Economics of spatial coexistence of genetically modified and conventional crops: Oilseed rape in Central France

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Abstract— **Europe is currently struggling to implement coherent coexistence regulations on genetically modified (GM) and non-GM crops in all EU 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.**

Keywords— **regulation, GIS modelling, domino-effect.**

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 [genetically modified] crop production, in compliance with the legal obligations for labelling 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 labelled 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 coexistence regulations. Our concern is that rigid rules, such as large distance requirements [2], 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 are currently facing the challenge of implementing coherent coexistence regulations tailored to a heterogeneous landscape of European agriculture. Since the publication of the European Commission's first report on coexistence [3], the debate has been centred on the potential costs of coexistence of GM and non-GM crops, but 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'). Both incentives play a crucial role: if one of them is lacking, there is no coexistence problem, *stricto sensu*. Finally, in the literature spatial coexistence of GM and non-GM crops is often regarded as a technical challenge, depending on spatial pollen dispersal and cross pollination [4,5,6], temporal and spatial distribution and interaction of crops [7,8,9], separation distances [9,10] and practical measures [11,12,13], but the interplay between incentives and costs of coexistence is poorly studied. Therefore, in this article we develop a modelling framework for simulating spatial coexistence measures and estimating the costs of these measures, which explicitly takes into account the incentives for coexistence.

This article is organized as follows. After this introduction, in Section 2 we derive a simple model for analyzing the economics of spatial coexistence. In Section 3, we link this model to a GIS (Geographic Information System) modelling framework and apply it to a sampled area in Central France. Section 4 presents the data. In Section 5 we present the results generated by our modelling framework for a set of simulations of realistic coexistence scenarios. Finally, Section 6 concludes.

II. ECONOMICS OF SPATIAL COEXISTENCE

Most EU Member States' spatial coexistence legislations include (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 [2]. In this article, we polarize the latter 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. We further assume that fields which are too close to fields planted with non-GM crops cannot be planted with GM varieties of the same crop species. We define buffer zones as cross-pollination zones between two farmers growing two different varieties (GM and non-GM) of the same crop. These zones are planted with non-GM crops and sold as GM. We model the example of narrow buffer zones and assume flexibility, i.e. regulations allow buffer zones to be negotiated and planted by GM as well as 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. A rational farmer who foregoes the GM rent will attempt to compensate this loss by attempting to capture the IP rent. The resulting costs are a trade-off between the GM rent (yield boost and cost reduction) and the IP rent (price premium):

$$C_{\mathrm{id}} = a_{\mathrm{id}}\,(\beta\, y_{\mathrm{c}}\, P_{\mathrm{g}} + \Delta C - y_{\mathrm{c}}\, P_{\mathrm{g}}\, \mu), \qquad (1)$$

where a_{id} represents the total area of GM-free fields of a particular crop to respect a certain isolation distance, $\beta = (y_{\mathrm{g}} - y_{\mathrm{c}})/y_{\mathrm{c}}$ 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 $\mu = (P_{\mathrm{n}} - P_{\mathrm{g}})/\, P_{\mathrm{g}}$ 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 neighbour (System b) of the field. 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 (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 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:

$$C_{\mathrm{bz}} = a_{\mathrm{bz}}\,(\beta\, y_{\mathrm{c}}\, P_{\mathrm{g}} + \Delta C), \qquad (2)$$

where a_{id} represents the total area of the buffer zone.

In System 2a, the non-GM farmer separately harvests his adjacent margins, which serve as buffer zones, next to the neighbouring 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 neighbouring non-GM farmer for the IP rent foregone:

$$C_{\mathrm{bz}} = a_{\mathrm{bz}}\, y_{\mathrm{c}}\, P_{\mathrm{g}}\, \mu\,. \qquad (3)$$

Equations 1, 2 and 3 clearly illustrate that the costs of spatial coexistence measures are a function of the incentives for coexistence, i.e. the GM rent and the IP rent.

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 14]. 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 buffer 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, 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. As a result, the dominance of one of the four systems will depend on the trade-off of (i) market price risks, (ii) moral hazard and (iii) loss of scale economies.

