than it for large x_gs !). Consequently, the incentive constraint in market 1 leads to a price distortion that is large, and detrimental to the company.

The following proposition describes the optimal product line of the seed company when it is not integrated with the upstream biotech company, and the biotech company charges a royalty r.

Proposition 1. *If the royalty is small ($r < \theta_1 x_g$), the seed company sells only GM seeds at a price P^*_g (product line G).*

For intermediary royalty levels ($r \in [\theta_1 x_g, \hat{r}_{BN}]$), the seed company sells both GM and conventional seeds. The prices on the seed market correspond either to a configuration (B1) or (BS), depending on the parameters.

If the royalty is high ($r > \hat{r}_{BN}$), the seed company rejects the license and sells only conventional seeds at a price P^*_n (product line N).

Proof. See appendix E. □

If the royalty is 0, the profit of the seed company is equal to the profit of the integrated company considered in lemma 3. The seed company then sells only GM seeds. When the royalty level increases, on the one hand, the marginal cost of producing GM seeds increases as well, leading to a decrease in the profit of the seed company. However, this decrease is more drastic if the company sells GM seeds in two markets (product line G) rather than in only one market (product line B). On the other hand, an increase in the royalty level leads to an increase in the optimal price of GM seeds in market 2. As a result, the price distortion induced by the incentive constraint in market 1, in a (B1) configuration, decreases with an increase in r. As r increases from 0, at one moment the latter effect will offset the former. Therefore, there is a royalty level over which the seed company earns more by selling the two types of seed.

Similarly, we can compare the cases where the seed company sells both conventional and GM seeds *vs* only conventional seeds. If the royalty is equal to

0, the profits are higher in the former case (see appendix E). This is due to the fact that although when discriminating, the seed company is constrained when setting prices, the benefit from pushing up the demand in market 2 by selling GM seeds at no costs, more than offsets the negative impact of price distortion. Therefore a product line B yields higher profits than a product line N. However, the seed company's profit decreases with the royalty level if the two types of seeds are sold, but does not change if only conventional seeds are sold. Hence, as r increases from 0, there is a threshold value over which the seed company gains more by selling only conventional seeds. Consequently, the seed company rejects the license agreement if the royalty is too high.

A more detailed analysis (cf. appendix E) enables to define the different threshold values of the royalty level for which the seed company changes its product line. Figure 2 illustrates this result.

6 The optimal licensing strategy of the biotech company and its impact on the social welfare

In this section we analyze the optimal licensing strategy of the biotech company. As we saw in the previous section, the royalty level impacts the product line of the seed company (proposition 1). Should the biotech company define a low royalty level to have GM seeds sold on both markets, or a higher royalty level and have only sales on market 2?

To solve this stage 1, we first found the local optimal royalty level for the cases in which the seed company chooses a product line G, or one of the configurations (B1), (BS) that correspond to a product line B[5]. We took into account the range of royalty values for which each product line is chosen. Note that the local optimal royalty may be interior to these ranges or equal to the upper or lower bounds. The computations are presented in detail in the appendix F. The global optimal royalty level is then inferred by comparing the profits of the biotech firm under each local optimum. The global optimum changes with the values of parameters θ_1, θ_2, and x_g. Its analytical formulation is rather complex and we do not present it in the paper. Figure 3 illustrates the royalty level and the product line at the equilibrium, at a particular value of θ_2 ($\theta_2 = 0.57$). Hereafter we focus on the main properties of the equilibrium. Their analytical proofs do not hinge on the complete description of the equilibrium.

Proposition 2. *The optimal licensing strategy of the biotech company leads the seed company to discriminate if the pest pressure on market 1, θ_1, is low enough.*

Proof. See appendix G. □

A major consequence of property 1 is that at intermediary royalty levels, the product line strategy of the seed company may correspond to a second degree

[5]The product line N will never appear at the equilibrium because the biotech company would then earn no profit. Moreover, the configuration (B2) is ruled out because the seed company is always better off with a product line N (cf. proposition 1).

price discrimination. For a B product line to become optimal, at given farmers' characteristics (i.e. at given θ_1 and θ_2), the royalty has to be high enough so the price distortion induced by the incentive constraint in market 1 is reduced. Yet, when θ_1 decreased, farmers become more differentiated and thus become less inclined to buy seeds preferred by farmers in the other market [6]. As a result, as θ_1 decreases the market 1 incentive constraint weakens, and discrimination occurs at lower and lower levels of r, and for wider and wider ranges of this variable. As θ_1 approaches 0, the seed company chooses to sell GM seeds only to segment 2 from very small until relatively high values of r. Given this, when θ_1 is small, it is optimal for the biotech company to renounce to market 1 in order to charge high prices for its GM trait, inducing thus a B product line. Conversely, as θ_1 increases from 0, the seed company starts to prefer a product line G to a (B1) configuration for higher and higher rs. Consequently, it becomes more and more attractive for the biotech company to induce a G line as it can charge higher royalties for larger quantities. Therefore, there exist a threshold value of θ_1 over which the biothech company earns higher profits by inducing a G product line rather than a (B1) configuration.

Lemma 4. *If the optimal licensing strategy of the biotech company leads the seed company to discriminate, then the introduction of the GM seed leads to an increase of the price of the conventional seed.*

Proof. See appendix H. □

In other words, this lemma states that if the optimal licensing strategy of the biotech company induces a (B1) or a (BS) configuration, the price of the conventional seed will be higher with respect to the price with a N product line. This result is not surprising. With respect to a (BS) configuration, when selling only conventional seeds (product line N) the seed company charges monopoly prices not only to farmers in market 1 but also to those in market 2. As these latter farmers have a lower demand, the price is lower with an N product line than in a (BS) configuration. In a (B1) configuration, the seed company is only a constrained monopoly. To discriminate it is forced to reduce the price of the conventional seeds with respect to the optimal prices. Yet, the price of conventional seeds remains above the price in an (N) equilibrium.

Lemma 5. *If the optimal licensing strategy of the biotech company leads the seed company to discriminate, then the introduction of the GM seed leads to a decrease in the farmers' surplus.*

Proof. See appendix I. □

The decrease in the farmers' surplus is mainly driven by the loss in farmers' surplus in market 1 due to the increase in the price of the conventional seed (as follows from lemma 4).

Figure 5 illustrates the changes in the farmers' surplus in markets 1 and 2, and in total, for all the possible values of parameters θ_1 and x_g in the case in

[6] Recall that the market 1 constraint is $p_g - p_n \geq x_g\theta_1$.

which $\theta_2 = 0.57$. This figures shows that farmers in market 1 almost always loose from the introduction of GM seeds. They gain only when they face, together with farmers in market 2, a sever pest problem and when the GM seeds are very efficient in fighting this pest. Otherwise they loose either because they are obliged to purchase expensive GM seeds since conventional seeds are not available, or because they have to buy the conventional seeds at higher prices. On the contrary, farmers in market 2 almost always gain from the introduction of GM seeds. They loose, however, if the technology is inefficient (low x_g) and farmers in market 1 have very different preferences (low θ_1). Then the introduction of the GM seeds serve merely as a discriminatory device and the two companies appropriate the benefits.

Proposition 3. *The introduction of a more efficient GM seed can lead to a welfare loss compared to the initial situation where only the conventional seed was sold. This loss can only be observed if the introduction of the GM seed leads the seed company to price discriminate by selling both types of seed.*

Proof. The appendix J proves : (i) that the welfare necessary increases when the royalty level is such that the seed company does not discriminate, and (ii) that a welfare loss can be observed in the particular case where $\theta_1 = 0$ □

The social welfare is the sum of the profits of the two firms and the farmers' surplus from both markets[7].

To understand the results in proposition 3 we first consider what happens in the benchmark case, where the seed and the biotech companies are integrated in one firm. We know from lemma 3 that an integrated firm chooses a product line G. The replacement of conventional seeds by GM seeds has two effects on farmers. On one side, they benefit from having a more efficient variety against pests. On the other side, they loose since they have to acquire these seeds at a higher price. The second effect dominates for low x_gs and low θ_1s, when farmers are highly differentiated but the GM seeds are not efficient in fighting pests. This is due to the fact that if farmers in market 1 do not need the GM trait, the increase in price has a negative effect on their welfare. Meanwhile, since the efficiency of the new variety is low, the benefits accrued by farmers in market 2 do not offset this loss. Then the total farmers' benefit might decline. Yet, the gain in profits of the integrated firm always offsets the potential decline in the farmers' surplus. Therefore, overall, the social welfare increases (see appendix K for a proof).

