Farmer Demand For Corn Rootworm Bt Corn: Do Insect Resistance Management Guidelines Matter?

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Introduction

Bt corn contains genes from the soil bacterium Bacillus thuringiensis. The bacterium produces a toxin targeted at the elimination of the European Corn Borer (ECB). The near complete control of this primary threat to corn resulted in widespread adoption since its commercial release in 1996. Corn is planted on about 80 million acres in the U.S., predominantly in the Midwest. The share of Bt corn has increased to about 22% of total corn acreage (MNDA/USDA, 2002). Minnesota is the forth-largest contributor to corn output with close to $1.7 billion in sales with average yields above U.S. level at 145 bushels per acre in 2000. Bt corn is planted on about 29% of Minnesota's corn acres (USDA, 2002).

New varieties of Bt corn targeting additional insects like the corn rootworm (CRW) have been developed and are now being approved for commercial use by the Environmental Protection Agency (EPA). The reduction of the use of conventional insecticides is believed to be the major benefit of Bt varieties and reason for the EPA to promote their sustainable adoption and further development.

However, the widespread adoption of Bt corn also carries the risk of insect resistance development, which poses an obstacle to the sustainability of Bt varieties. To reduce the risk of resistance development while acknowledging its common property character, the EPA issued insect resistance management (IRM) guidelines. The combination of a high-dose strategy and planting a non-Bt corn refuge is believed to delay the development of insect resistance for at least 99 years (EPA, 2001). IRM will only be effective if farmers comply with the regulations. However, increased costs give

farmers an incentive not to comply. Additionally, the regulations are difficult to enforce because Bt corn cannot easily be distinguished from non-Bt corn.

This research is aimed at estimating farmers' willingness to pay (WTP) for Bt corn varieties that target ECB and/or corn rootworm. New hybrids have been developed that in addition to ECB also target CRW. The question remains if the demand for new varieties with an increased target range for insect control is significant. Furthermore, the perceived costs of IRM regulations will be computed. Perceived costs (not necessarily true costs although they are expected to be similar) influence the decision to adopt Bt corn as well as compliance with IRM regulations.

The results can then be used to design an IRM strategy that is more likely to meet EPA objectives. The analysis is based on a survey conducted in Spring 2002 among 2000 Minnesota corn farmers. A probit model with 6 variations was used to test a variety of hypotheses and compute the expected farmer's WTP.

Bt corn

Bt crops contain a gene from the soil bacterium Bacillus thuringiensis (Bt) and have been used in many crops such as corn, cotton, and potatoes. They are designed to control specific insects that constitute a primary threat to the plant. Bt corn controls the European Corn Borer (ECB) and protects to a lesser extent against the corn earworm, the southwestern corn borer, and cornstalk borer (USDA, 2001a). Annual losses attributed to ECB are about $1 billion annually (Mason et al., 1996). In Minnesota alone, damage resulted in $285 million in lost corn in 1995 (Ostlie et al., 1997). Recently, a new variety of Bt corn has been developed to control the corn rootworm (CRW).

Benefits and Costs of Bt corn

Bt corn provides nearly 100% protection against ECB losses making it superior to conventional insecticide applications, which provide between 70 and 80% protection. It offers a variety of additional advantages over conventional insecticide use. The use of insecticide applications requires intensive scouting. This incurs costs of about $3 to $7 per acre. Insecticides need to be sprayed before insects reach the interior of the stalks, which leaves only a 4-day window for applications (Mason et al., 1996). Bt corn on the other hand, provides protection throughout the entire plant. This has a variety of advantages. Among others, it increases flexibility for the farmer, decreases management effort, and decreases chemical strain on the environment through a reduction in insecticide use.

In contrast, the profitability of Bt corn is widely argued and no definite result has surfaced. A study conducted by the Gianessi et. al. (NCFAP, 1999) estimated average economic impacts of Bt corn compared to insecticide use and untreated corn. They found positive net values of the adoption of Bt corn in low and high insect infestation years. Yet, especially in high years it was beneficial, resulting in a net value of about $37 million per year compared to $13 million with insecticide applications. Based on this study and one conducted by Marra, Carlson, and Hubbell (1998), the EPA (2001) estimates benefits of Bt corn to be between $2.11 and $12.10 per acre in low and high insect infestation years, respectively. Additionally, the price of corn influences profitability. Corn prices have been declining in recent years (USDA, 1996-2001) but average about $2.00 per bushel. Total annual monetary benefit depends highly on the level of insect infestation in a given year and the price of corn.

However, the decision to plant Bt corn is made before actual insect infestations and prices are known. Lastly, regional differences such as soil quality or climate influences the profitability of Bt corn. Although actual profits are uncertain at the time of planting, increasing adoption rates suggest that perceived expected benefits outweigh the additional costs in at least some areas. The latter arise predominantly due to a price premium on Bt corn that ranges between $6.50 and $10 per acre (NCFAP, 2002, EPA, 2001, Benbrook, 2001 and 2002). Benbrook (2002) estimated that every acre Bt corn planted increased farmer's seed expenditures by about $9.80 per acre.

Insect Resistance Development

The widespread adoption of Bt corn raises concerns about the development of resistance to the Bt toxin. Empirical evidence suggests that resistance development is a real threat, although it has not been found in the field yet (Hama, et. al., 1992, Tabashnik, et. al., 1992, Tabashnik, et. al., 1995, Martinez-Ramirez, et. al., 1995). Like other genetically modified crops, Bt corn is designed to target specific insects. Surviving pests propagate and make the insect population renewable. To add to the problem, development of resistance is considered irreversible. Consequently, the efficacy of the Bt crop is diminished (Hueth and Regev, 1974; Regev, Gutierrez, and Feder, 1976).

