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5th ICABR conference
"Biotechnology, science and modern agriculture: a new industry at the dawn of the century"
Ravello, June 15-18, 2001

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Potential adoption of GM rapeseed in France, effects on revenues of farmers and upstream companies: an ex ante evaluation[1]

Marion Desquilbet, Stéphane Lemarié, Fabrice Levert, INRA Economie, France

Abstract

In this paper, we conduct an empirical investigation of potential adoption of herbicide-tolerant (HT) genetically modified (GM) rapeseed in France, with two questions : how large would be potential benefits from adoption; and how would these potential benefits be shared between farmers and input suppliers. Our aim is to study ex ante the potential impact of their adoption in France, in terms of adoption level, economic gains, and distribution of these gains between farmers and input suppliers. We use French survey data about current plant protection practices, in order to compute pesticide costs with conventional (i.e., non GM) crops for individual farms. Then, based on results of technical studies about GM variety trials in France, we compute a predicted pesticide cost with the GM variety. Next, we study adoption rates and gains or losses of farmers (adopters and non adopters) and upstream companies (sellers of conventional herbicides, of the total herbicide to which GM rapeseed is tolerant, of GM seed), depending on the GM seed license price, the margin rate on herbicide sales and the price of conventional herbicides.

1. Introduction

GMOs with improved agronomic traits have been diffused quickly in North America. On the opposite, they have progressively raised a huge controversy in the European Union, resulting in a moratorium on these products. One aspect of the controversy on the benefits or evil spells of GMOs revolves on their economic impact. The high diffusion of these products in the United States has lead American economists to study this question (see e.g. Joly, Lemarié et *al.*, 2000, and OECD (2000) for a synthesis of these studies), most of these studies concluding that the economic impact of GM crops is positive. Besides the question of the economic impact, another question is how these benefits are shared between different groups,

[1] This research was funded by the French Commissariat Général du Plan (convention 01/2001). We thank Josiane Champolivier and Antoine Messéan from CETIOM (Centre Technique Interprofessionnel des Oléagineux Métropolitains), France, for providing us data and numerous helpful explanations and comments on our work. Any remaining errors are the responsibility of the authors.

from upstream companies to the final consumers. Although this question has been less studied in the United States (US), studies generally conclude that even though innovators (biotech and seed companies) take over a large share of benefits, the part accruing to farmers is important. Should we conclude, then, that non adoption of GMOs in the EU leads to an important economic loss for farmers and other groups? Though existing studies show the pertinence of this question, it seems difficult to transpose their results directly, because of the difference in distributions of crops and plant protection problems between North America and the European Union.

In this paper, we leave aside some aspects of the controversy on GMOs (their effects on health and on the environment), as well as the question of the costs of segregation and identity preservation of non GMO products. Based on an empirical study on genetically modified (GM) herbicide tolerant (HT) rapeseed, our aim is to explore three questions: what is the potential diffusion level in France of currently available GMOs? What is the optimal price of the GM seed for upstream companies? What is the impact of GMOs on gains of farmers, pesticide suppliers, suppliers of the GM innovation?

Our methodology relies on two lessons drawn from US studies. Firstly, it appears that potential gains from GMOs vary widely from one farm to another, largely due to differences in weed/insect infestations and weed control practices (see e.g. Bullock and Nitsi, 2000). Secondly, diffusion of GMOs happened very quickly, which seems to indicate that farmers have learned very quickly about this innovation. Drawing from these two lessons, we abstract from questions about learning about the innovation and we focus on heterogeneity of potential gains between farmers due to different pest problems and different pest control practices. Developments presented here have two main interests:

- They take into account heterogeneity of gains for farmers. As a matter of fact, the product studied here represents an innovation on plant protection functions. Then, the gain for a given farmer will depend on the scope of the plant protection problem he is facing. HT rapeseed may give a good protection on weeds, yet may not be interesting for a farmer having few weeds that are easily and cheaply controlled by conventional herbicides. In the case of rapeseed, heterogeneity among plant protection situations is heterogeneous enough in France to make it necessary to account for heterogeneity among farmers.
- Among the different variables entering in the calculus of gains for the farmer, the price premium paid on GM seed compared with conventional seed is one of the less well-known. Given differences in general context compared with the United States, a direct transposition of American data to the French case would be hazardous. However, we can reasonably

assume that the innovator introducing the GM program will have a behavior of profit maximization at the scale of France. The analysis we propose here allows to give an estimation of the profit level of this innovator, for different levels of price premia on the GM seed. It will then be possible to give an estimation of the profit of this innovator for different levels of the price premium on the GM seed, and to show the one that maximizes its profit.

2. Assumptions and framework

2.1. General assumptions

Simulations are conducted under five restrictive assumptions.

- We ignore the potential price decrease in farm prices and re-allocation of farm areas between crops. In a general way, in our framework, a farmer decides to adopt a GM variety on a given cop if the adoption leads to productivity gains, by a decrease in production costs and/or an increase in yield. At given farm prices, the profitability of this crop increases for farmers having adopted the GM variety. This may lead to an increase in the aggregate supply level of this crop, at given farm prices, for two reasons. Farmers may increase the area allocated to the considered crop, to the detriment of other crops, because of the increase in its profitability. This effect may be reinforced by an increase in yield. The adjustment towards a new equilibrium between supply an demand leads to a decrease in the farm price of the considered crop. The size of the effects on areas and prices depends on different factors, notably the nature of the change in the relation price - supplied quantity due to GM adoption, the relation price - quantity demanded, the public policy instruments used on the crop considered. Here, we examine the incentive to adopt for different kinds of farmers, given the expected effect on GMOs on their production costs, but we do not examine the aggregate effect of adoption at the national level on adjustment of supply and prices.
- We do not take into account negative externalities, from risks of gene transfer towards weeds.
- We do not take into account indirect effects. Some farmers may find it interesting to adopt GMOs because they have an interesting indirect effect (e.g., a gain in time at a critic period). Our simulations on GM adoption by farmers are only based on direct effects of GMOs on the profit level, by economies in herbicide use.
- The effect on herbicide prices is exogenous. As will be shown, for given prices of conventional herbicides, GMOs lead to a decrease in herbicide sells. In reaction, the optimal price of the GMO innovation tends to decrease too. Rigorously, the work on the GM

tariffication must then rely on an analysis of market equilibrium displacement. In this paper, we only consider scenarios of exogenous decrease in conventional herbicide prices.

- The cost of segregation of GM and non-GM channels is ignored. The estimated impact of GMOs assumes that farm production is sold on the standard market, and that the diffusion of GMOs does not affect the cost of other crops. If we assume GM diffusion in France, the most probable scenario is one where a GM and a non-GM channel co-exist. Having a GM production would then lead to an increase in the cost of segregation of these two channels. This effect is ignored here.

In our analysis, we retain three types of actors:

- *Farmers*. Each farmer arbitrates between the choice of a conventional plant protection program and a GMO plant protection program. His choice will go to the program appearing as the most profitable one. Because the GMO program is new, the farmer however may possibly stay on the conventional program if the gain brought about by the GMO program is not sufficiently high.

- *Suppliers of conventional herbicides*. We assume that they gain a constant margin from selling conventional herbicides. Given the lack of information on these margins, we were constrained to assume an identical margin on all products. In first place, we assume that the same conventional herbicides are supplied with the same price. Then, we assume that they react by decreasing their prices.

