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The Formation of GM-free and GM Coasean clubs

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The unintended presence of traces of genetically modified (GM) crops in the harvests of conventional crops plays a prominent role in the debate over the coexistence of GM and conventional crops. One way to address the issue is the formation of GM-free or GM-only clubs. We model the decisions of individual farmers to cultivate either GM or conventional crops and combine this with a game theoretic model of club formation to investigate the feasibility of clubs. We consider two liability regimes: GM farmers are liable or they are not. We also consider two benchmarks: Nash equilibrium without negotiations and the efficient configuration as well as partial cooperation through Coasean clubs. We find that relatively large clubs can form but they are not always necessary.

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1 Introduction

Although the societal debate on genetically modified (GM) food and feed is far from settled, GM and conventional crops are grown all over the world, often close together. In the European Union and the United States, as well as many other states and regions of the world, there is an increasing call to guarantee both producers and consumers of agricultural products their freedom of choice. For example, in its recommendation on guidelines for coexistence the European Commission (2010) states: "In principle, farmers should be able to cultivate the types of agricultural crops they choose – be it GM crops, conventional or organic crops." In the same document the Commission also notes that: "This possibility should be combined with the wish of some farmers and operators to ensure that their crops have the lowest possible presence of GMOs [genetically modified organisms]" (2010: 3). Finally it also wants "to provide European consumers with a choice between GM food and non-GM food" (2010: 3).

In order to offer a choice between GM and non-GM food, both food types have to be supplied through segregated supply chains. A few important implications arise from this need for segregation. First, the crops produced with each system have to be separated throughout the supply chain, and this separation starts at the farm level. Second, as consumers are unable to determine for themselves the origin of products, whether organic, conventional or GM, the products have to be labeled. Moreover, it is generally agreed that consumers are willing to pay a price premium for non-GM products, although its size is debated (Scatasta, Wesseler and Hobbs, 2007). Clearly, if farmers are able to capture a part of this premium, they have an incentive to separate their crops. Cultivating GM crops, in contrast, often provides a cost or yield advantage (Qaim, 2009).

A problem, however, is that GM crops can accidentally cross-pollinate nearby conventional varieties. This is called adventitious presence. If these fields are owned by different farmers, and the neighbors can no longer capture the price premium due to the adventitious presence, an external effect is present. As has been pointed out by Coase (1960), this externality is reciprocal: the farmer cultivating GM crops (henceforth "GM farmer") causes an external effect by planting GM crops and causing adventitious presence. One could, however, equally argue that the farmer cultivating conventional crops (henceforth "conventional farmer") causes an external effect by planting a conventional crop near a GM field, thus risking adventitious presence. Who has to bear the costs is an issue which is set by the property rights system that is in place. In Europe, GM farmers are generally liable for adventitious presence. In the US and Canada, the system is reversed and the problem mainly occurs for organic farming sold under certain private labels that require no adventitious presence. The US Department of Agriculture's organic label allows adventitious presence (Beckmann, Soregaroli and Wesseler, 2011). Farmers can reduce the probability of adventitious presence by taking ex-ante coexistence measures such as buffer zones, isolation distances, and differences in sowing time. The costs of these measures, too, are borne by the liable party. Another way is the formation of voluntary clubs that agree amongst each other to cultivate only one variety, possibly compensating other farmers in the landscape to do the same.

Voluntary clubs initiated by farmers are of interest under both liability regimes. If GM farmers are not liable, as in the US and Canada, conventional or organic farmers could form a club and only cultivate conventional or organic crops. This would allow them to have access to the previously described price premium, with a lower risk of losing it due to adventitious presence. Moreover, these clubs would reduce the costs of ex-ante coexistence measures. In the US, for example, organic farmers have dealt with these issues through cooperative agreements (see McEvoy, 2013).

Such GM-free clubs have been investigated by Furtan, Güzel and Weseen (2007). In their model, organic farmers form a club, drawing up a binding agreement to cultivate only organic crops. Furthermore, the club buys out former GM farmers to establish a buffer zone of conventional cultivation around its land. Furtan, Güzel and Weseen (2007) find that such clubs are feasible, in the sense that the captured premium is enough to compensate the former GM farmers. They do not, however, consider the individual incentives of farmers to join or exit such clubs.

If, in contrast, GM farmers are liable for adventitious presence, as in Europe, they could form a club and agree among each other to cultivate only GM crops in their region. This would allow them to have access to the superior GM variety and reduce both the ex-ante costs of the coexistence measures and the expected costs of ex-post liability.[1] An example of such a club in Portugal is described in Skevas, Fevereiro and Wesseler (2010). Moreover, if some of the farmers in that region still had a preference for conventional crops, the cost savings

[1] An interesting feature in Europe is that there are GM-free regions too, even though GM farmers would be liable in case of adventitious presence. This suggests that either the farmers do not trust the legal system (e.g. because of the difficulty of proof or high up-front costs) or that these regions are formed out of other concerns, such as tourism or social pressure. These are some of the main reasons found in the analysis of Consmüller, Beckmann and Petrick (2012).

introduced through the reduced ex-ante and expected ex-post costs could be used to compensate them.

Under both liability regimes the clubs reduce the ex-ante coexistence costs and mitigate the risks of adventitious presence of GM crops in conventional fields. If GM farmers are non-liable, these clubs thus reduce potential price premium losses of conventional farmers; if GM farmers are liable, clubs reduce the probability and amount of compensation payments to be paid by GM farmers. The problem for any club is that farmers outside the club enjoy the benefits, that is, the advantages of a reduction in the probability of adventitious presence, without bearing the costs. Consequently, there exists a free-riding problem and it may prove difficult to form a club that can solve the externality problem completely.

Clubs and the associated free-rider problem have received relatively little attention in the coexistence literature. To the best of our knowledge only the previously mentioned Consmüller, Beckmann and Petrick (2012), Furtan, Güzel and Weseen (2007), and Skevas, Fevereiro and Wesseler (2010) address clubs, but they do not consider strategic incentives and free-riding.

Beckmann and Wesseler (2007) and Beckmann, Soregaroli and Wesseler (2011) addressed spatial incentives due to adventitious presence in general. They found that the boundary between choosing one crop type or another shifts depending on the division of property rights between GM and non-GM farmers. Beckmann and Wesseler (2007) do consider a number of technical measures to reduce the damage. They do not, however, consider explicit spatial measures or the possibility of club formation. Groeneveld, Wesseler and Berentsen (2013) study the combination of spatially explicit measures and individual farmers' cultivation choices, and how these depend on the crop choices of their neighbors. They studied the incentives associated with a minimum distance requirement between GM and non-GM cultivation in the dairy industry and found that minimum distance requirements had a domino effect in causing farmers to switch to other crop types. The analysis of Groeneveld, Wesseler and Berentsen (2013) comprises a case study of Dutch dairy and therefore they only consider one liability regime and no club formation.

In this paper we use the basic model of Beckmann and Wesseler (2007) to model the individual farmers' decisions and extend it in two directions: (1) we make the model completely spatially explicit, and (2) we use it to investigate the possibility of forming a GM-only or GM-free club in the landscape. Whether a GM-only or GM-free club is formed depends on the liability regime, as described above. Such a club is formed to mitigate problems of adventitious presence and engages in Coasean bargaining, hence the name Coasean clubs.

In contrast to Furtan, Güzel and Weseen (2007) we take a strategic approach, that is, we look at the incentives for farmers to join a club, or to leave it once it has been formed. These incentives are investigated through the notion of cartel stability, first described by D'Aspremont *et al.* (1983) and later used in the environmental and resource agreements literature (see, e.g., Dellink, Finus and Olieman, 2008; Pintassilgo *et al.*, 2010; Weikard, 2009). The new contribution of this paper is therefore the consideration of strategic incentives in club formation in a spatially explicit model under both liability regimes. To the best of our knowledge we are also the first to investigate the potential problem of free-riding for GM-only and GM-free clubs.

We proceed as follows: We first introduce the basic farmer decision model in two variants: when the GM farmer is not liable and when liable. We then consider two benchmarks: the Nash equilibrium without negotiations, and an efficient configuration. Then clubs are introduced, and we investigate their stability. Because the analytical results of club stability are inconclusive, we then conduct simulations to investigate the stability of clubs and what they achieve in terms of efficiency. The last section discusses the results and concludes the paper.

2 Model description

2.1 A model of farmers' decisions

2.1.1 Preliminaries

In this paper we extend the model by Beckmann and Wesseler (2007) so that it becomes fully spatially explicit and directly accounts for adventitious presence as the source of a reduction in the price premium. We assume farmers have a single field that they can plant with either a GM crop or a conventional crop. We will assume that the conventional crop commands a price premium over the GM crop, whereas the GM crop is cheaper to produce. More formally, we have a landscape that contains a set N of farmers, denoted i.

The price a farmer $i \in N$ can claim given the quality of the crop is p^G for the GM crop and p^C for the conventional crop. Although prices would in principle be farmer specific, due for instance to quality differences, we do not consider these differences in this model. Without loss of generality, we normalize the cost of producing GM crops to zero, and denote the additional costs of cultivating conventional crops for farmer *i* as c_i. If both costs and prices are equal across farmers, there would be no externality effect because all farmers either plant GM or conventional crops, depending on the price premium and additional costs. However, often farmers do not face identical conditions due for instance to differences in land quality, managerial quality and machinery owned.

In the absence of adventitious presence, an individual farmer *i* will choose conventional crops if per unit of production:

$$p^C - c_i \geq p^G, \tag{1}$$

and will choose GM crops otherwise. We further divide the set *N* into two fixed subsets Φ and *X*, $\Phi \subseteq N$, $X \subseteq N$, defined through condition (1):

$$\begin{aligned} \Phi &= \{i \in N | \Delta p \geq c_i\} \\ \mathrm{X} &= \{i \in N | \Delta p < c_i\}, \end{aligned} \tag{2}$$

where $\Delta p = p^C - p^G$. The subsets Φ and X are independent of the actual cultivation decisions by farmers, which may change because of the presence of the externality.

The externality is introduced in the basic model through a potential reduction in the price premium due to adventitious presence. If GM farmers are not liable, the costs of this potential reduction is borne by the conventional farmers; if GM farmers are liable, they bear the costs. We divide the set of farmers *N* into two subsets, *F* and *G*, which describe the cultivation decisions of the farmers. The set *F* consists of $i \in N$ that choose to cultivate conventional crops. The set *G* consists of $i \in N$ that choose to cultivate GM crops. These sets *F* and *G* are dynamic in the sense that they change if a farmer switches from conventional to GM or vice versa. Given that GM crops are often the new trait or variety, if a farmer moves from set *F* to set *G*, we will refer to such a move as "switching", that is, switching from cultivating conventional crops to GM crops. Moving from set *G* to set *F*, in contrast, will be referred to as "reverting".

