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The Costs of Coexistence Measures for Genetically Modified Maize in Germany

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Abstract

We estimate the perceived costs of legal requirements ('coexistence measures') for growing genetically modified (GM) Bt maize in Germany using a choice experiment. The costs of the evaluated ex-ante and ex-post coexistence measures range from zero to more than €300 per measure and most are greater than the extra revenue the farmers in our survey expect from growing Bt maize or than estimates in the literature. The cost estimates for temporal separation, the highest in our evaluation, imply that the exclusion of this measure in Germany is justified. The costliest measures of the ones that are currently applied in Germany are joint and strict liability for all damages. Our results further show that neighbours do not cause a problem and opportunities for reducing costs through agreements with them exist. Finally, we find that farmers' attitudes towards GM crops affect the probability of adoption of Bt maize. Our results imply that strict liability will deter the cultivation of Bt maize in Germany unless liability issues can be addressed through other means, for example, through neighbours agreements.

Keywords: *Bt maize*; *coexistence measure cost*; *genetically modified crops*.

JEL classifications: *C25, C81, K23, Q12, Q16, Q18*.

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1. Introduction

The EU Commission has decided that both producers and consumers should be free to cultivate and consume the product of their choice: be it organic, conventional or genetically modified (GM) crops (European Commission, 2010). To ensure that GM crops can be separated from non-GM crops at the farm level, many EU countries have implemented coexistence measures (i.e. legal requirements to ensure coexistence)[2] (see Beckmann *et al.*, 2014 for an overview). Coexistence measures in the European Union include *ex-ante regulation requirements* that farmers must comply with when cultivating GM crops as well as *ex-post liability rules* that determine how legal cases of GM crop cultivation issues are handled. The success of coexistence measures is affected by different farming conditions in EU Member States.

Coexistence measures at the farm level are difficult to price and cost estimates are largely missing in the literature. Our main contribution is to analyse how farmers who have experience with coexistence measures value them. For the analysis, we conducted a survey among farmers in Germany who planted GM Bt maize (denoted as Bt farmers) and their neighbouring farmers (denoted as non-Bt or neighbour farmers).[3] We surveyed farmers using a choice experiment and econometrically estimated the costs of different coexistence measures with a conditional logit model (CLM).

Even though the cultivation of Bt maize in Germany has been prohibited since 2009, knowing the costs of coexistence measures is important for economic and political decisions. First, measures have been implemented in Germany, but their costs from a farmer's viewpoint have never been assessed econometrically. Second, the cost estimates can be used for comparisons with other countries. Third, similar coexistence measures may be considered for crops derived from other controversial cropping technologies, either to satisfy standards initiated by the private sector or because they fall under the GM regulation. One example that illustrates this possibility is the case of so-called New Plant Breeding Technologies (NPBTs). The decision at EU level of whether to regulate NPBTs as a GM or a conventional technology is still pending. Furthermore, the USDA has recently published a report (Greene *et al.*, 2016) discussing the importance of coexistence issues within US agriculture. They find that the major strategy for coexistence at farm level is the use of buffer strips. Hence, the issue is not only of interest for the EU but also for other regions where GM crops are cultivated.

Previous literature analysing the cost of coexistence measures relies on small case studies with either direct assessments based on accounting principles (e.g. Messean *et al.*, 2006; Consmüller *et al.*, 2010; Skevas *et al.*, 2010; Venus *et al.*, 2011) or on simulations (e.g. Messean *et al.*, 2006). Using simulations based on expert opinions and a Geographic Information System simulation Messean *et al.* (2006) find that the coexistence costs for the Poitou-Charentes region in France can vary widely, depending on the farming system. For instance, if farms share a combine harvester, the costs amount to €57 per cleaning. They estimate that shifting of the flowering time can add

[2]Coexistence refers to the conditions under which GM and non-GM agricultural products can be grown in the same territory, transported and marketed side by side, preserving their identity in accordance with the relevant labeling rules and purity standards (Schenkelaars and Wesseler, 2016).

[3]Bt maize is a GM crop that contains a trait, inserted through genetic modification, that makes crops resistant to the European Corn Borer (*Ostrinia nubilalis*).

a cost of more than €201/ha. For buffer zones, cost estimates range between €17/ha and €78/ha.

Case studies by Consmüller *et al.* (2010) and Venus *et al.* (2011) show that farmers perceive many coexistence measures as acceptable. A possible reason for the high acceptance in those studies was the well above average farm size, which allowed the farmers to plant Bt maize in areas where conflicts with neighbours can be avoided. However, farmers with many fields adjoining neighbours or with relatively small field sizes perceived the minimum distance requirement as having a stronger negative impact. An agreement made with a grain trader to buy Bt maize containing the potentially Bt-contaminated maize of neighbours helped to reduce liability issues. Both case studies report mostly good relationships with neighbouring farmers. However, Venus *et al.* (2011) report conflicts with representatives of the municipality and the church or landlords.

Although coexistence measures are meant to guarantee freedom of choice between GM and non-GM crop cultivation, several papers have shown that minimum distance requirements discriminate against small farms (e.g. Devos *et al.*, 2009; Beckmann *et al.*, 2010; Consmüller *et al.*, 2010). This result may explain why research findings show a positive impact of farm size on the GM adoption probability (e.g. Breustedt *et al.*, 2008). Beckmann *et al.* (2011) show that depending on the property right, in the presence of minimum distance requirements non-Bt farmers may pose a negative externality on the Bt farmers by increasing Bt farmers' coexistence costs. Minimum distance can severely limit the economic benefits of GM growers in areas with non-GM farmers such that potential GM growers remain or convert back to non-GM cultivation (Demont *et al.*, 2008; Groeneveld *et al.*, 2013). Demont *et al.* (2009) and Devos *et al.* (2013) argue that flexible coexistence regulations (e.g. buffer zones) instead of rigid ones (e.g. minimum distance requirements) may reduce a possible domino effect that pressures potential Bt farmers to shift to non-GM maize cultivation. Studies in countries without the minimum distance requirement, however, also document a size effect (i.e. that larger farms are more likely to adopt GM crops) (e.g. Hubbell *et al.*, 2000; Fernandez-Cornejo *et al.*, 2002) without explicitly identifying the reasons.

