Are EU spatial *ex ante* coexistence regulations proportional?

Demont M. [1, 2], Daems W. [2], Dillen, K. [2], Mathijs, E. [2], Sausse, C. [3] and Tollens E. [2]

[1] Africa Rice Center (WARDA), Saint-Louis, Senegal
[2] Centre for Agricultural and Food Economics, Katholieke Universiteit Leuven (K.U.Leuven), Leuven, Belgium
[3] Centre Technique Interprofessionel des Oléagineux Métropolitains (CETIOM), Thiverval Grignon, France

Abstract— **The EU is currently struggling to implement coherent coexistence regulations on genetically modified (GM) and non-GM crops in all member states. While it stresses that any approach needs to be "proportionate to the aim of achieving coexistence", very few studies have actually attempted to assess whether the proposed spatial ex ante coexistence regulations (SEACERs) satisfy this proportionality condition. In this article, we define proportionality as a functional relationship which is weakly increasing in the incentives for coexistence. We propose a spatial framework based on an existing landscape and introduce the new concept of shadow factor as a measure for the opportunity costs induced by SEACERs. This enables comparing the proportionality of (i) rigid SEACERs which are based on large isolation distances imposed on GM farmers versus (ii) flexible SEACERs based on pollen barrier agreements between neighboring farmers. Our theoretical and empirical findings argue for flexibility as rigid SEACERs violate the proportionality condition and, hence, are not consistent with the objectives of the EU.**

Keywords— **policy analysis, GIS, shadow factor.**

I. INTRODUCTION

Europe is currently struggling to implement coherent coexistence regulations on genetically modified (GM) and non-GM crops in all EU member states. According to the European Commission's (EC) guidelines, "Coexistence refers to the ability of farmers to make a practical choice between conventional, organic and GM 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 [...]" [1]. 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 [2].

In this article, our attention is drawn to the first group of *ex ante* regulations, and more specifically to spatial *ex ante* coexistence regulations (SEACERs). Our concern is that some of the proposed SEACERs may impose a severe burden on GM crop production and may not be proportional to farmers' economic incentives for coexistence. The European Commission has clearly emphasized the *proportionality condition* of SEACERs in a recent Communication to the Council and the European Parliament: "[…] coexistence measures should not go beyond what is necessary in order to ensure that adventitious traces of GMOs stay below the labelling threshold […] in order to avoid any unnecessary burden for the operators concerned. While some member states have taken this advice into account, others have decided to propose or adopt measures that aim to reduce adventitious presence of GMOs below this level. In some cases, proposed measures, such as isolation distances between GM and non-GM fields, appear to entail greater efforts for GM crop growers than necessary, which raises questions about the proportionality of certain measures. […] Given that the majority of member states have not yet proposed technical field measures for coexistence, and that little practical experience is available, a full evaluation of such measures has not yet been possible. While the Commission recognizes the legitimate right to regulate the cultivation of GM crops in order to achieve coexistence, it stresses that any approach needs to be proportionate to the aim of achieving coexistence" [2, p. 6].

In this paper, we analyze whether the current proposed SEACERs satisfy the proportionality condition. This question is extremely important and timely for EU policy makers who are currently facing the challenge of implementing coherent coexistence regulations tailored to a heterogeneous landscape of European agriculture. Therefore, in spite of the vague definition provided by the EC, we first need to agree upon a workable definition for *proportionality* and *to what* it relates. The fact that GM products are perceived by some consumers as 'weakly inferior' in quality, relative to their non-GM counterparts, implies that the mere introduction of GM crops affects the costs of non-GM food because of costly identity preservation [3] and coexistence measures [4], with potential negative welfare effects for society [5]. Why would society want to invest in costly measures to allow alternative production systems to coexist? The only possible answer is that markets provide incentives for providing both identity preserved (IP) non-GM crops and weakly inferior GM crops in response to a differentiated demand for both alternatives [6]. The incentives for coexistence may vary among regions, farmers, and even fields, and can be split up in (i) capturing *GM rents* through the cultivation of cost-reducing GM technologies, and (ii) capturing *IP rents* by ensuring the purity and preserving the identity of higher valued non-GM crops to serve the market for IP non-GM crops. In the remainder of this article, we simply call the latter *IP crops*, implicitly assuming that they are non-GM. Our three basic assumptions further in the article exclude the possibility of non-IP non-GM crops.

Demont and Devos [7] argue that "Coexistence is an issue only if both economic incentives 'coexist' in farming communities; if one incentive is lacking, strictly speaking there is no coexistence problem" (p. 354). Hence, the economic incentives for coexistence represent the benefits from belonging to one of two alternative classes of farmers, which we label 'GM' versus 'IP'. The farm level costs of coexistence represent all the costs (opportunity, transaction and operational) of the measures that need to be taken to ensure that the purity of farmers' IP crops is preserved throughout the production process. In this paper, we focus on the field level opportunity costs for complying with SEACERs. We argue that, in order to achieve coexistence, farmers will have to sacrifice part of their rents (incentives) derived from coexistence. We then assess whether the resulting opportunity costs of coexistence are proportional to the "the aim of achieving coexistence" [2, p. 6], where we define proportionality very broadly as a *functional relationship which is weakly increasing in both incentives for coexistence*.

In scientific and regulatory communities spatial coexistence of GM and non-GM crops is often regarded as a technical challenge and the debate has been centered mainly on (i) preventive coexistence measures needed to keep the adventitious presence of GM material in non-GM products below established tolerance thresholds [8-16], (ii) the feasibility of and costs of implementing such measures [13,17-21], (iii) segregation costs and potential economic losses resulting from adventitiously co-mingled products [5,22,23], (iv) who should bear the costs of coexistence measures [24,25], and on (v) who should redress the incurred economic losses due to adventitious mixing [2].

Although these aspects are of fundamental importance when discussing coexistence strategies, there is still limited information on the economic impact of alternative coexistence regulations. Munro [26] develops a simple model to assess the spatial impact of GM crops and shows that coexistence may be impossible without strong regulation on planting patterns. However, as his model is built on a simplified rectangular-shaped spatial economy, it does not take into account the geographical influence of landscape, land fragmentation, and field configuration on the impact of GM crops. His model predicts that the feasibility of SEACERs depends in part on the size of the barrier which must be maintained in order to avoid cross-fertilization between GM and non-GM crops. However, the question whether the SEACERs currently proposed by the EC satisfy the proportionality condition has received limited attention in the literature [7,27]. SEACERs interact with the spatial configuration of fields in a landscape, and therefore any modeling attempt to forecast the impact of alternative SEACERs needs to incorporate a market as well as a spatial component. The latter components are interlinked; the market outcomes depend on the spatial configuration of the landscape, which on its turn determines the market.

The problem of such dual models is that, in order to be informative, they require an extensive amount of spatial (GIS) and market data (farmer and market surveys) that is generally not available or extremely expensive to collect on a large scale. Moreover, the incentives for coexistence, and especially the IP rents, are largely unknown in *ex ante* and so far, no study has ever attempted to predict the evolution of the differentiated market of GM and IP crops in the EU. Therefore, in this article we focus on the spatial impact of SEACERs under exogenous market conditions to assess whether they satisfy the proportionality condition. In contrast with Munro [26], we will use a real geographical dataset to assess the influence of the spatial configuration of a landscape on the proportionality of alternative SEACERs. More specifically, we will use the area affected by SEACERs as a measure for the opportunity costs engendered by the coexistence of a theoretical GM crop with its non-GM counterpart. The article is organized as follows. After this introduction, in Section 2 we discuss the economics of SEACERs. In Section 3, we propose a spatial modeling framework, in Section 4 we present some results generated by the framework under a set of alternative scenarios, and Section 5 finally concludes.