Insect Resistance as a Public Good

Goods can roughly be categorized as pure public, pure private and quasi-private goods. In that context, Bt corn is a pure private good, but the development of insect resistance creates a negative externality affecting Bt corn farmers and other users of Bt technology. The theoretical characteristics for common property include open access with

non-existent, ill-defined, or unenforceable property rights over the use of the resource in question (Clark and Carlson, 1988). The common property character for agricultural pests is caused by two joint matters: the degree to which pests are becoming resistant and the mobility of pest populations. Increased mobility will increase the likelihood of farmers viewing the pests as common property. Resistant pests will spread enlarging the impact of insect resistance development beyond the individual farm (Clark and Carlson, 1988).

Compliance with insect resistance management practices is only verifiable by extensive lab testing of crops on every individual farm. This is costly to conduct, which requires farmers to comply voluntarily since enforcement of the regulations is difficult.

Both producers of Bt crops and farmers are negatively affected by the development of insect resistance. As targeted pests become resistant to the Bt toxin, adoption of the Bt crop will decline and the product will no longer be profitable. On the other hand, farmers would loose the currently most effective way to control for pests and would have to return to conventional methods. However, neither agent realizes the full cost for the future since the effects are widely spread. In turn, left to farmers, insect resistance management efforts will be underprovided.

Potential Consequences of Insect Resistance

The loss of the Bt toxin for pest control would be the main impact of resistance. This in turn, could result in higher costs, reduced yields, and lower quality grains. Additionally, it would make spray formulations of Bt less effective requiring a return to conventional insecticides. Organic farming depends on Bt for pest control since there are few organically certified insecticides. Given that R&D costs to develop genetically altered products are typically high, they require profitability for many years to recuperate

investments. Resistance development would jeopardize that. Lastly, public opinion on genetically modified crops might be negatively affected if resistance to Bt was viewed as having a negative impact on the environment (ILSI, 1998).

Insect Resistance Management

Insect resistance management (IRM) as defined by the EPA (2001) is the "set of practices aimed at reducing the potential for insect pests to become resistant to a pesticide." Since the 2000-growing season, strengthened requirements have been implemented. The current strategy is two-fold and focuses on a) the mitigation of any significant potential for pest resistance development by instituting IRM plans and b) efforts to better understand mechanisms leading to development of resistance. The combination of a high dose strategy and planting of a non-Bt refuge is commonly believed to sustain insect susceptibility (the converse of resistance).

The refuge requirement was implemented to allow resistant insects to mate with non-resistant ones, which delays the development of resistance for at least 99 years (EPA, 2001). Specifically, the agency requires a 20% non-Bt refuge for corn grown in the Corn Belt[1] and a 50% non-Bt refuge in regions where both Bt corn and cotton are commonly planted. The refuge cannot be planted more than ½ mile away from the Bt cornfield. Other regulations such as the signing of a grower agreement legally binding the grower to comply with the regulations, an IRM education program, IRM compliance monitoring,

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[1] Corn Belt is major agricultural region of the U.S. Mid-west where corn acreage once exceeded that of any other crop. It is now commonly called the Feed Grains and Livestock Belt. Located in the north central plains, it is centered in Iowa and Illinois and extends into S Minnesota, SE South Dakota, E Nebraska, NE Kansas, N Missouri, Indiana, and W Ohio. (Learning Network)

and insect resistance monitoring were also put in place. The refuge may be treated with conventional insecticides as needed to control for lepidopteron insects or other pests.

Compliance

Compliance with the regulations is crucial for the success of IRM. The decision to plant Bt corn is made on the premise that it provides higher profits by decreasing yield losses caused by ECB and reduced insecticide applications. Planting a non-Bt corn refuge is expected to lower profits. In accordance with IRM requirements, the Agricultural Biotechnology Stewardship Technical Committee (2002) conducted an annual grower survey. As expected, farmer awareness of the importance of IRM is high (92%) and awareness of IRM requirements is lower at 80%. Decreased profits and inability of government agencies to enforce IRM regulations give farmers an incentive not to comply. This is known as the "free rider" problem since a non-complying farmer trusts his/her neighbor to plant a refuge expecting it to be sufficient to prevent resistance development.

About 87% of ABSTC-surveyed farmers were said to be in compliance with the regulations, which leaves 13% free-riding on the insect resistance management of all other farmers. Estimated compliance based on the survey conducted as part for this research amounts to only 76% indicating an even higher percentage of free-riders. There is still controversy on the necessary rate of compliance to ensure prevention of insect resistance development but generally speaking, the higher the better. Since enforcement by government agencies cannot be expected due to costs, voluntary compliance needs to be increased.

If insect resistance requirements were designed in such as way as to minimize costs to farmers while maintaining effectiveness, compliance rates should improve which would delay resistance. Increased awareness of the common property nature of insect resistance through education programs would also contribute to boost voluntary compliance.

Part of this research focuses on the refuge requirement and planting restrictions. By eliciting the willingness to pay for specific regulations (e.g., the size of the refuge) and the impact they have on a farmer's decision to plant Bt corn, more effective IRM regulations can be designed. Additionally, knowing the regulations that have the biggest impact and constitute the biggest obstacle to farmers enables policy makers to choose an optimal strategy for dealing with pest resistance management.

Materials and Methods

The Survey

The research is aimed at estimating an average farmer's willingness to pay for Bt corn varieties and the cost of compliance with IRM regulations. Due to the common property nature of the benefits of insect resistance management 100% compliance with planting guidelines is not assured. By estimating the perceived costs IRM regulations impose on farmers, rules can be formulated that are a) effective in preventing insect resistance development and b) minimize the costs to farmers. If both objectives are met, voluntary compliance with the set of regulations can be improved and the development of insect resistance delayed.

