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# Insect Resistance Management for Bt Corn: An Assessment of Community Refuge Schemes

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Because of Bt corn's efficacy in controlling European corn borer, farmers are required to implement an insect resistance management (IRM) program that constrains each farmer to plant no more than 80% of the farm's corn to Bt varieties. This "refuge" must be planted within a half-mile of Bt corn and must be contained on the same farm. "Community refuge" schemes, those which allow the refuge area to be planted on a neighboring farm, have been proposed. In this analysis, we estimate the potential gains to all farms in the community in two representative locations: Pennsylvania and Iowa. The results of a decision analysis model show that the potential gains are very small; the greatest is only $652 over a 2000-acre community ($0.33 per acre). This gain would almost certainly be offset by the costs of developing such a community.

***Key words:*** Bt corn, community refuge, decision analysis, insect resistance management.

## Introduction

Ten years ago, farmers began to purchase transgenic Bt (*Bacillus thuringiensis*) corn to control European corn borer (ECB), *Ostrinia nubilalis* (Hübner). (Unless otherwise indicated, all references to Bt corn in this paper refer to that Bt corn designed to control ECB.) Historically, the ECB represents an important corn insect pest, causing $1-$2 billion in damages annually in the United States (Lauer & Wedberg, 1999). Thus, the ECB is the most damaging corn insect pest throughout the United States and Canada (Ostlie, Hutchison, & Hellmich, 1997). Just one ECB larva per corn plant can lead to a 5% loss of corn yields depending upon timing of the infestation (Bode & Calvin, 1990). Prior to the introduction of Bt corn, farmers had few effective methods for controlling ECB damage. Consequently, spraying for ECB occurred infrequently, even in those regions with relatively high ECB pressure (Pilcher and Rice, 2001).

With the introduction of Bt corn, and now with many other types of transgenic crops, serious concerns have been raised regarding the development of resistance to the toxins within a population of ECB. Expanded use of Bt corn over a large landscape provides selection pressure that favors Bt-resistant ECB moths (Siegfried, Spencer, & Nearman, 2000). The efficacy of Bt toxins, which are used outside of the transgenic varieties, often by organic producers, would be greatly reduced or erased if a resistant population of ECB were to emerge.

To address this issue, the Environmental Protection Agency (EPA) has mandated insect resistance management (IRM) requirements as part of the product registration process with agricultural biotechnology firms. (IRM requirements are not unique to Bt corn for ECB control. Other crops, including Bt cotton and corn rootworm (CRW) Bt corn, have also been targeted.) For ECB Bt corn, there are four key aspects to the IRM requirement (National Corn Growers' Association, 2003).

1. Growers must plant a structured refuge of at least 20% non-Bt corn. If they plant a refuge of 40% or greater, then the refuge may be treated with non-Bt insecticides as needed to control ECB or other insects.
2. When planting refuge in strips across the field, refuges must be at least four rows wide, though six rows are recommended.
3. External refuges (those planted outside of the Bt corn field) must be planted within a half-mile of the field, with a quarter-mile preferred.
4. Refuge areas can receive insecticide treatments for ECB control only if economic thresholds are reached. These thresholds will be determined using methods recommended by local professionals. At no time should refuges be treated with Bt insecticides.

Some refer to this as a "high-dose/refuge" approach to IRM (see, for example, Ostlie et al., 1997). That is, the Bt corn should express a high-dose of Bt toxin, killing all but the most resistant insects. The refuge allows an area for some ECB insects, which are primarily susceptible to Bt toxins, to live. Scientists believe that mating will occur among these insects such that the population as a whole remains susceptible to the Bt toxins (Ostlie et al.).[1]

One important aspect of the IRM requirements, as outlined above, is that they apply to an individual farm. The distance requirement (i.e., planting refuge within a half-mile) is specific to the farm. Therefore, a farmer wishing to plant Bt corn in one field can not declare a neighbor's adjacent non-Bt corn field as refuge area. Eliminating the farm-specific applicability of the IRM requirements may allow "communities" of farmers to collaborate in developing broader IRM plans. In theory, the community should be no worse-off than it was under the farm-specific IRM guidelines because this represents the removal of a single constraint. However, it is not costless to negotiate, develop, and submit a community refuge IRM plan.