These mechanisms keep holding for the cases in which the biotech company charges a small royalty fee that induces a product line G. In this case, the cumulated profits of the two companies decrease due to the double marginalization problem. Yet, these profits remain high enough to offset the possible losses in farmers' surplus. Therefore, the social welfare increases with respect to the initial situation when only conventional seeds are available.

[7] Farmers' surplus in market s, $s = 1, 2$ stemming from the consumption of type i seeds, $i = n, g$, is $S_{s,i} = (1 + u[x_i, p_i, \theta_s]^2)/4$. This surplus function takes into account the utility of the farmers that choose alternative options.

Now we turn to the case when in the equilibrium the seed company has a B product line and thus discriminates between farmers. In this case, as stated by lemma 5, the farmers' surplus declines. This decrease is larger if the GM seed is not very efficient and the farmers are highly differentiated with respect to the pest problem that they face. Then the new seed is merely used as a discriminatory device to extract farmers' benefit. For low levels of θ_1 and x_g the former effect dominates so the social welfare decreases.

ALTERNATIVELY, to understand the impact that the introduction of the GM variety has on the social benefit we start from the extreme situation when $\theta_1 = 0$. In this case the introduction of the GM seed can lead to a welfare loss if this new seed is not very efficient and the farmers are highly differentiated with respect to the pest problem that they face (thus if θ_2 is high and x_g is relatively low). This fact is illustrated by Figure 4 which represents graphically the ranges of parameters for which the social welfare decreases with respect to a situation in which only conventional seeds are available. When this is the case, as explained above, the introduction of the GM seed is to the benefit of the seed company (and through it to the biotech company) which extracts the farmers' surplus by means of a third degree price discrimination. Farmers in market 1 loose due to the increase in the price of the conventional seed (see Lemma 4). In this case even farmers in market 2 may experience a drop in their surplus. The gain in profits of the two companies are not enough to offset the losses in farmers' surplus.

As θ_1 increases from 0, both the negative effect that the availability of GM seeds has on the price of conventional seeds and the incentives of the seed company to discriminate between farmers will decrease (see Proposition 2). Therefore, if θ_1 becomes high enough, the social welfare when the two types of seeds are technically available will be bigger than the social welfare when the GM variety is not available.

7 The equilibrium when $x_n > 0$

Up to now we have considered the case when $x_n = 0$. In this section we briefly indicate, without providing analytical proofs, which are the properties of the equilibrium in the more general case: $x_n > 0$. [8]

When x_n increases (with a given x_g), the degree of differentiation between the two seed varieties decreases. This has two implications. First, the equilibria which appear when the two products are highly differentiated (e.g. equil (G) with $r = r_G^{opt}$ or equil (BS) with $r = r_{BS}^{opt}$ in Figure 3) appear less or disappear. Second, as the seeds become similar, the seed company is more inclined to go for a (N) product line which is the least costly, and therefore discriminates between products or chooses a (G) line only for low enough values of r. Therefore, to get high profits, the biotech company will be more and more prone to charge the highest rs that still induce a product line that contains the GM seed. As a result, among the possible equilibria, those that have the highest rs start to

[8] Our inferences are based on simulation results. They are available upon request.

dominate (i.e. equil (B1) with $r = \hat{r}_{B1N}$ or equil (BS) with $r = \hat{r}_{BSN}$ in Figures 3 and 5, or equil (G) with $r = \theta_1 x_G$ in Figure 3).

Regarding the impact that an increase in x_n has on the social welfare, the total farmers' surplus always decreases if the optimal strategy of the biotech company leads the seed company to discriminate. Much as before, this decrease is induced by the drop in farmers' surplus in market 1 due to the higher price they have to pay for the conventional seed. Yet, since with the increase in x_n the seed company accepts lower and lower rs, the GM seeds become relatively less expensive and therefore the farmers in market 2 tend to always gain from the introduction of GM seeds. This positive effect together with the gain in firms' profits offsets more and more the loss in farmers' surplus in the first market and therefore, as x_n increase the area where the social welfare decreases becomes less and less important until it disappears.

8 Conclusion

In this paper we propose a model that studies the impact of innovation on the product line strategy of firms in the case of GMOs and seed product line. In a simple case of two vertically related companies, we show that a technological innovation of the upstream agbiotech company can lead the downstream seed company to supply a product line which allows to discriminate among farmers. Due to discrimination, the welfare of consumers decreases and the total welfare may decrease.

Our results and mechanisms explain what occurs currently on the soybean seed and corn seed markets. Almost 100% of cultivated soybeans in USA are GM. Our model reveals that soybean farmers are homogeneous in their needs (for the GM technology). Note that, nevertheless, this homogeneity may lead to focus research only on the GM traits or on seed with the GM technology. On the contrary, on the corn seed market, we can observe discrimination because of some heterogeneity in the pest pressure. Our model suggests that we may observe prices increases, including on conventional seed (Moschini (2010) reveals high increases in corn seed prices since 1996 and the beginning of GM seed supply)). Nevertheless, our paper does not deal with stacking, which occurs in GM corn seed market.

Incidentally, among the number of possible extensions and improves of this work, we could imagine discrimination with several innovation (traits) ; leading to incentive to license innovations (traits) bundles.

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Figure 1: Stage 3 equilibrium with discrimination ($x_g < 1 - 1/2\theta_2$)

