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ECONOMICS OF SPATIAL COEXISTENCE OF GENETICALLY MODIFIED AND CONVENTIONAL CROPS: OILSEED RAPE IN CENTRAL FRANCE

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The EUWAB-project (European Union Welfare Effects of Agricultural Biotechnology)
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Since 1995, genetically modified crops have been introduced commercially into US agriculture. These innovations are developed and commercialised by a handful of vertically coordinated "life science" firms who have fundamentally altered the structure of the seed industry. Enforcement of intellectual property rights for biological innovations has been the major incentive for a concentration tendency in the upstream sector. Due to their monopolistic behaviour, these firms are able to extract a part of the total social welfare through. In the US, the first *ex post* welfare studies reveal that farmers and input suppliers are receiving the largest part of the benefits. However, few *ex ante* studies exist for the European Union. Hence, the K.U.Leuven presents the EUWAB-project (European Union Welfare effects of Agricultural Biotechnology), assessing the economic impact of agricultural biotechnology innovations in the EU and their welfare distribution among Member States, producers, processors, consumers, input suppliers, governments and the environment. This project has been financed by the Flanders Interuniversity Institute for Biotechnology (VIB), the European Commission's Sixth Framework Program and Monsanto.

Abstract

The EU is currently struggling to implement coherent coexistence regulations on genetically modified (GM) and non-GM crops in all Member States. We conduct simulations with the software ArcView® on a GIS dataset of a hypothetical case of GM herbicide tolerant oilseed rape cultivation in Central France. Our findings show that rigid coexistence rules, such as large distance requirements, may impose a severe burden on GM crop production in Europe. These rules are not proportional to the farmers' basic incentives for coexistence and hence not consistent with the objectives of the European Commission. More alarming, we show that in densely planted areas a domino-effect may occur. This effect raises coexistence costs and even adds to the non-proportionality of rigid coexistence regulations. Instead, we show that flexible measures would be preferable since they are proportional to the incentives for coexistence and, hence, less counterproductive for European agriculture.

Introduction

Europe is currently struggling to implement coherent coexistence regulations on genetically modified (GM) and non-GM crops. Since the publication of the European Commission's (2003) guidelines on coexistence, some Member States have developed, and others are still developing, a diversity of *ex ante* regulations and *ex post* liability rules on the coexistence of GM and non-GM crops (Beckmann, Soregaroli, and Wesseler, 2006). In this paper, our attention is drawn to the first group of regulations, and more specifically to spatial coexistence regulations. Our concern is that rigid rules, such as large distance requirements may impose a severe burden on GM crop production and may not be proportional to farmers' basic incentives for coexistence. This information is extremely important and timely for EU policy makers who currently face the challenge of implementing coherent coexistence regulations tailored to a heterogeneous landscape of European agriculture.

Some argue that biological coexistence of genetically modified (GM) and conventional crops is impossible because the movement of modified genes beyond their intended destinations damages the purity of non-GM seeds and biodiversity (Altieri, 2005). In the EU, most recent research on the economics of GM crops focuses on the potential costs of coexistence of GM and non-GM crops. This over-emphasis on costs is possibly an artefact of Greenpeace's (2002) press reaction on the European Commission's first report on coexistence (Bock *et al.*, 2002), which made Greenpeace to conclude that coexistence between GM and non-GM crops would be impossible in Europe. Since the appearance of this report, very few studies have focused on the 'incentives' for coexistence, i.e. (i) GM crop cultivation (in order to capture 'GM rents') versus (ii) identity preservation (IP) of non-GM crops (in order to capture ‘IP rents’), although the latter have to finance all the transaction and investment costs of the coexistence measures under research.

Within the coexistence issue, the cost-benefit aspect plays a key role: if one of the incentives is lacking, there is no coexistence problem. GM crop farmers will only invest in coexistence measures if the benefits of GM technology exceed the costs of the technology plus the costs of the additional measures to be taken. Non-GM crop farmers might have incentives to apply measures in order to avoid contamination and receive an IP price premium for their non-GM produce. However, the potential gains from the GM technology are opportunity costs to the non-GM market; hence price premiums must compensate foregone gains.

In a first phase, early GM adopters might face low coexistence costs due to low and diffuse regional adoption (Figure 1). As adoption increases, coexistence costs rise and price premiums of IP crops increase as non-GM products become scarcer. The latter attracts non-GM crop farmers, trying to capture the rents of IP. As long as there are farmers for whom GM rents are higher than coexistence costs, adoption will increase and non-GM crops will become scarcer. In this second phase, market equilibrium of incomplete adoption could be attained, with the market supplying both GM and higher priced IP crops[1]. However, this equilibrium is only stable to the extent that IP price premiums are stable in the long run.

Noussair, Robin, and Ruffieux (2004) argue that under a mandatory labelling system, the GM content of a product is a ‘search characteristic’ for labelled GM products and a ‘credence characteristic’ for an unlabelled product. During the introduction of GM food on the market, their safety and their equivalence to conventional products are also credence characteristics. In time, the segment of the market that purchased and consumed GM food would convince other segments of its safety and equivalence with conventional products, i.e. safety and equivalence would become experience characteristics rather than credence characteristics. If this occurs, the threshold issue[2] would become irrelevant in the long run and IP price premiums would collapse. This would lead to crowding out in the IP sector and increasing GM adoption levels if IP rents do not compensate foregone GM rents anymore, the latter increasing due to decreasing coexistence costs engendered by clustering and reallocation of crops. Hence, we do not expect the food market to reach equilibrium in the second phase; either the market will return to the first phase of limited adoption, either it will reach equilibrium in the third phase.

If IP market signals continue to be weak, as they currently are (Foster and French, 2007), the market will probably reach equilibrium in the third phase and long-run coexistence costs will purely reflect the costs of compliance with EU coexistence regulations instead of the economic incentives for coexistence. Probably, areas where the GM incentive is higher than the IP incentive will cluster as GM regions, while areas with lower GM incentives will rapidly form GM-free regions in an attempt to capture the initial IP rents, if they exist. In the long-run, we expect IP rents and the IP non-organic market segment to dissolve and be absorbed by the organic sector. The model of Moschini, Bulut, and Cembalo (2005) suggests an increase in the income of organic producers, due to the introduction and segregation of GM food in the EU.

Most of the recent literature focuses on technical discussions about gene flow, spatial contamination and coexistence management (Eastham and Sweet, 2002; Perry, 2002b; Devos *et al.*, 2004; Devos, Reheul, and De Schrijver, 2005; Damgaard and Kjellsson, 2005; Belcher, Nolan, and Phillips, 2005), but the interaction between incentives and costs of coexistence is poorly studied. Therefore, in this paper we undertake the first attempt to do more research in this area, in order to depart from the myopic view that the coexistence issue is solely about costs.[3] More specifically, we will develop a model for estimating spatial coexistence costs, which explicitly takes into account the incentives for coexistence.

This paper is organised as follows. In the second section, we derive the theoretical implications of the introduction of GM crops on the commodity market with a differentiated demand. In the third section we discuss the implementation of coexistence regulations in the EU. In the fourth section, we develop a theoretical framework for analysing the economics of coexistence. We derive models for assessing the costs of spatial, temporal and operational coexistence measures as well as monitoring costs and the costs of a system failure. In the fifth section, we assess the coexistence costs of a specific case study, i.e. the Beauce Blésoise region in Central France, through Geographic Information System (GIS) simulations of a set of realistic coexistence scenarios. Finally, the sixth section concludes.

Emergence of a demand for coexistence in the commodity market

As a result of the introduction of GM crops under differentiated demand, three distinct crop market segments emerge, supplied by four types of farmers and each characterised by its own market price (Table 1). In the first segment, commodities are sold at the lowest price. Both GM and non-GM products that tested positive for the presence of GM material, i.e. containing more than 0.9% of GM content, are sold at a price P_g to consumers who are not strictly averse to GM food. P_g is lower than P_n because of three reasons. First, the supply shift will drive the price level downwards in a market where GM commodities are sold. Secondly, the transaction costs associated with identity preservation may cause prices of identity preserved (IP) non-GM products to rise (Giannakas and Fulton, 2002). Thirdly, consumers belonging to this group perceive GM products as weakly inferior to similar non-GM products (Lapan and Moschini, 2004). This implies that in order to reach a critical mass of consumers in this segment, GM products have to be priced at a certain discount, *m*, relative to P_n. The size of this discount will depend on (i) the targeted share of consumers, (ii) the degree of aversion to GM products within the group of consumers and (iii) the adoption rate of GM crops, which influences the supply of non-GM, relative to GM crops. P_g is lower than the price in the third segment, P_b, because of the price markup, *w*, of certified organically produced products.[4]

Farmers in the first segment adopt GM crops to benefit from the GM rent, i.e. lower input costs, increased yields and economies in management time. Some farmers do not adopt GM crops because the expected potential benefits do not outweigh the expected additional costs. In this paper we assume that farmers who perceive no added-value[5] in growing GM crops will continue to grow non-GM crops, but will take part in an IP program in order to capture the IP rent.[6] Finally, some farmers adopt GM crops on part of their area, e.g. on heavily infested fields (in case of heterogeneous weed infestation) or on remote fields (for convenience and management flexibility).

Coexistence regulation in the European Union

According to the European Commission's (2003) guidelines, "Coexistence refers to the ability of farmers to make a practical choice between conventional, organic and GM [genetically modified] crop production, in compliance with the legal obligations for labeling and/or purity standards. The adventitious presence of GMOs [genetically modified organisms] above the tolerance threshold set out in Community legislation triggers the need for a crop that was intended to be a non-GMO crop, to be labeled as containing GMOs. This could cause a loss of income, due to a lower market price of the crop or difficulties in selling it. […] Coexistence is, therefore, concerned with the potential economic impact of the admixture of GM and non-GM crops [...]". Since the publication of these guidelines, some Member States have developed, and others are still developing, a diversity of *ex ante* regulations and *ex post* liability rules on the coexistence of GM and non-GM crops, reviewed by Beckmann, Soregaroli and Wesseler (2006).

At the farm level, these regulations translate into three levels of coexistence costs: (i) the costs of compliance to the *ex ante* coexistence regulations, developed to prevent cross-pollination and/or admixture, (ii) the expenses for *ex post* monitoring, because the product has to be tested for the presence of transgenic DNA, and (iii) the *ex post* costs that arise in case where the coexistence system fails, and thus a crop of a neighbouring farmer gets 'contaminated' with genetic material from the GM crop (Soregaroli and Wesseler, 2005). It is important to note that the three levels of coexistence costs are not mutually independent. The likelihood and cost of a system failure will be influenced by the cost of the system itself, the efforts and costs of the required coexistence measures and the monitoring efforts and expenditures. More stringent measures and monitoring procedures, if effective, lower the likelihood and costs of a system failure, because the prevention of commingling (avoiding a system failure) is the very reason of their existence.

Economics of coexistence

Preventive coexistence management costs

Figure 2 presents two alternative strategies for complying with distance requirements. Under the preventive approach farmers re-allocate crops within the spatial and temporal dimension of the pre-existing cropping systems. This approach requires perfect information about the spatial and temporal allocation of crops on the surrounding neighbours' fields and entails significant transaction costs. Moreover, changing crop allocations affects profitability as crops on top of the rotation cycle affect subsequent crops. Therefore farmers might incur additional costs by adopting second best and less profitable cropping systems.

Temporal isolation of crops exploits asynchrony in flowering periods between GM and non-GM varieties. The outcome of this measure is variable and highly dependent on weather influences. As a result, this measure is not particularly reliable. Successful yields depend on optimal sowing dates. Therefore, sowing beyond the optimal time entails additional costs for the farmer. The cost of achieving a difference in flowering dates can be modelled as

$$C_{\mathrm{df}} = a\, y\, (1 - j)\, P \qquad (1)$$

with a the allocated area, y the crop yield, j the proportionate yield loss of sowing on a non-optimal sowing date and P the market price.

Another option for achieving asynchrony in flowering periods is through the choice of varieties. Farmers temporally isolate their crops by exploiting heterogeneity within the range of varieties, i.e. from early to late flowering breeds. At the one hand, sowing different varieties at the same dates avoids the weather dependencies of the previous method. On the other hand, additional costs might be incurred as (i) farmers have to switch to lower-yielding varieties, (ii) farmers' choice becomes restricted to late flowering varieties (loss of option value), and (iii) selecting late instead of early flowering varieties narrows down the timing window for land preparation of the subsequent crop in the rotation. Hence, because of the various reasons mentioned before, we do not expect the preventive approach to become predominant in coexistence management.

Curative coexistence management costs

The curative approach (Figure 2) is a second, more pragmatic approach with minimal transaction costs and which is currently enforced by most EU Member States' coexistence legislations. This approach includes (i) minimal isolation distance requirements, implemented by 10 Member States, in combination with or as an alternative to (ii) buffer zones planted with non-GM crops of the same species between GM and non-GM fields, implemented by six Member States (Beckmann, Soregaroli, and Wesseler, 2006).