- *The innovator*. This actor supplies the event of transformation that allows to conduct a GMO-type program of plant protection. We assume here that the event of transformation has already created with sunk costs of research and development. In the case of an HT crop, simultaneous use of the GM seed and the total herbicide to which this seed is tolerant (called 'GMO herbicide" for simplicity reasons) are needed in the GMO program. The profit of the innovator is the sum of profits gained from selling GM seed, plus, possibly, profits gained from selling the complementary herbicide (different cases will be studied). The price premium paid on the GM seed is supposed to be a total gain for the innovator because the production cost of the GM seed is approximately equal to the production cost of the conventional seed. We consider that the innovator maximizes its profit by choosing the GM seed price premium level while he cannot change the price of the GMO herbicide. At least, for the time being, we assume that there is only one innovator.

Three types of actors are ignored:

- *Seed producers*. In reality, seed producers sign a license agreement with the innovator who allows them to use the GM event of transformation in their varieties. By assuming that all the price premium on the GM seed is a profit for the innovator, we assume that: (i) the license agreement stipulates the existence of royalties on each bag of GM seed, (ii) seed producers are in perfect competition on the supply of the GM event of transformation and are constrained to sell the GM seed at a price equal to the sum of the price of the conventional seed and the royalties that will be paid to the innovator. In other words, once royalties deduced, the seed producer has the same margin by bag of seed, whether GMO or conventional. This is an extreme assumption: we know from the American experience that the innovator is constrained to give an additional margin to the seed producer, in order that this seed producer is willing to realize the necessary investments to integrate the event of transformation is it varieties. The few available data suggest however that the margin given to the seed producer are small (around 10 to 20% of the price premium on the GM seed).

- *distributors* distribute GM or conventional seed and herbicides. Nothing lets believe that the margin they are realizing is higher for GMO solutions compared with non conventional solutions.

- *Downstream actors.* As indicated above, farm production prices are assumed constant. Then, no surplus transfer happens towards actors downstream to the farmer. In addition, downstream actors are assumed to yield the same utility from farm production, whether it comes from GM or conventional crops.

In summary, we adopted some reductive assumptions to keep our framework simple. Then, it is necessary to keep three observations in mind:

- What we consider here as the innovator profit actually covers the innovator profit and the profit of seed producers who create OGM, with the part going to seed producers being small.

- The innovator profit remunerates some sunk costs that have been encountered to bring the innovation on the market, i.e. research costs and costs of tests necessary to bring the innovation on the market.

- Gains of farmers do not take into account transfers to the downstream sectors that will happen if there is a price decrease. In other words, the gain of farmers should rather be considered as the gain of farmers and downstream actors.

Under this set of assumptions, we now define the simulation method. We start by an observation on the conventional program used by each farmer and its per hectare cost. For each type of conventional program, an alternative GMO program allowing to reach the same yield is proposed. In other words, farm gain relies only on a decrease in weeding costs. Depending on the cost decrease (or cost increase) of the GMO program compared with the conventional program, the farmer chooses to keep the same conventional program or to adopt the alternative GMO program. After aggregating farmers' choices, it is possible to draw the curve of demand for GM seed as a function of the price premium of the GM seed compared with the conventional seed, and to estimate the gains of the innovator and the losses of suppliers of conventional herbicides.

Even with this simplified framework, estimations depend on many variables, among which some are known better than others, with three cases:

- Some variables are well known and should not change much after the introduction of GMOs. They are the per hectare quantities of herbicides and the correspondence between conventional and GMO programs. These variables keep the same value in all our estimations.
- Some variables are not very well known or may change once GMOs are introduced. They are the margin on herbicides, the minimal gain that farmer anticipates to choose to adopt the GMO program, and the price of conventional herbicides that may decrease after the introduction of GMOs. For each of these variables, we conduct a sensitivity analysis.
- The price premium on the GM seed is endogenous in our model. Results are presented with a large range of values of this variable or at the optimum of the innovator (i.e. when the price premium on the GM seed maximizes the profit of the innovator).

2.2. Analytical framework

We use index j for farmers; index k of the type of rapeseed, taking two values, c for conventional rapeseed and g for GM rapeseed; index i for conventional herbicides. We let p denote the farm output price; w_s^g denote the additional price paid on the GM seed compared with the conventional seed (latter called "license price"); w_h^c denote the vector of prices of conventional herbicides (w_{hi}^c being the price of conventional herbicide i); w_h^g denote the price of the GMO herbicide g (i.e., the total herbicide to which GM rapeseed is tolerant); Δ denote additional profit for which the farmer adopts GM rapeseed. Variables specific to farmer j are y_j, denoting yield obtained by farmer j (assumed identical for GMO and conventional rapeseed); s_j , denoting rapeseed area for farmer j; h_{ij}^c denoting per hectare quantity of conventional herbicide i by farmer j; h_j^g, denoting per hectare quantity of GMO herbicide g by farmer j; c_j , denoting all other costs of farmer j including the cost of the conventional seed. Total area allocated to rapeseed is constant and given by $S = \sum_j s_j$.

Farmer j's profit on one hectare of conventional rapeseed is equal to his revenue (price multiplied by yield) minus his costs (cost of conventional herbicides, all other costs):

$$\pi_j^c(p, w_h^c, w_n) = p\, y_j - \sum_i (w_{hi}^c\, h_{ij}^c) - c_j$$

Farmer j's profit on one hectare of GM rapeseed is equal to his revenue (price multiplied vby yield) minus his costs (GMO herbicide cost, GM seed license price, all other costs):

$$\pi_j^g(p, w_h^g, w_s^g, w_n) = p\, y_j - w_h^g\, h_j^g - w_s^g - c_j$$

These profits are functions of input and output prices. In the case of a conventional program, per hectare quantities of conventional herbicide h_{ij}^c are assumed optimal for the farmer given his specific characteristics and given output and input prices.

In the case of GMO program, we establish a correspondence between the characteristics of the conventional program initially conducted and the characteristics of the GMO program appearing as optimal. This correspondence was established in link with the French technical institute for oilseeds, Centre Technique Interprofessionnel des Oléagineux Métropolitains (CETIOM). It depends on the number of herbicide applications.

Adoption condition

Farmer j adopts if the profit with the best GMO program yields an additional profit at least equal to Δ compared with the profit obtained with the best conventional program. Equivalently, farmer j adopts the GMO program if it yields a cost economy at least equal to Δ compared with the best conventional program.

$$\pi_j^g(p, w_h^g, w_s^g) - \pi_j^c(p, w_h^c) > \Delta$$
$$\Leftrightarrow \sum_i (w_{hi}^c\, h_{ij}^c) - w_h^g\, h_j^g - w_s^g > \Delta$$

Note that our comparison in profit levels is equivalent to a comparison in cost levels for two reasons: (i) we assume identical yields for both programs, (ii) we assume an identical output price for both types of rapeseed.

The preceding equation may also be written as:

$$\pi_j^g(p, w_h^g, w_s^g) - \pi_j^c(p, w_h^c) > \Delta$$
$$\Leftrightarrow w_s^g < \sum_i (w_{hi}^c\, h_{ij}^c) - w_h^g\, h_j^g - \Delta$$

We define a variable γ_j equal to1 if farmer j adopts the GMO program and 0 if farmer j stays on a conventional program:

$$\gamma_j = 1 \Leftrightarrow w_{sg} < \sum_i (w_{hi}^c\, h_{ij}^c) - w_h^g\, h_j^g - \Delta$$
$$\gamma_j = 0 \Leftrightarrow w_{sg} > \sum_i (w_{hi}^c\, h_{ij}^c) - w_h^g\, h_j^g - \Delta$$

In what follows, we analyze adoption as a function of the GMO seed license price, w_s^g, for given price levels of other inputs. For farmer j, the preceding equation shows that adoption occurs only when w_s^g if less than a threshold value, given by $\sum_i (w_{hi}^c h_{ij}^c) - w_h^g h_j^g - \Delta$. This threshold value is different among farmers. Moreover, it is a function of prices of conventional herbicides, w_h^c, price of the GMO herbicide, w_h^g, and the minimal additional profit level, Δ.