For farmers to adopt Bt maize, coexistence costs have to be outweighed by the extra revenue of Bt maize compared to conventional maize. This profitability depends on several agronomic and economic factors such as the European Corn Borer infestation rate, farm structure, pest control management or maize acreage per farm (e.g. Breustedt *et al.*, 2008; Consmüller *et al.*, 2010). Areal *et al.* (2011) find that the major reasons for farmers to adopt herbicide-resistant maize and oilseed rape in six European countries are a guaranteed higher income and the reduction in weed control costs. However, the social environment, farmer's knowledge about and attitudes towards GMOs, age and education have also been identified to affect potential adoption (e.g. Gyau *et al.*, 2009; Areal *et al.*, 2011; Skevas *et al.*, 2012). Several studies have used choice experiments to analyse factors influencing farmers' choice of adopting GM-crops (see Breustedt *et al.*, 2008, for an overview). However, these studies do not explicitly calculate the costs of coexistence measures.

As shown earlier, arguments on the choice and impact of coexistence measures are often based on theoretical models, simulations or narratives. To judge the importance of the impact on farmers, econometric cost estimates are missing in the literature. We provide these estimates derived from choice experiments with former Bt maize farmers and their neighbours in Germany – one of the few countries besides the Czech

Republic, Portugal and Slovakia, where farmers have experience in complying with a complete national coexistence regulation regime. The estimates form a basis for further discussion on this issue for researchers and policy-makers and constitute a validation for previous theoretical work.

2. Material and Methods

2.1. Coexistence measures in Germany

Germany is one of the EU Member States that allowed farmers to grow GM Bt maize after the EU approved its cultivation. The German government approved Bt maize cultivation in 2005, but banned it again in early 2009. During the period of 2005 to 2008, 91 farmers from 12 out of 16 German federal states registered Bt maize cultivation areas. The total area increased each year and reached a total of 3,171 hectares or 0.15% of the total German maize production in the last year before the ban (BVL, 2016). More than 92% of the Bt maize area was located in three federal states: Brandenburg (39%), Saxony (30%) and Mecklenburg-Western Pomerania (24%).

In 2008, coexistence measures for Germany were formulated in the German Genetic Engineering Act (GenTG), complemented by the Genetic Engineering Plant Act (GenTPflEV) and by the Regulation on the implementation of the EU regulation on labelling and application of genetically modified organisms (GMOs) (Federal Ministry of Germany, 1990, 2004, 2008). The *ex-ante* and *ex-post* coexistence measures for the cultivation of Bt maize include:

1 *Compulsory registration*. A farmer who plants a GM crop has to inform the Federal Office of Consumer Protection and Food Safety (BVL) 3 months before the intended GM plant seeding.
2 *Spatial isolation minimum distance*. Genetically modified maize must keep a distance of 150 m from conventional and 300 m from organic maize fields. Federal States have the right to implement additional minimum distance requirements to nature conservation areas. The Federal States of Brandenburg and Baden-Wuerttemberg, for example, require a minimum distance of 800 and 3,000 m, respectively, between a Bt maize field and a nature conservation area.
3 *Obligation to notify the BVL and neighbours about the intention to cultivate GM plants*. Neighbours are owners of a field within 300 m from the GM field.
4 *Private arrangements*. The Bt farmer can agree with the neighbour to reduce the obligatory minimum distance up to 3 months before seeding. The neighbour has to sign an admonition. If the neighbour does not answer the request within 1 month, it is considered as consent to the Bt farmer's request. The Bt farmer has to inform the BVL about the agreement.
5 *Obligation to inquire information from the lower nature conservation authority*. The Bt farmer has to ask for information about nature protected areas 3 months before seeding if all conditions for the environmental protection are pertinent.
6 *Obligation to document*. The Bt farmer has to document the seed used and the location of the genetically modified plants. Additionally, the document must contain the cultivation technique and potential growth of unintended GM maize in the following year (i.e. volunteers). The farmer has to destroy volunteer GM plants.
7 *Avoidance of commingling*. The farmer has to prevent GM seeding and GM harvest material from commingling with conventional material; the farmer must, for instance, clean all machinery that could potentially lead to an admixture.

8 *Crop rotation*. Farmers must wait for at least 1 year before cultivating conventional maize in a field if GM maize grew on that field before.

Prior to these regulations a 20-m pollen barrier was recommended as a best practice measure at farm level (Weber *et al*., 2007; Consmüller *et al*., 2010).

2.2. Selection of farms and study design

A total of 91 farmers planted Bt maize in the period of 2005–2008 in Germany. We approached those farmers as they have experience with coexistence measures. We also included their neighbour farmers because Bt maize producers need to inform neighbouring farmers about their intention to cultivate GM crops. Although the size of our sample does not allow inference about German farms in general, it does allow comparison of the estimated coexistence costs with the expected Bt maize benefits. Moreover, because the farmers in our sample cultivated Bt maize, our results are based on past experience rather than on expectations.