In this paper, we polarise these two types of spatial coexistence regulations to draw policy recommendations. We model the example of large isolation distances and assume rigidity, i.e. the regulations are imposed on GM farmers, regardless of local agreements between neighbouring farmers.[7] We further assume that fields which are too close to non-GM crop fields cannot be planted with GM varieties of the same crop. We define buffer zones as cross-pollination zones, planted with non-GM crops and sold as GM, between two farmers growing two different varieties (GM and non-GM) of the same crop. We model the example of buffer zones with a small width and assume flexibility, i.e. the regulations allow buffer zones to be negotiated and planted by GM and non-GM farmers.

In the case of rigid coexistence rules, such as isolation distances imposed on GM crop farmers, if a field is too close to a non-GM field of a particular crop, the field has to be planted with other crops or non-GM varieties of the same crop species. If the farmer chooses to plant the same crop, he foregoes the GM rent and, assuming he is rational, will attempt to compensate the GM rent foregone by minimizing contamination and trying to capture the IP rent. The resulting coexistence costs are a trade-off between the GM rent (yield boost and cost reduction) and the IP rent (price premium):

$$C_{\mathrm{id}} = a_{\mathrm{id}}\,[b\,y_{\mathrm{c}}\,P_{\mathrm{g}} + \Delta C - y_{\mathrm{c}}\,P_{\mathrm{g}}\,m]. \qquad (2)$$

with a_{id} the total area of GM-free fields of a particular crop to respect a certain isolation distance, $b = (y_{\mathrm{g}} - y_{\mathrm{c}})/y_{\mathrm{c}}$ the proportionate yield boost of the GM crop (y_{g}) relative to the conventional one (y_{c}), $\Delta C = c_{\mathrm{c}} - c_{\mathrm{g}}$ the per-hectare cost reduction generated by the GM crop (c_{g}) relative to the conventional one (c_{c}), and $m = (P_{\mathrm{n}} - P_{\mathrm{g}})/P_{\mathrm{g}}$ the price premium factor of IP crops relative to GM crops.

In the case of flexible coexistence regulations, we consider four practical solutions, depending on whether the buffer zone is cultivated on the GM field (System 1) or on the non-GM field (System 2) and whether it is planted and cultivated by the owner (System a) or the neighbor (System b) of the field. The dominance of one of the four systems will depend on the relative importance of the transaction costs involved. In this paper, we only focus on the opportunity costs involved in achieving spatial coexistence.

In System 1a, the GM farmer plants and cultivates a buffer zone with non-GM crops on his GM field next to his neighbour's non-GM field. However, in the context of herbicide tolerant crops, maintaining two different weed control systems on a single field may not be practical for organizational reasons. Therefore, in System 1b it is the non-GM farmer who plants and cultivates a buffer zone on the GM farmer's field. The latter reimburses part of the former's cultivation costs (sowing and herbicide treatments) and harvests his entire field, including the buffer zone. In either system, the GM farmer foregoes the GM rent on his buffer zone:

$$C_{\mathrm{bz}} = a_{\mathrm{bz}}\,[b\,y_{\mathrm{c}}\,P_{\mathrm{g}} + \Delta C]. \qquad (3)$$

In System 2a, the non-GM farmer separately harvests his adjacent margins, which serve as buffer zones, next to the neighboring farmer's GM fields, and delivers them to the collector as 'GM'. However, he foregoes any scale economies of harvesting and selling his full non-GM crop production in a single lot, such as in System 1b. Therefore, a variant which takes advantage of scale economies is System 2b: the GM farmer first harvests the field margin on the non-GM farmer's field (with a clean harvester to avoid contamination of subsequent crop rotations) and sells the harvested crops as 'GM'. In either system, the GM farmer has to compensate the neighboring non-GM farmer for the IP rent foregone:

$$C_{\mathrm{bz}} = a_{\mathrm{bz}}\, y_{\mathrm{c}}\, P_{\mathrm{g}}\, (s \;\; + m) \tag{4}$$

with $s \in [0,1]$ the discount factor on the revenue of the GM crop. The parameter s incorporates two effects: (i) the price discount[8] due to the small lot size and (ii) the loss of scale economies[9] due to the small plot size. Equations 2, 3 and 4 clearly illustrate that the cost of spatial coexistence measures is proportional to the incentives for achieving coexistence, i.e. the GM rent and the IP rent.

Coexistence management costs for assuring seed purity

As soon as GM crops are introduced, all non-GM seed will need to be tested for adventitious presence of transgenes. Seed needs to be pure for two reasons. First, impure seed can generate additional GM presence in the field through cross-pollination (Hanna and Jarboe, 2002). Secondly, commingling can accumulate in various stages of production. Starting with less pure seed can quickly result in GM presence levels that rise above the required thresholds (Sweet, 2005). Due to additional testing for GM presence, the costs of certified non-GM seed production will rise. Vrijens, Gabriels and Van Gijseghem (2004) estimate the extra seed costs for maize due to GM testing at about €1/ha. However, their cost calculation omits the extra quantitative testing costs in case of contamination. Therefore, we propose the following formula for estimating the cost of certified seed:

$$C_{\mathrm{cs}} = a\,(w_{\mathrm{cs}}\, q_{\mathrm{cs}} + c_{\mathrm{ql}}\, q_{\mathrm{cs}} + g_{\mathrm{s}}\, c_{\mathrm{qt}}\, q_{\mathrm{cs}}), \qquad (5)$$

with C_{cs} the cost of certified seed after introduction of GM, a (ha) the area sown, w_{cs} (€/kg) the price of certified seed before introduction, q_{cs} (kg/ha) the seeding rate, c_{ql} (€/kg) the cost for qualitative analysis, g_{s} the probability that the qualitative test indicates GM presence and c_{qt} (€/kg) the cost of quantitative testing.

Operational coexistence management costs

In addition to the use of pure seed, farmers have to pay special attention to prevent commingling of the seeds during sowing. If GM and non-GM fields are sown alternately, the sowing machine has to be cleaned very carefully between the sowing operations. Bullock, Desquilbet, and Nitsi (2000) estimate the required time for cleaning a sowing machine at 40 minutes for a 8-row planter and 55 minutes for a 12-row planter. If we assume that the sowing machine is cleaned at the end of the sowing season anyway, additional cleaning costs can be estimated as

$$C_{\mathrm{cs}} = (f_{\mathrm{s}} - 1)(t\, w), \qquad (6)$$

with f_s the number of cleaning operations of the sowing machine, t (h) the average time spent per operation, and w (€/h) the hourly wage. However, in some cases these costs can be avoided by planting non-GM fields first in order to avoid GM seed commingling with non-GM seed. The same applies to harvesting, which is also a potential source of admixture, especially when done by a contractor who has both GM and non-GM crop clients (Nielsen, 2003).

Potential costs for the cleaning of harvesting machinery hence depend on the flexibility of farmers or contractors in planning their operations. The following extreme-case scenarios illustrate this point. If a contractor is able to serve all his non-GM clients in the neighbourhood first, and afterwards starts harvesting the fields of his GM clients, additional costs for cleaning the machinery will be zero. If the same contractor has to harvest the fields of his GM and non-GM clients alternately, cleaning costs can be significant. Costs for cleaning combines, trucks and trailers can be calculated as labour costs, in function of the required cleaning time and the number of cleaning operations. There is an alternative way of cleaning the combine (trucks and/or trailers can only be cleaned manually) by flushing it with a non-GM variety. This approach tends to be cheaper than a fully manual cleaning (Bullock, Desquilbet, and Nitsi, 2000).

The additional costs of cleaning the harvesting machinery (usually one combine and 2 trucks/trailers) for a harvesting season, assuming that the equipment would be cleaned once a season anyway, can be modelled as

$$C_{\mathrm{ch}} = (f_{\mathrm{h}} - 1)[t\, w + q_{\mathrm{f}}\, (P_{\mathrm{n}} - (1 - s)\, P_{\mathrm{g}})], \qquad (7)$$

with f_{h} the number of cleaning operations needed for the harvesting machines (highly dependent on specific local circumstances, as described above), t (h) the cleaning time, w (€/h) the hourly wage, q_f (t) the required volume of crops for flushing, ΔP (€/t) the price premium that will be lost by the non-GM crop as flushing material, and s the price discount of selling a small lot of the harvested crop with GM presence.

Coexistence monitoring costs

Monitoring systems require a testing regime for GM presence at several stages. Inspired by Wilson and Dahl (2005), the costs of such a testing regime can be modelled as

$$C_{\mathrm{m}} = \sum_{k=1}^{n} T_k S_k V_{\mathrm{n},k} (c_{\mathrm{ql}k} + g_s c_{\mathrm{qt},k}), \tag{8}$$

with T_k being a binary variable reflecting whether or not tests are conducted at stage k, $c_{\mathrm{ql},k}$ is the cost of an individual qualitative test applied at location k, S_k is the sampling intensity (number of samples per lot), $V_{\mathrm{n},k}$ is the volume (number of lots) of non-GM found at location k, $c_{\mathrm{qt},k}$ is the cost of an individual quantitative test applied at location k and g_{s} expresses the probability that a qualitative test indicates GM presence.

Coexistence system failure costs

Gene flow from GM crops creates liabilities through seed dispersal and GM pollen fertilising non-GM crops (Smyth, Khachatourians, and Phillips, 2002). Table 2 describes the market segments in case of a system failure. The cost of a system failure depends on the status of the contaminated farm, i.e. IP, supplying the second segment, or organic, serving the third segment. Next, it is important to make a distinction between short term impacts on the one hand, and medium and long-term impacts on the other hand (Bock *et al.*, 2002). The cost can be calculated in function of the premiums forgone of contaminated products. In the short term (within the same growing year), IP and organic crop farmers lose the price premium in segment 2 and segment 3 for IP and organic products respectively.

In the case of organic farming, according to the European Union law on organic farming, the land has to go through a period of conversion of two years (Raad van de Europese Gemeenschappen, 1991). This implies that if an organic crop gets cross-pollinated by a GM crop, the cultivated land in question becomes unsuitable for organic culture in the two subsequent years. Contamination in the case of an organic farmer implies an immediate and certain loss of the organic price premium for three years on the contaminated parcel. Additionally, the organic farmer might lose his subsidies connected to organic farming. In the medium and long term, the contaminated farmer can experience the above-discussed losses in a few consecutive years. This could be the case when GM volunteers appear on, or around the field in the next growing seasons and contaminate IP, or organic crops. The farmer might lose the premiums for several consecutive years if he is unable to eradicate the GM volunteers. Canola seed for instance is very persistent and can emerge and flower in subsequent seasons (Lutman, 1993; Lutman, Freeman, and Pekrun, 2003). Farmers also face additional control costs of GM volunteers.[10] Hence, the possible costs of a system failure for an IP crop farmer can be modelled as

$$C_{\mathrm{sf}} = y\left[m P_{\mathrm{g}} a y_{\mathrm{c}} + \sum_{i=1}^{k} h_k \frac{m P_{\mathrm{g}} a y_{\mathrm{c}}}{(1+i)^k} + \sum_{\mathrm{i}=1}^{k} \frac{a\, c_{\mathrm{vc}}}{(1+i)^k}\right], \tag{9}$$

with y the probability of a system failure, m the IP price premium factor, a (ha) the area allocated to the crop, y_{c} (t/ha) the yield of the conventional IP crop, k the agricultural season, c_{vc} (€/ha) the extra cost for GM volunteer control, h_k the risk of adventitious presence caused by volunteers, decreasing over time, and i the interest rate (Wilson and Dahl, 2005). For an organic farmer, the costs can be modelled as

$$C_{\mathrm{sf}} = y\left[\sum_{i=0}^{k} \frac{w P_{\mathrm{g}} a y_{\mathrm{b}}}{(1+i)^k} + \sum_{\mathrm{i}=3}^{k} h_k \frac{w P_{\mathrm{g}} a y_{\mathrm{b}}}{(1+i)^k} + \sum_{\mathrm{i}=1}^{k} \frac{a\, c_{\mathrm{vc}}.(1+a)}{(1+i)^k} + \sum_{i=0}^{k} \frac{a\, S_{\mathrm{org}}}{(1+i)^k}\right], \tag{10}$$

with w the organic price premium factor, a a parameter to capture the increase in volunteer control costs to represent the restricted options in organic farming and S_{org} (€/ha) the subsidy for organic farming. The probability of a system failure, y, depends on at least six factors: (i) the adoption rate, (ii) the regional crop density, (iii) crop-specific traits, (iv) the required threshold level, (v) the efforts and expenses for coexistence measures and (vi) the efforts and expenses for monitoring.

The system failure costs modelled in equations 9 and 10 represent the total costs of a random single event. In reality, farmers can spread the risk and hence lower the costs of a system failure through insurance. For an insurance pricing model we refer to Ripplinger, Hayes, and Lamkey (2006), who determine the probability of transgenic contamination and the related losses, based on (i) a physical dispersion model of pollen in function of the distance to the GM field, and (ii) the expected revenue of the crop.

