Adoption of GMHT crops: Coexistence policy consequences in the European Union

Francisco J. Areal[1], Laura Riesgo[1], Manuel Gómez-Barbero[1,2], Emilio Rodríguez-Cerezo[1]

[1] European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Edificio Expo, Avda. Inca Garcilaso, 3 - E41092 Seville, Spain.

[2] Currently at European Commission, Directorate General for Agriculture and Rural Development (DG AGRI), Rue de la Loi 130 – 1040 Brussels, Belgium.

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1. Introduction

Since the adoption of genetically modified (GM) crops started in 1996, both its global area and the number of adopting countries have increased continuously. GM crops were grown in 25 countries, covering 8% of the total global arable land in 2008 (125 million hectares). Within GM crops, herbicide tolerance[1] (GMHT) is the dominant trait accounting for 63% of the global GM area (James, 2008). GMHT soybean is the main GM crop, reaching 53% of the global GM crop area in 2008 (65.8 million hectares) and 70% of the worldwide soybean production. GM maize is the second major crop, covering 30% of the total GM hectares (37.7 million hectares) and 24% of the total maize production. GM maize comprises GMHT and Bt[2] technologies, with respective shares of 17% and 19% at global level. GMHT oilseed rape (GMHT OSR) also represents a significant portion of the global GM area, reaching a total of 5.9 million hectares, which means 5% of the global biotech area (James, 2008). Besides these crops, other relevant GM varieties are cotton (12% of the global GM area), and to a lesser extent, alfalfa and sugar beet (less than 1%).

Economic benefits (derived from higher yields and/or reduced costs depending on the agronomic trait), production efficiency and flexibility, enhanced weed control and the facilitation of conservation tillage were pointed out as drivers to explain the rapid adoption of GMHT crops (Dill *et al*., 2008). With regard to yield improvement, some crop-trait combinations are reported to produce higher yields (such as Bt cotton, Bt rice and Bt maize – see Qaim and de Janvry, 2003; Qaim and Zilberman, 2003; Bennett *et al.*, 2006; Huang *et al*., 2005; Gómez-Barbero *et al*., 2008–). For other crop-trait combinations such as GMHT OSR, GMHT soybeans or GMHT maize, no significant differences were found in terms of yields between GMHT and conventional varieties (Qaim, 2009). While yields seem to be equal, net income gains from GMHT crops were reported. These income gains are due to the potential cost reduction of GMHT crops with respect to the conventional alternative through lower expenditures on herbicides, labour, machinery and fuel (Fernández-Cornejo *et al*., 2002; Phillips, 2003). Some authors have also reported environmental benefits associated with the adoption of GMHT crops, such as the substitution of selective herbicides (usually harmful for the environment) for less toxic broad-spectrum herbicides, or fuel savings associated with less spray runs and conservation tillage practices (Wolfenbarger and Phifer, 2000; Ervin *et al.*, 2000; Nelson and Bullock, 2003; Qaim, 2009). However, there are also potential environmental risks associated with weed management changes related to HT crops. Impacts on biodiversity, the selection of resistant weeds by intensive herbicide applications are some of the potential risks, or the appearance of HT volunteers (Hayes *et al.*, 2004; Graef *et al.*, 2007; Bonny, 2008). All these aspects, economic, environmental and technical, play a role in farmers' decision to adopt the new technology.

Currently there are no GMHT crops authorised for cultivation in the European Union (EU), although GMHT maize is the closest to commercial release for farmers since it is in the final steps of the regulatory pipeline. However, there are several GMHT crops approved for import into the EU but not yet approved for cultivation in the EU (GMHT soybean, GMHT maize and GMHT OSR). Bt maize and Amflora potato are currently the only GM crops authorised for cultivation in the EU since 1998 and 2010, respectively.

[1] Herbicide tolerant crops are tolerant to certain broad-spectrum herbicides such as glyphosate or glufosinate.
[2] Bt refers to insect resistant maize. This trait is based on genes from the *Bacillus thuringiensis* (Bt) soil bacterium.

Regarding the cultivation of GM crops, the European Commission recognises that 'European farmers should have a sustainable possibility to choose between conventional, organic and GMO production', underlining that economic damages or losses derived from the introduction of genetically modified organisms have to be avoided (European Council, 2006). Specific segregation measures during cultivation, harvest, transportation, storage and processing are required to ensure coexistence. These segregation measures should be targeted to ensure that non-GM harvests do not contain adventitious GM presence beyond the permitted 0.9% established by the EU. Currently, most of the European Member States have adopted or are in the process of developing legislation on measures that ensure coexistence between GM and non-GM crops. By February 2009, 15 EU countries had adopted specific legislation on coexistence (Austria, Belgium, the Czech Republic, Denmark, France, Germany, Hungary, Latvia, Lithuania, Luxemburg, the Netherlands, Portugal, Romania, Slovakia and Sweden) (European Commission, 2009). Since only Bt maize is approved for cultivation, most of the Member States' current legislation includes specific measures which relate only to GM maize cultivation.

Mandatory isolation distances per crop were established by European countries. The implementation of isolation distances is one of the coexistence measures put in place to prevent cross-pollination between GM and non-GM fields. For maize, distances range from 25 m (Slovenia) to 600 m (Luxembourg), whereas only Latvia and Lithuania have included 4,000 m as separation distances for OSR. In the case of potatoes, distances range from 3 to 50 m depending not only on the country but also on the variety chosen. For beets, isolation distance varies between 0.5 and 200 m.