Besides, we note in the preceding equation that the value of parameter γ_j (0 or 1) does not depend on variables w_s^g and Δ independently, but depends on the sum of these two variables, $(w_s^g + \Delta)$. Let us then consider the effect of an increase in parameter Δ from an initial value Δ_1 to a final value Δ_2 (i.e. an increase in the additional profit needed to "convince" farmers to adopt the GMO program). All other things equal, the adoption condition for farmer *j* stays unchanged if: $(w_{s1}^g + \Delta_1 = w_{s2}^g + \Delta_2)$, i.e., if the GM seed license price decreases from an initial value w_{s1}^g to a final value $w_{s2}^g = w_{s1}^g + \Delta_1 - \Delta_2$.

Adoption rate

When adopted by a farmer, the GMO program is adopted to its whole area allocated to rapeseed, s_j. The GMO adoption rate is defined as the share of total rapeseed area where the GMO program is adopted:

$$TA = \frac{1}{S} \sum_j \gamma_j \, s_j \, .$$

(From what precedes, we note that, all other things equal, the GMO adoption rate stays unchanged when parameter Δ increases from Δ_1 to Δ_2, if the GMO seed license price decreases from w_{s1}^g to $w_{s2}^g = w_{s1}^g + \Delta_1 - \Delta_2$).

Input demand

The total GMO area is the sum of GMO areas for farmers adopting the GMO program:

$$S^g = \sum_j \gamma_j \, s_j$$

Total sales of the GMO herbicide are equal the sum of per hectare quantities used multiplied by areas adopting the GMO program:

$$Q^g = \sum_j \gamma_j \, h_j^g \, s_j$$

Total sales of each conventional herbicide i are equal to the sum of per hectare quantities used multiplied by areas staying in a conventional program:

$$Q_i^c = \sum_j (1-\gamma_j)\, h_{ij}^c\, s_j$$

Profits

Here, we make the three following assumptions. The company selling the GMO innovation also sells the GMO herbicide. The margin rate on herbicides, denoted by ϕ, is identical for all products. The production cost of the GM seed is equal to the production cost of the conventional seed (in other words, the margin on sales on the GMO is equal to 100%).

The profit of the innovator selling the GM seed is equal to the sum of profits from sales of GM seeds (GM seed license price multiplied by the toal GMO area) and profits from sales of the GMO herbicide (margin rate on the GMO herbicide multiplied by the total quantity of GMO herbicide that is sold).

$$\Pi^g = w_s^g\, S^g + w_h^g\, \phi\, Q^g\ .$$

Profits from sales of the conventional herbicide i are equal to the margin rate on conventional herbicide i multiplied by the total quantity of herbicide i that is sold:

$$\Pi^i = w_i^h\, \phi\, Q_i^c\ .$$

Total profits of farmers on rapeseed are equal to the sum of profits of farmers adopting the GMO program and profits of farmers staying on a conventional program:

$$\Pi^a = \sum_j s_j \left[\gamma_j\, \pi_j^g + (1-\gamma_j)\pi_j^c\right].$$

This total profit may be written as: $\Pi^a = \Pi_0^a - CH^a$, where Π_0^a is the total margin realized by farmers on rapeseed before deducting herbicide costs, and CH^a is the sum of weeding expenses for all farmers:

$$\Pi_0^a = \sum_j s_j (p\, y_j - c_j)\ .$$

Under our assumptions, Π_0^a is a constant independent on the adoption rate of GMO programs.

$$\begin{aligned} CH^a &= \sum_j s_j \left[\gamma_j (w_h^g\, h_j^g + w_n\, n_j^g) + (1-\gamma_j)\left(\sum_i (w_{hi}^c\, h_{ij}^c) + w_n\, n_j^c\right)\right] \\ &= w_s^g\, S^g + w_h^g\, Q^g + \sum_i w_i^h\, Q^i \end{aligned}$$

The sum of weeding expenses is composed of two terms. The first one is equal to total expenses on the GMO herbicide. The second one is equal to total expenses on conventional herbicides.

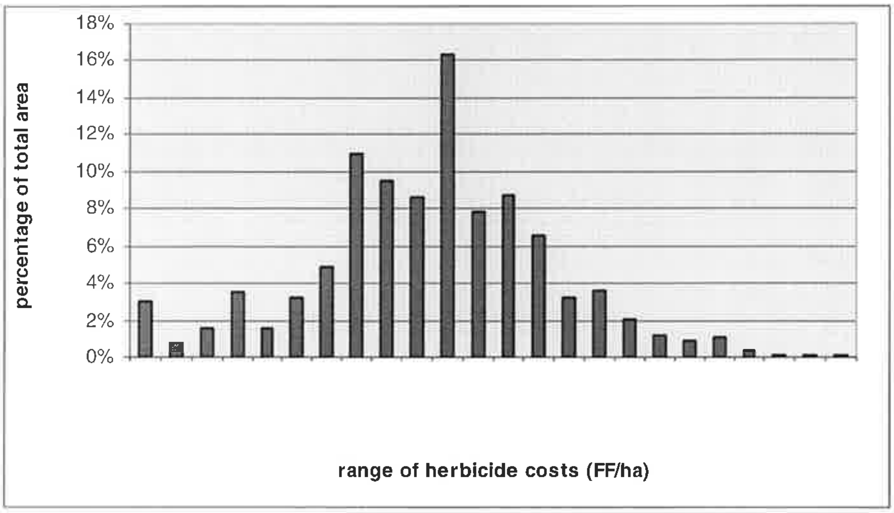
3. Simulations

3.1. Data

Our analysis is led using a data from the farm survey "charte environnement" from CETIOM led in 1999 (1999 harvest). Our database is composed of 1238 farms covering a total rapeseed area of around 32 000 hectares (2.4% of the French rapeseed area). Sampling bias was corrected attributing a weight to each farm in order to ensure national representativeness of French geographic departments and of rapeseed area classes. Then, results presented here are national projections on the 1.369 millions hectares of rapeseed in France.

The distribution of weeding costs in the sample (Figure 1) shows the important diversity of conventional strategies of plant protection. Globally weeding expenses vary between 0 and 1300 F/ha, with a mean of 547 F/ha.

Figure 1. Distribution of conventional herbicide costs in the sample



It may take up to three applications to weed rapeseed, at the following stages: pre-sowing, pre-emergence, and post-emergence. Each type of program was then defined by a three-digit code, each digit indicating whether there was application (code 1) or no application (code 2) at the pre-sowing stage (first digit), pre-emergence stage (second digit) or post-emergence stage (third digit). For example, a program "101" corresponds to two applications, the first one at the pre-sowing stage, the second one at the post-emergence stage. The GMO program considered here is a program combining the total herbicide Roundup (glyphosate) with a rape seed resistant to Roundup (or Roundup-Ready® seed). Strategies of conventional/GMO replacement (Table 1) have been defined using Gigandon and Pilorge (1997) and CETIOM data (2000). The herbicide cost of the GMO program varies between 100 and 200F/hectare, the average price used for RoundUp ($w^h{}_g$) being equal to 50 F/l.