Coexistence management costs in oilseed rape cultivation in Central France

Curative coexistence management costs

Technical issues of the coexistence of GM and non-GM oilseed rape in the European Union have been widely studied in literature (Lutman, 1993; Pessel *et al.*, 2001; Eastham and Sweet, 2002; Jørgensen *et al.*, 2003; Lutman, Freeman, and Pekrun, 2003; Devos *et al.*, 2004; Sweet, 2005; Damgaard and Kjellsson, 2005; Begg *et al.*, 2006). In the case of oilseed rape in Central France, flexible coexistence management systems could be sufficient to ensure spatial coexistence. Nevertheless, most of the EU Member States, including France, are incorporating rigid coexistence rules in the form of large isolation distances into their coexistence legislations (Beckmann, Soregaroli, and Wesseler, 2006). Therefore, in this paper we use the hypothetical example of herbicide tolerant (HT) oilseed rape adoption in Central France to compare the costs of rigid versus flexible systems for regulating coexistence.

The dominance of one of the four flexible systems mentioned before will depend on the relative importance of the transaction costs involved. In System b, there is a market price risk which can be borne by either the GM or the non-GM farmer, depending on the contract between both parties. Moreover, the system introduces transaction costs due to moral hazard. In System 2b, the GM farmer has incentives for underreporting yields of non-GM crops on his neighbour's field. In System 1b, the GM farmer pays the non-GM farmer for his cultivation services, but since the latter is not the residual claimant of the crops on the buffer zone, he has incentives to cheat and lower the quality of his services. As a result, the dominance of a system will depend on the trade-off of both (i) market price risks and (ii) moral hazard. System a avoids these transaction costs[11], but introduces losses of scale economies. In System 1a, the GM farmer has to manage two different weed management systems on his field and in System 2a, the non-GM farmer has to separately sell limited quantities of potentially contaminated non-GM crops to GM-labelled outlets.

In 2005 in the Beauce Blésoise region, nine farmers were surveyed on their coexistence strategies considering themselves alternatively as GM or non-GM farmers (Casagrande, 2005). Seven farmers mentioned buffer zones. Two of them perceived these practices as unfeasible, especially in relation to their neighbours, i.e. they perceived the transaction costs to be too high relative to the expected benefits. Five farmers accepted the use of buffer zones as coexistence management strategy. Three of them proposed system 2, while only one mentioned system 1. From these first survey data, it seems that the balance of transaction costs is in favour of system 2.

Operational coexistence management costs

Only 3 out of 21 surveyed farms store oilseed rape prior to delivery; most of the farmers deliver their harvest directly to the collector. Each farm possesses its own storage facilities, consisting of several cells (Sausse, 2005). Therefore, separate storage of GM and non-GM oilseed rape is possible without additional costs. According to our farmer survey, a single cleaning operation of harvesting machinery takes 6-12 person-hours (Casagrande, 2005). Taking into account an average hourly wage of €7.64 (Teyssier, 2004), total cleaning costs amount to €46-92. However, as machinery is rarely shared, such operational coexistence measures are rarely needed and omitted from the cost calculations in this paper. In cases where a non-GM crop farmer has to harvest a buffer zone (System 1b and System 2a), the risk can be sufficiently managed by first harvesting the rest of the field.

Coexistence monitoring costs

The regional stakeholders' prognosis on monitoring of GM and non-GM oilseed rape is very pragmatic. Testing could occur at the collector's stage where GM and non-GM oilseed rape could be stored in separate silos. Silos meant for the non-GM channel could be tested for the presence of GM content. Additional monitoring activities are currently not considered. Traceability would be assured by taking records and storing samples from the trucks before unloading. In case of GM content above the threshold, the source of contamination could be traced back by analysing the samples. As a result, the risk of a system failure would be shifted back to the farmers and would provide incentives to comply with *ex ante* coexistence regulations.

Cost of a system failure

In France, recently a regulatory framework has been constructed to deal with GM crops in the agricultural landscape. Specific rules, concerning measures and agricultural practices, will be stipulated in a future Decree. The current framework incorporates compensation mechanisms in case of a system failure. GM crop growers have to contribute a fixed per-hectare insurance premium to a fund administered by the ONIGC (Office National Interprofessionnel des Grandes Cultures). According to the latest information, this contribution could be around €10/ha, i.e. comparable to premiums in other EU countries, such as in the Netherlands and Denmark (Lahellec, 2006). The fund is a transitional measure and will be abandoned after a period of maximum five years. This period provides insurance companies with enough legal precedents for establishing insurance premiums against crop losses from transgenic contamination. Non-GM crop farmers with contaminated production can claim compensation from this fund.

Methodology

In this paper, we focus on the spatial coexistence costs that may arise in the hypothetical case of GM oilseed rape adoption in Central France. In other words, we assume that in the long-run farmers will first exploit all measures that minimise transaction costs (collecting information, negotiation, crop allocation …) before engaging in more costly coexistence management strategies.

As a case study, the Beauce Blésoise region in Central France was chosen. We select a sample square of about 100 km², i.e. 10,000 ha or about 6% of the case study region (159,505 ha). We conduct simulations through the software program ArcView® from ESRI on a GIS dataset of this sample square (Emeriau and

Adamczyk, 2000; Pessel and Lecomte, 2000; Pessel *et al.*, 2001; Deville, 2004). We start from a shapefile where the arable fields are represented as polygons (Figure 3). The modelled landscape counts 1,508 fields and a total field area of 4,233 ha.

Next, we randomly allocate oilseed rape fields in the landscape independently of farmers' land tenure[12] and randomly allocate GM traits among the oilseed rape fields (Figure 6). We furthermore assume that farmers plant the fields with pure seeds, i.e. free from GM contamination. In the benchmark scenario, oilseed rape is randomly allocated on 13% of the field area, i.e. the average regional planting density (Sausse, 2005), 50% of which is planted with GM traits. The latter assumption generates the most stringent situation for coexistence because it maximises the probability of a GM field being close to a non-GM field.

Next, we base our distance requirement assumptions on an existing gene flow model of oilseed rape, calibrated on regional data. Simulations with the Genesys model (Colbach, Clermont-Dauphin, and Meynard, 2001a; 2001b) carried out on a small spot from the study area demonstrate that from a distance of 10 m from the GM field, the presence of GM content in non-GM fields declines dramatically, assuming that the seeds are pure (Figure 4). Assuming 50% GM oilseed rape adoption in the landscape and no measures taken to prevent cross-pollination, only in 1 out of 600 simulated cases is the content of transgenic DNA in the silo of the collector above the conservative target threshold of 0.4%.[13] By increasing the adoption rate to 75%, the probability for a non-GM silo to be above the threshold increases (Figure 5). These simulations suggest that coexistence can be achieved by complying with minor distance requirements, because commingling is averaged out at the collector's stage. Based on these results, we model flexible coexistence regulations by designing 10 m buffer zones around GM fields as a benchmark. To contrast with the previous regulations, we model rigid coexistence regulations assuming a large benchmark isolation distance of 50 m.

Relative to the benchmark scenario, we simulate six additional alternative scenarios by varying (i) the adoption rate (scenarios 2 and 3), (ii) the share of oilseed rape in the arable area (scenarios 4 and 5), i.e. to capture regional heterogeneity of oilseed rape plantings, and (iii) the distance requirement (scenario 6), i.e. to capture regional heterogeneity of pollen dispersal (Table 5, Table 4 and Table 6). We recalculate the seven scenarios under three different IP price premium factors, i.e. m = 3%, 6%, and 12%, and three different GM seed price premiums, i.e. €11.5/ha, €23/ha, and €34.5/ha (*cfr. infra*), generating 77 combinations of coexistence scenarios in total (Table 8, Table 7 and Table 9). We perform 10 iterations[14] for each of the seven scenarios and calculate the averages of the aggregated oilseed rape area, aggregated GM oilseed rape area, aggregated buffer zone area, the number of buffer zones and the number of fields containing a buffer zone, i.e. the number of coexistence cases.

Shortcomings of the Arcview® simulations

It is important to note that our methodology and cost estimates are subject to three major shortcomings. First, the dataset we have at our disposal is not fully accurate. Ridges and gaps occur between polygons of adjacent fields, clearly visible in Figure 7, Figure 8 and Figure 9. Secondly, the agricultural utilisable area (AUA) of our sample represents 42% of the total area, while the AUA in the Beauce Blésoise region represents about 75% (120,319 ha) of the total area. This implies that our sample area is less dense than the regional average. Finally, as the GIS database of our sample area does not contain land tenure records, we treated all fields as independent and randomly allocated GM and non-GM oilseed rape among them. In reality, oilseed rape fields and GM and non-GM traits would be clustered (i) within farms (on-farm coexistence) and, (ii) in the medium and long-run, among farms in a region (*cfr. supra*), reducing transaction and coexistence management costs.

The first two sources of imprecision lead to an underestimation of the total buffer area and associated coexistence management costs. They relate to density issues, which are captured in our analysis through different scenarios of oilseed rape planting density and GM crop adoption (scenarios 2, 3, 5 and 7). The third source of imprecision probably generates an overestimation of coexistence management costs. Therefore, our cost estimates have to be interpreted as upper values of the expected medium and long-run coexistence management costs.

Data

We use a combination of data sources, such as farmer surveys, national statistics and literature. The average oilseed rape yield recorded during 2001-2004 in the case study area is about 3.13 tonne/ha (Agreste, 2005). To obtain a preliminary idea regarding the potential price premium of IP oilseed rape, we observe prices in a comparable market, i.e. the market for imported GM and IP soybeans for animal feed in the EU. In 2005, IP soybeans were sold at a price premium of €12/t or 6% of the market price (Neijens, 2005). Therefore, our benchmark scenario assumes a price premium of €13.5/t or 6% of the market price of oilseed rape, i.e. €225/tonne (Teyssier, 2004).

According to the local CETIOM engineer in Beauce, the glyphosate price (Roundup Bioforce, 360 g/l) amounts to €7.9/l. Given a market price of €0.225/kg and an average seed density of 3 kg per hectare (Teyssier, 2004), the opportunity cost of farm-saved seed is only €0.675/ha. The average cost of certified oilseed rape seed amounts to €37.5/ha (Teyssier, 2004). The average seed cost in the case study region is the average of farm-saved and certified seed, weighted according to their respective area shares, i.e. 30% and 70% (Sausse, 2005), and is estimated at €26.5/ha.[15]

Regarding the price premium for HT GM oilseed rape, the only indication from the literature is a Technology Use Agreement of about €23/ha reported for GM HT oilseed rape in Canada in 1999 (Phillips, 2003). As a result, the seed cost of GM HT oilseed rape seed is estimated at €60.5/ha. Farmers who are licensed to grow GM oilseed rape, are contractually prohibited to use own farm-saved seed and obliged to purchase certified seed every year. As a result, the effective average price premium perceived by farmers in the case study region is the difference between the GM seed cost and the weighted average seed cost, i.e. €34/ha. We assume a zero yield boost for HT oilseed rape, based on European field trials of HT crops (Schütte, 2003). Finally, we assume an average cost of €350 for a quantitative GM test (Neijens, 2005; ILVO, 2006).

Incentives for GM oilseed rape cultivation

Some farmers can reduce weed control costs by planting HT oilseed rape and replace their current herbicide programs by glyphosate treatments.[16] These farmers make up the category of the potential adopters. CETIOM surveyed the herbicide programs of 16 farmers in the case study region (Casagrande, 2005). Two farmers use two different programs for herbicide treatment, extending the sample to 18 observations. A total of 12 different herbicide programs are observed. We combine this data with actualised cost information from CETIOM (2005) to calculate the herbicide costs for the different programs. The observed costs range from €62/ha to €196/ha in the sample, resulting in an area-weighted average herbicide cost of €109/ha (Table 3).

We rely on Desquilbet *et al.* (2001) to specify replacement programs for the surveyed conventional herbicide programs represented in Table 3. Conventional herbicide programs may take up to three applications, at the pre-sowing, pre-emergence and post-emergence stages. We divide our sample in two sub-samples: (i) a category with 'light' treatment programs and (ii) a category with 'heavy' treatment programs. Conventional herbicide programs in the 'light treatment' sub-sample are replaced by one glyphosate application of 1.6 l/ha, while the 'heavy treatment' programs are replaced by two glyphosate applications, i.e. a dose of 3.2 l/ha.

Herbicide cost savings range from €49/ha to €170/ha, averaging €90/ha. Taking into account an effective GM seed price premium of €34/ha, the average net saving of adopting GM oilseed rape, or the GM rent, amounts to €56/ha. A 50% lower (higher) price premium of €11.5/€/ha (€34.5/ha) yields an average net saving of €67/ha (€44/ha) (Table 12).

Results of the Arcview® simulations

In Table 5 and Table 4 we report the estimated minimum, average and maximum costs for flexible coexistence management. The statistics are based on 10 iterations of random allocations of non-GM and GM oilseed rape fields. Total costs for the modelled sample square are reported, as well as costs per hectare of GM oilseed rape. In the 'worst-case' scenario 7 we design buffer zones of 20 m, i.e. twice the required distance estimated through the Genesys model, and allocate oilseed rape on 26% of the field area, i.e. twice the regional planting density. Even in this worst-case scenario, coexistence management costs only amount to €800-1,100 or €1.5-2.0/ha (Table 4 and Table 5).

