AES, 82nd Annual Conference 2008, RAC Cirencester
31st March to 2nd April

Forecasting the Adoption of GM Oilseed Rape: Evidence from a Discrete Choice Experiment

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Abstract

This paper explores farmers' willingness to adopt genetically modified oilseed rape prior to its commercial release and estimates the 'demand' for the new technology. The analysis is based upon choice experiments with 202 German arable farmers. A multinomial probit estimation revealed that GM attributes such as gross margin, expected liability from cross pollination, or flexibility in returning to conventional oilseed rape significantly affect the likelihood of adoption. Neighbouring farmers' attitudes towards GM cropping and a number of farmer and farm characteristics were also found to be significant determinants of prospective adoption. Demand simulations suggest that adoption rates are very sensitive to the profit difference between GM and non-GM rape varieties. A monopolistic seed price would substantially reduce demand for the new technology. A monopolistic seed supplier would reap between 45 and 80 per cent of the GM rent, and the deadweight loss of the monopoly would range between 15 and 30 per cent of that rent. The remaining rent for farmers may be too small to outweigh possible producer price discounts resulting from the costs of segregating GM and non-GM oilseed rape along the supply chain.

Keywords: adoption forecast, choice experiment, genetically modified oilseed rape, multinomial probit, technology adoption

JEL Classification: C42, C81, Q12, Q16

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Acknowledgements
Thanks are extended to Henrika Meyer-Schatz for designing and running the choice experiment as part of her MSc Thesis.

1 Introduction

Although genetically modified (GM) oilseed rape is yet to be approved for field-scale cultivation in the EU, stakeholders are beginning to gear up for the commercial release of GM varieties. Plant breeders and their downstream agents must devise strategies to launch the new technology and to promote their new varieties. Policy makers face difficult choices as to how to deal with potential externalities from cross pollination: oilseed rape pollen can be dispersed over large distances by wind or insects, 'contaminating' non-GM rape varieties. Under current EU and national legislation, farmers can be held liable for damages arising from cross pollination (Beckmann *et al.*, 2006). On the other hand, farmers can be expected to gain from the new technology, which offers higher gross margins than its conventional counterpart. Farmers may respond to the liability rules in a number of ways, for example, by concentrating GM varieties on adjacent plots or by coordinating the spatial pattern of GM cropping across different holdings so as to keep cross pollination to a minimum. In addition, the insurance sector may develop new products to underwrite the risks from cross pollination.

This paper aims to contribute to the debate surrounding the pending launch of GM oilseed rape in Europe by

exploring farmers' willingness to adopt GM oilseed rape *ex ante*, i.e. prior to its commercial release and

estimating the 'demand' for the new technology and ascertaining its key determinants.

More specifically, we wish to:

ascertain the characteristics of farmers who are likely to grow GM oilseed rape;

investigate which attributes of GM oilseed rape impact upon farmers' prospective adoption decisions;

explore the role of framing effects on the likelihood of adoption;

analyse the impact of a technology fee for GM on the demand for the new technology;

explore the distribution of net gains from the new technology between a monopolistic GM seed industry and farmers.

The analysis is based on a choice modelling case study with German arable farmers. In our choice experiment, farmers growing oilseed rape were presented with a series of choice sets containing two GM rape cropping options and a conventional oilseed rape alternative. Each of the alternatives was characterised by a number of attributes, including e.g. gross margin, likelihood of cross pollination, and neighbouring farmers' attitudes towards GM cropping. From each choice set, respondents were asked to choose their preferred alternative.

The article builds upon and extends earlier work by a subset of the authors (Breustedt *et al.*, forthcoming). The remainder of the article is organised as follows. Section 2 reviews the literature on the use of choice experiments for assessing technology adoption in agriculture, focussing on GM technology adoption. Section 3 describes the choice experiment and sets out the conceptual and empirical model. Section 4 presents and discusses the results. Section 5 presents the conclusions.

2 Choice experiments and GM technology adoption: a review of the literature

Choice experiments have been used widely to estimate the value of non-market goods (e.g. Adamowicz *et al.*, 1998; Mogas *et al.*,2006) or to explore the role of product attributes for consumer choice (e.g. Lusk, 2003; Lusk *et al.*, 2003 for GM-related consumer choices). Applications of choice experiments to agricultural technology choices are rare, and the few applications that do exist have focused on GM technology adoption. One noteworthy exception is Windle and Rolfe's (2005) analysis of enterprise diversification choices in Australian agriculture.

Choice experiments pertaining to the adoption of competing technologies in agriculture are based on random utility theory. The random utility as a latent variable of two or more options is compared and it is assumed that the observed decision for one of the options implies a higher utility of the option chosen. The relevant analyses in the literature – two are *ex post*, i.e. the GM crop had already been launched, and two are *ex ante* – are based on dichotomous choice contingent valuation experiments. Hubbell *et al.* (2000) as well as Qaim and de Janvry (2003) analyse – based on revealed and stated preferences – the dichotomous choice between adoption and non-adoption of Bt Cotton in the United States and in Argentina, respectively. Bt cotton is genetically engineered to express a toxin which serves as a biological insecticide. In both studies, education and farm size are found to increase the farmers' likelihood of choosing the Bt technology. In addition, willingness to pay (WTP) figures for Bt cotton seed are derived and average demand elasticities are estimated for both adopters and non-adopters. This was done by combining growers' stated and revealed preferences for the Bt crop. While revealed preferences were derived from the observed technology choices at the market price, stated preferences were obtained from the dichotomous choice experiment. Non-adopters were asked whether they would grow Bt cotton for randomly chosen prices below the current market price.

Kolady and Lesser (2006) as well as Krishna and Qaim (2007) conducted *ex ante* analyses of Bt eggplant adoption in India. Kolady and Lesser (2006) asked farmers their WTP for Bt and non-Bt eggplant varieties in two different ways, depending on the variety's breeding method (hybrid or non-hybrid). The WTP for the Bt hybrid variety was elicited using a 'modified' double-bounded dichotomous choice experiment. First, each farmer was offered the Bt eggplant seed at a maximum price. If the farmer rejected, he was made one other offer at a randomly chosen lower price. By contrast, the WTP for the non-hybrid Bt (the so-called Bt open-pollinated) variety was evaluated with an open-ended question. Since Bt hybrid and Bt non-hybrid seed varieties were to be offered in parallel, Kolady and Lesser (2006) estimate the *ex ante* adoption decision for Bt varieties jointly with the observed decision to choose hybrid or non-hybrid eggplant seed in several model specifications. The model results suggest that a higher price of Bt seed reduces the probability of adoption only in the early years after the launch of the Bt varieties. In later years, the Bt seed price was no longer significant.