In June 2012, the Federal Office of Consumer Protection and Food Safety sent out a letter to all 91 farmers. The letter asked them to provide their names and addresses to the project institution (Technische Universität München). Two out of the 91 letters were returned because the address was wrong or the recipient was unknown. Initially, 35 farmers replied to the letter. Of those who replied, 24 agreed to participate in the survey. The reasons of those who declined included: '... cultivation and coexistence are currently not relevant for agriculture', '... fed up with the ban by the politicians', '... had trouble in the first year. Yield was 20% extra, though', '... was criminalised by neighbours' and '... was forbidden by landowner to grow GM'. The 24 farmers who agreed received a personal phone call, in which four changed their mind about participating.

InnoPlanta e.V.,[4] an organisation at which all Bt farmers are registered, contacted five additional Bt farmers who had not replied to the BVL letter. Four of them agreed to participate in the survey.[5] The surveyed Bt farmers identified seven additional Bt neighbour farmers who initially had not replied to the BVL letter. Three of the Bt neighbours agreed to participate, resulting in a sample size of 27 Bt-farmers.

The 27 Bt farmers in the survey provided contact for 53 non-Bt neighbours. All of the neighbours received a request by phone to participate in the survey. 20 non-Bt neighbour farmers agreed to participate. The main reasons for refusal were '... no time', '... no interest in the topic', '... do not plant maize', '...area is leased out', '... responsible person is retired, sick, or passed away'. In summary, 27 Bt and 20 non-Bt farmers participated in the survey.

Our sample farms are in six out of the 16 German federal states (Table 1). Most sample farms are in Brandenburg, which was the state with the largest Bt maize production. Farms in Saxony, the second largest Bt maize cultivating state in Germany, are also well-represented. Farmers were mostly evenly spread within the states except

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[4]InnoPlanta e.V. is an association whose objective is to promote agro-biotechnological and modern plant breeding activities of farmers, companies, scientific institutions and others and to connect them in a network.

[5]The one who disagreed had problems with his landowners and did not want to be further connected with GMO activities.

Table 1
A summary of farmers' characteristics

	All $n = 47$	Bt $n = 27$	Non-Bt $n = 20$
Gender			
Male	45	27	18
Education			
University (of applied sciences) degree	37	22	15
Juristic person			
Yes	37	24	13
Federal state			
Bavaria	10	3	7
Brandenburg	14	11	3
Mecklenburg-W. Pom.	5	1	4
Saxony-Anhalt	3	2	1
Saxony	14	9	5
Thuringia	1	1	0

Source: Authors' survey.

for Bavaria where all farmers were in the northern part that has the highest application of insecticides against the European Corn Borer (Zellner *et al.*, 2009).

All respondents are highly involved in the arable production decision of the farm either as farm owners or managers (39 cases), or as plant department managers (8 cases). They were all employed during the time when Bt maize was planted and hence were well-informed; they were either involved in the decision in favour of or against Bt maize or, in case of non-Bt farmers, knew about their Bt neighbours' decision.

2.3. The survey questionnaire

The questionnaire included general questions on farm and farmers' characteristics. Farm characteristics included general farm type (arable, mixed, livestock or other), specific farm type (e.g. cereal, dairy or hog), farm-utilised agricultural area (UAA) (in hectares), and farm land leased. We also included questions on maize production, such as the cultivated maize; ranking of limits that prevented the farmer from receiving the maximum maize yield; as well as a 10-point scale ranking of the European Corn Borer damage and weed damage, if not or only insufficiently controlled.

The questionnaire also included socio-demographic characteristics such as the job position of the respondent within the farm, his or her farming experience, age, gender and level of education. Questions on the private farm household addressed the number of employees and farm income. Furthermore, we asked about the 2008 conventional and Bt grain and silage maize production. We gathered information on the planted area, number of fields and yield of the crops. In most cases, the exact yield, especially for silage maize, was not available, so the information was rather farmers' best estimate. Further information included the percentage of on-farm usage of maize, and if sold, the selling strategy and price per metric tonne. To examine farmers' attitudes, we used a Likert scale with 15 items about their perception of GM foods, food health and environmental issues, and of the role of the government.

Table 2
Attributes and levels of the choice experiment

	Attributes	Level 0	Level 1	Level 2
(1)	Liability	Not liable	Only if non-compliant with coexistence rules (negligence)	Joint and strict
(2)	Minimum distance	None	50 m	100 m
(3)	Information provision	None	Neighbour	Location register
(4)	Temporal isolation	None	2 weeks	4 weeks
(5)	Extra gross margin	€25	€75	€150

To examine the costs of coexistence, the survey included a discrete choice experiment requiring farmers to make a trade-off between a set of four coexistence measures and one monetary attribute – the extra gross margin from planting GM crops. The coexistence measures were some of those recommended by the European Commission (European Commission, 2003). We chose measures for which we expected a low correlation with one another. We excluded, for example, buffer zones because of a large correlation with minimum distance. Table 2 presents the five attributes.

Each attribute varies within three available levels. A full factorial design comprises $3^5 = 243$ possible combinations of attributes. Statistical design methods were then used to structure the presentation of the attribute levels within the choice sets. A D-optimal experimental design was constructed with only the main effects (Johnson *et al.*, 2006). A fraction of the full factorial design was employed to construct an efficient design with 12 choice sets, in which each level occurred once in each attribute and choice set. During the survey, each farmer was presented with those 12 choice sets, each containing two options to grow Bt maize and an option to 'opt out' by planting conventional maize with the information that this option could not lead to an additional gross margin but also does not require coexistence measures. This design results in a total of $47 \times 12 = 564$ responses.

Before the choice sets were presented, the respondents had to read a short text explaining that their decision in the choice set will have an effect on their economic outcome. Table 3 shows one of the 12 choice sets presented to the farmer.

