The Impacts of Adopting Genetically Engineered Crops in the USA:

The Case of Bt Corn

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Abstract. This paper develops an econometric model to analyze the onfarm impact of adoption of genetically engineered (GE) crops on pesticide use and yields after controlling for other factors. The model, which corrects for self-selection and simultaneity and is consistent with profit maximization, is used to estimate the relationship between Bt corn adoption and insecticide use and yields using data from a nationwide farm survey carried out in 2001. Statistically significant econometric results, controlling for other factors, show a moderate insecticide reduction and a small yield increase associated with adoption of Bt corn relative to using conventional corn varieties in 2001.

Keywords: Genetically engineered corn, Bt corn, insecticide use, technology adoption, yields.

Selected paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27, 2005

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Introduction

The development of agricultural chemicals and new crop varieties offering enhanced yields and pest resistance has contributed to unprecedented agricultural productivity growth in the U.S. during the past century. These seed and chemical technologies have been widely adopted by farmers, allowing them to increase yields and reduce production costs. However, the potential hazard of increased chemical pesticide use to human health and the environment have caused increased concern.

Modern biotechnology techniques, such as genetic engineering,[1] can increase the efficiency and precision of introducing improved traits into important crop varieties. The most important genetically engineered (GE) crops currently commercialized are those with enhanced pest management traits, such as herbicide tolerance and insect resistance, and often have been embraced as a potential means for maintaining agricultural productivity while decreasing the use of chemical pesticides.

Corn production in the U.S. uses a large amount of insecticides and 29 percent of the 70.7 million acres devoted to corn production in the 19 major states were treated with more than 9 million pounds of insecticides in 2001 (USDA, 2002). As shown in table 1, Chlorpyrifos was the top insecticide, as farmers applied around 3.7 million pounds of this chemical in 2001; terbufos was second (2.5 million pounds), followed by carbofuran and tefluthrin (nearly 0.5 million pounds each).

Changes in pesticide use associated with the adoption of genetically engineered crops are critically important and may determine the final acceptance of these crops (Royal Society, Henry A. Wallace Center). A poll of farmers and consumers in August 1999 indicated that 73 percent of consumers were willing to accept biotechnology as a means of reducing chemical pesticides used in food production. Also, 68 percent said that farm chemicals entering ground and surface water was a major problem (Farm Bureau/Philip Morris Gap Research). And more recently, a survey of consumer attitudes suggested that 70 percent of consumers would be likely to buy a variety of produce "if it had been modified by biotechnology to be protected from insect damage and required fewer pesticide applications." (IFIC Foundation).

Insect-resistant crops contain a gene from a soil bacterium, Bacillus thuringiensis (Bt), which produces a protein toxic to specific insects. Acreage shares of Bt corn vary across producing States, with adoption more concentrated in areas with high infestations of targeted pests. Bt corn, originally developed to control the European corn borer, was planted on 19 percent of corn acreage in 2001 and 24 percent in 2002.[2]

Published research about the economic benefits from using Bt corn suggests that the value of Bt corn relative to traditional varieties depends primarily upon the yield loss that can be attributed to damage from the ECB. Graeber, Nafziger, and Mies (1999) concluded that at $2.25 per bushel corn, and $12 per acre for the Bt technology, it takes about 5 bushels per acre more yield to pay for the ECB protection. Rice and Pilcher (1998) showed how returns to Bt corn vary with the expected corn yield, the number of corn borers per plant, and the effectiveness of pest control. Because the economic benefits from Bt corn are tied to the level of ECB infestation, studies in some areas have found that the value of protection from Bt corn is not likely to exceed its cost. Hyde et al. (1999) found that the value of protection offered by Bt corn under Indiana conditions is generally lower than the premium paid for Bt seed corn. Similarly, research under

Wisconsin conditions suggests that Bt seed may not be worth the additional cost because of a low probability of infestation (Lauer and Wedberg, 1999).[3]