The objective of this research is to determine the extent to which the entire community of farms can be made better-off as a result of easing the farm-specific constraint. The cost of developing such a plan is difficult to estimate because the program does not exist. However, a similar program developed for Bt cotton growers provides some insights into the factors that would affect the cost of developing a community IRM plan (International Association for the Plant Protection Sciences, 2002).

All farmers included in the Bt cotton community must work together to develop a community refuge plan and to sign and submit a Community Refuge Agreement. Under this approach, the farmers' time and possibly that of a seed company representative and/or an attorney may be included as costs. Because the specific costs of developing a community refuge plan are largely unknown, this research estimates the potential increase in benefits[2] (i.e., net income) that may accrue to the community. This provides an upper bound on the costs that may be borne for the community plan to be more economically attractive than the farm-specific plan.

## Methodology

Our model builds upon one developed by Hyde, Martin, Preckel, and Edwards (1999) to analyze farm-level Bt corn adoption decisions in Indiana. We model a two-farm community under typical Midwestern and northeastern corn-growing conditions. Each farm is comprised of 1,000 acres of corn. Within our model, we assume that each farmer maximizes the expected utility of returns to planting either Bt or non-Bt corn.

**Table 1. Potential corn planting periods with associated yield losses and probabilities.**

| Planting period | IA yield loss[a] | IA planting prob.[b] | PA yield loss[a] | PA planting prob.[b] |
|---|---|---|---|---|
| Before May1 | 0% | 26.0% | 0% | 16.3% |
| May 1 – 9 | 0% | 34.6% | 0% | 29.3% |
| May 10 – 16 | 5% | 18.5% | 5% | 20.7% |
| May 17 – 23 | 10% | 10.2% | 10% | 14.1% |
| May 24 – 30 | 15% | 5.6% | 15% | 9.8% |
| After May 30 | 20% | 5.1% | 20% | 9.8% |

[a] *Calvin et al. (2000).*
[b] *Calculated from NASS data.*

Each individual farm's decision is modeled similarly to Hyde et al.'s (1999) decision analysis (DA) framework. Raiffa (1970) points out that developing a DA model occurs in four steps. First, all possible events, including decisions to be made as well as random events, must be identified. Second, these events must be developed into a timeline. Third, the decision-maker assigns payoffs (or utility values) to each potential outcome. Fourth, the probability of each outcome occurring must be assigned.

We assume that the timeline for each farm's DA model is identical because they are neighboring farms. The first event for each farm is the choice of how many acres to plant with Bt corn. This can range from zero to 800 in the farm-specific IRM case and from zero to 1000 in the community refuge case in which the 200 acres of refuge is planted by the other farm. This decision differs from that of Hyde et al.'s (1999) model, which was based on a single acre planted either with Bt or non-Bt corn.

The next event is the planting date, which is random due to items that occur outside of the farmer's control, such as weather events. Planting can occur between early-April and mid-June (Table 1). The planting date is important for several reasons. For example, ECB damage is a function of the planting date because damage levels depend upon the growth stage of the plant at the time of ECB infestation. Additionally, later-planted corn fields tend to produce less than earlier-planted fields.

1. *As Ostlie, Hutchison, and Hellmich (1997) point out, this IRM plan, while designed to delay resistance development, may not in fact prohibit resistance.*
2. *Because the focus of this paper is on insect resistance management, we do not provide a complete review of the literature on farm-level Bt corn profitability. Interested readers should see Hyde et al. (1999), Hyde et al. (2003), and Hurley, Mitchell, and Rice (2004) for a representative set of publications on that topic.*

The next events in the timeline are a series of infestations by first and second generation ECB. Following each infestation, the model chooses whether to spray for ECB. The spray decision is based upon the expected utility from that point forward in time. If the expected utility of spraying exceeds the expected utility of *not* spraying, then the model chooses to spray the non-Bt corn for ECB.

The farmer harvests the corn crop at the end of the timeline and receives a payoff. In this model, the payoff in each possible outcome is equal to the utility of the net income (price * yield – related costs) associated with the outcome. Like Hyde et al. (2003) and Hyde et al. (1999), we model utility using a negative exponential function, $u(w) = -e^{-\rho w}$, where $u$ is utility, $w$ is the payoff amount, $e$ represents the exponential function, and ρ is the Arrow-Pratt measure of absolute risk aversion. Decision analysis models are solved via backward recursion.