Table 3
A sample choice set

	Alternative 1 Bt	Alternative 2 Bt	Alternative 3 Conventional
Liability	Liable only in case of non-compliance	Joint and strict	
Minimum distance	50 m	50 m	
Information provision	To public register	To neighbours	
Temporal isolation	Not needed	Not needed	
Additional gross margin	€25/ha	€25/ha	
Option choice	☐	☐	☐

2.4. Evaluation of coexistence costs

The coexistence value as defined by Beckmann and Wesseler (2007) represents a basic concept for the calculation of the coexistence cost. The coexistence value is computed by subtracting *ex-ante* and expected *ex-post* costs of coexistence from the additional gross margin derived from Bt maize compared to conventional maize. In the choice experiment, the coexistence measures are considered as attributes that a profit-maximising farmer only accepts if the coexistence value of Bt maize planting is positive following Lancaster's (1966) attribute concept. Since coexistence measures are negative characteristics (i.e. reduce utility), the farmer will only accept these measures if Bt maize yields extra value on top of the reference: conventional maize without coexistence measures.

Two types of predictor variables are distinguished: alternative-invariant and alternative-variant predictors. Alternative-invariant variables w_i' such as farmers' education or attitudes vary only over the farmer i, but do not vary over the alternative j. Alternative-variant variables are the attributes x_{ij}', that is, the coexistence measures as well as the gross margin that vary over the farmer i and also differ in each choice set with each of the two GM alternatives j.

The suitability of a conditional logit model for the evaluation of the data can be tested by checking for the independence from irrelevant alternatives (IIA), that is, whether the exclusion of one of the alternatives is truly irrelevant. We test for IIA using the Hausman specification test to compare a full CLM with two CLMs, each excluding one of the two Bt alternatives (Hausman and McFadden, 1984). In both cases, we find that the constrained and unconstrained estimated coefficients on the remaining categories are not significantly different, implying no rejection of the IIA, thus indicating the suitability of the CLM model.

The three alternatives a farmer can choose are {Bt1, Bt2, conv}, where Bt1 and Bt2 are the first two Bt choice options and conv is the third conventional option. Based on McFadden's (1974) random utility theory, the utility, U_{ij}, for the ith farmer to choose the jth maize alternative that maximises his or her utility is:

$$U_{ij} = x_{ij}'\beta + w_i'\gamma_j + \varepsilon_{ij}. \tag{1}$$

The coefficient γ_{conv} of the conventional alternative, which serves as the reference, is normalised to zero. There are two sets of coefficients, γ_j, however. Following Breustedt *et al.* (2008), we restrict the alternative-invariant coefficients not to vary between the two Bt alternatives, that is, $\gamma_{\text{Bt1}} = \gamma_{\text{Bt2}} = \gamma$. For the alternative-variant coefficient, the conventional alternative serves as the reference, such that the predictor $x_{ij}' = x_{ij}'^{*} - x_{i\text{conv}}'^{*}$ and the error terms become $\varepsilon_{ij} = \varepsilon_{ij}'^{*} - \varepsilon_{i\text{conv}}'^{*}$. The probability that the observed outcome, $y_j = j$, that is, that the ith farmer chooses alternative $j \in$ {Bt1, Bt2} is:

$$p_{ij} = \text{Prob}(y_i = j) = \frac{\exp(x_{ij}'\beta + w_i'\gamma_j)}{\sum_{k=1}^{3} \exp(x_{ij}'\beta + w_i'\gamma_k)}. \tag{2}$$

Interaction terms between some of the alternative-variant and alternative-invariant variables depend on i and j and are considered in x_{ij}'. Taking the derivative of the probability with respect to the alternative-variant variables yields the marginal effect of an increase in a regressor on the probability of selecting alternative j, that is:

$$\frac{\partial p_{ij}}{\partial x_{ik}} = p_{ij}[\text{Ind}(j = k) - p_{ik}]\beta, \tag{3}$$

where Ind $(\cdot)$ is an indicator function, equalling one if $j = k$, and zero otherwise.

The alternative-variant variable coefficients resulting from the CLM are used to estimate the coexistence costs, that is, the marginal rate of substitution of the coexistence measure attribute and the monetary gross margin attribute, which is given by:

$$W = -\left(\frac{\beta_{\text{coexistence measure}}}{\beta_{\text{gross margin}}}\right). \tag{4}$$

In this study, the interpretation of the non-monetary and monetary attribute parameter ratio is the willingness-to-accept rather than willingness-to-pay as farmers only accept coexistence measures if they get additional gross margin. Independently of this interpretation, however, W represents the cost of an attribute and hence the cost of coexistence measures.

2.5. Principal component analysis

Farmers were asked to rank several items on a Likert scale, to measure their attitudes towards GMOs. To include the attitudes in the choice experiment, we use a Principal Component Analysis (PCA).[6] The PCA explores if the variance of responses to an item overlaps with the variance of other items to form some common construct (component) (Costello and Osborne, 2005).

Even though explanatory factor analysis is more reliable in explaining an underlying construct, we use PCA as it is more robust because it assumes that all variance – the variance shared with other items and a part that is unique to the item – can be analysed compared to factor analysis, which explains the shared variance only (Costello and Osborne, 2005).[7]

The Kaiser-Meyer-Okin (KMO) (Kaiser, 1970) measure of sampling adequacy is used to test whether the sample is large enough and the Cronbach's alpha analysis to test the reliability of the component (see Appendix S2 in the online supplementary material, available at the publisher's website). Finally, the farmers' perception is measured by their score on each construct. This score is the weighted average of all item values that comprise a component.

3. Results

3.1. Statistics of sample farms

Our sample farms cover 0.03% of UAA in Germany and produce 9,174 hectares of maize (see online Appendix S1).[8] Our sample covers 30% of the Bt maize farms that planted 37% of the 2008 Bt maize area. Our sample contains farms that planted a somewhat larger area than the average Bt maize producer. The size of Bt maize parcels, however, is similar to the average of the 2008 registered parcels, as the share of

[6] A more detailed explanation of the procedure is outlined in online Appendix S2.