Figure 2 and Figure 3 indicate the cost distribution of the two sub-samples corresponding to GMO programs with respectively one and two RoundUp applications. In our first simulations, before the sensitivity analysis, prices of conventional herbicides are assumed constant and margin rate on conventional herbicides is assumed equal to 50%.

Table 1. Replacement of conventional programs by GMO programs

Code	Area	Average herbicide cost	Conventional program Detail	GMO program
100*	6%	248	Pre-sowing only (economical program)	One application, 2 l/ha (h^g= 2)
010*	17%	527	Pre-emergence only	
110*	24%	508	Pre-sowing – Pre-emergence	
001	2%	538	Post-emergence only	
101	16%	450	Pre-sowing – Post-emergence	Two applications, 2 l/ha each (h^g= 4)
011	11%	701	Pre-emergence – Post-emergence	
111	24%	674	Pre-sowing – Pre-emergence - Post-emergence	

** The absence of post-emergence application may result from the absence of an efficient product. In this case, a second application with the total herbicide could be pertinent. We do not account for this fact here.*

Figure 2. Distribution of herbicide costs for programs
100, 010, 110 and 001 (corresponding to an one-application GMO program)

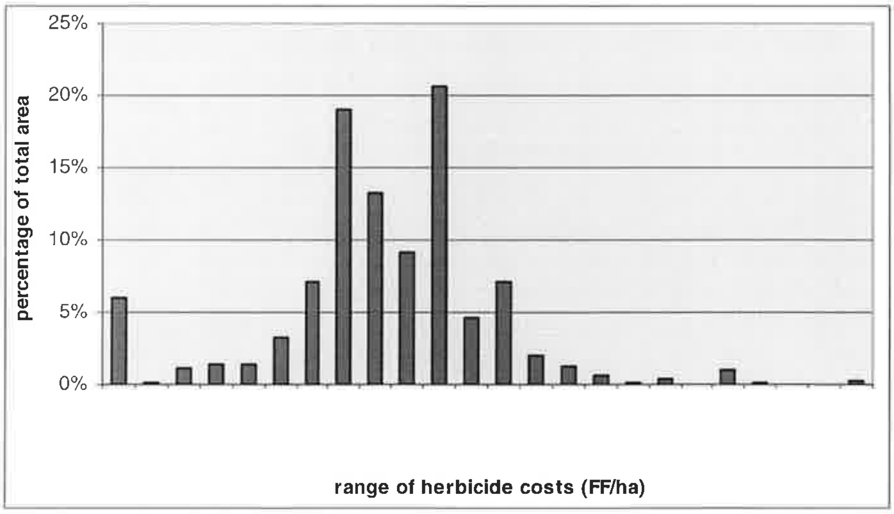
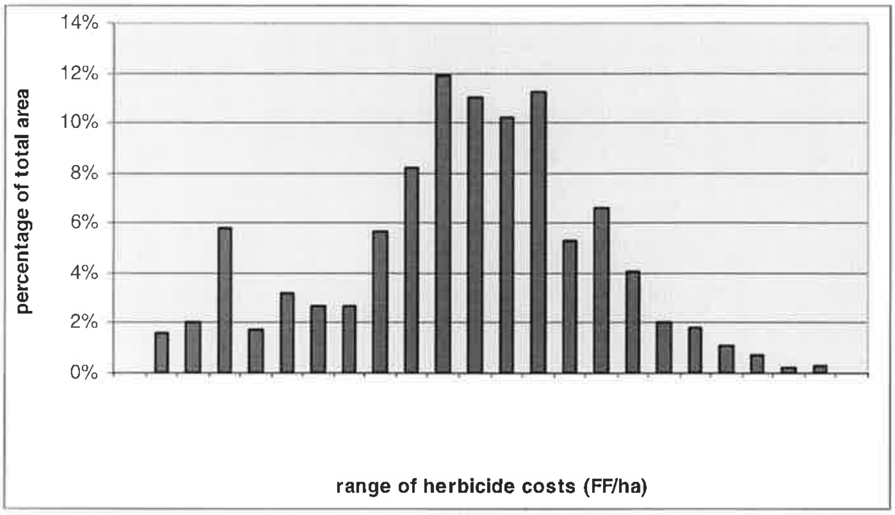


Figure 3. Distribution of herbicide costs for programs
101, 011, and 111 (corresponding to an two-application GMO program)



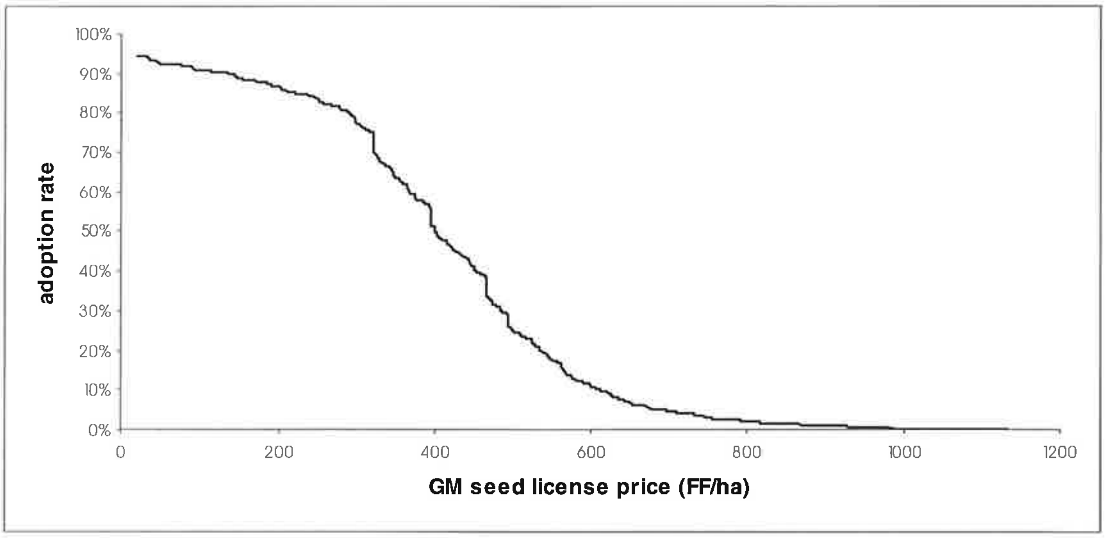
3.2. Base case

Adoption of GMOs

Figure 4 represents the adoption curve of GMOs as a function of the GM seed license price (w^g_s). When the GM seed price is equal to the conventional seed price (w^g_s=0), the adoption rate is higher than 90%. In this case, the cost of a GMO herbicide program varies between 100 and 200 F/ha. Then, from the conventional herbicide cost distribution (Figure 1), it is clear that GMOs are generating cost savings for many farmers. On the opposite, for a GM seed license price exceeding 600 F/ha, the adoption rate is less than 10%. Here too, from

Figure 1, not many farmers would be interested by a GMO program costing around 700 to 800 F/ha. Between these two extreme values, the slope of the adoption curve takes high values (especially between 300 F/ha and 500 F/ha), leading to decreases of around 3500 ha (or 0.25% of French areas) by additional Franc on the GM seed.

Figure 4. Adoption curve of GMOs as a function of the GM seed license price



Farmers' herbicide expenses

To begin with, we study the evolution of farmers' herbicide expenses for different levels of the GM seed license price (i.e., for different levels of adoption of GMOs).