### Model Formulation and Data

This model focuses on two 1000-acre farms. The objective function is defined as,

$$\max_{A_{a,Bt},A_{b,Bt}} E(u(\Pi)) = \sum_{i=1}^{I} \left[ \frac{\sum_{f=a}^{b} u(NR_{if})}{I} \right] \quad (1)$$

where $E$ is the expectation, $u$ is the utility function; ∏ is total net returns; $A_{a,Bt}$ and $A_{b,Bt}$ represent the number of acres planted with Bt corn on Farms $a$ and $b$; $f$ indexes farms; and $NR$ represents the net returns for each farm. The choice variables are the number of acres planted with Bt corn on Farm A and Farm B.

This maximization problem is constrained by IRM requirements related to refuge size. Two sets of constraints were specified, based upon the IRM plans available to the farmers. The first set represents the *non*-community plan, under which each farmer must individually comply with IRM requirements. The second set represents a community plan, under which the two farmers share the IRM requirements.

Following IRM requirements in a non-community plan, each farmer must meet the guidelines individually. Therefore, no more than 800 acres of the 1000 available on each farm can be allocated to Bt corn. These are represented in Equations 2 and 3. On each farm, all 1000 acres must be planted with corn, either Bt or *non*-Bt. This is reflected in Equations 4 and 5.

$$A_{a,Bt} \leq 800 \quad (2)$$

$$A_{b,Bt} \leq 800 \quad (3)$$

$$A_{a,Bt} + A_{a,non} = 1000 \quad (4)$$

$$A_{b,Bt} + A_{b,non} = 1000 \quad (5)$$

In the community plan model, the two farmers must collectively meet the requirement that no more than 80% of the combined fields is allotted to Bt corn and at least 20% to refuge. Among the 2000 acres available across the two farms, no more than 1,600 (80% of 2000) may be planted with Bt corn (Equation 6) and at least 400 (20% of 2000) must be reserved for refuge (Equation 7). On either farm, however, the full 1000 acres may be planted with Bt corn (Equations 8 and 9).

$$A_{a,Bt} + A_{b,Bt} \leq 1600 \quad (6)$$

$$A_{a,non} + A_{b,non} \geq 400 \quad (7)$$

$$A_{a,Bt} + A_{a,non} = 1000 \quad (8)$$

$$A_{b,Bt} + A_{b,non} = 1000 \quad (9)$$

In the model, both farms plant the maximum acreage if the value of the Bt technology is greater than zero. In the community refuge scenarios, the farm with the lower Bt value plants the refuge acreage.

The data used in this model are primarily the same as those used by Hyde and reflect probability distributions in the Midwest. These data include yield losses due to ECB infestations. Damage is a function of the ECB generation at time of infestation, the number of ECB per plant, and the planting period (Table 2). The conditional probability of ECB infestation (by generation, number of ECB, and planting date) is a function of the overall probability of ECB infestation, which is assumed for a given analysis (Table 3).

Hyde's results showed that Bt values are affected little by alternative assumptions about many of the yield loss and probability parameters. His work showed that the key factors that significantly affect Bt values are expected yields, corn prices, and the overall probability of ECB infestation. Thus, several sensitivity analyses were performed within this research. For each scenario other than the base cases, two separate models were run,

**Table 2. Percentage yield losses due to ECB infestations by generation, number of ECB per plant, and planting date.**

| 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: R.L. Hellmich (personal communication, 2000).*