Krishna and Qaim (2007) also used a double bounded dichotomous choice model (DBDCM). In their choice experiment, farmers were only offered Bt *hybrids* at a uniform price. If they rejected, the price was randomly lowered; if they accepted, the

price level was randomly raised. Because Bt technology was to be launched sequentially – the hybrid varieties first, and the Bt open pollinated varieties (OPV) some years later– Krishna and Qaim (2007) analysed the adoption of Bt hybrids with the Bt OPV as an alternative Bt option in the choice set. In their choice experiment, they first described the advantages and disadvantages of both varieties. Respondents were then asked to choose among the three options 'Bt hybrid', 'Bt OPV' and 'no adoption'. The first bid from the DBDCM was used as the price for Bt hybrids. The Bt OPV was randomly assigned a price bid within a double bounded price corridor. Krishna and Qaim (2007) find that the average WTP for Bt hybrids is more than four times the current price of non-Bt hybrids. Their results also indicate that the launch of Bt OPV varieties would reduce the WTP for Bt hybrid by 35 per cent.

The choice experiment underlying the present paper differs from the above studies in a number of ways. First, farmers in Hubbell *et al.'s* (2000), Qaim and de Janvry's (2003), Kolady and Lesser's (2006), and Krishna and Qaim's (2007) experiments were only once confronted with the choice between one GM and a non-GM crop. Respondents in the present study were asked several times to choose between several (two) GM options and a non-GM alternative. We thus obtained more observations than there were respondents in the survey. In addition, our GM options do not only differ in the price of the technology but also in technology attributes such as liability for damages from cross pollination, flexibility in returning to conventional oilseed rape growing, and attitudes of neighbouring farmers towards GM cropping. These attributes are particularly important in studying the adoption of GM oilseed rape in the EU context: first, because the risk of unintended cross pollination is higher in oilseed rape than in cotton or eggplant production and, second, because adoption decisions are likely to be affected by framing effects. Such framing effects result from the emotional debate surrounding genetic modification in the EU. None of the studies reviewed above considers framing effects or technological externalities as potential determinants of adoption.

3 Methodology

3.1 The farm survey

Since we aim to assess farmers' adoption decisions in an *ex ante* setting, i.e. prior to commercial release of GM oilseed rape varieties, we cannot resort to market data or other secondary data. Our empirical analysis thus relies upon primary data from potential GM oilseed rape growers. The data were collected with the use of an online survey of arable farmers - all oilseed rape growers. The online questionnaire was generated with the help of survey design tools developed by Globalpark (www.globalpark.de) and was easily made available on the Department's homepage. The survey was conducted in the spring of 2006. Farmers were invited to participate in the survey through adverts in agricultural magazines, online and offline newsletters, and online forums. The adverts outlined the purpose of the survey and displayed the web address where farmers could access further information and the questionnaires. The agricultural magazines reach the majority of German farmers. We counted 575 hits to the survey's homepage. 127 of those interested quit the survey at the starting page, 255 completed the questionnaire. Of these 255 questionnaires, 194 were suitable for inclusion in the subsequent data analysis. Farmers who

preferred to participate in the survey offline were given a telephone number where they could request a hard copy of the questionnaire. This yielded another eight fully filled-in questionnaires. The total number of questionnaires included in the analysis thus was 202.

In the questionnaire, the term GM was defined before farmers were first asked about their oilseed rape acreage and their key farming activities and enterprises. We then explained the choice sets, the meaning of the different attributes, and real-world rules for growing GM oilseed rape. The questionnaire confronted respondents with choice sets. Each choice set consisted of two GM oilseed rape options and one conventional oilseed rape alternative. Respondents were asked to choose their most preferred option. To keep things easy, we asked respondents to select exactly one out of the three cropping alternatives for their entire oilseed rape acreage. Table 1 exemplifies a choice set. Each of the GM cropping options is characterised by a set of six attributes, with varying attribute levels. The attribute levels for the GM options are expressed relative to the non-GM oilseed rape counterfactual. The attributes are:

difference in gross margin per hectare between GM and non-GM oilseed rape,
probability of being held liable for damages from cross pollination,
level of cross pollination damage,
waiting period, i.e. time elapsed before non-GM oilseed rape can be grown on GM plots without secondary growth of GM varieties,
increased time window for the first herbicide application in GM oilseed rape crops,
neighbouring farmers' attitudes towards GM oilseed rape growing.

Table 1 about here

Table 2 displays the levels chosen for each attribute. The SPSS software package was used to generate the choice sets. This yielded 27 choice sets out of all possible combinations representing a balanced, (perfectly) orthogonal, fractional-factorial design for the experiment. We excluded one choice set where both GM options were identical. Two further choice sets were eliminated because in each set one GM option clearly dominated the other. In both choice sets the waiting period (time window) was shorter (longer) for one GM option while the remaining attributes were the same. Following Hensher and Bradley (1993), such options do not contribute useful information. However, the remaining 24 choice sets did not represent a perfectly orthogonal design because its so-called D-efficiency is 2.3 below the optimal value of 100 for a balanced orthogonal design.[1] Each questionnaire contained eight choice sets.

