Estimating the Value of Bt Corn: A Multi-State Comparison

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Abstract

Bt corn offers a powerful tool to control European corn borers and some other pests. Because pest infestations and farming practices differ across the Corn Belt, economic benefits also differ. This research estimates the value of Bt corn across the Corn Belt. Results identify areas where Bt adoption is economically justified.

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Introduction

The European corn borer (ECB), *Ostrinia nubilalis* (Hübner), is responsible for losses totaling over $1 billion each year in the United States when accounting for lost yield and costs of ECB control (Russnogle). This is approximately five percent of the total value of U.S. corn production. However, the level of infestation pressure is highly variable across the Corn Belt. Some areas have infrequent (less than one in four years) infestations and damage levels are typically relatively low (Figure 1). Others may realize infestations more frequently than one out of every two years (Buschman; Hellmich).

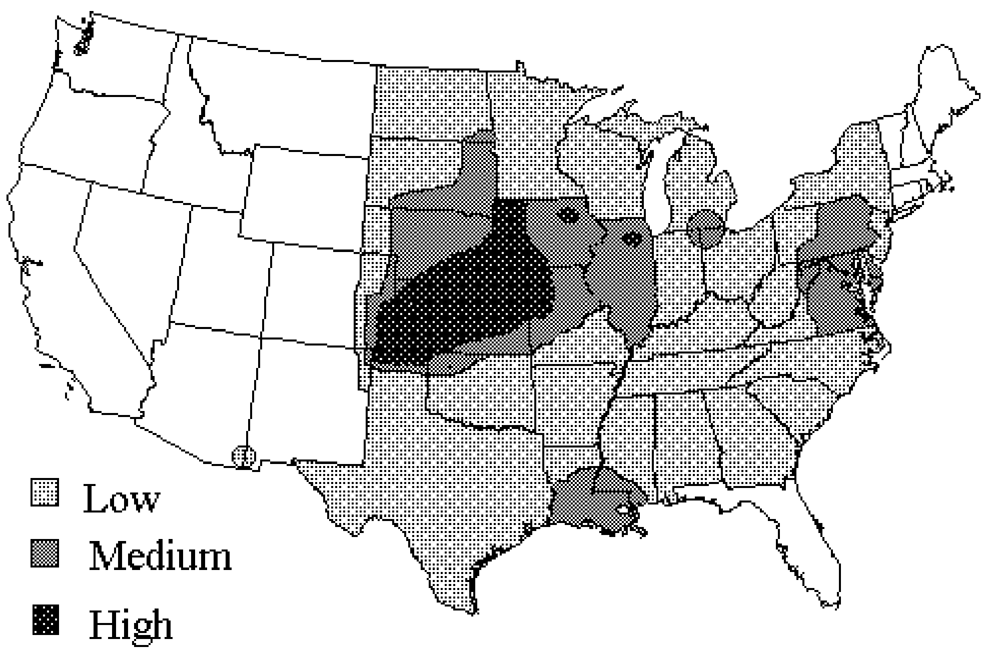

Figure 1. European corn borer pressure throughout the United States

Prior to the introduction of Bt corn, most farmers used cultural practices, insecticide applications, or a combination of the two to control ECB damage (Pilcher and Rice). Some examples of the types of cultural practices designed to minimize the economic impact of ECB include shredding stalks to kill overwintering larvae and harvesting early to minimize the amount of lodging that may occur. The effectiveness of insecticide applications is quite sensitive to timing of the application. With most insecticides, maximum efficacy reaches only about 80% against first generation borers and 67% against second generation (Ostlie, Hutchison, and Hellmich). However, more powerful insecticides have reached the market in recent years. Some of these may provide 90% or greater effective control (Buschman).

The introduction of Bt corn provides farmers with the most effective ECB control tool on the market. YieldGard® brand Bt corn provides nearly 100% protection against ECB damage. Also, the farmer does not need to worry about optimal timing because YieldGard® Bt corn expresses the toxin in all above-ground parts of the plant throughout the growing season.

The objective of this paper is to estimate the value of Bt corn in three U.S. Corn Belt regions covering Indiana, Illinois, Iowa, and Kansas. INIL covers Indiana and most of Illinois with the exception of a portion of southern Illinois that experiences southwestern corn borer infestations. IAKS includes Iowa and all of Kansas except the southwestern corner, which is the third region, SWKS (Figure 2). Because ECB pressure differs in each of these regions, the potential benefits of planting Bt corn will also differ in each region. The following section provides some background information about the European corn borer and Bt corn.

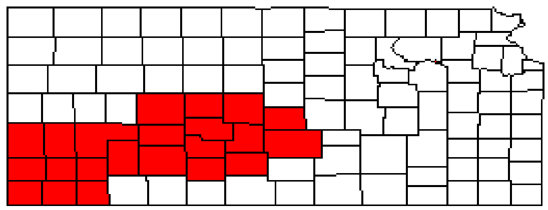

Figure 2. Approximate area analyzed as southwest Kansas

Background

A basic understanding of the European corn borer and Bt corn is necessary for a more complete understanding of the economic analysis in this paper. This section provides this information. The following subsection discusses ECB, including the insect's life cycle, number of generations per growing season, and how the ECB damages corn plants. Subsequently, background information on Bt corn is presented. That section discusses the different types (or "events") of Bt corn and how each kills corn borers. State specific background information is presented with the empirical results.