Many field-test and enterprise studies have examined the yield and cost effects of using genetically engineered crops (table 2). Results from field trials generally show that yields of Bt corn hybrids are higher than those of conventional varieties. Based on Iowa surveys, Duffy reported that the yield advantage of adopters of Bt corn was 13 bushels per acre compared with conventional corn. Using data from on-farm field trials conducted from 1997-1999 by cooperating farmers in 22 Iowa counties, Mitchell and Hurley found that as a result of controlling ECB, Bt corn increased mean yield 2.8-6.6% and no evidence of Bt corn yield drag. Dillehay et al. found an average yield gain of 5.5 percent in Pennsylvania and Maryland and Baute, Sears, and Schaafsma estimated that the yield reduction in Ontario (Canada) due to the European corn borer was 6 percent and 2.4 percent in 1996 and 1997, respectively. In a review article, Marra el al. show that the actual mean yield differences between users and nonusers of Bt corn range from 7.1- bushels per acre (for Iowa) and 18.2 bushels per acre (for Minnesota).

This paper presents an econometric method to estimate the farm-level effects of adopting Bt corn. In particular, we estimate the effect of Bt corn on insecticide use and crop yields using an econometric model that corrects for self-selection and simultaneity and using data from a nationwide farm-level survey carried out in 2001. Before introducing the econometric model, we briefly show survey results on the reasons, stated by farmers, for adopting these crops as well as the actual mean yields and insecticide usage by adopters and nonadopters of Bt corn.

Reasons for Adoption According to Farmers

The majority of corn farmers surveyed in 2001 that adopted Bt corn (79 percent of adopters) indicated that the main reason they adopted was to "increase yields through improved pest control." The second top reason, stated by nearly 9 percent of adopters, was "to decrease pesticide costs." All other reasons combined amounted to about 12 percent of adopters. These results confirm other adoption studies pioneered by Griliches who showed that expected profitability positively influences the adoption of agricultural innovations. Hence, factors expected to increase profitability by increasing revenues per acre (price of the crop times yield) or reducing costs are generally expected to positively influence adoption. Given that an objective of pest management in agriculture is to reduce crop yield losses, there is a high incentive to adopt innovations that reduce these losses.

Mean Yields and Insecticide Use for Adopters and Nonadopters of Bt Corn

Actual mean crop yields and pesticide use, calculated directly from a nationwide USDA survey of corn farmers in 2001, differs for adopters and nonadopters of Bt corn. As shown in the table below, average corn yield is 12.5 bushels per acre (9 percent) higher for adopters than for nonadopters, within the range of previous studies.[4] Average insecticide use by Bt corn adopters is 0.012 pounds of active ingredient per planted acre (8 percent) lower than for nonadopters.

The Impact of Adoption of Bt Corn, 2001 - Means of the Sample[1]

	Adopters	Nonadopters	Difference
Yield, Bushels per acre	139.6	127.1	+12.5
Insecticide, pounds per planted acre	0.143	0.155	-0.012

1 1751 observations. Source: ARMS data for corn.

While farm surveys have the potential to provide realistic results under farm conditions, many of the studies based on these types of data have been limited to comparing means of adopters and non adopters. A comparison of means may be illustrative but misleading when using data from "uncontrolled experiments," as is the case with farm-survey data, and can only lead to a definite conclusion in an ideal experimental setting, where factors other than adoption are "controlled" by making them as similar as possible.[5] Unlike controlled experiments, conditions other than the "treatment" are not equal in farm surveys. Thus, differences between mean estimates for yields from survey results cannot necessarily be attributed to the adoption of GE crops since the results are influenced by many other factors not controlled for, including weather, soils, pest management practices, other cropping practices, operator characteristics, pest pressures, etc. Moreover, farmers are not assigned randomly to the two groups (adopters and nonadopters), but make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different (for example, in terms of management ability) and these differences may manifest themselves in farm performance and could be confounded with differences due purely to adoption. This situation, called self-selection, would bias the statistical results, unless it is corrected.