III. ARCVIEW® MODELING

We use the hypothetical example of HT oilseed rape adoption in Central France to compare the costs of rigid versus flexible coexistence regulations. As a case study, the Beauce Blésoise region in Central France was chosen. We select a sample square of about 100 km² centred around the silo of Selommes (Loir-et-Cher), i.e. 10,000 ha or about 6% of the case study region (159,505 ha) and conduct simulations through the software ArcView® on a GIS dataset of this sample square [15]. We start from a GIS shapefile where the arable fields are represented as polygons (Figure 1). The modelled landscape counts 1,508 arable fields covering an area of 4,233 ha.

Next, through a constrained randomization process, we randomly allocate oilseed rape fields in the landscape independently of farmers' land tenure and randomly allocate GM traits among the oilseed rape fields (Figure 1), subject to different scenarios of oilseed rape planting density and GM trait adoption. 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, 50% of which is planted with GM traits. The latter assumption generates the most stringent situation for coexistence because it maximizes the probability of a GM field being close to a non-GM field.

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

In their study on pollen-mediated gene flow from HT OSR, Damgaard and Kjellsson [5] 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 [16] review 16 studies and conclude that 10 m buffer zones achieve a similar rate of 0.5%. Both rates largely fulfil the 0.9% threshold condition set by the EU labelling legislation and suggest that buffer zones are more spatially efficient than isolation distances with regard to minimizing cross-pollination [17]. Based on this empirical evidence and including a political safety factor, we introduce a GIS dataset of the sample square [15] in ArcView® and model (i) flexible segregation measures by designing buffer zones of 10-20 m on GM (System 1) or non-GM (System 2) field polygons, and (ii) rigid coexistence regulations by imposing 50-100 m isolation distances between GM and non-GM fields. To illustrate the main point of this article, we model both measures as polar components of a coexistence regulation. Buffer zones are modelled as 'flexible' in that they are only planted between neighbouring GM and non-GM fields so as to respect 10-20 m distance requirements, while isolation distances are modelled as 'rigid' as they are imposed on all GM fields.

Relative to the benchmark scenario (scenario 1), we simulate six additional alternative scenarios by varying (i) the adoption rate (scenarios 2 and 3), (ii) the share of oilseed rape in the total arable area (scenarios 4, 5 and 7), in order to capture regional heterogeneity of oilseed rape plantings, and (iii) the distance requirement (scenarios 6 and 7), in order to capture regional heterogeneity of pollen dispersal. We recalculate the seven scenarios under three different IP price premium factors, i.e. μ = 3%, 6%, and 12%, and three different GM seed price premiums, i.e. €12/ha, €23/ha, and €35/ha (*cfr. infra*), generating 77 combinations of coexistence scenarios (*cfr.* Table 1 and Table 2). We perform 10 iterations for each of the scenarios and calculate the averages of the total area planted by GM and non-GM oilseed rape fields and the total area covered by buffer zones (parameter a_{bz} in equations 2 and 3) and GM-free oilseed rape fields (parameter a_{id} in equation 1).

Farmers capture GM rents by reducing weed control costs by planting HT oilseed rape and replacing their current conventional herbicide programs by glyphosate treatments. The net average cost saving engendered by the adoption of GM oilseed rape in the case study region, or the 'GM rent', has been estimated at about €56/ha [18]. Finally, 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 GM market price [19]. Therefore, at an IP premium of 6% and an average yield of 3.13 tons/ha recorded in the case study region during the period 2001-2004 [20], the IP rent of oilseed rape in our benchmark scenario is estimated at €42/ha.

IV. RESULTS

In Table 1, the 'Phase 1' rows report the 'static' coexistence management costs, expressed per hectare of GM oilseed rape, entailed by rigid coexistence regulations, such as isolation distances of 50 m (scenarios 1-5) and 100 m (scenarios 6-7) imposed on potential adopters. These costs represent the static opportunity costs for adopters that arise as a consequence of complying with official distance requirements (equation 1). The observed static costs amount to about €4/ha in our benchmark scenario and vary from roughly €3/ha in sparsely planted areas (scenario 4) to €9/ha in densely planted areas subject to more stringent regulations (scenario 7). Increasing the adoption rate lowers static per-hectare costs as the latter are amortized over a larger adopted area. Total static costs on the other hand follow an inverse U-shaped curve with a maximum around an adoption rate of 50%, confirming that the latter represents the most stringent scenario of coexistence (*cfr. supra*). Halving (doubling) the oilseed rape planting density reduces (doubles) static costs to €3/ha (€8/ha). Doubling the required isolation distance has a marginal effect on costs, illustrating the static nature of these costs (*cfr. infra*).

