Dominos in the dairy: An analysis of transgenic maize in Dutch dairy farming

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Abstract

Isolation distances to limit the risk of cross-pollination from transgenic to non-transgenic crops can severely limit the potential use of transgenic crops through a so-called 'domino effect' where a field of non-transgenic crops limits adoption of transgenic crops not only on plots in its direct vicinity, but also in plots further away as its neighbors are forced to grow the non-transgenic varieties, forcing their neighbors to grow the non-transgenic variety, and so on. The extent to which this effect takes place, however, may depend crucially on the type of farm. For example, dairy farms can use grassland as a buffer between transgenic and conventional maize plots.

This article assesses the effects of isolation distances for transgenic maize in dairy farming. A spatially explicit farm model is applied to a region in the Southern Netherlands to identify to what extent a single farmer (who uses non-transgenic maize) can limit other farmers' potential to grow transgenic maize. The main findings are that 50% or more of the farms in the study area will not affect the potential adoption of transgenic maize by growing conventional maize at all. This result even holds under distance measures of 800m, which is the largest distance implemented by member states of the European Union. When they do have such effects, isolation distances can reduce the benefits from transgenic maize by €5,000 - €6,000, for a considerable part through a domino effect. Large net benefits of transgenic maize may limit the spatial effects as farmers are more willing to relocate maize production to areas where transgenic maize is allowed.

1 Introduction

Transgenic introduction of herbicide tolerance in agricultural crops has the potential to drastically reduce herbicide use in crops such as maize, oil seed rape, sugar beet, and cotton (Phipps and Park, 2002). Concerns over cross-pollination by transgenic of non-transgenic crops, however, have led to coexistence measures including isolation distances between transgenic and non-transgenic crops (Commission of the European Communities, 2009). EU member states, for instance, require farmers to maintain a distance between conventional and transgenic maize plots that varies from 15 meters in Sweden to 800 meters in Luxembourg.

Previous studies (Demont et al., 2008) warn that such isolation distances may lead to a so-called 'domino effect'. This effect occurs when one farmer plants the non-transgenic variety of a crop, thereby forcing his or her neighbors to also grow the non-transgenic variety, even if they would prefer the transgenic variety. In turn, their non-transgenic crops force their neighbors to grow non-transgenic crops, and so on. Demont et al. (2008) demonstrate this effect for oilseed rape in Central France, and show that if initially 50% of the study area is intended to be used for producing transgenic oilseed rape, distance requirements of 100 meters (which is common in the European Union) can reduce this by 38% of the cover area, 5% of which can be attributed to the domino effect. The domino effect’s part may seem minor in the entire reduction of transgenic oilseed rape area, but it causes about a third of the eventual costs of coexistence measures.

The direct and indirect effects of minimum distance requirements may depend crucially on whether the crop is used by arable farms or livestock farms. When an arable farmer wishes to grow a transgenic crop on a given plot, but the presence of a plot with a non-transgenic variety prevents him or her from doing so, the next best alternative is likely to also grow the non-transgenic variety, not another crop altogether. Livestock farms, however, typically produce a mixture of grass and fodder crops. In landscapes dominated by livestock farms, smart spatial planning of grass and maize production may avoid coexistence conflicts between transgenic and non-transgenic crops such as maize and fodder beet.

To understand the intuition behind this possibility, consider the configuration depicted in

Table 1. In this example there are three farms with two plots each, one of which is located close to the farm and another further away. For the sake of argument, assume that farmers need to produce grass on one plot, and maize on another. They prefer to produce grass on the plot located near the farm, and to produce maize on the other plot which is further away from the farm. This is a plausible assumption because grassland is harvested more frequently than maize, and when grassland is grazed by dairy cows farmers need to move the cows between the plot and the milking barn. Lastly, assume that the isolation distance in place prohibits growing transgenic maize on plots adjacent to plots where non-transgenic maize is grown.