Table 2 about here

Attribute levels were chosen with reference to available data. Higher gross margins (+40%) for GM canola in Canada due to reduced herbicide (-61%), fuel (-14%) and higher seed costs (+53%) are reported by the Canola Council of Canada (2001), based on farm surveys. The probability and level of damage result from the fact that oilseed rape is predominantly a cross pollinating plant whose pollen can be dispersed up to 3

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[1] Maximising the D-efficiency criterion is similar to minimising the variance of coefficient estimates in a linear model, or the inverse of the information matrix, $(X'X)^{-1}$ (Kuhfeld *et al.*, 1994). Our value of 97.7 for the 24 choice sets is close to optimum. Lusk *et al.* (2003) use a survey design consisting of three three-level and two two-level attributes with a D-efficiency of 97.

kilometres by wind or insects (e.g. Timmons, 1995; Rieger *et al.*, 2002). Cross pollination can result in economic damage if the 'contaminated' rape sells at a lower price than pure non-GM rape. Under EU and national legislation, European farmers can be held liable for damage arising from GM 'contamination' (Beckmann *et al.*, 2006). 'Contamination' can also occur through secondary growth of GM oilseed rape in a conventional rape crop (Momoh *et al.*, 2002), implying that growers of GM rape cannot easily revert to conventional oilseed rape cropping. The GenEERA (2007) webpage reports waiting periods of eight to ten years before non-GM rape can be grown without 'contamination'. Herbicides can be applied over a longer period in a GM rape crop than in a non-GM crop, increasing a farmer's operational flexibility. Since the debate in Germany surrounding genetic modification has been controversial and even the farming community does not appear to have reached consensus over the issue, we were interested in exploring whether farmers' willingness to grow GM oilseed rape was affected by their neighbouring peers' attitudes towards GM cropping. This was done by including an appropriate attitudes variable in the choice sets.

3.2 The Choice Model

As in Hubbell *et al.* (2000), Qaim and de Janvry (2003), Kolady and Lesser (2006), and Krishna and Qaim (2007) we base our modelling approach on Lancaster's characteristics theory of value. Previous work on GM adoption has focused on binary choices: farmers had to choose either one option out of two or had to make two choices between two options each. By contrast, our respondents had to choose one option out of three. Put differently, while previous analyses focus on (multivariate) binary choices our approach is multinomial. A farmer's utility resulting from his or her cropping decision depends upon several attributes associated with the cropping alternatives. Following Ben-Akiva and Lerman (1994) we define a random utility function which consists of a deterministic (V^*_{ij}) and a stochastic (ε^*_{ij}) component as:

$$(1) \qquad U^*_{ij} = V^*_{ij} + \varepsilon^*_{ij}$$

where U^*_{ij} is *i*th farmer's utility from choosing alternative *j*, V^*_{ij} is the systematic portion of utility determined by the attribute levels of alternative *j* given farmer *i*'s characteristics, and ε^*_{ij} is an error term with zero mean. The systematic portion of utility can be expressed as:

$$(2) \qquad V^*_{ij} = \beta_1 x^*_{ij1} + \ldots + \beta_a x^*_{ija} + \alpha^*_{j1} z_{i1} + \ldots + \alpha^*_{jm} z_{im} = \mathbf{x}^*_{ij}\boldsymbol{\beta} + \mathbf{z}_i \boldsymbol{\alpha}^*_j$$

where x^*_{ija} is the *a*th attribute of alternative *j* for farmer *i*, and z_{im} is the *m*th personal characteristic of farmer *i*, and the βs and α^*s are the coefficients to be estimated, while the variables in bold represent appropriately dimensioned vectors. The βs were constrained not to vary among the alternatives for reasons explained below. Although in our choice experiment (CE), each respondent made several choices among alternative cropping options, the following exposition refers, for simplicity, to only one choice decision. Since utility cannot be observed we turn to the probability that alternative *k* is chosen by farmer *i* in preference to any alternative $j \neq k$ as per (3):

$$(3) \qquad \text{Prob}\left\{U^*_{ik} \geq U^*_{ij};\ \text{for all } j \in \Omega_i\right\}$$

where Ω_i is the choice set for farmer i, that is Ω_i = {Option A (GM oilseed rape I), Option B (conventional oilseed rape), Option C (GM oilseed rape II)}.

We apply a multinomial probit model which assumes a multivariate normal distribution of the error terms among alternatives.[2] The error terms for each alternative have an expected value of zero and can be correlated among alternatives. However, since neither the location nor the scale of random utility is relevant for the inequalities in (3), restrictions must be imposed to ensure identification of model parameters. Location is normalised for by taking the difference between the utility of one alternative and the utilities of the remaining alternatives. In our case, Option B (conventional oilseed rape) is chosen as the natural reference for normalisation, i.e. k = B and $j \in$ {A, C}. Thus, we define differences in utility $U_{ij} = U^*_{ij} - U^*_{iB}$ and $V_{ij} = V^*_{ij} - V^*_{iB}$ as well as errors $\varepsilon_{ij} = \varepsilon^*_{ij} - \varepsilon^*_{iB}$. To normalise for scale, we set the variance of ε_{iA} (= the difference of the error term of the first GM option (Option A) minus the error term of Option B) to one.

From this follows

$$(4) \qquad U_{ij} = \left(\mathbf{x}^*_{ij} - \mathbf{x}^*_{iB}\right)\boldsymbol{\beta} + \mathbf{z}_i\left(\boldsymbol{\alpha}^*_j - \boldsymbol{\alpha}^*_B\right) + \varepsilon_{ij} = \mathbf{x}_{ij}\boldsymbol{\beta} + \mathbf{z}_i\boldsymbol{\alpha}_j + \varepsilon_{ij} = V_{ij} + \varepsilon_{ij}$$

where $\alpha_A = \alpha_C = \alpha$, implying that a farmer's characteristics is assumed to have the same impact on his utility difference between each of the GM options and the conventional oilseed rape alternative. Having expressed all attributes in relation to the conventional oilseed rape alternative and having constructed the experiment such that there are no other (unobserved) differences between the GM options, the impact of a change in the level of an attribute on the adoption probability does not vary between the two GM alternatives. For this reason, we have constrained the coefficients not to vary between GM alternatives, as indicated above.

Because of the Multinomial Probit we define

$$\left\{\varepsilon_{iA}, \varepsilon_{iC}\right\} \sim \text{bivariate normal } (0, \Sigma) \text{ with } \Sigma = \begin{bmatrix} 1 & \sigma_{\text{iA,iC}} \\ \sigma_{\text{iA,iC}} & \sigma^2_{iC} \end{bmatrix}$$

where σ_{iC} is the variance of ε_{iC} and σ_{iAiC} is the covariance between ε_{iA} and ε_{iC}.