**Table 3. Equations used to derive conditional probability distributions by ECB generation and planting date.**

| ECB generation | ECB | Before May 1 | May 1-9 | May 10-16 | May 17-23 | May 24-30 | After May 30 |
|---|---|---|---|---|---|---|---|
| **1** | **0** | 1-(1-*A*) x .4/.97 = *L* | 1-(1-*A*) x .3/.97 = *K* | 1-(1-*A*) x .2/.97 = *J* | 1-(1-*A*) x .1/.97 = *I* | 1-(1-*A*) x .05/.97 = *H* | 1-(1-*A*) x .03/.97 = *G* |
| | **1** | (1-*L*) x .90 | (1-*K*) x .90 | (1-*J*) x .90 | (1-*I*) x .90 | (1-*H*) x .90 | (1-*G*) x .90 |
| | **2** | (1-*L*) x .08 | (1-*K*) x .08 | (1-*J*) x .08 | (1-*I*) x .08 | (1-*H*) x .08 | (1-*G*) x .08 |
| | **3** | (1-*L*) x .02 | (1-*K*) x .02 | (1-*J*) x .02 | (1-*I*) x .02 | (1-*H*) x .02 | (1-*G*) x .02 |
| **2** | **0** | 1-(1-*A*) x .6/.97 = *F* | 1-(1-*A*) x .7/.97 = *E* | 1-(1-*A*) x .8/.97 = *D* | 1-(1-*A*) x .9/.97 = *C* | 1-(1-*A*) x .95/.97 = *B* | *A*[a] |
| | **1** | (1-*F*) x .65 | (1-*E*) x .65 | (1-*D*) x .65 | (1-*C*) x .65 | (1-*B*) x .65 | (1-*A*) x .65 |
| | **2** | (1-*F*) x .30 | (1-*E*) x .30 | (1-*D*) x .30 | (1-*C*) x .30 | (1-*B*) x .30 | (1-*A*) x .30 |
| | **3** | (1-*F*) x .04 | (1-*E*) x .04 | (1-*D*) x .04 | (1-*C*) x .04 | (1-*B*) x .04 | (1-*A*) x .04 |
| | **4** | (1-*F*) x .01 | (1-*E*) x .01 | (1-*D*) x .01 | (1-*C*) x .01 | (1-*B*) x .01 | (1-*A*) x .01 |

*[a] A represents the conditional probability of zero second-generation ECB when planted after May 30 (Hyde et al., 1999). All other probabilities are a function of A.*

one for each refuge plan. Each model incorporated parameters from Iowa (IA) and from Pennsylvania (PA), representing the Midwest and the Northeast, respectively.

Table 4 provides the cost and revenue parameters used in the models. These parameters are constant across all models, unless otherwise indicated in a given scenario. Additionally, the expected yields and prices across the two regions are based on published data (National Agricultural Statistical Service, 2005) from 1970 to 2004. To calculate the expected yield in each state, a linear regression model was used to fit a trend line to the yield data. The mean of each distribution was specified as the forecasted value for 2005. These were 155.95 bushels per acre in Iowa and 110.98 bushels per acre in Pennsylvania. For corn price, the mean of the historical series was used because each series is stationary. These were $2.21 per bushel in Iowa and $2.63 in Pennsylvania.

## Results

Analyses were performed across different scenarios representing the Northeast (Pennsylvania) and Midwest (Iowa) conditions. Iowa was chosen for analysis because of its prevalence of corn crops as a member of the Corn Belt. It is also subject to moderate ECB infestations. Pennsylvania was chosen for analysis because of its differences from Iowa. It typically experiences lower infestation pressure than Iowa, for example.

This presentation of results is divided into three sections. The first section presents and discusses the results of the Iowa models. The second section presents and discusses the results of the Pennsylvania models. The third section discusses the implications of the results as

**Table 4. Per-acre cost and revenue parameters.**

| Parameter | Value |
|---|---|
| Scouting cost | $4.00[a] |
| Spraying costs per spray (labor, machinery, and insecticide) | $14.00[a] |
| Bt seed cost per bag | $30.00[b] |
| Seeding rate per acre | 25,000[b] |
| First generation spraying efficacy | 72.8%[c] |
| Second generation spraying efficacy | 66.7%[c] |
| YieldGard® Bt effectiveness (all generations) | 100%[a] |

[a] *Hyde.*
[b] *Assumed value based upon production or market conditions.*
[c] *Calvin et al. (2000).*

they relate to the costs of establishing the community refuge plan.

**Table 5. Description of models representing Iowa.**

| Model | Model description | Relative risk aversion coefficient for Farm B ($R_B$) | Probability of zero ECB infestation for Farm B ($P(0)_B$) | Pest-free yield ($Y_B$) |
|---|---|---|---|---|
| IA-1 | Base case | 0 | 0.6 | 155.95 |
| IA-2 | Increased risk aversion | 5 | 0.6 | 155.95 |
| IA-3 | Increased probability of infestation | 0 | 0.5 | 155.95 |
| IA-4 | Increased expected yield | 0 | 0.6 | 175.95 |
| IA-5 | Decreased expected yield | 0 | 0.6 | 135.95 |

*Note. Each model is further differentiated to distinguish between the non-community (N) and the community (C) case.*

## Iowa Models

Using the Iowa price, yield, and probability data presented earlier, models were run to predict the returns to two 1000-acre farms under the constraints of current *non*-community and proposed community IRM guidelines. Table 5 describes the different scenarios modeled to represent Iowa conditions.