[7] We use Varimax rotation – an 'orthogonal rotation' that forces the factors to be uncorrelated with each other.

[8] Note that we asked farmers about their farm size in the year before the survey, that is, in 2012.

the number of parcels to the total number of parcels (63/200 = 31.5%) almost equals the share of Bt maize farmers to the total number of Bt maize farmers (30%). Of the 1,182 hectares, 77% was silage maize and 23% was grain maize.

Table 4 reports the mean socio-demographic and farm descriptive variables of all sample farms. For comparison, the fourth column represents data from Germany. The farms can be considered average maize producers at least in relative terms where maize occupies about 19.8% of their area, compared to 16% on average for Germany.

The SD and the ranges for all variables imply that the data are very heterogeneous. However, parametric as well as non-parametric statistical tests for differences indicate that the heterogeneity is independent from differences between sample Bt and non-Bt farms' and farmers' characteristics. The sample mean and mean for German data imply that the sample includes relatively large farms.

The average maize area per farm in the sample is 222 hectares. None of the 2008 maize variables (e.g. total maize area, average maize field size) differed significantly between Bt and non-Bt farmers. Although grain maize yield did not differ between Bt and non-Bt farmers, 11 farmers reported it was higher by 0.8 tonnes/ha for Bt maize (yield of 9.7 tonnes/ha) compared to the yield of their own conventional maize. The reported yield of Bt and conventional silage maize did not differ within farms. Four Bt maize farms planted Bt maize in 2008 for the first time. Except for one farm, all other Bt maize farms increased their Bt maize area from their first year of production until 2008 with reasons including: higher quality (n = 18); reduced pest damage (n = 14); a higher profit (n = 11). Crop rotation was also a reason why the area allocated to Bt maize changed between years (either increased or decreased) (n = 5).

Table 4

Socio-demographic and farm characteristics of the farm sample and Germany

		Sample			Germany*
	Unit	Mean	SD	Min–Max	Mean
Age	Years	51.0	11.2	23–75	>45.0
Farm employees	*N*	21.6	21.0	1.5–96	
Neighbours	*N*	14.0	18.1	2–100	
UAA per farm	Hectares	1,147.3	897.4	4–3,300	63.0†
UAA per farm (juristic)‡	Hectares	1,418.4	818.8	35–360	630.7
UAA per farm (single)§	Hectares	144.2	116.4	4–3,300	43.9
Share of rented area	%	65	11.2	0–95	60.0
Maize field size 2008	Hectares	17.0	11.7	0.04–55.7	
Total maize area 2008	Hectares	222.2	202.5	6–800	
Bt maize area 2008	Hectares	43.8	47.2	0.04–200	34.8
Bt grain maize area 2008	Hectares	20.5	15.6	2–50	
Bt silage maize area 2008	Hectares	50.8	52.7	0.04–200	
Observations	*N*	47			299,100¶

Note: *as of 2010, †only 'main livelihood' farms, ‡n(Bt) = 24, n(non-Bt) = 13, §n(Bt) = 3, n(non-Bt) = 7; ¶Total number of farms.
Source: Own calculations based on sample data; DEStatis (2012) data for Germany.

Out of the 17 farmers who stated that their revenue increased, only 13 were able to assess the increase. Their mean was €115/ha.

Most non-Bt maize farmers expected no price difference between Bt and non-Bt maize, probably (as indicated by some interviewees) due to the use of maize as feed. However, on average they expected a yield increase of 9.3% (about 0.9 tonnes) and additional gross margin of €34.4 (median value of €5) per hectare. The expected yield increase does not differ much from the one tonne yield increase found in the meta-analysis by Areal *et al.* (2013).

3.2. *Farmers' attitudes towards Bt maize cultivation*

A Likert scale consisting of 15 items was included in the questionnaire to survey farmers' attitudes towards GM crops and their perception of related benefits and risks of GM technologies and the role of the government.

Figure 1 shows the mean results of Bt and non-Bt farmers. We tested whether the distribution of given answers differs significantly using Fisher's exact test. Eight of 15 item response distributions differed significantly between Bt and non-Bt farmers. Bt and non-Bt sample farmers agreed on average that GM crops should be approved, if the majority of consumers is in favour of them (question 1). They also agree that GM crops should be approved if farmers find them useful (question 2). This result confirms results by Skevas *et al.* (2012) who asked similar questions in their survey of Greek farmers. Our results, however, differ from Skevas *et al.* (2012) for question 11, 12, and 13 on the potential environmental and health risks and the unnaturalness of GM crops, where our farmers disagree on average. On the other hand, farmers tended to agree that food safety risks are among the most important ones (question 8); that GM crops can eradicate diseases and pests (question 10); and that the rejection of GM crops makes EU farmers less competitive. Farmers were rather neutral about trust in food labels (question 3), harmfulness of food additives, and the ability of the government to manage potential health and environmental damages (questions 4 and 5). Bt farmers disagreed more strongly than non-Bt farmers that human interference in nature would have disastrous consequences.

3.3. *Estimation of coexistence costs*

Costs of coexistence measures were estimated from the choice experiment data. Each farmer's principal component score (PCS) on a single construct derived from the PCA (Table S1 in the online Appendix S1) was used as an alternative-invariant variable in the CLM. The higher the score of farmers on the component, the more they agree with items opposing GM crops.

We estimated two variations of the CLM of 47 farmers who filled out 12 choice sets each (Table 5). The first estimation is unrestricted while the second estimation is the parsimonious model excluding all insignificant variables that do not improve the model's goodness of fit when compared with a likelihood ratio test.