For these reasons, we specify an econometric impact model that statistically controls for factors considered relevant, and for which there are data, by holding them constant, so that the effect of adoption can be estimated.

The Theoretical Framework

The model takes into consideration that farmers' adoption and pesticide use decisions may be simultaneous, due, for example, to unmeasured variables correlated with both adoption and pesticide demand, such as the pest population, pest resistance, farm location, and grower perceptions about pest control methods (Burrows). The model also corrects for self-selectivity to prevent biasing the results (Greene, 1997). Finally, the model ensures that the pesticide demand functions are consistent with farmers' optimization behavior, since the demand for pesticidal inputs is a derived demand.

To account for simultaneity and self-selectivity we use a two-stage model. The first stage consists of the *adoption decision model* --for the adoption of Bt corn as well as for other management practices that might affect insecticide use. The adoption decision model is estimated by probit analysis. The second stage is the *impact model* that provides estimates of the impact of using Bt corn on insecticide use and yields. To achieve consistency, the insecticide demand and supply functions are derived from a profit function and estimated together as a system with the profit function.

The Adoption Decision Model. The adoption of a new technology is essentially a choice between two alternatives, the traditional technology and the new one. Growers are assumed to make their decisions by choosing the alternative that maximizes their perceived utility (Fernandez-Cornejo, Beach, and Huang; Fernandez-Cornejo, 1996, 1998). Assuming that the disturbances are independently and identically normally distributed, their difference will also be normally distributed and the probit transformation can be used to model the adoption decision. Thus, if F denotes the cumulative normal distribution, the probability of adoption of technology k is $P(I_k=1) = F(\boldsymbol{\delta_k}' \boldsymbol{Z}_k)$ and the adoption equation is $I_k = \boldsymbol{\delta_k}' \boldsymbol{Z}_k + \mu_k$, where I_k denotes the adoption of a technology, such as Bt corn *(k* = 1) and $\boldsymbol{Z_k}$ is the vector of explanatory variables.[6]

The factors or attributes influencing adoption (components of the vector $\boldsymbol{Z}$), with the rationale to include them in parentheses, include (i) farm size (other studies show that operators of larger farms are more likely to adopt innovations), (ii) farmer education (more educated farmers are often found to be more prepared to adopt innovations), (iii) operator experience (more experienced farmers are more willing to accept newer techniques), (iv) crop price (operators expecting higher prices are also more likely to expect higher margins and are more likely to adopt agricultural innovations), (v) the debt-to-asset ratio used as a proxy for risk (as risk-averse farmers are less likely to adopt agricultural innovations (Feder et al, 1985), (vi) contractual arrangements for the production/marketing of the crop (contracts often specify the acreage to be grown or quantity and quality of product to be delivered and may also require application of selected inputs). Variable definitions and sample means are presented in table 2.

The Impact Model. Unlike the traditional selectivity model, in which the effects are calculated using separately the subsamples of adopters and nonadopters, the impact model uses all the observations and is known as a "treatment effects model," used by Barnow, Cain, and Goldberger). In this model the observed indicator variable I, indicates the presence or absence of some treatment (e.g., use of Bt corn) (Greene, 1995).

Formally, given the unobserved or latent variable $I^* = \boldsymbol{\delta' Z} + \mu$ and its observed counterpart I (such that $I = 1$ if $I^* > 0$ and $I = 0$ if $I^* \# 0$), the treatment effects equation, which is the basis for our impact model, is $Y = \boldsymbol{\beta' X} + \alpha I + \boldsymbol{\varepsilon}$.