Throughout the analyses, Farm A maintains the base case values representing historical base conditions. These values are represented in model IA-1, where Farm A has the same parameters as Farm B. Across scenarios, Farm B's values were modified to represent other possible conditions in Iowa, creating a difference in the two farms that may cause Farm B's value of Bt technology, and thus its willingness to plant more or less Bt corn, to change. For each model, a community and *non*-community case was simulated. Only one parameter is changed from its base case level in each model to determine the sensitivity of the results to that specific parameter.

Each model uses several parameters to portray the conditions of the farm—risk aversion, level of ECB infestation, and yield. The relative risk aversion coefficient, $R=\rho/w$,[3] ranges from 0 to 5, where a lower value indicates a lower level of risk aversion (Anderson, Dillon, & Hardaker, 1985). A value of zero denotes risk neutrality and is modeled by maximizing expected net income rather than expected utility. If one farmer is more risk averse than the other, all else equal, he will place a greater value on the protection offered by Bt corn.

The next parameter analyzed in the model is the level of infestation, defined here as the probability of zero ECB infestation on the farm in any given year. A lower value for this parameter, $P(0)$, indicates that there is a higher likelihood of ECB infestation on that farm. An increase in the probability of infestation would increase the value that the farmer placed on Bt corn to protect his crop. Another parameter used in the sensitivity analysis is the expected yield. This is defined as the amount of corn that, if unaffected by ECB, could be harvested at the end of the season.

Model IA-2 represents a change in the risk aversion level of Farmer B. It is assumed that Farmer B (R=5) will be more risk averse than Farmer A, who is risk neutral, and therefore will place a greater value on the protection offered by Bt corn. Model IA-3 examines how the results are affected with a higher probability of infestation for Farm B. That farmer is expected to value Bt corn more to control the higher expected pest population. Model IA-4 examines the change in Bt value from an increase in expected yield for Farm B. Higher yield is expected to increase the Bt value to the respective farmer. On the other hand, lower expected yield is expected to decrease the Bt value for that farmer. This relationship is examined in model IA-5.

3. *For the wealth level, we use the per-acre expected returns. This is consistent with Hyde et al. (1999).*

**Table 6. Results of Iowa analyses.**

| Model | Description | Objective value | Net income A | Net income B | Bt value A | Bt value B | Bt acres A | Bt acres B |
|---|---|---|---|---|---|---|---|---|
| **IA-1-N** | **Base case** | $615,460 | $307,730 | $307,730 | $2.02 | $2.02 | 800 | 800 |
| **IA-2-N** | **Increased risk aversion** | $615,460 | $307,730 | $307,730 | $2.02 | $2.80 | 800 | 800 |
| **IA-2-C** | | $615,460 | $307,300 | $308,161 | | | 600 | 1000 |
| **IA-3-N** | **Increased ECB infestation** | $615,038 | $307,730 | $307,308 | $2.02 | $4.10 | 800 | 800 |
| **IA-3-C** | | $615,460 | $307,300 | $308,161 | | | 600 | 1000 |
| **IA-4-N** | **Increased yield** | $657,785 | $307,730 | $350,055 | $2.02 | $2.97 | 800 | 800 |
| **IA-4-C** | | $657,978 | $307,300 | $350,679 | | | 600 | 1000 |
| **IA-5-N** | **Decreased yield** | $573,135 | $307,730 | $265,405 | $2.02 | $1.07 | 800 | 800 |
| **IA-5-C** | | $573,328 | $308,161 | $265,168 | | | 1000 | 600 |

**Table 7. Description of models representing Pennsylvania.**

| Model | Model description | Relative risk aversion coefficient for Farm B ($R_B$) | Probability of zero ECB infestation for Farm B ($P(0)_B$) | Pest-free yield ($Y_B$) | Technology fee per acre |
|---|---|---|---|---|---|
| **PA-1** | **Base case** | 0 | 0.8 | 110.98 | $9.38 |
| **PA-2** | **Increased risk aversion** | 5 | 0.8 | 110.98 | $9.38 |
| **PA-3** | **Increased probability of infestation** | 0 | 0.6 | 110.98 | $9.38 |
| **PA-4** | **Increased expected yield** | 0 | 0.8 | 130.98 | $9.38 |
| **PA-5** | **Decreased expected yield** | 0 | 0.8 | 90.98 | $9.38 |
| **PA-6** | **Increased risk aversion** | 5 | 0.8 | 110.98 | $6.00 |
| **PA-7** | **Increased probability of infestation** | 0 | 0.6 | 110.98 | $6.00 |
| **PA-8** | **Increased expected yield** | 0 | 0.8 | 130.98 | $6.00 |
| **PA-9** | **Decreased Expected Yield** | 0 | 0.8 | 90.98 | $6.00 |