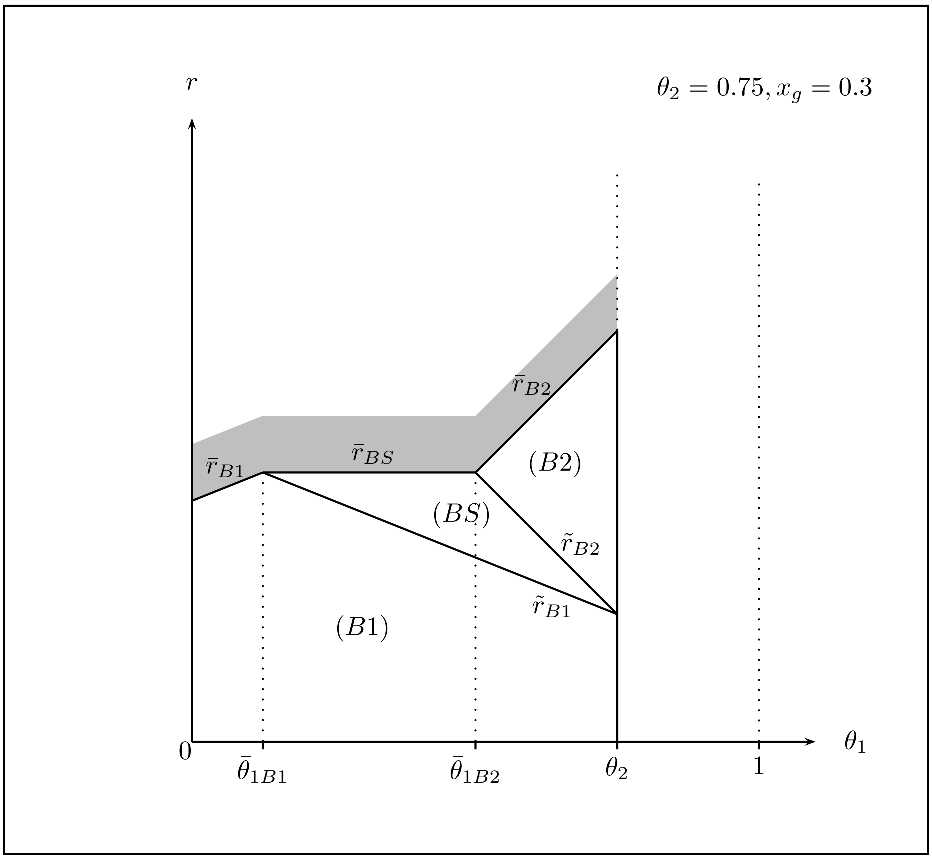


Figure 2: Stage 2 equilibrium

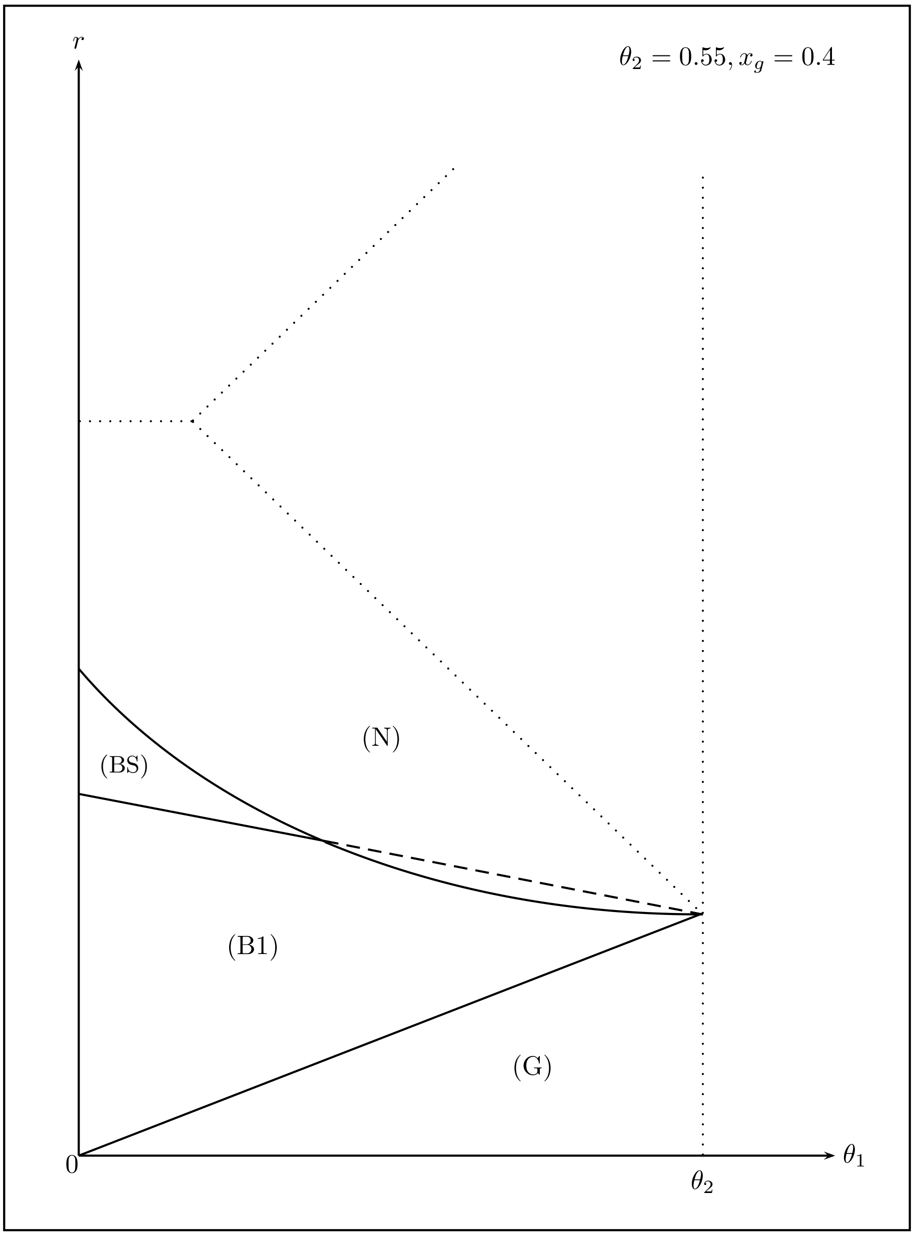


Figure 3: Stage 1 equilibrium with $\theta_2 = 0.57$

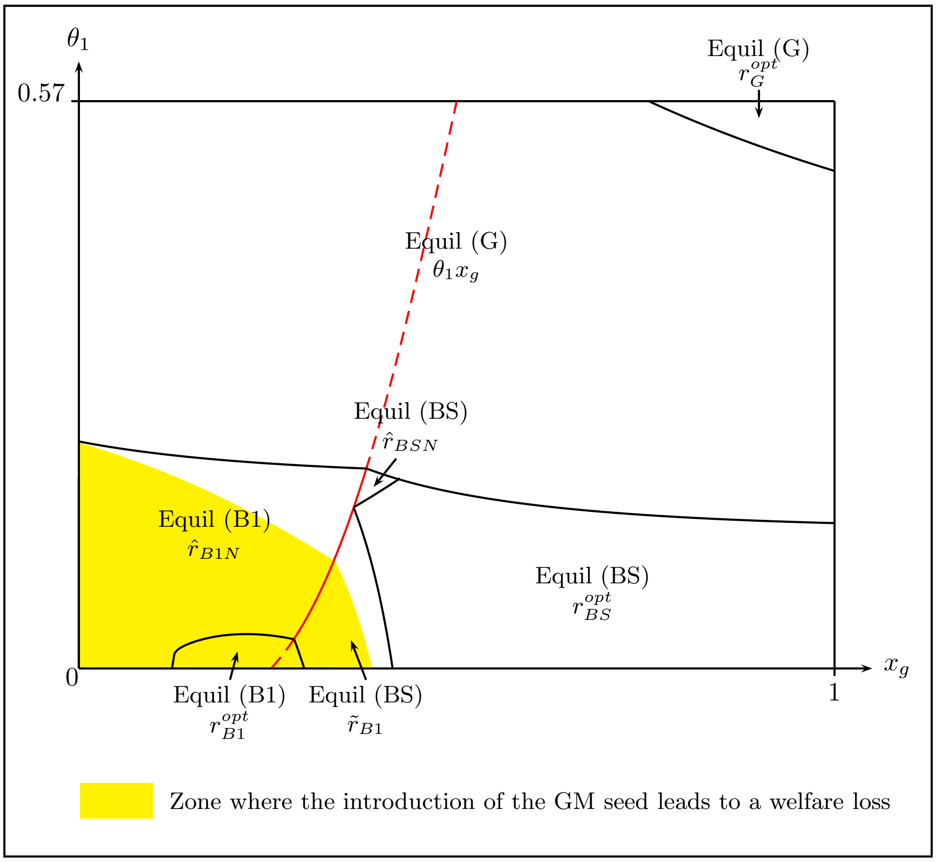


Figure 4: Stage 1 equilibrium with $\theta_1 = 0$

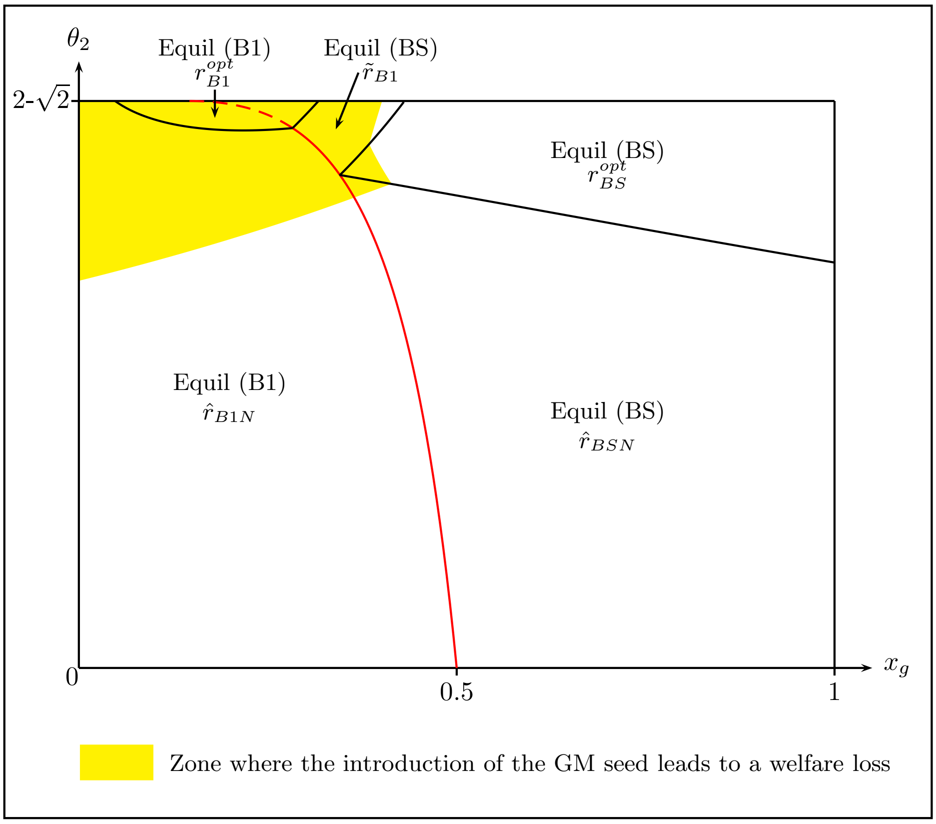
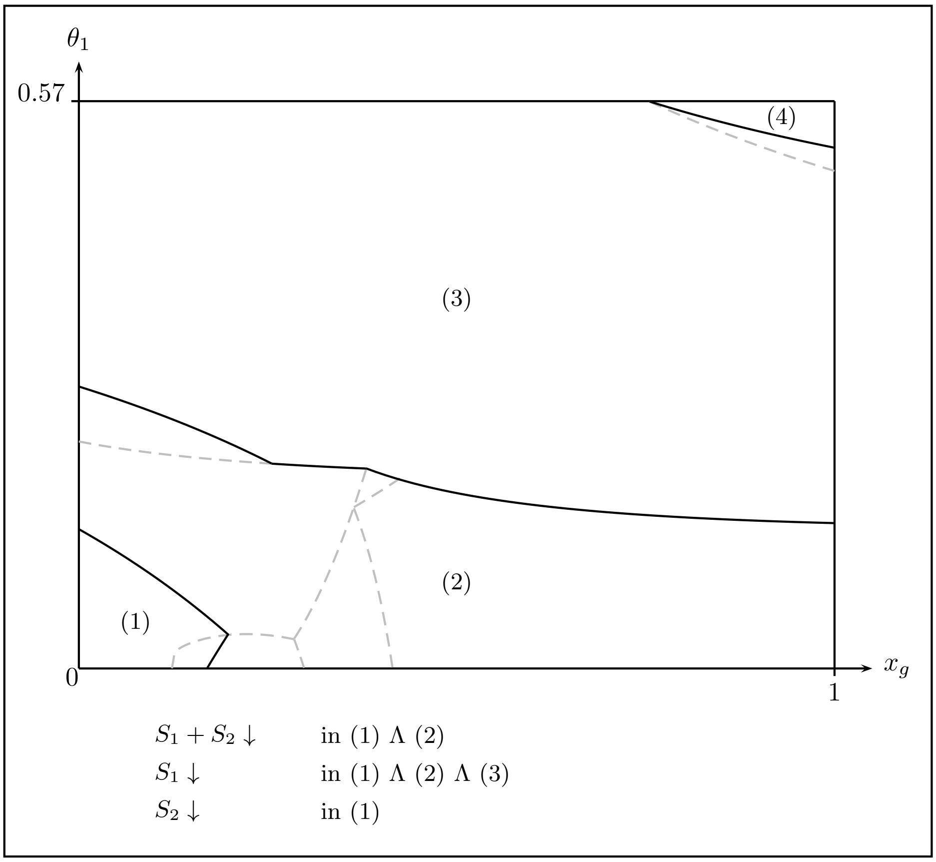


Figure 5: Farmer's surplus with $\theta_2 = 0.57$



Appendix

Notation for firm profit. When the seed company sells the product n at price p_n, the product g at price p_g and pays an royalty r, its profit is $\Pi_{seed}(p_n, p_g, r)$. We use the notation $p_i = \infty$ $(i = n, g)$ when the seed company does not sell the product i. The notation $\Pi^Z_{seed}(r)$ is used to refer to the seed company profit with optimal prices under the stage 2 subgame that correspond to the product line Z $(Z = N, G, B1, BS, B2)$. The corresponding biotech profit is $\Pi^Z_{btk}(r)$.

A Stage 3. Equilibrium with no discrimination

We first consider the case where only GM seed is sold at a price P_g. The seed company gets a profit $\Pi^G_{seed}(\infty, P_g, r) = \frac{2(1-P_g)-(\theta_1+\theta_2)(1-x_g)}{2\bar{u}}(P_g - r)$. Then the first order condition $\frac{\partial \Pi^G_{seed}(\infty, P_g, r)}{\partial P_g} = 0$ requires that $P^*_g = \frac{2(1+r)-(\theta_1+\theta_2)(1-x_g)}{4}$. At this optimal price the seed company earns a profit of $\Pi^G_{seed}(r) = \frac{[2(1-r)-(\theta_1+\theta_2)(1-x_g)]^2}{16\bar{u}}$.

If the GM seed is sold only in market s $(s = 1, 2)$ at a price $p_{g,s}$, the seed company gets a profit $\pi_{g,s}(p_{g,s}, r) = \frac{(1-p_{g,s})-\theta_s(1-x_g)}{2\bar{u}}(p_{g,s} - r)$. The first order condition $\frac{\partial \pi_{g,s}(p_{g,s}, r)}{\partial p_{g,s}} = 0$ implies that $p^*_{g,s} = \frac{(1+r)-\theta_s(1-x_g)}{2}$. At this optimal price the seed company earns a profit of $\pi_{g,s}(r) = \frac{[(1-r)-\theta_s(1-x_g)]^2}{8\bar{u}}$. Since this profits is decreasing in θ_s, $\pi_{g,1}(r) > \pi_{g,2}(r)$. Thus, if the seed company serves only one market it serves market 1.

The seed company gets higher profits by covering both markets instead of covering only market 1 if $\Pi^G_{seed}(r) > \pi_{g,1}(r)$. This condition is satisfied if r is smaller than $\tilde{r}_G$, where $\tilde{r}_G = 1 - (1 - x_g)\frac{\theta_2(1+\sqrt{2})-\theta_1}{\sqrt{2}}$. If $r > \tilde{r}_G$ the seed company sells GM seeds only in market 1, unless r is so high that $u_{g,1}(p^*_{g,1})$ is negative. This happens when $r > \bar{r}_G$, where $\bar{r}_G = 1 - \theta_1(1 - x_g)$.