We denote the probability that farmer *i* is affected by farmer *j* as α_{ij}. Equivalently, we can think of α_{ij} as the proportion of the harvest of farmer *i* that is affected because farmer *j* produces GM crops. In principle α_{ij} can be influenced by technical measures and is distance dependent. Moreover, it depends on the cultivation decisions *F* and *G*.

$$\alpha_{ij} = \begin{cases} 0 \text{ if } i \in G \text{ or } j \in F \\ \quad f(d_{ij}) \end{cases}, \tag{3}$$

where $f(d_{ij})$ is a monotonically decreasing function of the distance d_{ij} between farmer *i* and *j*. Then, given α_{ij} and the cultivation decisions, the probability that farmer *i* is *not* affected is:

$$A_i = \prod_{j \in N} (1 - \alpha_{ij}) \;\; \forall i \in N. \tag{4}$$

The profits of farmers depend on the liability regime and their crop choice. We introduce the double superscripts *l* to indicate that GM farmers are liable, and *n* for when they are not.

2.1.2 GM farmers not liable

When GM farmers are not liable for adventitious presence, the harvest of nearby conventional farmers may have to be sold as GM crops, due to adventitious presence. Therefore the expected profit of a conventional and a GM farmer per unit of production are respectively:

$$\begin{aligned} \pi_i^{C^n} &= A_i p^C + (1 - A_i) p^G - c_i = A_i \Delta p + p^G - c_i \;\forall i \in F, \\ \pi_j^{G^n} &= p^G \;\; \forall j \in G. \end{aligned} \tag{5}$$

2.1.3 GM farmers liable

When GM farmers are liable for adventitious presence, they have to compensate all the conventional farmers that they affect for the damage incurred by conventional farmer *i*, that is, Δp per unit of crop. We assume joint liability, that is, the source of adventitious presence, if it occurs, is not perfectly observable and consequently all GM farmers have to pay a share of the damage, proportional to the probability that they caused this damage. The probability that farmer *i* suffers from adventitious presence is $(1 - A_i)$. The total expected compensation that GM farmer *j* has to pay is then:

$$\sum_{i \in N} \frac{\alpha_{ij}(1 - A_i)\Delta p}{\sum_{k \in N} \alpha_{ik}} = D_j \Delta p, \tag{6}$$

where $D_j = \sum_{i \in N} \frac{\alpha_{ij}(1-A_i)}{\sum_{k \in N} \alpha_{ik}}$. Consequently the expected profits of a conventional and a GM farmer per unit of production are respectively:

$$\begin{aligned} \pi_i^{C^l} &= p^C - c_i = \Delta p + p^G - c_i \;\forall i \in F, \\ \pi_j^{G^l} &= p^G - D_j \Delta p \;\forall j \in G. \end{aligned} \tag{7}$$

We now consider two benchmarks: the Nash equilibrium when no negotiations take place and an efficient configuration. When no negotiations take place each farmer optimizes their payoff, given the behaviour of others. In the Nash equilibrium farmers do not coordinate their cultivation choices and do not compensate each other to switch or revert. Equivalently, one can consider this as a case where transaction costs are infinitely high. As Beckmann, Soregaroli and Wesseler (2011) show, this results in an increase in the type of cultivation that gets the property rights. In an efficient configuration the farmers maximize the sum of their payoffs, and the cultivation decisions under both systems of property rights should be equivalent, given zero transaction costs.

2.2 The Nash equilibrium without negotiations

2.2.1 GM farmers not liable

In our model farmers choose either GM or conventional crops; consequently we are dealing with an integer problem. The marginal effect *ME* from switching from conventional to GM crops for farmer *k* is therefore, from (5):

$$ME = p^G - \left(A_k \Delta p + p^G - c_k\right) = c_k - A_k \Delta p. \quad (8)$$

The marginal benefits of switching to GM are the incremental costs saved when farming GM, the marginal costs are the expected realized price premium that is given up. Consequently a farmer *k* will switch from conventional to GM if $c_k > A_k \Delta p$. In the Nash equilibrium no individual player has an incentive to deviate. Therefore, in the Nash equilibrium, when GM farmers are not liable the following must hold:

$$\begin{aligned} c_i &\leq A_i \Delta p \ \forall i \in F^{*^n} \\ c_j &\geq A_j \Delta p \ \forall j \in G^{*^n}, \end{aligned} \quad (9)$$

where F^{*^n} and G^{*^n} denote the equilibrium sets with cultivation decisions when GM farmers are not liable. Appendix 1 establishes that equilibrium (9) always exists. The equilibrium is not necessarily unique. Since the set $\Phi = \{i \in N | \Delta p_i \geq c_i\}$, whereas $F^{*^n} = \{i \epsilon N | A_i \Delta p_i \geq c_i\}$ and $0 \leq A_i \leq 1$, F^{*^n} is a subset of Φ. The presence of the externality requires that farmers account for the expected price premium rather than the price premium itself. In this Nash equilibrium, farmers cultivate conventional crops only if the expected price premium is larger than the additional costs of conventional crops. Thus the number of GM farmers is the same or higher than in the absence of the externality.

A rather unusual feature of our model is that the marginal costs of switching go *down* when the number of GM farmers is increasing. The reason is that the expected revenue from cultivating conventional crops decreases with an increasing number of GM farmers. This also implies that some sort of a domino effect can be present: it may only pay for some farmers to switch once a number of others have switched.

2.2.2 GM farmers liable

If the property rights lie with the conventional farmer, the marginal effect from switching for farmer k is:

$$\begin{aligned} ME &= \left(p^G - D_k\Delta p\right) - \left(\Delta p \quad + p^G - c_k\right) \\ &= c_k - (1 + D_k)\Delta p. \end{aligned} \tag{10}$$

The marginal benefits of switching to GM are the incremental costs saved when farming GM, the marginal costs are the price premium that is given up plus the expected compensation paid to other conventional farmers. In the Nash equilibrium no individual player has an incentive to deviate. Therefore in the Nash equilibrium where the GM farmers are liable, the following must hold:

$$\begin{aligned} c_i &\leq (1 + D_i)\Delta p \ \forall i \in F^{*^l} \\ c_j &\geq \left(1 + D_j\right)\Delta p \ \forall j \in G^{*^l}, \end{aligned} \tag{11}$$

where F^{*^l} and G^{*^l} denote the equilibrium cultivation decisions when GM farmers are liable. Appendix 1 establishes that equilibrium (11) always exists. The equilibrium is not necessarily unique. Since the set $\mathrm{X} = \{i \in N|\Delta p_i < c_i\}$, whereas $G^{*^l} \ = \left\{i \in N\middle|\left(1 + D_j\right)\Delta p_i < c_i\right\}$ and $D_j \geq 0 \ \forall i \in N$, G^{*^l} is a subset of X. In this Nash equilibrium, farmers cultivate GM crops only if the additional costs of conventional farming are larger than a multiple of the price premium. Obviously, under this property rights regime, switching is less attractive: not only does a switching farmer give up the full price premium, but in addition compensation must be paid to conventional neighbors. Thus the number of GM farmers is the same or lower than it would be in the absence of the externality. Consequently, when there are no negotiations and everyone optimizes their own payoff, an individual finds it generally more attractive to cultivate the crop type that has the property rights.

2.3 *The efficient configuration*

In an efficient configuration we sum the profits of all farmers in a region. In that case all external effects are internalized and the final results are the same for both systems of property rights in terms of the configuration, although the distribution of benefits and costs over the individual farmers is different. When GM farmers are not liable, total profits *W* are:

$$W = \sum_{i \in F} \left(A_i \Delta p + p^G - c_i \right) + \sum_{j \in G} p^G . \tag{12}$$

The marginal effect *ME* on total profit *W* of farmer *k* switching from conventional to GM crops is:

$$ME = c_k - A_k \Delta p - \sum_{i \in N} (\alpha_{ik} A_i \Delta p). \tag{13}$$

The marginal benefits to society of a switching farmer consist of c_k, the original additional costs of farmer *k* when cultivating conventional crops. The marginal costs consist of the expected price premium lost by farmer *k* plus the sum of the additional reduction in price premium of all the other conventional farmers, which is the external effect. Although the last term in (13) is summed over the full set *N*, $\alpha_{ik} = 0 \; \forall i \in G$, and hence the reduction in price premium only applies to conventional farmers. In an efficient configuration, switching continues until the marginal costs exceed the marginal benefits, that is, in an efficient configuration the following holds:

$$\begin{aligned} c_i &\leq A_i \Delta p + \sum_{l \in N} (\alpha_{li} A_l \Delta p) \;\; \forall i \in F^E \\ c_j &\geq A_j \Delta p + \sum_{l \in N} \left(\alpha_{lj} A_l \Delta p \right) \;\; \forall j \in G^E, \end{aligned} \tag{14}$$

where F^E and G^E denote the efficient cultivation decisions.

According to the Coase theorem, in the absence of transaction costs, the efficient solution can be reached independently of the initial allocation of property rights. To see this, assume we allocate the property rights to the conventional farmers and sum all profits:

$$\begin{aligned} W &= \sum_{i \in F} \left(\Delta p + p^G - c_i \right) + \sum_{j \in G} \left(p^G - D_j \Delta p \right) = \\ &\sum_{i \in F} \left(\Delta p + p^G - c_i \right) + \sum_{j \in G} \left(p^G - \sum_{i \in N} \left((1 - A_i) \Delta p \right) \right). \end{aligned} \tag{15}$$

Note that by (3) $A_i = 1, \forall i \in G$. The corresponding marginal effect from a conventional farmer k switching to GM crops is:

$$ME = c_k - A_k \Delta p - \sum_{i \in N} \alpha_{ik} A_i \Delta p. \quad (16)$$

Note that although the switching farmer is losing the full price premium when switching, the net effect is only the expected price premium because the rest is a transfer from the GM farmers. The last term is the increase in compensation the GM farmers now have to pay because the probability of adventitious presence has increased for the remaining conventional farmers. Because the marginal effect is the same, the optimum must also be the same.

An efficient configuration is not necessarily privately optimal; the individual profit considerations of some farmers might lead them to switch or revert. If $\forall j \in G$ it holds that both $c_j \geq A_j \Delta p$ and $c_j \geq A_j \Delta p + \sum_{i \in N} \alpha_{ij} A_i \Delta p$, and the reverse for $\forall i \in F$, then the Nash equilibrium $\{F^{*^n}, G^{*^n}\}$ coincides with $\{F^E, G^E\}$. Similarly if $\forall j \in G$: $c_j \geq (1 + D_j)\Delta p$ and $c_j \geq A_j \Delta p + \sum_{i \in N} \alpha_{ij} A_i \Delta p$ hold, and the reverse for $\forall i \in F$, then the Nash equilibrium $\{F^{*^l}, G^{*^l}\}$ coincides with $\{F^E, G^E\}$. Both are likely to happen in extremes, that is, when additional costs of cultivation are high (small) and price premiums are small (large). In these situations the external effect is dominated by the other economic forces.