From (3) follows the probability that Option B is chosen (Prob_B) (see for example Bolduc, 1999):

$$\begin{aligned} \text{Prob}_\text{B} &= \text{Prob}\left\{U_{iA} \le 0 \text{ and } U_{iC} \le 0\right\} \\ (5) \qquad &= \text{Prob}\left\{\varepsilon_{iA} \le -V_{iA} = -\mathbf{x}_{iA}\boldsymbol{\beta} - \mathbf{z}_i\boldsymbol{\alpha} \text{ and } \varepsilon_{iC} \le -V_{iC} = -\mathbf{x}_{iC}\boldsymbol{\beta} - \mathbf{z}_i\boldsymbol{\alpha}\right\} \\ &= \int_{-\infty}^{-V_{iA}} \int_{-\infty}^{-V_{iC}} \phi_{bi}\left(\varepsilon_{iA}, \varepsilon_{iC}, \Sigma\right) d\varepsilon_{iA} d\varepsilon_{iC} \end{aligned}$$

with ϕ_{bi} representing the density function for a bivariate normal distribution. To solve for Σ, a and β (including a constant which accounts for unobserved differences in utility between GM and non-GM cropping option), simulation or numerical

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[2] We do not apply a Multinomial Logit Model (MNL) which assumes, among other things, independently distributed error terms among choice alternatives. A Hausman Test (Hausman and McFadden, 1984) rejected the assumption of independently distributed error terms for our data sets.

integration procedures have to be applied. We estimate the model using the asmprobit-routine in Stata 9.2 which applies a simulated log-likelihood function to (5).

For estimating the sample marginal effects for the probability of choosing a GM alternative Prob_{GM}, we simulate the negative change in the probability of choosing the conventional oilseed rape option Prob_{B} (see (6)) when varying an exogenous variable *x*. The marginal effects across the sample of *I* respondents with N_i observations each are:

$$\text{(6)} \qquad \frac{\Delta \text{Prob}_{\text{GM}}}{\Delta x} = -\frac{\Delta \text{Prob}_{\text{B}}}{\Delta x} = -\frac{\sum_{i=1}^{I}\sum_{n=1}^{N_i}\frac{\Delta \text{Prob}_{\text{B}n}}{\Delta x}}{\sum_{i=1}^{I}\sum_{n=1}^{N_i} n}$$

4 Results

4.1 Descriptive Statistics

Table 3 presents the descriptive statistics of our sample of 202 respondents. The average age of respondents is 43, nearly half of them have a college or university degree, 41 per cent of respondents have children aged 16 or below; only three per cent of respondents are female. The distribution of farm acreage is skewed to the right, with a mean of 315 hectares and a median of 123 hectares. The average oilseed rape share is 18 per cent. Although the regional distribution of respondents corresponds well with the regional distribution of the oilseed rape acreage in Germany the median farm size is around twice the German average full-time farm (Agrarbericht 2007).

Table 3 about here

A total of 1577 choice sets were included in the estimation. Each choice set contained two GM options, hence *n* = 3154. Some farmers made fewer than eight choices. To ease interpretation, we have condensed the probability and the level of damage into one variable: ‘expected liability’, implying the assumption of farmers being risk neutral. Conducting the estimations with both variables, i.e. level *and* probability of damage, instead of ‘expected liability’ did not change the significance of any estimation parameter when both variables are significant.[3] Furthermore, we modelled neighbours’ attitudes towards GM cropping with the use of two dummy variables, one for ‘GM hostile neighbours’ and one for ‘GM friendly neighbours’. The dummy variables assume a value of zero if neighbours’ attitudes are neutral and a value of one if they are GM hostile or GM friendly, respectively.

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[3] Estimations results for this specification, which is not an expected utility model, can be obtained from the authors upon request.

4.2 Estimation Results

We estimate multinomial probit (MNP) models as outlined in section 3.2. Since 50 per cent of respondents did not choose a GM alternative at least once from their eight choice sets, we conduct the estimations separately for the whole sample of respondents and the subset of respondents who did choose GM alternatives. In the whole sample, 35 per cent of the choices are in favour of GM options. In the remainder of the article, we shall refer to the two samples as the 'whole sample' and the 'GM farmer sample', respectively.

Tables 4 and 5 report the results for the two samples. All estimations are highly significant. In the whole sample estimations (Table 4), all variables but four ('time window', 'image', 'one plot' and the constant) are significant at an error probability of 10 per cent or less. In addition, following an LR test the dummy variable 'arable crops' and the 'oilseed rape share (region)' were omitted from the estimation. The results of this parsimonious estimation are displayed in the right hand column of Table 4.[4]

Tables 4 and 5 about here

All of the GM crop attributes except 'time window' as well as farm characteristics such as farm size, existence of a successor, presence of children, and academic education are significant in the parsimonious estimation for the GM farmer sample and affect the probability of choosing GM in the expected direction (see Table 5). A lower gross margin, a longer waiting period to return to non-GM rape as well as GM hostile neighbours tend to decrease the utility of growing GM oilseed rape and thus reduce the willingness to adopt GM. The opposite is true for a smaller expected liability, GM friendly neighbours, and larger farm size.

The farm type variables 'bovine', 'pigs', and 'poultry' are significant in both samples, while 'image' and 'arable crops' are significant only in the GM sample. One might hypothesise that farmers in such sectors as pig, poultry, direct selling and farm holidays are more innovative than farmers in the heavily policy-influenced milk, beef and arable crops sectors. The above variables may thus be interpreted as proxies for a farmer's propensity to adopt innovations. The estimated signs of these variables appear to support this conjecture. On the other hand, the strong positive impact of the 'image' variable representing direct selling activities and farm holidays appears to be somewhat out of step with the strong public opinion against GM food in Germany: growing GM varieties may spoil the image of farmers with direct selling and farm holiday activities. Farm size also has a positive impact on the adoption probability, confirming findings by Hubbell *et al.* (2000) and Qaim and de Janvry (2003).

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[4] We found slight multicollinearity among 'oilseed rape share (farm)', 'oilseed rape share (region)', and 'arable crops'. However, inclusion of the last two variables in the parsimonious estimation does not cause any considerable changes in the estimation results.

Our results are also consistent with *ex post* adoption studies by Fernandez-Cornejo and McBride (2002) and Marra *et al.* (2001). The former found a positive impact of farmers' education as well as farm size on Bt and herbicide tolerant corn adoption in the US. Marra *et al.'*s (2001) study revealed a positive influence of education and farm profit on Bt cotton adoption in US. By contrast, Weaver's (2005) analysis of the determinants of *ex post* adoption of transgenic soybeans in the US revealed a negative influence of education on adoption decisions. The share of income from cotton production was found not to have an impact on Bt cotton adoption Marra *et al.'s* (2001) study. This is contrary to our finding that a farm's oilseed rape share exerts negative influence on adoption probabilities – a somewhat unexpected result. Since one would expect fixed costs of adoption (e.g. seeking of information, learning) to decline with the GM rape share, an increase in that share should make GM oilseed rape more attractive. The negative impact may be explained by farmers' risk considerations: a greater share of the new technology implies greater risk. Hubbell *et al.* (2000) report similar effects of the income share of the potential GM crop on the acreage of GM adoption.

