11a

Minimum distance requirements and liability: implications for co-existence

Claudio Soregaroli[#] *and Justus Wesseler*[##]

Abstract

The co-existence of conventional and transgenic products in the food chain introduces new elements in the evaluation of the profitability of transgenic crops and, consequently, on the farmer's adoption decision. In particular, one emerging problem farmers are facing in Europe is related to the legal liability of transgenic-crop cultivation. In Europe, a mixture of *ex-ante* regulations and *ex-post* liability rules governing transgenic crops emerges.

One of the predominant *ex-ante* regulations discussed at the EU level is a minimum-distance requirement to neighbouring fields in order to avoid cross-pollination. The *ex-post* liability rules differ. They depend on the legal frameworks of individual members of the EU. The current interpretation of, for example, Italian and German law does not exclude *ex-post* liability for farmers planting transgenic crops in the case of cross-pollination.

In this paper, we analyse the value of planting transgenic crops when farmers face *ex-ante* regulatory and *ex-post* liability costs under irreversibility and uncertainty. The regulatory instrument analysed is the minimum distance to neighbouring fields. First results indicate that under irreversibility and uncertainty the value of cultivating transgenic crops presents a trade-off between *ex-ante* regulatory and *ex-post* liability costs with respect to farm size. From this, it is not possible to conclude *a priori* the net effect on the size of the adopting farms, if, *ceteris paribus*, a minimum distance regulation is adopted within the EU and farmers can be held liable *ex-post*.
Keywords: co-existence; *ex-ante* regulation; *ex-post* liability; irreversibility; uncertainty

Introduction

The cultivation of biotech crops is continuously expanding worldwide. According to the International Service for the Acquisition of Agri-biotech Applications (James 2002), 58.7 million hectares were planted with genetically modified (GM) organisms in 2002, an increase of 12% over the previous year. This involved nearly 6 million farmers. The United States (66.4%), Argentina (23.0%), Canada (6.0%) and China (2.1%) have the largest world share of transgenic crops. However, new countries are

[#] Istituto di Economia Agro-alimentare, Università Cattolica del Sacro Cuore, Italy
[##] Environmental Economics and Natural Resources Group, Wageningen University, The Netherlands. E-mail: justus.wesseler@wur.nl

emerging: for example in 2002 India, Colombia and Honduras introduced biotech crops in their fields.

Considering the different commodities, soybean production has the largest world share with 36.5 million hectares in 2002. Cultivation of this crop has expanded so much in the last years that today transgenic soybean represents more than half of the total world production of these seeds. This crop is followed in importance by maize with 12.4 million hectares, cotton with 6.8 million hectares and canola with 3 million hectares.

Considering that in 1996 the total area of GM crops was less than 3 million hectares, the adoption has undoubtedly been rapid and massive. The economic reasons are mainly considered in farmers' expectations on the profitability of transgenic crops, in particular as regards yield and/or cost savings. However, as reviewed by Demont and Tollens (2001) studies often do not show a significant difference in profitability between conventional and GM crops when yields and costs are considered. One important factor in determining the choice of transgenic crops is the convenience given to the farmer (Marra 2001). These crops allow for a greater flexibility in growing practices, which reduces the time specificity of labour and capital. This can translate into increased labour productivity and impact on farm restructuring. Moreover, as the report of the Directorate-General for Agriculture of the European Union underlines, "…the effective profitability of a GM crop can only be properly assessed on the basis of several years of cultivation and commercialization. Several years have to be considered for two main reasons. First, many other factors have an impact on profitability. In particular, there are important yearly fluctuations in yields and prices. Second, effective profitability depends on developments on the supply and on the demand side" (European Commision 2000, chapter 3).

Initial development and adoption of transgenic crops were supply-driven. The target of biotech firms was the farmer, and the crops produced had agronomic traits that favoured farm practices and output volumes. However, upstream effects from the demand side started to be important as the consumers' awareness and knowledge of GM organisms increased. Consumer concern about the possible negative effects of biotech on health and the environment induced part of the population, even in countries where GM cultivation is largely allowed, to demand GM-free products (Winston 2002). As a consequence, a double channel may develop, one including GM products and the other GM-free. This implies the segregation of agricultural products along the vertical food chain and the eventual development of an Identity Preservation (IP) and a traceability system together with opportune labelling requirements (Gaisford et al. 2001). The co-existence of conventional and transgenic products in the food chain introduces new elements in the evaluation of the profitability of GM crops and, consequently, in the farmer's adoption decision. In particular, one emerging problem farmers are facing is related to the legal liability of GM cultivation. As will be discussed in the next section, farmers face the risk of litigation with neighbouring farmers, biotech companies and public institutions. This introduces a new element in the farm adoption process. The value of the new technology will not only depend on the incremental changes in revenues and variable production costs but also on costs from *ex-ante* regulations and *ex-post* liability.

However, while it is possible to enumerate the factors influencing the farmer's actions when considering the adoption of biotech crops, the direction and interrelation of their effects is not clearly defined. For example, what is the influence of an *ex-ante* regulation imposing standards for GM cultivation? It probably increases field costs while reducing legal liability.

Given that, at least at the EU level, there is much debate on the type and level of regulation that should be adopted in order to govern co-existence, the purpose of the study is to highlight the implication on farm's GM adoption of an *ex-ante* regulation setting standards for GM farm cultivation practices in combination with *ex-post* liability rules. Awareness of these effects can help to evaluate the consequences of policy actions and, eventually, to identify the impact of those policy instruments on adoption of the new technology.

The paper is structured as follows. First, legal issues related to co-existence are discussed, followed by a model that values transgenic crops including *ex-ante* regulations and *ex-post* liability rules at farm level. Third, the effects of changes in regulations and liability rules on adoption are discussed before we conclude.

Legal issues of co-existence

There are different sources of litigation that can hold a GM farmer liable for his cultivation practices. Actions are likely to be taken by non-GM farmers who consider their business damaged when GM contamination occurs. This is summarized in the following paragraphs:

Product depreciation

A farmer growing GM crops can be sued by neighbouring non-GM farmers who find their crops contaminated by GM material. The mixing of GM and non-GM material can result from cross-pollination or volunteers (self-sown plants) carried by different agents (wind, animals…) from the GM field to the neighbouring soils (Kershen 2002; Schmidt 2002). Contamination causes harm to non-GM farmers since they risk not being able to sell their products as GM-free, with negative consequences for the value of the product[1]. This is especially true in the case of organic production, where the utilization of GM products is excluded. Financial losses to organic farmers can also be higher if the adventitious GM contamination implies the loss of their organic status: in this case the access to important markets could be precluded for several years.