Currently, Bt corn primarily targets ECB and the profitability is not secured at every insect infestation level. If the target for Bt corn could be expanded to other insects like the corn rootworm, profitability and in turn adoption and farmer's willingness to pay for the hybrid is expected to increase. Bt corn varieties targeting both insects have been developed but have not been marketed yet. These products vary in effectiveness, which is incorporated into survey questions. Eliciting the willingness to pay for different hybrid variations will give indications about demand and future marketability of them.

The survey was conducted between April and June 2002 following procedures outlined in Dillman (2002) in order to secure a response rate of about 50%. The survey was mailed to 2000 Minnesota corn farmers producing a minimum of $1000 worth of farm commodities. The sample of farmers was drawn randomly from the Minnesota Agricultural Statistic Service's farmer database.

Survey Design

The survey consisted of 4 separate sections. In the first one, general information about the farming background (e.g., farm size, years of farming, and previous experience with genetically altered crops) was collected. The following section aimed at farmers' experience with insects, management methods used to control pests, and knowledge about current EPA regulations for planting Bt corn. The concluding part of the survey elicits demographic information. The third section is the relevant part for this research and will be described in further detail. It focuses on the value of a new program to manage insects with Bt corn (See Appendix for an example).

The Contingent Valuation Method (CV) is a widely used method to elicit people's preferences for public goods to find out what they would be willing to pay for their

provision. It provides a tool to circumvent the absence of markets for public goods by presenting consumers with hypothetical markets in which they have the opportunity to buy the good in question (Mitchell and Carson, 1989, p. 2-3). The design of this survey follows the same principles. Each survey describes one of four varieties of Bt corn. For example, the hybrid eliminates

- more than 95% of CRW and reduces lodging and yield loss due to CRW by more than 95%. (Product1)
- more than 75% of CRW and reduces lodging and yield loss due to CRW by more than 95%. (Product2)
- more than 95% of CRW and reduces lodging and yield loss due to CRW by more than 95%. It also eliminates more than 95% of ECB and reduces stalk breakage, eardrop, and yield loss due to ECB by more than 95%. (Product3)
- more than 75% of CRW and reduces lodging and yield loss due to CRW by more than 95%. It also eliminates more than 95% of ECB and reduces stalk breakage, eardrop, and yield loss due to ECB by more than 95%. (Product4)

Elimination of the specified insect would have an impact in the current as well as future years while a reduction in yield loss and stalk breakage is oriented towards the present. Additionally, each survey describes a set of IRM regulations. The surveys were broken up into 2 categories. In 200 surveys, farmers were not required to follow any of the guidelines while the remainder had to follow all of them. The guidelines were arranged around 9 different refuge configurations:

- Planting refuge corn in a seed mix with your Bt corn
- Planting refuge corn in a block in the same field as your Bt corn
- Planting refuge corn in multiple strips in the same field as your Bt corn
- Planting refuge corn in multiple strips in the same field as your Bt corn or in a seed mix with your Bt corn
- Planting refuge corn in a block or multiple strips in the same field as your Bt corn
- Planting refuge corn in a block or multiple strips in the same field as your Bt corn or in a seed mix with your Bt corn
- Planting refuge corn in a separate field within ½ mile of your Bt corn
- Planting refuge corn in a separate field within ½ mile of your Bt corn or in a block in the same field as your Bt corn
- Planting refuge corn in a separate field within ½ mile of your Bt corn or in a block or multiple strips in the same field as your Bt corn

Additionally, 50% of the individuals were told they could not treat the refuge with insecticides, while the remaining 50% were told they could use insecticides based on economic thresholds. A value of 10, 20, 30, 40, and 50% for the size of the refuge was randomly assigned such that one fifth (400 individuals) of the surveys got one of these values. Out of every one of these groups one half of the individuals were told the corn was approved for sale in the U.S. and for export. For the other half, individuals were told the corn was approved for sale in the U.S. but not for export. Furthermore, it was randomly assigned if individuals were allowed to treat their non Bt-corn refuge with conventional insecticides.

The figure below shows the distribution of the prices for the product used for each group of 200. The offered price differential between conventional corn and the Bt hybrid ranged from $5 to $40. These prices were also randomly assigned and their distribution is depicted in the graph below:

Figure 1: Distribution of Bids

Distribution of Bids
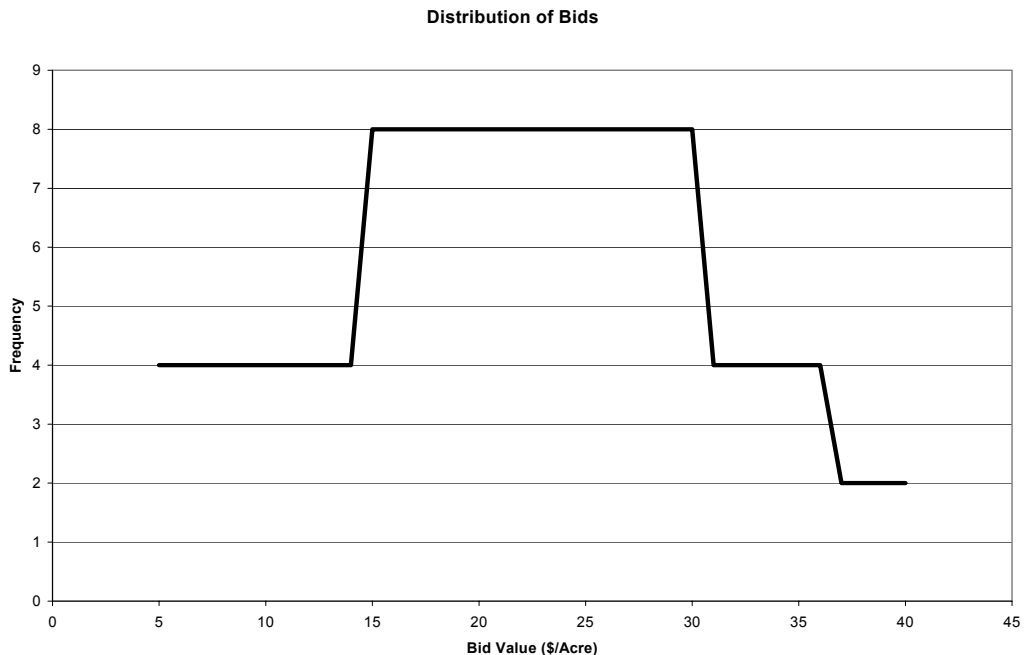
Summary Statistics - Results