Table 1: Example configuration of three farms with two plots each

Farmer	Near	Far from farms
A	1	2
B	3	4
C	5	6

Suppose farmer A prefers non-transgenic maize over transgenic maize, and this maize will be produced on plot 2. This means that farmer B cannot grow transgenic maize on his or her preferred plot 4. This leaves farmer B two options: either grow non-transgenic maize on plot 4, or grow grass on plot 4 and transgenic maize on plot 3. The first option will also affect farmer C's ability to grow transgenic maize, and hence create a domino effect. Note, however, that the second option will not create a domino effect because in that case farmer C can still grow transgenic maize on either plot 5 or 6. Another important observation is that farmer B is more likely to grow transgenic maize on plot 3 if the benefits from adopting transgenic maize outweigh the costs from allocating maize production to a plot that would have been the preferred plot for grassland. This implies that a domino effect is less likely when transgenic maize is more profitable compared to conventional maize.

This article analyzes to what extent isolation distances may limit dairy farms' adoption of transgenic fodder crops, taking explicitly into account their ability to allocate fodder production in a way that allows them to grow transgenic varieties despite the presence of a dairy farmer who does not do so. More specifically, it seeks to address the question to what extent a single dairy farmer can prevent other dairy farmers from adopting transgenic fodder crops, what proportion of that effect should be attributed to a domino effect, and how these effects depend on the cost difference between transgenic and non-transgenic fodder crops. The transgenic fodder crop considered in the paper is herbicide-tolerant maize.

The research questions are addressed with a spatially explicit dairy farming model that simulates land use decisions of 213 dairy farms in a region in the province of Noord-Brabant, the Netherlands. The model includes the fodder demand of dairy cows as well as the farm's production, purchase, and sale of grass, maize, and concentrates. Similarly to Demont et al. (2008), the model simulates farmers' land use decisions in a number of iterations, where after each iteration spatial conflicts between transgenic and non-transgenic maize are identified and resolved in the next iteration.

2 Model and data

2.1 Introduction

The model used in this paper is a spatially explicit farm management model based on farm management models developed by Berentsen and Giesen (1995), with additional insights from Nijssen and van Scheppingen (1995) and (Groeneveld et al., 2005), and updated for price levels of 2008 (ASG, 2008).

2.2 Model structure

For each dairy farm *f* in the study area the model maximizes the gross margin, defined as the difference between revenues and specific costs. This definition of gross margin excludes fixed costs that are exogenous to the decision to adopt transgenic maize, such as maintenance and depreciation of buildings. The objective function of the model for a given farm *f*, given the choices of all other farms, is therefore:

$$\max\left\{ I_f = rK_f + \sum_v \tau_v T_{vf} - \sum_{p\in \mathbf{O}_f} \sum_{v\in \mathbf{Q}} o_{vp} A_{vp} - \sum_v p_v P_{fv} \right\} \qquad \forall f\,, \tag{1}$$

where I_f denotes the gross margin of farm *f*, r_c denotes net revenues per dairy cow; K_f denotes the number of dairy cows on farm *f*; τ_v denotes the sales price of fodder type *v*; T_{vf} denotes the sales of fodder type *v*; $\mathbf{O}_f$ denotes the set of plots *p* used by farm *f*; **Q** denotes the set of fodder types produced by dairy farms; o_{vp} denotes the costs of producing fodder type *v* on plot *p*; A_{vp} denotes the area of fodder type *v* on plot *p*; p_v denotes the purchase price of fodder type *v*; and P_{fv} denotes the purchases of fodder type *v*. The model includes three fodder types, namely grass, maize, and concentrates.