By comparing the first three scenarios in Table 4 and Table 5, we observe that under increasing levels of adoption total coexistence management costs evolve following an inverse U-shape, as predicted in Figure 1. The highest average costs for the sample area (€72-97) are observed for adoption rates around 50%. For lower as well as higher adoption rates, lower costs are estimated. If we express the costs per hectare of GM crops on the other hand, the costs decline under increasing adoption rates because they are amortised over a larger area planted with GM crops.

In scenario 4 (6% oilseed rape share, 50% adoption), average costs are at their lowest level (€21-28). Doubling the oilseed rape share to 26% (scenario 5) increases total costs with a factor of almost five and more than doubles per-hectare costs. In the worst-case scenario 7, doubling both the oilseed rape share and the buffer zone width results in 11 times higher total costs and 5-6 times higher per-hectare costs. As the agricultural utilizable area (AUA) of the case study area Beauce Blésoise is about 28 times larger than the modelled sample area, total costs of flexible coexistence management amount to respectively €23,000-31,000 for the Beauce Blésoise region.

In Table 7, the per-hectare coexistence costs of System 1 are repeated for alternative values of the GM rent. The most uncertain element of the latter is the expected GM seed price premium. Under the very unlikely scenario of an extremely low premium, the costs amount to €2.4 in the worst-case scenario 7. We also have to note the interdependency between adoption rates and GM seed price premium. Smaller GM seed price premiums lead to high adoption rates (scenario 3) and hence to smaller coexistence management costs. In reality however, the evidence from literature suggests that GM seed price premiums are significant, leading to an average value distribution of 2:1, i.e. two thirds are captured by the farmer and one third by the input suppliers (Demont, 2006). High seed price premiums lower (i) the incentive for GM crop cultivation but also (ii) the cost of coexistence in System 1 as the latter factor is essentially an opportunity cost of the former.

In Table 8, the same exercise is repeated for system 2 by varying the IP price premium. Little is known about the expected price premium of IP oilseed rape, once the technology is adopted on a commercial scale in Europe. As the coexistence management costs are a simple homothetic function of the premium (Equation 4), halving and doubling the latter respectively halves and doubles the per-hectare coexistence management costs. Even in the worst-case scenario (26% oilseed rape, 50% adoption, buffer zones of 20 m and 12% price premium), average coexistence management costs only amount to €3.0/ha in System 1. From Table 7 and Table 8 it becomes clear that the costs generated through flexible coexistence regulations are proportional to the incentives of coexistence.

In Table 6, we report the static coexistence management costs engendered by rigid coexistence regulations, such as isolation distances of 50 m (scenarios 1-5) or 100 m (scenarios 6-7) imposed on the GM crop farmer. We conduct the iterations for similar scenarios as in the case of flexible coexistence management and estimate the immediate GM farmers' opportunity costs that arise as a consequence of complying with the distance requirements (equation 2). The observed static costs can be as high as €9.1/ha or €4,900 in total, i.e. significantly higher than in the case of flexible coexistence management. Assuming that farmers are rational and compensate the GM rent foregone with the IP rent, the estimated costs are a function of both rents (Table 9). If IP price premiums are low, rigid coexistence management costs are high. In other words, if consumers do not express their preferences in the market, imposing rigid coexistence rules is very costly because it denies farmers access to potentially cost-reducing technologies. On the other hand, if IP price premiums rise, due to increasing demand for IP crops, rigid coexistence costs become negative. In the latter case, farmers would not consider to plant GM crops and there would be no coexistence issue. In our benchmark scenario, the break-even point is estimated at about 8%, i.e. if IP premiums rise above this level, the coexistence issue becomes irrelevant, *stricto sensu*.

The costs represented in Table 6 and Table 9 are generated in the first phase of adoption as a result of rigid coexistence rules. In case of densely planted oilseed rape areas and stringent rules, e.g. isolation distances of 100 m, a domino-effect may occur. We illustrate the effect in Table 10 for the most stringent coexistence scenarios 5 and 7. In Phase 0, we simulate an 'intended adoption rate', i.e. the adoption rate that would result from the deliberate actions of all farmers. In this phase, some 300-350 ha or 100-130 fields of intended GM oilseed rape are identified in too close proximity of non-GM fields (50-100 m). On these fields, farmers are obliged to plant non-GM oilseed rape, implying that the originally intended adoption rate shrinks to 18-23% in Phase 1. In converting, farmers forego the GM rent, but capture the IP rent; the coexistence cost (€8-9/ha totalling €4,000-5,000) is the trade-off between both incentives. In Phase 1, some additional 60 ha or 20-30 fields are identified in too close proximity of non-GM fields (intended and obligatory), which gives rise to additional coexistence costs (€3-4/ha totalling €800). This process is repeated (€0.2-0.4 totalling €34-56 in Phase 2) until the isolation distances between all GM and non-GM fields are respected (Phase 3).

In scenarios with low oilseed rape planting densities and low isolation distances of 50 m, the domino-effect is limited (additional effect of 2-11%). In scenario 5 and 7, we observe that the domino-effect can lower adoption rates by some 30-40% and increase total coexistence costs with 20% or with 50% on a per-hectare basis. So far, this phenomenon has not been described in the literature (Perry, 2002a; Damgaard and Kjellsson, 2005; Belcher, Nolan, and Phillips, 2005; Qvist, Lundsgaard, and Brandt, 2006; Beckmann, Soregaroli, and Wesseler, 2006).

Coexistence monitoring costs

We finally estimate the costs of testing non-GM oilseed rape for the entire case study area, based on extrapolation of the total production of non-GM oilseed rape in the sample area, simulated by the GIS landscape model. We extrapolate the total production of oilseed rape to the level of the Beauce Blésoise region and estimate the number of silos required to store this production (Table 11). We simulate two scenarios: one with a silo capacity of 5,000 t and another with a silo capacity of 10,000 t. The calculated number of silos required to store the total production of oilseed rape in the case study area ranges from 1 to 10. If we assume a single test per silo of 5,000 t at a unit cost of €350 (Neijens, 2005; ILVO, 2006), the testing costs per hectare of GM oilseed rape[17] range from €0.07/ha to €0.66/ha and are mainly a function of the supply of non-GM relative to GM oilseed rape or the adoption rate (scenarios 1-3 in Table 11).

Incentives for GM coexistence under flexible coexistence management

Total coexistence costs of GM and non-GM oilseed rape cultivation in the Beauce Blésoise region can be calculated as the sum of (i) coexistence management costs (Table 4, Table 5, Table 7, Table 8), (ii) coexistence monitoring costs (Table 11), assuming that collectors transmit all testing costs to GM farmers, and (iii) a fixed insurance fee, assumed to be around €10/ha (Lahellec, 2006). By subtracting the total coexistence costs from the benefits of GM oilseed rape adoption, presented in Table

3, we observe that in all 18 cases of our sample and all modelled scenarios of flexible coexistence regulations, farmers benefit from adopting GM oilseed rape while paying for flexible coexistence management. In Table 12 we report the incentives for GM and IP oilseed rape cultivation under three alternative GM seed price premiums and IP price premiums. In columns 5 and 6 we obtain the net benefits of adopting GM oilseed rape and applying coexistence management under the benchmark scenario for System 1 and System 2. We assume that GM crop farmers pay all costs of coexistence management. Net average benefits range from €34/ha to €57/ha depending on corporate pricing strategies of the GM seed suppliers and do not significantly differ between both systems.

However, some farmers might have incentives for capturing the rents of IP by cultivating IP crops. The per-hectare gain depends on the IP price premium (column 7). If the premium is high, gains from IP are high and non-GM farmers may have an incentive to apply coexistence measures to ensure the purity of their produce. In our benchmark scenario, assuming a price premium of 6%, farmers are, on average, indifferent between adopting GM oilseed rape (GM rent of €45/ha) or supplying IP oilseed rape (IP rent of €42/ha). In the last column of Table 12, we report break-even IP price premium factors for different assumptions on GM seed price premiums. The more expensive GM oilseed rape seed is marketed, the lower the break-even IP price premiums are at which farmers will supply IP oilseed rape. Hence, as the benefits of GM crops are more or less established in the world (Demont, 2006), the trade-off between GM crop adoption and IP will largely depend on the market signals stemming from consumer demand for IP crops.

Sensitivity analysis

In Table 4, Table 5, Table 6, Table 7, Table 8, Table 9, Table 10, Table 11 and Table 12 we assessed the sensitivity of our simulated coexistence management and monitoring costs through 77 alternative scenarios, which are a combination of three systems (one rigid and two flexible), seven main scenarios, three alternative values for the IP price premium and three alternative values for the GM seed price premium. To visualise the sensitivity of our model to the assumed parameter values, in Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15 we present our coexistence management cost simulations in a spider diagram (Pannell, 1997). Figure 10 and Figure 12 demonstrate that per-hectare flexible coexistence management costs are mostly sensitive to values of the width of the buffer zone, followed by the planting density of oilseed rape in the landscape and the price premium of IP oilseed rape. The per-hectare flexible coexistence costs decrease with increasing levels of adoption, in other words they react less than proportionally to the increase of GM area. The figures also visualise how the costs of flexible coexistence regulations are a function of the incentives of coexistence, i.e. the GM rent in System 1, represented by the GM seed price premium (Figure 10) and the IP price premium in System 2 (Figure 12). Total flexible coexistence management costs are primarily affected by the planting density of oilseed rape and secondly by the width of the buffer zone (Figure 13 and Figure 11).

The per-hectare costs of rigid coexistence rules on the other hand are primarily defined by the IP and GM rents. Low IP premiums raise coexistence costs and high ones crowd-out GM production and dissolve coexistence problems. Total costs of rigid coexistence rules are strongly correlated to the planting density of oilseed rape. Remarkable is the fact that distance requirements do not play a major role in both cost estimates. This can be explained by the fact that in our definition, isolation distances are non-proportional coexistence rules which increase the costs of coexistence, even when demand for IP crops is low (low IP price premium). From a socio-economic point of view, the latter is unacceptable.

As predicted in Figure 1, total coexistence management costs follow an inverse U-shaped curve under increasing adoption levels (Figure 11, Figure 13 and Figure 15). Maximum coexistence costs are reached at an adoption level of 50%. At this 'rupture point' (Figure 1), costs of coexistence are the highest from a societal point of view. as mentioned before, this equilibrium of partial adoption is only stable in the long run if demand for IP crops is stable.

Finally, the central point in this paper was to show the burden of coexistence on GM crop farmers in a concrete case study of GM oilseed rape in the Beauce Blésoise region in Central France. Despite the shortcomings of the methodology, the main message we draw from our estimates is that spatial coexistence costs can be reasonable in this context, both at the field, silo and regional level, even under very stringent scenarios of GM crop adoption levels, oilseed rape planting densities, IP price premiums, and GM seed price premiums. Flexible coexistence regulations generate low coexistence costs. Rigid coexistence regulations on the other hand entail higher coexistence costs and are not proportional to the demand for coexistence. Hence, they are not consistent with the objectives of the European Commission's (2003) guidelines on coexistence.

Conclusion

We developed a theoretical framework for analysing the farm level costs of managing and monitoring coexistence of GM and non-GM crops and applied it in a concrete case study. We showed that spatial coexistence of GM and non-GM oilseed rape in the Beauce Blésoise region in Central France would be achievable at an acceptable cost. However, the trade-off between GM adoption and identity preservation will largely depend on the market signals stemming from consumer demand for non-GM crops. Only if consumers have (i) strong and sustainable preferences for non-GM crops and (ii) are willing to pay high price premiums for them, will some farmers have an incentive to supply IP crops. If the opposite holds, there is no coexistence issue *strictu sensu* and coexistence costs will purely reflect the costs of compliance to EU coexistence laws instead of the economic incentives for coexistence. These empirical findings are important for policy makers, as the debate on coexistence has been too often centred on costs instead of incentives. We show that flexible regulations are preferable to rigid ones since they are proportional to the incentives for coexistence and, hence, less counterproductive for European agriculture.

However, in our paper we did not attempt to estimate the transaction costs involved in collecting information, planning and negotiating coexistence measures among farmers. We assumed that farmers would chose measures that minimise transaction costs in the long run. Moreover, it could be that in a first phase no measures are taken in our case study region. Both farmer groups might wait and observe contamination levels at the collectors' stage. Collectors would take samples from each delivery and store them. By shifting monitoring and testing procedures to the collectors' stage, risks of contamination are averaged out and mitigated at the regional level. In case of contamination, farmers are traced back by cooperatives and merchants, but the *ex post* liability costs will need to be fed by strong market signals for IP crops. Otherwise, the system will quickly evolve to a corner solution of high adoption and low coexistence costs.