II. ECONOMICS OF SEACERS

Most EU member states' SEACERs include (i) minimal isolation distance requirements, implemented by 10 member states, in combination with or as an alternative to (ii) pollen barriers planted with non-GM crops of the same species between GM and non-GM fields, implemented by six member states [2]. *Isolation distances* are rules governing the minimum distance between GM and non-GM crop fields of the same species. If a farmer's field is too close to a neighboring farmer's non-GM field of a particular crop, the field has to be planted with other crops or the same crop species but with non-GM varieties. In this paper, we label such fields as *GM-free*. Hence, the difference between a non-GM and a GM-free field is that the latter is exempt from GM variety planting of a certain species, while the former is not. *Pollen barriers*, on the other hand, are coexistence measures that rely on field margins that are planted with non-GM crops of the same species and of which the harvest will need to be labeled as 'GM'. Pollen barriers serve as cross-fertilization zones between GM and non-GM varieties of the same crop and can be planted on donor or recipient fields; the specifics of the barriers can be negotiated between neighboring farmers [7]. Imposing measures on GM crop farmers only, i.e. complying with the *newcomer principle* [1], introduces rigidity in SEACERs, whereas leaving measures open for negotiation between farmers introduces flexibility. Hence, in our definition, pollen barriers are better-suited measures than isolation distances for building flexibility into coexistence regulations.

In this article, we polarize rigid versus flexible SEACERs to draw policy recommendations. Based on evidence from the literature, we compare large isolation distances assuming *rigidity*, i.e. the regulations are imposed on GM farmers regardless of local agreements between neighboring farmers, versus narrow pollen barriers assuming *flexibility*, i.e. regulations allow pollen barriers to be negotiated and planted by GM as well as non-GM farmers. More specifically, we assume that with regards to the *civilian responsibility* of undertaking the coexistence measures, the newcomer principle is strictly enforced by rigid SEACERs, while it is recommended but not enforced by flexible SEACERs (similar to the advisory speed limits in German traffic law). However, we assume that the newcomer principle applies to both SEACERs with regards to the *financial responsibility* of undertaking the coexistence measures and, hence, that GM farmers reimburse non-GM farmers if the latter undertake measures in order to ensure coexistence. Our framework in the remainder of the paper is built on three basic assumptions: (i) *compliance*, i.e. farmers comply with the proposed SEACERs, (ii) *effectiveness*, i.e. the proposed SEACERs are effective in minimizing cross-fertilization and keeping the GM content of non-GM crops below the EU threshold of 0.9%, and (iii) the *newcomer principle* [1] holds, i.e. GM farmers will bear the costs of coexistence measures and compensate non-GM farmers for incurred losses of crop purity.

It is interesting to note that these contrasting definitions and basic assumptions imply that GM-free zones can be interpreted as external halo-effects (regulatory protection) of non-GM crops as a consequence of compliance with rigid SEACERs (GM farmers have to avoid proximity to non-GM fields), while pollen barriers can be interpreted as external halo-effects (cross-fertilization) of GM crops under flexible SEACERs (both farmers coordinate in order to ensure coexistence). Alternatively and analogously to Munro's [26, p. 3] formulation, we could interpret a GM-free field as the *shadow* of a non-GM field in the context of rigid SEACERs and a pollen barrier as the *shadow* of a GM field in the context of flexible SEACERs. In the remainder of this article, we will use the term *shadow area* to designate the area of GM-free fields (in the context of rigid SEACERs) or planted with pollen barriers (in the context of flexible SEACERs). As shadow areas induce opportunity costs which are assumed to be financially borne by GM farmers and amortized over their GM area, we introduce a new concept and define the *shadow factor*, α_s, as the ratio of the shadow area, a_s, to the GM area, a_g, i.e. $\alpha_s = a_s / a_g$. The shadow factor provides an interface between spatial and market models and is a measure for the average opportunity costs borne by GM farmers per hectare of GM planting for achieving coexistence under rigid and flexible SEACERs and given market conditions. The shadow factor is a monotonically increasing function of field density. Increased field densities both raise the occurrence of spatial interactions in the landscape and expand the shadow area a_s. However, at the same time, they accelerate the rate of GM to GM-free conversion and reduce the GM area a_g. The shadow factor can be used to assess the impact of alternative SEACERs in different landscapes under given market conditions. It summarizes the multiplicator effect of a landscape on market opportunity costs as a result of the interaction between SEACERs and the spatial configuration of the landscape. SEACERs which progressively drive GM crop production out of the landscape, for example, will yield large shadow factors as opportunity costs need to be amortized over a smaller GM area.

In the case of rigid SEACERs, such as isolation distances imposed on GM crop farmers, we assume that a rational farmer who foregoes the GM rent on a GM-free field will try to compensate this loss by attempting to capture the IP rent. The resulting market opportunity costs per unit of shadow area, are $c_{id} = g - p$, and hence are a trade-off between the GM rent g and the IP rent p, both expressed per unit of shadow area. The GM rent is calculated as the per-hectare cost reduction generated by the GM crop relative to the conventional one. The IP rent is calculated as the product of the yield of the non-GM crop, the price of the GM crop, and the price premium factor of IP crops relative to GM crops [27]. In our definition, IP crops are intended to be free of GM material, but may contain adventitious presence of GM genes. If the content of the latter is above the official EU threshold of 0.9%, they lose their IP label and have to be labelled and commercialized as 'contains GM'. The average coexistence costs, C_{id}, borne by GM farmers per unit of GM area induced by complying with an isolation distance can be split up in a variable part, proportional to the shadow area, and a fixed part:

$$C_{id} = \frac{a_s}{a_g}(g-p) + t_{id} = \alpha_s(g-p) + t_{id}, \tag{1}$$

where a_s represents the total shadow area, i.e. the total GM-free area of a particular crop, a_g the total area of GM plantings, t_{id} the transaction and operational costs, and α_s the shadow factor induced by rigid SEACERs.