The European Corn Borer

The European corn borer is a lepidopteran insect. That is, it develops in four general stages: eggs, larvae, pupae, and adult moth (Edwards, Foster, and Obermeyer). In the spring, larvae that have overwintered (survived the winter, usually in stalk residue) pupate and later emerge as adult moths. These moths mate and then lay eggs on the undersides of the corn leaves. The eggs later hatch and the emerging larvae begin another cycle.

Each cycle is known as a generation. Different areas of the country may have between one and four generations per year. As a general rule, the number of ECB generations increases as one moves southward throughout the United States (Mason, *et al*.). In most of the major corn producing states (e.g., Indiana, Illinois, Iowa, Missouri, Kansas, and Nebraska), farmers are typically concerned with only two generations.

It is during the larval stage that the ECB damages the corn plant. Hyde, *et al*. (1999a) describe two types of corn damage, physiological and mechanical. Physiological damage happens when the ECB tunnels into the stalk. This tunneling destroys pathways crucial for the flow of nutrients to the ears. Mechanical damage is a result of the ECB weakening stalks and/or ear shanks. The weakened stalks are more likely to lodge in strong winds. Ear shank feeding may cause the ear to fall to the ground without being harvested. In addition to physiological and mechanical damage, ECB feeding has also been shown to increase the probability of stalk rots and mycotoxins in corn plants (Munkvold). However, Bt corn can reduce the incidence of damaging mycotoxins (Munkvold, Hellmich, and Rice).

Bt Corn

Bt corn became available for commercial use in 1996. To date, five events have been registered in the United States (Hyde, *et al*., 1999a). These differ by the type of protein expressed by the plant and how that protein is expressed. Some events (176 and DBT418) have declining efficacy as the corn senesces because the Bt is expressed in green tissues. Other events (MON810 and Bt11, both sold under the YieldGard® brand name) express the Bt toxins season-long throughout the above ground portion of the plant. The fifth event, CBH-351, has the Bt gene stacked with a gene for resistance to Liberty® herbicide. The types of proteins expressed are Cry I(A)b, Cry I(A)c, and Cry 9(c) (Hyde, *et al*., 1999a).

Bt corn was created by introducing a gene from a naturally occurring soil bacterium, *Bacillus thuringiensis kurstaki*, into the corn's DNA. Bt has been used for many years as an applied insecticide[1]. However, Bt corn now produces the insecticidal proteins to kill corn borers that feed on the plant.

Bt kills ECB, and some other insects, by rupturing cells in the insect's gut. Once the Cry protein is ingested, it reacts to the insect's digestive enzymes and becomes toxic. That toxin then destroys the lining of the intestine. Within two hours of taking a bite, the ECB will stop feeding. Death occurs between two and three days later (Ostlie, Hutchison, and Hellmich).

Methodology and Data

This section presents the general model formulation, how the models can be solved to determine the value of Bt corn within the region, and a brief discussion of the data used. This research employs a spreadsheet-based decision analysis (DA) framework. This analytical framework is appropriate because each of the decision sets and probability distributions are discrete. Except for the overall frequency of ECB

[1] Bt insecticides have been widely used by organic producers. Because the insecticide comes from a naturally occurring bacterium, its use does not harm the organic status of the product. Organic producers are particularly concerned with ECB resistance management since they could lose their most effective control tool if it becomes widespread.

infestation, conditions are not suspected to differ significantly within individual regions analyzed but are expected to differ across regions (Buschman; Hellmich; Steffey). Thus, each region requires a unique model. Some specific modeling issues are presented along with the results.

General Model Formulation

The model maps out a decision tree for an entire growing season. A timeline helps to clarify the structure of the decision tree (Table 1). The seed choice decision is the most crucial for the objective of this paper. However, this choice forms only the "root" of the decision tree to be modeled. As time progresses (moving down through Table 1), the farmer is faced with a series of random events and subsequent choices.

The model considers only two choices for seed corn, Bt and non-Bt. The Bt choice is YieldGard® seed. The two types of seed corn are considered to be sister-lines. That is, each has the same background genetics. The only difference is the expression of the Bt toxin. Thus, each has the same yield potential.

Common to all three regions is a random planting period. Realization of planting date is important for two reasons. First, corn planted after a particular date tends to yield less than earlier planted corn. (That date differs by region.) Second, the probability of infestation differs by corn planting date.

In INIL and IAKS, farmers are then faced with a series of corn borer infestations and an accompanying decision to spray to control the damage. The decision to spray is based on the outcome of the random infestation event as well as the expected results from spraying or not. If the farmer expects that spraying will lead to higher returns, then the farmer will choose to spray. This behavior is reflected in the model.