Table 1 suggests that static costs of rigid coexistence regulations are extremely sensitive to the incentives of coexistence, assuming that rational farmers compensate the lost GM rent with the IP rent (equation 1). Higher technology fees of GM seed lead to lower GM rents and hence lower static opportunity costs, ranging from €0.5 to roughly €2/ha. The opposite holds for lower technology fees (static costs of €5-17/ha). On the other hand, if IP price premiums rise, due to increasing demand for IP crops, static costs decline and become negative. If the IP rent is higher than the GM rent, farmers would not consider to plant GM crops and the coexistence issue would become irrelevant, *stricto sensu*.

In our benchmark scenario, the break-even point is estimated at about 8%, i.e. if IP premiums rise above this level, coexistence costs are zero. However, under low IP premiums rigid coexistence regulations would still entail significant static costs in the range of €6 to €23/ha. In other words, if consumers do not express their preferences in the market, imposing rigid coexistence rules is costly for society because it denies farmers access to potentially cost-reducing technologies. These findings suggest that rigid coexistence regulations are not proportional to the farmers' basic incentives for coexistence and hence not consistent with the objectives of the European Commission [1].

Table 1 Average costs of simulated rigid coexistence regulations under alternative scenarios. Areas and costs are averages, based on 10 random allocations of GM and non-GM OSR fields. Standard deviations are shown between brackets. Theoretically, negative coexistence costs would not exist and be zero as rational actors would not consider planting GM crops when the IP rent is higher than the GM rent (last column). The domino-effect expresses the relative difference in per cent between the cumulative value in Phase 4 and the value in Phase 1.

Phase	GM area (ha)	Adoption	GM-free area (ha)	Costs (€/ha)	Tech. fee +50%	Tech. fee -50%	IP prem. -50%	IP prem. +100%
Scenario 1								
Phase 1	280	50%	81	4.05 (1.12)	0.73	7.36	10.08	-8.02
Phase 2	199	36%	90	6.55 (2.26)	1.18	11.92	16.32	-12.99
Phase 3	190	34%	91	6.99 (2.40)	1.26	12.72	17.42	-13.86
Phase 4	189	34%	91	7.03 (2.38)	1.27	12.79	17.52	-13.94
Domino	-33%	-33%	+16%	+73% (33%)	+73%	+73%	+73%	+73%
Scenario 2								
Phase 1	137	25%	67	6.85 (1.89)	1.24	12.46	17.06	-13.58
Phase 2	70	13%	70	15.74 (8.04)	2.84	28.64	39.21	-31.20
Phase 3	67	12%	71	16.61 (8.14)	3.00	30.22	41.37	-32.92
Phase 4	66	12%	71	16.78 (8.03)	3.03	30.54	41.81	-33.27
Domino	-52%	-52%	+9%	+136% (55%)	+136%	+136%	+136%	+136%
Scenario 3								
Phase 1	410	75%	77	2.64 (1.20)	0.48	4.79	6.56	-5.22
Phase 2	333	61%	102	4.58 (2.86)	0.83	8.33	11.40	-9.07
Phase 3	308	56%	106	5.30 (3.56)	0.96	9.65	13.21	-10.51
Phase 4	303	55%	106	5.41 (3.69)	0.98	9.85	13.48	-10.73
Domino	-26%	-26%	+41%	+96% (59%)	+96%	+96%	+96%	+96%
Scenario 4								
Phase 1	131	50%	24	2.52 (1.25)	0.45	4.58	6.27	-4.99
Phase 2	107	41%	24	3.36 (2.07)	0.61	6.10	8.36	-6.65
Phase 3	107	41%	24	3.39 (2.11)	0.61	6.16	8.44	-6.72
Phase 4	107	41%	24	3.39 (2.11)	0.61	6.16	8.44	-6.72
Domino	-19%	-19%	+2%	+27% (19%)	+27%	+27%	+27%	+27%
Scenario 5								
Phase 1	548	50%	310	7.93 (1.12)	1.43	14.43	19.76	-15.72
Phase 2	238	22%	357	22.00 (6.00)	3.97	40.03	54.81	-43.61
Phase 3	191	17%	362	28.11 (7.93)	5.07	51.14	70.02	-55.72
Phase 4	186	17%	362	28.70 (7.74)	5.18	52.22	71.50	-56.90
Domino	-66%	-66%	+18%	+256% (55%)	+256%	+256%	+256%	+256%
Scenario 6								
Phase 1	280	50%	97	4.89 (1.16)	0.88	8.91	12.19	-9.70
Phase 2	182	33%	117	9.39 (3.04)	1.69	17.08	23.38	-18.61
Phase 3	162	29%	119	10.88 (3.89)	1.96	19.79	27.09	-21.56
Phase 4	161	29%	119	11.01 (4.01)	1.99	20.04	27.44	-21.84
Domino	-42%	-42%	+22%	+119% (44%)	+119%	+119%	+119%	+119%
Scenario 7								
Phase 1	548	50%	361	9.24 (1.07)	1.67	16.81	23.02	-18.32
Phase 2	187	17%	411	32.42 (8.14)	5.85	59.00	80.77	-64.28
Phase 3	136	12%	419	45.82 (12.13)	8.27	83.38	114.16	-90.84
Phase 4	128	12%	420	48.47 (11.68)	8.75	88.19	120.74	-96.08
Domino	-77%	-77%	+17%	+420% (93%)	+420%	+420%	+420%	+420%