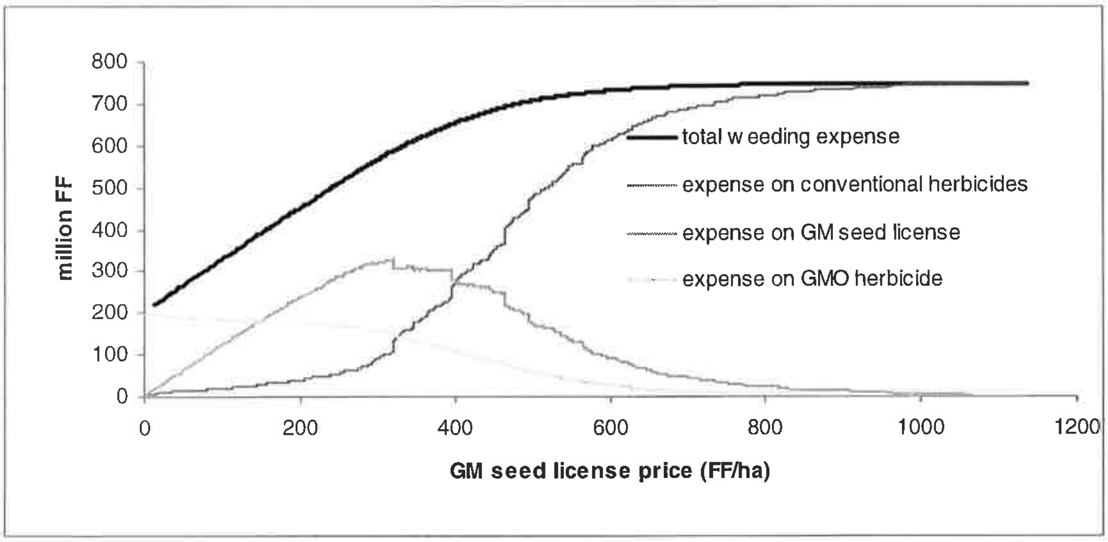
On the right of

Figure 5, the GM seed license price is very high and deters all farmers from adopting, even farmers with high conventional herbicide expenses. All farmers keep their conventional herbicide cost: this is the reference situation of the survey, where total herbicide expenses are around 750 MF.

When going to the left, the GM seed license price decreases and becomes attractive for some farmers. These farmers adopt as soon as the cost of the GMO program equals the cost of conventional herbicides. When adopting, farmers stop having expenses on conventional herbicides. Weeding expenses then are composed of expenses on conventional herbicides, expenses on the GMO herbicide, and additional expenses due to the GM seed license cost.

Then, as the GM seed license price decreases, the increasing adoption leads to a high decrease in total weeding expenses by farmers. Under our assumptions, the expenses decrease from 750 MF to 200 MF when the GM seed price equals the conventional seed price.

Figure 5. Evolution in weeding expenses for farmers in the sample



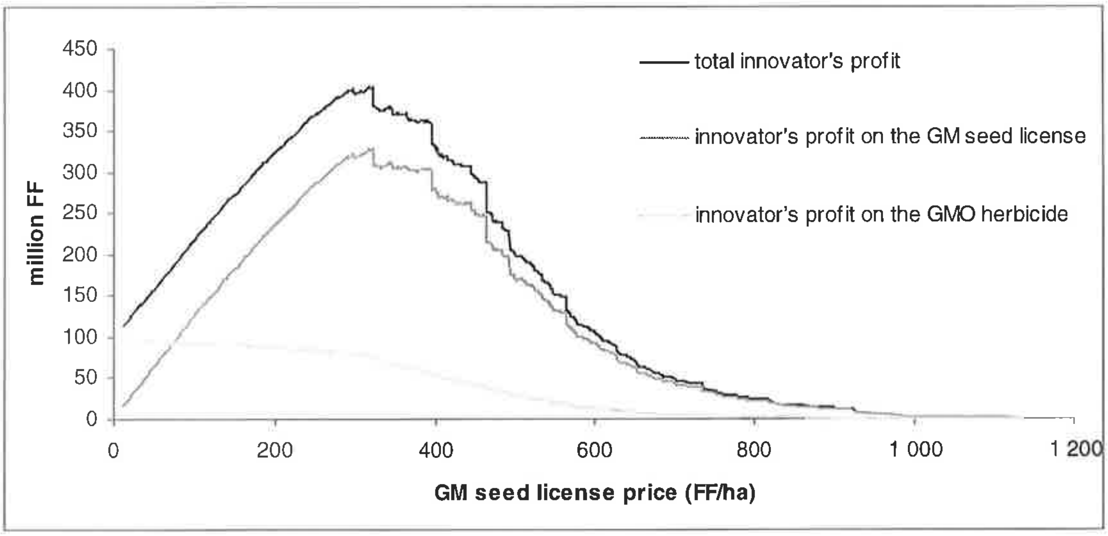
Gains and losses of upstream companies

Here we assume that the innovator sets the GM seed license price in order to maximize its profits. Then, he arbitrates between a small license price allowing a large adoption of the innovation but yielding a small unit margin, and a high license allowing a large unit margin but restricting the adoption of GMOs.

Figure 5 gives a first indication on this optimum.

If the profit of the innovator is only based on royalties on sales of GM seeds, a maximum is reached for a GM seed license price equal to 321 F/ha. The profit of the innovator is then equal to 329 MF and GM varieties are adopted on 75% of French areas (Figure 4). Assuming that the innovator's profit also includes gains on sales of the complementary GMO herbicide (Figure 6), then the optimum GM seed license price is also equal to 321 F/ha. In other words, counting or not margins on sales of the GMO herbicide in the innovator's profit does not change the optimal GM seed license price. This results is due to the low price of the complementary GMO herbicide.

Figure 6. Gains of the innovator, with or without taking into account revenues from sales of the GMO herbicide



Let us now consider the competitors on conventional herbicides. Assuming a margin rate (ϕ) equal to 50%, losses of upstream companies on conventional herbicides increase from 0 to 371 MF when the GM seed license price decreases from 1000 F/ha to 0 F/ha. When the innovator chooses the optimal price (w^{s}_{g}=321 F/ha), losses are equal to 321 MF, i.e. 85% of the initial profit. Then, it can be expected that conventional herbicide sellers react by decreasing their prices. This case will be studied latter (sensitivity analysis).