Each farm is assumed to maximize its gross margin under restrictions regarding the cattle's fodder requirements, available land, and possible restrictions on production of GM maize. The cattle's fodder ration must supply sufficient energy, protein, and fiber. Moreover, the rumen degraded protein balance must at least be positive. These requirements are included in the following equation:

$$\sum_v n_{iv} S_{fsv} \geq \delta_{fis} K_f \qquad \forall f, i, s\,, \tag{2}$$

where n_{iv} denotes the nutritional value of fodder type *v* with regard to criterion *i*; S_{fsv} denotes the supply on farm *f* in season *s* of fodder type *v*; δ_{fis} denotes the demand on farm *f* for fodder nutritional element *i* in season *s*. There is a limit to how much fodder a cow can digest, included through the following equation:

$$\sum_v \zeta_v S_{fsv} \leq \psi_s K_f \qquad \forall f, s\,, \tag{3}$$

where ζ_v denotes the satiety value of fodder type (*v*); and ψ_s denotes the fodder intake capacity per cow in season *s*. Fodder production is defined by

$$Q_{fv} = \sum_{p\in \mathbf{O}_f} d_v A_{vp} \qquad \forall f, v \in \mathbf{Q}\,, \tag{4}$$

where $\mathbf{O}_f$ denotes the set of plots used by farm *f*; Q_{fv} denotes production on farm *f* of fodder type *v*; d_v denotes production of fodder type *v*; and **Q** denotes the set of fodder types produced on dairy farms. Differences between production and supply must be resolved by either purchases or sales of fodder:

$$P_{fv} - T_{fv} = \sum_s S_{fsv} - Q_{fv} \qquad \forall f, v\,, \tag{5}$$

where P_{fv} denotes the purchases by farm f of fodder type v; T_{fv} denotes the sales by farm f of fodder type v. Only concentrates and maize can be traded; purchases and sales of grass are fixed at zero. The land area on a given plot p devoted to fodder type v is restricted by the size of p:

$$\sum_{v \in \mathbf{Q}} A_{vp} \leq a_p \qquad \forall p \tag{6}$$

Considerations of coexistence between transgenic and non-transgenic maize are included as follows. Let **X** denote the set of transgenic fodder types, in this case transgenic maize, and **Y** the set of their non-transgenic counterparts. Moreover, assume that any given plot must be designated either a plot for the transgenic variety, a plot for the non-transgenic variety, or a plot for another crop altogether. Denote these designations by the index l, and let L_{lp} be a binary variable denoting whether plot p is used for land designation type l. Then whenever a fodder type is a member of **X** or **Y**, its production in a given plot is restricted by whether that plot has the right designation:

$$\sum_{v \in \mathbf{V}_l} A_{vp} \leq a_p L_{lp} \quad \forall l \in \mathbf{X} \cup \mathbf{Y}, p\,, \tag{7}$$

where $\mathbf{V}_l$ denotes the set of fodder types associated with land designation type l; and. Land designation types are mutually exclusive:

$$\sum_{l} L_{lp} \leq 1 \qquad \forall p\,. \tag{8}$$

When considering isolation distances between plots it is important to distinguish two situations: one where both plots involved are used by the same farm, and one where one plot is used by one farmer and the other plot by another. In the first case, the decision on land cover lies with one and the same person, who faces the following restriction:

$$L_{lp} \leq 1 - L_{l'p'} \quad \forall l \in \mathbf{X}, l' \in \mathbf{Y}, p \in \mathbf{O}_f, p' \in \mathbf{O}_f, p' \in \mathbf{N}_p\,, \tag{9}$$

where $\mathbf{N}_p$ denotes the set of plots p' within a distance from plot p equal to or smaller than the isolation distance. When plot p is owned by farmer f, and plot p' is owned by another farmer, the land cover type of p' is exogenous to f's decision:

$$L_{lp} \leq 1 - \lambda_{l'p'} \quad \forall l \in \mathbf{X}, l' \in \mathbf{Y}, p \in \mathbf{O}_f, p' \notin \mathbf{O}_f, p' \in \mathbf{N}_p\,, \tag{10}$$

where $\lambda_{l'p'}$ is a binary parameter denoting whether plot p' is used for land use type l'.

2.3 Data

The study area lies in the province of North-Brabant, the Netherlands (Figure 1). The dataset used in this study was originally developed for a land reallotment scheme (Schmitz, 1996). This dataset describes a sufficiently realistic situation to analyze to analyze farmers' land use decisions under different spatial coexistence rules. About

36% of the 377 farms in the study area have dairy cows, with an average of 46 head of dairy cattle per farm (Schmitz, 1996). Other agricultural activities in the area include beef cattle farming, arboriculture and arable farming.