Litigation is not limited to neighbouring farmers but can also occur between landlords and tenants. A landlord can claim that the loss of organic status due to GM cultivation has a negative impact on the land value and that the tenant did not comply with the rules of 'good husbandry' included in many tenancy agreements (Network of Concerned Farmers NCF 2003). As the Network of Concerned Farmers (NCF) underlines, depreciation of land can also cause concerns to banks, when secured loans are linked to the land value. Hence, if GM cultivation is proved to have effects on land values, landlords and banks could play a role in engaging legal disputes with the responsible GM farmer.

Legal actions by biotech companies

Companies producing GM seed invest a great deal of effort in protecting their property rights on the use of transgenic crops. Especially for those crops, such as oil-seed rape, where it is possible for the farmer to use seeds kept from the harvest of the previous year, contracts between farmers and agro-biotech companies explicitly state that the farmers cannot use as seed their own harvested GM crops (and, of course, they cannot give or sell seeds to other farmers). Moreover, companies reserve the right to control and take samples from harvested crops of the farms in the following years.

The behaviour of agro-biotech companies has consequences both on GM and non-GM farms as recent court cases demonstrate. Well-known is the case of a Canadian farmer (Schmeiser) sued by Monsanto and held liable by the Federal Court of Canada (Monsanto Canada Inc. vs. Schmeiser 2001). The farmer was found guilty of knowingly growing canola containing a gene patented by Monsanto (gene Roundup®-tolerant). One of the motivations of the judge that held the farmer liable was that "*…a farmer whose field contains seed or plants originating from seed spilled into them, or blown as seed, in swaths from a neighbour's land or even growing from germination by pollen carried into his field from elsewhere by insects, birds, or by the wind, may own the seed or plants on his land even if he did not set about to plant them. He does not, however, own the right to the use of the patented gene, or of the seed or plant containing the patented gene or cell*" (Monsanto Canada Inc. vs. Schmeiser 2001, p. 92). The farmer was considered guilty because he used seeds knowing they included the Monsanto gene: as the judge writes "*his infringement arises not simply from occasional or limited contamination of his Roundup-susceptible canola by plants that are Roundup-resistant. He planted his crop for 1998 with seed that he knew or ought to have known was Roundup-tolerant*" (Monsanto Canada Inc. vs. Schmeiser 2001, p. 125).

The above case highlights the importance of the effects of contamination. Legal actions by biotech companies put pressure on farmers to identify GM contamination and to take action to eliminate such plants from the field. However, this influences the farming practices and there is no unanimous opinion on the effect on costs and the effectiveness of the control[2].

Damages to the downstream vertical chain

Labelling of food products is an important issue related to biotechnology. Bodies such as the European Union (EU) require labelling of food products as GM if they contain more than 1% of transgenic material. Also, firms can voluntarily certify their products as GM-free or organic with a guarantee of a certifying institution. One key element in this system is the maintenance of a separate channel of GM-free products and the possibility to trace back the food components up to the producing farmer. This implies that, if GM contamination is found in the food product, liability can be transferred to the responsible non-GM farmer (if any). Hence, the cost of contamination would not only be the depreciation of the product, but also the payment for damages caused to the downstream food chain. According to NCF (Network of Concerned Farmers NCF 2003), this would expose farmers to high liability levels with difficulties also in obtaining an insurance coverage. These facts would be a further incentive for the non-GM farmer to sue neighbouring GM producers, with an overall increase of legal disputes.

In conclusion, farmers adopting transgenic crops face the risk of being held liable if they plant transgenic crops. Also, the introduction of transgenic crops often includes regulations, such as the refuge areas for *Bt*-corn in the United States. In the EU, minimum distance requirements to avoid cross-pollination are discussed. The distance requirements discussed range from a few meters up to several thousand meters (Agnet 2002; Bock et al. 2002). However, the risk of being held liable depends on the specific liability systems of the different countries. This will be discussed in the next section.

Legislation and specificities of different countries

GM farmers' liability is likely to be included in the category of 'damage to property' (so-called traditional damage). More specifically, this can be distinguished in two main categories: negligence and strict liability. Negligence, in the biotech case, occurs when the farmer fails to take adequate action in order to avoid GM contamination. If it can be proved that the GM farmer did not provide sufficient care (did not meet the standards established by law) to avoid contamination and that this caused prejudice to the non-GM farmer, the former could be held liable by the court. On the other hand, strict liability does not require fault or negligence by the person who caused harm. Hence, a farmer can be held liable simply because his activity is causing damages.

In order to evaluate the relationship between *ex-ante* regulation and *ex-post* liability on the farmer's GM adoption decision, the relevant question is whether strict liability is indeed applicable to the GM farmer[3]. The answer is different depending on the countries considered: as will be discussed below, in the US strict liability is not likely to occur, whereas there are more possibilities in the European Union.

US legislation

In the US regime of legal liability, biotechnology is regulated by laws that are generally applicable to agricultural products. Biotechnology in agriculture is considered by US legislation to be equivalent to other agricultural breeding practices (Office of Science and Technology Policy OSTP 1986, General Recommendation 2).

In order to claim, strict liability damages have to be demonstrated. For example, in the case of organic production the organic standards are set by the United States Department of Agriculture (USDA) under the federal law given by the National Organic Program (NOP). This programme explicitly states that the use of GM organisms is excluded for organic production. However, it is a process-based standard. USDA does not set specific tolerance levels for the presence of GM material. It is sufficient to respect the production standards to obtain the certification. Therefore, "*...organic producers may face significant difficulties in proving that the farmer growing transgenic crops caused damage*" (Kershen 2002, p.7). Even if the organic farmer complies with stricter private standards (from a non-governmental institution) the court under the US legislation could consider it an "*abnormally sensitive character*" of the plaintiff's activity (Kershen 2002).