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Table 1: Market segments in case of coexistence and no system failure

Segment	Supplier	Product	Demand	Price
1	GM crop farmer Non-IP crop farmer	GM crop Non-IP crop	GM neutral consumer	P_g
2	IP crop farmer	IP crop	GM averse consumer	$P_n = P_g\ (1 + m)$
3	Organic farmer	Organic crop	Organic consumer	$P_b = P_g\ (1 + w)$

Table 2: Market segments in case of coexistence and system failure

Segment	Supplier	Product	Demand	Price
1	GM crop farmer Non-IP crop farmer IP crop farmer Organic farmer	GM crop Non-IP crop GM commingled crop GM commingled crop	GM neutral consumer	P_g
2	IP crop farmer	IP crop	GM averse consumer	$P_n = P_g\ (1 + m)$
3	Organic farmer	Organic crop	Organic consumer	$P_b = P_g\ (1 + w)$

Table 3: Survey data on conventional herbicide programs and glyphosate replacement programs

Farm	Pre-sowing	Pre-emergence	Post-emergence	Weight[a] (%)	Herbicide cost (€/ha)	Glyphosate dose (l/ha)	Glyphosate cost (€/ha)	Savings (€/ha)
						Light treatment		
1	tréflan	butisan		3%	62	1.6	12.64	49
2	tréflan	colzor		6%	80.5	1.6	12.64	68
3	tréflan	colzor		8%	80.5	1.6	12.64	68
4	tréflan	colzor		9%	80.5	1.6	12.64	68
4	tréflan	novall		9%	74.5	1.6	12.64	62
5	tréflan	colzor		11%	80.5	1.6	12.64	68
6		colzor		3%	79.5	1.6	12.64	67
7	tréflan	novall		1%	74.5	1.6	12.64	62
						Heavy treatment		
7	tréflan	colzor	fusillade	1%	111.5	3.2	25.28	86
8	tréflan	colzor	kerb	8%	150	3.2	25.28	125
9	tréflan	colzor	kerb	8%	150	3.2	25.28	125
10	tréflan		kerb	.	80	3.2	25.28	55
11	tréflan + dévrinol	colzor	kerb	2%	195.5	3.2	25.28	170
12		colzor	devin + dash	7%	112	3.2	25.28	87
13		colzor	fusillade	5%	113.5	3.2	25.28	88
14		novall	kerb	8%	158	3.2	25.28	133
15		novall	kerb	3%	158	3.2	25.28	133
16		novall	pilot	6%	128	3.2	25.28	103
Weighted average				100%[b]	108.76	2.4	18.83	90

Notes: sample size $n = 18$. Farmers 4 and 7 use two different programs on different fields.

[a] Based on planted oilseed rape areas.

[b] sum of the weights

Table 4: Simulated range of flexible coexistence management costs of GM and non-GM oilseed rape under alternative scenarios in system 1

Scenario	Adoption rate	OSR share	Buffer zone width		Min	Average	Max
1 (benchmark)	50%	13%	10 m	Per ha GM (€/ha)	0.19	0.34	0.49
				Total (€)	40	97	175
2	25%	13%	10 m	Per ha GM (€/ha)	0.54	0.52	0.65
				Total (€)	49	72	130
3	75%	13%	10 m	Per ha GM (€/ha)	0.12	0.17	0.16
				Total (€)	40	72	103
4	50%	6%	10 m	Per ha GM (€/ha)	0.05	0.24	0.50
				Total (€)	3	28	87
5	50%	26%	10 m	Per ha GM (€/ha)	0.77	0.82	0.96
				Total (€)	357	449	575
6	50%	13%	20 m	Per ha GM (€/ha)	0.49	0.88	1.27
				Total (€)	101	250	458
7	50%	26%	20 m	Per ha GM (€/ha)	1.28	1.97	2.30
				Total (€)	645	1,087	1,469

Notes: OSR = oilseed rape

Table 5: Simulated range of flexible coexistence management costs of GM and non-GM oilseed rape under alternative scenarios in system 2

Scenario	Adoption rate	OSR share	Buffer zone width		Min	Average	Max
1 (benchmark)	50%	13%	10 m	Per ha GM (€/ha)	0.19	0.30	0.46
				Total (€)	30	72	131
2	25%	13%	10 m	Per ha GM (€/ha)	0.29	0.39	0.42
				Total (€)	30	54	77
3	75%	13%	10 m	Per ha GM (€/ha)	0.11	0.13	0.19
				Total (€)	36	54	97
4	50%	6%	10 m	Per ha GM (€/ha)	0.03	0.18	0.37
				Total (€)	2	21	65
5	50%	26%	10 m	Per ha GM (€/ha)	0.57	0.63	0.73
				Total (€)	268	336	431
6	50%	13%	20 m	Per ha GM (€/ha)	0.49	0.77	1.20
				Total (€)	76	187	343
7	50%	26%	20 m	Per ha GM (€/ha)	1.10	1.51	1.84
				Total (€)	483	814	1,100

Notes: OSR = oilseed rape

Table 6: Simulated range of static rigid coexistence management costs of GM and non-GM oilseed rape under alternative scenarios

Scenario	Adoption rate	OSR share	Isolation distance		Min	Average	Max
1 (benchmark)	50%	13%	50 m	Per ha GM (€/ha)	2.72	4.55	4.69
				Total (€)	526	1,232	1,958
2	25%	13%	50 m	Per ha GM (€/ha)	4.31	6.31	6.54
				Total (€)	324	844	1,322
3	75%	13%	50 m	Per ha GM (€/ha)	1.06	2.64	3.41
				Total (€)	341	1,050	2,019
4	50%	6%	50 m	Per ha GM (€/ha)	0.00	2.18	2.55
				Total (€)	0	275	488
5	50%	26%	50 m	Per ha GM (€/ha)	1.83	6.98	8.55
				Total (€)	813	3,688	5,205
6	50%	13%	100 m	Per ha GM (€/ha)	3.31	5.15	6.17
				Total (€)	742	1,328	1,794
7	50%	26%	100 m	Per ha GM (€/ha)	9.26	9.11	9.26
				Total (€)	3,917	4,927	5,882

Notes: OSR = oilseed rape

Table 7: Simulated average flexible coexistence management costs (€/ha) of GM and non-GM oilseed rape under alternative scenarios and GM seed price premiums, System 1

Scenario	Adoption rate	OSR share	Buffer zone width	GM seed price premium +50% (€/ha)	Average cost (€/ha)	GM seed price premium -50% (€/ha)
1 (benchmark)	50%	13%	10 m	0.27	0.34	0.41
2	25%	13%	10 m	0.41	0.52	0.63
3	75%	13%	10 m	0.14	0.17	0.21
4	50%	6%	10 m	0.19	0.24	0.29
5	50%	26%	10 m	0.65	0.82	0.98
6	50%	13%	20 m	0.70	0.88	1.06
7	50%	26%	20 m	1.56	1.97	2.37

Notes: OSR = oilseed rape

Table 8: Simulated average flexible coexistence management costs (€/ha) of GM and non-GM oilseed rape under alternative scenarios and IP price premiums, System 2

Scenario	Adoption rate	OSR share	Buffer zone width	IP price premium -50% (€/ha)	Average cost (€/ha)	IP price premium +100% (€/ha)
1 (benchmark)	50%	13%	10 m	0.15	0.30	0.60
2	25%	13%	10 m	0.19	0.39	0.78
3	75%	13%	10 m	0.07	0.13	0.26
4	50%	6%	10 m	0.09	0.18	0.37
5	50%	26%	10 m	0.31	0.63	1.26
6	50%	13%	20 m	0.39	0.77	1.55
7	50%	26%	20 m	0.76	1.51	3.02

Notes: OSR = oilseed rape

Table 9: Simulated average static rigid coexistence management costs (€/ha) of GM and non-GM oilseed rape under alternative scenarios, GM seed price premiums and IP price premiums

Scenario	Adoption rate	OSR share	Distance requirement	GM seed price premium +50% (€/ha)	Average cost (€/ha)	GM seed price premium -50% (€/ha)
1 (benchmark)	50%	13%	50 m	0.82	4.55	8.28
2	25%	13%	50 m	1.14	6.31	11.48
3	75%	13%	50 m	0.48	2.64	4.80
4	50%	6%	50 m	0.39	2.18	3.96
5	50%	26%	50 m	1.26	6.98	12.71
6	50%	13%	100 m	0.93	5.15	9.37
7	50%	26%	100 m	1.64	9.11	16.57
				IP price premium -50% (€/ha)	Average cost (€/ha)	IP price premium +100% (€/ha)[a]
1 (benchmark)	50%	13%	50 m	11.34	4.55	0 (-9.02)
2	25%	13%	50 m	15.72	6.31	0 (-12.51)
3	75%	13%	50 m	6.57	2.64	0 (-5.23)
4	50%	6%	50 m	5.43	2.18	0 (-4.32)
5	50%	26%	50 m	17.40	6.98	0 (-13.84)
6	50%	13%	100 m	12.83	5.15	0 (-10.21)
7	50%	26%	100 m	22.69	9.11	0 (-18.05)

Notes: OSR = oilseed rape

[a] The figures between brackets represent the real simulated values. Assuming that farmers are rational implies that there are no negative coexistence costs as farmers will not consider to plant GM crops as long as the IP rent is higher than the GM rent. In the latter case, the coexistence costs are zero, *stricto sensu*.

Table 10: Illustration of the domino-effect on rigid coexistence management costs

Phase	OSR area	GM OSR area	Ad. rate	Obl. non-GM area	# obl. non-GM fields	Coex. costs (€)	Coex. costs (€/ha)	Seed price +50%	Seed price -50%	IP prem. -50%	IP prem. +100%
Scenario 5 (OSR share of 26%, adoption rate of 50%, 50 m isolation distance)											
Phase 0	1,104	549	50%	298	108	4,181	7.61	1.37	13.85	18.96	-15.09
Phase 1	1,104	251	23%	60	18	836	3.32	0.60	6.05	8.28	-6.59
Phase 2	1,104	192	17%	2	4	34	0.18	0.03	0.32	0.44	-0.35
Phase 3	1,104	190	17%	0	0	0	0.00	0.00	0.00	0.00	0.00
Cumulative	1,104	190	17%	360	130	5,050	11.11	2.00	20.21	27.68	-22.02
Domino-eff.		-65%	-33%	+21%	+20%	+21%	+46%	+46%	+46%	+46%	+46%
Scenario 7 (OSR share of 26%, adoption rate of 50%, 100 m isolation distance)											
Phase 0	1,104	549	50%	349	130	4,903	8.92	1.61	16.24	22.23	-17.69
Phase 1	1,104	200	18%	59	27	828	4.14	0.75	7.54	10.32	-8.21
Phase 2	1,104	141	13%	4	5	56	0.40	0.07	0.72	0.99	-0.79
Phase 3	1,104	137	12%	0	0	0	0.00	0.00	0.00	0.00	0.00
Cumulative	1,104	137	12%	412	162	5,787	13.46	2.43	24.50	33.54	-26.69
Domino-eff.		-75%	-37%	+18%	+25%	+18%	+51%	+51%	+51%	+51%	+51%

Notes: OSR = oilseed rape

Table 11: Simulated coexistence monitoring costs under alternative scenarios

Scenario	Adoption rate	OSR share	Buffer zone width	Total net non-GM OSR production (t)	Non-GM silos (5,000 t)	Non-GM silos (10,000 t)	Total GM OSR area	Maximum monitoring costs (€/ha)[a]
1 (benchm)	50%	13%	10 m	24,801	5	2	6,862	0.25
2	25%	13%	10 m	37,249	7	4	3,972	0.66
3	75%	13%	10 m	12,050	2	1	11,658	0.07
4	50%	6%	10 m	10,335	2	1	3,242	0.22
5	50%	26%	10 m	47,745	10	5	15,190	0.22
6	50%	13%	20 m	24,560	5	2	6,862	0.25
7	50%	26%	20 m	46,923	9	5	15,312	0.21

Notes: [a] Based on a single test per silo of 5,000 t, at a cost of €350 (Neijens, 2005; ILVO, 2006).

Table 12: Simulated incentives for GM and non-GM oilseed rape cultivation under different GM seed price premiums and IP price premium factors and break-even IP price premium factors

GM oilseed rape						IP oilseed rape		
Average conventional herbicide costs (€/ha)	Nominal GM seed price premium (€/ha)	Effective GM seed price premium (€/ha)	Area-weighted[a] average benefits (€/ha)	Net benefits, System 1 (€/ha)	Net benefits, System 2 (€/ha)	IP price premium factor	IP premium benefits (€/ha)	Break-even IP price premium factor
109 (36)	11.5	23	67 (30)	56.72	56.83	3%	21	8%
109 (36)	23	34	56 (30)	45.29	45.33	6%	42	6%
109 (36)	34.5	46	44 (30)	33.86	33.83	12%	84	5%

Notes: Sample size *n* = 18; standard deviations between brackets

[a] The weighing factors are represented in Table 3.