Figure 7. Losses of sellers of conventional herbicides

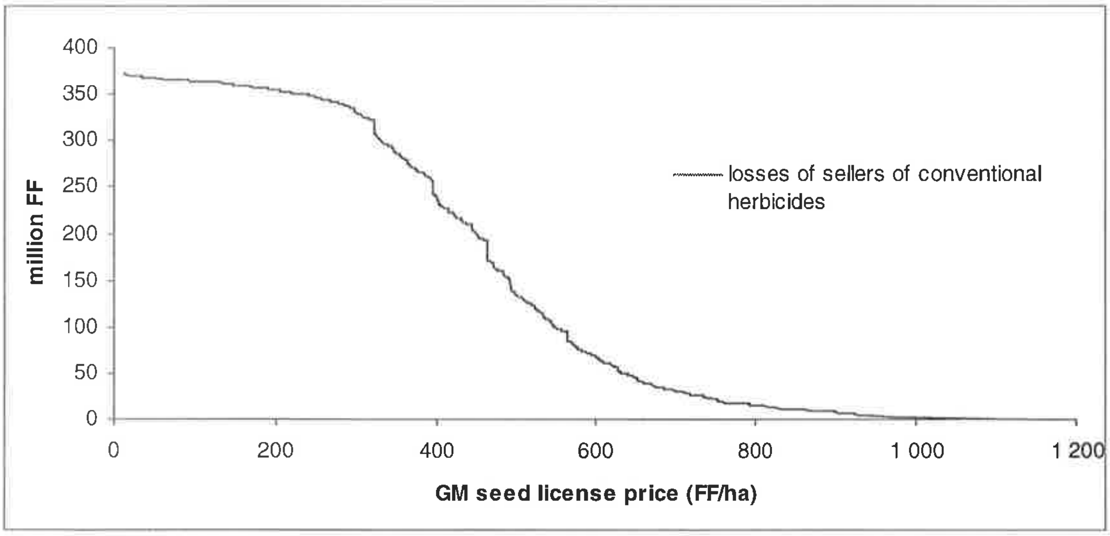
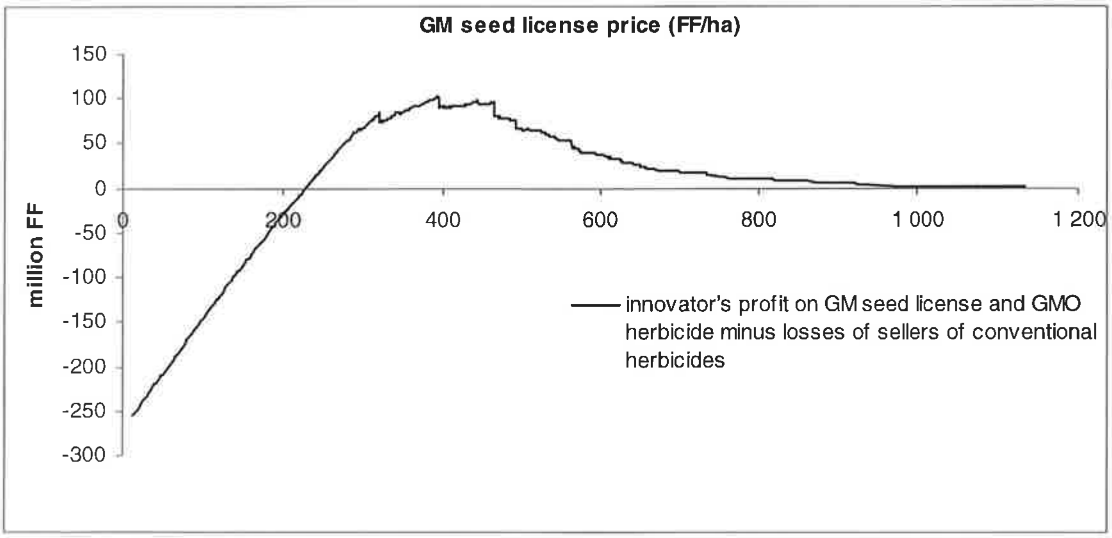


Figure 8 sums up gains and losses by all upstream companies. For a GM seed license price smaller than 228 FF/ha, losses on conventional herbicides are higher than gains of the GMO innovator. The upstream sector is then globally loosing compared with the reference situation. On the opposite, if the GM seed license price is higher than 228 FF/ha, then the upstream sector globally wins compared with the initial situation. This situation is due to a smaller herbicide production costs for the GMO program compared with conventional programs. Effectively, the production cost of the GM seed is equal to the production cost of the conventional seed. The production cost of the GM herbicide represents 50 to 100 F/ha depending on the type of GMO program (1 or 2 applications). The production cost of conventional herbicides represents 50% of sales of conventional herbicides and is generally higher than 100 F/ha. Note, however, that these estimations depend on the rather arbitrary assumption of an identical margin rate on all conventional pesticides. This will be discussed latter with the sensitivity analysis.

Figure 8. Gains and losses of all upstream companies



Global assessment of gains and losses

Table 2 summarizes gains and losses of different actors by combining the reference situation with the situation in which the GM seed license price is set to its optimal level by the innovator (321 F/ha). The adoption of GMO programs leads to a global gain of 245.3 MF. Two thirds of these gains are transmitted to farmers while one third of these gains accrues to upstream companies. A high share of the innovator's gains is realized to the detriment of upstream companies. Their profit decreases by around 321 MF, which is roughly equivalent to gain on the GM seed.

Table 2. Gains and losses due to the GMO adoption (MF)

	Reference	with GMO*	Variation
Revenue on the GM seed license	0	328,9	+328,9
Revenue on sales of the GMO herbicide	0	75,8	+75,8
Revenue on sales of conventional herbicides	374,2	53,2	-321,0
Farmers' weeding costs	-748,5	-586.9	+161,6
Total gain in the situation with GMOs	-	-	+245,3

* *The GM seed license price is equal to 321F/ha.*

Impact on the use of conventional herbicides

We observed that commercialization of GMOs with a GM seed license price equal to 321 F/ha leads to a 85% decrease in total sales of conventional herbicides. This decrease, however, is not homogenous on all products (Table 3). Thus, among the main conventional products, Colzor and Novall suffer a higher decrease (95%) than Treflan and Fusilade (70%). This difference is mainly explained by the cost of these herbicides in a conventional weeding program. Based on the average per hectare quantity in conventional programs (before the introduction of GMO), Colzor and Novall represent a cost higher than 450 F/ha, while Tréflan and Fusilade represent a cost smaller than 150 F/ha. Thus, when a product represents a high cost, he is mainly used in high cost conventional programs, which will be more easily replaced by GMO programs.

Table 3. Impact of GMO introduction on sales of conventional pesticides

Product	Price (F/l or F/kg)	Per hectare quantity (l/ha or kg/ha)	Initial market share	Initial sales	Sales after GMO introduction *	Losses in sales in link with GMOs
Colzor	99	5,0	36,45%	272 836 465	14 843 812	-95%
Butisan S	234	1,4	20,03%	149 894 335	28 903 917	-81%
Novall	250	1,8	12,50%	93 593 180	4 533 717	-95%
Tréflan	28	2,4	6,94%	51 925 414	16 266 073	-69%
Devrinol	170	2,0	5,92%	44 301 151	11 729 254	-74%
Fusilade X2	358	0,4	3,19%	23 900 530	6 482 120	-73%
Targa D+	610	0,4	2,50%	18 729 312	1 487 264	-92%
Pilot	221	0,7	2,36%	17 691 892	2 743 811	-84%
Eloge	510	0,3	2,11%	15 783 686	3 797 996	-76%
Stratos Ultra	137	1,2	2,01%	15 057 311	3 636 853	-76%
Agil	344	0,4	1,36%	10 216 389	1 948 409	-81%
Brassix	28	2,4	1,30%	9 733 337	2 662 752	-73%
Cent 7	212	0,5	0,71%	5 335 793	2 021 334	-62%
Pradone TS	166	3,0	0,59%	4 404 848	638 906	-85%

Quartz	120	0,5	0,47%	3 526 928	2 261 407	-36%
Lontrel	345	0,8	0,45%	3 401 268	853 394	-75%
Légurame PM	105	2,1	0,37%	2 795 722	943 732	-66%
Chrono	180	1,0	0,24%	1 795 283	201 946	-89%
Colzamid	170	3,8	0,22%	1 661 510	164 036	-90%
Kerb Flo	262	1,0	0,14%	1 073 780	0	-100%
Tichrey	28	2,5	0,06%	440 455	166 274	-62%
Sting ST	31	1,0	0,02%	134 980	49 464	-63%
Isoproturon	41	1,5	0,01%	93 761	93 761	0%
Zodiac TX	186	0,4	0,01%	87 442	40 358	-54%
Candrelex	28	2,3	0,01%	62 352	0	-100%
Karmex	60	0,3	0,00%	10 953	0	-100%