Following Maddala (p. 260) and Greene (1995, p. 642, 643) we can obtain consistent estimates of $\boldsymbol{\beta}$ and α by regarding self-selection as a source of endogenity. Thus, there are two sources for the endogeneity of the variable I, namely the simultaneity discussed earlier (farmers' adoption and insecticide use decisions are simultaneous) and self-selection. Because of this endogeneity (of I), we can not use the actual adoption values I in the impact model. For this reason, we use the predicted probability of adoption, obtained from the probit equation, as instrumental variable for I.

To examine the impact of using Bt corn on insecticide use and yields, we specify the insecticide demand functions, the seed demand function, the supply function, and the variable profit function as a simultaneous system. Using a normalized quadratic restricted profit function (Diewert and Ostensoe; Fernandez-Cornejo, 1996, 1998), considering land as a fixed input and a single output (corn), imposing symmetry by sharing parameters and linear homogeneity by normalization; using the price of labor as numeraire, and appending disturbance terms, the per acre profit function (π), per acre supply function (Y), and the two per-acre demand functions (vector with two components, X_1 and X_2 for the insecticides and seed), become:

$$\widetilde{\pi} = A_0 + A_y P + \sum_j A_j W_j + \sum_k C_k R_k + 0.5\, G_{yy} P^2 + \sum_j G_{yj} P W_j + \sum_k F_{yk} P R_k + + 0.5 \sum_j \sum_i G_{ij} W_i W_j + \sum_k \sum_j E_{jk} W_j R_k + 0.5 \sum_i C_{ik} R_i R_k + \varepsilon_\pi \tag{1}$$

$$\widetilde{Y} = A_y + G_{yy} P + \sum_j G_{yj} W_j + \sum_k F_{yk} R_k + \varepsilon_y \tag{2}$$

$$\widetilde{X}_1 = A_1 + G_{y1} P + \sum_j G_{1j} W_j + \sum_k E_{1k} R_k + \varepsilon_1 \tag{3}$$

$$\widetilde{X}_2 = A_2 + G_{y2} P + \sum_j G_{2j} W_j + \sum_k E_{2k} R_k + \varepsilon_2 \tag{4}$$

where P and W are the output and input prices, A, C, E, F, and G are parameters. The vector of other factors $\boldsymbol{R}$ includes the predicted probability of adoption of Bt corn (obtained from the probit equations) as well as cropping practices that might affect the use of insecticides, such as crop rotation. The vector ***R*** also includes farm size, a proxy for operator attitude towards risk, farm typology, and off-farm employment.

Data and Estimation

The model is estimated using data obtained from the nationwide Agricultural Resource Management Survey (ARMS) developed by the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) of USDA and conducted in 2001. The ARMS survey was designed to link the resources used in agricultural production to technologies and farm financial/economic conditions for selected field crops. In particular, ARMS survey data can be used to link the adoption of genetically engineered crops with yields, other management techniques, chemical use, and profits.

The data were obtained using a three-phase process (screening, obtaining production practices and cost data, and obtaining financial information) (Kott and Fetter). The 2001 survey was conducted through on-site interviews based on a probability sample, drawn from a list frame based on all known commercial corn growers of the states selected. The 2001 corn survey covered 19 states accounting for 93 percent of the U.S. corn production. After excluding observations with missing values, 1751 observations from 17 states were available for analysis.

The survey included a section on pesticide use by active ingredient. In addition to pesticide use, the survey included questions on yields, prices, cropping practices, and usage of other inputs. The survey also included questions regarding the use of GE varieties.

For the empirical evaluation, the equations for the second stage (equations 1-4) are estimated together to gain estimation efficiency. That is, the per acre supply and demand equations are estimated together with the per acre profit function in an iterated seemingly unrelated regression (ITSUR) framework (Zellner).

The impact of adoption of Bt corn on insecticide use is calculated from equation (3): $\partial X_1/\partial R_1 = E_{11}$. The elasticity of insecticide use with respect to the probability of adoption of Bt corn is $E_{11}*(R_1/X_1)$. Similarly, the elasticity of yields with respect to the probability of adoption of Bt corn is $F_{y1}*(R_1/Y)$.