Figure 1: Plots included as dairy plots in the model

Schmitz (1996) classifies the farms in De Leijen according to the fraction of farm size equivalents devoted to several agricultural activities. In this system, the fraction of agricultural activities in the total farm size determines the type of farm. This classification yields classes of farms with, for instance, 60-80% of farm size equivalents devoted to arable farming, 20-40% devoted to horticulture and less than 20% devoted to other, agricultural activities. For this study farms are selected with more than half the farm size equivalents devoted to cattle farming, and with more than 20 dairy cows. This selection includes 213 farms, together using 1235 plots with a total area of 4746 ha. Average farm size is 22.3 ± 9.1 ha (Figure 2).

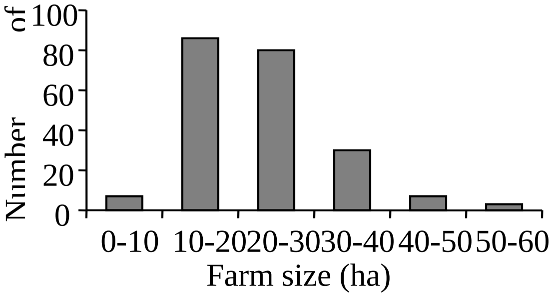

Figure 2: Farm size distribution in the study area

Data on market prices of fodder, fertilizer, hired labor and other farm inputs come from ASG (2008). Maize production costs about €1261 per ha, €35 of which is spent on herbicides (ASG, 2008). Data on the average number of young cattle per dairy farm come from de Jong (2006). Lastly, data on feed quality of conventional grass and maize are taken from CVB (2008).

Demarcation of the study area always raises the question what to assume with respect to the plots at its fringe. Moreover, some farms in the database own plots within as well as outside the study area. We assume that plots outside the study area, but not used by the farms in the database, are not used at all for maize production. Farms in the database are allowed to allocate maize production to plots outside the study area if they own such plots. We assume that these plots cannot be used for transgenic maize, but that they are sufficiently far from the study area to avoid coexistence problems.

2.4 Modeling procedure

The spatial externalities between farmers require that the model be run in a series of phases. The first phase maximizes the sum of farm profits (I_f) with $\lambda_{lp} = 0$ for all land use types, assuming that one of the 213 farms considered will not grow transgenic maize. Hence, the first phase gives the land use allocation if farmers only have to mind distances between transgenic and non-transgenic crops on their own farm. Under the assumptions made, a given farm will either grow transgenic or non-transgenic maize, and not both. The exceptions to this rule are farms owning plots outside the study area, but these plots are assumed to be sufficiently far away not to affect land use decisions in the study area.

Each phase consists of two model runs. The first model run maximizes the profits of each farm. The second run minimizes the area of plots with non-transgenic maize that conflict with transgenic maize, under the restriction that the profits of each farm are equal to the profits found in the first run. This second run is carried out to minimize any influence from the choice of optimization algorithm and starting solution. It is very well possible that the same farm income can be generated with many different land use allocations. In that case, conflicts between non-transgenic and transgenic maize, and hence the estimate of the domino effect, could be an outcome not of the farmers' incentive structure, but of the researcher's choice of optimization algorithm and starting solution. To reduce this arbitrary element, and to focus our analysis on the farmers' financial incentives, we proceed as follows. Let F_p denote whether the vicinity of plot p is free of transgenic maize:

$$F_p \leq 1 - \sum_{l \in \mathbf{X}} L_{lp'} \; \forall p, p' \in \mathbf{N}_p \, . \tag{11}$$

Note that F_p can only be equal to 1 if none of the plots in $\mathbf{N}_p$ contain transgenic maize. Let C_p denote whether plot p contains non-transgenic maize that conflicts with transgenic maize in its vicinity:

$$C_p \geq \sum_{l \in \mathbf{Y}} L_{lp} - F_p \qquad \forall p \, . \tag{12}$$

One could minimize the number of plots with non-transgenic maize that conflict with transgenic maize (i.e. the sum of C_p), under the restriction that the profits of each farm