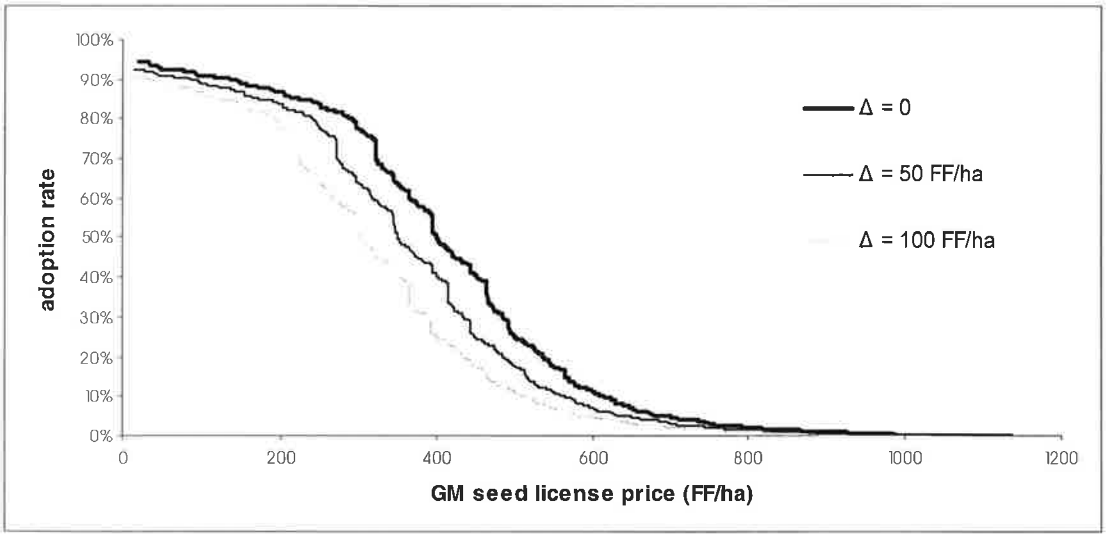
* *The GM seed license price is equal to 321F/ha.*

3.2. Sensitivity analysis

Sensitivity to the additional profit at which farmers adopt GMO programs (Δ)

Figure 9 gives some indications on the sensitivity of our results to the minimal gain that has to be anticipated by the farmer in order to adopt (variable Δ). As shown in section 2, the adoption rate stays unchanged when the GM seed license price, w_s^g, decreases by Δ.. This leads to a translation of the demand curve to the left (when Δ increases). The estimated adoption loss when Δ increases by 100 F/ha varies between 10% and 25% depending on the GM seed license price. In the same way, we could observe that the curve of conventional weeding costs (Figure 4) translates to the left by Δ..

Figure 9. Sensitivity of the adoption curve to Δ



The profit curve of the innovator (Figure 10) decreases because of a given license price the adoption rate is always smaller. The maximum of these curves translates to the left when Δ increases: in reaction to the more difficult adoption of GMOs, the innovator increases its profit if he decreases the GM seed license price by Δ. Then, the adoption rate at the optimum stays unchanged.

Figure 10. Sensitivity of the innovator's profit to Δ

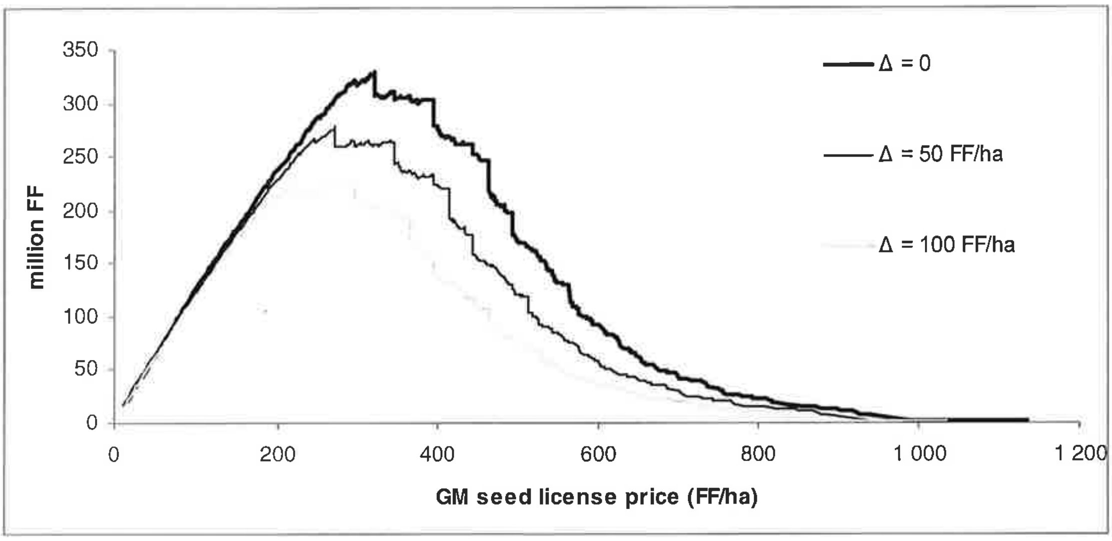


Table 4. Global balance with different values of Δ (MF)

	[A] Référence	[B] with GMO and Δ=0*	[C] with GMO and Δ=100*	Variation [B-A]	Variation [C-A]
Revenue on the GM seed license	0	328.9	226.0	+328.9	+226.0
Revenue on sales of the GMO herbicide	0	75.8	75.8	+75.8	+75.8
Revenue on sales of conventional herbicides	374.2	53.2	53.2	-321.0	-321.0
Farmers' weeding costs	-748.5	-586.9	483.0	+161.6	+264.0
Total gain (from A to B or from A to C)	-	-		+245.3	+245.3

** The GM seed license price is equal to 321F/ha.*

When we examine the global balance of gains and losses of different actors (Table 4), we note that an increase in Δ leads to a surplus transfer of some of the innovator's gains to farmers. This transfer is integral and the global surplus variation stays unchanged. We note that in this case, the surplus variation of upstream companies is negative. The observation made in Figure 8 that the innovator's gains are higher than the losses of sellers of conventional herbicides is not confirmed here.

Sensitivity to the margin rate on conventional herbicides (ϕ)

The margin rate on conventional herbicides (ϕ) does not affect the adoption curve (Figure 4) and has a limited effect on the innovator's profit curve, so that the optimal level of the GM seed license price stays unchanged. The adoption rate of GMOs is then unchanged.

The effect of a change in ϕ on gains and losses of different actors is illustrated in Table 5. In the case studied here, estimations corresponding to the reference situation (before the introduction of GMOs) are also modified. Farmers' gains and innovator's gains on sales of the GM seed are unchanged. However, because the margin rate is smaller, the loss of sellers of conventional herbicides is less important. Under these conditions, the gain of upstream actors is more important and this directly affects the total gain. The share of farmers in the total gains is now smaller.