Table 1. Model timeline of important events

Date	INIL	IAKS	SWKS
Winter	Seed choice	Seed choice	Seed choice
Apr.1- Jun. 15	Planting	Planting	Planting
June 7	1st generation ECB[a]		
June 15[b]			1st generation ECB
June 15-28			Spray
June 16		1st generation ECB[a]	
June 28[a]			1st generation SWCB
Late July - Early August[c]			CRW Adulticide Program[a]
August 4			2nd generation ECB[a,c]
August 5-11			Spider mites[d]
August 6	2nd generation ECB[a]		
August 10		2nd generation ECB[a]	
August 11			2nd generation SWCB
September 2	3rd generation ECB[a]		

[a] Indicates that a spraying choice is made at that time. In SWKS, the spraying decision is based upon realization of ECB infestation and expectation of SWCB and spider mite infestation.
[b] Infestation dates are assumed to be four days after peak flight in the state or region analyzed. This represents the time it takes for larvae to emerge after egg laying (Buschman).
[c] In some portions of SWKS, a corn rootworm adulticide program is employed. In these areas, the farmer typically sprays Capture® about a week before normally spraying for second generation ECB, expecting a three to four week residual (Buschman).
[d] It is assumed that infestation occurs sometime around 2nd generation corn borer pressure. This assumption is based on the understanding that spraying for spider mites often occurs at this time and that Capture®, the most commonly used insecticide, has a relatively long residual period (Buschman).

In SWKS, the decision framework is not as straightforward. Farmers in this region must consider a wide array of corn insect pests in addition to ECB. These other pests include southwestern corn borer (SWCB), spider mites, and corn rootworms (CRW). Although, the other regions also experience CRW infestations, SWKS farmers control them differently in Bt than in non-Bt corn. Thus, the SWKS model must be flexible enough to analyze alternative control techniques. A brief discussion of SWCB, CRW, and spider mites is included later.

The decision tree branches at each choice or random event. Starting at the root, for example, the tree begins with two branches, one for each type of seed. In INIL and IAKS, each of those branches off again six times, representing the six potential planting periods. At this point, there are 12 possible outcomes (two seed choices times six possible outcomes of the planting period). The tree develops in this manner as the entire growing season is modeled, resulting in hundreds of potential outcomes.

Each possible outcome has an associated payoff, also called "leaves" in the decision tree framework. These payoffs are equal to the revenue associated with each outcome less the costs of scouting and spraying. Other costs are assumed the same in both Bt and non-Bt corn and are not included. In SWKS, it is common to use a soil insecticide program for CRW in Bt corn but to use an adulticide program in non-Bt corn. Therefore, these costs are included in the SWKS model.

The model uses a negative exponential (NE) utility function to adjust payoffs (Arrow). The NE utility function is characterized as $U = -\exp(-\rho W)$, where U is the utility level, exp is the exponential operator, ρ is the coefficient of risk aversion, and W is the payoff. The NE function has all the desirable properties of a utility function of wealth. It is strictly increasing in W, but at a decreasing rate, i.e., $dU/dW > 0$ and $d^2U/dW^2 < 0$. Finally, the NE utility function exhibits constant absolute risk aversion (which is equal to the parameter ρ) and increasing relative risk aversion

<u>Model Solution</u>

To solve for the value of Bt corn, the model begins at the leaves of the decision tree and moves backward in time toward the root. As modeled, the final event in each of the models is a choice to spray or not. This decision is made based upon the value of the payoff (or associated utility level) of each of the two possible choices (spray or don't spray). If the utility for spraying is greater than the utility for not spraying, then the model simulates the decision to spray. The model simulates each decision based on the same criterion, except that decisions made earlier in the year are based on expected, rather than actual, utility levels.

At random events, such as a second-generation infestation, the model calculates the expected utility beyond that point in time. Because the probability distributions are discreet, the expected value is simply the sum of the utility times the probability of that utility level.

The model continues this general process until it reaches the initial seed choice decision. At that point, the expected utility for each seed type is known. These expected utility levels are then converted to certainty equivalents[2]. The certainty equivalent for the NE utility function can be found by inverting it to arrive at W as a function of U.

The final step in the solution process is to take the difference in certainty equivalents to determine the value of Bt corn (CE_{Bt} - CE_{Non} = value of Bt). This difference represents the maximum amount that the farmer can pay for the Bt seed and still be as well off, in expected utility terms, as growing non-Bt corn. This should be compared to a relevant technology fee of $7.80 to $11.70 per acre[3]. Using a utility function allows for the effects of risk-aversion to be quantified in the context of the seed

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[2] A certainty equivalent (CE) is that dollar amount that causes the decision maker to be indifferent between taking the gamble, in this case planting the seed and realizing an uncertain outcome, or receiving CE.
[3] The per-acre technology fee is simply the premium per seed unit, $26 (Hopf), times the percentage of the unit used per acre. The range of $7.80 to $11.70 represents seeding rates from 24,000 to 36,000 per acre.

purchase decision. Relative risk aversion levels of 0 (risk-neutral) to 5 (very risk averse) are used in this analysis (Anderson, Dillon, and Hardaker).

Data

Data are from three general sources. First, information on yields and planting dates are from USDA sources. Second, data on losses from delayed planting and some cost variables are from agronomists, agricultural economists, crop consultants, and seed salesmen. Finally, nearly all data and information on corn insect pests are from cooperating entomologists in each of the states analyzed. These include Larry Bledsoe and John Obermeyer in Indiana, Kevin Steffey in Illinois, Rick Hellmich in Iowa, and Larry Buschman and Randy Higgins in Kansas. This section provides a description of the data and sources.

Data on potential yields, efficacy of spraying, and scouting and spraying costs were collected to calculate economic payoffs (Table 2). Notice that yields tend to increase as one moves from east to west, from low ECB pressure to high ECB pressure. No corn price is assumed at this point. The analysis allows a range of corn prices and expected yields to be analyzed.