Moreover, as underlined by (Kershen 2002, p.12-13), in the US "*...courts are unlikely to endorse* [claims] *that insist on zero tolerance of pollen flow or volunteer plants. Courts expect neighbors to have reasonable tolerances toward one another as the court engages in balancing of gravity of the harm against the social utility of each neighbor's use and enjoyment of their own land*". The basis of the court's view is the substantial equivalence, in the US case, of the biotech cultivation to the traditional farming practices.

From the above discussion it appears that the possibility of legal actions against a GM farmer is limited according to the US legislation over biotech practices. Excluding negligence, the non-GM farmer will have a hard task demonstrating that transgenic cultivation caused significant damage.

EU legislation

In the EU, damage to property is not covered by EU legislation (or proposals) and is left to the civil liability systems of the Member States (European Commision 2002). Moreover, from the policy debate on co-existence, it seems that much will be left to the specific legislations of Member States. In this regard, the following paragraphs will discuss the examples of Italian and German legislation.

Italian and German legislation

In this context, the starting point of the Italian legislation is article 844 of the Civil Code stating: "a farmer cannot impede the emission of smoke, heat, odours, noise, vibrations and similar propagations originating from a neighbouring field, if they do not exceed the normal tolerability while taking into account the conditions of the area". The emission can be forbidden if it is 'intolerable', that is it has to be over any reasonable tolerance of its external effects (Germanò 2002). A similar position can be found in Germany. §903 of the German Civil Code is similar to the article 844 of the Italian Civil Code. In combination with §906 of the German Civil Code organic farmers have to tolerate cross-pollination as long as this does not impose important constraints on their freedom to farm and if cross-pollination cannot be avoided by methods that are tolerable from an economic point of view. However, there is no precise definition of reasonable cost and considerable economic losses. Hence, the point is to define the nature and the level at which an emission can be considered 'intolerable'.

Different EU legislations pose constraints to non-GM farmers. For example, under regulation 2092/91 as amended by regulation 1804/99, organic farmers can receive certification for their products only if they avoid GM products in their farming practices. In Italy, farmers receiving subsidies within the framework of the regional Rural Development Plan (RDP) are often required to produce GM-free products. Also, the Protected Designation of Origin (PDO) certification requires practices that do not allow the use of GM products. However, although PDO and organic certification are process-based, the eventual contamination of GM material would preclude their labelling status if the GM content were over a threshold level. This has been defined at 1% for food (EC 49/2000) and 0.1% for organic products[4]. In the first case food would lose its organic status, while in the second case the product has to be labelled as GM. Hence, the key difference with respect to the US legislation is the mandatory labelling system: the definition of intolerable emission is likely to depend on its size and could be determined by the court on a case-by-case basis.

The European case illustrates that farmers planting transgenic crops risk *ex-post* liability costs, even if *ex-ante* regulations are implemented. The legal framework in the United States reduces the risk of *ex-post* liability costs. While *ex-post* liability will be less relevant for adoption of transgenic crops in the US, it may pose important additional adoption costs to farmers in the EU.

In the next step we model the value of transgenic crops at farm level including *ex-ante* regulatory and *ex-post* liability costs. The regulation we use is the minimum distance a farmer planting transgenic crops has to keep between his field and neighbouring fields to reduce cross-pollination. We show that indeed, *ex-post* liability adds additional costs that reduce the likelihood of adoption and, what is also important, that they will not be scale-neutral.

Theoretical framework for the GM farmer

As underlined in the previous section, the farmer's decision on whether to adopt a GM crop is not a simple one. The value of adopting a transgenic crop depends not only on the incremental profit from growing the transgenic crops, but also on *ex-ante* regulatory and *ex-post* liability costs.

Ex-ante **regulation and** ***ex-post*** **liability**

The starting point of the conceptual framework is the definition of the GM farmer's value function. The value of the option to adopt the GM crop can be defined as the expected value of the difference between the extra profit obtainable from the GM cultivation (as compared to the conventional one) considering the sole cultivation practices (Π) and the costs related to liability and its control (L):

$$V = E(\Pi - L)\,. \tag{1}$$

If, for the moment, we assume that the farmer does not face any reduction in costs related to the adoption of a transgenic crop, he/she is assumed to adopt the transgenic crop when V is equal to or grater than zero. The expected costs related to liability are the sum of the costs of respecting *ex-ante* regulations (C) and the value of tort liability (TL):

$$L = E(C + TL)\,. \tag{2}$$

Following Kolstad, Ulen and Johnson (1990) the above relation can be reformulated as

$$L = C + \mu * D * R \tag{3}$$

where μ is the probability of causing an accident (for example, contamination of the neighbouring non-GM fields), D is the monetary value of the accident, and R is the probability that the injurer will pay the damages. In our case, R can be interpreted as a function of the court view and the probability of being sued by the neighbour who has suffered damage.

From the previous equations the value function for the GM farmer can be formulated as follows:

$$V = E\left[\Pi\left(p,y,c,s\right) - C\left(s,reg\right) - \mu(s,reg)D\left(s,reg\right)R(law)\right] \tag{4}$$

where p is a vector of output prices, y is the vector of the per-hectare yields, c is the vector of the cost of inputs, s is the size of the field, *reg* is the enforced GM legal standard for the country, *law* is the tort-liability system of the country and E the expectation operator.

The above framework can be used to assess the impact of regulation standards on a farm's adoption of GM crops. One possibility is to evaluate the effect of the variable *reg* on the 'relevant' farm size. The relevant farm size for the given problem is the dimension at which the cultivation of the GM crop starts to be convenient, that is the value function is greater than or equal to zero.