The gross response rate was relatively high, but 273 could not be used because the survey was no longer applicable to the farmer or the farmer returned it indicating a desire not to participate. Additionally, some farmers did not complete the necessary information or indicated they would never plant Bt corn. The final sample used for the analysis included 591 observations or 29.55% of the original sample.

The average farmer in the survey was male, 52 years old with at least a high school degree, earns less than $20,000 annually, and farms on about 500 acres. 56% of surveyed farmers also worked off-farm and 39% raised livestock in addition to planting corn. The expected price per bushel of corn averaged about $2.00 with an average expected yield of 137 bushels per acre. This would lead to average expected revenues of $274 per acre. The survey confirms the pattern across the US in terms of increasing adoption rates for Roundup Ready soybeans as well as Bt corn.

Additionally, responses suggest a potential demand for pest management targeted at ECB and CRW. Farmers were asked about their experiences with insects and 55.4 % indicated to have had damage to their crops caused by CRW and even more farmers (83.9%) experienced damage due to the ECB. This leads to the conclusion that a Bt hybrid targeted not only at ECB but also CRW would be desirable. On average, farmers estimated the loss due to ECB and CRW, respectively to be around 17 bushels per acre for either pest. At a price of $2 per bushel, revenues will be reduced by $32 per acre due to CRW and ECB damage. The most important factors in deciding to conduct pest control are costs followed by yield and the time it takes to harvest.

The majority of farmers did not indicate having experience with insect resistance. Reported compliance rates with Bt corn planting regulations is relatively high, 72%, but lower than the grower survey conducted by the ABSTC (2002). More than 80% expressed concern for ECB resistance.

The Empirical Model

Binary-choice models are used when the dependent variable takes a discrete value of either 0 or 1 since conventional regression methods are inappropriate. In this analysis, the objective is to estimate the likelihood that an individual will plant Bt corn taking into account all imposed restrictions and specifications about planting guidelines and hybrid variations. A relationship between an individual's choice and specifications can then be derived.

We used a probit model that assumes a symmetric normal distribution of the error term to compute the model. As opposed use of a linear model, probit models (as well as logit models) translate values for the coefficient to a probability, which ranges in value from 0 to 1. (Pindyck and Rubinfeld, 1997)

The information from the survey was used to determine a) the probability of planting Bt corn depending on a variety of requirements and b) the willingness to pay (WTP) for it.

Respondents would express a willingness to plant Bt corn based on their individual WTP_i and the price differential to traditional corn. Individual willingness to pay is assumed to depend on the efficacy of the hybrid, access to markets and planting guidelines. A respondent would be willing to plant Bt corn only if his individual WTP_i is

greater or equal to the additional amount he would have to pay as compared to the price for conventional corn. Thus if $Bid \leq WTP_i$ the respondent would be willing to plant Bt corn under the specified conditions.

WTP$_i$ for the i-th respondent was assumed to be an exponential combination of 11 (k=11 in the most general model: Model 4) explanatory variables that are clarified in Table 1. This proposition for the functional form of the WTP can only be made if the initial WTP is non-negative. It appears logical and intuitive to assume that farmers who in general would be willing to plant Bt corn would also have a positive (though possibly small) WTP. This assumption would not necessarily be true if a farmer would under no circumstances be willing to plant the hybrid. In the latter case, the farmer might obtain a disutility from planting Bt corn and his willingness to pay would be negative. For this reason, respondents that indicated they would never plant Bt corn were excluded from the analysis. WTP can then be written as:

(1) $\quad WTP_i = exp(\beta_0 + \beta_1 X_{1i} + ... + \beta_{11} X_{11i} + \varepsilon_i)$ or

$$ln\,WTP_i = \beta_0 + \beta_1 X_{1i} + ... + \beta_{11} X_{11i} + \varepsilon_i = \sum_{k=1}^{11} \beta_k X_{ki} + \varepsilon_i.$$

The $\beta's$ capture the true influence of every explanatory variable on the willingness to pay for Bt corn.

The configurations specifying the planting guidelines in the survey were transformed into 4 variables that captured the essence of the restrictions. For example "Multi" would be the requirement to plant the non-Bt refuge in multiple strips throughout the field. If the additional price a farmer has to pay is lower or equal to the farmer's

willingness to pay, the probability of a positive outcome (planting Bt corn) can be expressed as

(2) $\quad Pr(Y_i^* = 1) = Pr(Bid_i \leq WTP_i)$.

Rearranging and plugging in equation (1) leads to

(3) $\quad Pr(Y_i^* = 1) = Pr(ln\,Bid_i \leq ln\,WTP_i) = Pr(ln\,Bid_i \leq \sum_{k=1}^{11} \beta_k X_{ki} + \varepsilon_i)$.