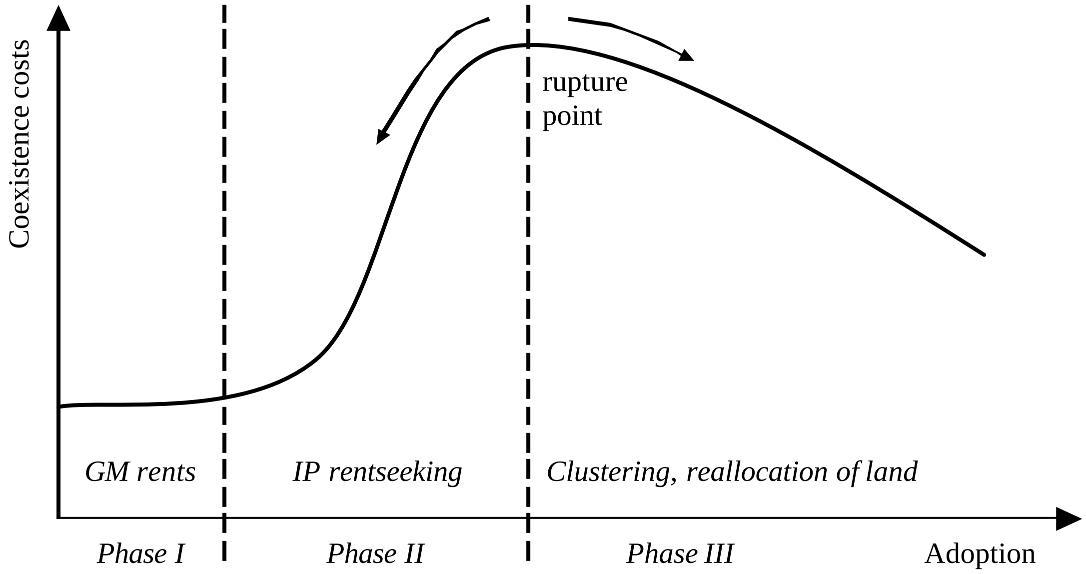


Figure 1: Incentives and possible long-term evolution of coexistence costs

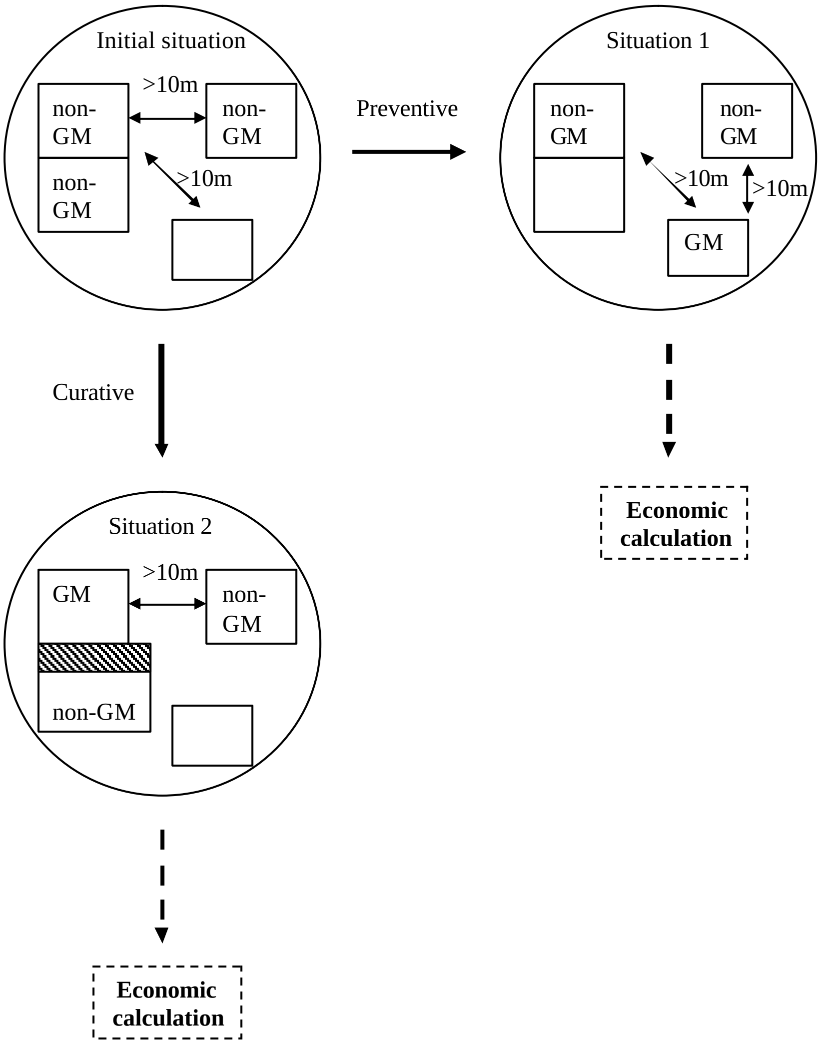


Figure 2: Preventive and curative coexistence management

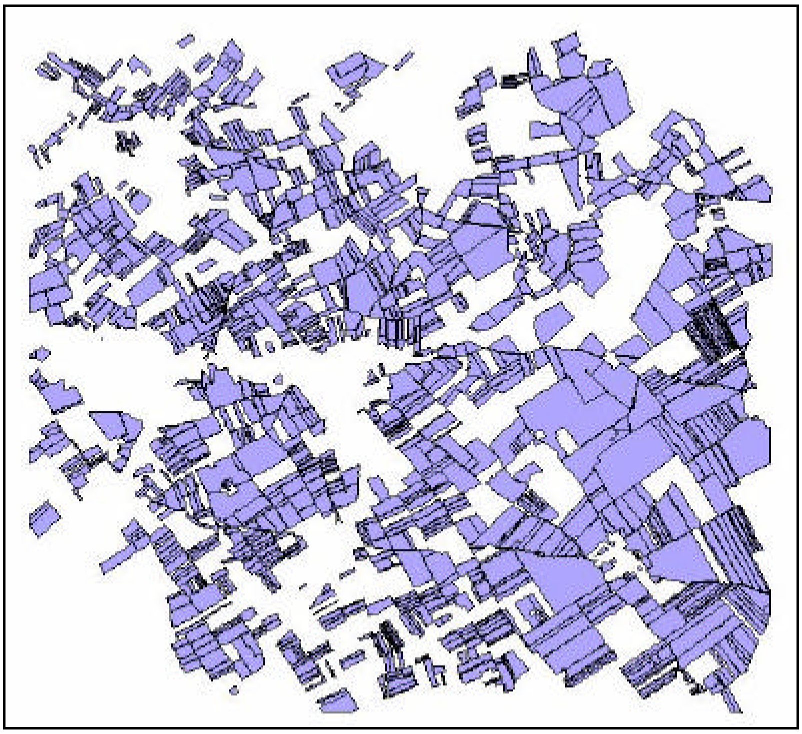


Figure 3: Shapefile with field plots of the sample area (Emeriau and Adamczyk, 2000; Pessel and Lecomte, 2000; Pessel *et al.*, 2001; Deville, 2004)

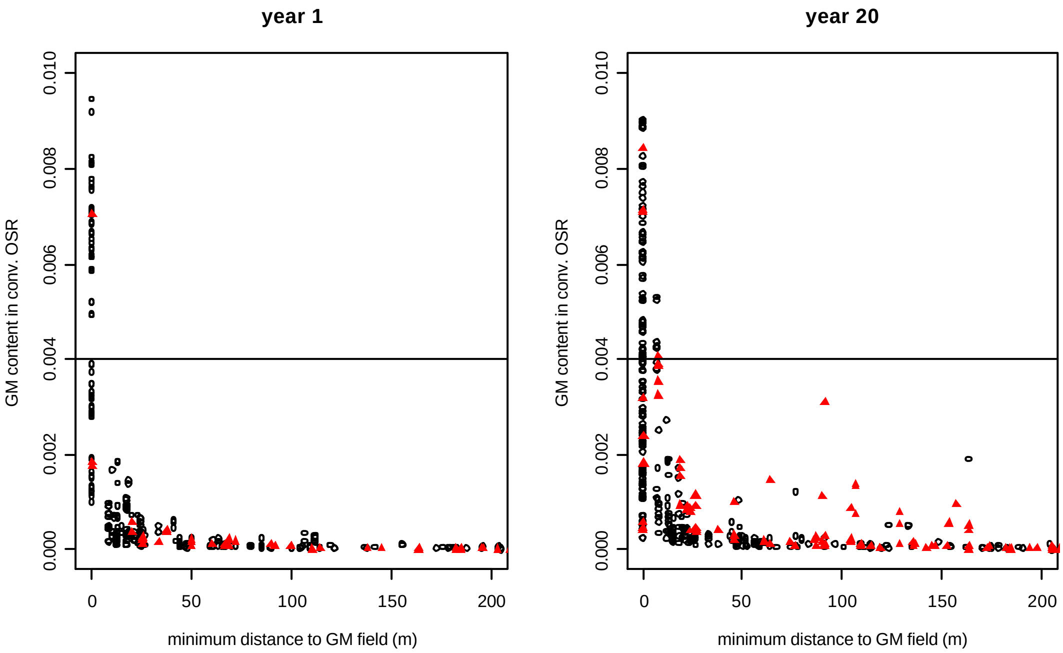
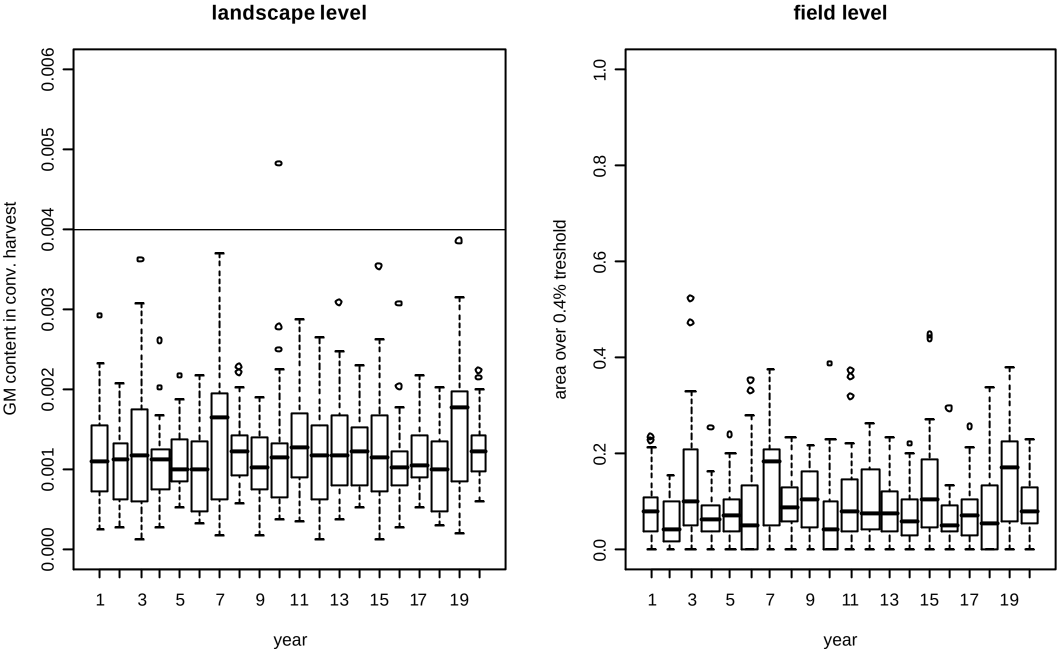
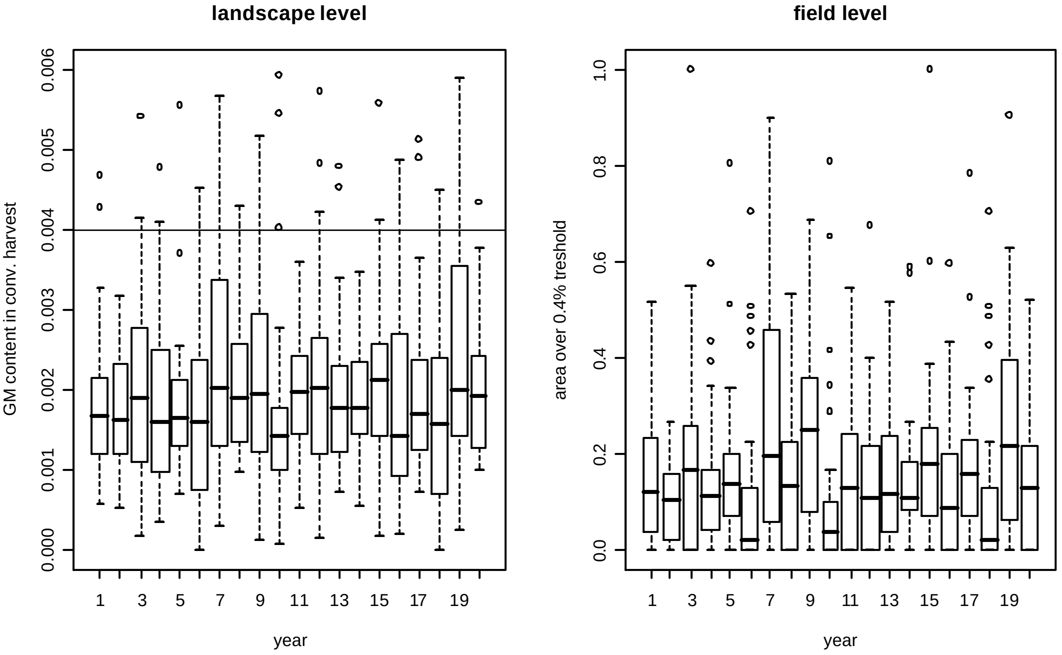


Figure 4: Percentage of GM content in conventional fields in function of distance

GENESYS simulations were carried out in a 243 ha landscape with a priori high risk toward gene flow (20% oilseed rape in agricultural utilizable area; scattered small fields). The following hypotheses were used: pure seeds, isogenic varieties, conventional or GM oilseed rape are not cultivated alternatively on the same field in the rotation. The 0.9% threshold corresponds to 0.4% on the chart due to model inaccuracy. The red points are fields under 0.5 ha.