Assuming the farm is a single field and interpreting the variable *reg* as the minimum distance (*d*) between the GM crop and the farm's external limits, it is possible to evaluate the relationship between the minimum adoption size ($\underline{s}$) and the severity of regulation. Assuming all of the other variables are constant, $\underline{s}$ can be solved from the following equation:

$$V = \Pi(s) - C(s,d) - \mu(s,d)D(s,d)R = 0 \tag{5}$$

where

$\partial\Pi(s)/\partial s > 0$ and $\partial^2\Pi(s)/\partial s^2 \leq or \geq 0$;
$\partial C(s,d)/\partial s > 0$ and $\partial^2 C(s,d)/\partial s^2 \leq 0$;
$\partial C(s,d)/\partial d > 0$ and $\partial^2 C(s,d)/\partial d^2 \leq 0$;
$\partial\mu(s,d)/\partial s > 0$ and $\partial^2\mu(s,d)/\partial s^2 \leq 0$;
$\partial\mu(s,d)/\partial d < 0$ and $\partial^2\mu(s,d)/\partial d^2 \geq 0$;
$\partial D(s,d)/\partial s > 0$ and $\partial^2 D(s,d)/\partial s^2 \leq 0$;
$\partial D(s,d)/\partial d < 0$ and $\partial^2 D(s,d)/\partial d^2 \geq 0$.

From the implicit function theorem it is possible to write

$$\partial\underline{s}/\partial d = -\frac{\partial V/\partial d}{\partial V/\partial s},$$

hence applying the above relation to equation (5) the resulting expression is

$$\partial\underline{s}/\partial d = -\frac{-\partial C/\partial d - R\big(\mu(s,d)\partial D(s,d)/\partial d + D(s,d)\,\partial\mu(s,d)/\partial d\big)}{\partial\Pi(s)/\partial s - \partial C/\partial s - R\big(\mu(s,d)\partial D(s,d)/\partial s + D(s,d)\,\partial\mu(s,d)/\partial s\big)}. \tag{6}$$

Given that at the break-even point $\underline{s}$, an increase in size determines a higher increase in the extra profit than in the implementation and liability costs, the denominator of the above equation can be assumed to be positive around $\underline{s}$. Hence, the discussion can be focused on the numerator of the equation. For simplicity, ignore the denominator and rewrite equation (6) as

$$\text{sign}\left[\partial\underline{s}/\partial d\right] = \text{sign}\left[\partial C/\partial d + R\{\mu(s,d)\partial D(s,d)/\partial d + D(s,d)\,\partial\mu(s,d)/\partial d\}\right]. \tag{7}$$

The first term on the right-hand side of the above equation is positive, while the second term is negative. With an increase in distance there is a trade-off between an increase in implementation costs and a decrease in the expected value of liability. This implies that the effect on the minimum adoption size of a policy that poses higher standards on distances between GM and non-GM fields is uncertain. Hence, it is not possible to conclude that an increase in distance will exclude smaller farms. Indeed, if the decrease in expected liability is superior to the increase in implementation costs it is possible to have smaller farms adopting the technology. Or rather, the more severe legislation would not have any impact, given that those smaller farms were already adopting the technology imposing higher crop distances on themselves.

The case of irreversibility and uncertainty

In the previous discussion it was assumed that incremental profits Π are certain and the farmer did not face reduced costs while deciding to adopt the GM technology. However, some of the costs could be irreversible: for example, the transgenic crop may require specific machinery, or as discussed in the introduction, the GM cultivation could make it difficult for the farmer to switch back to the non-GM status. These difficulties could include additional practices for the control of volunteers or a required minimum number of years of non-GM cultivation for a field to be considered for producing non-GM products. The multi-period time frame also adds uncertainty to the farmer's adoption decision as future yields, prices and costs are not known with certainty.

In the presence of net-irreversible costs, uncertainty and flexibility, the value of a GM crop is not simply the difference between the present value of future benefits and costs, as from equation (1), but the sum of this difference plus the value of the option to plant transgenic crops (Wesseler 2003). More formally, when some costs are irreversible, costs and benefits are uncertain and the decision to invest can be postponed, the farmer maximizes the option value of the investment. Hence, equation (1) can be reformulated as follows

$$F(V) = max\, E\left[\left(V(\Pi, C, TL) - I\right)e^{-\rho T}\right] \tag{8}$$

where $F(V)$ is the value of the investment opportunity, $V(\Pi, C, TL)$ is the value of the reversible net-benefits, and I are the net-irreversible costs of the investment.

As the time frame gets longer than a sowing season, the benefit of using a GM crop becomes uncertain. Profit from farm practices can change over time and there is always the risk of liability. It is possible to represent this uncertainty by the following stochastic process

$$d(\Pi - C) = \alpha(\Pi - C)dt + \sigma(\Pi - C)dz + (\Pi - C)dq \tag{9}$$

where (Π-C) evolves under a combined geometric Brownian motion and Poisson process. The first two terms are common for modelling incremental benefits of transgenic crops (e.g. Demont, Wesseler and Tollens 2002; Morel et al. 2003; Wesseler 2003). α is the drift of the Brownian motion, dz is the increment of a Wiener process, dt is the marginal increment in time and dq is the increment of a Poisson process. The third term represents tort liability modelled as the risk of a jump in the profit when the farmer is held liable. More precisely,

$$dz = \varepsilon_t \sqrt{dt}\text{, and}$$

$$dq = \begin{cases} 0 & \text{with probability } 1 - \lambda dt \\ -\phi & \text{with probability } \lambda dt \end{cases}$$

where ε_t is normally distributed with zero mean and unit standard deviation, λ is the mean arrival rate of a Poisson process, and ϕ the percentage of the *ex-post* liability costs of (Π-C).

From the above equation and the opportune boundary conditions, as shown in Appendix 1, it is possible to obtain the following relation defining the rule for the investment decision, assuming ϕ = 1:

$$(\Pi - C)^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)(\rho - \alpha + \lambda)I \tag{10}$$

where

$$\beta_1 = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(\rho + \lambda)}{\sigma^2}} > 1. \tag{11}$$

From the last two equations it is possible to evaluate the effect of a change in the regulation regarding co-existence. Taking again as an example the case of the distance between GM and non-GM fields it is possible to see the effect of an increase in distance on the hurdle rate, assuming $\partial I/\partial d$ = 0. The same approach used in the case without irreversibility can be used to compare the effects of a change in the regulation on the minimum adoption size of the farm (s). This can be solved rearranging equation (10) and applying the implicit function theorem leading to the following derivative:

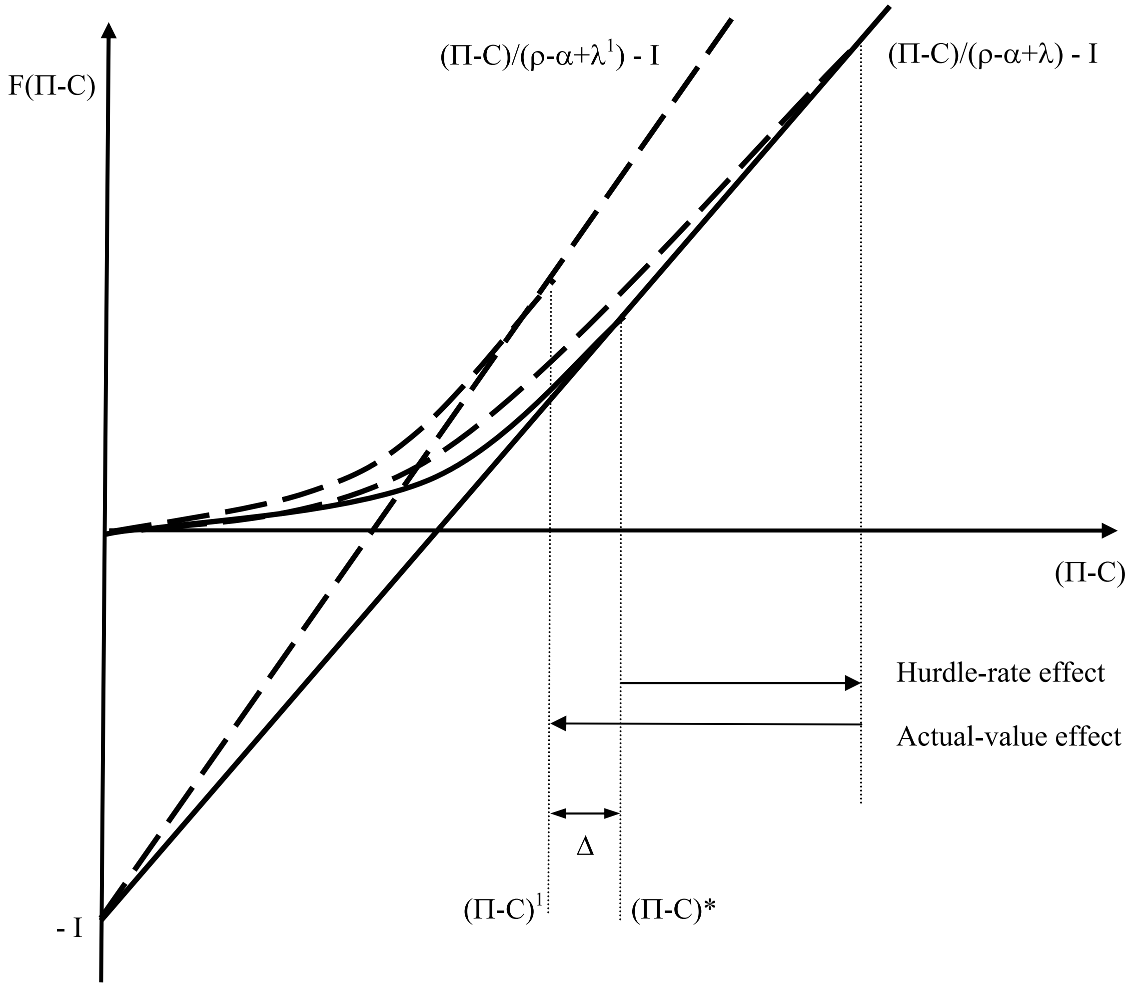
$$\partial \underline{s}/\partial d = -\frac{\dfrac{\partial(\Pi - C)}{\partial d} - \left[\dfrac{\partial\left(\dfrac{\beta_1}{\beta_1 - 1}\right)}{\partial d}(\rho - \alpha + \lambda) + \left(\dfrac{\beta_1}{\beta_1 - 1}\right)\dfrac{\partial(\rho - \alpha + \lambda)}{\partial d}\right]I}{\dfrac{\partial(\Pi - C)}{\partial s} - \left(\dfrac{\beta_1}{\beta_1 - 1}\right)(\rho - \alpha + \lambda)\dfrac{\partial I}{\partial s}} \tag{12}$$

Given that we are observing a break-even point, as in the case under certainty it is possible to assume that the denominator or the above equation is positive. Hence, equation (12) can be rewritten as

$$\text{sign}\,\partial \underline{s}/\partial d = \text{sign} \underbrace{-\frac{\partial(\Pi - C)}{\partial d}}_{(+)} + \left[\underbrace{\frac{\partial\left(\dfrac{\beta_1}{\beta_1 - 1}\right)}{\partial d}(\rho - \alpha + \lambda)}_{(+)} + \underbrace{\left(\frac{\beta_1}{\beta_1 - 1}\right)\frac{\partial(\rho - \alpha + \lambda)}{\partial d}}_{(-)}\right] I \tag{13}$$