To derive the probit model, we need to rearrange equation (3) to single out the error term. This results in:

(4) $\quad Pr(Y_i = 1) = Pr(\varepsilon_i \geq ln\,Bid_i - \sum_{k=1}^{11} \beta_k X_{ki}) = Pr(\varepsilon_i < \sum_{k=1}^{11} \beta_k X_{ki} - ln\,Bid_i)$.

Taking into account the standard deviation of the error term and normalizing the coefficients we obtain the model to estimate as:

(5) $\quad Pr(Y_i^* = 1) = Pr(\dfrac{\varepsilon_i}{\sigma_\varepsilon} < \sum_{k=1}^{11} \dfrac{\beta_k}{\sigma_\varepsilon} X_{ki} - \dfrac{1}{\sigma_\varepsilon} ln\,Bid_i)$.

Since we are looking at a probit model, the underlying distribution of the error term is a normal distribution with $\varepsilon \sim N(0, \sigma_\varepsilon^2)$. The probability of planting Bt corn with the specifications given can then be defined as

$$Pr(Y_i^* = 1) = \Phi(\sum_{k=1}^{11} \dfrac{\beta_k}{\sigma_\varepsilon} X_{ki} - \dfrac{1}{\sigma_\varepsilon} ln\,Bid_i).$$

Since the standard deviation of the error term is unknown, we have to convert the coefficients we can estimate with standard data analysis software to obtain their true values β_k. The model estimation software will compute $\hat{b}_k$ and $\hat{a}$ as

(6) $\quad P(Y_i^* = 1) = \Phi(\sum_{k=1}^{11} \hat{b}_k X_{ki} - \hat{a}\,ln\,Bid)$

with

(7) $\quad \hat{b}_k = \beta_k \Big/ \sigma_k \ \text{ and } \ \hat{a} = 1 \Big/ \sigma_k \ .$

Willingness to pay for a farmer i is defined as

(8) $\quad WTP_i = exp(\beta_0 + \beta_1 X_{1i} + ... + \beta_{11} X_{11i} + \varepsilon_i) = exp(\sum_{k=1}^{11} \beta_k X_{ki})*exp(\varepsilon) .$

To find the average WTP we take the expectation of the WTP

(9) $\quad E(WTP) = exp(\sum_{k=1}^{11} \beta_k X_{ki})*E(exp(\varepsilon)) .$

The error term by assumption has a normal distribution with $\varepsilon \sim N(0, \ \sigma_\varepsilon^2)$. The mean of exp($\varepsilon$) can then be computed and the average WTP can be calculated as

(10) $\quad E(WTP) = exp(\sum_{k=1}^{11} \beta_k \overline{X}_k + 0.5\sigma_\varepsilon^2) ,$

where $\overline{X}_k$ is the value of interest for the *k*-th variable. The willingness to pay for a specific configuration and different varieties of Bt corn can then be estimated by subtracting hypothetical willingness to pay without configurations from hypothetical willingness to pay with configuration settings kept constant. Hence, we can set the "value taken" to zero canceling out the impact of that specific configuration on WTP and only compute it for a specific configuration.

The analysis was conducted stepwise starting with the most restrictive model and gradually the remaining explanatory variables were added ending with Model 4:

(11) $\quad \begin{aligned} Pr(Y=1) = Pr(\varepsilon < \ &\hat{b}_0 + \hat{b}_1 \ Pr oduct1 + \hat{b}_2 \ Pr oduct2 + \hat{b}_3 \ Pr oduct3 \\ &+ \hat{b}_4 Market + \hat{b}_5 Guide + \hat{b}_{51} Mix + \hat{b}_{52} Block + \hat{b}_{53} Multi \\ &+ \hat{b}_{54} Separa + \hat{b}_6 Treatment + \hat{b}_7 \ Re \ fuge - \hat{a} \ln Bid \ ) . \end{aligned}$

Hypotheses

In the general model, 11 variables and the price differential to the price of conventional corn were used to estimate the probability for planting Bt corn. The model focused on planting guidelines, marketability, and hybrid specifications.

Firstly, we would like to find out if Bt corn that targets ECB and corn rootworm and/or has a higher efficacy of controlling insects is perceived as more valuable. It is hypothesized that the willingness to pay should increase with either variation.

Secondly, it can be proposed that more restrictive planting guidelines decrease WTP. Finally, marketability constraints on Bt corn in terms of the hybrid not being approved for export should also negatively affect farmer WTP. With an increasing price differential between conventional corn and Bt corn, the probability of planting Bt corn is expected to decline.

Results

The analysis of the data did not support all expectations. Table 2 lists the estimated coefficients for each independent variable, table 3 converted coefficients and Table 4 lists average WTP. The standard t-test and the log-likelihood ratio test[2] were used to test for significance of the coefficients. Overall, the t-test gave more significant results.

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[2] $L \sim \chi^2 = 2(LR_{UR} - LR_R)$ with LR_{UR} = Log-Likelihood Ratio of the unrestricted model and L_R = the Log-Likelihood Ratio of the restricted model.

Model Variations

The data was analyzed in 6 different models that varied a) by number of independent variables and b) by combination of the Bt corn hybrids. Gradually more dependent variables were included leading up to the most general model with 11 explanatory ones (Model 4).

Model 1 was solely aimed at eliciting farmers' WTP for different Bt corn hybrids and access to export markets. Model 2 introduced planting guidelines as an explanatory variable and tested if planting restrictions are relevant for the decision to plant Bt corn.

The following Model 3 was used to test for significance of treatment options for the non-Bt corn refuge and the refuge size. The addition of the last two explanatory variables resulted in the best model fit since omission of both variables could be rejected at the 5% level. The inclusion of specific planting regulations in the last model (4) that increased the number of parameters to 12 did not lead to significantly better results. Consequently, Model 3 with can be viewed as the best fit for this analysis.