Besides separation distances, other measures can be adopted in order to guarantee coexistence (European Commission, 2009). Amongst these, it is worth mentioning the request to farmers to notify public authorities and third parties (i.e. neighbours) of their intention to grow a GM crop, and other technical measures, different to spatial distances, such as segregation measures required during transportation, handling (e.g. cleaning machinery) or storage processes. Regarding liability provisions, the GM grower is generally responsible for the application of the mandatory coexistence measures. No insurance for the economic risks related to GM admixture is currently available in the European market (European Commission, 2009). However, in four countries insurance cover or alternative types of financial guarantee is legally required (Austria, France, Italy and Luxembourg).

A number of previous publications on GM related issues have focused on consumer attitudes towards GM food (Burton *et al.*, 2001; Grimsrud *et al.*, 2004; Lusk *et al.*, 2004; Rigby and Burton, 2005). There is also great interest from both policy makers and the EU agricultural sector in knowing what farmers' views and attitudes are towards this new technology and how the implementation of coexistence measures may affect the likelihood of them adopting new GM crops. Taking this issue into account, the main objective of this article is to provide an insight into the factors affecting the *ex ante* likelihood of adoption of some GM crops, including economic, environmental, technical factors and the regulations to ensure coexistence highlighted above. The analysis focuses on two particular GM crops, GMHT OSR and GMHT maize, both not yet approved for cultivation within the EU but widely adopted by farmers elsewhere. Previous research identified that the producer's adoption depends on the current and perceived future profitability, the convenience of the new technology (i.e. ease of use relative to the current technology used), environmental concerns and uncertainty of outcomes (Hillyer, 1999; Breustedt *et al*., 2008). Coexistence policy is specific to the EU and may shape GMHT adoption in the EU. Few studies have focused on the effect of spatial coexistence measures on GM adoption using simulation techniques (Demont *et al*., 2008 and 2009). However there is a lack of studies on the effect of a wider number of policy regulations (registration, segregation measures and insurance covering) on adoption currently under debate in the EU. This article aims to help overcome this shortage, through the evaluation of the effect of regulations associated with coexistence between current and new technologies, on the adoption of new technologies. The incorporation of such measures or regulations in the analysis is crucial for examining the potential level of adoption of GM technology if measures to ensure coexistence between the current and the new technology are to be implemented.

The paper is organised as follows. Section 2 presents the methodology, with a brief description of the questionnaire utilised for this research and an explanation of the econometric approach to analyse farmers' willingness to adopt GMHT crops. Section 3 presents the results and aims to determine the heterogeneity of farmers' adoption. Finally, Section 4 contains a discussion of the results and the conclusions drawn.

2. Methodology

2.1 The surveys

In order to estimate farmer's willingness to adopt GMHT OSR and GMHT maize, a survey questionnaire was designed including questions on farm characteristics, and a wide list of reasons which may encourage/dissuade farmers from adopting GM crops including economic, environmental, technical, administrative aspects, and socio-demographic farmers' characteristics.

A total of 426 farmers were interviewed face-to-face in the Czech Republic, Germany and the United Kingdom on their willingness to adopt GMHT OSR during March and July 2007. During the same period 280 farmers were interviewed in France, Hungary and Spain on their willingness to adopt GMHT maize. Therefore, the total number of interviews is greater than the minimum sample size to ensure that all countries are adequately represented at EU level for each crop.

2.2 Questionnaire structure

A questionnaire was designed to collect information about the potential adoption of GMHT OSR and GMHT maize. The questionnaire consisted of four sections. The first section aimed to select those farmers that were professionally farming OSR or maize in 2006, i.e. production was marketed. The second section included questions about farm characteristics such as farm size, hired workers, and machinery. The third contained specific questions on the management of each crop (e.g. the variety of seeds bought by farmers, the use of herbicides and pesticides, crop price and production) as well as questions on willingness to adopt GMHT varieties. The last section requested socio-demographic information from the respondents.

For both case studies, adoption cannot be observed quantitatively because these crops are not yet approved for commercial cultivation in the EU. Thus, in order to analyse the level of farmers' acceptance with regard to new crops we only count the opinion of farmers on the potential introduction of these crops in their crop mix. In the questionnaire, farmers were asked whether they would grow GMHT OSR/ GMHT maize. Respondents could choose from 5 ordered alternatives: a) *It's very unlikely I would change to GMHT OSR (GMHT maize)*; b)

It's somewhat unlikely I would change to GMHT OSR (GMHT maize); c) *It's uncertain I would change to GMHT OSR (GMHT maize)*; d) *It's likely I would change to GMHT OSR (GMHT maize)*; and e) *It's very likely I would change to GMHT OSR (GMHT maize)*.

2.3 Conceptual framework

This paper studies the acceptability and potential adoption of two new crops, GMHT OSR and GMHT maize. The willingness to adopt these crops (WTAd) depends on the utility farmers derive from growing GM alternatives. In this paper, as it was mentioned above, WTAd and farmers' utility may be influenced by a number of factors related to economic benefits, efficiency and facilitation of weed control or conservation tillage. WTAd models were set up in an ordered probit regression framework in which the dependent variable is given as a likelihood of farmers adopting GMHT OSR or GMHT maize, on a 5-point scale. The use of the ordered probit is appropriate when the dependent variable involves more than two alternatives that must take a logical ordering form as in our case. The ordered probit model can be determined by:

$$y_i^* = x_i^{'}\beta + \varepsilon_i \qquad [1]$$

where y_i^* is a latent variable (i.e. unobservable) that represents the WTAd (or farmers' utility); x_i is a vector of factors that may influence respondents' views; β is a vector of parameters to be estimated associated with the explicative variables; ε_i represents unobservable factors that are assumed to be independently and normally distributed across observations and it is normalised with mean zero and standard deviation one. In order for all probabilities to be positive, the relationship between the latent variable y_i^* and the observable y_i must be:

$$\begin{aligned} y_i &= 1 \text{ if } y_i^* \le \gamma_1 \\ y_i &= 2 \text{ if } \gamma_1 < y_i^* \le \gamma_2 \\ y_i &= 3 \text{ if } \gamma_2 < y_i^* \le \gamma_3 \\ y_i &= 4 \text{ if } \gamma_3 < y_i^* \le \gamma_4 \\ y_i &= 5 \text{ if } y_i^* > \gamma_4 \end{aligned} \qquad [2]$$