A proof for the case when only the conventional variety is available is done in a similar manner, replacing both x_g and r by 0, and the index g by n. Then the optimal profits of the seed company when both markets are covered and when only market s $(s = 1, 2)$ is covered are, respectively, $\Pi^N_{seed} = \frac{[2-(\theta_1+\theta_2)]^2}{16\bar{u}}$ and $\pi_{n,s} = \frac{[1-\theta_s(1-x_n)]^2}{8\bar{u}}$. As in the case of GM seeds, $\pi_{n,1} > \pi_{n,2}$. Yet here $\pi_{n,1}$ is always positive. Therefore the seed company will sell conventional seeds at least in market 1.

The seed company sells conventional seeds in both markets if $\Pi^N_{seed} > \pi_{n,1}$, thus if $\theta_1 > \tilde{\theta}_{1n}$, where $\tilde{\theta}_{1n} = \theta_2(1 + \sqrt{2}) - \sqrt{2}$. Otherwise it sells its seeds only in market 1.

B Stage 3. Proof that $\Pi^N_{seed} > \pi_{g,1}(r), \forall r \in [\tilde{r}_G, \bar{r}_G]$

The proof is established by showing that $\pi_{g,1}(r) < \pi_{g,1}(\underline{r}) < \Pi^N_{seed}$ with $\underline{r} = 1 - \frac{\theta_2(1+\sqrt{2})-\theta_1}{\sqrt{2}}$.

The first part of the inequality ($\pi_{g,1}(r) < \pi_{g,1}(\underline{r})$) comes directly from the fact that $\underline{r} < \tilde{r}_G$.

The second part of the inequality is established as follow:

$$\begin{aligned}\Pi^N_{seed} > \pi_{g,1}(\underline{r}) \quad &\Leftrightarrow \quad \frac{[2-(\theta_1+\theta_2)]^2}{16\bar{u}} > \frac{[(1-\underline{r})-\theta_s(1-x_g)]^2}{8\bar{u}} \\ &\Leftrightarrow \quad 2-(\theta_1+\theta_2) > \theta_2(1+\sqrt{2}) - \theta_1 - \theta_1\sqrt{2}(1-x_g) \\ &\Leftrightarrow \quad 2-\theta_2(2+\sqrt{2}) + \sqrt{2}(1-x_g)\theta_1 > 0\end{aligned}$$

But since $\theta_2 < 2-\sqrt{2}$,

$$2-\theta_2(2+\sqrt{2}) + \sqrt{2}(1-x_g)\theta_1 > \sqrt{2}(1-x_g)\theta_1 > 0.$$

C Stage 3. Equilibrium with discrimination

The prices in the equilibrium (BS) have been already derived when proving Lemma 1. In order for (p^*_{n1}, p^*_{g2}) to be the equilibrium it is necessary to be incentive compatible for the farmers: the convention seed has to be preferred on the market 1, so $u_{n1}(p^*_{n1}) > u_{g1}(p^*_{g2})$, and the GM seed has to be preferred on the market 2, so $u_{g2}(p^*_{g2}) > u_{n2}(p^*_{n1})$. The first condition implies that $r > \tilde{r}_{B1}$, while the second commands that $r < \tilde{r}_{B2}$. Therefore, if $r \in [\tilde{r}_{B1}, \tilde{r}_{B2}]$, (p^*_{n1}, p^*_{g2}) is the equilibrium.