A result inconsistent with our expectations was the decline in WTP when the hybrid is most effective in controlling European corn borer as well as corn rootworm (Product3). One explanation would be that farmers do not value higher elimination levels for corn rootworm more which was tested in Model 3a. However, the restrictions imposed were rejected at the 5% level using a Log-Likelihood ratio test. In turn, Model 3a is not an adequate model to use.

A second derivation of Model 3 aims at the value farmers place on a combination hybrid that not only controls for CRW but also for ECB. It was hypothesized that Bt corn that controls for both would increase WTP. Combining products 1 and 2 and products 3

and 4 leads to Model 3b, which confirmed the above hypothesis. Furthermore, Model 3b turns out to fit even better than Model 3. Estimates for the coefficients and WTP of Model 3a and 3b can be found in tables 5 and 6.

Significant Results

Only the coefficients for product varieties 1, 2 and 4 were significantly different from zero. The lack of ECB control significantly lowers farmers' WTP if control for CRW, which was also confirmed by the analysis conducted in Model 3b. As expected, farmers' willingness to pay declines with decreased efficacy. Willingness to pay significantly increases by 34% if Bt corn controls for ECB and CRW instead of just CRW if there are certain regulatory guidelines to follow when planting the hybrid (based on Model 3b).

Surprisingly, permission of insecticide treatments leads to a negative coefficient that is significant at the 1% and hence lowers average WTP. This is counterintuitive since one would presuppose that the option to treat the non-Bt field would positively affect WTP. Further analysis is needed to clarify the direction of this effect.

Consistent with our expectations, the size of the refuge matters (at 10% level) and lowers WTP since it increases costs. On average, an additional 10% refuge lowers willingness to pay by about $1.20.

Insignificant Results

Access to export markets increases willingness to pay as expected. However, the coefficient is not significant. This could be due to the fact that most Minnesota farmers use their corn for livestock feeding or sell it domestically.

Although not significant, planting guidelines increased WTP, which is a counterintuitive result. Regardless, the extent of the restrictions seems to matter. If for example, farmers are required to follow certain guidelines and are required to plant a refuge of more than 10% that can be treated with conventional insecticides, willingness to pay declines (results based on Model 3b).

A variety of explanations can be hypothesized for the positive effect of guidelines on WTP. Farmers might realize the importance of IRM requirements and implications for insect resistance development. If that is the case, the willingness to support guidelines indicates that farmers perceive to still be better off if everybody is required to comply with the rules, even though there are losses associated with having to follow them. If farmers realize that insect resistance development can be delayed and the hybrid remains effective in the long run, the costs of it are spread across every farmer and a moral principle of fairness is pursued they might be willing to accept certain planting regulations. On the other hand, if farmers only care about the present we would again expect a negative effect. Alternatively, it could indicate that farmers like the existence of planting guidelines because the regulations are viewed as the optimal planting strategy and alleviate the pressure on farmers to experiment on their own. In a way then, guidelines make the decision process for farmers easier and faster. Additionally, they might expect less consumer opposition, better access to markets, and a lower probability of market discounts if their customers believe the technology is being responsibly managed (i.e. IRM is good PR for their product).

Under the premise that ECB control is irrelevant (results from model variation 3a), the analysis concluded that an increased elimination level of CRW lowers WTP

although it should also be noted that the coefficient is insignificant. This result would support the hypothesis that farmers realize the common property nature of agricultural pests and only care about pest damage in the present. A definite answer could not be found since a broader spectrum for controlling pests significantly influences WTP. In turn, the assumption is flawed and the results are irrelevant.

Neither one of the planting restrictions for the refuge that were tested in Model 4 turned out to be significant. It can be concluded that a requirement on how to plant the refuge will neither significantly affect willingness to pay nor the adoption of Bt corn. Allowing the use of a seed mix, planting the non-Bt corn refuge as a block in the same field, or a separate field next to the Bt corn field increased the WTP. The decline in WTP if the refuge has to be planted in strips throughout the Bt corn field can be explained with the additional effort it requires to do so.

A study conducted by Hyde et al. (2001) estimated the costs of planting a within-field non-Bt corn refuge. The impact of a) cost of additional time associated with planting a refuge and b) decreased corn production resulting from lower yields on acres planted later due to increased planting time. In effect, the costs were considered minor amounting to at most 2.7% of all variable costs. This study confirms these results to some extent.

The most general analysis of Model 4 allows us to compute the average WTP for the planting regulations that are currently in place. If a farmer was required to plant a 20% refuge that can be treated with conventional insecticides but has to be planted in a separate field and he uses a hybrid with the characteristics of Product 4 that cannot be exported, his willingness to pay would be $15.99. If no restrictions were in place, the farmer's WTP would be higher at $17.91.

Although some of the results appear to be counterintuitive and require further research, the argument that they are simply wrong, the model inappropriate, or responses not representative can be rejected. Considering that the survey was sent out to 2000 Minnesota farmers, the response rate was relatively high with about 600 usable surveys and all 5 model variations came to the same conclusion, this explanation seems unlikely.

Conclusion

Existing guidelines for planting corn require a non-Bt corn refuge of 20% for corn grown in the mid-West region and it cannot be planted more than ½ mile away from the Bt corn field. The treatment with conventional insecticides to target other pests is allowed. Currently, Bt corn only targets ECB and the study confirms that there is a demand for a new hybrid that controls for ECB and corn rootworm, which constitute the major threats to corn yields. The technology fee ranges around $10 and compliance rates are between 70 and 85%.