Results

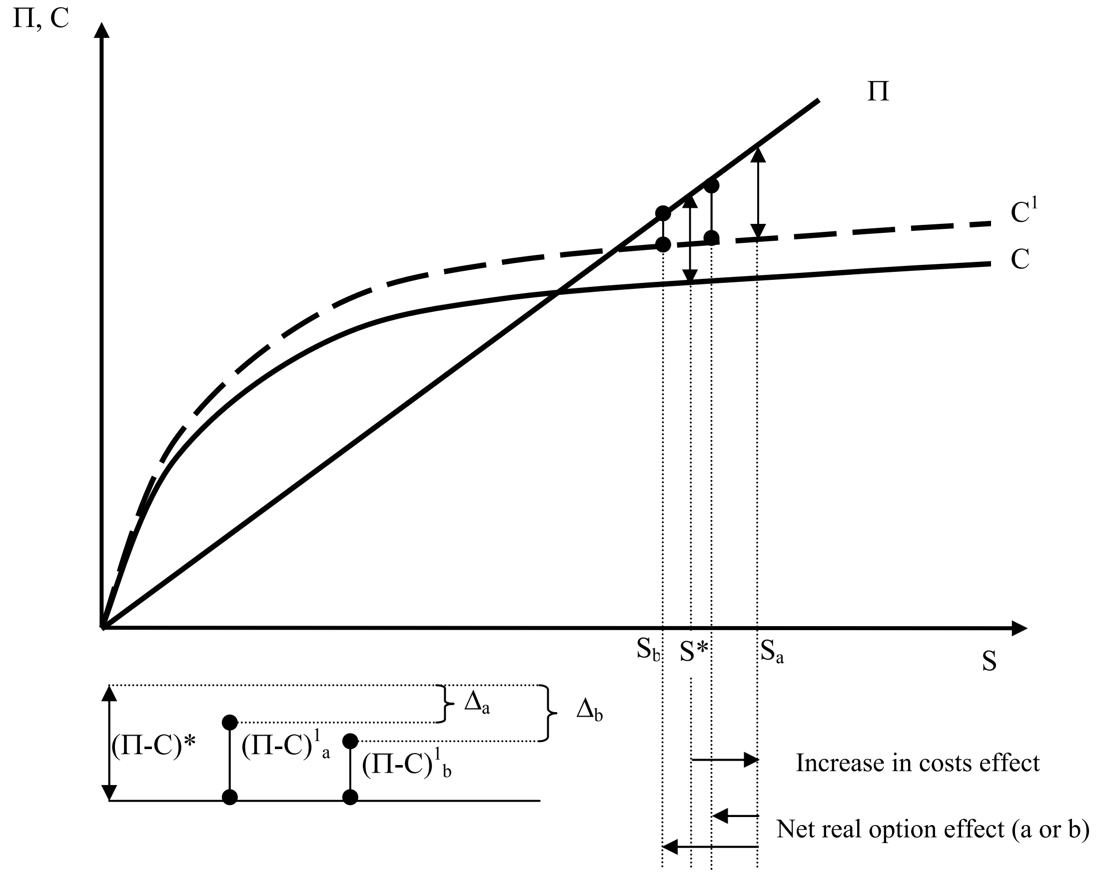
The result in equation 13 is similar to the case without irreversibility and uncertainty. The first term in the square brackets indicates the effect on the hurdle rate, which is positive. This is the positive effect of an increase in the future value of transgenic crops due to an increase in distance requirements, which can be explained by the decrease in *ex-post* liability costs (the option to wait is worth more). The second term in the square brackets is the effect on the annualized hurdle rate. This captures the effect on the reversible value of the transgenic crop. This effect is negative as an increase in the distance reduces directly the probability of *ex-post* liability, which increases the actual value of adopting transgenic crops. The overall sign of the terms in the square brackets cannot be determined and will depend on the specific parameter values (see the solution in Appendix 2). However, numerical examples show a very robust negative sign of the square bracket. This means that with an increase in distance requirement the greater value of the investment opportunity is outweighed by the increase in the actual value of the project. This is shown in Figure 1.



Legend:
Π = per hectare extra profit of the transgenic crop
C = per hectare costs of minimum distance
F (Π-C) = value of the investment opportunity
I = irreversible costs when adopting the technology
ρ = discount rate
α = drift of the Brownian motion
λ = mean arrival rate of the Poisson process
λ^1 = mean arrival rate after the increase in distance requirements
(Π-C)* = minimum net extra profit in order to adopt the technology at the initial state
$(\Pi\text{-}C)^1$ = minimum net extra profit in order to adopt the technology after the increase in distance
Δ = net effect on the minimum net extra profit given by the increase in distance

Figure 1. Effect of an increase in distance requirements on the threshold level of (Π-C) for the adopting farm

If what described above was the only force in action the effect of the policy would be a lower minimum adoption size. However, the increase in the minimum distance determines a raise in costs reducing the value of (Π-C). Hence, for the most common values of the parameters it is not possible, *a priori*, to conclude what is the effect on the minimum adoption size of the *ex-ante* regulation. This is shown in Figure 2.



Legend:
Π = per hectare extra profit of the transgenic crop
C = per hectare costs of minimum distance
(Π-C)* = minimum net extra profit in order to adopt the technology at the initial state (see Figure 1)
$(\Pi\text{-}C)^1_{a,b}$ = minimum net extra profit in order to adopt the technology after the increase in distance
$\Delta_{a,b}$ = net effect on the minimum net extra profit given by the increase in distance (see figure 1)
S^* = minimum adoption size at the initial state
$S_{a,b}$ = minimum adoption size after the increase in distance

Figure 2. Effect of an increase in distance requirements on the minimum adoption size of the farm (S)

Only the case of very high drift rates α and low mean arrival rates λ, that is, low probability of *ex-post* liability, turns the sign of the square brackets positive. In this case the option value is prevailing and *ex-ante* regulations would be biased towards larger farms.

Conclusions

The release of transgenic crops in Europe will most likely be controlled by *ex-ante* regulations and *ex-post* liability rules. The regulations chosen and liability rules imposed, affect the expected benefits from adopting transgenic crops at farm level. In this paper we have shown that for the case of a minimum distance requirement this will not always be scale-neutral. However, for reasonable parameter ranges the net direction of the effect needs to be verified empirically. The presence of irreversible costs seems to play a role in determining *ex ante* the policy effect only in extreme cases. This observation holds for the case where *ex-post* liability costs, if a farmer is held liable, equal the *ex-ante* expected benefits. We expect the results to be similar, if the liability costs are linear in *ex-ante* expected benefits.

Appendix 1

From the definition of the value of the farmer's investment opportunity in GM crops

$$F(\Pi - C) = \max E\left[(V(\Pi - C) - I)e^{-\rho t}\right] \tag{A1}$$

the investment problem can be solved by dynamic programming. The first step is to define the Bellman equation as

$$\rho F(\Pi - C)dt = E\left[dF(\Pi - C)\right] . \tag{A2}$$

This equation equates the return over dt computed from a capital whose value is F using a discount rate ρ to the expected change in the value of the investment opportunity F. This means that the optimality condition for the farmer is when the value of the investment opportunity in GM crops changes over time in the same way as a normal capital investment.