*Note. Each model is further differentiated to distinguish between the non-community (N) and the community (C) case.*

***Base Case Scenario in Iowa.*** In the base case scenario (IA-1), both farms plant Bt corn on 80% of their respective acreages. This occurs because the value of Bt corn ($2.02 per acre) is positive (Table 6). Because the farms are identical in the base case, planting a community refuge provides no change in benefits that accrue to the community.

***Sensitivity of Results to Level of Risk Aversion in Iowa.*** When risk aversion increases for Farm B, the value of Bt corn on Farm B increases to $2.80. Farm A must receive at least $2.02 per acre to plant non-Bt in place of Bt corn, while Farm B is willing to pay up to $2.80 per acre to plant Bt corn instead of non-Bt corn. Once a community plan is imposed (IA-2-C), Farm A, which has the lower Bt value, plants 600 acres of Bt

**Table 8. Results of Pennsylvania analyses with technology fee of $9.38 per acre.**

| Model | Description | Objective value | Net income A | Net income B | Bt value A | Bt value B | Bt acres A | Bt acres B |
|---|---|---|---|---|---|---|---|---|
| **PA-1-N** | **Base case** | $519,410 | $259,705 | $259,705 | -$2.36 | -$2.36 | 0 | 0 |
| **PA-2-N** | **Increased risk aversion** | $519,410 | $259,705 | $259,705 | -$2.36 | -$1.98 | 0 | 0 |
| **PA-2-C** | | $519,410 | $259,705 | $259,705 | | | 0 | 0 |
| **PA-3-N** | **Increased ECB infestation** | $516,932 | $259,705 | $257,227 | -$2.36 | $0.74 | 0 | 800 |
| **PA-3-C** | | $517,101 | $259,705 | $257,396 | | | 0 | 1000 |
| **PA-4-N** | **Increased yield** | $569,455 | $259,705 | $309,750 | -$2.36 | -$1.82 | 0 | 0 |
| **PA-4-C** | | $569,455 | $259,705 | $309,750 | | | 0 | 0 |
| **PA-5-N** | **Decreased yield** | $469,364 | $259,705 | $209,659 | -$2.36 | -$2.90 | 0 | 0 |
| **PA-5-C** | | $469,364 | $259,705 | $209,659 | | | 0 | 0 |

corn while Farm B plants all of its acres with Bt corn. The community system is no better off than the non-community system because risk aversion has no impact on the dollar-measured returns. Later, we discuss the potential impacts of changes in Bt values even though actual returns in this scenario are the same as the base case.

***Sensitivity of Results to Level of ECB Infestation Probability in Iowa.*** The largest spread between Bt values occurs in the IA-3-N and IA-3-C models, where Farm B has a higher probability of ECB infestation. For this analysis, Farm A has a 60% probability of zero ECB infestation and Farm B has a 50% probability of zero ECB infestation. The results of the sensitivity analysis show that both Farm A and Farm B will want to plant Bt corn on the maximum 800 acres under the non-community IRM requirements. Farm A must receive at least $2.02 per acre to plant non-Bt in place of Bt corn, while Farm B is willing to pay up to $4.10 per acre to plant Bt corn instead of non-Bt corn. Once a community plan is imposed (IA-3-C), Farm A plants 600 acres of Bt corn while Farm B plants all of its 1000 acres to Bt corn. The community system experiences net returns of $416 more than *non*-community system's returns.

***Sensitivity of Results to Changes in Expected Yield in Iowa.*** Models IA-4 and IA-5 show the results of an increased and decreased expected yield, respectively. This is defined as the pest-free potential corn yield. A higher expected yield should increase the value of Bt corn to that farmer. For analysis of IA-4-N and IA-4-C, Farm A had an expected yield of 155.95 bushels per acre and Farm B had an expected yield of 175.95 bushels per acre. The results of the sensitivity analysis show that both Farm A and Farm B plant Bt corn on the maximum 800 acres under the non-community IRM requirements. Farm A must receive at least $2.02 per acre to plant non-Bt in place of Bt corn, while Farm B is willing to pay up to $2.97 per acre to plant Bt corn instead of non-Bt corn. Once a community plan is imposed (IA-4-C), Farm A plants 600 acres of Bt corn while Farm B plants 1000 acres to Bt corn. The net returns for the community refuge plan are $190 greater than the *non*-community system.