(B1): If $r < \tilde{r}_{B1}$, the incentive constraint on market 1 is binding. The prices should be such that farmers in market 1 do not want to consume GM seeds. Thus, they should be such that $u_{n1}(p_n) \geq u_{g1}(p_g)$ which yields: $p_g \geq p_n + x_g\theta_1$. Consequently, the seed company will choose (p_n, p_g) to solve the following maximization problem

$$\begin{aligned}&max\ \pi_{1,n} + \pi_{2,g} \\ &s.t.\ p_g \geq p_n + x_g\theta_1.\end{aligned}$$

As a result $p^{B1}_n = \frac{(2+r)-\theta_1(1+2x_g)-\theta_2(1-x_g)}{4}$ and $p^{B1}_g = p^{B1}_n + x_g\theta_1$. So $p^{B1}_g = \frac{(2+r)-\theta_1(1-2x_g)-\theta_2(1-x_g)}{4}$.

Further on, these prices should be also incentive compatible for farmers in market 2. It is immediate to verify that indeed (p^{B1}_n, p^{B1}_g) are so that $u_{n2}(p^{B1}_n) \leq u_{g2}(p^{B1}_g)$.

(B2): Similarly as before, if $r > \tilde{r}_{B2}$, the incentive constraint on market 2 is binding. The prices should be such that farmers in market 2 do not want to consume conventional seeds. Therefore $u_{n2}(p_n) \leq u_{g2}(p_g)$ which implies that $p_g \leq p_n + x_g\theta_2$. Then (p_n, p_g) should be the solution of the following maximization problem

$$max\ \pi_{1,n} + \pi_{2,g}$$
$$s.t.\ p_g \leq p_n + x_g\theta_2.$$

which implies that $p_n^{B2} = \frac{(2+r)-\theta_1-\theta_2(1+x_g)}{4}$ and $p_g^{B2} = p_n^{B2} + x_g\theta_2$. So $p_g^{B2} = \frac{(2+r)-\theta_1-\theta_2(1-3x_g)}{4}$.

In addition, $u_{n1}(p_n^{B2}) \geq u_{g1}(p_g^{B2})$, so these prices are incentive compatible for farmers in market 1.

For the above equilibria to be possible, it is necessary that the farmers in market 2 have positive utility at the corresponding equilibrium price of the GM variety:

$$\begin{array}{llll} u_{g2}(p_g^{B1}) > 0 & \Leftrightarrow & r < \bar{r}_{B1} & \text{with: } \bar{r}_{B1} = 2 + \theta_1(1-2x_g) - 3\theta_2(1-x_g) \\ u_{g2}(p_{g2}^*) > 0 & \Leftrightarrow & r < \bar{r}_{BS} & \text{with: } \bar{r}_{BS} = 1 - \theta_2(1-x_g) \\ u_{g2}(p_g^{B2}) > 0 & \Leftrightarrow & r < \bar{r}_{B2} & \text{with: } \bar{r}_{B2} = 2 + \theta_1 - \theta_2(3-x_g) \end{array}$$

It can be observed that $\bar{r}_{BS} = \bar{r}_G$

D Stage 2. Integrated firm

The profits of the integrated firm equal the profits of the seed firm when $r = 0$. Therefore, from Appendix A we have that the profits of the integrated firm in a G equilibrium are $\Pi_{seed}^G(0) = \frac{[2-(\theta_1+\theta_2)(1-x_g)]^2}{16\bar{u}}$, and in an N equilibrium are $\Pi_{seed}^N(0) = \frac{[2-(\theta_1+\theta_2)]^2}{16\bar{u}}$. The former are bigger than the latter: while the marginal costs of the two types of seeds are the same the GM seed reduces the severity of the pest and thus impacts positively the demand and through it, the marginal revenue. Further, from lemma 1 we know that when $r = 0$ among the B equilibria the one that is feasible is (B1). But $\Pi_{seed}^G(0) - \Pi_{seed}^{B1}(0) = \frac{x_g\theta_1[4-(6-5x_g)\theta_1+2(1-x_g)\theta_2]}{16\bar{u}} \geq 0$. Thus the integrated firm earns the highest profit having a product line G.

We also show in this appendix that $\Pi_{seed}^{B1}(0) - \Pi_{seed}^N(0) \geq 0$. Indeed this holds since $\Pi_{seed}^{B1}(0) - \Pi_{seed}^N(0) = \frac{x_g((1-x_g)(2\theta_1-\theta_2)^2+\theta_2(4-3\theta_2-2\theta_1+2x_g\theta_2))}{16\bar{u}}$, and since $4 - 3\theta_2 - 2\theta_1 + 2x_g\theta_2 \geq 0$.

E Stage 2: Proof of proposition 1

- Variation of the seed company profit with the royalty level. The profit of seed company is decreasing with the royalty level in the equilibrium B and G because the royalty directly affect the marginal cost. It can be shown that the profit decrease more drastically in the equilibrium G compared to the equilibrium B. This result is established below for the two configuration (B1) and (BS) of the equilibrium B[9]:

- Configuration (B1) ($r \in [0, min[\bar{r}_{B1}, \tilde{r}_1]]$).

$$\frac{\partial \Pi^{B1}_{seed}(r)}{\partial r} - \frac{\partial \Pi^{G}_{seed}(r)}{\partial r} = \frac{2 - 3r + \theta_1(4x_g - 3) + \theta_2(1 - x_g)}{8\bar{u}}$$

  This difference is decreasing with r and positive for all $r < \tilde{r}_1$.

$$\left.\frac{\partial \Pi^{B1}_{seed}(r)}{\partial r}\right|_{r=\tilde{r}_1} - \left.\frac{\partial \Pi^{G}_{seed}(r)}{\partial r}\right|_{r=\tilde{r}_1} = \frac{(1 - \theta_2) + x_g(\theta_2 - \theta_1)}{4\bar{u}} > 0$$

- Configuration (BS) ($r \in [\tilde{r}_1, min[\bar{r}_{BS}, \tilde{r}_2]]$).

$$\frac{\partial \Pi^{B1}_{seed}(r)}{\partial r} - \frac{\partial \Pi^{G}_{seed}(r)}{\partial r} = \frac{1 - r - \theta_1(1 - x_g)}{4\bar{u}}$$

  Remind that $\bar{r}_G = 1 - \theta_1(1 - x_g)$. This difference is decreasing with r and positive because we always have $r < \bar{r}_G$.

- Product line of the seed company depending on the royalty level. We now define threshold values on the royalty level by comparing the profit of the seed companies under the different equilibrium.

- *Equilibrium G vs B1 ($r < \tilde{r}_{B1}$).*

The stage 3 equilibrium is G if the seed company sells only g, and B1 if it sells both n and g. According to Section 4, in equilibrium B1 the price difference between g and n is $\Delta = x_g\theta_1$. Therefore, given the price p_g of the GM variety we can write the seed company's profit respectively when it sell only g or both n and g :

$$\begin{aligned} \Pi_{seed}(\infty, p_g, r) &= (p_g - r) \cdot (D_{1g}(p_g) + D_{2g}(p_g)) \\ \Pi_{seed}(p_g - \Delta, p_g, r) &= (p_g - \Delta) \cdot D_{1n}(p_g - \Delta) + (p_g - r) \cdot D_{2g}(p_g) \end{aligned}$$

But $D_{1n}(p_g - \Delta) = D_{1g}(p_g)$ because in a (B1) equilibrium the incentive constraint on market 1 is binding ($u_{1n} = u_{1g}$). With the same price p_g, the two product lines lead to the same profit of the seed company on the market 2, and to the same quantity sold on the market 1. Hence, between these two situations, the profit differs only because of the different price markup on the market 1 :

$$\Pi^{G}_{seed}(\infty, p_g, r) - \Pi^{B1}_{seed}(p_g - \Delta, p_g, r) = (\Delta - r) \cdot D_{1g}(p_g).$$

If $r < \Delta$ then the profit at the equilibrium is greater in the equilibrium G because :

$$\Pi^{G}_{seed}(r) = \Pi_{seed}(\infty, P^*_g, r) > \Pi_{seed}(\infty, p^{B1}_g, r) > \Pi_{seed}(p^{B1}_g - \Delta, p^{B1}_g, r) = \Pi^{B1}_{seed}(r)$$

[9]The comparison with the configuration B2 is skipped here because we will see later in this proof that the seed company prefer not to sell GM seed at all rather than to sell the two types of seed with a B2 type of equilibrium

Conversely, $r > \Delta$ then the profit at the equilibrium is greater in the equilibrium B1 because :

$$\Pi_{seed}^{B1}(r) = \Pi_{seed}(p_g^{B1}-\Delta, p_g^{B1}, r) > \Pi_{seed}(P_g^*-\Delta, P_g^*, r) > \Pi_{seed}(\infty, P_g^*, r) = \Pi_{seed}^{G}(r)$$

Finally we can conclude that the seed company earns more in the equilibrium G, compared to the equilibrium B1 if and only if $r < \Delta = x_g\theta_1$.