Data on corn planting dates are important in this analysis (Table 3). For INIL and IAKS, six distinct planting periods are used. Only five are used for SWKS because those farmers typically have better early season weather than do farmers in the other regions.

Table 2. Per-acre cost and revenue parameters

Parameter	INIL	IAKS	SWKS
Scouting cost	$3.00[a]	$0.50-$2.00	$1.50
Spraying costs (labor, machinery, and Insecticide)	$15.00[b]	$12.30	Variable[c]
Base yield	144 bu.[d]	150.5 bu.[d]	191.8 / 75.5 bu.[d]
First generation Spraying efficacy	80%	70%	70%
Second generation Spraying efficacy	60%	50%	80% (ECB) 85% (SWCB)
Third generation Spraying efficacy	50%	NA	NA
YieldGard® Bt effectiveness (all generations)	100%	100%	100%

Note: Unless indicated otherwise, INIL data were provided by Bledsoe and Steffey, IAKS data by Hellmich, and SWKS data by Buschman.
[a] Larson
[b] Doster, 1996
[c] It is assumed that Penncap M is applied for first generation infestations at a total cost of $16.00 per acre. For second generation applications, Capture® is used at a cost of $20.00 per acre (Buschman).
[d] Used the 1992-96 state average yields; 132 and 140.5 bushels/acre in Indiana and Iowa, respectively (USDA/NASS, 1996-97), and probabilities and yield loss coefficients presented earlier. For SWKS, the average yield in crop districts 30 and 60, 171.7 bushels/acre (irrigated) and 67.6 (dryland), was used.

Table 3. Potential corn planting periods and associated yield losses and probabilities

	INIL		IAKS		SWKS		
Planting Period	Yield Loss[a]	Planting Prob.[b]	Yield Loss[a]	Planting Prob.[b]	Planting Period	Yield Loss[a]	Planting Prob.[b]
Before May1	0%	36.5%	0%	26.0%	April 1-15	0%	6.7%
May 1 – 9	0%	27.0%	0%	34.6%	April 16-30	0%	35.6%
May 10 – 16	5%	12.3%	5%	18.5%	May 1-15	2%	39.6%
May 17 – 23	15%	7.6%	10%	10.2%	May 16-30	15%	14.2%
May 24 – 30	25%	5.2%	15%	5.6%	After May 30	25%	3.9%
After May 30	39%	11.4%	20%	5.1%			

[a] INIL, IAKS, and SWKS yield losses were provided by Doster, *et al.*, Hellmich, and Buschman, respectively.
[b] Probabilities derived from USDA/NASS, 1999a.

Finally, data on yield losses due to corn borer damage as well as probability distributions of that damage are critical. For this analysis, yield losses were collected as the percentage yield damage per insect per plant by generation and corn planting date

(Tables 4-6). The yield losses are multiplicative in the sense that potential yield for later generation infestations may be decreased by earlier season infestations.

Table 4. Percentage yield losses due to ECB infestations by generation, number of ECB per plant, and planting date in INIL

Generation	ECB/plant	Before May 1	May 1-9	May 10-16	May 17-23	May 24-30	After May 30
1	1	.05	.06	.04	.03	.01	0.0
	2	.07	.08	.06	.05	.01	0.0
	3	.09	.10	.08	.06	.01	0.0
2	1	.02	.04	.05	.05	.06	.06
	2	.03	.06	.07	.07	.09	.09
	3	.04	.07	.08	.09	.11	.012
3	1	.02	.02	.02	.02	.03	.04
	2	.03	.03	.03	.03	.04	.06
	3	.04	.04	.04	.04	.05	.07

Sources: Bledsoe; Edwards, Foster, and Obermeyer.

Table 5. Percentage yield losses due to ECB infestations by generation, number of ECB per plant, and planting date in IAKS

Generation	ECB/plant	Before May 1	May 1-9	May 10-16	May 17-23	May 24-30	After May 30
1	1	0.06	0.07	0.07	0.06	0.04	0.02
	2	0.10	0.10	0.09	0.09	0.06	0.03
	3	0.12	0.12	0.11	0.11	0.07	0.03
2	1	0.04	0.04	0.04	0.04	0.05	0.05
	2	0.05	0.06	0.07	0.07	0.07	0.08
	3	0.06	0.07	0.08	0.08	0.09	0.10
	4	0.07	0.08	0.09	0.09	0.10	0.11

Source: Hellmich, 2000.

The probability of infestation in each state is based upon available test plot data and the expert opinion of collaborating entomologists. The collaborators provided three conditional probability distributions, which were used to generate the overall probability distributions used in the models.

1. The probability of infestation from a particular generation given that corn was planted in a particular planting period and that infestation of one or more insects per plant occurs

2. The probability of the number of corn borers per plant given that infestation occurs
3. The probability of realizing an infestation in a particular growing season

Using the responses, a conditional probability distribution was generated for each combination of planting date, number of borers per plant, and corn borer generation in INIL and IAKS (Tables 7 and 8). Hyde, *et al*. (1999a) describes the method for determining these distributions in Indiana.