For analysis of IA-5-N and IA-5-C, Farm A had an expected yield of 155.95 bushels per acre and Farm B had an expected yield of 135.95 bushels per acre. Again, both Farm A and Farm B plant Bt corn on the maximum 800 acres as allowed under the non-community IRM requirements. In this case, Farm A has a higher Bt value and is willing to pay up to $2.02 per acre to plant Bt in place of non-Bt corn, while Farm B must receive at least $1.07 per acre to plant non-Bt corn instead of Bt corn. Once a community plan is imposed (IA-5-C), Farm A plants all 1000 acres of Bt corn while Farm B plants only 600 acres to Bt corn. The net returns

**Table 9. Results of Pennsylvania analyses with technology fee of $6.00 per acre.**

| Model | Description | Objective value | Net income A | Net income B | Bt value A | Bt value B | Bt acres A | Bt acres B |
|---|---|---|---|---|---|---|---|---|
| **PA-6-N** | **Increased risk aversion** | $521,116 | $260,558 | $260,558 | $1.01 | $1.40 | 800 | 800 |
| **PA-6-C** | | $521,116 | $260,345 | $260,771 | | | 600 | 1000 |
| **PA-7-N** | **Increased ECB infestation** | $520,455 | $260,558 | $259,897 | $1.01 | $4.27 | 800 | 800 |
| **PA-7-C** | | $521,116 | $260,345 | $260,771 | | | 600 | 1000 |
| **PA-8-N** | **Increased yield** | $571,604 | $260,558 | $311,046 | $1.01 | $1.56 | 800 | 800 |
| **PA-8-C** | | $571,715 | $260,345 | $311,370 | | | 600 | 1000 |
| **PA-9-N** | **Decreased yield** | $470,628 | $260,558 | $210,070 | $1.01 | $0.47 | 800 | 800 |
| **PA-9-C** | | $470,739 | $260,771 | $209,967 | | | 1000 | 600 |

for the community refuge plan are $190 greater than the *non*-community system.

### *Pennsylvania Models*

As in the Iowa analysis, Farm A maintains the base case values representing historical base conditions (Table 7). Farm B's values were modified to represent other possible conditions in Pennsylvania. For Pennsylvania, the farms value of Bt corn is negative under all but one scenario. To analyze the choice with a positive Bt value, we assumed a per-acre technology fee of $6.00 relative to $9.38[4] in the base case (scenarios PA-6 through PA-10).

***Base Case Scenario in Pennsylvania.*** The base case non-community scenario (PA-1) results show that neither farm plants Bt corn (Table 8). Both Farm A and Farm B have Bt values of -$2.36 per acre. This negative value implies that the farmers would benefit more from planting non-Bt corn over Bt corn. The net income for the farms is $519,410.

***Sensitivity of Results to Level of ECB Infestation Probability in Pennsylvania.*** The only scenario in which either farm desires to plant Bt corn when the technology fee is $9.38 is PA-3-N, and is PA-3-C when the probability of ECB infestation is increased. For this analysis, Farm A has an 80% probability of zero ECB infestation and Farm B has a 60% probability of zero ECB infestation. The results of the sensitivity analysis show that Farm A will plant entirely non-Bt and Farm B will plant Bt corn on the full 800 acres allowed under the non-community IRM requirements. Farm A places a value of -$2.36 per acre on planting Bt corn. Farm B has a Bt value of $0.74 per acre to plant Bt corn in place of non-Bt corn. Once a community plan is imposed (PA-3-C), Farm B increases it Bt acreage to 1000. The non-community system experiences net returns of $516,932 while the community system would yield $517,101, a gain of $148.