- *Equilibrium B1 ($r < \tilde{r}_{B1}$) vs N*

The difference $\Pi_{seed}^{B1}(r) - \Pi_{seed}^{N}$ is concave in r and its lowest root is :

$$\begin{aligned} \hat{r}_{B1N} &= 2 + (1-2x_g)\theta_1 - 3(1-x_g)\theta_2 - \sqrt{\delta} \\ \text{with : } \delta &= (2 + (1-2x_g)\theta_1 - 3(1-x_g)\theta_2)^2 \\ &\quad + x_g(2(3-2x_g)\theta_1\theta_2 - 4((1-x_g)\theta_1^2 + \theta_2) + (2-x_g)\theta_2^2 \end{aligned} \tag{4}$$

It is useful here to define the following threshold on θ_1 :

$$\hat{\theta}_{1BN} = \theta_2 - \frac{4(1-2x_g)(1-\theta_2)}{3 - 8x_g + 8x_g^2} \tag{5}$$

Note that $3 - 8x_g + 8x_g^2 > 0$ so that $\hat{\theta}_{1BN} < \theta_2$ iff $x_g < 1/2$. Note also that $\hat{r}_{B1N} < \hat{r}_1$ iff $\theta_1 \in [\hat{\theta}_{1BN}, \theta_2]$.

If $r = \tilde{r}_{B1}$ we have :

$$\Pi_{seed}^{B1}(\tilde{r}_{B1}) - \Pi_{seed}^{N} = \frac{(\theta_2-\theta_1)(3-8x_g+8x_g^2)}{16\bar{u}} \cdot (\hat{\theta}_{1BN} - \theta_1) \tag{6}$$

Finally two cases need to be distinguished :

- If $\theta_1 < \hat{\theta}_{1BN}$ then the seed company earns more by selling n and g (equilibrium B1) rather than selling only n. Indeed we have $\hat{r}_{B1N} > \tilde{r}_{B1}$ and $\Pi_{seed}^{B1}(r) - \Pi_{seed}^{N} > 0$ for $r = \tilde{r}_{B1}$.
- If $\theta_1 > \hat{\theta}_{1BN}$ then the seed company earns more by selling n and g (equilibrium B1) if $r < \hat{r}_{B1N}$. Conversely, if $r \in [\hat{r}_{B1N}, \tilde{r}_{B1}]$ the seed company prefers to reject the license and sell only n.

- *Equilibrium BS ($r \in [\tilde{r}_{B1}, \min[\bar{r}_{BS}, \tilde{r}_{B2}]]$) vs N.*

The difference $\Pi_{seed}^{BS}(r) - \Pi_{seed}^{N}$ is concave in r and its lowest root is :

$$\hat{r}_{BSN} = \underbrace{1 - \theta_2(1-x_g)}_{=\bar{r}_{BS}} - \sqrt{1 - 2\theta_2 + (\theta_2^2 - \theta_1^2 + 2\theta_1\theta_2)/2} \tag{7}$$

Note also that $\hat{r}_{BSN} < \tilde{r}_{B1}$ iff $\theta_1 \in [\hat{\theta}_{1BN}, \theta_2]$.

As before, two cases need to be distinguished :

- If $\theta_1 < \hat{\theta}_{1BN}$ the seed company earns more by selling n and g (equilibrium B1) if $r < \hat{r}_{BSN}$. Conversely, if $r > \hat{r}_{BSN}$, the seed company prefers to reject the license and sell only n.

- If $\theta_1 > \hat{\theta}_{1BN}$ then the seed company earns more by selling only n rather then n and g. Indeed we have $\hat{r}_{BSN} < \tilde{r}_{B1}$ and $\Pi^{BS}_{seed}(\tilde{r}_{B1}) - \Pi^{N}_{seed} < 0$. [10]

- Equilibrium B2 ($r > \tilde{r}_{B2}$) vs N

We can show that an equilibrium (B2) is never possible since the seed company gains higher profits by selling only conventional seeds. Let $\Delta = x_g\theta_2$. At a given price p_n of the conventional variety:

$$\begin{aligned}\Pi_{seed}(p_n,\infty,0) &= p_n\cdot(D_{1n}(p_n)+D_{2n}(p_n))\\ \Pi_{seed}(p_n,p_n+\Delta,r) &= p_n\cdot D_{1n}(p_n)+(p_n+\Delta-r)\cdot D_{2g}(p_n+\Delta)\end{aligned}$$

But $D_{2n}(p_n) = D_{2g}(p_n+\Delta)$ because in a (B2) equilibria the incentive constraint on market 2 is binding. Also, an equilibrium (B2) is possible only if $r > \tilde{r}_{B2}$. Consequently we have $\Delta - r < 0$ because $\Delta = x_g\theta_2 < \tilde{r}_{B2} < r$. Therefore $p_n + \Delta - r < p_n$ and $\Pi_{seed}(p_n, p_n + \Delta, r) < \Pi_{seed}(p_n, \infty, 0)$ for any price p_n. The seed company always reject the license because :

$$\Pi^{N}_{seed} = \Pi_{seed}(P^*_n,\infty,0) > \Pi_{seed}(p^{B2}_n,\infty,0) > \Pi_{seed}(p^{B2}_n, p^{B2}_n+\Delta, r) = \Pi^{B2}_{seed}(r)$$

- Synthesis. The table below synthesize the product line strategy decided by the seed company at the stage 2, depending on θ_1 and r. The figure 2 illustrates this result.

Table E

Equilibrium	$\theta_1 < \hat{\theta}_{1BN}$	$\theta_1 > \hat{\theta}_{1BN}$
G	$r < x_g\theta_1$	
B1	$x_g\theta_1 < r < \hat{r}_{B1N}$	$x_g\theta_1 < r < \tilde{r}_{B1}$
BS	*impossible*	$\tilde{r}_{B1}\theta_1 < r < \hat{r}_{BSN}$
N	$r > \hat{r}_{B1N}$	$r > \hat{r}_{BSN}$

F Stage 1: local optimum royalty level

We first define three unconstrained local optimum that correspond to the maximization of the biotech company profit for each of the product line strategy chosen by the seed company.

$$\begin{aligned}r^{opt}_{G} &= \text{argmax}_r[r\cdot(D_{1g}(P^*_g)+D_{g2}(P^*_g))] = \frac{2+(\theta_1+\theta_2)(1-x_g)}{4}\\ r^{opt}_{B1} &= \text{argmax}_r[r\cdot D_{g2}(p^{B1}_g)] = \frac{2+\theta_1(1-2x_g)-3\theta_2(1-x_g)}{2}\\ r^{opt}_{BS} &= \text{argmax}_r[r\cdot D_{g2}(p^*_g)] = \frac{1+\theta_2(1-x_g)}{2}\end{aligned}$$

[10] Note that $\Pi^{BS}_{seed}(\tilde{r}_{B1}) = \Pi^{B1}_{seed}(\tilde{r}_{B1})$. Hence we can use the result of the equation 6.

We now compile the local optimum royalty level when the conditions that define the seed company strategy (cf. table E) are taken into account.