A key difference in estimation results between the two samples is the impact of the variables 'age', 'sex' (0 = male, 1 = female), and 'close to city'. These exert a negative impact on the likelihood of GM adoption in the whole sample estimations, while they are not significant in the GM farmer estimations. We interpret this result to imply that these variables explain whether or not a farmer dismisses GM categorically. However, they cannot explain how many times a non-dismissive farmer chooses a GM alternative out of the eight choice sets. The higher absolute impact of the 'children' variable in the whole sample compared to the GM sample estimations (see Table 5) may be explained along similar lines. However, the 'children' variable is significant in both samples, indicating that the presence of children on a farm has an impact on both the general willingness to adopt GM oilseed rape and on the frequency of adoption. The constant being significant in the GM sample (Table 5) indicates that there are more determinants of GM adoption than were included in the regressions. Previous analyses of GM technology adoption, which have focused on developing countries, have neither found any significant impact of farmer's age, nor have they considered the presence of children, farmer's sex, or proximity to a city as potential determinants of adoption.

The effects of the variables 'gross margin' and 'expected liability' are all significant and their signs support literature results: Hubbell *et al.* (2000), Qaim and de Janvry (2003), and Kolady and Lesser (2006) found that a technology fee and farmers' price bids for GM exert a significantly negative impact on the willingness to adopt GM cropping alternatives. The same authors also report that higher levels of education increase the willingness to pay for GM or to adopt GM technology.

Table 6 reports the sample marginal effects for the probability of choosing a GM alternative as per expression (7). The value of 3.08 for the gross margin means that a €10 per hectare increase in the gross margin difference increases the likelihood of

choosing GM cropping options by 3.08 per cent points. As is clear from Table 6, these effects differ between samples. As one would expect, the 'GM farmers' respond more strongly to changes in the attribute levels (see right-hand column in Table 6) than the average farmer in the sample.

It is noteworthy that, in both samples, the marginal effect of a change in the gross margin difference is greater than that of a change in expected liability from cross pollination. From this we draw the tentative conclusion that our survey farmers did not appear to have reacted in a risk-averse manner to the challenge of cross pollination. This appears plausible in that oilseed rape production only accounts for a limited portion of a farm's economic activities and because we control for the effect of farm size and oilseed rape share in the farm rotation. Furthermore, Table 6 shows that the reduction in the probability of choosing GM oilseed rape due to a €10 per hectare insurance premium (= €10/ha lower gross margin) is not compensated for by the respective probability increase from a €10/ha reduction in expected liability. Thus, the monetary gain resulting from insurance against liability will not be sufficient to cover an insurance company's transaction costs and profit. Consequently, in our experiment an economically sustainable insurance against damages from cross pollination would not increase demand for GM oilseed rape.

Of the remaining variables in the whole sample estimations, the differential impact of neighbours' attitudes towards GM is particularly noteworthy. It is clear from Table 7 that the demand effect of 'GM hostile neighbours' is three times greater than that of 'GM friendly neighbours', both compared to neighbours with neutral attitudes towards GM cropping. Roughly speaking, in the GM farmer sample the demand effect of 'GM hostile neighbours' outweighs a €20 per hectare increase in the gross margin difference. Likewise, an extension of the waiting period by one year outweighs a €5/ha higher gross margin.

Table 6 about here

4.3 Demand simulations

The econometric results enable us to simulate the demand for GM oilseed rape cropping under a set of assumptions relating to the attributes of the GM options and farmer characteristics. We use two alternative measures of demand. First, we measure demand by aggregating the hectares of oilseed rape grown across all respondents willing to adopt GM varieties. Second, we measure demand by the number of respondents willing to adopt GM oilseed rape assuming that every farmer grows the same area of oilseed rape, say, one hectare. The latter metric is used to mitigate the impact of very large individual oilseed rape acreages on aggregate demand.

The analysis in this section comprises three steps: we first compute, based on the estimation results in section 4.2, a demand curve for the GM technology which reflects respondents' willingness to pay (WTP). We then use the demand curve to derive a monopolistic technology fee. We finally assess the distribution of rents between a monopolistic technology provider (GM seed supplier) and farmers and compute the deadweight loss resulting from the monopoly.

In order to derive demand curves we need a willingness-to-pay measure for each farmer, WTP_i. This measure is constructed as follows. We first assume a general profit difference Δ which is given exogenously and is assumed equal for all farmers. Δ represents the gross margin difference (net of any technology fee) between GM and conventional oilseed rape varieties, minus expected liability. Δ does not include any technology fee for reasons explained below.[5] From this profit difference we then deduct an amount of money representing the disutility facing a farmer from growing GM oilseed rape. This disutility arises from the waiting period, GM hostile neighbours etc and can be interpreted as a reservation profit difference, RPD_i. In other words, RPD_i is the amount of money that exactly compensates a farmer for this disutility. An individual farmer's WTP thus is defined as $WTP_i = \Delta - RPD_i$. If $RPD_i = \Delta$, farmer i will be indifferent between growing conventional and GM oilseed rape. RPD_i is computed such that $\hat{V}_{iGM}(\hat{\beta}, x_i, RPD_i) = 0$, where $\hat{V}_{iGM}$ represents the estimated difference in utility between a GM option and the non-GM alternative as per equation (4), and x_i represents both a farmer's personal characteristics and the GM attribute levels except gross margin difference and expected liability. We use the coefficients of the parsimonious MNP model for the whole sample, $\hat{\beta}$, and assume that gross margin has the same absolute effect on the likelihood of adoption as has expected liability. We thus use the coefficient for gross margin (0.0135 in Table 4) as the coefficient for Δ. We further set the 'waiting period' variable to eight years and assume GM hostile neighbours. Assuming risk neutrality, we can now compute RPD_i and thus WTP_i.