(I_f) are equal to that in the first run. Note, however, that this procedure gives all plots equal weight, so that the results may still depend to some extent on the choice of algorithm and starting solution. To minimize this influence further, we do not minimize the number of non-transgenic plots that conflict with transgenic plots, but their total area, M:

$$\min\left\{M = \sum_p a_p C_p\right\} \text{s.t.}\, I_f = I_f^* \qquad \forall f\,, \tag{13}$$

where I_f^* denotes the profits of farm f in the first run. This procedure may still leave some room for influence by the choice of algorithm and starting solution, but this influence will be a lot smaller than if we took the results of the profit maximization for granted. Note also that although we minimize the area of non-transgenic plots conflicting with transgenic plots, this does not necessarily mean that the model will seek to eliminate non-transgenic maize. After all, conflicts between transgenic and non-transgenic maize can also be resolved by moving the transgenic variety.

The first phase gives a value of L_{lp} to which λ_{lp} is updated, and the two model runs are repeated with this updated value. The result of the second phase gives the land use allocation after some farms (notably the neighbors of the farm with non-transgenic maize) have changed their land use allocation in order to comply with the isolation distance. Hence, we can interpret the differences between the first and second run as the direct effect of the isolation distance. After the second phase λ_{lp} is again updated to the value of L_{lp} and the model is run again for the third phase. From the third phase on the model traces a possible domino effect through the landscape until there are no more plots with transgenic maize within the isolation distance from a plot with non-transgenic maize. Hence, we can interpret the difference between the second phase's result and the final result as the domino effect.

This procedure is repeated for 2556 different combinations of cost difference, farm, and isolation distance. Four different levels of cost difference were considered, namely €5, €15, €25, and €35. For each of the 213 farms in the study area the model was run assuming that this particular farm chooses not to adopt transgenic maize, regardless of the cost difference. Lastly, three isolation distances were considered, namely 15 meters, 250 meters, and 800 meters, which are applied by Sweden, The Netherlands, and Luxembourg, respectively (Commission of the European Communities, 2009).

3 Results

3.1 Null scenario

When no transgenic maize is available, the model predicts that the 213 farms in the model generate a total annual gross margin of about € 12.8 mln, with an average of €1206 ± 130 per dairy cow. LEI (2010) suggests that farms of the size class found in the study area had an average gross margin of €1894 per dairy cow in 2008. This rather large difference between predicted and observed gross margin is mainly caused by a difference in revenues. The model predicts average revenues of €2354, whereas the observed revenues are €3139 per dairy cow. Predicted costs (€1148) are quite close to their observed counterparts (€1245). The costs are much more relevant to our analysis than the revenues, because revenues consist mainly of sales of milk and meat, whereas the costs depend mainly on the farm's land use decisions.

The model predicts that out of 213 farms, 123 farms grow maize, 39 of which have devoted exactly 30% of their land to maize production. This result is due to manure regulations that require farms to have at least 70% grassland to apply for looser nitrate restrictions. All in all, about 11.2% of the dairy farming area in the model is used as maize land, whereas the average figure according to LEI (2010) is 14.8%.

3.2 First phase: potential area and benefits of transgenic maize

The first phase of the model gives the allocation of transgenic maize that would be realized if no isolation distance were imposed (Table 2). Depending on the price premium of transgenic maize, the area of transgenic maize could increase to about 562 ha, with about 81 ha non-transgenic maize, including plots outside the study area.

Table 2: Total area of transgenic maize in the absence of isolation distances under four different cost differences between transgenic and non-transgenic maize (average and standard deviation over 213 scenarios, in each which another farm abstains from growing transgenic maize)

Cost difference	5	15	25	35
Average	491	501	506	548
Standard deviation	3.13	3.20	3.20	3.25

Depending on the cost difference between transgenic and non-transgenic maize the total benefits of transgenic maize for adopting farmers in the area can be up to € 17,700 per year. Although in

Table 1 the area of transgenic maize takes a sudden leap between a cost difference of €30 per ha and €35 per ha, farm profits increase quite linearly with cost difference between transgenic and non-transgenic maize: for each €1 decrease in the price of transgenic maize total annual farm profits rise by between €473 and €561.