If all farmers could negotiate together and compensate each other through multilateral agreements the externality could be internalized. However, it is unlikely that transaction costs are absent in this case because many agents are involved, and in some cases agreements between multiple farmers are required to settle the compensation. In the next section we investigate whether partial cooperation through clubs is feasible.

3 The formation of Coasean clubs

3.1 Preliminaries

If conventional farmers are liable, a number of them may form a club, pool their profits and compensate a number of GM farmers to revert to conventional farming. This will increase their profits because it lowers the probability that their harvests will be affected by adventitious presence. However, such a club also increases the profits of the conventional farmers outside the club. Thus there is an incentive to free-ride. Similarly, if GM farmers are liable they may form a club, pool their profits, and compensate a number of conventional farmers to switch to GM.[2] This reduces the expected compensation to be paid, but again this holds for GM farmers both inside and outside the club, with possible free-riding effects.

We assume that a single club can be formed among the players with the largest incentive to form a club. Thus if GM farmers are not liable, the potential club members are those farmers for whom $\Delta p > c_i$ holds (set Φ), and if GM farmers are liable, the farmers for whom $\Delta p < c_i$ holds (set X). We will assume open membership, that is, current members cannot bar entry of other farmers that want to join the club.

Club formation is modeled as a three-stage game. In the first stage the farmers in set Φ (X) announce their membership decisions. In the second stage the club members $S \subset \Phi$ ($T \subset \mathrm{X}$) engage in Coasean bargaining with all members of set X (Φ), maximizing the sum of the profits of the club members and the farmers in set X (Φ). In the third stage non-members pick their cultivation type independently. The game is solved through backward induction.

We introduce Coasean bargaining in the second stage of the game to abstract from the issue of modeling the actual bargaining process, as well as the order of offers, and the size of the side payments. We assume that farmers will simply switch or revert if the farmer in question gets at least the profit difference between GM and conventional cultivation. The farmers addressed in this bargaining process have a dominant strategy to cultivate the other type, unless they are bought out, and hence there is no preemptive behavior. Finally, because not all farmers are involved in the club the outcome is not necessarily fully efficient.

We define a partition function that assigns a payoff to every player outside the club as well as to the club as a whole. The stability of a club is investigated with cartel stability concepts originally derived by D'Aspremont *et al.* (1983). A club of S members is internally stable if no member in the club can gain by leaving the club, that is,

$$V_k(S) \geq V_k(S \backslash k) \quad \forall k \in S, \tag{17}$$

where $V_k(S)$ is the payoff to club member k if in club S and $V_k(S \backslash k)$ is the payoff to club member k if not a club member, but the rest of the club stays intact. Similarly a club is externally stable if no player outside the club can gain by joining the club:

$$V_o(S) > V_o(S \cup o) \quad \forall o \in F \backslash S, \tag{18}$$

[2] Alternatively farmers may form a club to set up a fund to compensate affected conventional farmers. However, this would require a different model formulation and the similarities between the liability regimes would be lost. In addition, it may be cheaper to buy out conventional farmers.

where $V_o(S \cup o)$ is the payoff to club member o who joins club S.[3] Thus stability is based on a Nash conjecture of the first stage of the game.

Clearly internal and external stability depend on the sharing rule used within the club. We do not specify an explicit sharing rule but use the Claim Rights Condition (CRC) (Weikard, 2009). A club is internally stable if each member can be paid at least the amount received if leaving the club (the "claim"). The remaining surplus can then be shared in any arbitrary way. Thus for the CRC to be satisfied we must have:

$$\sum_{k \in S} V_k(S) \geq \sum_{k \in S} V_k(S \backslash k). \qquad (19)$$

Moreover, as Weikard (2009) shows, a club is externally stable if it cannot be enlarged to a club that satisfies the CRC. This guarantees the existence of at least one Nash equilibrium in the first stage, if the Nash equilibrium in the last stage is unique for each club that could form.

The use of the CRC and Coasean bargaining in the second stage also allows us to establish the following theorem:

Theorem 1:

When clubs are formed by the farmers in set Φ (X), the result of the CRC when all farmers in set X (Φ) are considered club members is equivalent to the result of the CRC when only those farmers in set X (Φ) that are bought out are considered members and equivalent to the result of the CRC when none of the farmers of set X (Φ) are considered members.

Proof: see Appendix 1.

The intuition is that when farmers $S \subseteq \Phi$ form the club, the farmers of set X always have the same claim: p^G, and they are only bought out if the sum of the gains of the S farmers in the club outweighs the required compensation.

We use this feature within our simulations, but for clarity of the presentation we will not consider bought-out farmers as club members when we present our results, analytical or otherwise. Thus bought-out farmers or the wider set of farmers considered in Coasean bargaining are not considered or referred to as members. In contrast to the literature on environmental and fisheries agreements (e.g., Finus, 2003; Pintassilgo *et al.*, 2010), we do,

[3] The tie-breaking rule is introduced following Weikard (2009).

however, allow for a club size 1, that is, an individual farmer trying to negotiate with neighbors.[4]

3.2 Analysis

3.2.1 Conventional clubs

Conventional clubs form when GM farmers are non-liable, hence the profit functions used for individual farmers are those in (5). If a number of conventional farmers form a club $S \subseteq \Phi$, pool their profits, and buy out $H \subseteq \mathrm{X}$ GM farmers, the club earns:[5]

$$\pi^S = \left(\sum_{i \in S} (\pi_i)\right) + \left(\sum_{h \in H} (A_h \Delta p - c_h)\right). \tag{20}$$

The first term of (20) is left unspecified because it is in principle possible that a member of S cultivates GM crops. The last term is negative because $H \subseteq \mathrm{X}$ and $\mathrm{X} = \{i \in N | \Delta p < c_i\}$, and $0 \leq A_i \leq 1 \; \forall i \in N$. This term constitutes the compensation payments to the reverted GM farmers.

In the second stage of the game the club S maximizes:

$$\max(\pi^S + \sum_{i \in \mathrm{X}} \pi_i). \tag{21}$$

For the remaining singletons the conditions in (9) still apply. As a result the Nash equilibrium in the last stage can be characterized as follows:

[4] As a consequence in the literature on environmental agreements, there are $2^{|\Phi|} - |\Phi| \; (2^{|\mathrm{X}|} - |\mathrm{X}|)$ possible clubs; in our model there are $2^{|\Phi|} \; (2^{|\mathrm{X}|})$ possible clubs

[5] By Theorem 1 and the fact that we use Coasean bargaining we could have equally formulated the profits of the club as including the bought-out GM farmers as members, or even all GM farmers in set X. The stability results would have been the same.

$$\forall i \in F^{*^{CC}} \begin{cases} \{c_i \leq A_i \Delta p\} \ \& \ \{i \in \Phi \backslash S\} \text{ or} \\ \left\{ c_i - A_i \Delta p \leq \sum_{l \in S \cup X} \left(\alpha_{li} A_l \Delta p + \sum_{k \in \Phi \backslash S} \alpha_{ki} A_k \Delta p \right) \right\} \ \& \ \{i \in (S \cup X)\} \end{cases}$$

$$\forall j \in G^{*^{CC}} \begin{cases} \{c_j \geq A_j \Delta p\} \ \& \ \{j \in \Phi \backslash S\} \text{ or} \\ \left\{ c_j - A_j \Delta p \geq \sum_{l \in S \cup X} \left(\alpha_{lj} A_l \Delta p + \sum_{k \in \Phi \backslash S} \alpha_{ki} A_k \Delta p \right) \right\} \ \& \ \{j \in S \cup X\} \end{cases} \quad (22)$$

where $F^{*^{CC}}$ and $G^{*^{CC}}$ denote the Nash equilibrium decisions of the last stage when conventional clubs are present. The intuition behind this equilibrium is as follows: Farmers that are not a member of club *S* or targeted by club *S* in Coasean bargaining still follow the conditions in (9). Members of *S* or those targeted in Coasean bargaining will only cultivate conventional crops if the compensation payment required not to cultivate GM crops is smaller than the marginal external effect their GM cultivation would have on *S* plus the effect of other farmers that will revert as a consequence of this buyout. The last effect is accounted for because the club moves first with its Coasean bargaining. The equilibria in (22) include the efficient solution and Nash equilibrium without negotiations as special cases for $S = \Phi$ and $S = \emptyset$ respectively.

Having established the equilibrium in the last stages, we move to the first stage. The stability of club *S* depends on the outside option payoffs. The outside option payoff of the conventional farmer *i* is the payoff received if club *S**i* is formed. Summing all claims we find:

$$\sum_{i \in S} \left(A_i' \Delta p + p_i^G - c_i \right) \quad (23)$$

where $A_i' \Delta p$ denotes the expected price premium of farmer *i* in the last stage of the game when the club *S**i* is formed, that is, when free-riding. If we deduct (23) from (20) we find the following condition for the claim rights condition:

$$\sum_{i \in S} \left((A_i - A_i') \Delta p \right) + \sum_{h \in H} \left(A_h \Delta p - c_h \right) > 0. \quad (24)$$

In (24) the first term is the sum of the gains of the club members relative to being outside of the club, whereas the last term is the compensation payments made to the bought-out GM farmers. Recall that the last term of (24) is always negative. Thus for a club to be stable, the sum of the gains from joining club *S* of all members $i \in S \subseteq \Phi$ must be larger than the sum of compensation payments. Moreover, clubs are more likely to be stable if they achieve more than the clubs that form with one member less. In contrast, if a club without this farmer achieves exactly the same, there is no reason to join the club, as one will be obliged to be involved in the compensation payments without any additional gains.

3.2.2 GM clubs

If the GM farmers are liable, the payoff functions of the farmers change. If a club $T \subseteq X$ of GM farmers compensates $U \subseteq \Phi$ conventional farmers, the club earns:

$$\pi^T = \left(\sum_{u \in U} (c_u - (1 + D_u)\Delta p)\right) + \left(\sum_{t \in T} \pi_t\right). \tag{25}$$

The first term of (25) is the total of compensation that has to be paid to farmers that the club buys out. Since $U \subseteq \Phi = \{i \in N | \Delta p \geq c_i\}$ and $D_i \geq 0 \ \forall i \in N$, this first term is negative. The last term is again unspecified, for reasons given above.