50% GM oilseed rape in the area (30 simulations/year)



75% GM oilseed rape in the area (30 simulations/year)

Figure 5: Transgenic DNA detected in silos and area above the threshold

GENESYS simulations were carried out in a 243 ha landscape with a priori high risk toward gene flow (20% oilseed rape in agricultural useable area; scattered small fields). The following hypotheses were used: pure seeds, isogenic varieties, conventional or GM oilseed rape are not cultivated alternatively on the same field in the rotation. The 0.9% threshold corresponds to 0.4% on the chart due to model inaccuracy.

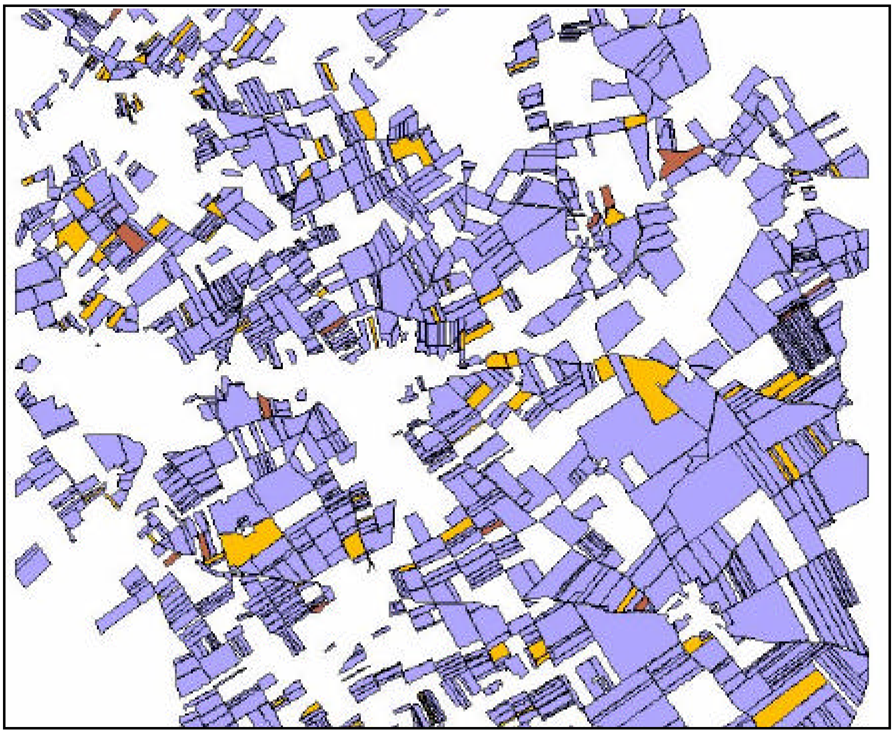


Figure 6: Shapefile with simulated GM (yellow) and non-GM (brown) oilseed rape fields (scenario with 75% adoption)

Figure 7: Shapefile with 10 m buffer zones on the non-GM fields (brown)

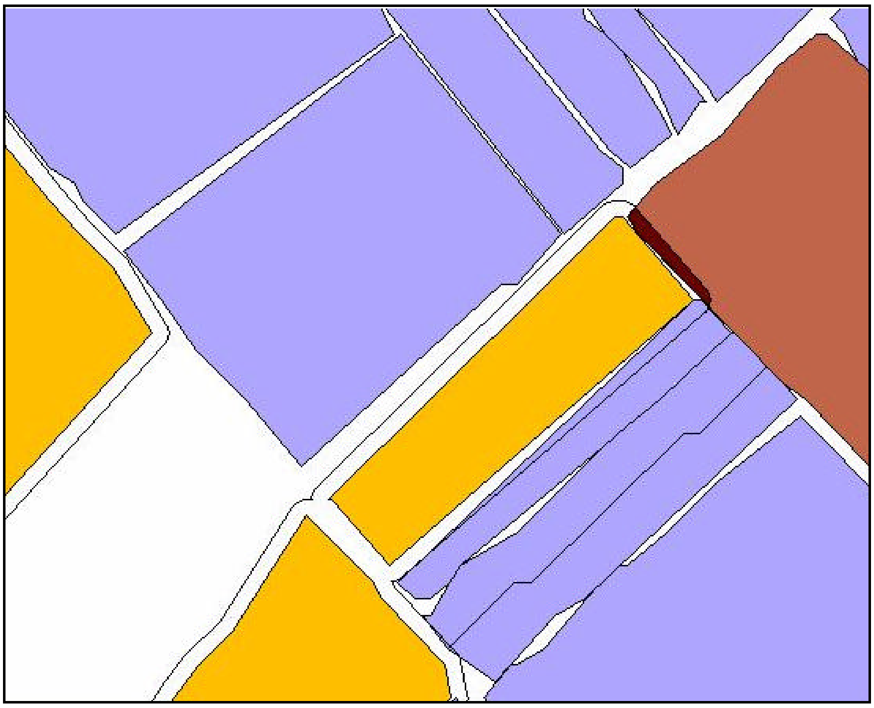


Figure 8: Shapefile with 10 m buffer zones on the non-GM field, zoomed in on the buffer zone

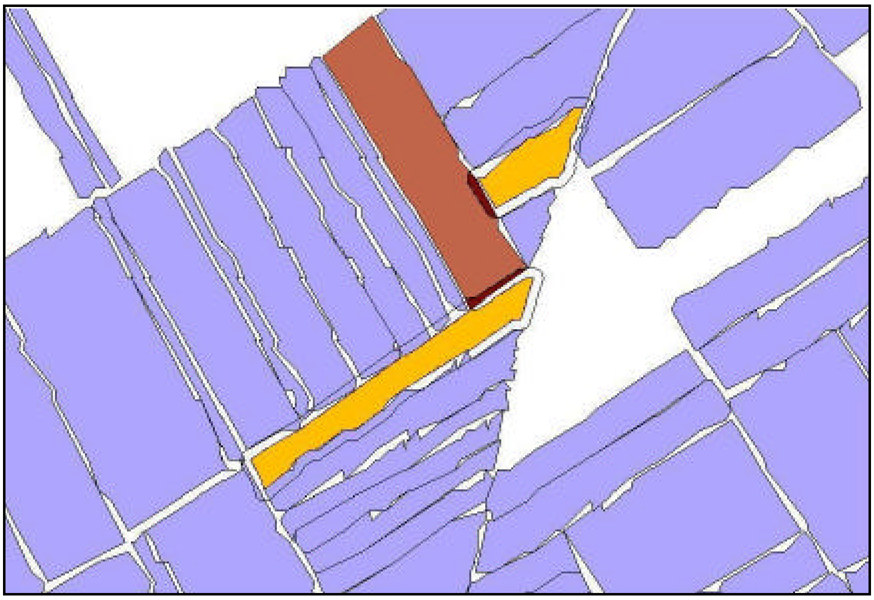


Figure 9: Non-GM field (brown) with two buffer zones

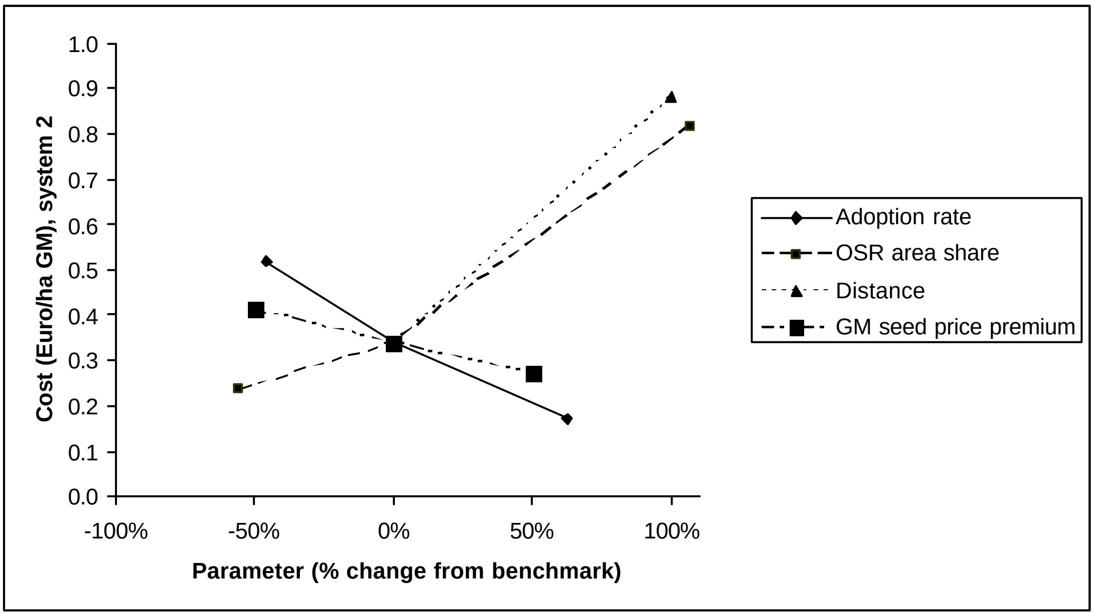


Figure 10: Sensitivity of per-hectare flexible coexistence management costs (€/ha) to alternative parameter values, System 1

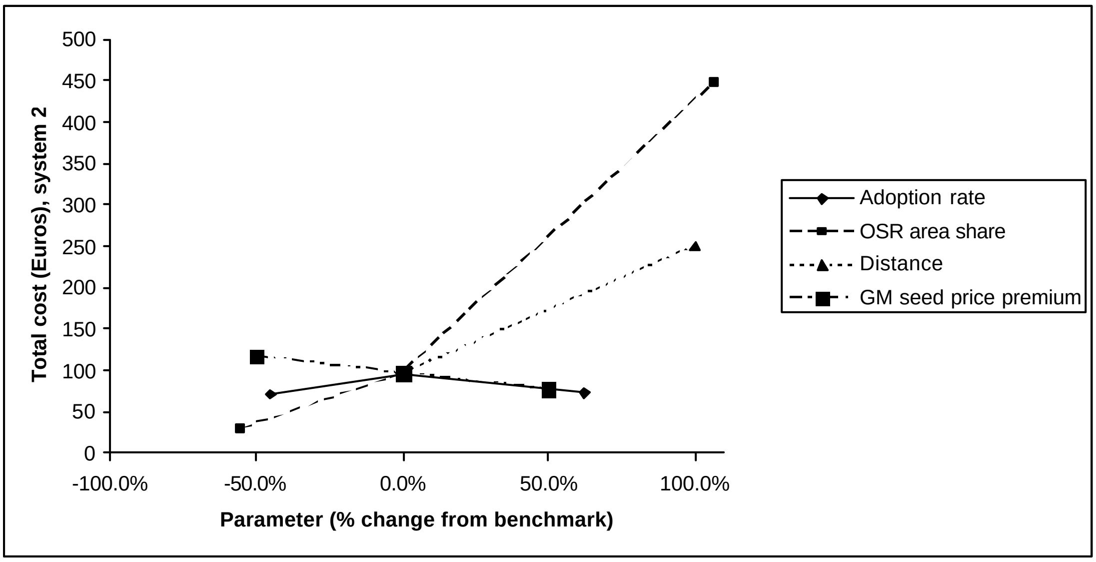


Figure 11: Sensitivity of total flexible coexistence management costs (€) to alternative parameter values, System 1