The reference level for the coefficient estimates of the alternative-invariant variables is conventional production. Therefore, a positive value implies that a larger value of the respective variable relates to a higher likelihood of choosing Bt maize. The reference level for the alternative variant variables (i.e. the coexistence measures) is the zero level of each attribute (i.e. not liable, no isolation distance, no information provision, and no temporal isolation distance). On average, 56.2% farmers chose the

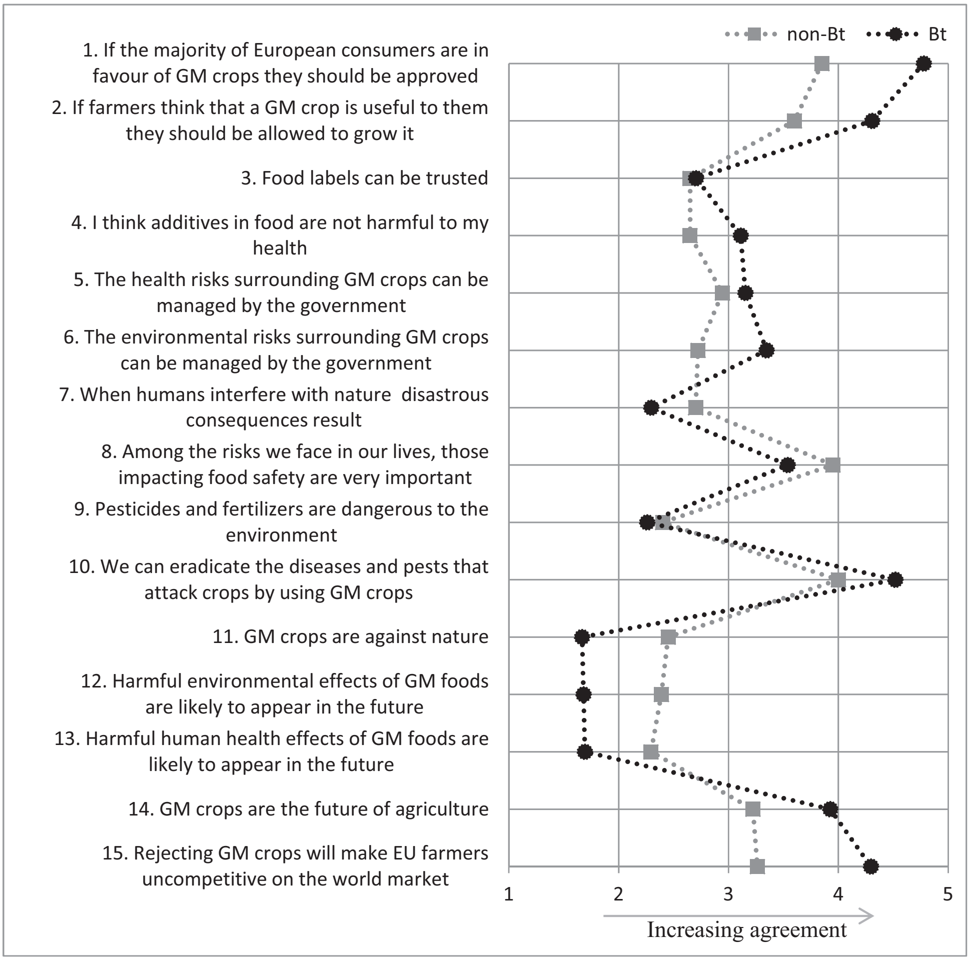

Figure 1. Mean values of Likert scale values for Bt and non-Bt farmers (n = 47). The scale rages from strongly disagree (1) to strongly agree (5).
Note: Items for which Fisher's exact test for differences between the distribution of Bt and non-Bt farmers is statistically significant are: 1, 4, 7, 10, 11, 12, 13, 14, 15.

conventional alternative (i.e. the reference category), 22.3% the first Bt alternative (Bt1), and 21.5% the second Bt alternative (Bt2).

Only two alternative-invariant coefficient estimates were significant: the PCS and the number of neighbours. Unlike previous studies, which found a positive impact of farm size measured by UAA on the adoption (Hubbell *et al*., 2000; Qaim and de Janvry, 2003; Breustedt *et al*., 2008), we found no effect. It is, however, important to stress that the sample Bt maize farms in our sample were much larger than the average German farm. This size effect is probably due to self-selection of larger farms cultivating Bt maize. If this is the case, farm size positively affects the adoption, and we cannot identify a size-effect due to a self-selection bias. Two further insignificant coefficients were found for farmer's age and education. Previous studies show either a positive or a negative impact of education on the adoption of GM crops (Breustedt

Table 5
Determinants of Bt maize adoption of Bt and non-Bt farmers

Variable/attribute	Attribute level	Unrestricted model	Parsimonious model
Constant		1.87** (0.86)	1.64*** (0.44)
PCS		0.74*** (0.15)	0.71*** (0.14)
Number of neighbours		−0.02*** (0.01)	−0.02*** (0.01)
Education		−0.03 (0.09)	
Farmer's age		−0.01 (0.01)	
Farm size		−0.00 (0.00)	
Arable farm		−0.28 (0.45)	
Liability	Negligence	−1.06*** (0.31)	−0.63*** (0.19)
	Joint and strict	−1.86*** (0.39)	−1.98*** (0.25)
Isolation distance	50 m	−1.26 (0.34)	−0.80** (0.31)
	100 m	−2.22*** (0.61)	−1.82*** (0.42)
Information provision	Neighbour	0.02 (0.35)	
	Public register	0.39 (0.44)	
Temporal isolation	2 weeks	−1.10*** (0.36)	−0.98*** (0.23)
	4 weeks	−3.93*** (0.56)	−3.43*** (0.33)
Negligence × Bt		0.53 (0.34)	
Joint and strict × Bt		−0.29 (0.46)	
50 m × Bt		1.36** (0.52)	0.76** (0.32)
100 m × Bt		1.44* (0.80)	0.75** (0.35)
Neighbour × Bt		−0.30 (0.37)	
Public register × Bt		−0.65 (0.52)	
2 weeks × Bt		−0.26 (0.40)	
4 weeks × Bt		0.60 (0.63)	
Gross margin × Bt		−0.004 (0.005)	
Gross margin		0.012*** (0.003)	0.010*** (0.002)
Log-likelihood		−420	−428
Akaike information criterion		905	885