The γ_j s are unknown ordered threshold parameters to be estimated with the unknown coefficients β. The probability that the ordered dependent variable y takes the different possible values is:

$$\begin{aligned} P(y=1|x) &= \Phi(\gamma_1 - x'\beta) \\ P(y=2|x) &= \Phi(\gamma_2 - x'\beta) - \Phi(\gamma_1 - x'\beta) \\ P(y=3|x) &= \Phi(\gamma_3 - x'\beta) - \Phi(\gamma_2 - x'\beta) \\ P(y=4|x) &= \Phi(\gamma_4 - x'\beta) - \Phi(\gamma_3 - x'\beta) \\ P(y=5|x) &= 1 - \Phi(\gamma_4 - x'\beta) \end{aligned} \qquad [3]$$

where Φ indicates a cumulative normal distribution. The cut points γ_j divide the categories of the dependent variable. Therefore, the probability that alternative 1 is chosen is the probability that the latent variable y_i^* is equal to or below γ_1. To calculate the probability that alternative 2 is chosen we need to calculate the probability that the latent variable y_i^* is between γ_1 and γ_2, and so on.

In order to identify those factors that may influence GMHT crops' adoption, farmers were asked to evaluate a number of reasons according to how important they considered them. Within these factors we distinguished economic aims, reasons of disbelief, the implementation of coexistence measures and other socio-demographic issues.

2.4 Impact of economic reasons on willingness to adopt

Farmers were asked to evaluate a set of economic statements that may be related to a farmer's decision to adopt GMHT crops. These statements are shown in Table 1. Farmers assessed the importance of each statement by assigning a value from 1 (completely unimportant) to 5 (very important).

Table 1. Economic statements

Variables	Description
'It guarantees the reduction of losses caused by weed growth'	Describes the degree of importance farmers assign to diminishing the problem of harvesting losses caused by weed infestations due to adopting GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying a very important factor in GMHT OSR/GMHT maize adoption.
'It guarantees higher income'	Describes how important an increase in income is for farmers if GMHT OSR/GMHT maize was adopted. This is a categorical variable having values from 1 to 5, with 5 signifying a very important aspect in GMHT OSR/GMHT maize use.
'It reduces weed control costs'	Describes how important weed control costs are in GMHT OSR/GMHT maize adoption. This is a categorical variable having values from 1 to 5, with 5 signifying a very important aspect in GMHT OSR/GMHT maize adoption.

In order to analyse these statements, we created a dummy variable (ECONOMIC) to analyse whether economic reasons are an important factor in GMHT crops adoption (see Table 5). In this case, the new variable takes the value of 1 if the farmer considered at least one of the economic reasons important, quite important or very important, and a value of 0 otherwise. A positive relationship between economic factors and likelihood to adopt is anticipated.

2.5 Disbelief in GM technology

GM technology, like any other innovation may have detractors and face criticism. Besides, producers may have concerns with respect to the new technology (Feder and Umali, 1993; Hillyer, 1999; Negatu and Parikh, 1999; Fernández-Cornejo *et al*., 2002; Marra *et al*., 2001 and 2003). As a consequence potential adopters may not "believe" in the new technology for a number of reasons (Table 2). Not accounting for this may lead to wrongly attributing the unwillingness to adopt the new technology to other factors.

Table 2. Variables based on reasons of disbelief in GM technology

Variables	Description
'I do not think there would be an improvement in financial returns'	Describes the degree of disbelief the farmer assigns to the idea that GMHT OSR/GMHT maize would improve financial returns. This is a categorical variable having values from 1 to 5, with 5 signifying a great disbelief.
'I do not belief in these new products'	Describes the degree of disbelief the farmer assigns to GMHT OSR/GMHT maize technology. This is a categorical variable having values from 1 to 5, with 5 signifying a great disbelief.

'I prefer not to change the type of crop. I do not really like change'	Describes the degree of dislike for crop changes. This is a categorical variable having values from 1 to 5, with 5 signifying a great dislike.
'I have been advised not to use this type of crop'	Describes the degree of disbelief originating from others which the farmer assigns to the new technology. This is a categorical variable having values from 1 to 5, with 5 signifying a great disbelief.
'I think it would be difficult to market the grain'	Shows how worried the farmer is about consumer acceptance of the new product. This is a categorical variable having values from 1 to 5, with 5 signifying a great concern.
'It will not be well received by society in general'	Shows how worried the farmer is about society's acceptance of GM products. This is a categorical variable having values from 1 to 5, with 5 signifying a great concern.

Therefore, in order to take into account these prior beliefs a dummy variable (DISBELIEF) was created to account for those farmers who showed a strong concern or disbelief for growing GM crops (see Table 5). Farmers who responded either *'I do not think there would be an improvement in yield'*; or *'I do not think there would be an improvement in financial returns'*; or *'I do not believe in these new products'*; or *'I prefer not to change the type of crop. I do not really like change'*; or *'I have been advised not to use this type of rape'*; or *'I think it would be difficult to market the grain'*; or *'It will not be well received by society in general'* showed a certain degree of disbelief or concern for the new technology. A dummy variable accounted for farmers displaying this attitude by taking a value of 1 if at least one of the reasons was considered very likely by the farmer to cause rejection in the adoption of GMHT OSR and GMHT maize and 0 otherwise (see Table 5).