Table 6. Percentage yield losses due to ECB and SWCB infestations by generation, number of ECB or SWCB per plant, and planting date in SWKS (SWCB losses in parentheses)

Generation	ECB/ Plant	SWCB/ Plant	April 1-15	April 16-30	May 1-15	May 16-31	After May 31
1	1	.1-.2	0.065	0.054	0.051	0.040	0.000
			(0.039)	(0.052)	(0.036)	(0.025)	(0.015)
	2	.3-.4	0.097	0.081	0.076	0.060	0.000
			(0.090)	(0.114)	(0.083)	(0.060)	(0.037)
2	1	.1-.2	0.029	0.029	0.041	0.057	0.061
			(0.043)	(0.043)	(0.043)	(0.037)	(0.052)
	2	.3-.4	0.043	0.043	0.062	0.086	0.091
			(0.101)	(0.101)	(0.101)	(0.086)	(0.114)
	3	.5-.6	0.054	0.054	0.076	0.105	0.111
			(0.159)	(0.159)	(0.159)	(0.143)	(0.177)
	NA	.7-.8	NA	NA	NA	NA	NA
			(0.203)	(0.203)	(0.208)	(0.191)	(0.239)
	NA	.9-1.0	NA	NA	NA	NA	NA
			(0.260)	(0.260)	(0.266)	(0.240)	(0.301)
	NA	1.1+	NA	NA	NA	NA	NA
			(0.275)	(0.275)	(0.281)	(0.253)	(0.312)

Source: Buschman.

The probability distributions for SWKS are confounded because of the presence of SWCB and spider mites. The probabilities listed here were provided by Buschman (Tables 9-11).

Table 7. Conditional infestation probability distributions by ECB generation, number of ECB per plant, and corn planting date in INIL

Generation	ECB/plant	Before May 9	May 10-23	After May 23
1	0	83.9	87.9	98.7
	1	9.7	7.2	0.8
	2	5.2	3.9	0.4
	3	1.3	1.0	0.1
2	0	90.6	89.3	83.9
	1	5.6	6.4	9.7
	2	3.0	3.4	5.2
	3	0.8	0.9	1.3
3	0	98.7	96.0	90.6
	1	0.8	2.4	5.6
	2	0.4	1.3	3.0
	3	0.1	0.3	0.8

Note: The probabilities are the same across some planting dates in Indiana. Thus, the six potential periods have been combined into three groups in this table.

Table 8. Conditional infestation probability distributions by ECB and SWCB generation, number of borers per plant, and corn planting date in IAKS

Generation	ECB/plant	Before May 1	May 1-9	May 10-16	May 17-23	May 24-30	After May 30
1	0	82.7	87.0	91.3	95.7	97.8	98.7
	1	15.6	11.7	7.8	3.9	1.9	1.2
	2	1.4	1.0	0.7	0.3	0.2	0.1
	3	0.3	0.3	0.2	0.1	0.0	0.0
2	0	74.0	69.7	65.4	61.1	58.9	58.0
	1	16.9	19.7	22.5	25.3	26.7	27.3
	2	7.8	9.1	10.4	11.7	12.3	12.6
	3	1.0	1.2	1.4	1.6	1.6	1.7
	4	0.3	0.3	0.3	0.4	0.4	0.4

Table 9. Probability of ECB and SWCB infestation generation by planting date given that infestation occurs in SWKS

Planting period	1st generation ECB	2nd generation ECB	1st generation SWCB	2nd generation SWCB
April 1-15	0.05	0.95	0.02	0.98
April 16-30	0.00	1.00	0.01	0.99
After April 30	0.00	1.00	0.00	1.00

Source: Buschman

Table 10. Probability of number of ECB or SWCB per plant by generation given that infestation occurs in SWKS (SWCB probabilities in parentheses)

ECB/plant	SWCB/plant	1st generation	2nd generation
1	0.1-0.2	0.90 (0.95)	0.70 (0.40)
2	0.3-0.4	0.10 (0.05)	0.20 (0.24)
3	0.5-0.6	NA	0.10 (0.16)
	0.7-0.8	NA	NA (0.10)
	0.9-1.0	NA	NA (0.06)
	1.1+	NA	NA (0.04)

Source: Buschman

Table 11. Probability of type of infestation in a given year in SWKS

Type of infestation	Probability
Corn borers (ECB & SWCB)	0.25
Corn borers and spider mites	0.25
Spider mites only	0.25
None	0.25

Source: Buschman

Region Specific Background, Modeling Issues, and Results

As mentioned throughout the paper, each of the regions analyzed has certain differences. Thus, a brief section is devoted to each. For this reason, this section is divided into three subsections, each focusing on a different region. Each subsection discusses issues unique to that region, modifications to the general model, and results.

In each region, the choice must be made whether a corn borer spraying program is economical. In areas where it pays to use a program to scout and spray for ECB, the relevant comparison is Bt corn versus non-Bt with a spraying program. In areas where it does not pay to scout and spray, Bt corn values should be determined relative to non-Bt without a spraying program. The cost effectiveness of a spraying program is determined in each of the analyses.

INIL

Results based on an analysis of Indiana have been published (Hyde, *et al.*, 1999a). The interested reader is encouraged to see that reference for modeling and data issues. The results are summarized here so that the reader can easily make comparisons across the three regions under analysis. Although the same model is used for the entire INIL region, the probability of infestation is significantly different between Indiana and Illinois. Thus, results are presented separately for the two states.

The returns to spraying average only $0.38 per acre under typical INIL conditions. Comparing this to the per-acre scouting fee of $3.00, one can conclude that it does not pay to use an ECB spraying program in INIL, on average. Therefore, the basis of comparison in determining Bt value is non-Bt corn without a spraying program.