***Pennsylvania Results with a Technology Fee of $6.00 Per Acre.*** As noted earlier, the base case Pennsylvania results provide little information. Therefore, we modeled the Pennsylvania scenarios using a lower technology fee such that the farms have a positive value of Bt corn. As was the case in Iowa, risk aversion (PA-6) impacts the farm's Bt values but does not impact the total net returns to the two farms (Table 9). The greatest impact on net returns occurs when the probability of infestation increases from 20% to 40% for Farm B (PA-7). Farm B's value of Bt corn increases from $1.01 per acre to $4.27. Thus, the community refuge scenario increases the total net income by $652.

The changes in expected yields have a minimal impact on total net returns. Increasing yield on Farm B by twenty acres (PA-8) increases its value of Bt corn from $1.01 to $1.56 which, in turn, leads to a $110 increase in total net returns in the community system

4. *25,000 seeds per acre divided by 80,000 seeds per bag times $30 per bag.*

relative to the *non*-community system. Lowering Farm B's expected yield by twenty bushels per acre leads to a $108 increase in total net returns in the community system relative to the *non*-community system.

### Room for Transactions Costs

For each pair-wise comparison of *non*-community and community results, the value of the objective function changed very little. The largest difference was only $416 in Iowa and $652 in Pennsylvania. That is, the expected increase in actual dollars to cover the costs of developing a community refuge plan is very low. However, because this is a utility maximization model, the farmer may be willing to pay more than that to plant Bt corn. Thus, the room for transaction costs must be calculated from the Bt values. Table 10 provides the calculated room for transaction costs.

The total available for transaction costs is simply the maximum of Bt values across the farms multiplied by the number of acres being converted. Scenario IA-3, for example, shows that Farm B is willing to pay up to $4.10 per acre to plant Bt corn. Multiplying this by the 200 acres being converted yields $820. Of this total, $404 must be provided for Farm A to induce the owner to plant non-Bt corn on those acres. Thus only $416 is available to cover the costs associated with this transaction. Across 2000 acres represented by both farms, this amounts to only $0.21 per acre. This is very little and, in fact, is likely to prohibit the development of community refuge schemes.

Transaction costs may include such things as hiring a mediator to witness the transaction, administrative costs to the seed company, registration fees, and the opportunity cost of the time allotted to complete the transaction. Without precedent, there is no estimate for these costs. From the results in Table 10, the highest amount available for transaction costs under the current parameters is $652 ($0.33 per acre). Given the low value available for transaction costs, it is unlikely that the community plan would benefit the two farms. The farms analyzed in these models cannot produce great enough revenue to cover all the expected transaction costs.

**Table 10. Estimated room for transaction costs.**

| Scenario | Farm planting refuge | Amount needed to induce refuge planting | Total available | Available for transaction costs |
|---|---|---|---|---|
| **IA-1 Base case** | -- | $404 | $404 | $0 |
| **IA-2 Increased risk aversion** | A | $404 | $560 | $156 |
| **IA-3 Increased ECB** | A | $404 | $820 | $416 |
| **IA-4 Increased yield** | A | $404 | $594 | $190 |
| **IA-5 Decreased yield** | B | $214 | $404 | $190 |
| **PA-3 Increased ECB** | A | $0 | $148 | $148 |
| **PA-6 Increased risk aversion** | A | $202 | $280 | $72 |
| **PA-7 Increased ECB** | A | $202 | $854 | $652 |
| **PA-8 Increased yield** | A | $202 | $312 | $110 |
| **PA-9 Decreased yield** | B | $94 | $202 | $108 |

## Conclusion

An underlying purpose of this research is to supply stakeholders with useful information regarding Bt corn's IRM program as it currently exists and other options available. The primary stakeholders include members of the industry, such as seed companies, the academic community which has an interest in Bt corn research, entomologists, individual growers, the National Corn Growers Association and other such interest groups, and government agencies such as the Environmental Protection Agency and the United States Department of Agriculture.

This research could be enhanced with alternative data. For example, we examined two hypothetical farms. If real farm-level data were accessible, the research could be more finely tuned. Additionally, we examined only two regions, Iowa and Pennsylvania. There are many other areas within the US where Bt corn is planted or may be a potential crop. Analyzing these additional regions may provide insight into what other parameters should be examined as well. There may be significant parameters in some regions, such as the South, that are not apparent in the Northeast and Midwest.

One potential shortcoming of this analysis is that we used only one representation of utility: the negative exponential function. It is possible that the results would differ with an alternative formulation. Because the results indicate a consistently low value for the change in net returns with the implementation of a community refuge system, we suspect that the general conclusions drawn from this analysis would be changed little with the implementation of a different utility function.

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