2.6 Impact of coexistence measures on willingness to adopt

In order to test the influence of some coexistence measures on GM crop adoption, farmers were asked about how eventual mandatory measures to ensure coexistence between GMHT and conventional OSR and maize would affect their decision to adopt GMHT OSR and GMHT maize. These eventual measures were taken into consideration by including a number of explanatory variables in the model. We have grouped these measures into four categories: administrative measures, technical measures, separation distances and insurance policy.

2.6.1 Administrative measures

First we analysed the impact of non-technical (administrative) coexistence measures on the adoption of GMHT crops. We considered 3 explanatory variables, as can be seen in Table 3.

Table 3. Variables based on administrative measures

Variables	Description
'The farm must be identified in a public register'	Describes the degree of importance that farm registration in a public register has in a farmer's decision to adopt GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying a very serious administrative problem associated with GMHT OSR/GMHT maize adoption.
'The neighbouring farmers must be notified'	Describes the degree of importance that notifying neighbouring farmers about GMHT OSR/GMHT maize being grown has in a farmer's decision to adopt GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying a very serious administrative problem associated with GMHT OSR/GMHT maize adoption.
'If the land is rented, the owner has to be notified'	Describes the degree of importance that notifying farm owners about GMHT OSR/GMHT maize being grown has in a farmer's decision to adopt GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying a very serious administrative problem associated with GMHT OSR/GMHT maize adoption.

In order to account for this, a dummy variable (ADMINISTRA) was created with a value of 1 if the farmer answered that situations where *'the farmer must be identified in a public register'* or *'the neighbouring farmers must be notified'* or *'if the land is rented, the owner has to be notified'* would lead to their rejection of the idea of cultivating genetically modified crops, and takes a value of 0 otherwise. These measures may be important in farmers' decisions to adopt if they are averse to the risks associated with being identified as a GM grower.

2.6.2 Technical measures

To guarantee the coexistence between conventional and GMHT crops, some technical measures should be applied during harvesting and transportation (Messean *et al*., 2006). In the questionnaire two specific measures were considered for evaluation by farmers, namely cleaning the combine harvester both before and after harvesting, and the separation of harvesting and transportation (see Table 4).

Table 4. Variables based on technical measures

Variables	Description
'The combine harvester must be thoroughly cleaned both before and after harvesting'	Describes the degree of importance that the cleaning of machinery has in a farmer's decision to reject GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying that cleaning machinery is a very important aspect in deciding whether or not to reject GMHT OSR/GMHT maize.
'The compulsory of separate harvesting and transportation'	Describes the degree of importance that keeping compulsory separation of harvesting and transportation in a farmer's decision to reject GMHT OSR/GMHT maize. This is a categorical variable having values from 1 to 5, with 5 signifying a very important technical measure to take into account in deciding whether or not to reject GMHT OSR/GMHT maize.

Regarding technical measures we created a dummy variable (TECHNICAL), which accounts for cleaning and separation processes taking a value of 1 if the farmer stated that either *'the combine harvester must be thoroughly cleaned both before and after harvesting*' or *'the compulsory implementation of separate harvesting and transportation*' were reasons likely to cause the rejection of the idea of cultivating genetically modified crops and 0 otherwise (see Table 5). These cleaning and separation processes are not easy to implement and would be time consuming, leading to an extra cost for the farmer. Due to this time consumption, it is expected that the implementation of these types of measures impact negatively on the likelihood of adopting GMHT OSR and GMHT maize.

2.6.3 Separation distances

Farmers were asked about the maximum separation distance they would be willing to introduce before ceasing cultivation of GMHT OSR/GMHT maize. A dummy variable (SEPARATION) was created with a value of 1 for those farmers who answered that they would stop growing GMHT OSR/GMHT maize if the distance was 25m or more and 0 otherwise (see Table 5). This distance was the median obtained from the farmers' responses. The same distance was used for GMHT maize since the same median was obtained for this case. Separation distances between fields is one of the main measures to ensure coexistence between GM and non-GM crops and, as in the case of cleaning and separating measures, separation distances are expected to have a negative impact on the farmer's views towards adopting the new technology.

2.6.4 Insurance policy

Another coexistence measure included was the requirement that they be covered by *'an insurance policy to cover claims for neighbours'* (INSURANCE) for the presence of adventitious GM material in the neighbour's crops (see Table 5). Such an insurance policy is anticipated to have a negative effect on the adoption of GM technology as it would imply an extra cost for the farmer.

2.7 Other explanatory variables

Apart from the variables presented above, others related to farmers' socio-demographic characteristics (age, high education level –university degree or higher– or farmers' income level), farm size, farmers' location, and environmental reasons to encourage GM adoption or the ease of use of the new technology, are also considered in the ordered probit model.

Reasons that might persuade farmers to adopt the new technology included environmental factors such as *'the environmental impact on my farm is reduced because it involves a cut down in herbicides'*; and convenience such as *'It facilitates my work being a technology that makes cultivation easier'*. A dummy variable was created to account for the environmental reasons (ENVIRONMENT) and for the ease of use (EASE) associated with the probability of adopting GMHT OSR or GMHT maize. They take a value of 1 if the farmer considered it important or very important to adopt the new technology due to the possibility of the environmental impact on the farm being reduced because the use of the new technology reduces the use of herbicides (the ease of use), and 0 otherwise (see Table 5). It is expected that ease of use will have a positive impact on the willingness to adopt GMHT OSR and GMHT maize (Carpenter and Gianessi, 1999; Fernández-Cornejo *et al*., 2005; Bonny, 2008; Gardner *et al*., 2009).