In the last stage the conditions in (11) still apply to the remaining singletons, whereas in the second stage the club maximizes:

$$\max(\pi^T + \sum_{i \in \Phi} \pi_i). \tag{26}$$

Therefore the equilibrium in the third stage can be characterized as follows:

$$\forall i \in F^{*^{GC}} \begin{cases} \{c_i \leq (1+D_i)\Delta p\} & \& \{i \in X \backslash T)\} \text{ or} \\ \left\{(1+D_i)\Delta p - c_i \geq \sum_{t \in T \cup \Phi} (D_t - D_t{}')\Delta p\right\} & \& \{i \in (T \cup \Phi)\} \end{cases}$$
$$\forall j \in G^{*^{GC}} \begin{cases} \{c_j \geq (1+D_j)\Delta p\} & \& \{j \in X \backslash T\} \text{ or} \\ \left\{(1+D_j)\Delta p - c_j \leq \sum_{t \in T \cup \Phi} (D_t - D_t{}')\Delta p\right\} & \& \{j \in (T \cup \Phi)\} \end{cases} \tag{27}$$

where $D_t{}'$ denotes the new damage payments for $t \in T \cup \Phi$, when the player switches. $F^{*^{GC}}$ and $G^{*^{GC}}$ denote the Nash equilibrium decisions of the last stage when GM clubs are present. The intuition behind this equilibrium is as follows: Farmers that are not a member of club *T* or targeted by club *T* in Coasean bargaining still follow the conditions in (11). Members of *T* or those targeted in Coasean bargaining will only cultivate GM crops if the compensation payment required not to cultivate conventional crops is smaller than the marginal external effect their conventional cultivation would have on *T*. This effect consists of four parts: the reduction in payments from *T* to *j* because *j* no longer cultivates conventional crops; the reduction in payments to other conventional farmers because the total burden is shared by more GM farmers; an increase in payments because of the additional adventitious presence; and a decrease because of the other conventional farmers that will revert as a result of the buying out (see Appendix 1 for details). The last effect is accounted for because the club moves first with its Coasean bargaining. The equilibria in (22) include the efficient solution and Nash equilibrium without negotiations as special cases for *T* = X and *T* = ∅ respectively.

Having established the equilibrium in the last stages, we move to the first stage. The stability of club *T* depends on the outside option payoffs. The outside option payoff of the farmers in club *T* is the payoff they get if a club is formed with the same GM farmers, but without them personally. Summing all claims we find:

$$\sum_{j \in T} \left(p_j^G - D_j{}'\Delta p\right) \tag{28}$$

where $D_j{}'\Delta p$ denotes the expected compensation to be paid by *j* if *j* leaves club *T*, that is, when free-riding. If we deduct (28) from (25) we find the following condition for the claim rights condition:

$$\sum_{k\in U}(c_k - (1 + D_k)\Delta p) + \sum_{j\in T}(D_j{}' - D_j)\Delta p > 0. \quad (29)$$

The first term of (29) is the total compensation that has to be paid to farmers that the club buys out; the second term is the reduction in the compensation that has to be paid to conventional farmers if farmer *j* joins the club. The first term is always negative, whereas the second term is positive if a larger club achieves more than any of the smaller ones, and zero otherwise. Thus, for a club to be stable, the sum of the gains from joining club *T* in reducing the compensation payments to conventional farmers must be larger than the sum of compensation payments within the club.

The intuition is similar to that for conventional clubs. Clubs are more likely to be stable if they achieve more than smaller clubs; if not, there is no reason to join.

3.3 Simulations

3.3.1 Parameter initial values

Within the previous model, more precise results about what clubs would form and what they would achieve in efficiency terms can only be obtained through simulations. In this section we investigate the Nash equilibrium without negotiation, the efficient configuration, and clubs in a grid and along a line, for both liability regimes. The externality is more severe in a grid as every farmer has at most eight neighbors as a direct possible source of adventitious presence, rather than two as in a line. We assume that the individual probability of adventitious presence α_{ij} is a declining function of Euclidian distance between farmer *i* and *j*. The parameter values are given in Table 1. In Appendix 2 we report the individual probabilities α_{ij} resulting from our distance function, as well as the frequency distribution of the overall adventitious presence $(1 - A_i)$ over all possible configurations and farmers. The price of GM crops is based on the average price of maize in European countries in the period 2000–2005 (Eurostat). The price premium for certified non-GM soybeans has been relatively stable at 10% (U. Felhölter, feed retailer, cited in Wesseler, 2014). For many other crops it has been even less (Foster, 2010). Therefore we have assumed a price of conventional crops that is 10% higher than that of GM crops. The range of additional costs and the distance function were chosen such that both types of cultivation would be practiced in the draw.

[Table 1 around here]

3.3.2 Stability likelihood and performance indices

Following Pintassilgo *et al.* (2010) we investigate three important parameters: the stability likelihood θ, the efficiency gain Ω (called "social gain" in Pintassilgo *et al.*),[6] and closing the gap Γ. Stability likelihood is the probability that a random *m* size club is stable and is estimated through the sampling proportion:

$$\widehat{\theta_m} = \frac{Y}{n_{sim}}$$

where *Y* is the number of times a randomly chosen *m*-size club was stable and n_{sim} is the total number of draws for a fixed number of players.

The efficiency gain is an index measuring how much is to be gained from an efficient solution compared to the Nash equilibrium without negotiations and is defined as:

$$\Omega = \frac{W - \sum_{i \in N} \pi_i^{Nash}}{W} \times 100$$

where *W* is the sum of profits in an efficient configuration, as before, and π_i^{Nash} is the profit of farmer *i* in the Nash equilibrium without negotiations. $\bar{\Omega}$ is the arithmetic mean over all draws. Similarly, closing the gap is an index measuring what proportion of the efficiency gain clubs on average realize. For a stable club S^* it is defined as:

$$\Gamma(S^*) = \frac{\left(\Pi(S^*) + \sum_{i \in N \setminus S} \pi_i^S\right) - \sum_{i \in N} \pi_i^{Nash}}{W - \sum_{i \in N} \pi_i^{Nash}}$$

with $\Pi(S^*)$ the profits of club S^* and π_i^S the profits of farmers outside of club S^*. $\check{\Gamma}$ is the arithmetic mean of all $\Gamma(S^*)$ of stable clubs in one draw and $\bar{\Gamma}$ is the arithmetic mean of all $\check{\Gamma}$ in the number of draws under consideration.

3.3.3 Sampling procedure

Following Pintassilgo *et al.* (2010), we originally opted for 50,000 draws to investigate the stability of clubs, which would have resulted in a standard deviation of maximally 0.004 for the stability likelihood. However, because a number of draws had multiple Nash equilibria in the second stage of the game, we increased the number of draws by 10%, for a total of 55,000 draws.

[6] We refrain from calling this social gain because we do not model consumer effects and transaction costs.

The draws consisted of random cost vectors out of the range specified in Table 1. We conducted 55,000 draws for a line of eight farmers and 55,000 draws for a grid of four by three farmers. Because we sample the costs for all the individual farmers at the same time, the maximum number of club members, that is, the number of farmers in sets Φ and X, within a draw is determined by the sampling procedure. Cost vectors were drawn such that there were always a minimum of two farmers with $\Delta p - c_i \geq 0$ and two farmers with $\Delta p - c_i < 0$. In this way the sets Φ and X always contained at least two members that could form clubs. Farmers that had $c_i = 10$ were assumed to be part of set Φ.

Runs were discarded if a Nash equilibrium in the last stage of the game was not unique. The reason is that in this case there is a selection problem: it is unclear which one of these multiple equilibria is to be used as a reference when the internal stability of a club is checked.[7] In addition, if there are multiple equilibria in the Nash equilibrium without negotiations, which is a last-stage Nash equilibrium as well, the indices Efficiency Gain and Closing the Gap are not well defined. The problem of multiple equilibria occurs in 4% of the draws, except for the grid when GM farmers are liable, where it occurs in 20%.

For the grid, this procedure resulted in a very low number of draws for $|\Phi| = 10$ and $|\mathrm{X}| = 2$. Therefore we ran an additional 2,000 draws for both situations, using a different sampling procedure. In this procedure we drew cost vectors such that, although randomized, the sample always contained 10 farmers for whom $\Delta p - c_i > 0$, resulting in the desired $|\Phi| = 10$ and $|\mathrm{X}| = 2$. Their location within the 4x3 grid was random. The results remain qualitatively the same. The reason for the small number of draws with $|\Phi| = 10$ and $|\mathrm{X}| = 2$ is twofold: the probability of drawing a vector with $|\Phi| = 10$ and $|\mathrm{X}| = 2$ is low; and draws with $|\Phi| = 10$ and GM farmers not liable face multiple equilibria in roughly 50% of the draws.

3.3.4 Simulation results

In Tables 2 and 3 we report the stability likelihood as well as the two indices from our simulation results. Examples of typical draws along a line and in a grid are shown in Figures 1 and 2. From the tables we see that the efficiency gain is in general small. The main reason for this is the relatively small price premium for conventional crops in the simulations. As a

[7] Alternative ways of dealing with multiple equilibria are checking whether the payoff for players in the club is larger than the best payoff of the multiple Nash equilibria (Olieman and Hendrix, 2006), or ensuring a dominant strategy (Dellink, Finus and Olieman, 2008). Dominant strategies are not present for all players in our game, and instead of making an additional assumption we opted for discarding the draw altogether.

sensitivity analysis we used price premiums of 15%. Price premiums of 15% are rare but are in principle possible for high value crops and seeds. The results are shown in Appendix 3. They are qualitatively the same.

[Table 2 around here]

The efficiency gain increases with the maximum number of club members. Only when GM farmers are liable does it decrease again. The increase is driven by several factors: In the case of non-liable GM farmers, the lost price premium is larger because there more farmers of set Φ are GM farmer in the Nash equilibrium, and conventional farmers face a higher probability of adventitious presence. If, in contrast, GM farmers are liable, more farmers in , requiring compensation from the remaining GM farmers in the Nash equilibrium and driving up the difference between the efficient configuration and the Nash equilibrium. The decrease in efficiency gain when the maximum number of club members increases and GM farmers are liable is due to the fact that there are fewer conventional farmers to compensate.

Comparing both liability regimes it can be seen that in most cases the efficiency gain is larger when GM farmers are liable, and that larger clubs have a relatively higher probability of being stable. However, these larger clubs realize less of the full potential. This is a general pattern: if the gains from cooperation increase, clubs are able to realize a smaller part of this efficiency gain, even though they realize more in absolute terms. This is a result of free-riding: although it would be in the collective interest of the group for certain farmers to join and participate in buying out other farmers, it is not in the individual interest of these farmers to join. Hence they prefer to free-ride on the efforts of the group. The clubs in the grid constitute an exception to this rule: the clubs at the end are better able to close the gap. This is, most likely, a sample effect. The draws constitute configurations where small clubs suffice. Configurations where larger clubs would have been necessary were dropped more often because they have multiple Nash equilibria and hence are not part of the calculations.

When the externality becomes more severe, as in the grid compared to the line, the model tends more toward solutions where everyone cultivates the same variety. In that case the Nash equilibrium without negotiations will more often coincide with the efficient configuration for at least one type of liability regime (see also Figure 1, example 3 and 4, and Figure 2, example 3). The reason is that in the Nash equilibrium without negotiations the crop type that is allocated the property rights becomes more attractive to cultivate. The fact that the Nash equilibrium without negotiations and the efficient configuration coincide reduces the efficiency gain and as such increases the stability of clubs. Clubs are generally also able to realize more of the potential difference.