Indiana

The probability of infestation differs across areas of Indiana. In general, the northern portion of the state is more likely to realize ECB infestations. In this area, the probability of infestation may reach as high as four out of ten years (Bledsoe). Thus, a range of 20-40% is analyzed as the probability of infestation in Indiana.

The Bt values represent several possible combinations of expected revenue and probability of ECB infestation within a given year (Tables 12 and 13). The results are further separated by level of risk aversion.

Under the assumption of risk-neutrality, only farmers with frequent infestations and fairly high revenues (yields and/or corn price) should consider planting Bt corn in Indiana (Table 12). Given a minimum technology fee of $7.80, Indiana farmers expecting greater than $400.00 per acre in revenues and who realize infestations in four out of ten years would benefit from planting Bt corn.

Table 12. Risk-neutral value of Bt corn given expected revenue and probability of ECB infestation in Indiana

Expected Revenue	Probability of ECB Infestation		
Per Acre	20%	30%	40%
$250	$2.43	$3.77	$5.20
$300	$2.91	$4.53	$6.24
$350	$3.40	$5.28	$7.29
$400	$3.88	$6.04	$8.33
$450	$4.37	$6.79	$9.37
$500	$4.85	$7.55	$10.41

The general results change little when the farmer is assumed to be highly risk-averse (Table 13). Risk-avers farmers with higher revenues from more yield and/or higher corn price may benefit from growing Bt corn when the probability of ECB infestation is 30% or greater.

Table 13. Risk-Averse Value of Bt corn in Indiana Given Expected Revenue and Probability of ECB Infestation

Expected Revenue	Probability of ECB Infestation		
Per Acre	20%	30%	40%
$250	$2.71	$4.18	$5.72
$300	$3.33	$5.12	$6.99
$350	$3.97	$6.09	$8.31
$400	$4.65	$7.11	$9.67
$450	$5.35	$8.17	$11.09
$500	$6.08	$9.27	$12.55

Illinois

The likelihood of infestation is much greater in some portions of Illinois than in Indiana (Steffey). The northwest portion of the state has the greatest probability of realizing ECB infestations, up to eight years out of ten. In the southeast, this probability may be only one in five years. Therefore, this analysis uses a range of 30-75% for the probability of an ECB infestation in a given year. A generalized presentation of ECB pressure in Illinois is provided below.

Table 14. Risk-neutral value of Bt corn given expected revenue and probability of ECB infestation in Illinois

Expected Revenue	Probability of ECB Infestation			
Per Acre	30%	45%	60%	75%
$250	$3.77	$5.97	$8.49	$11.49
$300	$4.53	$7.17	$10.18	$13.79
$350	$5.28	$8.36	$11.88	$16.09
$400	$6.03	$9.57	$13.58	$18.39
$450	$6.79	$10.75	$15.27	$20.68
$500	$7.55	$11.94	$16.97	$22.98

In areas of Illinois that realize frequent ECB infestations, Bt corn easily pays for itself (Table 14). Once the probability of infestation reaches near 50%, most farmers will benefit, even those with less productive land and/or who are not able to sell corn at higher prices. The risk-averse farmer values the Bt corn even more (Table 15).

Table 15. Risk-neutral value of Bt corn given expected revenue and probability of ECB infestation in Illinois

Expected Revenue	Probability of ECB Infestation			
Per Acre	30%	45%	60%	75%
$250	$4.18	$6.53	$9.14	$12.17
$300	$5.12	$7.97	$11.13	$14.76
$350	$6.10	$9.47	$13.17	$19.41
$400	$7.12	$11.01	$15.27	$20.12
$450	$8.17	$12.61	$17.43	$22.88
$500	$9.27	$14.26	$19.64	$25.69

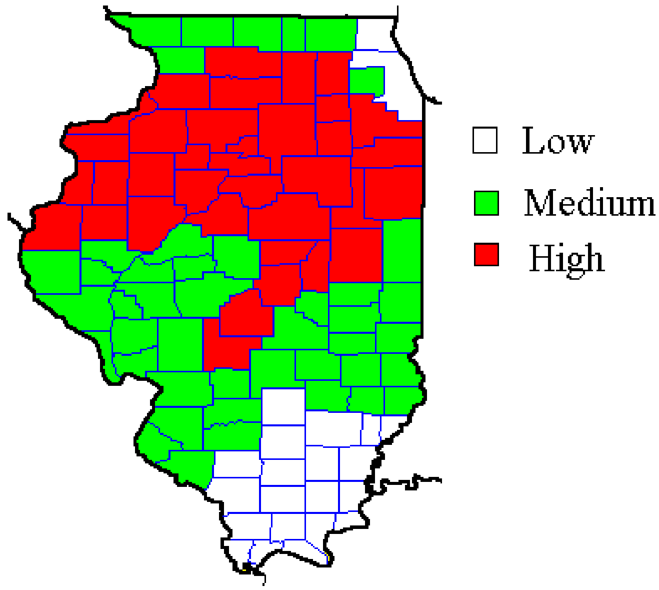

Figure 3. Generalized map of ECB pressure in Illinois
Note: ECB pressure differs across regions of the state. This map is intended to display general ECB pressure only.