Table 5. Explanatory variables in the ordered probit model

Variables	Description	Type of variable
Economic reasons (ECONOMIC)	Describes if economic reasons are important for farmers' decision-making on GMHT OSR/GMHT maize adoption.	Binary variable, ECONOMIC=1 if the respondent considered at least one of the economic reasons as important, quite important or very important, and ECONOMIC=0 otherwise.
Environmental impact reduction (ENVIRONMENT)	Describes if farmers consider that environmental impact on their farms is reduced because GMHT OSR/GMHT maize involves a cut in herbicides	Binary variable, ENVIRONMENT=1 if the respondent considered this environmental issue as quite important or very important and ENVIRONMENT=0 otherwise.
Ease of use (EASE)	Describes if farmers consider that cultivation is easier because GMHT OSR/GMHT maize involves a reduction in agricultural tasks.	Binary variable, EASE=1 if the respondent considered this as important, quite important or very important, and EASE=0 otherwise.
Disbelief in GM technology (DISBELIEF)	Describes if farmers' disbelief has an influence in GMHT OSR/GMHT maize adoption by farmers	Binary variable, DISBELIEF=1 if the respondent considered at least one of the reasons of disbelief as very important, and DISBELIEF=0 otherwise.
Administrative reasons (ADMINISTRA)	Describes if administrative reasons are important in GMHT OSR/GMHT maize adoption by farmers	Binary variable, ADMINISTRA=1 if the respondent considered at least one of the administrative reasons as quite important or very important, and ADMINISTRA=0 otherwise.
Technical measures (TECHNICAL)	Describes if technical measures are important in GMHT OSR/GMHT maize adoption by farmers	Binary variable, TECHNICAL=1 if the respondent considered at least one of the technical measures as quite important or very important, and TECHNICAL=0 otherwise.
Separation distance (SEPARATION)	Describes if the implementation of separation distances has an influence on GMHT OSR/GMHT maize adoption	Binary variable with SEPARATION=1 if the respondent falls in the distance above the median separation distance (25 meters for OSR and maize), and SEPARATION=0 otherwise
Insurance policy (INSURANCE)	Describes the possibility of obtaining an insurance to cover claims for neighbours	Binary variable, INSURANCE=1 if the respondent considered the insurance policy as quite important or very important issue to comply with GMHT OSR/GMHT maize, and INSURANCE=0 otherwise.
Age (AGE)	Age of farmers (years)	Continuous variable
High education level	Education level of farmers	Binary variable with EDUCATION=1 if farmer has a

(EDUCATION)		high education and EDUCATION=0 if not.
Farm size (SIZE)	Size of the farm (hectares)	Continuous variable
Income (INCOME)	Annual family income	Binary variable with INCOME=1 if the respondent falls in the income level below the median income (35,000 €/year for OSR and 17,000 €/year for maize), and INCOME=0 if otherwise.
Germany (GE)	Describes if OSR farmers surveyed are located in Germany	Binary variable with GE=1 if farmer is located in Germany and GE=0 if not.
Czech Republic (CZ)	Describes if OSR farmers surveyed are located in the Czech Republic	Binary variable with CZ=1 if farmer is located in the Czech Republic and CZ=0 if not.
United Kingdom (UK)	Describes if OSR farmers surveyed are located in the United Kingdom	Binary variable with UK=1 if farmer is located in the United Kingdom and UK=0 if not.
France (FR)	Describes if maize farmers surveyed are located in France	Binary variable with FR=1 if farmer is located in France and FR=0 if not.
Spain (SP)	Describes if maize farmers surveyed are located in Spain	Binary variable with SP=1 if farmer is located in Spain and SP=0 if not.
Hungary (HU)	Describes if maize farmers surveyed are located in Hungary	Binary variable with HU=1 if farmer is located in Hungary and HU=0 if not.

3. Results

3.1. Estimation results

Table 6 shows the summary statistics of the explanatory variables used for both the GMHT OSR and GMHT maize adoption models. A large percentage of the farmers responded that economic (78% for GMHT OSR and 84% for GMHT maize) and environmental reasons (64% for GMHT OSR and 69% for GMHT maize) as well as facilitation of the work (82% for GMHT OSR and 84% for GMHT maize) were important or very important factors in their decision to adopt. On the other hand farmers showed disparity in their concerns about adopting the new technology if coexistence measures are put in place. While the implementation of administrative measures posed an insignificant concern in a farmer's decision to adopt GMHT crops, the rest of the measures caused higher concern amongst farmers. Over 60% of farmers reported that the requirement that they be covered by insurance is an important or very important factor in the rejection of the idea of cultivating GMHT crops. The requirement that they clean combine harvesters before and after harvesting, and separate harvesting and transportation (technical measures) led 30% of farmers to affirm that these measures would negatively influence the probability of them adopting GMHT crops. The introduction of separation distances, in particular a separation distance beyond 25m, causes different reactions within OSR and maize farmers. Only 14% of farmers asked about the possibility of growing GMHT OSR considered separation distances an important or very important factor in rejecting the idea of cultivating this GMHT variety, while over 42% of possible GMHT maize farmers perceived separation distances beyond 25 m as an obstacle to adopting GMHT. Some farmers, especially those asked about GMHT OSR (35%) showed a strong degree of disbelief in the new technology.

Therefore, economic reasons and the convenience of the new technology seem to be positive factors affecting GMHT crop adoption whereas the requirement that they be covered by insurance is largely considered an important negative factor in GMHT varieties adoption.