Total liability is still considered the maximization problem and defined as a percentage ϕ of (∏-C) that follows a jump process with a mean arrival rate of λ. Hence, the following combined stochastic process for (Π-C) and TL is assumed:

$$d(\Pi - C) = \alpha(\Pi - C)dt + \sigma(\Pi - C)dz + (\Pi - C)dq \tag{A3}$$

where dz is a Wiener process with the property $dz = \varepsilon_t \sqrt{dt}$, where ε_t has zero mean and unit standard deviation and the relative expected values are *E(dz)*=0 and $E(dz^2)=dt$, dq is the increment of the jump process and

$$dq = \begin{cases} 0 & \text{with probability } 1 - \lambda \text{dt} \\ -\phi & \text{with probability } \lambda \text{dt} \end{cases} .$$

Using Ito's lemma for the combined Brownian motion and Poisson process, the expected value of dF can be defined as

$$E[dF] = \frac{\partial F(\Pi - C)}{\partial(\Pi - C)}\alpha(\Pi - C)dt + \frac{1}{2}\frac{\partial^2 F(\Pi - C)}{\partial(\Pi - C)^2}\sigma^2(\Pi - C)^2 dt$$
$$+ \lambda\{F[(\Pi - C) + (\Pi - C)(-\phi)] - F(\Pi - C)\}dt \quad \text{(A4)}$$

Substituting (A4) into (A2) and simplifying for dt gives the following second-order differential equation

$$\frac{1}{2}\left(\frac{\partial^2 F(\Pi - C)}{\partial(\Pi - C)^2}\sigma^2(\Pi - C)^2\right) + \frac{\partial F(\Pi - C)}{\partial(\Pi - C)}\alpha(\Pi - C) - \lambda\{F(\Pi - C) - F[(1-\phi)(\Pi - C)]\} = \rho F(\Pi - C)$$

which can be rearranged as

$$\frac{1}{2}\left(\frac{\partial^2 F(\Pi - C)}{\partial(\Pi - C)^2}\sigma^2(\Pi - C)^2\right) + \frac{\partial F(\Pi - C)}{\partial(\Pi - C)}\alpha(\Pi - C)$$
$$-(\rho + \lambda)F(\Pi - C) + \lambda F[(1-\phi)(\Pi - C)] = 0 \quad \text{(A5)}$$

Knowing that the value of the investment opportunity must also satisfy the following boundary conditions

$$F_{(\Pi - C)=0} = 0 \quad \text{(A6.1)}$$

$$F^*(\Pi - C) = \frac{\Pi - C}{(\rho - \alpha + \lambda)} - I \quad \text{(A6.2)}$$

$$F'^*(\Pi - C) = \frac{1}{(\rho - \alpha + \lambda)} \quad \text{(A6.3)}$$

a solution must take the form

$$F(\Pi - C) = A_1(\Pi - C)^{\beta_1} + A_2(\Pi - C)^{\beta_2} \text{ with } \beta_1 > 1 \text{ and } \beta_2 < 0 \quad \text{(A7)}$$

To ensure condition (A6.1) the coefficient A_2 must be assumed equal to zero. Hence, from equation (A7), (A5) simplifies to

$$\frac{1}{2}\beta_1(\beta_1 - 1)\sigma^2 + \beta_1\alpha - (\rho + \lambda) + \lambda(1-\phi)^{\beta_1} = 0. \quad \text{(A8)}$$

Assuming $\phi = 1$ this leads to the solution

$$\beta_1 = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(\rho + \lambda)}{\sigma^2}} > 1. \quad \text{(A9)}$$

Boundary conditions (A6.2 – A6.3) can be used to get the value of the unknown variable A_1 and the optimal value of (Π-C) for the investment decision. This results in the following relation

$$(\Pi - C) = \left(\frac{\beta_1}{\beta_1 - 1} \right) (\rho - \alpha + \lambda) I \,. \tag{A10}$$

Appendix 2

Given $\frac{\partial \lambda(d)}{\partial d} < 0$ and $\rho > \alpha$ the sign of $\frac{\partial \beta_1}{\partial d} < 0$ while $\frac{\partial \left(\frac{\beta_1}{\beta_1 - 1} \right)}{\partial d} > 0$.

This can be easily seen from the following derivative:

$$\frac{\partial \left(\frac{\beta_1}{\beta_1 - 1} \right)}{\partial d} = \frac{\partial \beta_1}{\partial d} (\beta_1 - 1)^{-1} + \beta_1 \frac{\partial (\beta_1 - 1)^{-1}}{\partial d}$$

$$= \frac{1}{\sigma^2} \left[\left(\frac{\alpha}{\sigma^2} - \frac{1}{2} \right)^2 + \frac{2(\rho + \lambda)}{\sigma^2} \right]^{-\frac{1}{2}} \frac{\partial \lambda}{\partial d} (\beta_1 - 1)^{-1} - \beta_1 (\beta_1 - 1)^{-2} \frac{1}{\sigma^2} \left[\left(\frac{\alpha}{\sigma^2} - \frac{1}{2} \right)^2 + \frac{2(\rho + \lambda)}{\sigma^2} \right]^{-\frac{1}{2}} \frac{\partial \lambda}{\partial d}$$

Setting $K = \frac{1}{\sigma^2} \left[\left(\frac{\alpha}{\sigma^2} - \frac{1}{2} \right)^2 + \frac{2(\rho + \lambda)}{\sigma^2} \right]^{-\frac{1}{2}}$

we can write

$$\frac{\partial \left(\frac{\beta_1}{\beta_1 - 1} \right)}{\partial d} = \frac{K \frac{\partial \lambda}{\partial d}}{\beta_1 - 1} \left(1 - \frac{\beta_1}{\beta_1 - 1} \right).$$

Given that both of the factors of the right-hand side are negative, the sign of the derivative is positive. Now, what is the prevailing sign of the following derivative?

$$\underbrace{\left(\frac{\beta_1}{\beta_1 - 1} \right) \frac{\partial (\rho - \alpha + \lambda)}{\partial d}}_{(-)} + \underbrace{\frac{\partial \left(\frac{\beta_1}{\beta_1 - 1} \right)}{\partial d} (\rho - \alpha + \lambda)}_{(+)}.$$

Substitute for the above result

$$\left(\frac{\beta_1}{\beta_1 - 1} \right) \frac{\partial (\rho - \alpha + \lambda)}{\partial d} + \frac{K \frac{\partial \lambda}{\partial d}}{\beta_1 - 1} \left(1 - \frac{\beta_1}{\beta_1 - 1} \right) (\rho - \alpha + \lambda)$$

and collect terms

$$\underbrace{\frac{\partial \lambda}{\partial d}}_{-}\left[\underbrace{\left(\frac{\beta_1}{\beta_1 - 1}\right)}_{+} + \underbrace{\frac{K}{\beta_1 - 1}}_{+}\underbrace{\left(1 - \frac{\beta_1}{\beta_1 - 1}\right)}_{-}\underbrace{(\rho - \alpha + \lambda)}_{+}\right].$$

The prevailing sign is ambiguous and depends on the specific values of the parameters.