Unlike Burrows, who used expenditures (because of lack of data) in the pesticide demand equation, this paper uses the rate of insecticide applications in pounds of active ingredient per planted acre, per year, which is a better measure of pesticide use. The average rate of insecticide use is calculated by dividing the sum (over all active ingredients) of the total pounds of insecticides applied by the number of planted acres. The definition and means of the main variables are presented in table 3.

Because of the complexity of the survey design (the sample is not a simple random sample) a weighted least squares (WLS) technique is used to estimate the parameters using full-sample weights developed by the National Agricultural Statistics Service (NASS) of the USDA. A delete-a-group jackknife method is used to calculate the variances and standard errors because of the survey design and also because the conventional variance formulas do not apply to this type of model (Lee, Maddala, and Trost). The method follows the logic of the standard jackknife method except that a group of observations is deleted in each replication. It consists of partitioning the sample data into r groups of observations (r=15 in this survey) and resampling; thus forming 15 replicates and deleting one group of observations in each replicate (Rust; Kott;

Kott and Stukel). A set of sampling weights is calculated by NASS for each replicate. The model is run first with the full-sample weights to obtain the parameter estimates ***b***. The model is then run 15 additional times (using each of the 15 replicate weights) and the vector of parameters obtained in each case ***b(k)*** is compared to the full-sample parameter vector ***b*** in order to calculate the standard errors *se(**b**)*:

$$se(\mathbf{b}) = \sqrt{c \sum_{k} [\mathbf{b}(k) - \mathbf{b})][\mathbf{b}(k) - \mathbf{b}]'} \text{ , where } k=1, 2, ...15 \text{ and } c=14/15$$

Results

Table 4 presents results from the probit regressions of the adoption of Bt corn. Among the statistically significant variables in the adoption of Bt corn, the size and experience (age) coefficients are positive, corroborating other findings (Feder, Just, and Zilberman) that larger operations and more experienced operators are more likely to adopt agricultural innovations. Adoption is more likely when the operator spouse works off-farm (coefficient is positive and very significant) indicating that the technology may free up these resource from the household. However, the coefficient for off-farm work of the operator had the opposite sign, which was unexpected and indicates that there may be some multicollinearity problem in the probit regression. However, collinearity is not a big problem in our context because the objective of the probit estimation is to obtain predicted values of the probability of adoption (to be used in the impact model), which are not generally affected by multicollinearity. Production of livestock is significant and positive, as expected, because the operator is likely to be less dependent on the marketing of corn and thus less concerned about a GE marketing risk. Another significant factor is the use of production/marketing contracts. This factor has a negative association with adoption as expected, since farmers using contracts may be required to produce non GE corn. Factors not having a significant influence on adoption include education, a proxy for risk (debt-to-assets ratio), tenure, farm typology, and location in the cornbelt.

Table 5 presents the results of the adoption impacts model using the ITSUR estimation framework. The model has a total of 51 estimated parameters and more than 30 percent of them are significant. Focusing first on the results for insecticide demand, insecticide use is negatively related to the adoption of Bt corn (and statistically significant). The elasticity of demand of insecticides with respect to the probability of adoption of Bt corn (calculated at the means) is -0.411 (table 6).[7] That is, a 10 percent increase in the probability of adoption of Bt corn is associated with a decrease in insecticide use of 4.11 percent, controlling for other factors. This is an important result given that the total amount of insecticides used in 2001 was more than 9 million pounds of active ingredient (table 1).

Table 5 also shows that the effect of adoption of Bt corn on yields is positive and statistically significant, but small. The elasticity of yields with respect to the probability of adoption of herbicide-resistant soybeans is 0.039 (table 6), meaning that a 10 percent increase in the probability of adoption of Bt corn is associated with an increase in corn yields of 0.39 percent. Finally, the effect of adoption of Bt corn on variable profits (corn revenues minus variable costs) is calculated by taking the derivative of equation 1 with respect to the probability of adoption ($M\pi/MR_1$) using the ITSUR parameter estimates of the profit function (table 4). The adoption of Bt corn does not have a statistically significant effect on variable profits.