The omission of the technology fee from the definition of Δ in the above exposition demands an explanation. While this omission does not conform to the standard definition of the term 'profit', the WTP we wish to compute is to be interpreted as the maximum technology fee a farmer is willing to pay to obtain the GM technology. Figure 1 displays demand curves for GM oilseed rape for profit differences Δ of €200, €100, and €50 per hectare, respectively. Demand is measured along the horizontal axis in terms of the hectares of land devoted to GM oilseed rape. For example, at a profit difference of €100/ha and a technology fee of €50 per hectare, approximately 4,000 ha would be devoted to GM oilseed rape.

Figure 1 about here

Table 7 about here

Table 7 reports the results of the demand simulations in greater detail. The simulations were carried out for six scenarios, each representing an alternative combination of the two measures of demand (based on individual and identical oilseed rape acreages) and the three assumed profit differences (€50, €100, €200 per hectare). The columns labelled 'technology fee = 0' assume that farmers do not have to pay a higher price for GM seed. At a profit difference of €100/ha, this would result in 36 farmers adopting the technology, with 7,100 hectares of GM oilseed rape being grown. To put this number into context, note that all farmers included in the simulations grow a total of 12,449 hectares of oilseed rape. The GM rents reported in

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[5] However, Δ may include differences in seed costs resulting from different seed production costs.

the column labelled 'technology fee = 0' (Table 7) are represented by the areas under the respective demand curves in Figure 1. For a €100 per hectare profit difference, for example, the utility gain measured in monetary terms is €440,000 in total for 36 farmers adopting 7,100 hectares of GM oilseed rape.

It seems unrealistic, however, to assume that GM plant breeders would sell GM seed at the price of conventional seed. Especially if there are approved GM varieties of only one seed supplier on the market, the technology fee may reflect monopolistic pricing behaviour. This raises a number of questions: what is the monopolistic technology fee, how would it affect demand for the GM technology, and how would the GM rent be split between a monopolistic seed supplier and farmers? We utilised the demand curves of Figure 1 to determine profit-maximising technology fees for each of the six scenarios.[6] According to Table 7, the monopoly price is €61 per hectare in scenario II and €49.99 per hectare in scenario III.[7]

It is clear from Table 7 that the demand for the new technology is very sensitive to the technology fee: both the number of adopters and the GM rape acreage would decline substantially if a seed company were to impose a monopolistic technology fee. According to our simulations, between 46 and 78 per cent of the GM rent would accrue to a monopolistic GM seed supplier; the deadweight loss of the monopoly would range between 14 and 32 per cent, depending on the scenario. Consequently, farmers' share of the GM rent would be small as would be the absolute adopters' rent relative to the total oilseed rape area. This raises the question as to whether farmers would actually gain from the approval of GM oilseed rape for commercial cultivation.
For the farming sector as a whole to benefit from the approval of GM rape varieties, the costs of ensuring coexistence incurred by farmers would have to remain below adopters' rents. Although the survey implicitly assumed away the existence of direct on-farm segregation costs (by assuming that a farmer would either adopt GM varieties for the whole on-farm rapeseed acreage or not adopt at all), segregation costs further down the supply chain may result in discounted producer prices. For GM rape to remain financially attractive in scenario II (€100 per hectare profit difference), this price discount would have to remain below one per cent of the current oilseed rape price.[8]

We emphasise that this conclusion is contingent upon the assumption of monopolistic price setting behaviour and that it is sensitive to the levels of the GM attributes assumed in the survey. The reader should further note that the sample of respondents is not representative of the German arable farming sector, with a median farm size of around twice the German

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[6] The assumptions needed for computing profit-maximising technology fees are that the GM seed supplier also sells conventional seed (but at a competitive price) and faces no difference in marginal production costs between conventional and GM seed.

[7] The monopoly price in scenario IV (€54 per hectare) is less than in scenario V (€61 per hectare) because the demand in the latter scenario is less elastic in the range of €80 to €40 per hectare. In scenario V only 9 adopters exhibit a willingness to pay in this range while there are 68 in scenario IV.

[8] In scenario II, total adopters' rent is roughly 114,000 € or approximately €2.30 per tonne (assuming a yield of 4 tonnes per hectare on 12,449 hectares). This is less than one per cent of the current oilseed rape price of approximately €280 per tonne.

average arable farm. Results cannot therefore be extrapolated to estimate demand curves for Germany as a whole. Criticism may also be levelled at the assumption of uniform profit differences Δ. As highlighted by one of the reviewers, it may be more realistic to assume that Δ varies among farmers who may have experienced different levels of weed infestation in the past – a variable that had not been elicited in the survey. We argue that the assumption of uniform profit differences will indeed affect WTP figures for individual farmers, but will leave aggregate demand estimates largely unchanged: some farmers (those with a high PD) will display a higher WTP, while other farmers (those with a low PD) will be willing to pay less. On aggregate, the effects are likely to counterbalance each other.

5 Conclusions

This paper has explored farmers' willingness to adopt GM oilseed rape prior to its commercial release and has estimated the 'demand' for the new technology. The analysis is based upon choice experiments with German farmers where respondents were asked to choose between two oilseed rape options and a conventional rape alternative. The data were collected through a combination of an online survey and paper-based questionnaires. The sample comprises 202 respondents who between them grow 12,449 hectares of oilseed rape, representing 1.2 per cent of Germany's oilseed rape area. A multinominal probit model was employed to estimate the impact of GM rape attributes and farmers' characteristics on the likelihood of GM rape adoption. These results were then used to estimate the 'demand' for the new technology under six alternative scenarios and to analyse how GM rents would be split between a monopolistic GM seed supplier and oilseed rape growers.

We find that *ex ante* GM adoption decisions are driven by profit expectations, framing effects, and personal as well as farm characteristics. Monetary determinants such as the difference in gross margin between GM and non-GM oilseed rape varieties, expected liability from cross pollination and restricted flexibility in returning to conventional oilseed rape growing affect the willingness to adopt GM rape in the expected directions. Female farmers, older farmers, farmers with children aged 16 and below, and farmers living in the vicinity of a city are significantly less likely to adopt GM oilseed rape than farmers who do not display these characteristics. Farm size, secure farm succession and a college or university degree have a opposite effect on adoption probabilities. The variables age, sex and proximity to a city only explain whether a farmer dismisses GM categorically; they cannot explain how many times a non-dismissive farmer chooses a GM alternative out of the eight choice sets. Compared to GM neutral neighbours, farmers with neighbours who are hostile to GM cropping are significantly less likely to adopt GM oilseed rape, while the impact of consenting farmers is positive but much less pronounced. The large negative influence of the "GM hostile neighbour" variable indicates that

neighbourhood effects and public attitudes matter a lot, such that individual farmers are not entirely free in their technology choice.