- *Local optimum royalty with the product line G.* After observing that $r_G^{opt} < \theta_1 x_g$ if θ_1 is high enough, we conclude that the local optimal royalty level is :

$$r_G^* = \begin{cases} \theta_1 x_g & \text{if } \theta_1 < \frac{2-\theta_2(1-x_g)}{1+3x_g} \\ r_G^{opt} & \text{otherwise} \end{cases} \tag{8}$$

- *Local optimum royalty with the product line B1.* Note first that $r_{B1}^{opt} > \theta_1 x_g$ when $\theta_2 < 2-\sqrt{2}$. Remind that there is an upper bound on r to have a B1 type of equilibrium : ($\tilde{r}_{B1}$ if $\theta_1 < \hat{\theta}_{1BN}$ or $\hat{r}_{B1N}$ if $\theta_1 > \hat{\theta}_{1BN}$). Finally the local optimal royalty level is defined as follow:

$$r_{B1}^* = \begin{cases} \tilde{r}_{B1} & \text{if } \theta_1 < \hat{\theta}_{1BN} \text{ and } \theta_1 > \frac{5\theta_2(1-x_g)-2)}{3(1-2x_g)} \\ \hat{r}_{B1N} & \text{if } \theta_1 > \hat{\theta}_{1BN} \text{ and } \theta_1 < \frac{6(2x_g-1)+\theta_2(9-39x_g+26x_g^2)}{3-28x_g(1-x_g)} + \dots \\ & \dots \frac{2\sqrt{48x_g(1-x_g)+x_g\theta_2(-96+80x_g+16x_g^2+\theta_2(48-31x_g-24x_g^2+8x_g^3))}}{3-28x_g(1-x_g)} \\ r_{B1}^{opt} & \text{otherwise} \end{cases} \tag{9}$$

- *Local optimum royalty with the product line BS.* The equilibrium BS is possible only if $\theta_1 < \hat{\theta}_{1BN}$. Under this condition, the local optimal royalty level is defined as follow:

$$r_{BS}^* = \begin{cases} \tilde{r}_{B1} & \text{if } \theta_1 < \frac{5\theta_2(1-x_g)-2)}{3(1-2x_g)} \\ \hat{r}_{BSN} & \text{if } \theta_1 < \theta_2 - \sqrt{\frac{(3(1-2\theta_2+\theta_2^2)-2x_g\theta_2(1-\theta_2)-x_g^2\theta_2^2}{2}} \\ r_{BS}^{opt} & \text{otherwise} \end{cases} \tag{10}$$

It can be observed that $r_{BS}^{opt} = \bar{r}_{BS}/2$, so that the constraint $r < \bar{r}_{BS}$ is always fulfilled.

The compilation of the global equilibrium is not presented here but we briefly present the principle of this compilation. First, we intersect the different condition on θ_1 defined in the equations 8, 9 and 10. For each combination of conditions on θ_1 we compare the biotech profit with each local optimal royalty level in order to define the global optimal royalty level. Note that if $\theta_1 < \hat{\theta}_{1BN}$ the global optimal royalty level is either r_G^{opt}, $x_g\theta_1$, r_{B1}^{opt} or $\hat{r}_{B1N}$ and corresponding equilibrium are either G or B1. Note that if $\theta_1 > \hat{\theta}_{1BN}$ the global optimal royalty level is either r_G^{opt}, $x_g\theta_1$, r_{B1}^{opt}, $\tilde{r}_{B1}$ or $\hat{r}_{BSN}$ and corresponding equilibrium are either G, B1 or BS.

G Stage 1 : Proof of Proposition 2.

The proof is made by showing that the interest of the biotech firm is to define a royalty level that induce a (B) type of equilibrium when θ_1 tend toward 0 (upward), and conversely, that induce a (G) equilibrium when θ_1 tend toward θ_2 (downward).

- *Limit of the biotech firm profit when* $\theta_1 \to 0$. Under the (B) type of equilibrium, this limit is equal to the biotech profit when $\theta_1 = 0$. This profit level is defined in the table G with all the possible local type (B) local optimal royalty level. All these expression are positive if $\theta_1 = 0$. Hence $\lim_{\theta_1 \to 0} \Pi_{btk}^{B1}(r_{B1}^*) > 0$, and $\lim_{\theta_1 \to 0} \Pi_{btk}^{BS}(r_{BS}^*) > 0$.

The type (G) equilibrium is possible only if $\theta_1 > 0$. If θ_1 is close from 0, we have $r_G^* = x_g \theta_1$ and the profit is

$$\Pi_{btk}^G(x_g\theta_1) = \frac{x_g\theta_1(2 - \theta_1(1 + x_g) - \theta_2(1 - x_g)}{4\bar{u}}$$

Hence $\lim_{\theta_1 \to 0} \Pi_{btk}^G(r_G^*) = 0$.

Table G

r	*Biotech firm profit if* $\theta_1 = 0$
r_{B1}^{opt}	$\frac{1}{32}(2 - 3(1 - x_g)\theta_2)^2$
$\tilde{r}_{B1}$	$\frac{1}{4}(1 - x_g)\theta_2(1 - 2(1 - x_g)\theta_2)$
$\hat{r}_{B1N}$	$\frac{\sqrt{4+\theta_2(9\theta_2-12+8x_g(1-(2-x_g)\theta_2))}\cdot\left(2-3(1-x_g)\theta_2+\sqrt{4+\theta_2(9\theta_2-12+8x_g(1-(2-x_g)\theta_2))}\right)}{8}$
r_{BS}^{opt}	$\frac{1}{16}(1 - (1 - x_g)\theta_2)^2$
$\hat{r}_{BSN}$	$\frac{\sqrt{2(1-\theta_2)^2-\theta_2^2}(\sqrt{2}(1-(1-x_g)\theta_2)-\sqrt{2(1-\theta_2)^2-\theta_2^2})}{8}$

- *Limit of the biotech firm profit when* $\theta_1 \to \theta_2$. First consider a royalty level that induces a (B) type of equilibrium. At this limit, the equilibrium is (B1) if $x_g < 1/2$ and (BS) otherwise. In any case we have : $\lim_{\theta_1 \to \theta_2} r_{B1}^* = \lim_{\theta_1 \to \theta_2} r_{BS}^* = \theta_2 x_g$. The limit of the biotech firm profit is :

$$\lim_{\theta_1 \to \theta_2} \Pi_{btk}^{B1}(r_{B1}^*) = \lim_{\theta_1 \to \theta_2} \Pi_{btk}^{BS}(r_{BS}^*) = \frac{x_g\theta_1(1 - \theta_2)}{4\bar{u}}$$

We now consider a royalty level that induces a (G) equilibrium. The limit of the biotech firm profit is equal to the profit when $\theta_1 = \theta_2$. This profit is equal to the profit when $r = \theta_2 x_g$, which is equal to $\frac{x_g\theta_1(1-\theta_2)}{2\bar{u}}$.

Finally, when $\theta_1 \to \theta_2$ the biotech firm at least double its profit by choosing a royalty level that induces a (G) equilibrium.

H Stage 1. Proof of Lemma 4.

We know from stage 3, Section 4, that among the prices for conventional seeds in a (B1) and a (BS) equilibrium, the former are the lowest. Therefore for the proof it is sufficient to show that $p_n^{B1} > p_n^N$. Indeed, from Lemma 2, for a given r, $p_n^{B2} = \frac{(2+r)-\theta_1-\theta_2(1+x_g)}{4}$; from Lemma 1, $P_n^* = \frac{2-(\theta_1+\theta_2)}{4}$.

$$p_n^{B1} > p_n^N \qquad \Leftrightarrow \qquad r + x_g(\theta_2 - 2\theta_1) > 0.$$

Since in an (B1) equilibrium $r > x_g\theta_1$, the above inequality holds.

I Stage 1 : Proof of Lemma 5.

Farmers' surplus in market s, $s = 1, 2$, equals

$$S_{is}(p_i) = \frac{1}{2\bar{u}} \int_0^{u_{is}(p_i)} u_{is}(p_i)\, du + \frac{1}{2\bar{u}} \int_{u_{is}(p_i)}^{\bar{u}} u\, du.$$

The first term represents the surplus accrued by those farmers in market s that buy and cultivate seeds of type i ($i = n, g$) at the price p_i. The second term captures the surplus of the remaining farmers, who instead of buying seeds i pursue alternative options. $S_{is}(p_i)$ is then equal with

$$S_{is}(p_i) = \frac{u_{is}(p_i)^2}{4\bar{u}} + \frac{1}{4\bar{u}}.$$

If the seed company sells only conventional seeds (product line N), farmers in both markets get a total surplus

$$S^N = \frac{1}{2\bar{u}} + \frac{1}{64\bar{u}}(2 + \theta_1 - 3\theta_2)^2 + \frac{1}{64\bar{u}}(2 - 3\theta_1 + \theta_2)^2.$$

Below we show that when the parameters are such that the optimal licensing strategy of the biotech company leads the seed company to discriminate (configurations (B1) or (BS)), the corresponding farmers' surplus is lower than S^N.