Concluding Comments

This paper estimates the on-farm impacts of adopting Bt corn on insecticide use and yields using an econometric model that corrects for self-selection and simultaneity and is consistent with profit maximization. The model is estimated using 2001 national survey data.

Actual survey results show that, on average, corn yield was 12.5 bushels per acre (9 percent) higher for adopters than for nonadopters and insecticide use is 0.012 pounds of active ingredient per planted acre (8 percent) lower for adopters in 2001.

Econometric results show that there was a moderate insecticide reduction and a small yield increase associated with farmers adopting Bt corn relative to those using conventional corn varieties. After controlling for other factors, a 10 percent increase in Bt adoption is associated with an increase of corn yields of 0.39 percent and a decrease in insecticide use of 4.11 percent in 2001.

The implications of these results should be regarded carefully, and only within the constraints of the analysis. As mentioned before, the economic impacts of adopting GE crops may vary with several factors, most notably pest infestations, seed premiums, prices of alternative pest control programs, and any premiums paid for segregated crops. These factors have, and will likely continue to change over time as technology, marketing strategies for GE and conventional crops, and consumer perceptions of GE crops continue to evolve. Finally, this study has two limitations. The modeling of the substitution possibilities between pesticides and other purchased inputs, particularly fertilizers, is incomplete and production risk was excluded from the model. In the first case, the limitations are attributable to the lack of farm-level price data for some inputs. Panel data would be needed to address the second issue satisfactorily. When better data become available, these limitations may be surmounted, helping to improve our understanding of technology adoption in agriculture.

Notes

1. Genetic engineering (genetic modification of organisms by recombinant DNA techniques) is used to develop crops containing genes that impart a crop the ability to express desirable traits, allowing the targeting of single plant traits and facilitating the development of characteristics not possible through traditional plant breeding techniques.

2. The recent increases in acreage share (29 percent in 2003 and 32 percent in 2004) may be largely due to the commercial introduction in 2003/04 of a new Bt corn variety resistant to the corn rootworm, a pest that may be even more destructive to corn than the European corn borer.

3. Research by Hyde et al. (2000) suggests that the value of Bt corn relative to conventional varieties increases as one moves from east to west in the corn belt because ECB infestations are much more frequent and severe in the western corn belt.

4. Moreover, as a reference point, and according with previous research (Iowa State) the yield loss by a single corn borer per plant is estimated to be between 5 and 6 bushels per acre,

5. Comparison of means is sometimes used to analyze results from experiments in which factors other than the item of interest are "controlled" by making them as similar as possible. For example, means can be compared for pesticide use of two groups of soybean plots that are equal in soil type, rainfall, sunlight, and all other respects, except that one group receives a "treatment" (e.g., GE crops), and the other group does not. As an alternative to controlled experiments, the subjects who receive treatment and those who don't can be selected randomly.

6. As Burrows notes, it is convenient to interpret this equation as the probability, conditional on Z that a particular grower will adopt.

7. Results are typically expressed as a unitless measure, elasticity -- the percent change in a particular effect (insecticide use or yields) relative to a small percent change in adoption of the technology from current levels. The results can be viewed in terms of the aggregate effect (across an entire agricultural region or sector) from aggregate increases in adoption (as more and more producers adopt the technology). However, in terms of a typical farm --that has either adopted or not-- the elasticity is usually interpreted as the (marginal) farm-level effect associated with an increase in the probability of adoption. Moreover, as with most cases in economics, elasticities examine small changes (say, less than 10 percent) away from a given, e.g., current level of adoption.