Surprisingly, the analysis revealed a positive attitude of farmers towards the existence of guidelines for planting Bt corn. The true reason is unknown and requires further study, but it could be hypothesized that farmers acknowledge the need for guidelines in this case.

Based on the results of this survey, an optimal IRM regulation should

1) not allow for insecticide treatments on the non-Bt corn field
2) minimize the refuge size to the biologically needed level and
3) does not require farmers to plant it in pieces throughout the Bt corn field.

Additionally, the EPA and USDA should strive for a fast approval of Bt corn that controls both European corn borer and corn rootworm and negotiate trade agreements allowing for the export of genetically altered crops. However, export possibilities do not appear to significantly diminish the desire to adopt Bt corn in Minnesota where a large portion of the corn crop is fed to livestock and not exported.

Additionally, the counterintuitive result that farmers seemingly like the existence of planting restrictions but dislike the option to treat the refuge with insecticides should be analyzed further. If it could be proven that farmers realize the common property nature of insect resistance development and possibly other externalities, implementing guidelines for other varieties would not result in decreased adoption rates. The results imply the opposite in that as long as guidelines are not too restrictive, they increase the likelihood of adoption.

It should be noted that the survey was biased towards respondents answering they would not plant Bt corn under the circumstances given. This is mainly due to the large number of high bid values offered to farmers. The current technology fee for Bt corn is about $10 per acre. The survey ranged from values ranging between $5 and $40. As hypothesized, an increase in the price differential between Bt corn and traditional corn decreased the probability of a farmer adopting the GE crop. A revised survey that specifies the technology fee closer to current costs associated with Bt corn should give better and more significant results.

Tables

Table 1: Independent Variables

Variables X_{ik}	Possible Value	Value taken	Description
Product1			For example, one hybrid eliminates more than 95% of CRW and reduces lodging and yield loss due to CRW by more than 95%.
Product2			For example, one hybrid eliminates more than 75% of CRW and reduces lodging and yield loss due to CRW by more than 95%.
Product3			For example, one hybrid eliminates more than 95% of CRW and reduces lodging and yield loss due to CRW by more than 95%. It also eliminates more than 95% of ECB and reduces stalk breakage, eardrop, and yield loss due to ECB by more than 95%.
Product4 (dropped due to colinearity)			For example, one hybrid eliminates more than 75% of CRW and reduces lodging and yield loss due to CRW by more than 95%. It also eliminates more than 95% of ECB and reduces stalk breakage, eardrop, and yield loss due to ECB by more than 95%.
Market			Bt corn was approved for marketing in the U.S. and all major corn export markets
Guide			Bt corn could be planted only if you follow all guidelines described
Multi			Planting refuge in multiple strips in the same field as the Bt corn
Block			Planting refuge in a block in the same field as the Bt corn
Mix			Planting refuge as a seed mix in the same field as the Bt corn
Separa			Planting refuge in a separate field within ½ mile of the Bt corn
Treatment			Using insecticides on your refuge corn to control CRW or ECB is permitted
Refuge	10-50%	10 - 50	Planting at least 10 to 50 percent of your total corn acreage to non-Bt corn for refuge
Price (lnBid)	$5-$40	5 - 40	Difference in seed costs per acre between conventional corn varieties and the Bt corn hybrid

Table 2: Estimated Coefficients

	Model 1 b^1_k	Model 2 b^2_k	Model 3 b^3_k	Model 4 b^4_k
Hybrid				
95% CRW Control	-0.24^c (0.17)	-0.25^c (0.17)	-0.24^c (0.17)	-0.22 (0.18)
75% CRW Control	-0.399^b (0.18)	-0.398^b (0.18)	-0.41^b (0.19)	-0.39^b (0.19)
95% CRW Control & 95% ECB Control	-0.209 (0.17)	-0.208 (0.17)	-0.18 (0.17)	-0.16 (0.17)
75% CRW Control & 95% ECB Control	1.29^a (0.38)	1.05^a (0.42)	1.41^a (0.45)	1.43^a (0.45)
Access to Export Markets	0.13 (0.12)	0.13 (0.12)	0.12 (0.13)	0.10 (0.13)
Regulatory Guidelines		0.27 (0.21)	0.29 (0.27)	0.17 (0.31)
Seed Mix				0.23 (0.17)
Block planted in the same Field				0.20 (0.14)
Multiple Strips in Field				-0.18 (0.15)
Separate Field				0.08 (0.17)
Insecticide Treatment on Refuge is allowed			-0.31^a (0.13)	-0.30^b (0.13)
Refuge Size			-0.0061^c (0.005)	-0.0062^c (0.005)
Log-Likelihood	-263.65	-262.82	-259.08	-257.10
χ^2 as compared to previous model	-	1.66	7.43^b	3.96

[a] significant at 1% level
[b] significant at 5% level
[c] significant at 10% level

Table 3: Converted Coefficients

	Model 1 β^1_k	Model 2 β^2_k	Model 3 β^3_k	Model 4 β^4_k
Hybrid				
95% CRW Control	-0.35	-0.35	-0.33	-0.30
75% CRW Control	-0.57[b]	-0.57[b]	-0.57[b]	-0.54[b]
95% CRW Control & 95% ECB Control	-0.30	-0.30	-0.26	-0.21
75% CRW Control & 95% ECB Control	1.84[a]	1.50[b]	1.96[a]	1.95[a]
Access to Export Markets	0.19	0.19	0.16	0.13
Regulatory Guidelines		0.38	0.40	0.24
Seed Mix				0.31
Block planted in the same Field				0.27
Multiple Strips in Field				-0.25
Separate Field				0.10
Insecticide Treatment on Refuge is allowed			-0.43[b]	0.41[b]
Refuge Size			-0.00911[c]	-0.00901[c]
Log-Likelihood	-263.65	-262.82	-259.08	-257.10
Standard Deviation of error term	1.427	1.421	1.392	1.365