Note: ***0.01, **0.05, *0.1 significance level. Standard errors in parentheses. Dependent variable = 'Probability of choosing Bt maize instead of conventional maize'. ×, interaction; PCS, Principal Component Score on farmer's attitudes towards GMOs.

et al., 2008). We also did not find an effect of the dummy for arable farming, which is one if the farm is a pure arable farm, and zero if the farm also has livestock. We expected a negative effect assuming that Bt maize can be used as feed without affecting the outcome of animal production, whereas marketing Bt maize could be more problematic. However, agreements of grain traders to buy Bt and conventional maize at equal prices may weaken or refute the marketing problem argument.

All statistically significant non-monetary attribute coefficients (i.e. coexistence measure) are negative, meaning that when the respective attribute is present, the Bt alternative containing this attribute is less likely to be chosen. For example, the 4-week temporal isolation coefficient of −3.43 in the parsimonious model indicates that if farmers had to implement this measure, they would be less likely to adopt Bt maize. Furthermore, farmers value the lower level of each attribute as less demanding. For example, the absolute value of the 2-week temporal isolation distance of −0.98 is lower than the value for 4-week isolation. The sign of the coefficient of the monetary attribute, that is, the extra gross margin from growing Bt maize is, as expected, positive.[9] The only insignificant coexistence measure is information provision for both attribute levels: the neighbours and the public register. The model also includes the alternative-invariant Bt variable as an interaction term to the alternative-variant coexistence measures. This variable equals one when the individual is a Bt farmer, and zero otherwise, and is used to check whether cost estimates differ between Bt and non-Bt farmers. Significant differences are only observed for isolation distances.

The PCS estimate is positive, indicating that farmers with a high PCS (i.e. with positive responses towards GMOs) are more likely to choose one of the Bt options. The more positive perception relationship with higher adoption likelihood is consistent with a survey on Bt maize adoption in Spain (Gómez-Barbero *et al.*, 2008).

Table 6 presents the marginal effects in the third column and the coexistence costs in the fourth column. Both estimates are derived from the parsimonious model. The marginal effects refer in percentage points to the effect of an increase in the respective variable by one unit on the probability of choosing Bt maize instead of conventional maize. The interpretation of the marginal effects of the coexistence measures – those are included as dummy variables in the choice set – is that if the respective coexistence measure is present, the probability of choosing Bt maize changes by the marginal effect's percentage points. The coexistence costs are computed by dividing coexistence measure coefficients (e.g. −3.43 in the case of 4-week isolation) by the gross margin coefficient (e.g. 0.010). The ordering of magnitudes of coexistence costs follows the ordering of magnitudes of the estimated coefficients.

If a farmer has one additional neighbour, the farmer's probability of choosing Bt maize decreases by 0.2 percentage points. This may have several reasons. The more neighbours a farmer has, the more coordination is necessary. Even though the estimated costs are zero for informing the neighbours about Bt maize cultivation,

Table 6

Marginal effects and coexistence costs of coexistence attributes

Attribute	Attribute level	Marginal effect (percentage points)	Coexistence costs (€/ha)
Liability	Negligence	−9.5	60.6
	Joint and strict	−29.8	189.1
Isolation distance	50 m (non-Bt)	−5.4	76.1
	50 m (Bt)	−0.2	4.0
	100 m (non-Bt)	−20.9	174.1
	100 m (Bt)	−16.2	100.4
Information provision	Neighbour		0.0
	Public register		0.0
Temporal isolation	2 weeks	−14.8	93.9
	4 weeks	−51.6	328.0
Principal Component Score		8.6	
Number of neighbours		−0.2	

[9]Note that we tested also for non-linearity of the gross margin as was suggested by an anonymous referee. The coefficient for the squared gross margin was insignificant.

Breustedt *et al.* (2008) show a GM-hostile neighbour can negatively affect the adoption probability, while a GM-friendly neighbour can positively affect adoption.

Our results show that the highest coexistence costs of about €328 for farmers are related to the temporal isolation distance of 4 weeks. This result is consistent with estimates of about €201 for France showing that temporal isolation can be one of the most expensive measures (Messean *et al.*, 2006). The high cost reflects the need to switch between very late and late varieties.[10] Our results also support the arguments of Messeguer *et al.* (2006), Weber *et al.* (2007) and Devos *et al.* (2009) that temporal scheduling to isolate Bt maize flowering from non-Bt maize flowering is not an effective measure if the seeding window is very short as in non-Mediterranean regions like Germany. This may explain the exclusion of temporal isolation distance from the obligatory coexistence measures in Germany, as is the case at present.

Of the obligatory measures, joint and strict liability has the highest cost of €189/ha. If liability is restricted to negligence, the cost is lower at €61/ha. Isolation distance of 100 m is the third costliest measure at €174 for non-Bt farmers, and €100 for Bt farmers. Similarly, Bt farmers valued the 50-m isolation distance lower than their non-Bt neighbours. Since we control for attitudes towards Bt (with the PCS variable), and since the Bt vs. non-Bt differences exhibit solely on the costs of isolation, this implies that the actual costs of isolation are lower than those expected *ex ante*. Alternatively, Bt farmers have other unobserved differences which account for these lower costs.