In the case of flexible SEACERs, we consider four practical solutions, depending on whether the pollen barrier is cultivated on the GM field (System 1) or on the non-GM field (System 2) and whether it is planted, cultivated and/or harvested by the owner (System a) or the neighbor (System b) of the field. While the placement of the pollen barrier (System 1 versus System 2) determines the magnitude of the opportunity costs, the transaction and operational costs may vary among the four systems and also among regions, farmers and fields. In System 1a, the GM farmer plants and cultivates a pollen barrier with non-GM crops on his GM field next to his neighbor's non-GM field. However, in the context of herbicide tolerant (HT) 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 pollen barrier on the GM farmer's field. The latter reimburses part of the former's cultivation costs (sowing and herbicide treatments), harvests his entire field, including the pollen barrier, and sells his crops as GM. In either version of System 1, the GM farmer foregoes the GM rent *g* on his pollen barrier. In System 2a, the non-GM farmer separately harvests his adjacent margins, which serve as pollen barriers, 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 in a single lot with the rest of his GM crops. In either version of System 2, the GM farmer has to compensate the neighboring non-GM farmer for the IP rent *p* foregone. 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 [e.g., see 28]. In System 2b, the GM farmer has incentives for underreporting yields of non-GM crops on his neighbor'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 barrier crops, he has incentives to lower the quality of his services. System a avoids these transaction costs, but introduces loss of scale economies. In System 1a, for example, 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-labeled outlets. The separate sale of contaminated non-GM crops to the GM outlet could be checked through an invoice after the transaction has taken place; no over-reporting of yields would be possible. However, the non-GM farmer has incentives to exaggerate the pollen barrier area. Moreover, price differences between IP and GM crops as compensation premiums are easily confounded with price discounts for small GM crop lots. Finally, additional transaction costs may arise in collecting information, planning and negotiating coexistence measures among farmers.

We can reasonably assume that farmers will choose the system that minimizes total (opportunity, transaction and operational) costs in the long run. If, for example, System 1a turns out to be the most widely applied system despite GM rents superior to IP rents, this would suggest that transaction and operational costs are minimized under this system, i.e. the additional management costs owing to scale inefficiency are inferior to the transaction costs from farmer coordination. Therefore, the average coexistence costs, C_{pb}, borne by GM farmers per hectare of GM planting as a result of implementing a pollen barrier can be algebraically presented as follows:

$$C_{\mathrm{pb}} = \min\left(\alpha_{\mathrm{s}} g + t_{1\mathrm{a}}, \alpha_{\mathrm{s}} g + t_{1\mathrm{b}}, \alpha_{\mathrm{s}} p + t_{2\mathrm{a}}, \alpha_{\mathrm{s}} p + t_{2\mathrm{b}}\right), \qquad (2)$$

where α_{s} is the shadow factor of pollen barriers, a_{s} the total shadow area, i.e. the total area under pollen barriers, a_{g} the total area of GM plantings, and $t_{1\mathrm{a}}$, $t_{1\mathrm{b}}$, $t_{2\mathrm{a}}$ and $t_{2\mathrm{b}}$ the per-hectare transaction and operational costs for implementing System 1a, 1b, 2a and 2b, respectively. Note that C_{pb} is also composed of a fixed and a variable part, the latter proportional to the pollen barrier area.

Equation 2 clearly illustrates that, according to our definition, the costs of flexible SEACERs are proportional to the incentives for coexistence as the function is weakly increasing in both incentives (GM and IP rent). If IP rents are negligible compared to GM rents, GM farmers will have incentives to propose System 2 to their neighboring farmers. They might even persuade the latter to convert their fields to GM. If IP rents rise, coexistence costs will rise proportionally until farmers switch to System 1 as System 2 becomes more expensive. Further rising IP rents will not affect coexistence costs under System 1 and, therefore, the relationship is weakly and not strictly increasing in both incentives. However, GM farmers may be attracted by high IP rents and abandon GM crop production. This would raise the shadow factor, but the increase would be proportional to the high IP incentive. However, in the case of rigid SEACERs, Equation 1 shows that the costs are not weakly increasing in both incentives, but only in their trade-off. Application of the newcomer principle implies that the costs of rigid SEACERs are strictly increasing in the GM rent, but strictly decreasing in the IP rent. If IP rents decline, the costs of rigid SEACERs increase instead of decrease in the case of flexible SEACERs. While equations 1 and 2 respond theoretically to the central question in this article, in the next sections we will analyze how the spatial configuration of the landscape may have an additional effect on the proportionality of alternative SEACERs.

Fig. 1 GIS shapefile of the sample square in Selommes (Loir-et-Cher). The figure represents a random draw of the benchmark scenario (crop planting density of 13% and GM adoption rate of 50%). Arable fields are dotted, non-GM crop fields grey and GM crop fields black.

III. SPATIAL MODELING FRAMEWORK

In this section, we simulate the adoption of a theoretical GM crop in a real landscape in Central France to compare the shadow factors of rigid versus flexible SEACERs. We select a sample square of about 100 km² centered around a grain silo (Selommes, Beauce region, Loir-et-Cher), and conduct simulations through the software ArcView® on a GIS dataset of this sample square [29]. The Beauce region is famous for its cereals. This small region is almost exclusively devoted to farming; 75% of the land is occupied by agriculture and 80% of the farms are classified as producing ‘cereals and protein oil crops’, which is an exceptional proportion (44% in the Loir-et-Cher region, 46% for the Centre region and 15% for France as a whole). 63% of the arable land is planted with cereals and 13% with oilseed rape, the latter however by 67% of the farmers [30]. We start from a GIS shapefile where the arable fields are represented as polygons (Figure 1). The sample square is less densely farmed (42%) than the regional average (75%). The modeled landscape counts 1,508 arable fields with an average field size of 2.8 ha and covering an area of 4,233 ha. This implies that the average field width is 168 m and the average distance between the fields amounts to 90 m.

We base our distance requirements for the SEACERs on the available literature evidence on two important European crops, i.e. oilseed rape and maize, where it is suggested that the extent of cross-fertilization is reduced much more effectively by a pollen barrier than an isolation perimeter of bare ground of the same width [31]. In their study on pollen-mediated gene flow from HT oilseed rape, Damgaard and Kjellsson [11] observe that isolation distances of 50 m between GM and non-GM OSR fields should be sufficient to achieve a cross-fertilization rate of 0.3%. In contrast, Hüsken and Dietz-Pfeilstetter [14] review 16 studies and conclude that 10 m pollen barriers achieve a similar rate of 0.5%. Both rates largely fulfill the 0.9% threshold condition set by the EU labeling legislation and suggest that pollen barriers are more spatially efficient than isolation distances with regard to minimizing cross-pollination [32]. Comparable results are found for maize, where the effectiveness of 10-20 m pollen barriers, ideally planted around the recipient field [33-37], is shown to be comparable to 50 m isolation distances of bare ground [10,12,13,15,34,38]. Sanvido et al.’s [15] recent meta-analysis of 13 studies concluded that an isolation perimeter of 50 m would be sufficient to keep cross-fertilization levels below the 0.5% at the border of the recipient maize field. Based on this empirical evidence and including a political safety factor, we model (i) flexible SEACERs by designing pollen barriers of 10-20 m on GM (System 1) or non-GM (System 2) field polygons, and (ii) rigid SEACERs by imposing 50-100 m isolation distances between GM and non-GM fields. Although the outer rows of a recipient field (System 2) tend to reduce cross-fertilization more efficiently than a pollen barrier of the same width around the donor (System 1), our flexible measures only concern neighboring fields. Therefore, a similar efficiency in reducing cross-fertilization was assumed among both systems.