Farmers' surplus in a (B1) configuration vs. S^N

At a given royalty, r, the farmers' surplus in a (B1) configuration is

$$S^{B1}(r) = \frac{1}{2\bar{u}} + \frac{1}{64\bar{u}}(2-r+\theta_1(1-2x_g)-3\theta_2(1-x_g))^2 + \frac{1}{64\bar{u}}(2-r-\theta_1(3-2x_g)+\theta_2(1-x_g))^2.$$

At the equilibrium we can show that $S^{B1}(r^*_{B1}) \leq S^{B1}(\theta_2 x_g) \leq S^N$.

The first inequality ($S^{B1}(r^*_{B1}) \leq S^{B1}(\theta_2 x_g)$) is explained by the fact that $S^{B1}(r)$ is decreasing in r and that $r^*_{B1} \geq \theta_2 x_g$. The first order derivative of $S^{B1}(r)$ is $\frac{\partial S^{B1}(r)}{\partial r} = -\frac{1}{16\bar{u}}(2 - r - \theta_1 - \theta_2(1 - x_g))$, is negative if $r < 2 - \theta_1 - \theta_2(1-x_g)$. This expression is indeed negative because $r^*_{B1} < \hat{r}_{B1N}$ (see appendix F) and $\hat{r}_{B1N} < 2 - \theta_1 - \theta_2(1 - x_g)$. To show that $r^*_{B1} \geq \theta_2 x_g$, we observe that (i) $\tilde{r}_{B1} \geq \theta_2 x_g$, (ii) $\hat{r}_{B1N} \geq \theta_2 x_g$, and (iii) $r^{opt}_{B1} = \frac{(2-3\theta_2)+\theta_1(1-x_g)+x_g(\theta_2-\theta_1)}{2} + \theta_2 x_g \geq \theta_2 x_g$.

The second inequality $S^{B1}(\theta_2 x_g) \leq S^N$ is derived by making the direct compilation :

$$S^{B1}(\theta_2 x_g) - S^N = -\frac{1}{8\bar{u}}(2 - x_g)(\theta_2 - \theta_1) \leq 0$$

Farmers' surplus in a (BS) configuration vs. S^N

Much as above, the farmers' surplus in a (BS) configuration at a given royalty, r, is

$$S^{BS}(r) = \frac{1}{2\bar{u}} + \frac{1}{16\bar{u}}(1 - (2 - \theta_1)\theta_1) + \frac{1}{16\bar{u}}(1 - r - \theta_2(1 - x_g))^2.$$

At the equilibrium we can show that $S^{BS}(r^*_{BS}) \leq S^{BS}(\tilde{r}_{B1}) = S^{B1}(\tilde{r}_{B1}) \leq S^N$.

The first inequality ($S^{BS}(r^{opt}_{BS}) \leq S^{BS}(\tilde{r}_{B1})$) comes from the fact that $S^{BS}(r)$ is decreasing in r and that $r^{opt}_{BS} > \tilde{r}_{B1}$. Remind that, by construction, $r^*_{BS} \in [\tilde{r}_{B1}, \bar{r}_{BS}]$. The first order derivative of $S^{BS}(r)$ is $\frac{\partial S^{BS}(r)}{\partial r} = -\frac{1}{8\bar{u}}(1 - r - \theta_2(1 - x_g))$, is negative because $r < 1 - \theta_2(1 - x_g) = \bar{r}_{BS}$. Also, we have $r^{opt}_{BS} \geq \tilde{r}_{B1} \geq \theta_2 x_g$.

J Stage 1. The social welfare

The social welfare is the sum of the profits of the two firms and the farmers' surplus in the two markets ($S + \Pi_{seed} + \Pi_{btk}$).

- The social welfare when $\theta_1 = 0$ When only conventional seeds are sold in the market, the social welfare is

$$W^N = \frac{1}{32\bar{u}}(3(2 - \theta_2)^2 + 4\theta_2^2).$$

The introduction of the GM variety leads, depending on the values of the parameters x_g and θ_2, to the five different types of equilibria that are represented in Figure 4. The following table gives for each of these equilibria the corresponding social welfare.

r^*	*Social welfare* (W^*)
r^{opt}_{B1}	$\frac{1}{128}\left(28 - 4(1 - x_g)\theta_2 + 7(1 - x_g)^2\theta_2^2\right)$
$\hat{r}_{B1N}$	$\frac{4(2-\theta_2)^2+16(1-(1-x_g)\theta_2)M-(7-16(1-x_g)^2\theta_2^2)M^2}{64}$
$\tilde{r}_{B1}$	$\frac{1}{8}\left(3 - 4(1 - x_g)\theta_2 + 2(1 - x_g)^2\theta_2^2\right)$
r^{opt}_{BS}	$\frac{1}{64}\left(19 - 14(1 - x_g)\theta_2 + 7(1 - x_g)^2\theta_2^2\right)$
$\hat{r}_{BSN}$	$\frac{4+4\theta_2-\theta_2^2+4\sqrt{2}\sqrt{2(1-\theta_2)^2-\theta_2^2}(1-(1-x_g)\theta_2)}{32}$

where $M = \sqrt{(2-3(1-x_g)\theta_2)^2 - x_g\theta_2(4-(2-x_g)\theta_2)}$.

By comparing the above welfare levels with W^N we then find for each region the ranges of parameters for which due to the introduction of the GM seed the social welfare decreases. A graphical representation is given in Figure 4.

Social welfare with a G vs. an N product line

In what follows we would like to show that if the biotech company would set a royalty level that induces the seed company to choose a product line G, the social welfare would increase with respect to the initial situation when only the conventional seed was available.

We know from the appendix F that the local optimal royalty is either $\theta_1 x_g$ if $\theta_2 < \frac{2-\theta_1(1+3x_g)}{1-x_g}$, or r_G^{opt} otherwise. Since $\frac{\partial W^G}{\partial r} = -\frac{1}{8\bar{u}}(2(1+r)-(\theta_1+\theta_2)(1-x_g)) < 0$, W^G decreases with r. Thus, when $\theta_2 > \frac{2-\theta_1(1+3x_g)}{1-x_g}$ and the optimal royalty is r_G^{opt}, the corresponding welfare is higher than $W^G|_{r=\theta x_g}$. Therefore to prove the above property it is sufficient to show that $W^G|_{r=\theta x_g} > W^N$. But

$$W^G|_{r=\theta x_g} - W^N = \frac{x_g}{32\bar{u}}\big(2\theta_2(6-7\theta_2+\theta_1)+2\theta_1(2+3\theta_2-5\theta_1)+x_g(7\theta_2^2-\theta_1^2)\big)$$

which, due to the constraints we have on the parameters ($\theta_1 < \theta_2 < 2-\sqrt{2}$), is positive (all 3 terms in the big paranthesis are positive).

K Stage 1 : The social welfare with an integrated company.

The replacement of conventional seeds by GM seeds has two effects on farmers. First, they benefit from having a more efficient variety against pests. Second, they loose from the fact that they have to acquire these seeds at a higher price. As the price is more adapted for the farmers in market 2, where the introduction of GM seeds has higher effect on the demand, the first effect always offsets the second one for segment 2: $\Delta S_2 = S_2^G - S_2^N = \frac{x_g(3\theta_2-\theta_1)(4-(2-x_g)(3\theta_2-\theta_1))}{16}$. Yet, farmers in market 1 loose from the introduction of GM seeds if they face pests to a much lower extent than farmers in market 2: $\Delta S_1 = S_1^G - S_1^N = \frac{x_g(3\theta_1-\theta_2)(4+(2-x_g)(\theta_2-3\theta_1))}{16}$ (thus if $\theta_1 < \frac{\theta_2}{3}$). Therefore, the surplus of the farmers decreases if the GM seeds are not efficient enough, thus when $x_g < 2 - \frac{4(\theta_1+\theta_2)}{5\theta_1^2-6\theta_1\theta_2+5\theta_2^2}$. However, the gain in profits for the integrated firm, which is equal with $\Delta\Pi = \Pi^G - \Pi^N = \frac{x_g(\theta_1+\theta_2)(4-(2-x_g)(\theta_1+\theta_2))}{16}$ always offsets this loss. Consequently, the social welfare $\Delta W = W^G - W^N = \frac{x_g(\theta_1(12-\theta_2-7(2-x_g)\theta_1))(\theta_2(12-\theta_1-7(2-x_g)\theta_2))}{32}$ increases regardless of the values of the parameters.