4. Discussion

Coexistence measures such as joint and strict liability rules and the public register were put in place in Germany for Bt maize between 2005 and 2008. Isolation distance and information provision to neighbours were introduced in 2008. Our high cost estimates of joint and strict liability (€189/ha) appear to contradict the idea of profit-maximising farmers since the average additional revenue for Bt farmers was estimated at only €115/ha and the additional gross margin found by Areal *et al.* (2013) was €65. However, farmers may have planted Bt maize in the presence of joint and strict liability because, as some farmers mentioned, one of the grain traders paid the same price for conventional and Bt maize while the GM seed supplying company safeguarded potential economic damage given farmer compliance with the laws. In the absence of such private insurance by grain traders and seed suppliers, compensation funds are a potential way to reduce liability costs. These funds cover accidental cross pollination as long as the farmer follows *ex-ante* regulations. Since the fund would only be paid if farmers complied with the *ex-ante* measures, it would reduce the coexistence costs from €189 to €61 in our estimates. The funds can be financed through a small tariff, for example, on the price of the GM seed bag by private stakeholders, as is the case for measures in the Netherlands, Portugal and Ireland or paid by the GM farmer and the government as in Denmark (Beckmann *et al.*, 2006).

An alternative solution to compensation funds is the grouping of Bt maize farmers in clubs as implemented for Bt maize in Portugal (Skevas *et al.*, 2009) but also reported for identity preservation of organic mustard in Canada (Furtan *et al.*, 2007). Punt and Wesseler (2015) show that famers form clubs depending on the property

[10]These costs are smaller if farmers have to switch from a late to a mid-early variety and larger, if they must switch from a very late to a mid-early variety (Messean *et al.*, 2006).

rights as well as the liability regime. The perceived high costs related to liability in our study supports the results of Punt and Wesseler (2015) that clubs will be large and stable but may not always completely solve the problem.

The presence of minimum distance requirements might have been one of the reasons why Bt farmers decided to plant Bt maize while their neighbours did not, as Bt farmers valued minimum distance as less costly. However, we cannot exclude potential reverse causation: farmers valued the distance requirement attribute less because they already had a positive experience from Bt maize cultivation and found it unproblematic to keep the minimum distance. Nevertheless, minimum distance costs for 100-m distance may restrict Bt maize adoption as those costs are greater than the average gross margin. The 50-m isolation distance, however, was estimated to be much lower. This lower distance would be sufficient to maintain cross-fertilisation levels below 0.5% at the border of the recipient maize field (Sanvido *et al.*, 2008). A further reduction in coexistence costs to more efficiently reduce the extent of cross-fertilisation might be achieved through a negotiability or replacement of isolation distance by pollen barriers (Demont *et al.*, 2009). A 10- to 20-m pollen barrier may be comparable to a 50-m isolation distance of bare ground (Devos *et al.*, 2005).

Our estimates for information provision to the neighbour and the public register were insignificant, implying zero *ex-ante* coexistence costs of information provision. An explanation for the insignificant result might be that the information provision process *per se* is inexpensive. However, information provision may have some potential negative externalities ignored by farmers. Negative externalities can be field destruction by anti-GMO activists, since the information enables or facilitates finding out the exact place of the Bt maize fields. For example, environmental non-governmental organisations '… linked the location register with [their] own geographical maps and internet information on how to reach GM fields' (Vaasen *et al.*, 2006). Field destruction was of concern to Bt maize farmers in our sample as well as in previous case studies. However, this externality may be of less concern to farmers when the GM seed provider agrees to compensate farmers for damage due to vandalism as is, for example, the case in Portugal (Skevas *et al.*, 2009). Furthermore, the primary aim of the register is to monitor adverse environmental effects. This monitoring would be possible without public access. The register is only publically available to increase transparency.

That informing neighbours has been assessed by farmers as inexpensive is further supported by the low negative affect of an additional neighbour on the decision to adopt Bt maize. This is an important result. Even so, GM crops are controversial, perhaps also among farmers, though they do not appear to increase conflicts between farmers in our sample.

5. Conclusion

Former Bt farmers and their non-Bt neighbours in Germany present a unique case for evaluating the practicality and cost of coexistence measures. Our sample contains about 30% of the former Bt maize farmers and some of their neighbours. Descriptive statistics of Bt farm characteristics reveal that mainly above average size farms chose to plant Bt maize.

Farm size as well as other farm characteristics of the sample Bt farmers were not found to differ statistically significantly from their non-Bt neighbours, but their attitudes towards GM crop cultivation do. On the one hand, the above average farm size character due to a self-selection bias allows us to draw only limited conclusions for a larger population with different characteristics. On the other hand, the similarity between Bt farms and non-Bt neighbour farms in our sample indicate that farmers' attitudes plays a major role in the Bt maize adoption decision in common with other studies.

We find that farmers value temporal isolation as the costliest coexistence measure, confirming its unsuitability in non-Mediterranean countries and explaining its exclusion from the set of coexistence measures in Germany. Strict liability is the costliest obligatory coexistence measure in Germany followed by large minimum distance requirements. Compensation funds may help reduce liability costs. The effect of information provision to neighbours or the public register on the adoption probability was insignificant. Further, an increase in the number of neighbours had only a negligible negative effect on the adoption decision. Hence, we conclude, agreements between neighbours can be a suitable and cost-efficient strategy to reduce the costs of minimum distance requirements. In this sense, voluntary solutions by farmers seem to be very suitable for achieving coexistence. This should come as no surprise since cooperation between neighbouring farmers for many different reasons is more common than conflict.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Utilised agricultural area (UUA), Bt silage and Bt maize grain area.

Appendix S2. Principal Component Analysis results.

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