In the benchmark scenario, we consider a theoretical crop which is assumed to be planted at a planting density equal to the regional average of 13% for oilseed rape [30]. We furthermore assume a benchmark GM adoption rate of 50% (Figure 1). The latter assumption maximizes the probability of a GM field being close to a non-GM field. The benchmark scenario further assumes a pollen barrier width of 10 m (flexible SEACERs) versus an isolation distance of 50 m (rigid SEACERs). In addition to the benchmark scenario (scenario 1), we define six alternative scenarios (see Table 1 and Table 2) by varying (i) the adoption rate to 25% (scenario 2) and 75% (scenario 3), (ii) the planting density to 6% (scenario 4) and 26% (scenarios 5 and 7), and (iii) the distance requirements to 20 m (flexible SEACERs) and 100 m (rigid SEACERs) (scenarios 6 and 7). A well-known fact in spatial analysis is the nonlinear relationship between field counts and field areas, due to unequal field sizes in the landscape. Since crops can be easier attributed to fields, we develop a *constrained randomization procedure* to allocate GM and non-GM crops in the landscape, independently of farmers' land tenure. We introduce planting densities and GM crop adoption rates from our scenario assumptions into a random function which randomly allocates GM and non-GM crops in the landscape. We repeat the random function until we find 10 allocations per scenario which satisfy the planting density assumptions with a precision of 1%. Our constrained randomization procedure yields 50 independent random crop allocations (scenarios 1 and 6 and scenarios 5 and 7 share a single set of 10 allocations as they are based on the same planting assumptions). We furthermore assume that farmers plant the fields with pure seeds, i.e. free from GM contamination, and comply with the proposed SEACERs to minimize cross-fertilization. We finally model the alternative SEACERs in ArcView® defined by the scenarios for all 50 crop allocations and calculate the means of the total GM, non-GM and shadow area. We observed that the standard errors (SE) of the outcomes (Table 1 and Table 2) were satisfactory low after 10 random draws.

IV. RESULTS

In Table 1, we report the average area proportions generated by imposing rigid SEACERs on our random crop allocations. Differences in average crop areas, despite similar planting assumptions, are due to the precision of the constrained randomization procedure which has been set at the planting density level at 1% (e.g., 12.5% = 12.6% = … = 13.4% = 13%). The low standard errors (SE) of the shadow factors in the last column suggest that our constrained randomization procedure causes the Monte Carlo simulation to converge rapidly and to produce robust estimates after only 10 random draws. The 'Phase 1' rows report the initial GM-free areas and shadow factors generated by imposing rigid SEACERs in a landscape with GM and non-GM farmers. Initial shadow factors vary from 0.18 to 0.66, suggesting that the spatial configuration of the landscape is such that the average coexistence costs per hectare of GM plantings amount to 18-66% of the market opportunity costs per unit of shadow area. This suggests that farmers can sufficiently amortize the opportunity costs over their GM area.

However, these estimates are not stable; if farmers convert their GM planting decisions to non-GM in response to rigid SEACERs, a *domino-effect* of planting decision conversions may occur [7,27]. The domino-effect is the theoretical spillover effect of farmer decisions induced by enforcing rigid coexistence regulations on potential GM crop adopters. In the absence of any regulation, GM and non-GM planting options would coexist in a population of farmers. Through compliance with isolation distances, some potential GM crop adopters will have to modify their planting decisions (i.e. from GM to non-GM varieties) and will attempt to capture IP gains by complying with IP standards. These new IP farmers might, in turn, restrict planting options and convert planting decisions of neighboring GM farmers (Phase 2). Subsequently, this might affect other GM farmers' planting options and impinge on planting decisions, etc. (Phase 3-4), until all distance requirements between GM and non-GM fields are met at the landscape level. The 'Phase 2-4' rows in Table 1 report the cumulative influence of the domino-effect on the number and area of GM-free fields and the shadow factor. Depending on the scenario, the domino-effect expands the initial shadow area in

Phase 1 with 2-41% and reduces adoption with 19-77% until only small clusters of GM crop plantings remain. While the static relationship between the proportion of land available for GM crops and the isolation distance (e.g., in 'Phase 1' rows of Table 1) has been recognized in scholarly research on coexistence [18,39], the theoretical possibility of the domino-effect on adoption intentions has been largely ignored [7,27].

Table 1 Average shadow factors of rigid SEACERs under alternative scenarios. All estimates are averages, based on 10 random allocations of GM and non-GM crop fields. Differences in average crop areas among scenarios with equal plantings are due to the precision of the constrained randomization procedure which has been set at the level of the planting density at 1%. The domino-effect expresses the relative difference in per cent between the cumulative value in Phase 4 and the value in Phase 1. The shadow factor is the ratio of GM-free to GM area. Source: Authors' calculations based on GIS dataset of the sample square [29].

Phase	Crop area (ha)	Planting density	GM area (ha)	Adoption	Isolation distance (m)	GM-free fields	GM-free area (ha)	Shadow factor ± SE
Scenario 1								
Phase 1	559	13%	280	50%	50	29	81	0.29 ± 0.03
Phase 2	559	13%	199	36%	50	32	90	0.47 ± 0.05
Phase 3	559	13%	190	34%	50	33	91	0.50 ± 0.05
Phase 4	559	13%	189	34%	50	33	91	0.50 ± 0.05
Domino			-33%	-33%		+14%	+16%	0.73 ± 0.10
Scenario 2								
Phase 1	547	13%	137	25%	50	23	67	0.49 ± 0.04
Phase 2	547	13%	70	13%	50	25	70	1.12 ± 0.18
Phase 3	547	13%	67	12%	50	25	71	1.18 ± 0.18
Phase 4	547	13%	66	12%	50	25	71	1.20 ± 0.18
Domino			-52%	-52%		+7%	+9%	1.36 ± 0.17
Scenario 3								
Phase 1	546	13%	410	75%	50	22	77	0.19 ± 0.03
Phase 2	546	13%	333	61%	50	28	102	0.33 ± 0.06
Phase 3	546	13%	308	56%	50	30	106	0.38 ± 0.08
Phase 4	546	13%	303	55%	50	30	106	0.39 ± 0.08
Domino			-26%	-26%		+36%	+41%	0.96 ± 0.19
Scenario 4								
Phase 1	262	6%	131	50%	50	9	24	0.18 ± 0.03
Phase 2	262	6%	107	41%	50	9	24	0.24 ± 0.05
Phase 3	262	6%	107	41%	50	9	24	0.24 ± 0.05
Phase 4	262	6%	107	41%	50	9	24	0.24 ± 0.05
Domino			-19%	-19%		+3%	+2%	0.27 ± 0.06
Scenario 5								
Phase 1	1,097	26%	548	50%	50	90	310	0.57 ± 0.03
Phase 2	1,097	26%	238	22%	50	105	357	1.57 ± 0.14
Phase 3	1,097	26%	191	17%	50	107	362	2.00 ± 0.18
Phase 4	1,097	26%	186	17%	50	108	362	2.05 ± 0.17
Domino			-66%	-66%		+20%	+18%	2.56 ± 0.17
Scenario 6								
Phase 1	559	13%	280	50%	100	37	97	0.35 ± 0.03
Phase 2	559	13%	182	33%	100	43	117	0.67 ± 0.07
Phase 3	559	13%	162	29%	100	44	119	0.78 ± 0.09
Phase 4	559	13%	161	29%	100	44	119	0.78 ± 0.09
Domino			-42%	-42%		+18%	+22%	1.19 ± 0.14
Scenario 7								
Phase 1	1,097	26%	548	50%	100	112	361	0.66 ± 0.02
Phase 2	1,097	26%	187	17%	100	130	411	2.31 ± 0.18
Phase 3	1,097	26%	136	12%	100	133	419	3.27 ± 0.27
Phase 4	1,097	26%	128	12%	100	133	420	3.45 ± 0.26
Domino			-77%	-77%		+19%	+17%	4.20 ± 0.30