[Table 3 around here]

Both along a line and in a grid, coordination becomes more difficult if the maximum number of club members increases. This can be seen from the stability likelihood and $\bar{\Gamma}$ in Tables 2 and 3. The stability likelihood of the largest club decreases with the maximum number of club members. In the grid this partly compensated by an increase in stability of smaller clubs. However, the maximum club size is not a necessity to reach the efficient configuration; often a smaller club is sufficient (see Figures 1 and 2), especially for a low maximum number of club members. Generally, however, smaller clubs are unable to realize the full potential due to the free-riding problem. This is illustrated by the decreasing $\bar{\Gamma}$, although clubs do realize a sizable amount of the potential gain. In addition, if there are more farmers a club is more likely to be found that solves a local problem but not the complete one, as they are mainly bothered by their neighbor's externality. This can also be observed in Figure 2, for instance in example 1 when GM farmers are not liable and in example 3, when GM farmers are liable. Smaller clubs are able to realize the full potential efficiency gain when the maximum number of club members is small, but this typically means that the gain is also small.

[Figures 1&2 around here]

Larger clubs do have a relatively larger probability of being stable. These results hinge on a number of driving factors. First and foremost there is the non-linearity in the externality, which generates a tendency toward solutions where everyone cultivates the same variety. As shown in the marginal effects above, the marginal cost seen over all farmers together is largest for the first farmer who switches from conventional to GM and decreases rapidly afterwards. Who bears these marginal costs depends on the liability regime: the affected conventional farmers when the GM farmer is not liable and the GM farmer when liable. Hence it is often more effective to buy out either a large number of farmers or none. The second factor is the relatively low number of farmers in the simulations: it can be seen from the tables that stability decreases with the maximum number of club members. Finally, these large clubs also form because of a particular case of the new member problem that occurs in our model. As a simple illustrative example, consider a situation with three farmers, where one prefers to cultivate GM crops and is not liable. The other two are conventional farmers, but only one of those two is able to buy out the GM farmer if the conventional farmer is alone in the club, that is, in a club of size 1. This farmer and the GM farmer form a club and they now both cultivate conventional crops. The remaining farmer has the option to join the club, and will do so. To see why, note that this farmer's claim is the same as when he (she) is not part of the club because, if he (she) leaves, the first club initiator will still buy out the GM farmer. If the first club initiator leaves, however, the other cannot buy out the GM farmer and hence the claim of the first club initiator is much lower. Thus the second one will join, get at least what is earned when free-riding, and more if there is a surplus.

Although we have not explicitly modeled the ex-ante costs of regulation we can infer some of their effects through the model. If GM farmers are not liable, the costs of ex-ante coexistence measures are shouldered by the conventional farmers. *Ceteris paribus*, this means that their c_i increases. In contrast, if GM farmers are liable they have to shoulder the costs, meaning that c_i decreases as the incremental costs of farming conventional crops decreases. In order to investigate the effect of ex-ante costs we look at the effect of the average c_i for a fixed maximum number of club members on the efficiency gain and closing the gap. The effect for four potential club members along a line and six potential club members in a grid are presented in Tables 4 and 5.

[Table 4&5 around here]

In the tables we observe a consistent pattern: when GM farmers are not liable, the introduction of ex-ante costs, that is, increasing the average c_i, reduces the efficiency gain. The reason is that an increase in c_i makes GM farming more attractive. Thus, in the efficient configuration more farmers cultivate GM, and as the Nash equilibrium favors GM cultivation as well, the difference between the two becomes smaller. A similar effect is at work when GM farmers are liable: ex-ante coexistence costs decrease the average c_i making conventional farming more attractive in both the Nash equilibrium and the efficient configuration, thus decreasing the efficiency gain. In addition, we observe that the smaller the gains the more the clubs are able to realize the potential gain.

In total, these findings on ex-ante coexistence costs provide us with a mixed message for clubs. On the one hand, clubs introduce flexibility and lower ex-ante coexistence costs. This drives up the difference between the Nash equilibrium and the efficient configuration, increasing the potential gains from cooperation. However, this in turn reduces the stability of the clubs, and less of the potential gain is realized by these clubs due to free-riding.

4 Discussion and conclusions

In this paper we investigated the stability of clubs that form to mitigate the externality caused by the adventitious presence of GM crops under different liability regimes. Using a simple farmer decision model combined with the notions of stability that are generally used in the literature of international environmental agreements, we derived the prospects for clubs under different liability regimes.

We find that clubs very often reach a large part of the potential gain, or at least mitigate the local externality. This is in contrast with the existing literature that uses very different models but the same concepts of stability and stability likelihood, for example in fisheries and climate change (see, e.g., Dellink, Finus and Olieman, 2008; Pintassilgo *et al.*, 2010). This may be due to two effects. First of all it may be due to the relatively low potential gains from cooperation. In the climate agreement literature (Barrett, 1994) and the fisheries agreement literature (Pintassilgo *et al.*, 2010), cooperation becomes more difficult when the gains from cooperation increase, and becomes easier when the gains are small. This is due to the free-riding effect. Large gains from cooperation mean that there are large free-riding incentives. The opposite is true when gains are small. A second effect is the particular functional form chosen in the models. Karp and Simon (2013) have shown that this particularly affects stability.

We also find that clubs are not always necessary: sometimes the Nash equilibrium without negotiation can already establish an efficient configuration. This occurs when the externality effect is small compared to the other economic parameters. In that case, however, it is very important that property rights are allocated correctly. Which type is required depends on the efficient configuration: if it contains many GM farmers they should receive the property rights, and vice versa. If the property rights are not allocated correctly, clubs are needed to reach the optimum and, as we have shown, these clubs do not always succeed due to free-riding.

Our results are in part, of course, driven by the non-linear probability that causes decreasing marginal costs of switching from conventional to GM crops. However, in our view, this is a more realistic approach than, for example, considering the probability of adventitious presence to increase linearly with the number of GM farmers. In addition, we do not consider the possibility of multiple fields, which would give farmers more flexibility, and the effects of adventitious presence would probably be less severe.

Our findings are different from those of Furtan, Güzel and Weseen (2007) who investigate the possibility that organic farmers form a club and buy out neighboring GM farmers to act as a buffer zone. The main reason is that they only investigate whether or not the club can compensate the reverting farmers, but they do not consider the outside option payoff of the farmers in the club, or free-riding. Our paper adds an extra dimension to their paper: the clubs they report could form, but farmers do not necessarily have an incentive to stay in such clubs.

Although we perform some comparative statics regarding coexistence costs, we do not consider the effects of further regulations such as minimum distance requirements in our paper. It has been shown that these regulations can affect farmers' decisions to cultivate GM or conventional crops via the domino effect (Groeneveld, Wesseler and Berentsen, 2013). When regulations raise coexistence costs, clubs may offer some flexibility to decrease the costs again, but as shown in the simulations, whether or not clubs are able to realize the full gains remains to be seen.

Our particular model has a few drawbacks. One is that we consider only the formation of a single club. In certain cases multiple clubs may form. However, we have also shown that in certain cases the externalities can be mitigated by the formation of a single club, in which case there is no reason to form multiple clubs. Moreover, it is likely that, if multiple clubs form, they address different regional externalities as it does not make sense to have multiple clubs addressing the same issue.

A further drawback is that we do not consider price effects. This is in principle justified in the small-scale setting with a maximum of 12 farmers in which we applied the model, but becomes an issue when we consider the effects at a country scale. What the net effect would be is not clear because it depends on the demand and supply functions.

We also did not consider the possibility of a compensation fund, mainly because we would lose the similarities between the two property rights regimes. A compensation fund would have enriched the possibilities for solutions, but important questions remain about the decisions relating to who will contribute how much, and who will decide about payments. Moreover, a compensation fund may not be enough to cover all claims, whereas in other cases it may simply be cheaper to buy out a farmer. Therefore compensation funds should definitely be included in future research.

Finally, the model itself is static and, as such, dynamic incentives are not considered. Thus it is assumed that bought-out farmers actually stick to their decision and do not cheat.

One can justify this assumption in this context with an assumption of enforceable contracts. Future possible extensions of the model thus include equilibrium effects in general and dynamic formulations with possible enforcement issues.

In future research it is important to address two other important topics: first, the influence of spatial correlation in the additional cost parameter and second, the effect of using alternative probability-distance functions. The additional cost parameter is driven by many factors, but a number of the agroecological conditions are likely to be spatially correlated. This means that potential GM farmers and conventional farmers are more likely to be clustered in the landscape. This in turn would reduce the probability of adventitious presence. We hypothesize that that would make the formation of clubs easier.

We used a simple exponential function to describe the probability of adventitious presence. However, a number of functional forms have been used in the literature, for example, Bivariate student (Clark, 1998), Compound exponential (Damgaard and Kjellsson, 2005), or Normal inverse Gaussian (Klein *et al.*, 2003). The main difference between these forms is in the dispersal distance and the fatness of their tails. An increase in either of these two parameters would increase the probability of adventitious presence.

We conclude that there is scope for the formation of clubs that will result in either GM-free zones or GM-only zones, depending on who has the property rights, and that these clubs will usually be large but not necessarily achieve their full economic potential.

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Appendix 1: Proofs

Proof of existence of the Nash equilibrium in (9)

Consider a landscape with only conventional farmers, i.e. $F = N$ and $G = \emptyset$. Without loss of generality let us order the farmers $i \in F$ such that $\Delta p - c_1 \leq \Delta p - c_2 \leq \cdots \leq \Delta p - c_n$. If $\Delta p - c_1 \geq 0$ the first farmer will not switch, and neither will any of the other farmers, because in that case $\Delta p - c_i \geq 0\ \forall i \in N$. Consequently if $\Delta p - c_1 \geq 0$ we are in a Nash equilibrium.

In contrast if $\Delta p - c_1 < 0$ then farmer 1 will switch. Consequently we get a new set $F' = F \backslash \{1\}$ and a new set $G' = \{1\}$. The payoff of the remaining conventional farmers decreases and becomes $A_i \Delta p - c_i, \forall i \in F'$. Let us now reorder the remaining set F' such that $A_i \Delta p - c_i \leq A_j \Delta p - c_j \leq \cdots \leq A_i \Delta p - c_k$. If $A_i \Delta p - c_i \geq 0$ farmer i will not switch. Also, a farmer who has previously switched will never revert because the expected price premium has decreased. Hence we are in a Nash equilibrium if $A_i \Delta p - c_i \geq 0$, and if $A_i \Delta p - c_i < 0$ we are not.

By induction we can reason that this process continues until we reach a Nash equilibrium either described by $\begin{Bmatrix} A_i \Delta p \geq c_i\ \forall i \in F^{nl,*} \\ A_i \Delta p \leq c_j\ \forall j \in G^{nl*}, \end{Bmatrix}$ or a Nash equilibrium where everyone cultivates GM crops, i.e. $G = N$.