3.3 Direct effects of minimum distance requirements

The difference between the first and second iterations give an indication of the direct effects of the minimum distance requirements (Table 3). About half or more of the farms in the study area can produce non-transgenic maize without imposing any restrictions on their neighbors' production of transgenic maize. Not surprisingly, this number declines with the minimum distance to be kept: under a minimum distance of 15 meters about 150 farms will have no external effects, whereas under a minimum distance of 800 meters this holds for about 103 farms.

Table 3: Direct effects of minimum distance requirements under different levels of net cost savings (*d-m*)

	Largest income reduction			Largest GM area reduction (ha)			Farms with no effect		
d-m	15m	250m	800m	15m	250m	800m	15m	250m	800m
€5	€145	€224	€389	27	44	73	150	122	103
€15	€266	€434	€708	24	43	68	150	122	103
€25	€380	€644	€1,035	22	40	65	149	122	103
€35	€492	€843	€1,361	22	40	65	149	122	103

Interestingly, the largest reduction found in transgenic maize production area declines with the net cost savings for farmers. This suggests that as farmers have more to gain from growing transgenic maize, they become more willing to do so on plots where they would not have allocated the non-transgenic variety. Forgone profits, however, rise fairly evenly with net cost savings.

3.4 Domino effects of isolation distances

The changes in farm profits and land use allocation after the second iteration are due not to the direct effect of the non-transgenic farm, but to indirect effects, i.e. the domino effect (Table 4).

Table 4: Domino effects of isolation distances under different levels of net cost savings (*d-m*)

	Largest income reduction			Largest GM area reduction (ha)			Average share in total income reduction		
d-m	15m	250m	800m	15m	250m	800m	15m	250m	800m
€5	€285	€560	€1,041	56	111	212	32%	41%	67%
€15	€514	€1,023	€2,095	50	97	211	21%	37%	67%
€25	€756	€1,255	€3,149	48	74	211	26%	36%	64%
€35	€995	€1,612	€4,204	48	72	211	16%	35%	64%

Especially for larger distance measures the domino effect can become substantial. For those plots that are affected by the minimum distance requirements, the share of the direct effect increases with the minimum distance requirements.

4 Conclusion

Isolation distances for transgenic crops can seriously limit the potential area of transgenic crops. Given the reductions in herbicide use possible with herbicide-tolerant crops, this effect has environmental as well as purely financial implications. Due to the spatial nature of these measures, however, the scale of their implications depends heavily on the spatial configuration of plots in an agricultural area.

This paper demonstrates that the type of farming considered may also matter. Dairy farms are characterized by a variety of crops, all of which are necessary for cattle feeding. When faced with a ban on transgenic crops on a particular plot, a reorganization of their crop production may enable them to adopt the transgenic crop. This may come at a price, however, so the transgenic crop must be sufficiently better than the non-transgenic variety for them to do so.

Our analysis suggests that this effect will indeed likely occur. The results show that as transgenic maize is cheaper to use than non-transgenic maize, a single dairy farmer in a Dutch dairy farming region who declines to grow transgenic maize has a smaller effect on his colleagues’ propensity to grow transgenic maize. This can be observed for the direct effect of the non-transgenic plots on other farmers, as well when the so-called domino effect is taken into account. This effect is not strong enough, however, to offset the effect that the benefits forgone because of the isolation distances are also larger when transgenic maize is cheaper.

Overall, these results show that the total costs of isolation distances (defined as the benefits from transgenic maize forgone) can be in the order of €5,000 - €6,000 per year for the entire study area, or about €25 per year per farm. Although this is not large, it is somewhat alarming that a substantial part of these costs are due to the indirect, or domino, effect, which is the least observable. Nevertheless, the results also show that about half of the dairy farms in the study region can abstain from adopting transgenic maize without having negative consequences for other farms.

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