For our simple distribution of cross pollination damages, farmers seem to act as risk-neutral adopters of GM oilseed rape. Thus, insurance against cross pollination, which reduces the variability of profits from GM cropping, would be unlikely to have a positive effect on adoption rates. However, in our experimental setting respondents knew the distribution of damages. This may not be the case in real-world settings with complex liability rules. Liability rules should thus be kept clear and simple so as to allow farmers to forecast potential liability claims with some degree of accuracy, thereby mitigating the riskiness of GM cropping. Insurance solutions may also have a role to play in this respect.

According to our demand simulations, a monopolistic seed price would be set at between €40 and €100 per hectare. This would result on average in over 50 per cent of the GM rent accruing to a monopolistic GM seed supplier and a deadweight loss of up to 32 per cent of the total benefit from growing GM oilseed rape. As a consequence, farmers' share of the GM rent would remain small, and it is unclear whether adopters' rents would be sufficiently high to outweigh possible producer price discounts resulting from downstream segregation costs. Given the assumptions made, the results thus raise doubts as to whether German rape growing farmers would actually benefit from the approval of herbicide-tolerant GM rape if the profit difference were less than €100 per hectare.

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Tables

Table 1. Sample choice set

Which oilseed rape cropping alternative would you choose for your whole oilseed rape area? *(Choose Option A, Option B, or Option C by checking the appropriate box)*

	Option A (GM oilseed rape)	Option B (conventional)	Option C (GM oilseed rape)
Difference in gross margin	+ €100/ha	conventional (non-GM) oilseed rape	+ €100/ha
Probability of being held liable for damage	40%		0%
Level of damage	€50/ha		€50/ha
Waiting period	10 years		12 years
Longer time window for herbicide applications	45 days		35 days
Neighbouring farmers' attitude towards GM cropping	consenting		hostile
I would choose …	☐	☐	☐

Table 2. Attributes and attribute levels in the choice experiment

Attributes	Attribute levels	Description	Regression variable
Gross margin	+ €40/ha + €70/ha + €100/ha	Difference in gross margins between GM and non-GM oilseed rape (€/ha)	gross margin
Probability	0% 20% 40%	Probability of being held liable for damage from cross pollination (%)	expected liability
Damage	€50/ha €100/ha €150/ha	Damage caused by cross pollination of non-GM oilseed rape crops (€/ha)	
Waiting period	8 years 10 years 12 years	Time elapsed between last year of GM cropping and first year of non-GM cropping (years)	waiting period
Time window for herbicide applications	25 days 35 days 45 days	Extended period for the first herbicide application compared to conventional oilseed rape (days)	time window
Neighbour's attitude toward GM cropping	consenting neutral hostile	Neighbouring farmers' attitudes towards GM cropping	GM hostile neighbours GM friendly neighbours

Table 3. Summary statistics of survey respondents, n = 202

Variable	Mean	Standard Deviation	Explanation
age	42.9	11.1	farmer's age (years)
farm acreage	315	534	hectares of arable land on farm
oilseed rape share (farm)	0.18	0.09	share of oilseed rape in the farm's rotation
oilseed rape share (region)	0.08	0.046	share of oilseed rape in the region

Dummy-Variables	Proportion of affirmative responses	Explanation
one plot	42%	contiguous farm
barriers	7%	plots are surrounded by (natural) barriers mitigating dispersion of pollen
successor	41%	farmer has a successor
children	41%	children aged 16 and below on the farm
bovine	39%	farm with cattle as major enterprises
pigs/poultry	26%	farm with pigs or poultry as major enterprises
arable crops	93%	farm specialising in arable production
image	10%	farm with agro-tourism or direct selling as major enterprises
sex	3%	female farmer
education	46%	farmer with a college or university degree
close to city	14%	farm located near a city > 500,000 population

Table 4. Determinants of GM oilseed rape adoption for the whole sample

n = 4731	unrestricted estimation			parsimonious estimation		
log of simulated likelihood	-1193.0			-1196.3		
	coefficient	standard error	prob > |z|	coefficient	standard error	prob > |z|
gross margin	0.014	0.0022	0.00	0.0135	0.0022	0.00
expected liability	-0.013	0.0023	0.00	-0.0122	0.0022	0.00
waiting period	-0.059	0.020	0.00	-0.059	0.020	0.00
time window	-0.0022	0.0035	0.54			
GM hostile neighbours	-0.328	0.085	0.00	-0.320	0.084	0.00
GM friendly neighbours	0.128	0.070	0.07	0.125	0.069	0.07
farm size	0.0012	0.00014	0.00	0.001	0.0001	0.00
oilseed rape share (farm)	-1.714	0.626	0.01	-1.901	0.615	0.00
bovine	-0.505	0.117	0.00	-0.487	0.113	0.00
pigs, poultry	0.330	0.121	0.01	0.334	0.120	0.01
arable crops	-0.348	0.207	0.09			
image	0.012	0.175	0.94			
one plot	0.099	0.120	0.41			
barriers	0.626	0.205	0.00	0.572	0.194	0.00
successor	0.275	0.122	0.02	0.270	0.121	0.03
age	-0.014	0.0055	0.01	-0.013	0.005	0.02
children	-0.496	0.108	0.00	-0.522	0.106	0.00
sex	-0.638	0.310	0.04	-0.653	0.302	0.03
education	0.348	0.111	0.00	0.329	0.108	0.00
oilseed rape share (region)	-2.332	1.326	0.08			
close to city	-0.429	0.149	0.00	-0.364	0.146	0.01
constant	0.22	0.442	0.62	-0.318	0.364	0.38