Table 6. Explanatory variables for adoption and summary statistics

	GMHT OSR		**GMHT maize**	
Explanatory variable	*Mean*	*SD*	*Mean*	*SD*
ECONOMIC	0.76	0.41	0.84	0.36
ENVIRONMENT	0.60	0.48	0.69	0.46
EASE	0.83	0.38	0.85	0.36
DISBELIEF	0.35	0.48	0.16	0.36
ADMINISTRA	0.03	0.18	0.01	0.11

TECHNICAL	0.32	0.46	0.29	0.16
SEPARATION	0.54	0.35	0.41	0.49
INSURANCE	0.70	0.47	0.62	0.49
AGE	47.69	11.29	47.61	11.13
EDUCATION	0.42	0.49	0.43	0.50
SIZE	850.79	950.48	269.50	617.28
INCOME	0.25	0.44	0.06	0.50
GE	0.48	0.48	-	-
CZ	0.29	0.46	-	-
FR	-	-	0.33	0.47
SP	-	-	0.35	0.47

Table 7 shows the results from the ordered probit model estimated for both GMHT OSR and GMHT maize. A likelihood ratio test was carried out to assess the goodness-of-fit of the models. These tests indicate that the models had satisfactory explanatory power.

Table 7. Determinants of farmers' willingness to adopt for GMHT OSR and GMHT maize

	GMHT OSR		**GMHT maize**	
Explanatory variable	*Coefficient* (1)	*z-statistic*	*Coefficient* (1)	*z-statistic*
Constant	1.159***	3.43	1.133***	2.62
ECONOMIC	0.560***	4.10	0.283	1.34
ENVIRONMENT	0.347***	2.98	0.175	1.06
EASE	0.674***	4.37	0.459**	2.17
DISBELIEF	-0.385***	-3.22	-1.441***	-6.16
ADMINISTRA	-0.466	-1.61	-1.303	-1.56
TECHNICAL	-0.601***	-4.68	-0.698***	-3.92
SEPARATION	-0.211**	-1.92	-0.360**	-2.45
INSURANCE	-0.258**	-2.13	-0.344**	-2.28
AGE	-0.009*	-1.93	-0.002	-0.29
EDUCATION	0.261**	2.19	0.167	0.99
SIZE	0.000	-0.61	0.000	0.22
INCOME	-0.252**	-2.06	-0.442	-1.48
GE	0.284**	1.97	-	-
CZ	-0.231	-1.39	-	-
FR	-	-	0.164	0.85
SP	-	-	0.424**	2.14
Cut-off parameters (2)				
Cut-off_2	0.63***	10.52	0.81***	10.15
Cut-off_3	1.37***	21.46	1.76***	20.82
Cut-off_4	2.57***	29.18	2.86***	25.13
Log –likelihood	-574.88		-366.10	
Likelihood Ratio test	165.69***		138.83***	
Pseudo R-squared	0.13		0.16	
N	426		280	

(1) *statistically significant at the 0.10 level of significance, **at 0.05-level, ***at 0.01-level

(2) The first cut-off parameter (cut-off_1) is normalised to zero

Most of the estimated coefficients were statistically significant for GMHT OSR. The sign of a parameter estimate indicates how the associated explanatory variable is related to the willingness to adopt. Thus, the positive signs for the ECONOMIC and ENVIRONMENT variables support the hypothesis that a farmer's willingness to adopt GMHT OSR increases as economic aspects and environmental impacts become relevant in their decision-making. On the contrary, these variables were not statistically significant in explaining a farmer's willingness to adopt GMHT maize. Note that the latter does not mean that farmers ignore economic and environmental factors in their decision-making process. The meaning of such a result is that the probability of adopting GMHT maize for those farmers who consider such aspects important and those who do not does not differ.

A farmer's willingness to adopt GMHT OSR/GMHT maize increases with the degree of importance assigned to the facilitation of work associated with the new technology (EASE). As expected, those farmers who do not believe in GM technology show a lower probability of adopting GMHT OSR/GMHT maize than those farmers who did not show a strong disbelief. Also, coefficients associated with coexistence variables showed a negative sign. This suggests that farmers for whom coexistence measures are crucial in their decision are less likely to adopt GMHT OSR/GMHT maize than those for whom such measures are irrelevant. Among the socio-demographic characteristics included, age, education and income were found to be determinant in a farmer's willingness to adopt GMHT OSR. Younger farmers and farmers with a high education level were more willing to adopt GMHT OSR than older farmers and less educated farmers. Farmers with annual revenues below the median income (35,000 €/year for OSR) were less inclined to adopt GMHT OSR than those above the median. Although the sign of these parameters associated with socio-demographic characteristics is shared for the GMHT maize case, these were found not to be statistically significant in this case. Considering a farm's location, farmers in Germany were more likely to adopt GMHT OSR than farmers in the UK (benchmark country for OSR). In the case of maize, farmers in Spain would be more willing to adopt GMHT than farmers in Hungary (benchmark country for maize).

3.2. Marginal effects on the probability of willingness to adopt GMHT OSR/GMHT maize

Marginal effects of the explanatory variables on the probabilities are the change in the probability of a category with respect to a change in the value of an explanatory variable while holding the parameters β and μ constant. Marginal effects for both models GMHT OSR and GMHT maize are shown in Table 8 and Table 9 respectively. The sum of the marginal effects associated with an explanatory variable is equal to zero, because an increase in the probability in one category of the dependent variable (willingness to adopt GMHT OSR/GMHT maize) shall be compensated by corresponding probability decreases in other categories.