The costs represented in the 'Phase 1' rows of Table 1 reflect the static effect of rigid coexistence rules on initial adoption intentions. However, they are not stable as they exclude the possibility of a dynamic domino-effect, unleashed by subsequent conversions of local adoption intentions in the landscape and first described by Demont et al. [18]. Table 1 shows the successive GM area restrictions that emerge for potential adopters in densely planted areas by complying with stringent rules. Under scenarios 5 and 7, for example, in a first phase a total area of 310-361 ha is identified which conflicts with pre-existing oilseed rape fields and restricts deliberate adoption. If farmers plant these areas with non-GM oilseed rape in an attempt to capture the IP rent, they potentially create new distance conflicts with other potential adopters, cancelling about 47-50 ha in a second phase. This process is repeated until the isolation distances between all GM and non-GM oilseed rape fields are respected, i.e. after four phases in our example. In the first phase, static coexistence costs amount to €8-9/ha. However, the domino-effect raises these costs to €29-48/ha, i.e. an increase of 256-420%, and restricts adoption to 12-17%.

Table 2 Average costs of simulated flexible coexistence measures under alternative scenarios. Costs are averages, based on 10 random allocations of GM and non-GM OSR fields. Standard deviations are shown between brackets.

Sc.	Adopt.	Planting density	Buffer width	System 1 costs (€/ha)			System 2 costs (€/ha)		
				Benchmark	Tech. fee +50%	Tech. fee -50%	Benchmark	IP prem. -50%	IP prem. +100%
1	50%	13%	10 m	0.35 (0.06)	0.28 (0.05)	0.42 (0.08)	0.26 (0.05)	0.13 (0.02)	0.52 (0.09)
2	25%	13%	10 m	0.78 (0.24)	0.62 (0.19)	0.94 (0.29)	0.49 (0.19)	0.25 (0.10)	0.98 (0.38)
3	75%	13%	10 m	0.22 (0.08)	0.17 (0.07)	0.26 (0.10)	0.20 (0.06)	0.10 (0.03)	0.39 (0.12)
4	50%	6%	10 m	0.24 (0.15)	0.19 (0.12)	0.29 (0.19)	0.18 (0.12)	0.09 (0.06)	0.36 (0.23)
5	50%	26%	10 m	0.84 (0.15)	0.67 (0.12)	1.01 (0.18)	0.63 (0.11)	0.31 (0.06)	1.26 (0.23)
6	50%	13%	20 m	0.95 (0.15)	0.75 (0.12)	1.14 (0.18)	0.71 (0.11)	0.36 (0.06)	1.42 (0.23)
7	50%	26%	20 m	2.22 (0.37)	1.76 (0.29)	2.68 (0.44)	1.66 (0.27)	0.83 (0.14)	3.33 (0.55)