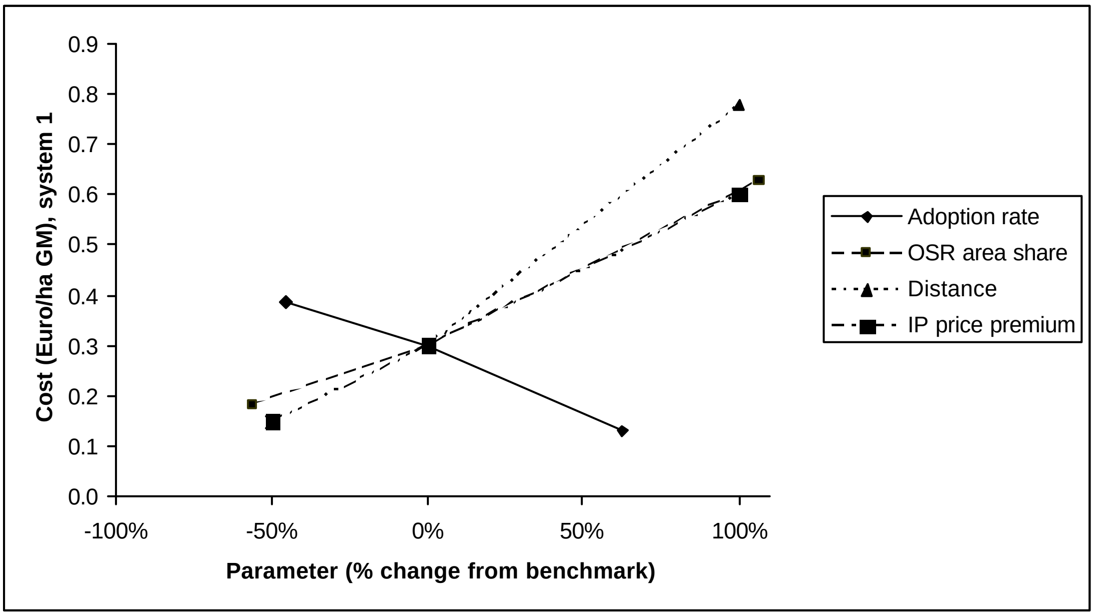


Figure 12: Sensitivity of per-hectare flexible coexistence management costs (€/ha) to alternative parameter values, System 2

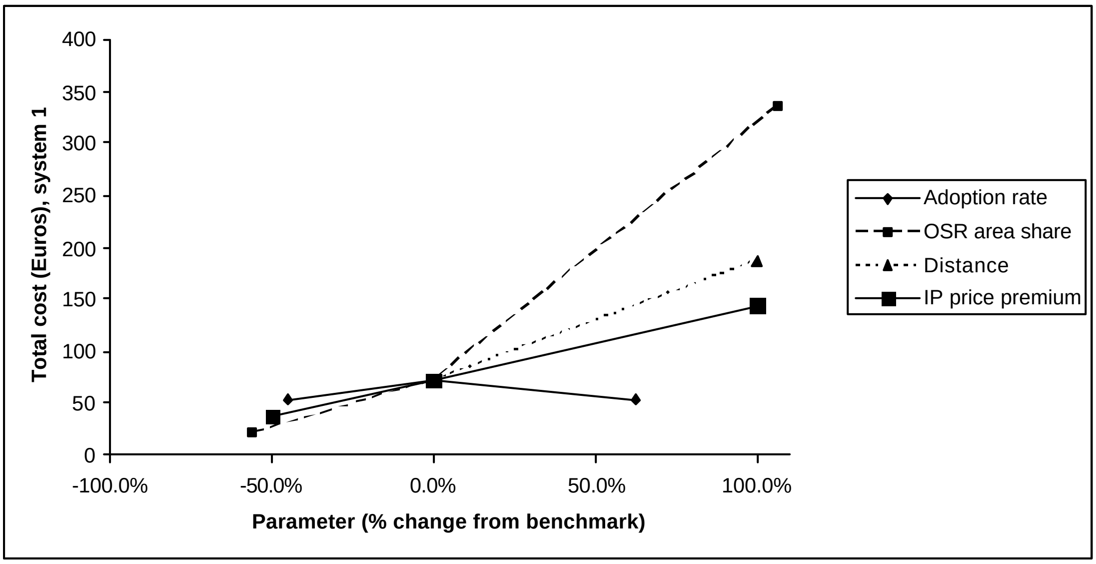


Figure 13: Sensitivity of total flexible coexistence management costs (€) to alternative parameter values, System 2

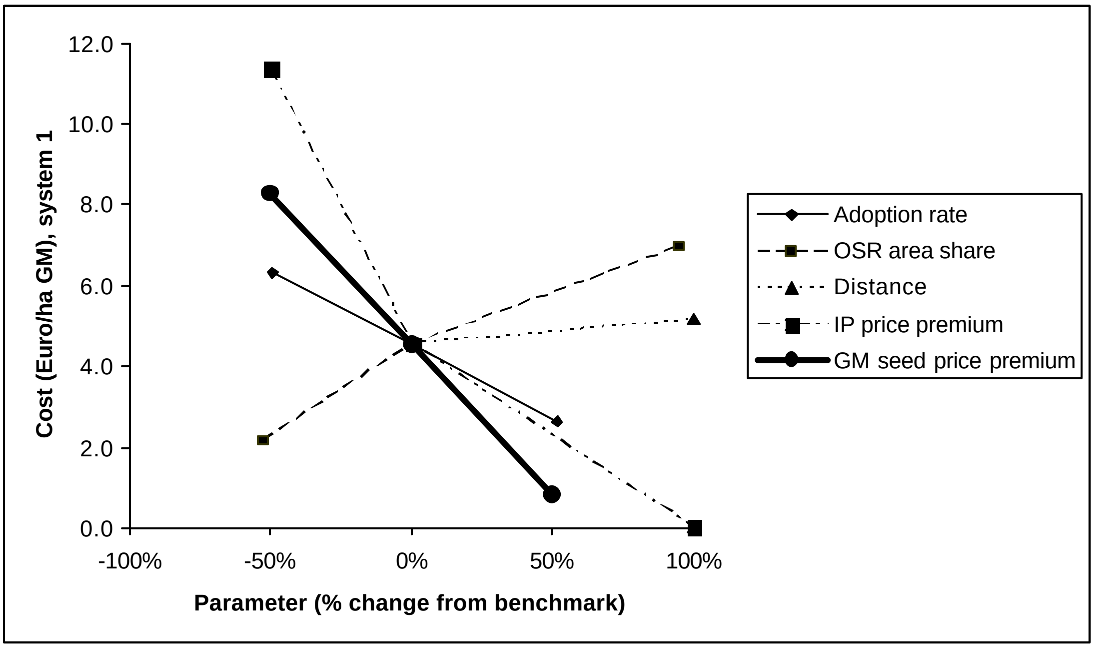


Figure 14: Sensitivity of per-hectare rigid coexistence management costs (€/ha) to alternative parameter values

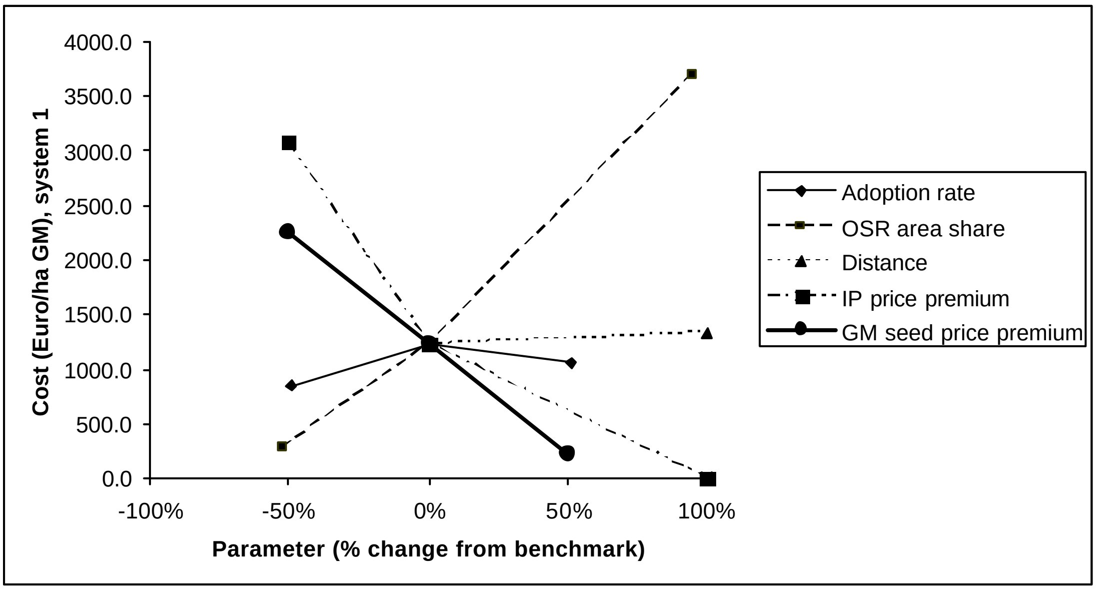


Figure 15: Sensitivity of total rigid coexistence management costs (€) to alternative parameter values

Annex: ArcView® simulations

In a first stage, we add two columns, *'GM'* and *'OSR'* to the attributes table of the shapefile of the area. In the '*OSR*' column, we use the function <*MakeRandom*>, to randomly allocate oilseed rape to the fields. In the *'GM'* column, we repeat this step to allocate GM or non-GM traits to the fields (Figure 6).

In a second step, we use the query builder function to make three new shapefiles. We create a shapefile with oilseed rape fields, a second with GM oilseed rape fields and a third with non-GM oilseed rape fields. From the statistics window of these shapefiles, we save the total simulated oilseed rape and GM oilseed rape area in a spreadsheet for all iterations. In a third step we use the function <*create buffers*> to create a buffer zone outside the GM fields. These zones are saved in a separate shapefile '*buffers*' (Figure 7). Next, we use the <*geoprocessing*> extension to intersect the shapefile containing non-GM fields with the shapefile '*buffers*' as overlay. In this way, we obtain a new shapefile with areas on the non-GM fields, within a distance of less than the required distance from a GM field. These areas are the buffer zones, i.e. areas of non-GM oilseed rape that will have to be harvested and marketed as GM (Figure 8).

In the attributes table of the shapefile with the buffer zones we calculate the area of these zones with the command <*[Shape].ReturnArea*>. From the statistics window we save the total area and number of buffer zones that emerge. In some cases more than one buffer zone emerges on the same field (Figure 9). In a summary table, we filter out these doubles, count the fields that contain a buffer zone and aggregate the area of those fields.

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[1] In our definition, identity preserved (IP) crops are intended to be GM-free, but may contain adventitious presence of GM genes. If the content of the latter is above the threshold, they lose their IP-label and have to be labeled and commercialized as ‘contains GM’.

[2] The European Commission has defined a threshold of 0.9% representing the maximum GM content beyond which the product has to be labeled as ‘contains GMOs’.

[3] Within the SIGMEA project and in this paper, private costs that may result from coexistence issues within the farm (on-farm coexistence) are not examined. Moreover, the cost calculations are restricted to crop production only; seed production is not addressed.

[4] Since organic farming standards exclude planting GM crops, organic products are per definition GM-free.

[5] Farmers are heterogeneous with regard to insect and weed infestations.

[6] Non-GM crop farmers who do not participate in any IP program are unable to reach the second consumer segment in case of GM crop contamination of their produce. In the long run, this category of ‘slow movers’ is expected to disappear because rational economic actors would eventually move to one of the other alternatives.

[7] In reality, some degree of flexibility is possible, e.g. agreements between GM and non-GM farmers on field exchange or coordination of crop allocation.

[8] Whether smaller lots get a price discount depends on the collector.

[9] In the short run, these transaction costs could be important. In the long-run, farmers will make bilateral contracts that minimize transaction costs (*cfr. infra*).

[10] However, by rotating crops, the probability of GM volunteers contaminating the next crop can be reduced (Burris, 2000).

[11] The separate sale of contaminated non-GM crops to the GM outlet can be checked through an invoice after the transaction has taken place. No overreporting of yields is possible. However, the non-GM farmer has incentives to unnecessarily increase the area of the margin, beyond the technically required area. The difference between the IP price and GM price can be (i) entirely or (ii) partly bargained as the compensation premium, as the price premium is easily confounded with the price discount due to the small size of the GM lot.

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[12] Randomly assigning GM and non-GM oilseed rape fields also generates on-farm coexistence situations. Therefore, our calculated coexistence costs must be interpreted as upper limits of the expected coexistence costs in the sample area.

[13] In spite of the official threshold of 0.9% required by European labelling regulation, a more conservative target of 0.4% was chosen to take into account simulation error.

[14] Manual calculation of a single iteration takes 4-5 minutes. Increasing the number of iterations per scenario would be feasible if the simulation process could be automated. However, after 10 iterations, the variance of the outcomes is satisfactory low.

[15] Non-adopters may continue to use farm-saved seed, but in order to maintain seed purity they have to collect their seed at a minimum distance of 200 m from a GM field, i.e. the current contractually defined isolation distance for seed production. Since farmers in the region are used to purchase certified seed at regular intervals (Sausse, 2005), in this paper we assume that the introduction of GM oilseed rape would not change the behaviour of non-adopters.

[16] The combination of transgenic seed combined with a post-emergence herbicide, offers farmers additional non-pecuniary benefits such as broad-spectrum weed control, flexibility in the timing of applications and reduced need for complex compositions of spray solutions. These benefits are not incorporated in our analysis.

[17] We express the coexistence monitoring costs per unit of area of GM crop adoption assuming that theses costs will be transmitted to GM crop farmers.

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