<u>IAKS</u>

The IAKS model is quite similar in structure to the Indiana model. However, several of the parameters differ, as shown in the previous section on data. One of the most important difference is that the typical Iowa farmer has 6.5 bushel potential yield advantage. Thus, Iowa farmers should value Bt corn more highly than Indiana farmers, *ceteris paribus*. This is shown to be true in the analysis (Tables 16 and 17). A probability of infestation as high as 60% is analyzed (Hellmich). A map showing general areas of low, medium, and high ECB pressure in Iowa is presented below (Figure 4).

Like INIL, the value of Bt corn is determined relative to non-Bt corn without a spraying program because the cost of scouting outweighs the expected benefits of the spraying program. The expected value of spraying is $0.90 when the frequency of infestation is 60%. This compares to a scouting cost of $1.50.

Table 16. Risk-Neutral Value of Bt corn in Iowa Given Expected Revenue and Probability of ECB Infestation

Expected Revenue	Probability of ECB Infestation				
Per Acre	20%	30%	40%	50%	60%
$250	$2.63	$4.01	$5.46	$6.99	$8.60
$300	$3.15	$4.81	$6.55	$8.39	$10.32
$350	$3.68	$5.62	$7.64	$9.79	$12.04
$400	$4.20	$6.42	$8.74	$11.19	$13.76
$450	$4.73	$7.22	$9.83	$12.59	$15.48
$500	$5.25	$8.02	$10.92	$13.99	$17.20

Table 17. Risk-Averse Value of Bt corn in Iowa Given Expected Revenue and Probability of ECB Infestation

Expected Revenue	Probability of ECB Infestation				
Per Acre	20%	30%	40%	50%	60%
$250	$2.92	$4.43	$5.98	$7.59	$9.25
$300	$3.59	$5.42	$7.30	$9.26	$11.26
$350	$4.28	$6.45	$8.68	$10.98	$13.33
$400	$5.00	$7.53	$10.10	$12.75	$15.45
$450	$5.75	$8.64	$11.57	$14.58	$17.64
$500	$6.53	$9.80	$13.10	$16.47	$19.88

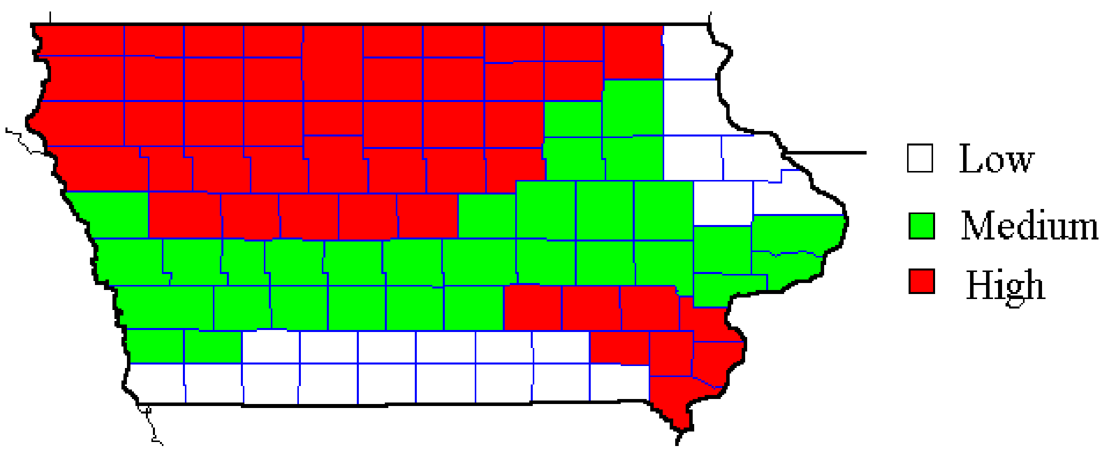

Figure 4. Generalized map of ECB pressure in Iowa
Note: ECB pressure differs across regions of the state. This map is intended to display general ECB pressure only.

Results show that farmers in Iowa and Kansas, who realize ECB damage in four or more out of ten years are very likely to benefit from adopting the Bt corn technology. This is particularly true for risk-averse farmers who may place a premium on the Bt corn.

SWKS

As discussed previously, the analysis for SWKS is not as straightforward as for the other two regions. The need to control SWCB, spider mites, and CRW makes the modeling much more complex. In general, farmers in this region use one of two tactics to control the array of insect pests often present (Buschman). In non-Bt corn, farmers are rapidly adopting a corn rootworm adulticide program. Under this program, farmers spray a broad-based insecticide, such as Capture®, which kills adult rootworms, ECB, SWCB, and spider mites. In Bt corn, farmers use traditional soil insecticides and then spray for spider mites if economic thresholds are reached. Before presenting the results of the SWKS analysis, these insects and the implications they have for modeling, which are unique to this region, are discussed.

Southwestern corn borer

The southwestern corn borer, *Diatraea grandiosella* (Dyar), develops in much the same way as the ECB. That is, it goes through four general stages: egg, larvae, pupae, and moth. Like the ECB, it damages the corn plant in the larval stage. The SWCB is primarily present in only the southwestern portion of the Corn Belt. In the present analysis, its presence is the main criterion used to distinguish SWKS from the rest of the state.