In the benchmark scenario, characterized by a planting density of 13% and a GM adoption rate of 50%, the initial shadow factor amounts to 0.29 and nearly triples to 0.73 as a result of the domino-effect on the GM-free area (+16%) and on the GM area (-33%). Scenario 2 yields a higher initial shadow factor (0.49) as the shadow area is amortized over a smaller initial GM area (25% adoption), which is further eroded by the domino-effect (-52%). However, owing to the lower density of GM fields in the landscape, the domino-effect on shadow area is modest (+9%) and nearly triples the initial shadow factor (1.36). Scenario 3 generates a lower initial shadow factor (0.19) as the shadow area is amortized over a greater GM area (75% adoption), but the high GM field density entails the most prominent domino-effect on the shadow area (+41%) among all scenarios, boosting the shadow factor to its five-fold (0.96). Scenario 4, on the other hand, yields the lowest shadow factor (0.27) and the smallest domino-effect on the shadow area (+2%) due to its assumed low crop planting density of 6%, which is comparable to oilseed rape planting in the Fife region of Scotland [40]. The initial shadow factor (0.57) in scenario 5 looks similar to scenario 2, but the increased planting density (26%) generates an important domino-effect on the shadow area (+18%) and the GM area (-66%), which raises the shadow factor to nearly its five-fold (2.56). A similar but less dramatic effect is obtained by doubling the isolation distance (100 m) in scenario 6, which, compared to the benchmark scenario, less than doubles the initial shadow factor (0.35), which is more than tripled (1.19) as a result of the domino-effect on the shadow area (+22%) and the GM area (-42%). Finally, combining a large isolation distance with a high planting density in scenario 7 leads to the highest shadow factor (4.20), i.e. a six-fold increase from the initial shadow factor (0.66), as a result of an average domino-effect on the shadow area (+17%), but a large-scale domino-effect on the GM area (-77%).

These findings suggest that the domino-effect exacerbates the non-proportionality of rigid SEACERs through its multiplicator effect on shadow factors, i.e. by increasing the shadow area and driving GM crop production out of the landscape. Only if IP rents are competitive to GM rents are the costs of rigid SEACERs minimized (equation 1) as farmers become indifferent between supplying GM and IP crops. If IP rents decline, however, the costs of rigid SEACERs increase (equation 1) instead of decrease in the case of flexible SEACERs (equation 2) and this effect is exacerbated by the domino-effect. If IP rents become negligible, shadow factors need to be less than one in order to allow farmers to profitably adopt GM crops and comply with rigid SEACERs. Table 1 shows that in our landscape sample this condition is only met under low-medium planting densities (6-13%) with medium-high adoption rates (50-75%) subject to small (50 m) isolation distances (scenarios 1, 3, and 4).

Table 2 Average shadow factors of flexible SEACERs under alternative scenarios. All estimates are averages, based on 10 random allocations of GM and non-GM crop fields. Differences in average crop areas among scenarios with equal plantings are due to the precision of the constrained randomization procedure which has been set at the level of the planting density at 1%. The shadow factor is the ratio of pollen barrier to GM area. Source: Authors' calculations based on GIS dataset of the sample square [29].

Sc.	Crop area (ha)	Planting density	GM area (ha)	Adoption	Pollen barrier (m)	Pollen barrier area (ha)	Shadow factor ± SE
1	559	13%	280	50%	10	1.8	0.006 ± 0.000
2	547	13%	137	25%	10	1.9	0.014 ± 0.001
3	546	13%	410	75%	10	1.6	0.004 ± 0.000
4	262	6%	131	50%	10	0.6	0.004 ± 0.001
5	1,097	26%	548	50%	10	8.2	0.015 ± 0.001
6	559	13%	280	50%	20	4.7	0.017 ± 0.001
7	1,097	26%	548	50%	20	21.8	0.040 ± 0.002

Pollen barriers, on the other hand, yield substantially smaller shadow factors owing to their higher spatial effectiveness in reducing cross-fertilization [31]. Our estimated shadow factors range from a value of 0.004 under low planting densities (6%) or high adoption rates (75%) to its ten-fold of 0.040 under a combination of high planting densities (26%), medium adoption rates (50%) and large distance requirements (20 m) (Table 2). Doubling the planting density from 13% to 26% more than doubles the shadow factor, i.e.

from 0.006 in the benchmark scenario to 0.015 in scenario 5. This is equivalent to doubling the distance requirement from 10 m to 20 m, which yields a similar shadow factor of 0.017 in scenario 6. These shadow factors need to be multiplied by the relevant market opportunity costs to obtain average opportunity costs, but our examples have shown that flexible SEACERs can be designed in such a way that they encourage farmers to minimize total (opportunity, transaction and operational) coexistence costs and satisfy the proportionality condition (equation 2), in contrast with rigid SEACERs (equation 1).

Our framework is subject to strengths and limitations. Its major strength is probably its simplicity; its major limitation is related to data requirements. GIS datasets are difficult to obtain due to their proprietary nature and rarely contain a complete set of spatially linked information on land tenure, farmer practices, intentions and strategies of coordination, production costs, etc.. This data gap has forced us to make simplifying assumptions and the most important one is the assumption of homogeneity of GM and IP rents, which introduces homogeneity bias into our shadow factor estimates. In the literature on GM crops, it is widely accepted that GM rents captured by farmers are heterogeneous, as they operate under heterogeneous conditions with respect to land quality, pest pressure, managerial expertise, education and market access [3,41-43]. Although IP price premiums are more or less homogenous among farmers as they are generated by the interaction of aggregate demand and supply (i.e. market share) on a differentiated market for GM and IP crops, IP rents are more heterogeneous as they also depend on heterogeneous yield levels. Since we were interested in the average spatial impact of alternative SEACERs in this article, we empirically interpreted coexistence costs in equations 1 and 2 as sample area averages in order to reduce variability. However, they can be alternatively interpreted as stochastic at the field level. If field-level data can be obtained on shadow areas, homogeneity bias can be removed and owing to Jensen's inequality [44], the mean of the field-level shadow factors will be different from the mean of the sample-level shadow factors we reported in Table 1 and Table 2. Moreover, if field-level shadow factors can be weighted with field-level data on GM and IP rents, the statistical distribution of field-level coexistence costs can be estimated, which can be used to further refine impact assessments and policy recommendations.