References

ACPC, 1999. *Canola's producers perspective on biotechnology*. Alberta Canola Producers Commission ACPC, Edmonton. [http://www.canola.ab.ca/tec/gmo.shtml]

Agnet, 2002. *GM free & the 6-mile (10km) exclusion zone*, September 19. [http://131.104.232.9/agnet/2002/9-2002/agnet_september_19.htm]

Bock, A.K., Lheureux, K., Libeau-Dulos, M., et al., 2002. *Scenarios for co-existence of genetically modified, conventional and organic crops in European agriculture*, Institute for Prospective Technological Studies and Joint Research Centre of the European Commission IPTS-JRC. Sevilla. [ftp://ftp.jrc.es/pub/EURdoc/eur20394en.pdf]

Clark, E.A., 2001. On the implication of the Schmeiser decision: the crime of Percy Schmeiser. *Genetics Society of Canada Bulletin,* June 2001.

Demont, M. and Tollens, E., 2001. *Uncertainties of estimating the welfare effects of agricultural biotechnology in the European Union*. Department of Agricultural and Environmental Economics, K.U. Leuven, Leuven. Working Paper no. 2001/58. [http://www.agr.kuleuven.ac.be/aee/clo/wp/Demont2001c.pdf]

Demont, M., Wesseler, J. and Tollens, E., 2002. *Biodiversity versus transgenic sugar beet: the one Euro question*. Department of Agricultural and Environmental Economics, K.U. Leuven, Leuven. Working Paper no. 2002/69. [http://www.agr.kuleuven.ac.be/aee/clo/wp/demont2002d.pdf]

European Commision, 2000. *Economic impacts of genetically modified crops on the agri-food sector: a first review*. European Commision, Brussels. Working Document Rev. 2, Directorate-General for Agriculture. [http://europa.eu.int/comm/agriculture/publi/gmo/fullrep/index.htm]

European Commision, 2002. *Frequently asked questions on the Commission's proposal on environmental liability*. European Commission, Brussels. Press Releases MEMO/02/10, 24 January 2002. [http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.getfile=gf&doc=MEMO/02/10|0|AGED&lg=EN&type=PDF]

Gaisford, J.D., Hobbs, J.E., Kerr, W.A., et al., 2001. *The economics of biotechnology*. Edward Elgar, Cheltenham.

Germanò, A., 2002. *Voce "Biotecnologie in agricoltura". IV. Digesto discipline privatistiche*. Utet, Torino.

James, C., 2002. *Global status of commercialized transgenic crops*. International Service for the Acquisition of Agri-biotech Applications ISAAA, Ithaca. ISAAA Briefs no. 27. [http://www.isaaa.org/kc/Publications/pdfs/isaaabriefs/Briefs%2027.pdf]

Kershen, D.L., 2002. *Legal liability issues in agricultural biotechnology*. National Agricultural Law Center, University of Arkansas School of Law, Fayetteville. [http://www.nationalaglawcenter.org/assets/article_kershen_biotech.pdf]

Kolstad, C.D., Ulen, T.S. and Johnson, G.V., 1990. Ex post liability for harm vs. ex ante safety regulation: substitutes or complements? *American Economic Review,* 80 (4), 888-901.

Marra, M.C., 2001. Agricultural biotechnology: a critical review of the impact evidence to date. *In: IFPRI & AARES preconference workshop "Agricultural biotechnology: markets and policies in an international setting", Adelaide, January 22 2001*.

Monsanto Canada Inc. vs. Schmeiser, 2001. Decision by Judge MacKay, Federal Court of Canada FCT 256, March 29, 2001.

Morel, B., Farrow, S., Wu, F., et al., 2003. Pesticide resistance, the precautionary principle and the regulation of *Bt* corn: real and rational option approaches to decision making. *In:* Laxminarayan, R. ed. *Battling resistance to antibiotics and pesticides: an economic approach*. Resources for the Future, Washington, 184-213.

Network of Concerned Farmers NCF, 2003. *Issues & information*. [http://www.non-gm-farmers.com/issues_legal_litigation.asp]

Office of Science and Technology Policy OSTP, 1986. *Coordinated framework for regulation of biotechnology, 51 Fed. Reg. 23302, June 26, 1986*.

Schmidt, H., 2002. *Die heutigen rechtlichen Rahmenbedingungen für die Koexistenz der biologischen Landwirtschaft mit benachbarten transgenen Kulturen in Deutschland, Diskurs Grüne Gentechnik*. Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, Berlin.

Wesseler, J., 2003. Resistance economics of transgenic crops under uncertainty. *In:* Laxminarayan, R. ed. *Battling resistance to antibiotics and pesticides: an economic approach*. Resources for the Future, Washington, 214-237.

Winston, M.L., 2002. *Travels in the genetically modified zone*. Harvard University Press, Cambridge.

---

[1] For examples on short and long term impacts of GM contamination on conventional and organic farmers see Bock et al. (2002).

[2] For some authors the control of volunteers can be easily implemented by using other herbicides, such as 2,4-D or MCPA, in association with Roundup (ACPC 1999). Other scientists see this issue as much more problematic with important implications for farm practices (Clark 2001). Moreover, in the case of canola, the GM farmer willing to switch back to the conventional crop will face severe problems due to the control of volunteers with the risk of not being able to save seed for the following sowing season and the threat of being sued by the seed developer.

[3] If this is true, as will be clear in the model specification, *ex-ante* regulations are not the sole forces influencing the profitability of the GM crop and, consequently, the adoption decision.

[4]Council Regulation (EC) 1804/1999 of July 19, 1999 under article (10) states that products labelled as organic have to be free of genetically modified organisms or parts thereof. As the current analytical limit is at a level of about 0.1%, this has been interpreted as a *de facto* threshold (Bock et al. 2002).