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 [9,10], the theoretical possibility of the domino-effect on adoption intentions has been ignored. In contrast to rigid coexistence regulations, costs of flexible coexistence measures are at most €3/ha (Table 2) and hence significantly lower than static and dynamic costs of rigid coexistence regulations. They display a similar sensitivity to adoption rates, but are significantly more affected by high planting densities and distance requirements. We also observe that costs of flexible coexistence measures are proportional to the incentives of coexistence. If there is limited demand for coexistence, reflected by low or inexistent market premiums, potential GM adopters have incentives to negotiate flexible coexistence measures with their neighbours. Under System 2, compensation payments for buffer zones are negligible, i.e. €0.1-0.8/ha for IP premiums around 3%, and there is hardly any coexistence issue, *stricto sensu*. Rigid coexistence regulations on the other hand would still entail significant static costs of €6-23/ha (Table 1) by denying farmers access to cost-reducing technologies while they are not able to capture any significant compensatory IP rents. Moreover, a domino-effect may be unleashed in the landscape, further raising the dynamic costs of these regulations to €8-121/ha, and increasing their non-proportional character with respect to the incentives for coexistence. Due to the constrained randomization process, the variance of our cost estimates is low, reflected by the low standard deviations shown between brackets in Table 1 and Table 2.

The domino-effect is also likely to occur in less densely planted areas, although less pronounced. If we halve the OSR planting density to 6% (scenario 4), the domino-effect boosts static coexistence costs by 27% (compared to 256-420% in our worst-case scenarios). The radius of action and intensity of the domino-effect are essentially a function of (i) the degree of land fragmentation, (ii) the planting density of OSR in the landscape, (iii) the legally required isolation distance, and (iv) the IP rent. Surprisingly, the domino-effect is not a direct function of the crop and the trait; it only depends on the latter to the extent that scientific evidence on crop-specific gene flow influences regulatory decisions on distance requirements.

Although we analyzed a specific case study of OSR cultivation in the Beauce Blésoise region in Central France, some general observations can be made. First, for any given degree of land fragmentation, planting density and isolation distance, our cost estimates can be easily extrapolated to other regions, other countries and even other crop-trait combinations by accounting for differences in prices, yields and GM and IP rents. Further research is needed to relate the domino-effect to an index of land fragmentation and to reproduce our methodology in other landscapes and for other GM crops/traits. Secondly, our coexistence cost estimates are based on hypothetical random allocations of crops in a given landscape and, hence, represent the most stringent scenarios of coexistence in the region. In this context, our estimated opportunity costs may be interpreted as upper limits. On the other hand, by analyzing a single season, we implicitly assumed that farmers comply with the modelled coexistence measures and that these measures are sufficient for maintaining seed purity and limiting the development of volunteers over time. This is a strong assumption and would lead to complex management measures and additional costs which are not considered here. Moreover, our cost estimates are purely based on opportunity costs and do not include transaction costs of implementing coexistence measures. However, we can reasonably assume that in reality GM and non-GM farmers would probably try to coordinate their crop allocations in time and in space and would take decisions that minimize transaction costs in the long run. All resulting non-random actions, such as, e.g., clustering, would tend to reduce total coexistence costs.

V. CONCLUSIONS

The trade-off between adopting GM varieties versus identity preservation of non-GM varieties 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 significant price premiums for them, will some farmers have an incentive to supply IP crops. If the opposite holds, there is no coexistence issue *stricto sensu* and coexistence costs will purely reflect the costs of compliance to EU coexistence laws instead of the economic incentives for coexistence.

So far, countries that grow significant area to GM crops have seen little premiums at the farm level. The price differentials for non-GM crops varied from almost zero (Brazil) to 1-3% in the USA and Canada [21]. Similarly, no price premium has emerged in international oilseed rape markets, but this might change if availability of non-GM supplies declines due to worldwide adoption of GM varieties [22-23]. However, if market signals for IP oilseed rape remain weak, incentives for agglomeration would be limited and rigid coexistence regulations would entail significant opportunity costs for potential adopters of GM varieties in a landscape with scattered non-GM fields.

According to a recent Communication from the European Commission 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].

We developed a modelling framework for analyzing the farm level costs of managing spatial coexistence of GM and non-GM crops, which explicitly takes into account the incentives for coexistence, and applied it on the hypothetical case of GM oilseed rape cultivation in the Beauce Blésoise region in Central France. Our analysis shows that rigid regulations, such as large isolation distances violate the proportionality condition and jeopardize the ability of farmers to adopt and utilize GM crops, due to the possibility of a dynamic domino-effect in the landscape. These empirical findings have been ignored in the current literature and 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 since they are proportional to the incentives for coexistence and, hence, less counterproductive for European agriculture.

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