Related limitations are our assumptions that all farmers operating under rigid SEACERs will convert their entire GM field to GM-free, and that all those operating under flexible SEACERs will implement pollen barriers. We made this assumption for the benefit of simplicity and to ensure the polarization between rigid and flexible SEACERs. An isolation distance could be implemented through a less expensive pollen barrier in the case of rigid SEACERs, but an expensive pollen barrier can be perceived as an isolation distance in the case of flexible SEACERs. The question comes down to an additional assumption of threshold, which defines (i) in the case of flexible SEACERs, how large the share of the pollen barrier area in the field may be before it is perceived and implemented as an isolation distance and, (ii) in the case of rigid SEACERs how small the share of the GM-free area in the field has to be before the isolation distance is implemented through a pollen barrier. Hence, in these border cases we underestimate the costs of flexible SEACERs, as on some fields farmers would abandon GM production right away, and overestimate the costs of rigid regulations, as on some fields farmers would comply with isolation distances through pollen barriers. By not introducing this threshold parameter in our framework, we implicitly set it equal to zero and polarize the two alternative SEACERs, knowing that for some farmers, the distinction between both alternative SEACERs may be less pronounced. In any case, the threshold parameter would not affect our qualitative findings about the proportionality condition.

Another limitation of our framework is the fact that the GIS database of our sample area does not contain land tenure records, which forced us to treat all fields as independent. Randomly assigning GM and non-GM crop fields among these fields, subject to a set of planting constraints, also generates on-farm inter-field coexistence situations, which are generally not classified under coexistence. Therefore, our assumption of independent fields probably biases shadow areas and factors upwards. However, despite the fact that land tenure is relatively scattered in the analysed region [30], we expect that minimization of coexistence costs will drive clustering of farms in the medium and long-run [17,39]. As a result, our overestimation originates both from the independence assumption and from the constrained randomization procedure. Therefore, our shadow factor estimates have to be interpreted as upper values of the expected medium and long-run values.

A further limitation of our proposed framework is the fact that our shadow factors are based on a single landscape. In order to relax this limitation and widen somewhat the range of landscape configurations captured by our framework, we varied planting densities from 6%, i.e. comparable to oilseed rape planting in the Fife region of Scotland [40], to its fourfold of 26%. However, this variation still failed to capture alternative degrees of land fragmentation as planting density does not affect the average field size in our sample. Therefore, research efforts need to be done in order to reproduce our spatial methodology for different landscape configurations. The constrained randomization procedure dramatically increased the convergence rate of the Monte Carlo simulation. Nevertheless, modeling in ArcView® remains extremely time-consuming, and future research needs to automate the entire procedure in a single software module to enable rapid calculations. Another solution could be to summarize landscape configuration in a single measure such as the concept of the land fragmentation index. In the literature, different indices of land fragmentation have been proposed, e.g. based on the number and size of plots, between-plot distances, and combining size and shape [45]. Future research could provide a useful and innovative contribution by mathematically deriving our shadow factor as a function of an index of land fragmentation. This will enable efficiently reproducing our framework for a variety of European landscapes and will provide valuable information for policy makers on the compared spatial impact of alternative SEACERs.

An additional issue which is not captured in our framework is the important issue of irreversibility, a weakness which our framework shares with Munro's [26] model. The issue of irreversibility has been widely applied on regulatory approval and adoption of GM crops [46], but less frequently on the regulation of coexistence [24]. By analyzing a single season, our framework implicitly relies on the compliance and effectiveness assumptions, which suppose that the modeled SEACERs are sufficient for maintaining seed purity and limiting the development of volunteers over time. In the case of oilseed rape, this is a strong assumption which implicitly ignores additional costs due to management complications over time. Messéan et al. [47] show that over time the rate of GM seeds admixture in the harvest largely exceeded the European threshold in 6 out of 18 cases and conclude that "Unless appropriate management and agronomical guidelines to manage volunteers are implemented, it will indeed be hazardous for a farmer to go back to a conventional non-GM farming system, even 5 years after the last transgenic OSR harvest" (p. 121). Moreover, oilseed rape has a number of cross-compatible wild and weedy relatives which increases the possibilities for the establishment of a feral population of the crop. In contrast, maize has no cross-compatible wild/weedy relatives in the European Union [8], whilst wheat have some potential partners [48]. Hence, while our framework focused only on the spatial dimension, future research on coexistence will need to assess the impact of alternative SEACERs in the temporal dimension. It may well be that for some crops inclusion of time will argue for more conservative SEACERs.

Another data constraint is related to the *ex ante* nature of the coexistence question in Europe, which inspired us to split the problem into two parts and focus on the spatial component, while exogeneizing the market component. As long as the EU has limited experience with a differentiated market of GM and IP crops, policy makers can use the concept of the shadow factor as a proxy variable for opportunity costs. SEACERs can be designed based on a meta-analysis of distance requirements from cross-fertilization studies. Once policy makers have established a set of shadow factors for a variety of landscapes, they can easily compare the regional impact of alternative SEACERs through a single measure. GM rents, although heterogeneous, have been more or less established after a decade of global GM crop adoption [49]. The literature reports GM rent estimates for maize ranging from €23/ha in Hungary and €31/ha in the Czech Republic [41] to €47/ha in Spain [50] and €70/ha in France [51], while estimates for oilseed rape range from €29/ha in Hungary to €55-56/ha in the Czech Republic and France [27,41].

Future IP rents, on the other hand, are still uncertain in the EU, owing to limited experience with the large-scale diffusion of GM crops. However, they can be approximated through analogy in comparable import markets (e.g., soybeans in the EU), or not approximated at all and replaced by break-even values (e.g., equal to GM rents), as illustrated by Demont et al. [27]. Break-even assumptions are widely used strategies in *ex ante* impact assessment for assuming away and avoiding imposing strong prior assumptions on unknown or highly uncertain parameters [46] or for sharpening a model's prediction on potential quantitative results [5]. To date, price differentials for GM-free crops have been weak in international agricultural markets [52,53]. This does not imply that, under weak market signals for IP crops, the entire European landscape will be planted with GM crops and crowd out IP crop production. Experience has shown that GM crop adoption is usually incomplete. Proprietary GM seed technologies are protected by intellectual property rights (i.e. patents) that confer monopoly rights to the discoverer – with some limitations. As a result, GM seed prices are higher than they would be in a perfectly competitive market, despite competition from chemical alternatives. If biotechnology companies set the GM seed price at a uniform, monopolistic level among a heterogeneous group of farmers, some farmers would find it profitable to adopt the innovation, while others would not. Other reasons for incomplete adoption include farmers' uncertainty about anticipated GM gains, and risk aversion towards new technologies, a well-known phenomenon in the literature on agricultural innovation.

The latter leads us to a limitation of our three basic assumptions (compliance, effectiveness, and the newcomer principle), which excludes the possibility of consumers with strong preferences for IP crops being prevented from having access to IP crops as a result of cross-fertilization due to under-regulation of coexistence. Indeed, in this paper we argue that flexible SEACERs are preferable to rigid SEACERs, assuming that they are both complied with and effective, and therefore, based on the literature, we compared small pollen barriers with large isolation distances. Hence, if these distance requirements were to be insufficient, coexistence would be under-regulated and this would engender important welfare losses for consumers of IP crops. However, over-regulation could entail similar welfare losses. From Table 1 we would tend to conclude that rigid SEACERs protect and favor IP crop farmers and consumers and harm GM crop farmers. However, if consumer preferences for IP crops are not competitive to farmer preferences for GM crops, i.e. if they generate smaller IP incentives than GM incentives for farmers, an inverse domino-effect could occur triggered by GM farmers who try to convince their non-GM neighbors to revisit their planting decisions. It is possible that both types of domino-effect will coexist and complement regional specialization in the European landscape and that highly productive areas, in which the incentive for growing GM crops is higher than the incentive for supplying IP crops, will cluster as GM regions, whereas low productive areas will rapidly form 'GMO-free' zones [17,39] in an attempt to capture the IP rents.