Proof of existence of the Nash equilibrium in (11)

The proof of the existence of the Nash equilibrium when liability is reversed follows a similar pattern. Starting from a landscape where everyone is a GM farmer, i.e. $G = N$ and $F = \emptyset$, let us order the farmers $j \in G$ such that $\Delta p - c_1 \leq \Delta p - c_2 \leq \cdots \leq \Delta p - c_n$. If $\Delta p - c_j \leq 0\ \forall j \in G$ we are in a Nash equilibrium because no farmer will want to revert back to conventional crops.

In contrast, if $\Delta p - c_1 > 0$, farmer 1 will revert. Consequently we get a new set $F' = \{1\}$ and a new set $G' = G \backslash \{1\}$. The payoff of the remaining GM farmers decreases and becomes:

$\pi_j^G = p_j^G - D_j \Delta p\ \ \forall j \in G'$. Let us reorder set G' such that $\Delta p - c_j + D_j \leq \Delta p - c_k + D_k \leq \cdots \leq \Delta p - c_l + D_l$. If $\Delta p - c_j + D_j \leq 0$ farmer j will not revert. Also, a farmer who has previously reverted will never switch because the expected damage payments have increased. Hence we are in a Nash equilibrium if $\Delta p - c_j + D_j \leq 0$, and if $\Delta p - c_j + D_j > 0$ we are not.

By induction we can reason that this process continues until we reach a Nash equilibrium either described by $\left\{\begin{matrix} c_i \leq \Delta p + D_i \; \forall i \in F^{l,*} \\ c_j \geq \Delta p + D_j \; \forall j \in G^{l,*}, \end{matrix}\right\}$ or a Nash equilibrium where everyone cultivates conventional crops, i.e. $F = N$.

Proof of Theorem 1

When farmers in set Φ form a club, the claim of farmers in set X is p_i^G, independent of whether or not the farmer is bought out, because if they leave the club they will revert back to GM cultivation.

If only those farmers that are bought out are considered members, their profit contribution to the club is:

$$\sum_{h \in H \cap X} \left(A_h \, \Delta p + p_h^G - c_h\right), \qquad \text{(A.1)}$$

and their claim is:

$$\sum_{h \in H \cap X} \left(p_h^G\right). \qquad \text{(A.2)}$$

Thus their claim net of what they already earn themselves, i.e. (A.1) minus (A.2), is:

$$\sum_{h \in H \cap X} \left(A_h \, \Delta p - c_h\right). \qquad \text{(A.3)}$$

When all farmers in set X are considered club members their profit contribution to the club is:

$$\left(\sum_{h \in H \cap X} \left(A_h \, \Delta p + p_h^G - c_h\right)\right) + \sum_{g \in X \setminus H} \left(p_g^G\right), \qquad \text{(A.4)}$$

and their claim is:

$$\sum_{g \in X} \left(p_g^G\right). \qquad \text{(A.5)}$$

Thus their claim net of what they already earn themselves, i.e. (A.4) minus (A.5), is:

$$\sum_{h \in H \cap X} \left(A_h \, \Delta p - c_h\right). \qquad \text{(A.6)}$$

When farmers in set X are not considered members, the ones that are bought out need compensation. The minimum compensation amount they require is:

$$\sum_{h \in H \cap X} (A_h \, \Delta p - c_h). \tag{A.7}$$

This amount thus needs to be deducted from the profits of the club members. In the two other cases no deduction is needed because the compensation payments are accounted for in the claims. In all cases the sum of the claims of the club initiators are still those of (23). Therefore, combining (23) with the compensation or the net claims, irrespective of the formulation used, the CRC then requires for stability:

$$\sum_{i \in S} \left((A_i \; - A_i') \Delta p \right) + \sum_{h \in H} (A_h \, \Delta p - c_h) > 0. \tag{A.8}$$

The proof for the situation where property rights are reversed follows similar reasoning.

Nash equilibrium in the last stage of GM club formation

Let us rewrite the compensation that a GM farmer has to pay to:

$$D_j \Delta p = \sum_{i \in N} \frac{\alpha_{ij}(1 - A_i)\Delta p}{\sum_{k \in N} \alpha_{ik}} = \sum_{i \in N} \sigma_{ij}(1 - A_i)\Delta p, \tag{A.9}$$

with σ_{ij} the share farmer *j* pays of the damages of farmer *i*.

If the club *T* considers buying out a farmer $k \in \Phi$ in Coasean bargaining it considers the marginal effect of this farmer switching to GM on the club and all farmers in set Φ. This marginal effect is

$$
\begin{aligned}
ME = \Bigg(& c_k - \left(1 + \sum_{l \in N} \left(\sigma_{lk}(1 - A_l)\right)\right)\Delta p \Bigg) \\
& + \left(\sum_{t \in T \cup \Phi} \left(\sigma_{kt}(1 - A_k)\Delta p + \sum_{l \in \mathrm{X} \setminus T} \sigma_{lt}(1 - A_l)\Delta p \right)\right) \\
& + \left(\sum_{i \in N \setminus k} \left(\sum_{t \in T \cup \Phi} (\sigma_{it} - \sigma_{it}{}')\,(1 - A_i) \right) \Delta p \right) \\
& - \left(\sum_{i \in N} \left(\sum_{t \in T \cup \Phi} \left((\sigma_{it}{}')(\alpha_{ik} A_i)\Delta p + \sum_{l \in \mathrm{X} \setminus T} (\alpha_{il} A_i)\Delta p \right)\right)\right),
\end{aligned}
\tag{A.10}
$$

where $\sigma_{it}{}'$ denotes the new distribution of shares because there is an additional GM farmer. The first term above is the compensation payment necessary to farmer *k*, to switch to GM crops. The second term is the reduction in damage payments for the group *T* and the farmers within Φ that have switched, to farmer *k* because *k* no longer cultivates conventional crops, plus the reduction in payments to other farmers that may switch as a result of this buyout. The group knows this effect because they move first in their Coasean bargaining. The third term is the reduction in payments for this group because the burden of payments is now divided over a larger group of GM farmers. The last term represents the increase in payments for this group because an additional GM farmer increases the probability of adventitious presence plus the increase in adventitious presence due to other farmers that will switch as a result. The group will continue to buy out farmers until (A.8) is no longer positive. In that case we have arrived at the Nash equilibrium.

Appendix 2: Information on probabilities

Table A1: Individual probabilities of adventitious presence ($f(d_{ij})$) in a line of eight farmers

	1	2	3	4	5	6	7	8
1	-							
2	0.2231	-						
3	0.0498	0.2231	-					
4	0.0111	0.0498	0.2231	-				
5	0.0025	0.0111	0.0498	0.2231	-			
6	0.0006	0.0025	0.0111	0.0498	0.2231	-		
7	0.0001	0.0006	0.0025	0.0111	0.0498	0.2231	-	
8	0.0000	0.0001	0.0006	0.0025	0.0111	0.0498	0.2231	-

The matrix is symmetric; therefore the upper part is not shown.

Table A2: Individual probabilities of adventitious presence ($f(d_{ij})$) in a 4x3 grid

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	0.2231	-										
3	0.0498	0.2231	-									
4	0.0111	0.0498	0.2231	-								
5	0.2231	0.1199	0.0349	0.0087	-							
6	0.1199	0.2231	0.1199	0.0349	0.2231	-						
7	0.0349	0.1199	0.2231	0.1199	0.0498	0.2231	-					
8	0.0087	0.0349	0.1199	0.2231	0.0111	0.0498	0.2231	-				
9	0.0498	0.0349	0.0144	0.0045	0.2231	0.1199	0.0349	0.0087	-			
10	0.0349	0.0498	0.0349	0.0144	0.1199	0.2231	0.1199	0.0349	0.2231	-		
11	0.0144	0.0349	0.0498	0.0349	0.0349	0.1199	0.2231	0.1199	0.0498	0.2231	-	
12	0.0045	0.0144	0.0349	0.0498	0.0087	0.0349	0.1199	0.2231	0.0111	0.0498	0.2231	-

The matrix is symmetric; therefore the upper part is not shown. Farmers are numbered in reading order:

1	2	3	4
5	6	7	8
9	10	11	12

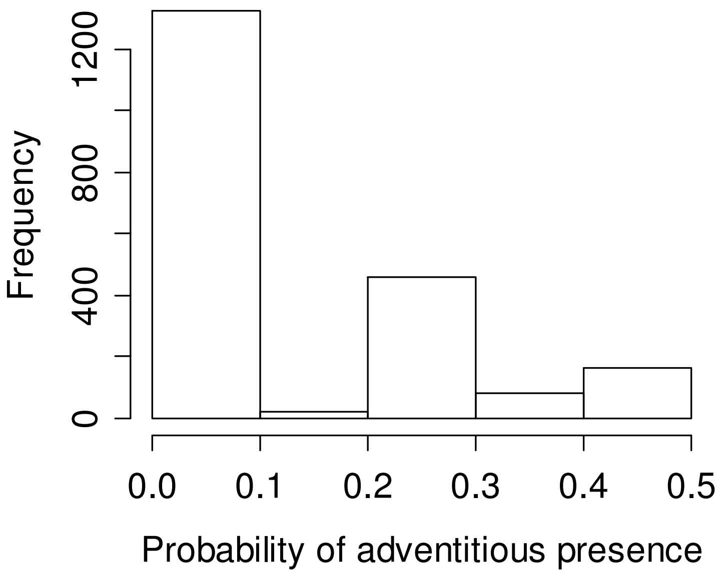

Figure A1: Histogram of probabilities of experiencing adventitious presence ($1 - A_i$) as defined by the possible configurations on the line over all farmers.

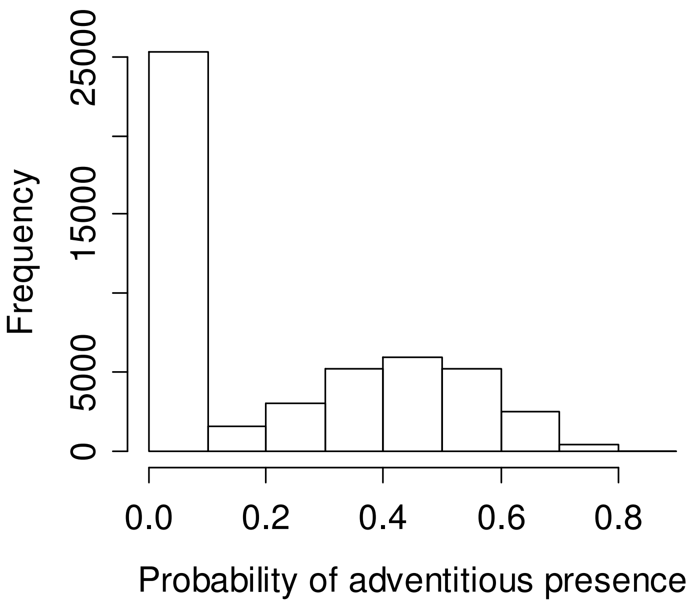

Figure A2: Histogram of probabilities of experiencing adventitious presence ($1 - A_i$) as defined by the possible configurations on the grid over all farmers.