The marginal effect of dummy variables on the probabilities measures the effect on those probabilities derived from a discrete change of the dummy variable (from 0 to 1). Table 8 illustrates that when farmers consider economic factors an important driver in their decision-making the probability that a respondent belongs to category 5 (i.e. those farmers that stated they would be very likely to adopt GMHT OSR) or 4 (i.e. those farmers that stated they would be likely to adopt GMHT OSR) increases by 8.7% and 13% respectively. In the same way, if either environmental impact or ease of use was an important factor in a farmer's decision the probability of adopting increases. However, the largest positive marginal effect on the probability of adopting GMHT OSR resulted from cases where facilitation of work based on the use of the new technology is crucial in a farmer's decision.

Table 8. Marginal effects of explanatory variables on the probability to adopt GMHT OSR

Explanatory variable[(1)]	$P(y=1\|x)$	$P(y=2\|x)$	$P(y=3\|x)$	$P(y=4\|x)$	$P(y=5\|x)$
ECONOMIC	-0.111***	-0.078***	-0.027***	0.130***	0.087***
ENVIRONMENT	-0.060***	-0.050***	-0.027***	0.075***	0.062***
EASE	-0.146***	-0.090***	-0.019*	0.160***	0.095***
DISBELIEF	0.069***	0.056***	0.028***	-0.085***	-0.067***
ADMINISTRA	0.100	0.064*	0.014	-0.113	-0.065
TECHNICAL	0.115***	0.084***	0.035***	-0.136***	-0.098***
SEPARATION	0.034*	0.031*	0.019*	-0.044*	-0.040*
INSURANCE	0.040**	0.038**	0.025*	-0.052**	-0.051**
AGE	0.002*	0.001*	0.001*	-0.002*	-0.002*
EDUCATION	-0.042**	-0.038**	-0.240*	0.054**	0.050**
SIZE	0.000	0.000	0.000	0.000	0.000
INCOME	0.045*	0.037**	0.018**	-0.056*	-0.043**
GE	-0.046*	-0.041*	-0.025*	0.060**	0.053*
CZ	0.041	0.034	0.017	-0.051	-0.040

[(1)] *statistically significant at the 0.10 level of significance, **at 0.05-level, ***at 0.01-level

Marginal effects of coexistence measures illustrate that when farmers take into account such measures the probability of adopting GMHT OSR decreases. For instance, when cleaning the combine harvester and segregating harvesting and transportation (technical measures) were important aspects in a farmer's decision the probability that the respondent belongs to category 4 or 5 diminishes by 13.6% and 9.8% respectively. This measure was found to be more important than paying for insurance and implementing a separation distance beyond 25 metres.

With respect to socio-demographic characteristics, high education level was found to be the most important factor in affecting positively the probability of adopting GMHT OSR, followed by an income above the median (35,000 €/year). Results show that a year increase in a farmer's age diminishes the probability of adopting GMHT OSR by 0.2% for both categories 4 and 5.

Finally, farmers in Germany show a higher probability of belonging to category 4 or 5 than farmers in the UK.

Marginal effects for GMHT maize are shown in Table 9. Again, the largest positive marginal effect on the probability of adopting GMHT maize came from cases where facilitation of the work (EASE) associated with the use of the new technology is crucial in a farmer's decision. Considering economic and environmental reasons important factors positively affect the probability of adoption, although this was found not to be statistically significant.

Table 9. Marginal effects of variables on the probability of willingness to adopt GMHT maize

Explanatory variable[(1)]	$P(y=1\|x)$	$P(y=2\|x)$	$P(y=3\|x)$	$P(y=4\|x)$	$P(y=5\|x)$
ECONOMIC	-0.059	-0.048	0.013	0.067	0.026
ENVIRONMENT	-0.034	-0.031	0.004	0.042	0.018
EASE	-0.102*	-0.073**	0.030	0.107**	0.038**
DISBELIEF	0.416***	0.112***	-0.180***	-0.266***	-0.081***
ADMINISTRA	0.415	0.060	-0.204	-0.219***	-0.052***
TECHNICAL	0.154***	0.109***	-0.042	-0.160***	-0.061***
SEPARATION	0.070**	0.063**	-0.009	-0.086**	-0.037**
INSURANCE	0.061**	0.062**	0.000	-0.082**	-0.040**
AGE	0.000	0.000	0.000	0.000	0.000
EDUCATION	-0.030	-0.030	0.002	0.040	0.018
SIZE	0.000	0.000	0.000	0.000	0.000
INCOME	0.102	0.068**	-0.033	-0.102	-0.035**
FR	-0.029	-0.030	0.001	0.039	0.018*
SP	-0.072**	-0.076	-0.003	0.101**	0.051

[(1)] *statistically significant at the 0.10 level of significance, **at 0.05-level, ***at 0.01-level

As far as coexistence measures are concerned, all the measures (administrative, technical, separation distance and insurance) diminish the probability of adopting GMHT maize, the implementation of administrative requirements being the most influential followed by technical measures, the implementation of a separation distance and being covered by insurance. Despite being most influential factor it cannot be ignored that the implementation of administrative requirements was considered as important or very important by only 1% of the farmers interviewed. Hence, its impact on adoption rates in case was implemented would be insignificant. When compared with GMHT OSR coexistence measures have a larger hampering effect on GMHT maize adoption.

In contrast with GMHT OSR, income level is the only socio-demographic variable that has an influence on willingness to adopt GMHT maize. Having a yearly income level below the median (17,000 €) leads to a reduction in the willingness to adopt.

The lack of belief in the new technology was found to be the major reason why farmers are less likely to adopt GMHT maize. Thus, if farmers do not believe in GM technology the probability of adopting GMHT maize diminishes by 34.7% (for both categories 4 and 5).

4. Conclusions

Despite the widespread adoption of GM crops at international level, the commercial area cultivated in the EU is still negligible since a single GM crop is authorised for cultivation (Bt maize). This paper examines the impact of the EU regulatory framework for coexistence between GM and non-GM crops on the EU farmers' willingness to adopt GMHT technology which is the dominant GM technology worldwide.