Finally, it is important to draw the reader's attention to the fact that our proposed distance requirement assumptions are illustrative in any case. They have been borrowed from literature evidence on cross-fertilization from available case studies of oilseed rape and maize, but policy makers may double or triple these distance requirements in order to include a political safety factor. These benchmark assumptions nevertheless provided useful information on how the spatial configuration of a particular landscape affects the proportionality of alternative SEACERs, which is the central question in this article.

V. CONCLUSIONS

In its struggle to implement coherent coexistence regulations on GM and non-GM crops in all member states, the EU has clearly emphasized that any approach needs to be proportionate to the aim of achieving coexistence. We defined the proportionality condition as a functional relationship which is weakly increasing in both incentives for coexistence, which we defined as the rents derived from cultivating GM crops (GM rents) and preserving the identity of non-GM crops (IP rents). We developed a spatial framework for analyzing the proportionality of alternative spatial *ex ante* coexistence regulations (SEACERs) based on a geographic model of a real landscape in Central France. We introduced the novel concept of shadow factor as a measure for farmers' opportunity costs of complying with SEACERs in a given landscape. Our empirical findings suggest that rigid SEACERs which are based on large isolation distances imposed on GM farmers violate the proportionality condition and, hence, are not consistent with the objectives of the EU. Our findings argue for incorporating a certain degree of flexibility into SEACERs by advising pollen barrier agreements between farmers rather than imposing rigid isolation distances on GM farmers, since the shadow factors of pollen barriers are proportional to the incentives for coexistence.

The empirical questions of proportionality and flexibility have been largely ignored in the literature on coexistence and provide timely information for EU policy makers. Authorities may be reluctant to adopt flexible *ex ante* regulations, but in the absence of clear market signals for IP crops, regulatory rigidity should be shifted from *ex ante* to *ex post* to avoid jeopardizing the economic incentives for coexistence in EU agriculture [7]. Germany for example – perhaps inspired by their advisory speed limits in traffic law – is currently planning to introduce flexibility into its coexistence regulations, an issue which is currently highly debated among politicians and interest groups [54]. German traffic law also shifts regulatory rigidity from *ex ante* to *ex post*. In case of a road accident, the driver can be held *ex post* liable for negligence if he did not comply with the *ex ante* speed limit during the accident [55]. The same model could be applied in coexistence regulation; if any incident of GM contamination occurs and affects the welfare of farmers and consumers, GM farmers are held *ex post* liable for negligence and have to pay *ex post* tort liability costs if they did not comply with the *ex ante* coexistence regulations [24].

Finally, coexistence of agricultural production systems is a complex research subject and our proposed framework is just a small building stone in an emerging field of economic and policy research on coexistence which still largely needs to be developed. Further research is needed to forecast the market response to the introduction of GM crops in Europe and to link our framework to a generalized index of land fragmentation. However, the major weakness of the framework remains due to the *ex ante* nature of the coexistence problem in Europe and therefore, we hope that it may inspire other researchers to go further and obtain the relevant data to analyze the problem in its entirety.

ACKNOWLEDGMENT

The financial support of the European Commission's 6th Framework Programme SIGMEA project (Sustainable Introduction of Genetically Modified organisms into European Agriculture) is gratefully acknowledged.

REFERENCES

1. EC (2003) Commission Recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming. Official Journal of the European Communities L189:36-47
2. EC (2006) Report on the implementation of national measures on the coexistence of genetically modified crops with conventional and organic farming. Commission of the European Communities, Brussels
3. Lapan HE, Moschini G (2004) Innovation and trade with endogenous market failure: The case of genetically modified products. Am J Agr Econ 86:634-648
4. Bock A-K, Lheureux K, Libeau-Dulos M, Nilsagård H, Rodríguez-Cerezo E (2002) Scenarios for co-existence of genetically modified, conventional and organic crops in European agriculture. European Communities, Brussels
5. Moschini G, Bulut H, Cembalo L (2005) On the segregation of genetically modified, conventional, and organic products in European agriculture: a multi-market equilibrium analysis. J Agric Econ 56:347-372
6. Giannakas K, Fulton M (2002) Consumption effects of genetic modification: What if consumers are right? Agricultural Economics 19:97-109
7. Demont M, Devos Y (2008) Regulating coexistence of GM and non-GM crops without jeopardizing economic incentives. Trends Biotechnol 26:353-358