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Table 1. Major Insecticides Used on Corn, 2001[1]

Insecticide active ingredient	Area applied	Appli- cations	Rate per application	Rate per crop year	Total applied
	Percent	Number[2]	---- Lbs/acre ----		Million lbs.
Bifenthrin	2	1.0	0.05	0.05	67
Carbofuran	*	1.0	0.83	0.83	476
Chlorpyrifos	4	1.1	1.04	1.22	3,663
Cyfluthrin	4	1.0	0.006	0.006	16
Dimethoate	*	1.0	0.51	0.51	164
Esfenvalerate	*	1.0	0.02	0.02	1
Fipronil	3	1.0	0.11	0.11	259
Lambda-cyhalothrin	2	1.0	0.02	0.02	23
Methyl parathion	1	1.3	0.40	0.53	386
Permethrin	3	1.0	0.10	0.11	236
Petroleum distillate	*	1.0	0.99	0.99	56
Phorate	*	1.0	0.87	0.87	73
Propargite	*	1.0	1.40	1.40	156
Tebupirimphos	4	1.0	0.12	0.12	371
Tefluthrin	6	1.0	0.12	0.12	466
Terbufos	3	1.0	1.02	1.02	2,491
Total[3]	29				9,004

1 Planted acres: 70.7 million acres for the 19 states surveyed (States included are CO, GA, IL, IN, IA, KS, KY, MI, MN, MO, NE, NY, NC, ND, OH, PA, SD, TX and WI).
2 Number of times a treated acre receives the particular active ingredient.
3 Includes other insecticides not listed
* Area applied is less than one percent.

Source: USDA, 2002.

Table 2—Summary of Previous Studies on the Effects of Bt Corn on Yields, Insecticide Use, and Returns

Researchers/ Date of publication	Data source	Effects on		
		Yield	Insecticide use	Returns
Rice and Pilcher, 1998	Survey	Increase	Decrease	Depends on infestation
Marra et al., 1998	Survey	Increase	Decrease	Increase
McBride & El-Osta, 2002[1]	Survey	na	na	Decrease
Duffy, 2001	Survey	Increase	na	Same
Pilcher et al., 2002	Survey	Increase	Decrease	na
Baute, Sears, and Schaafsma, 2002	Experiments	Increase	na	Depends on infestation
Dillehay et al., 2004[2]	Experiments	Increase	na	na

na = not available
[1] Results using 1998 data.
[2] Results using 2000-2002 data.

Table 3. Definition and Sample Means of Main Variables - Corn Producers, 2001

Variable	Definition	Mean
HCORN	Size of the farm, corn acres	384.6
OP_AGE	Age of the operator, years	51.53
EDUCOLL	Education, dummy = 1 if operator has college	0.460
HIGHPLUS	Education, dummy = 1 if operator has at least high school	0.915
TENURE	Land tenure dummy = 1 if operator owns the land	0.481
DARAT	Dummy variable = 1 if the actual debt-to-assets ratio is greater or equal to 0.4	0.120
CB_TYPOL	Combined ERS farm typology index (ranges from 1 to 3)	2.39
FAMIFARM	Family farm dummy	0.848
OPOFFARM	Dummy = 1 if operator works off-farm	0.251
SPOFFARM	Dummy = 1 if operator spouse works off-farm	0.447
CONTRAC	Share of corn revenues under contract	0.074
LIVESTOCK	Dummy = 1 if livestock is principal production	0.367
PSEED	Price of seed, $ per bag (80, 000 kernels)	89.04
PCORN	Price of corn, $ per bushel	1.657
CORNBELT	Dummy = 1 if farm is located in cornbelt	0.320
ROTATION	Dummy = 1 if crops in the field were rotated in the last 3 years	0.664
BTORN01	Dummy = 1 if field uses Bt corn	0.199
YIELD	Corn yield measured in bushels per acre	131.7

Source: Calculated from 2001 ARMS data for corn.