Ordered probit models were used to identify the influence of different drivers on EU farmers' decisions to adopt/reject GMHT oilseed and GMHT maize. Amongst the variables considered in the analysis, economic and environmental issues and ease of use were found to have a positive influence on farmers' willingness to adopt oilseed rape GMHT technologies. In the case of GMHT maize, ease of use is the only significant variable to encourage maize farmers' willingness to adopt GMHT. Regarding socio-demographic variables they only have an influence on farmers' willingness to adopt GMHT oilseed rape. Younger and educated farmers with a yearly income above 35,000 € will be more likely to adopt the new technology.

In addition to the farmer's profile, the geographical location of the farm (i.e. country) is a significant driver of farmer's willingness to adopt. Farmers in Germany are more likely to adopt GMHT oilseed rape than British farmers as well as Spanish farmers' willingness to adopt GMHT maize is higher than Hungarian farmers'. Such difference in adopting GMHT crops between countries may reflect different levels of weed infestation, different consumer/producer attitudes towards GM crops, as well as the fact that farmers may be receiving different types of information about this technology from groups of interest (GM industry, environmental groups, cooperatives, farmers' unions).

The incentives for GMHT adoption by EU farmers may be offset by the implementation of coexistence rules in EU member states (Moschini, 2008). The need for regulating coexistence in the EU stems from a system of ensuring consumer choice based on mandatory labelling of GM–containing food products. In this situation of mandatory labelling in the food chain, economic externalities associated with GM crop production (admixture) may occur. To prevent this from happening, the EU member states have developed mandatory coexistence rules to prevent admixture at the level of agricultural production. These rules include a number of technical measures for GM crop cultivation and non-technical, administrative measures and liability provisions directed to farmers intending to plant GM crops. In this institutional setting, currently unique internationally, the innovators (GMHT growers) are considered the economic externality producers and the ones who should bear the costs (monetary or not) associated with coexistence measures. The hypothesis that this setting represents *a priori* a disincentive for adoption of new technologies by EU farmers is confirmed. The decision on whether or not to adopt GMHT technology in the EU is shaped by the implementation of coexistence measures. In particular, technical measures (cleaning and segregation processes) have a relatively large effect on the probability of adopting either GMHT oilseed rape or GMHT maize when compared to other coexistence measures. Thus the probability that a farmer who stated that is very likely or likely to adopt GMHT oilseed rape or maize diminishes by 23.4% and 22.1%, respectively when technical measures would have to be implemented by the farmer. The rest of coexistence measures considered in the analysis, such as 25-metre separation distances and insurance cover would also affect farmers' willingness to adopt GMHT but their implementation would have a lesser impact on adoption. Putting in place isolation distances between GM and non GM crops would reduce farmers' probability to adopt by 10.3% for GMHT oilseed rape and by 12.2% for GMHT maize. In a similar way, the compulsory insurance cover would decrease the probability of adopting GMHT oilseed rape and maize by 8.4% and 12.3% respectively. Considering these results, it is worth to highlight that the implementation of all these coexistence measures together may have a great influence on EU farmers' adoption of GMHT technology. Thus the probability of adopting any GMHT crop might diminishes by over 40%. This indicates that effectively GMHT adoption may be 'forced' to share an insignificant role in EU agriculture and even be excluded in case disproportionate measures such as the implementation of extremely large isolation distances are put in place (Beckmann *et al*., 2006).

Apart from the coexistence measures, the disbelief in new technologies also shapes farmers' willingness to adopt GMHT. A significant number of the farmers in the sample showed some degree of disbelief in the new technology (35% of for GMHT OSR and 16% for GMHT maize). These farmers showed a lower probability of adopting GMHT technology. The probability of adopting the new technology is also sensitive to the prior information received by the farmer on GM technology from groups of interest. GMHT crops are not yet grown in the EU and this is a handicap for farmers' knowledge on the new technology, therefore new sound information about the technology may alter farmers' outlook on adoption of GMHT crops.

The EU coexistence policy is a unique case worldwide to ensure the farmer's freedom of choice between cultivating GM and non GM crops. This is ensured through the implementation of coexistence measures to prevent admixture. In other countries, such as the United States, Argentina, Brazil or India, GM crop adoption is market driven and no regulations interfere in the farmer's decision making. Therefore, the difference between the EU and the rest of the world is that the EU differentiates between GM and non-GM products by labelling whereas for other countries such differentiation is not mandatory. By distinguishing between GM and non-GM products the EU policy generates a situation in which externalities associated with GM crop production (admixture) may occur. This market failure, derived from the way in which the EU interprets the introduction of a new technology, gives the public sector a reason to implement coexistence measures to prevent admixture (internalise the externality). According to this view the innovators (GMHT growers) are the externality producers and the ones who should bear the costs associated with coexistence measures. This effectively means that their average costs are increased, rendering GM technology relatively less competitive than non-GM technologies (i.e. obstructing GM adoption) and GM producers from outside the EU. This is reflected in their willingness to adopt as mentioned above. From the EU policy's viewpoint coexistence measures also ensure the consumer's freedom of choice between products derived from GM crops and GM free products, which is a benefit guaranteed through labelling. In contrast, the fact that consumers in other countries do not distinguish between GM and non-GM products does not imply any additional cost to farmers. Even in countries where this distinction is made, the tolerance level that distinguishes a GM crop from a non-GM crop is crucial since different tolerance levels imply different coexistence measures and costs (i.e. different isolation distances and possibly different insurance costs). For instance, in Japan and South Korea, where the tolerance levels are 5% and 3% respectively, the impact of coexistence measures on GM production costs may be lower than for the EU.

Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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