8. Eastham K, Sweet J (2002) Genetically modified organisms (GMOs): The significance of gene flow through pollen transfer. European Environment Agency, Copenhagen, Denmark
9. Devos Y, Reheul D, De Schrijver A, Cors F, Moens W (2004) Management of herbicide-tolerant oilseed rape in Europe: A case study on minimizing vertical gene flow. Environ Biosaf Res 3:135-148
10. Devos Y, Reheul D, De Schrijver A (2005) The co-existence between transgenic and non-transgenic maize in the European Union: A focus on pollen flow and cross-fertilization. Environ Biosaf Res 4:71-87
11. Damgaard C, Kjellsson G (2005) Gene flow of oilseed rape (Brassica napus) according to isolation distance and buffer zone. Agr Ecosyst Environ 108:291-301
12. Van De Wiel CCM, Lotz LAP (2006) Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: A case study of the situation in the Netherlands. NJAS Wageningen Journal of Life Sciences 54:17-35
13. Messéan A, Angevin F, Gómez-Barbero M, Menrad K, Rodríguez-Cerezo E (2006) New case studies on the coexistence of GM and non-GM crops in European agriculture. European Communities, Luxembourg
14. Hüsken A, Dietz-Pfeilstetter A (2007) Pollen-mediated intraspecific gene flow from herbicide resistant oilseed rape (*Brassica napus* L.). Transgenic Res 16:557-569
15. Sanvido O, Widmer F, Winzeler M, Streit B, Szerencsits E, Bigler F (2008) Definition and feasibility of isolation distances for transgenic maize cultivation. Transgenic Res 17:317-335
16. Hoyle M, Cresswell JE (2007) The effect of wind direction on cross-polination in wind-pollinated GM crops. Ecol Appl 17:1234-1243
17. Furtan WH, Guzel A, Weseen AS (2007) Landscape clubs: Co-existence of genetically modified and organic crops. Can J Agr Econ 55:185-195
18. Perry JN (2002) Sensitive dependencies and separation distances for genetically modified herbicide-tolerant crops. Proc Roy Soc London 269:1173-1176
19. Belcher K, Nolan J, Phillips PWB (2005) Genetically modified crops and agricultural landscapes: Spatial patterns of contamination. Ecol Econ 53:387-401
20. Devos Y, Reheul D, Thas O, De Clercq E, Cougnon M, Cordemand K (2007) Implementing isolation perimeters around genetically modified maize fields. Agron Sustain Dev 27:155-165
21. Devos Y, Thas O, Cougnon M, De Clercq E, Cordemans K, Reheul D (2008) Feasibility of isolation perimeters for genetically modified maize on an intra-regional scale in Flanders. Agron Sustain Dev 28
22. Kalaitzandonakes NG, Maltsbarger R, Barnes J (2001) Global identity preservation costs in agricultural supply chains. Can J Agr Econ 49:605-615
23. Bullock DS, Desquilbet M (2002) The economics of non-GMO segregation and identity preservation. Food Pol 27:81-99
24. Beckmann V, Soregaroli C, Wesseler J (2006) Coexistence rules and regulations in the European Union. Am J Agr Econ 88:1193-1199
25. Jank B, Rath J, Gaugitsch H (2006) Co-existence of agricultural production systems. Trends Biotechnol 24:198-200
26. Munro A (2008) The spatial impact of genetically modified crops. Ecol Econ doi:10.1016/j.ecolecon.2008.01.030
27. Demont M, Daems W, Dillen K, Mathijs E, Sausse C, Tollens E (2008) Regulating coexistence in Europe: Beware of the domino-effect! Ecol Econ 64:683-689
28. Allen DW, Lueck D (1998) The nature of the farm. J Law Econ 41:343-386
29. Pessel FD, Lecomte J, Emeriau V, Krouti M, Messéan A, Gouyon PH (2001) Persistence of oilseed rape (Brassica napus L.) outside of cultivated fields. Theor Appl Genet 102:841-846
30. Sausse C (2005) Case study Beauce/Rapeseed. SIGMEA Project, Grignon
31. Della Porta G, Ederle D, Bucchini L, Prandi M, Verderio A, Pozzi C (2008) Maize pollen mediated gene flow in the Po valley (Italy): Source-recipient distance and effect of flowering time. Eur J Agron 28:255-265
32. Staniland BK, McVetty PBE, Friesen LF, Yarrow S, Freyssinet G, Freyssinet M (2000) Effectiveness of border areas in confining the spread of transgenic Brassica napus pollen. Can J Plant Sci 80:521-526
33. Gustafson DI, Brants IO, Horak MJ, Remund KM, Rosenbaum EW, Soteres JK (2006) Empirical modeling of genetically modified maize grain production practices to achieve European Union labeling thresholds. Crop Sci 46:2133-2140
34. Messeguer J, Peñas G, Ballester J, Bas M, Serra J, Salvia J, Palaudelmàs M, Melé E (2006) Pollen-mediated gene flow in maize in real situations of coexistence. Plant Biotechnol J 4:633-645
35. Pla M, La Paz J-L, Peñas G, García N, Palaudelmàs M, Esteve T, Messeguer J, Melé E (2006) Assessment of real-time PCR based methods for quantification of pollen-mediated gene flow from GM to conventional maize in a field study. Transgenic Res 15:219-228
36. Weber WE, Bringezu T, Broer I, Eder J, Holz F (2007) Coexistence between GM and non-GM maize crops -

Tested in 2004 at the field scale level (Erprobungsanbau 2004). J Agron Crop Sci 193:79-92

37. Weekes R, Allnutt T, Boffey C, Morgan S, Bilton M, Daniels R, Henry C (2007) A study of crop-to-crop gene flow using farm scale sites of fodder maize (*Zea mays* L.) in the UK. Transgenic Res 16:203-211
38. Hüsken A, Ammann K, Messeguer J, Papa R, Robson P, Schiemann J, Squire G, Stamp P, Sweet J, Wilhelm R (2007) A major European synthesis of data on pollen and seed mediated gene flow in maize in the SIGMEA project.In: Stein AJ, Rodríguez-Cerezo E Third International Conference on Coexistence between Genetically Modified (GM) and non-GM Based Agricultural Supply Chains, Seville (Spain), 20-21 November 2007: Book of Abstracts. Office for Official Publications of the European Communities, Luxembourg, pp. 53-56
39. Beckmann V, Wesseler J (2007) Spatial dimension of externalities and the Coase theorem: Implications for co-existence of transgenic crops.In: Heijman W Regional Externalities. Springer, Berlin Heidelberg New York, pp. 223-242
40. Copeland JE, Kasamba E (2007) Economics of coexistence measures of GM and conventional crops: Oilseed rape in Fife (Scotland).In: Stein AJ, Rodríguez-Cerezo E Third International Conference on Coexistence between Genetically Modified (GM) and non-GM Based Agricultural Supply Chains, Seville (Spain), 20-21 November 2007: Book of Abstracts. Office for Official Publications of the European Communities, Luxembourg, pp. 149-152
41. Demont M, Cerovska M, Daems W, Dillen K, Fogarasi J, Mathijs E, Muška F, Soukup J, Tollens E (2008) Ex ante impact assessment under imperfect information: Biotechnology in New Member States of the EU. J Agric Econ 59
42. Oehmke JF, Wolf CA (2004) Why is Monsanto leaving money on the table? Monopoly pricing and technology valuation distributions with heterogeneous adopters. J Agric Appl Econ 36:705-718
43. Weaver RD (2004) R&D incentives for GM seeds: restricted monopoly, non-market effects, and regulation.In: Evenson RE, Santaniello V The Regulation of Agricultural Biotechnology. CAB International, Wallingford, UK, pp. 143-151
44. Greene WH (1997) Econometric analysis. Prentice Hall, Upper Saddle River NJ
45. Gonzalez XP, Alvarez CJ, Crecente R (2004) Evaluation of land distributions with joint regard to plot size and shape. Agric Sys 82:31-43
46. Demont M, Wesseler J, Tollens E (2004) Biodiversity versus transgenic sugar beet: The one Euro question. Eur Rev Agric Econ 31:1-18
47. Messéan A, Sausse C, Gasquez J, Darmency H (2007) Occurrence of genetically modified oilseed rape seeds in the harvest of subsequent conventional oilseed rape over time. Eur J Agron 27:115-122
48. Loureiro I, Escorial MC, García-Baudín JM, Chueca MC (2006) Evidence of natural hybridization between *Aegilops geniculata* and wheat under field conditions in Central Spain. Environ Biosaf Res 5:105-109
49. Demont M, Dillen K, Mathijs E, Tollens E (2007) GM crops in Europe: How much value and for whom? EuroChoices 6:46-53
50. Demont M, Tollens E (2004) First impact of biotechnology in the EU: Bt maize adoption in Spain. Ann Appl Biol 145:197-207
51. ORAMA (2007) GM maize in the field: Conclusive results. http://www.agpm.com/en/iso_album/technical_results_btmaize_2006.pdf
52. Falck-Zepeda JB (2006) Coexistence, genetically modified biotechnologies and biosafety: Implications for developing countries. Am J Agr Econ 88:1200-1208
53. Foster M, French S (2007) Market acceptance of GM canola. Australian Bureau of Agricultural and Resource Economics, Canberra
54. Crowley L (2008) Germany enables easier GM cultivation. http://www.foodnavigator.com/news/ng.asp?n=82867-monsanto-germany-gm-crops
55. Müller D (2007) Geschwindigkeit als Unfallursache. Zeitschrift für die Praxis des Verkehrsjuristen 1:1-6

Address of the corresponding author:

- Author: Matty Demont (PhD)
- Institute: Africa Rice Center (WARDA)
- Street: B.P. 96
- City: Saint-Louis
- Country: Senegal
- Email: m.demont@cgiar.org