Table 4. Probit Estimates of Adoption of Bt Corn, U.S. Corn Producers, 2001

Variable	Parameter	Standard Error	t-value
Constant	-2.02932	0.7415	-2.737
HCORN	0.00029	0.0001	2.644
OP_AGE	0.05425	0.0265	2.046
OP_AGESQ	-0.00056	0.0003	-2.239
EDUCOLL	-0.02183	0.0852	-0.256
HIGHPLUS	-0.14226	0.1386	-1.026
TENURE	-0.03435	0.1205	-0.285
DARAT	-0.09458	0.1320	-0.717
CB_TYPOL	0.06916	0.0734	0.943
FAMIFARM	-0.05422	0.1372	-0.395
OPOFFARM	-0.29256	0.1059	-2.763
SPOFFARM	0.26861	0.0810	3.316
CONTRAC	-0.50116	0.2779	-1.804
LIVESTOC	0.43038	0.1016	4.236
PSEED	-0.00011	0.0008	-0.143
PCORN	-0.24501	0.1197	-2.046
CORNBELT	-0.07458	0.0858	-0.869

Log Likelihood function -1769

Table 5. ITSUR Parameter Estimates of the Profit Function, U.S. Corn Producers, 2001

Obs.	Variable	Parameter Estimates	Standard Errors[1]	t-statistic
1	a0	1.921	9.778	0.1964
2	ay	71.129	10.520	6.7614
3	a1	0.122	0.088	1.3934
4	a2	0.294	0.026	11.1449
5	c1	-25.460	20.410	-1.2474
6	c2	-5.870	4.017	-1.4612
7	c3	-4.636	4.557	-1.0175
8	c4	-1.716	5.270	-0.3257
9	c5	0.003	0.009	0.3656
10	c6	-4.817	7.029	-0.6853
11	gyy	113.242	58.145	1.9476
12	gy1	1.472	0.353	4.1642
13	gy2	0.266	0.263	1.0123
14	g11	-0.031	0.012	-2.5386
15	g12	-0.005	0.005	-0.9876
16	g22	-0.003	0.001	-3.8836
17	fy1	25.896	14.392	1.7993
18	fy2	12.572	5.957	2.1106
19	fy3	-4.472	9.703	-0.4609
20	fy4	2.494	5.206	0.4791
21	fy5	0.026	0.006	4.5246
22	fy6	17.207	7.007	2.4555
23	e11	-0.410	0.219	-1.8758
24	e12	-0.054	0.033	-1.6289
25	e13	-0.032	0.025	-1.2653
26	e14	0.047	0.022	2.1474
27	e15	0.000	0.000	2.1925
28	e16	-0.098	0.037	-2.6733
29	e21	0.064	0.037	1.7235
30	e22	0.025	0.009	2.7352
31	e23	0.004	0.011	0.3305
32	e24	0.005	0.005	1.0321
33	e25	0.000	0.000	1.3421
34	e26	0.015	0.005	2.7112
35	c11	208.343	143.410	1.4528
36	c12	26.154	15.066	1.7359
37	c13	-4.361	6.537	-0.6672
38	c14	-3.495	6.901	-0.5064
39	c15	-0.016	0.008	-1.8595
40	c16	3.501	5.925	0.5909
41	c23	5.504	4.105	1.3409
42	c24	0.89339	1.73340	0.5154
43	c25	-0.00549	0.00387	-1.4202
44	c26	-2.36890	4.80755	-0.4928
45	c34	-0.26561	2.30933	-0.1150
46	c35	0.00513	0.00734	0.6983
47	c36	5.50874	6.54788	0.8413
48	c44	-1.49089	1.72877	-0.8624
49	c45	0.00119	0.00216	0.5536
50	c46	2.64511	3.29442	0.8029
51	c56	-0.00289	0.00407	-0.7095

[1] Using the jackknife variance estimator

Table 6. The Impact of Adoption of Bt Corn, 2001

Elasticity of	Elasticity with respect to the probability of adoption
Yields	+0.039
Insecticide	-0.411