Table 5. Gains and losses with a smaller margin rate on conventional pesticides

	[A] Reference ϕ=25%	[B] with GMO and ϕ=25%*	Variation [B-A]
Revenue on the GM seed license	0	328.9	+328.9
Revenue on sales of the GMO herbicide	0	37.9	+37.9
Revenue on sales of conventional herbicides	187.1	26.6	-160.5
Farmers' weeding costs	-748.5	-586.9	+161.6
Total gain (from A to B)			+367.9

Sensitivity to herbicide prices

As indicated below, we may think that sellers of conventional herbicides would decrease their prices in reaction to a loss of 85% of their sales. We have to limit our analysis here to the very simple case where all farmers staying on a conventional program always choose the same application program. This assumption is verified if we assume an homothetical decrease in prices of all products. We present here some results assuming a 40% decrease in prices of conventional herbicides.

The adoption curve of GMOs is translated to the left: for a given GM seed license price, much less farmers adopt (Figure 11). This has a direct effect on the profit of the innovator, which also decreases, leading to a displacement of the optimal GM seed license price to the left. When the price of conventional pesticides decreases by 40%, the optimal level of the GM seed license price decreases from 321 F/ha to 153 F/ha. In this case, counting or not counting gains on GMO herbicide sales has a higher effect on the optimal GM seed license price. This price decreases from 153 F/ha to 138 F/ha when these sales are taken into account. This decrease in the GM seed license price almost compensates the translation on the adoption curve, in the sense that GMO adoption now attains 67% of areas wit a GM seed license price equal to 153 F/ha.

Figure 11. Impact of the decrease in conventional herbicide prices on the adoption curve

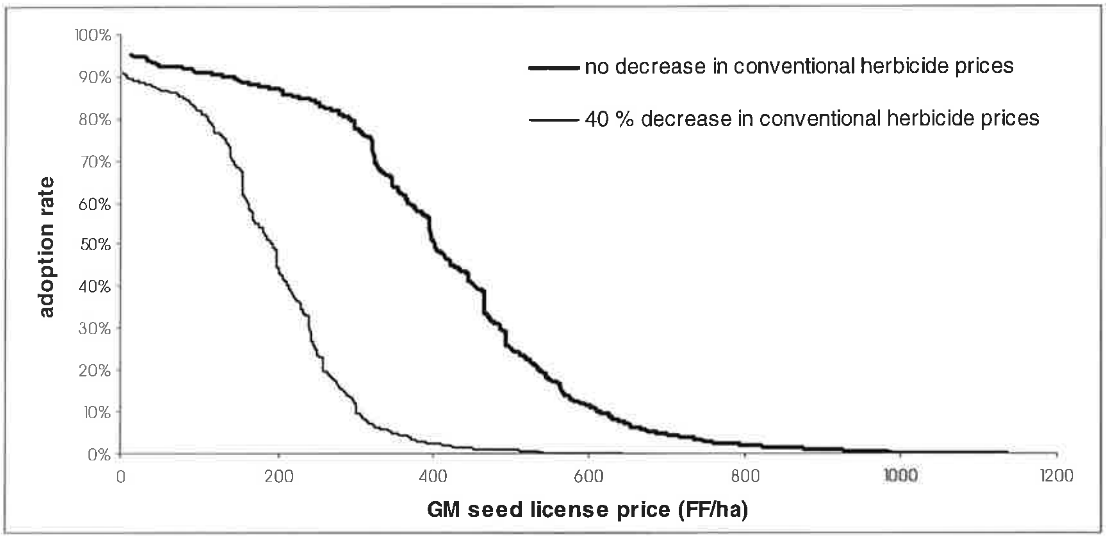


Table 6 shows the effect on gains and losses of different actors. The decrease in the license price and the decrease in the herbicide prices lead to a clear gain for farmers, from +161 MF to +378 MF. This figure represents not only the gain of adopters, but also the gain of non adopters. It should be noted however that the highest share of farmers' gains goes to adopters who benefit from the important decrease in the license price, while the increase in gains for non adopters is only equal to 10 MF. The gain for upstream companies diminishes clearly. For conventional herbicide sellers, the loss is higher than it was with unchanged prices. This follows from the very high decrease in the margin rate, from 50% to 17%. A 40% decrease in prices, then, does not allow these actors to limit their losses. However, it is possible that a less important decrease would allow them not to loose so much. For the innovator, benefits decrease clearly, because of the decrease in the price of the GM seed. Here again, we note that the innovator's gain no more compensates the losses for conventional herbicide sellers.

Table 6. Gains and losses with a decrease in conventional herbicide prices (MF)

	[A] Reference	[B] with GMO at the same price*	[C] with GMO and price decrease**	Variation [B-A]	Variation [C-A]
Revenue on the GM seed license	0	328.9	140.4	+328.9	+140.4
Revenue on sales of the GMO herbicide	0	75.8	65.4	+75.8	+65.4
Revenue on sales of conventional herbicides	374.2	53.2	16.7	-321.0	-357.5
Farmers' weeding costs	-748.5	-586.9	-369.6	+161.6	+378.9
Total gain (from A to B or from A to C)	-	-		+245.3	+227.2

* *The GM seed license price is equal to 321F/ha.*
* *The GM seed license price is equal to 153F/ha.*

4. Conclusion

Here, we always consider the case where the innovator applies the optimal level of the GM seed license price. The sensitivity analysis allows to bring out several conclusions (Table 7):

- The important adoption level observed in the base case (75%) is roughly confirmed in all cases. We saw that changing the additional profit at which farmers adopt the GMO program (Δ) or changing the price of conventional herbicides leads to an important translation in the adoption curve. Yet, in both cases, the innovator adjusts his choice by decreasing its license price, so that the adoption rate at the optimum changes very little. Thus, the observation on the adoption rate seems quite robust.
- The global estimated gain does not change much from on case to the other, because the change in parameters mainly leads to transfers between actors. It should be noted however that the assumption on the margin rate on herbicides has an important effect on the global gain: the smaller this margin rate is, the smaller are the losses on conventional herbicides, and the higher is the total gain.

- Farmers' gains in the base case correspond to a lower limit. Adopters' gains increase clearly when a change in a parameter brings the innovator to decrease the GM seed license price.

- Estimating losses of conventional herbicide sellers is tricky because they depend on the margin rate on which we don't have accurate information. The higher the margin rate is, the higher the losses will be. We may note however that the losses are always the same in proportion (85% decrease in sales).

- The gains of the innovator are very sensitive to assumptions made on Δ and on the reaction of conventional herbicide sellers. The estimations realized here are rather an upper limit.

- The gains of the innovator are in some cases higher, and in some cases smaller, than the losses of conventional herbicide sellers. The reason is that estimations of gains/losses for upstream companies are very sensitive to parameters, so that the difference between the two is also sensitive.

Table 7. Synthesis of the effects observed

	Base case	$\Delta \uparrow$	$\phi \downarrow$	$w^h_c \downarrow$
License	321 F/ha	Decreases (variation equal to Δ variation)	Unchanged	Decreases roughly proportionally
Adoption rate	75%	Unchanged	Unchanged	Decreases lightly
Losses of conventional herbicide sellers	- 321 MF	Unchanged	Smaller (proportional to ϕ)	Does not change much
Gains on the GM seed	+140 MF	Decreases (integral transfer towards farmers)	Unchanged	Decreases (transfer to farmers)
Gains on the GMO herbicide	+75.8 MF	Unchanged	Smaller (proportional to ϕ)	Decreases lightly
Farmers' gains	+161 MF	Increases	Unchanged	Increases
Total gain	+245 MF	Unchanged	Increases	Increases lightly

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