Table 5. Determinants of GM oilseed rape adoption for the GM farmer sample

n = 2343	unrestricted estimation			parsimonious estimation		
log of simulated likelihood	-640.1			-642.8		
	coefficient	standard error	prob > |z|	coefficient	standard error	prob > |z|
gross margin	0.032	0.0035	0.00	0.0316	0.0035	0.00
expected liability	-0.030	0.0039	0.00	-0.0294	0.0039	0.00
waiting period	-0.156	0.040	0.00	-0.154	0.040	0.00
time window	-0.00265	0.0070	0.71			
GM hostile neighbours	-0.758	0.161	0.00	-0.750	0.160	0.00
GM friendly neighbours	0.221	0.141	0.12	0.214	0.139	0.12
farm size	0.0003	0.0002	0.05	0.0003	0.0002	0.04
oilseed rape share (farm)	-2.62	1.16	0.02	-3.01	1.09	0.01
bovine	-0.451	0.185	0.02	-0.527	0.180	0.00
pigs, poultry	0.801	0.236	0.00	0.868	0.206	0.00
arable crops	-2.39	0.560	0,00	-2.42	0.545	0.00
image	1.287	0.365	0.00	1.25	0.35	0.00
one plot	0.107	0.196	0.59			
barriers	0.306	0.354	0.39			
successor	0.618	0.231	0.01	0.666	0.178	0.00
age	0.00549	0.0097	0.57			
children	0.433	0.185	0.02	0.416	0.175	0.02
sex	-0.698	0.702	0.32			
education	0.583	0.186	0.00	0.527	0.173	0.00
oilseed rape share (region)	-3.15	2.20	0.15			
close to city	-0.207	0.255	0.41			
constant	2.30	0.873	0.01	2.38	0.728	0.00

Table 6. Marginal effects on the probability of adoption (from parsimonious estimations)

Variable	Change	marginal effect (per cent points); whole sample	marginal effect (per cent points); GM farmer sample
gross margin	+ €10/ha	3.08	5.22
expected liability	+ €10/ha	-2.78	-4.86
waiting period	+ 1 year	-1.31	-2.74
GM hostile neighbours	+ 1 if x = 0 (neutral)	-5.08	-9.64
GM friendly neighbours	+ 1 if x = 0 (neutral)	1.76	2.32
farm size	+ 100 ha	2.51	0.57
oilseed rape share (farm)	+ 0.03	-1.27	-1.59
bovine	+ 1 if x = 0	-6.68	-5.94
pigs, poultry	+ 1 if x = 0	5.62	10.3
image	+ 1 if x = 0	not significant	16.1
arable crops	+ 1 if x = 0	not significant	-1.99
barriers	+ 1 if x = 0	12.5	not significant
successor	+ 1 if x = 0	3.72	6.88
age	+ 3 years	-0.84	not significant
children	+ 1 if x = 0	-6.86	-4.13
sex	+ 1 if x = 0 (female)	-13.0	not significant
education	+ 1 if x = 0	4.09	4.87
close to city	+ 1 if x = 0	-6.72	not significant

Table 7. Demand simulations

			technology fee = 0 €			technology fee = monopoly price			
Scenario	measure of demand	profit difference	GM rent[*]	adopters	GM fee = monopoly price	adopters	GM fee	adopters' rent	dead weight loss
		€/ha	€	# (1000 ha)	€/ha	# (1000 ha)	as per cent of GM rent[*]		
I	individual oilseed rape acreage	200	1.46m	173 (12.0)	103	36 (7.9)	50%	29%	22%
II		100	0.44m	36 (7.1)	61	12 (4.6)	60%	26%	14%
III		50	0.16 m	13 (4.6)	49.99	5 (2.7)	78%	0%	22%
IV	uniform oilseed rape acreage (1 ha per respondent)	200	12080	173	54	104	46%	36%	17%
V		100	1481	36	61	12	50%	19%	32%
VI		50	411	13	43	6	62%	9%	29%

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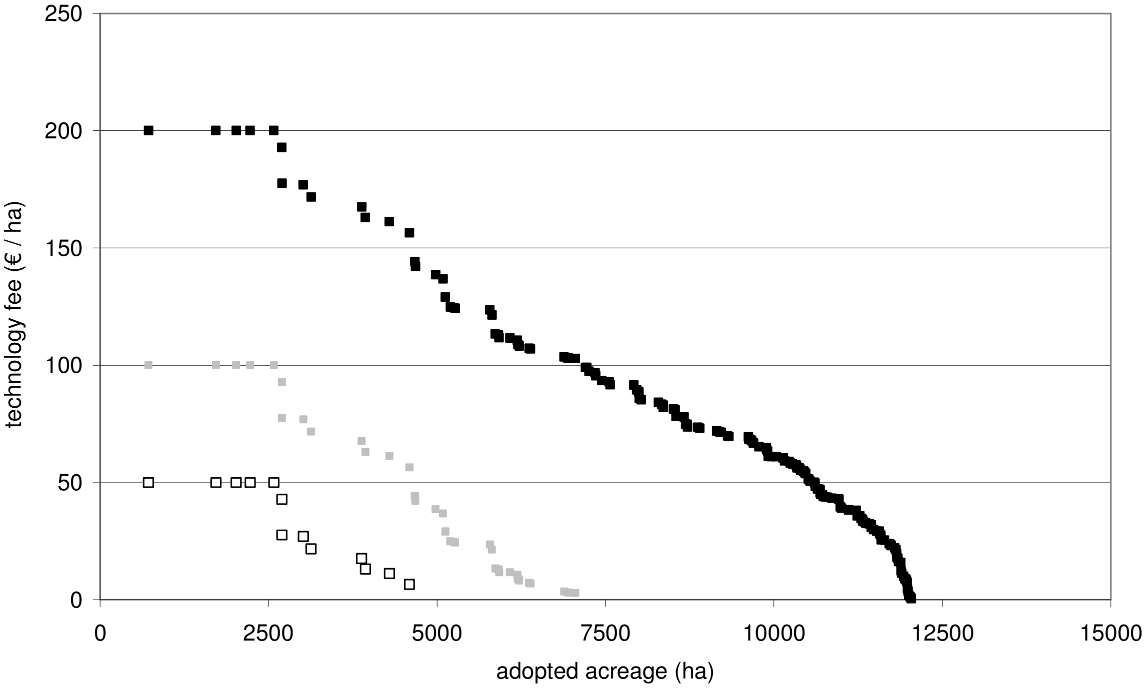
[*] **The GM rent is the area under the demand curves in Figure 1 and under equivalent demand curves for scenarios IV, V, and VI, respectively, assuming a zero GM fee.**

Figures

Figure 1. Simulated demand curves



Note that the first five values of each demand curve were set equal to the respective profit difference although the underlying willingness to pay exceeded the profit difference.