Appendix 3: Stability results when the price premium is 15%

GM farmers not liable

		Stability likelihood for club size *m*						Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Total number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6			
Maximum number of club members	$|\Phi|=2$	0.35%	99.65%	-	-	-	-	0.02%	100%	2271
	$|\Phi|=3$	0.08%	4.73%	94.52%	-	-	-	0.09%	98%	7575
	$|\Phi|=4$	0.00%	2.01%	12.96%	79.97%	-	-	0.23%	95%	13726
	$|\Phi|=5$	0.00%	1.27%	5.69%	19.22%	58.45%	-	0.43%	92%	15705
	$|\Phi|=6$	0.00%	1.18%	3.09%	8.21%	18.09%	42.35%	0.61%	90%	10951

GM farmers liable

		Stability likelihood for club size *m*						Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Total number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6			
Maximum number of club members	$|X|=2$	1.24%	98.76%	-	-	-	-	0.04%	100%	12684
	$|X|=3$	0.28%	6.86%	91.64%	-	-	-	0.14%	98%	15602
	$|X|=4$	0.53%	3.37%	14.46%	74.89%	-	-	0.31%	95%	11512
	$|X|=5$	0.42%	2.70%	7.00%	17.56%	57.65%	-	0.50%	93%	5188
	$|X|=6$	0.00%	1.63%	3.83%	6.92%	13.68%	50.73%	0.53%	92%	1228

GM farmers not liable

		Stability likelihood for club size *m*										Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6	*m*=7	*m*=8	*m*=9	*m*=10			
Maximum number of club members	|Φ|=2	0.00%	100.00%	-	-	-	-	-	-	-	-	0.00%	100%	129
	|Φ|=3	0.00%	1.04%	98.96%	-	-	-	-	-	-	-	0.00%	94.70%	672
	|Φ|=4	0.00%	0.18%	3.28%	95.69%	-	-	-	-	-	-	0.02%	92.82%	2225
	|Φ|=5	0.00%	0.18%	1.71%	9.99%	85.56%	-	-	-	-	-	0.11%	88.94%	5438
	|Φ|=6	0.00%	0.24%	1.70%	8.32%	21.55%	57.06%	-	-	-	-	0.41%	82.53%	9017
	|Φ|=7	0.00%	0.40%	3.44%	10.47%	17.83%	19.89%	18.67%	-	-	-	1.01%	79.79%	10226
	|Φ|=8	0.00%	1.21%	5.94%	11.74%	13.42%	9.50%	5.08%	2.36%	-	-	1.72%	83.22%	7682
	|Φ|=9	0.00%	3.14%	9.80%	11.77%	9.00%	4.11%	1.35%	0.45%	0.22%	-	2.35%	86.53%	4011
	|Φ|=10	0.31%	6.93%	10.66%	8.64%	4.82%	2.72%	0.62%	0.23%	0.00%	0.00%	2.73%	90.35%	1285

GM farmers liable

		Stability likelihood for club size *m*										Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6	*m*=7	*m*=8	*m*=9	*m*=10			
Maximum number of club members	|X|=2	0.00%	100.00%	-	-	-	-	-	-	-	-	0.00%	100%	3590
	|X|=3	0.00%	0.01%	99.99%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	99.19%	7873
	|X|=4	0.00%	0.01%	0.24%	99.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	97.19%	11867
	|X|=5	0.00%	0.06%	0.47%	3.18%	95.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	89.89%	12703
	|X|=6	0.00%	0.13%	1.74%	5.72%	14.06%	71.74%	0.00%	0.00%	0.00%	0.00%	0.24%	81.81%	9420
	|X|=7	0.02%	1.00%	4.07%	9.02%	12.96%	16.50%	31.36%	0.00%	0.00%	0.00%	0.75%	79.41%	4914
	|X|=8	0.12%	3.54%	9.61%	12.13%	10.51%	8.47%	6.25%	5.65%	0.00%	0.00%	1.58%	81.48%	1665
	|X|=9	1.01%	7.58%	12.37%	9.34%	5.30%	2.53%	0.76%	0.00%	0.00%	0.00%	2.49%	87.19%	396
	|X|=10	2.78%	16.67%	11.11%	5.56%	0.00%	2.78%	0.00%	0.00%	0.00%	0.00%	3.09%	92.28%	36

In text tables

Table 1: Parameter values in the draws

Parameter	Value
p^C	110 (€/tonne)
p^G	100 (€/tonne)
c_i	Integer ∈ [1,25] (€/tonne)
α_{ij}	$e^{-1.5(\text{distance})}$

Table 2: Stability likelihood and potential of clubs along a line

GM farmers not liable										
		Stability likelihood for club size *m*						Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Total number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6			
Maximum number of club members	$\|\Phi\|=2$	0.06%	99.94%	-	-	-	-	0.01%	100.00%	10986
	$\|\Phi\|=3$	0.03%	3.61%	96.17%	-	-	-	0.03%	96.74%	17413
	$\|\Phi\|=4$	0.01%	0.97%	8.21%	87.75%	-	-	0.09%	94.03%	14517
	$\|\Phi\|=5$	0.00%	0.70%	2.81%	12.57%	73.96%	-	0.17%	90.63%	7430
	$\|\Phi\|=6$	0.00%	0.39%	1.94%	4.31%	15.04%	58.60%	0.28%	87.39%	2321

GM farmers liable										
		Stability likelihood for club size *m*						Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Total number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6			
Maximum number of club members	$\|X\|=2$	3.55%	96.45%	-	-	-	-	0.05%	99.89%	2677
	$\|X\|=3$	1.02%	9.19%	87.10%	-	-	-	0.12%	98.09%	8016
	$\|X\|=4$	1.08%	3.44%	14.04%	73.47%	-	-	0.21%	96.10%	14773
	$\|X\|=5$	0.87%	1.54%	4.91%	13.14%	64.19%	-	0.25%	94.69%	16877
	$\|X\|=6$	0.00%	0.38%	0.93%	4.64%	12.34%	63.92%	0.19%	90.45%	10273

Parameters as in Table 1. The line consists of eight farmers with always a minimum of two farmers who would cultivate conventional crops in the absence of the externality and two that would cultivate GM crops. The maximum number of club members is determined by the draw itself. Since draws are discarded when there are multiple Nash equilibria in the last stage, the numbers do not add up to 55,000.

Table 3: Stability likelihood and potential of clubs in a grid

GM farmers not liable														
		Stability likelihood for club size *m*										Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6	*m*=7	*m*=8	*m*=9	*m*=10			
Maximum number of club members	|Φ|=2	0.00%	100.00%	-	-	-	-	-	-	-	-	0.00%	100%	2935
	|Φ|=3	0.00%	0.64%	99.36%	-	-	-	-	-	-	-	0.00%	96.81%	7802
	|Φ|=4	0.00%	0.24%	2.18%	96.99%	-	-	-	-	-	-	0.01%	93.98%	11861
	|Φ|=5	0.00%	0.10%	0.94%	5.11%	91.03%	-	-	-	-	-	0.02%	89.94%	12716
	|Φ|=6	0.00%	0.07%	0.65%	2.90%	9.39%	78.97%	-	-	-	-	0.06%	85.32%	9637
	|Φ|=7	0.00%	0.19%	0.74%	2.41%	6.95%	16.54%	54.60%	-	-	-	0.18%	78.86%	5267
	|Φ|=8	0.00%	0.29%	1.24%	3.48%	7.53%	10.67%	16.82%	25.63%	-	-	0.46%	73.13%	2099
	|Φ|=9	0.00%	0.19%	2.04%	5.58%	8.74%	9.48%	8.92%	7.81%	6.51%	-	0.91%	71.99%	538
	|Φ|=10	0.00%	1.49%	1.49%	4.48%	10.45%	7.46%	7.46%	2.99%	1.49%	0.00%	1.33%	73.03%	67

GM farmers liable

		Stability likelihood for club size *m*										Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
		m=1	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6	*m*=7	*m*=8	*m*=9	*m*=10			
Maximum number of club members	|X|=2	0.00%	100.00%	-	-	-	-	-	-	-	-	0.01%	100.00%	122
	|X|=3	0.00%	4.42%	95.58%	-	-	-	-	-	-	-	0.03%	94.87%	678
	|X|=4	0.00%	2.43%	14.47%	79.65%	-	-	-	-	-	-	0.13%	90.57%	2260
	|X|=5	0.06%	2.61%	11.84%	26.54%	45.32%	-	-	-	-	-	0.39%	85.39%	5015
	|X|=6	0.04%	3.54%	11.98%	20.31%	18.95%	14.28%	-	-	-	-	0.73%	81.07%	8408
	|X|=7	0.06%	4.41%	12.93%	15.84%	11.80%	6.57%	3.59%	-	-	-	1.02%	80.32%	10339
	|X|=8	0.17%	5.31%	12.26%	13.16%	8.04%	4.21%	2.56%	2.61%	-	-	1.14%	80.93%	9032
	|X|=9	0.44%	6.33%	10.52%	9.92%	6.91%	4.12%	2.41%	2.43%	3.36%	-	1.05%	81.67%	5685
	|X|=10	0.00%	6.24%	7.40%	7.59%	5.37%	3.77%	3.63%	2.47%	4.01%	8.99%	0.75%	83.46%	2068

Parameters as in Table 1. The grid consists of four by three farmers with always a minimum of two farmers that would cultivate conventional crops in the absence of the externality and two that would cultivate GM crops. The maximum number of club members is determined by the draw itself. Since draws are discarded when there are multiple Nash equilibria in the last stage, the numbers do not add up to 55,000.

Table 4: Effect of ex-ante costs along a line

GM farmers not liable				GM farmers liable			
Average c_i	Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws	Average c_i	Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
< 9	0.19%	95.34%	246	< 9	0.12%	94.90%	215
9 – 10.5	0.11%	94.23%	2559	9 – 10.5	0.15%	94.52%	2424
10.5 – 12	0.08%	94.06%	5825	10.5 – 12	0.19%	95.89%	5899
12 – 13.5	0.07%	93.96%	4662	12 – 13.5	0.24%	96.83%	4927
> 13.5	0.07%	93.26%	1225	> 13.5	0.31%	96.68%	1308

Maximum number of club members n=4 for both liability regimes.