Table 4: Willingness to Pay

	Model 1	Model 2	Model 3	Model 4
	WTP	WTP	WTP	WTP
Hybrid				
95% CRW Control	11.59	8.62	13.41	13.22
75% CRW Control	9.28	6.98	10.57	10.47
95% CRW Control & 95% ECB Control	12.17	9.14	14.41	14.47
75% CRW Control & 95% ECB Control	16.41	12.29	18.61	17.91
		Change in WTP		
Access to Export Markets	3.44	2.59	3.27	2.48
Regulatory Guidelines		5.74	9.07	4.82
Seed Mix				6.44
Block planted in the same Field				5.61
Multiple Strips in Field				-3.96
Separate Field				1.95
Insecticide Treatment on Refuge is allowed			-6.48	-5.98
Refuge Size				
10%			-1.52	-1.46
20%			-2.92	-2.81
30%			-4.21	-4.04
40%			-5.39	-5.17
50%			-6.47	-6.21

	Model 3a	Model 3a	Model 3a
	$\hat{b}_k$	$\beta^{3a}{}_k$	WTP
Hybrid			
95% CRW Control & 95% reduction in yield loss due to CRW & 95% ECB Control	-0.02 (0.12)	-0.03	13.62
75% CRW Control & 95% reduction in yield loss due to CRW & 95% ECB Control	1.22[a] (0.44)	1.27[b]	14.02
			Δ WTP
Access to Export Markets	0.13 (0.12)	0.17	2.65
Regulatory Guidelines	0.29 (0.27)	0.40	6.97
Seed Mix			
Block planted in the same Field			
Multiple Strips in Field			
Separate Field			
Insecticide Treatment on Refuge is allowed	-0.30[b] (0.13)	-0.42[b]	-4.77
Refuge Size	-0.0062[c] (0.0047)	-0.01[c]	
10%			-1.16
20%			-2.22
30%			-3.19
40%			-4.09
50%			-4.90
Log Likelihood Ratio -261.52		$\chi^2(2)=4.87$[c]	
Standard Deviation of Error Term 1.3814			

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[a] significant at 1% level
[b] significant at 5% level
[c] significant at 10% level

	Model 3b	Model 3b	Model 3b
	$\hat{b}_k$	β^{3b}_k	WTP
Hybrid			
CRW Control & reduction in yield loss due to CRW	-0.21^c (0.13)	-0.29^c	11.93
CRW and ECB Control & reduction in yield losses due to CRW and ECB	1.31^a (0.44)	1.82^a	16.00
			Δ WTP
Access to Export Markets	0.12 (0.12)	0.17	2.96
Regulatory Guidelines	0.29 (0.27)	0.40	7.77
Seed Mix			
Block planted in the same Field			
Multiple Strips in Field			
Separate Field			
Insecticide Treatment on Refuge is allowed	-0.31^a (0.13)	-0.43^a	-5.61
Refuge Size	-0.006^c (0.0047)	-0.008^c	
10%			-1.27
20%			-2.44
30%			-3.52
40%			-4.52
50%			-5.43
Log Likelihood Ratio -260.09		$\chi^2(2)=2.01$	
Standard Deviation of Error Term 1.3831			

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^{a} significant at 1% level
^{b} significant at 5% level
^{c} significant at 10% level

Relevant Part of the Survey (Example)

> **Please Tell Us About The Value Of A New Program For Managing Insects:**

New Bt corn hybrids are genetically engineered to control the corn rootworm (CRW). Some also control the European corn borer (ECB). The Environmental Protection Agency (EPA) is reviewing these new hybrids for registration and commercial sale to farmers. For example, one hybrid eliminates more than 95% of CRW and reduces lodging and yield loss due to CRW by more than 95%.

To reduce the chance of ECB resistance to Bt corn, EPA guidelines currently request farmers to plant non-Bt corn hybrids for refuge. The guidelines specify how much refuge corn to plant, where to plant refuge corn, and when to use insecticides on refuge corn. Similar guidelines are being considered for the new Bt corn hybrids. For example, the guidelines for the new hybrid might include:
- Planting at least 20 percent of your total corn acreage to non-Bt corn for refuge.
- Planting refuge corn in a seed mix with your Bt corn.
- Using insecticides on your refuge corn to control CRW is not permitted.

D1. **Suppose the example of a new Bt corn hybrid described above:**
- was registered by the EPA for commercial sale to farmers,
- was the same as the non-Bt corn hybrids you commonly plant except for its insect control benefits (for example, if had the same maturity, yield potential, and herbicide tolerance),
- was approved for marketing in the U.S., but not in all major corn export markets, and
- could be planted only if you follow **all** of the guidelines described above.

   Would you have planted this new hybrid in 2002 if it were available and its seed costs were $5 per acre higher than the non-Bt hybrids you commonly plant?
   (Please ✓ your answer)
   ☐ Yes   ☐ No

D2. **If you would not have planted this hybrid in 2002, please tell us why not?**
                          (Please ✓ all that apply)
   ☐ Would cost too much to plant it.

   ☐ Would want to first wait and see how it did in University performance trials or on a neighbor's farm.

   ☐ Would never plant a Bt corn hybrid.

   ☐ Would be concerned about being able to sell it.

   ☐ Would be concerned about getting a lower price for it.

   ☐ Would be concerned about possible environmental or safety issues.

   ☐ Would worry about having to keep it separate from my non-Bt corn.

   ☐ Other *(Please describe)*: _____
   _____

D3. **What is the most important reason why you would not have planted this new hybrid in 2002?** *(Please circle your response in question D2)*

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