The SWCB damages the corn plant in much the same way as the ECB. It feeds on leaves and other plant tissue before tunneling into the stalk and destroying nutrient pathways. However, the SWCB causes damage in other ways. The most important difference in yield damage between SWCB and ECB is that the southwestern corn borer girdles the corn plant (Sloderbeck, Higgins, and Buschman). That is, it chews a complete circle around the corn plant, just inside the outer stalk surface. It does this in preparation for overwintering. However, this girdling significantly weakens the stalk, making the plant very susceptible to lodging in fall windstorms.

Buschman indicates that yield losses from girdling can be very high. He reports that yield losses in the range of 70 bushels per acre have been experienced in test plots in SWKS. In areas where girdling damage is widespread, a falling plant often begins a domino effect, knocking down several other plants. These fallen plants can not be easily harvested.

Spider mites

Spider mites, *Tetranychidae spp*., are not lepidoteran insects and are not susceptible to the Bt toxins. However, control of spider mites differs depending on whether or not Bt corn is planted. Therefore, it must be accounted for in this analysis.

Spider mites feed on plant leaves (Sloderbeck, Buschman, and Higgins). Once enough leaves are destroyed, the yield potential of the plant falls significantly. Yield losses in the 50 to 75% range have been seen in extreme cases.

Control of spider mites takes two general forms. First, some beneficial insects prey on spider mites. This is the main reason why spider mites enter the DA model. That is, many of the corn borer insecticides kill these beneficial insects without killing the mites. Thus, spider mite infestations can be worse in non-Bt corn that is sprayed than in Bt corn, even though the mites are not susceptible to the Bt toxins.

The second major control tool is insecticide applications. The most widely used of these, Capture® (or bifenthrin), is a miticide (i.e., it is specifically designed to control mites). However, Capture® is highly effective against corn borers and CRW, in addition to spider mites. Therefore, it is often used against second generation corn borer infestations and spider mites in a single application. This is possible because of the relatively long residual action of the insecticide (Buschman).

Corn rootworm

As mentioned previously, control of CRW, *Diabrotica spp*., often differs in Bt and non-Bt corn in SWKS (Buschman). In Bt corn, a soil insecticide is often used at planting time. In non-Bt corn, several producers in this region have adopted a CRW adulticide program. In this program, a broad-spectrum insecticide, often Capture®, is applied about a week before first generation European corn borers appear. A three to four week residual is expected, meaning that the adulticide program also controls ECB, SWCB, and spider mites. The benefits in terms of CRW control actually accrue in the following growing season. The soil insecticide method is not often used in non-Bt corn because it would effectively add one spraying pass relative to the adulticide program.

CRW damage corn differently than the other important insect pests in the region. CRW larvae feed on the corn plant's roots, often causing the plant to "gooseneck" or lodge (Higgins). This limits the plant's ability to collect sunlight and soil nutrients. Adults may clip the silks before the plant is pollinated.

Empirical results for SWKS

As might be suspected, Bt corn has tremendous potential benefits in this region. The standard of comparison is non-Bt corn with a corn borer spraying program in both irrigated and dryland corn. The model indicates that the expected benefits from spraying are greater than the cost of scouting, even in dryland fields. The value of spraying is $30.21 and $3.34 in irrigated and dryland corn, respectively. The cost of scouting is only $1.50 (Buschman).

Relative to non-Bt with a spraying program, the value of Bt corn is shown to be $29.35 per acre in irrigated corn and $21.00 per acre in dryland corn. Analysis of changing infestation frequencies was not performed because the SWKS region is small enough such that conditions are not expected to differ greatly across the region (Buschman). Furthermore, because these values are much greater than the premium levels (which may be around $6.00 per acre in dryland corn because of the very low seeding rates), an analysis of the impact of risk aversion was not performed.

Conclusions, Related Issues, and Suggestions for Further Research

Results show that, in general, the value of Bt corn increases as one moves from east to west in the Corn Belt. The value of Bt corn is shown to be greatest where infestations are frequent and where an array of insect pests must be controlled. In areas with relatively infrequent infestations, farmers may not benefit from planting Bt corn.

This is consistent with *a priori* expectations. The decision analysis framework allows for the magnitude of the effects to be quantified.

In areas where Bt corn is likely to be widely adopted, scientists worry that insect resistance to the Bt toxins may quickly develop. Hence, farmers could lose a very powerful corn borer control tool. However, producers must agree to plant a 20% non-Bt corn refuge within a half-mile of the Bt cornfield[4]. This could mean a within-field refuge or an adjacent field planted to non-Bt corn. The economics of within field refuges has been analyzed (Hyde, *et al.*, 1999b) and planting in adjacent fields would have little to no economic impact on the producer in terms of changes in the farm's cost structure. A sacrificial refuge strategy (Hellmich, 1998) may be of tremendous benefit in this region[5]. However, an economic analysis is needed to determine if sacrificial refuges are more profitable than a 20% non-Bt corn refuge.

Although this analysis provides a representative set of results for the Corn Belt, a more thorough analysis should include other states such as Minnesota and Nebraska. Work is underway to analyze southern Illinois. However, the results presented in this paper provide farmers with a set of guidelines to use in making the decision to adopt Bt corn or not.

[4] Refuges allow Bt susceptible corn borers to survive and mate with Bt resistant borers that may survive exposure to the Bt toxins.

[5] Sacrificial refuges are crops, such as popcorn, that are highly attractive to corn borers. Planting small patches may provide a 20% effective refuge. However, these refuges are expected to be so densely infested that harvest will be uneconomical.

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