Table 5: Effect of ex-ante costs in a grid

GM farmers not liable				GM farmers liable			
Average c_i	Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws	Average c_i	Efficiency gain $\bar{\Omega}$	Closing the gap $\bar{\Gamma}$	Number of draws
< 9	0.49%	78.30%	39	< 9	0.04%	92.09%	44
9 – 10.5	0.14%	81.37%	1145	9 – 10.5	0.40%	83.69%	1074
10.5 – 12	0.07%	84.78%	4692	10.5 – 12	0.73%	81.71%	3919
12 – 13.5	0.03%	89.39%	3326	12 – 13.5	0.83%	79.47%	2939
> 13.5	0.01%	91.14%	435	> 13.5	0.97%	80.18%	432

Maximum number of club members n=6 for both liability regimes.

Example number 1

GM farmers not liable

Club size \ c_i	13	9	21	1	9	12	10	6	Configuration							
0*	-	0	-	0	0	-	1	0	GM	GM	GM	CV	GM	GM	GM	CV
3**	-	1	-	0	1	-	1	1	GM	GM	GM	CV	CV	CV	CV	CV
3**	-	1	-	1	0	-	1	1	GM	GM	GM	CV	CV	CV	CV	CV
3**	-	1	-	1	1	-	1	0	GM	GM	GM	CV	CV	CV	CV	CV
4	-	1	-	1	1	-	1	1	GM	GM	GM	CV	CV	CV	CV	CV

GM farmers liable

Club size \ c_i	13	9	21	1	9	12	10	6	Configuration							
0*	0	-	0	-	-	0	-	-	GM	CV	GM	CV	CV	CV	CV	CV
2**	0	-	1	-	-	1	-	-	GM	GM	GM	CV	CV	CV	CV	CV
2**	1	-	0	-	-	1	-	-	GM	GM	GM	CV	CV	CV	CV	CV
3	1	-	1	-	-	1	-	-	GM	GM	GM	CV	CV	CV	CV	CV

Example number 2

GM farmers not liable

Club size \ c_i	7	11	3	25	3	14	11	9	Configuration							
0*	0	-	0	-	0	-	-	0	CV	GM	CV	GM	CV	GM	GM	GM
3**	0	-	1	-	1	-	-	1	CV	CV	CV	GM	CV	GM	GM	GM
3**	1	-	0	-	1	-	-	1	CV	CV	CV	GM	CV	GM	GM	GM
4	1	-	1	-	1	-	-	1	CV	CV	CV	GM	CV	GM	GM	GM

GM farmers liable

Club size \ c_i	7	11	3	25	3	14	11	9	Configuration							
0*	-	0	-	0	-	0	0	-	CV	CV	CV	GM	CV	CV	CV	CV
3**	-	1	-	0	-	1	1	-	CV	CV	CV	GM	CV	GM	GM	GM
3**	-	1	-	1	-	0	1	-	CV	CV	CV	GM	CV	GM	GM	GM
3**	-	1	-	1	-	1	0	-	CV	CV	CV	GM	CV	GM	GM	GM
4	-	1	-	1	-	1	1	-	CV	CV	CV	GM	CV	GM	GM	GM

Example number	GM farmers not liable	GM farmers liable

Example 3 – GM farmers not liable

Club size \ c_i	6	8	15	8	6	15	6	4	Configuration							
0*	0	0	-	0	0	-	0	0	CV	GM	GM	GM	GM	GM	CV	CV
5**	0	1	-	1	1	-	1	1	CV	CV	CV	CV	CV	CV	CV	CV
5**	1	0	-	1	1	-	1	1	CV	CV	CV	CV	CV	CV	CV	CV
5**	1	1	-	0	1	-	1	1	CV	CV	CV	CV	CV	CV	CV	CV
5**	1	1	-	1	0	-	1	1	CV	CV	GM	CV	CV	GM	CV	CV
6	1	1	-	1	1	-	1	1	CV	CV	CV	CV	CV	CV	CV	CV

Example 3 – GM farmers liable

Club size \ c_i	6	8	15	8	6	15	6	4	Configuration							
0	-	-	0	-	-	0	-	-	CV	CV	CV	CV	CV	CV	CV	CV
2**	-	-	1	-	-	1	-	-	CV	CV	CV	CV	CV	CV	CV	CV

Example 4 – GM farmers not liable

Club size \ c_i	15	16	8	15	13	7	14	19	Configuration							
0*	-	-	0	-	-	0	-	-	GM	GM	GM	GM	GM	GM	GM	GM
2**	-	-	1	-	-	1	-	-	GM	GM	GM	GM	GM	GM	GM	GM

Example 4 – GM farmers liable

Club size \ c_i	15	16	8	15	13	7	14	19	Configuration							
0*	0	0	-	0	0	-	0	0	GM	GM	CV	GM	GM	CV	GM	GM
3**	0	1	-	1	0	-	0	1	GM	GM	GM	GM	GM	CV	GM	GM
3**	0	1	-	1	0	-	1	0	GM	GM	GM	GM	GM	CV	GM	GM
5**	1	0	-	1	1	-	1	1	GM	GM	GM	GM	GM	GM	GM	GM
5**	1	1	-	0	1	-	1	1	GM	GM	GM	GM	GM	GM	GM	GM
6	1	1	-	1	1	-	1	1	GM	GM	GM	GM	GM	GM	GM	GM

Figure 1: Club formation along a line. Four draw examples are presented. The c_i of each farmer is listed in the top row. Each line represents a club, with the club size listed first. In the figure only the clubs that are fully stable as well as the Nash equilibrium (club size 0) and the largest club (the last line) are shown. Club members are marked in grey and labeled 1, non-members are left blank and labeled 0. The members addressed through Coasean bargaining are labeled with (-). Internally stable clubs are marked with *, fully stable clubs with **. The configuration shows the corresponding cultivation decisions by the club and the non-members. GM cultivation is marked hatched and labeled GM, while conventional cultivation is left blank and labeled CV.

Example number		GM farmers not liable			GM farmers liable		
	c_i	Club size	Club members	Configuration	Club size	Club members	Configuration
1	3 11 17 9 12 5 23 2 9 3 5 15	0*	0 - - 0 - 0 - 0 0 0 0 -	CV GM GM GM GM GM GM CV GM CV GM GM	0	- 0 0 - 0 - 0 - - - - 0	CV CV CV CV CV CV CV CV CV CV CV CV
		6**	0 - - 1 - 1 - 1 1 1 1 -	CV GM GM GM CV CV GM CV CV CV CV GM	5**	- 1 1 - 1 - 1 - - - - 1	CV CV GM GM CV CV GM CV CV CV CV GM
		6**	1 - - 1 - 0 - 1 1 1 1 -	CV CV GM GM CV CV GM CV CV CV CV GM			
		5**	1 - - 1 - 1 - 0 1 1 0 -	CV CV GM GM CV CV GM CV CV CV CV GM			
		6**	1 - - 1 - 1 - 1 1 0 1 -	CV CV GM GM CV CV GM CV CV CV CV GM			
		7	1 - - 1 - 1 - 1 1 1 1 -	CV CV GM GM CV CV GM CV CV CV CV GM			

Example number		GM farmers not liable			GM farmers liable		
	c_i	Club size	Club members	Configuration	Club size	Club members	Configuration
		0*	- 0 - - 0 - - 0 0 0 - 0	GM GM GM GM CV GM GM CV GM CV GM GM	0*	0 - 0 0 - 0 0 - - - 0 -	CV CV CV CV CV CV CV CV CV CV CV CV
		5**	- 1 - - 0 - - 1 1 1 - 1	GM CV GM GM CV GM GM CV CV CV GM GM	5**	1 - 0 1 - 1 1 - - - 1 -	GM CV GM GM CV GM GM CV CV CV GM GM
		5**	- 1 - - 1 - - 1 0 1 - 1	GM CV GM GM CV GM GM CV CV CV GM GM	5**	1 - 1 0 - 1 1 - - - 1 -	GM CV GM GM CV GM GM CV CV CV GM GM
2	15 4 18 20 3 25 25 2 8 2 16 9	5**	- 1 - - 1 - - 1 1 0 - 1	GM CV GM GM CV GM GM CV CV CV GM GM	5**	1 - 1 1 - 0 1 - - - 1 -	GM CV GM GM CV GM GM CV CV CV GM GM
		6	- 1 - - 1 - - 1 1 1 - 1	GM CV GM GM CV GM GM CV CV CV GM GM	5**	1 - 1 1 - 1 0 - - - 1 -	GM CV GM GM CV GM GM CV CV CV GM GM
					5**	1 - 1 1 - 1 1 - - - 0 -	GM CV GM GM CV GM GM CV CV CV GM GM
					6	1 - 1 1 - 1 1 - - - 1 -	GM CV GM GM CV GM GM CV CV CV GM GM

Example number		GM farmers not liable			GM farmers liable		
	c_i	Club size	Club members	Configuration	Club size	Club members	Configuration
3	18 3 18 16 16 11 8 23 2 4 3 21	0*	- 0 - - - - 0 - 0 0 0 -	GM CV GM GM GM GM GM GM CV CV CV GM	0*	0 - 0 0 0 0 - 0 - - - 0	GM CV GM GM CV CV CV GM CV CV CV GM
		5**	- 1 - - - - 1 - 1 1 1 -	GM CV GM GM GM GM GM GM CV CV CV GM	4**	1 - 1 1 0 0 - 0 - - - 1	GM CV GM GM GM CV GM GM CV CV CV GM
					5**	1 - 0 0 1 1 - 1 - - - 1	GM CV GM GM GM CV CV GM CV CV CV GM
					5**	1 - 0 1 0 1 - 1 - - - 1	GM CV GM GM CV CV CV GM CV CV CV GM
					5**	1 - 0 1 1 1 - 0 - - - 1	GM CV GM GM GM CV CV GM CV CV CV GM
					5**	1 - 0 1 1 1 - 1 - - - 0	GM CV GM GM GM CV CV GM CV CV CV GM
					5**	1 - 1 0 0 1 - 1 - - - 1	GM CV GM GM GM GM GM GM CV CV CV GM
					5**	1 - 1 1 0 1 - 1 - - - 0	GM CV GM GM GM GM GM GM CV CV CV GM

6**	0	-	1	1	GM	CV	GM	GM
	1	1	-	1	GM	GM	GM	GM
	-	-	-	1	CV	CV	CV	GM
7	1	-	1	1	GM	CV	GM	GM
	1	1	-	1	GM	GM	GM	GM
	-	-	-	1	CV	CV	CV	GM

Figure 2: Club formation in a grid. Three example draws are presented. The second column lists the c_i of each farmer. Each square represents a club. In the figure only the clubs that are fully stable as well as the Nash equilibrium (club size 0) and the largest club (the last square) are shown. Club members are marked in grey and labeled 1, non-members are left blank and labeled 0. The members addressed through Coasean bargaining are labeled with (-). Internally stable clubs are marked with *, fully stable clubs with **. The configuration shows the corresponding cultivation decisions by the club and the non-members. GM cultivation is marked hatched and labeled GM, conventional cultivation left blank and labeled CV.